UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

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HYDRAULIC LABORATORY REPORT NO. 37

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REPORT ON INSPECTION TRIP TO CORRELATE PRESENT HYDRAULIC DESIGN PRACTICE AND THE OPERATIONS OF STRUCTURES IN THE FIELD

By

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Denver, Colorado

August 8, 1938

HYD 37

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From Engineer J. E. Warnock

To Chief Engineer

Subject: Report on inspection trip to correlate present hydraulic design practice and the operation of structures in the field.

1. In accordance with your instructions of April 26, the Boise-Payette and Owyhee projects were visited from May 17 to 24 and the Yakima project from May 25 to June 6. The flood flow conditions through the construction at Grand Coulee Dam were observed on June 7. While not included in the itinerary, stops were made on the return trip to observe such conditions as might prevail at Jackson Lake, Bull Lake, Alcova, Pathfinder, and Seminoe Dams.

2. While many types of hydraulic structures were observed, emphasis in this report will be placed on the problem of canal drops, chutes, and inverted siphons as the chief difficulty of operation lies with them. Insofar as possible contacts were made with the operation and maintenance staffs to obtain their viewpoint. In practically all cases, both still and motion pictures were made of the structures in operation. Typical examples in this report will be illustrated by the use of the former, and the latter have been edited for demonstration purposes. The structures studied are classified as follows:

Canal drops and chutes.
Canal siphons.
Spillways and outlet works.
Fishways and fish screens.
Miscellaneous.

CANAL DROPS AND CHUTES

3. Since the problem of drops and chutes had been studied in the laboratory during the past winter in the case of the remodeling and replacement of certain structures on the Sun River project and since the general problem of developing a more satisfactory canal drop structure is now being studied in the laboratory, considerable time was spent in studying such structures in the field. The drop structures observed have been classified as:

(1) Trapezoidal inclined drops.
(2) Rectangular inclined drops.
(3) Rectangular weir drops.
(4) Trapezoidal weir drops.

A type of structure known as a check drop and constructed in the Sunnyside Main canal will be discussed as a special case.

4. Many examples of the first two types of drops were examined during the trip. Without exception, the trapezoidal inclined drops were functioning unsatisfactorily while the flow conditions in the rectangular inclined drop were very good. The design of the typical drop utilizing a trapezoidal section in the stilling pool has been found in the laboratory to be fundamentally wrong and the observations in the field verify those findings. Every structure of this type examined behaves in the same manner and appears to be grossly underdesigned, especially where used in easily eroded soil. The high-velocity jet down the slope of the drop is concentrated in the center of the structure by the sloping sides and this jet prevails through the structure with practically no dissipation of energy. The energy is finally dissipated by boundary friction on the floor of the channel but the turbulent zone accompanying the dissipation continues for a considerable distance downstream with sufficient force to scour the banks even at flows below capacity. For instance, on the Owyhee project at station 137+00 on the Kingman Lateral (figure 1), the original riprap was soon piled in the center of the canal below the structure. Heavier riprap did not stay in place primarily because the most severe turbulence occurs downstream from the structure instead of on the concrete apron. The riprap was finally grouted in place to hold it. The extent of

Owyhee North Canal Lateral 10.5 (Spec. 681-D, Drawing No. 40-D-2074

Owyhee Kingman Lateral Sta. 137+00 (Spec. 577, Drawing No. 48-D-845)

FIGURE 1 - HYDRAULIC CONDITIONS IN TRAPEZOIDAL DROPS

maintenance can be seen in the photograph. Smaller structures of the same type, such as used on North Canal Lateral 10.5, have presented similar problems of maintenance. The length of stilling pool was insufficient and the turbulence was partly in the pool and partly on the riprap. In those cases, because of the lesser energy content, hand-placed riprap has been sufficient protection. On South Canal Lateral 17.7 in a distance of 1.1 miles, there is a series of 22 drops, including the turnout from the main canal. The first five of these structures at the upper end of the canal were observed in operation in company with Watermaster George A. Haycock at Nyssa, Oregon. The turnout drop (Spec. 619, Dwg. 48-D-1093) with a designed capacity of 66 second-feet has a rectangular pool in which a hydraulic

Trapezoidal Drop at
Sta. 2+90

Turnout Drop

FIGURE 2 - STRUCTURES IN OWYHEE SOUTH CANAL LATERAL 17.7

jump forms (figure 2) whereas the other structures in the lateral are of the trapezoidal type. The dissipation of energy at the turnout drop is entirely within the pool and according to the watermaster, very little maintenance has been required. On the other hand, at the trapezoidal drops immediately downstream (figure 2) where the same amount of water is flowing, about 50 feet of riprap has been added to stop scouring. Even then the disturbance extends downstream to the end of the riprap. Another fault of these particular structures has been the deficiency of the cut-off wall at the upstream end. During the first months of operation, practically every one of the trapezoidal structures was undermined at least once and some of them more often.. The maintenance crew extended the cut-off walls vertically downward at least four feet below lateral grade without sloping them to correspond to the banks of the canal. The additional cut-off wall and the additional riprap finally stabilized the structures. It might be well to emphasize the desirability of constructing cut-off walls with vertical instead of sloping ends as this particular point was encountered at several phases. A line of similar drops in a lateral on the Vale project was described by Superintendent J. S. Moore at Yakima as an "operator's nightmare." The scour and seepage question on a similar line of structures on the Kittitas South Branch canal extension was solved by paving the lateral between the drops.

5. The more recent design of drop using the rectangular pool in which a jump forms was observed only on the Owyhee project and the operation in every case was satisfactory. On the Jacobson's Gulch Pick-up, four of these structures (Spec. 944-D, Dwg. 40-D-2626) were in operation (figure 3). While the flow in them was only a

Figure 3 - Rectangular Inclined Drop in Jacobson's Gulch Pick-up Station 73+40 (Spec. 944-D, Dwgs. 43-D-1926 and 40-D-2626)

fraction of their capacity, they functioned far better than the trapezoidal pool under similar circumstances. Another example of this type was examined at station 122+25 on the Owyhee South Canal Lateral 5.7-2.5. Unfortunately, it was only flowing 6 second-feet while it is designed for 24 second-feet but it can readily be seen (figure 4) that the turbulence is confined to the stilling pool.

On drawing no. 40-D-2620, the wing walls are shown at right angles to the center line of the lateral. This causes sharp corners at the entrance which tends to crowd the stream to the center of the drop. The wing should be curved in plan or placed at an angle of about 45 degrees to the center line. The principal objection that could be obtained to this type of structure was that of excessive first

Figure 4 - Rectangular Inclined Drop at Owyhee South Canal
Lateral 5.7 - 2.5, Station 122+25

cost. Appearances are that some savings could be made in the present structures by reducing the pool length, particularly if dentates or sills are used at the end of the pool. This excess of length has been previously noted in the laboratory and was verified in the field. The exact amount of reduction can only be determined at the conclusion of the studies now in progress. It is the belief of the writer that if the cost of maintenance of the trapezoidal inclined drops were added to the first cost that there will be little cost difference between a trapezoidal inclined drop and a properly designed rectangular inclined drop. To date we have found no way to properly design a trapezoidal inclined drop. Furthermore, it is recommended that in future designs, a single rectangular chute be used where possible instead of a series of drops.

6. A third type of drop (figure 5) found on a lateral of the Gem District D-line is referred to as a "rectangular weir drop."

Figure 5 - Rectangular Weir Drop in Gem District D-Line

Although this structure is in an erodible material and has been in operation several years, there is no evidence of serious scour and little maintenance has been required. This structure was particularly interesting in comparison with conditions found at a check drop structure on Owyhee South Canal Lateral 5.7 - 2.5 at station 313+55 (figure 6). The latter structure is a standard no. 10 rectangular inclined drop such as shown on drawing no. 40-D-2626 with

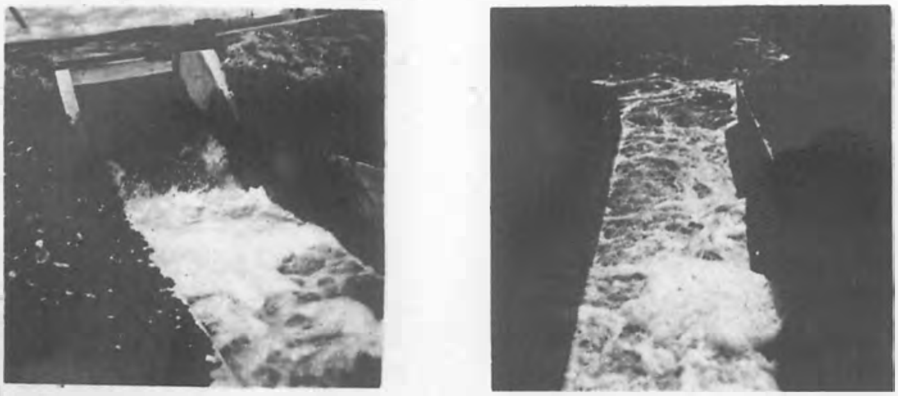


Figure 6 - Flow Conditions in Inclined Rectangular Drop at Station 313+55 on Owyhee South Canal Lateral 5.7 - 2.5

slots formed in the side walls at the crest in both this structure and the one below so that check boards could be inserted to raise the water surface in the lateral above and below to admit water to the turnouts. With these check boards in place, the conditions were very poor because the check board on the crest caused a disrupted flow down the inclined portion and the excessive tail water below caused drowning of the jump. It is one thing to design a structure for a given set of conditions and another to have them completely altered in the field as is the case when check boards are inserted. A drowned hydraulic jump is undesirable in that the jet of water continues through the pool causing scour in the channel below. It was in this connection that the rectangular weir drop in the Gem District D-line proved interesting. A drop of this type or a modification thereof appears as a possible solution to the problem of checking in drop structures. The head could be varied to meet any irrigating condition and the structure will still function properly. Furthermore, it does not appear to be an expensive structure. Its effectiveness in preventing scour in the channel below could probably be improved by a study of different shapes of floor. It is suggested that an attempt be made to design a satisfactory structure of this type.

7. A fourth type of drop is illustrated in figure 7. In

Figure 7 - Trapezoidal Weir Drop in Kittitas North Branch Canal Lateral 17.7

this case, it is an 8-foot Cipolletti weir used to measure the flow in Kittitas North Branch Canal Lateral 17.7. After five years of operation there is no evidence of scour, which can be accounted for by the fact that a large amount of the energy in the free-falling sheet of water is destroyed by impact on the exposed inclined slope and by the fact that the soil is gravelly and nonerodible at this point. An improvement could be made, however, in the upstream protection in this structure. A slab of concrete conforming to the section of the lateral extends about three feet upstream. In the early spring, pocket gophers, field mice, and sage rats favor the region beneath these slabs in hunting for tender roots. When the canal is started water flows through the passages made by the rodents undermining the structure. The maintenance department then has difficulty excavating under the sloping slab to puddle the earth and form a tight seal. If, instead of paving the slope, vertical wing walls were placed at an angle of 45 degrees upstream from the cross wall intersecting the canal bank at or slightly above maximum water surface, a puddle pocket would be formed on each end of the cross wall. During construction these pockets could be backfilled by puddling. Later, if rodents get into these sealing pockets, their passages could be closed by wetting and rodding. If it is necessary to excavate, it is a simple matter to backfill.

8. As mentioned in paragraph 3, the check drop used on the Sunnyside Main canal is a special case. The original designed capacity of the canal was much less than that now being carried. As the demand increased, larger quantities were handled. The resulting increase of velocity scoured the canal to such an extent that a series of 23 or 24 check drops were constructed in the canal. The scour downstream from at least 18 of these drops has been a source of continuous trouble since the drops were constructed.

Figure 8 - Drop 2 at Station 156+00 on Yakima Sunnyside Main Canal

The first two were designed for a capacity of 1,076 second-feet and for many years have been handling 1,300 second-feet. Attempts to stop this scour have been primarily by riprapping, but little or no improvement has been accomplished. At Drop 2 (figure 8) the width of the canal a short distance downstream from the structure is at least 50 percent greater than the normal width, and Superintendent Moore says that the hole in the center is about 15 feet deep. The size of the hole scoured below these structures is excessive considering the very small amount of drop. The stream of water through the control is concentrated in the center of the canal and the high velocity prevails for several hundred feet downstream with little dissipation. As this high velocity water leaves the drop, there is a difference in water level due to the velocity head. This causes an inflow of water on each side near the structure. This inflow is harmful; (1) as it causes a heavy flow upstream to replace that carried away by the high-velocity stream; and (2) as it disrupts all tendency toward the formation of a hydraulic jump. To completely solve this problem it will be necessary to make a model study of a typical structure. It is believed that the majority of the faults can be remedied by extending the abutment wall sufficiently far downstream so that the adjacent water will not be drawn into the stream and a hydraulic jump is permitted to form. The intermediate training walls were included in the Marshall Ford stilling pool for this same purpose. The flow conditions through the structure itself can be greatly improved by streamlining the steel brackets which support the flashboards. Consideration has been given for several years to a redesign of these structures and Superintendent Moore at Yakima has submitted a request for this redesign. Design and construction of a model is in progress now and it is planned to proceed with the study so that plans for remodeling one or two structures will be available by October 1.

9. The canal chutes inspected can be divided into three groups according to cross section. Examples of each are as follows:

(1) Rectangular chute and rectangular pool.--

(a) Owyhee South Canal Lateral 5.7, station 471+50 (figure 9).
(b) Owyhee North Canal Lateral 43.6 (figure 10).
(c) Mabton Canal (figure 11).

(2) Trapezoidal chute and rectangular pool.--

(a) Owyhee North Canal Lateral 38.7, station 7+40 (figure 12).
(b) Owyhee South Canal Lateral 5.7, station 26+50 (figure 13).
(c) Owyhee Advancement Lateral, station 9+50 (figure 14).

(3) Rectangular chute and trapezoidal pool.--

(a) Owyhee Mitchell Butte Lateral, station 86+60 (figure 15).
(b) Owyhee North Canal, station 2877+00 - Jacobson's Gulch Wasteway (figure 16).
(c) Kittitas Wippel Creek Wasteway (figure 17).

With the exception of an unnecessary disturbance in the pool of the chute on the Mabton Canal at the proposed site of the Mabton pumping plant, all of the chutes in groups 1 and 2 were functioning in an excellent fashion. The action in the pool of the chute at Owyhee South Canal Lateral, station 471+50 (figure 9) can best be described as a "thing of beauty." The chutes of group 3 have required considerable maintenance to prevent serious erosion both in the stilling pool and downstream from it.

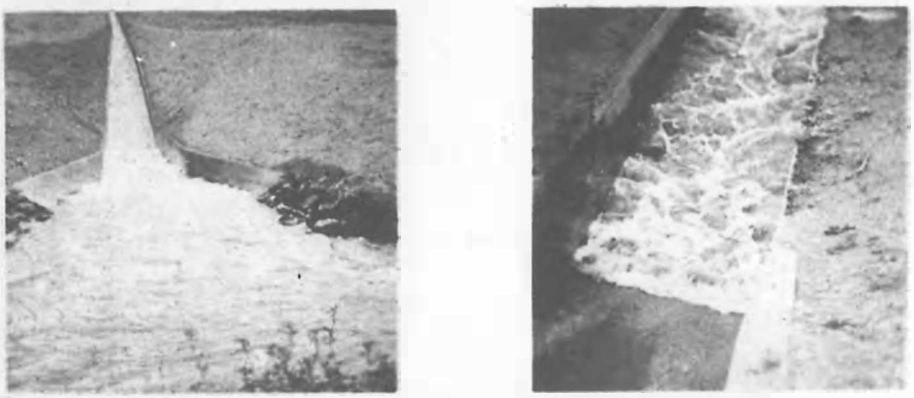


Figure 9 - Chute at Sta. 471+50 on Owyhee South Canal Lateral 5.7

10. The designed capacity of the chute at station 471+50 (Dwg. 48-D-1944) is 26 second-feet. The discharge in figure 9 is practically full capacity. The flow down the chute and through the hydraulic jump was well distributed with no back flow. Even though the water from the chute enters the Gem District Canal at an angle of 90 degrees there is no erosion except a little "beaching" due to surface waves. A small chute on Owyhee North Canal Lateral 43.6 (figure 10) with a drop of 210.5 feet and a designed capacity of

FIGURE 10 - CHUTE ON OWYHEE NORTH CANAL LATERAL 43.6

7 second-feet was operated for the first time on the day of the writer's visit. The structure was designed by the field office and there was much skepticism as to what would happen when it was operated. A flow of 1.1 second-feet while far from the designed capacity behaved very well and there was indication that the pool would handle the maximum capacity satisfactorily. The waves of water and air shown in figure 10 are very interesting and will be discussed at length under Jacobson's Gulch Wasteway where the same phenomenon was observed. At the Mabton Canal Chute (figure 11), which is also

Flow in Chute and Pool

Flow Entering Pool from Right

FIGURE 11 - MABTON CANAL CHUTE

a field design, the flow conditions would have been good except for one error in design. The chute has very slightly sloping sides and the pool sides are vertical. An offset on each side was inserted to care for the difference in slope. This offset allows back flow in the pool which disrupts the dissipation of energy.

11. The chute at station 7+40 (figure 12) on Owyhee North Canal Lateral 38.7 with a designed capacity of 26 second-feet was performing nicely with a flow of 15 second-feet. There was no evidence of scour below and little maintenance has been required. The design of this structure is shown on drawing no. 48-D-1591, specifications no. 725-D. The chute at station 26+50 (figure 13) on Owyhee South Canal Lateral 5.7 has a designed capacity of 126 second-feet and was flowing at approximately 60 second-feet when examined. There was some "beaching" in the canal banks due to wave action as can be seen in the upper center of figure 13, but there was no evidence of ground scour. A similar structure (figure 14) at the end of Owyhee Advancement Lateral (Spec. 665-D, Dwgs. 48-D-1250 and 1260) has a capacity of 18 second-feet and was carrying

FIGURE 12 - CHUTE AT STA. 7+40 ON OWYHEE NORTH CANAL LATERAL 38.7

FIGURE 13 - CHUTE AT STA. 26+50 ON OWYHEE SOUTH CANAL LATERAL 5.7

4 second-feet when inspected. The jet of water down the chute was shooting into the pool on the left side and a return whirl or eddy current which develops on the right, flows over the jet disrupting

FIGURE 14 - CHUTE POOL AT STA. [illegible]+50 ON OWYHEE ADVANCEMENT LATERAL

the feeble attempts to form a hydraulic jump. The lower end of the chute should have been flared much more gradually so that the sides of the transition would be vertical. A photograph of the complete structure could not be obtained because of a wooden flume over it. Considering the second group of structures as a type, it appears that if the transition between the sloped paving in the chute and the vertical pool walls is correct, the combination is a good one.

12. In the third group of chutes, the flow conditions in the chute portions were satisfactory except in the Mitchell Butte Lateral Chute at station 88+60 (Spec. 563, Dwg. 48-D-639) (figure 15).

Turbulence in Pool — Spray at Vertical Curve — Jet Entering Pool

FIGURE 15 - CHUTE AT STATION 88+60 ON OWYHEE MITCHELL BUTTE LATERAL

There the vertical curve is too sharp and the water tends to spring free from the channel causing considerable spray. It was stated in the field that at the time of construction, it would have been necessary to fill under the chute portion to conform to the specifications and that the steep portion of the structure was moved back into the mountainside to obtain an undisturbed foundation. It was conjectured, but not confirmed, that the vertical curve was not altered in the change. If that is the case, the change should not affect the flow conditions. The trouble appears to be one of designing a vertical curve in which the degree of curvature is greater than the natural trajectory of the water stream. The same condition was observed by Assistant Engineers Thomas and Wilsey on Kittitas Main Canal Wasteway, station 1146+30 and has been reported as existing on a similar chute on the Sun River Spring Valley Canal at station 677+00. The designed capacity of this chute is 200 second-feet, the maximum flow to date has been 166 second-feet and the flow at the time the photographs were made was 115 second-feet. As this spray condition increases in severity with an increasing discharge, there is some doubt whether 200 second-feet can be carried past this vertical curve. In the stilling pools the same turbulence or violent disturbance consisting of unstable and fluctuating boils, eddies, and whirls occur as in the drops of the trapezoidal inclined type previously described. The jet of high-velocity water continues through the pool to the downstream end. This jet carries away the water in the pocket on each side of the transition and the water flowing in to replace it causes the eddy on each side. Despite the large size of the pool, the disturbance extends beyond the end of the pool. The rock fill in the channel opposite the end of the Wippel Creek Wasteway on the Kittitas North Branch Canal as shown in figure 16 is

Turbulence in Stilling Pool

Rock Fill Opposite End of Lined Pool to Check Erosion

FIGURE 16 - CHUTE AT KITTITAS WIPPEL CREEK WASTEWAY

mute evidence of the maintenance required to control a structure of this design. When the pool of the Mitchell Butte Chute was unwatered last fall, a hole was found in the middle of the stilling pool apparently cut by the milling action of rocks either carried down the chute or carried back into the pool by the severe return eddy which prevails continuously. Photos 1306 and 1307 (Owyhee) showing the extent of the hole were examined during the discussion of this damage. Although extensive riprapping has already been done along the canal bank downstream from the pool, there is still some erosion.

13. Considerable time was spent at Jacobson's Gulch Wasteway (figure 17) studying a wave phenomenon in which the lower or

Wave Forming at Sta. 5+56 — Wave of Air and Water Down Steep Portion of Chute — Wave in Pool Caused by Traveling Wave

FIGURE 17 - JACOBSON'S GULCH WASTEWAY AT STA. 2877+60 ON OWYHEE NORTH CANAL

boundary layer was traveling at a considerably lower velocity than the waves on top. This curious condition was first studied where the chute entered the stilling pool. While the flow was only about 5 second-feet there was considerable disturbance as each of these waves or slugs of air and water reached the pool surface. The first reaction was that these waves were caused by the entrance condition at the upper end of the chute. Subsequent examination disclosed that such was not the case. Beginning at the upper end the water flows down the first section of the chute with a ripply surface resembling curly hair. As it passes the first vertical curve, very distinct waves form which gradually draw apart as the velocity of the water accelerates. As these waves pass over the last vertical curve, they absorb air to such an extent that they give the impression of having been inflated. In figure 17, the picture on the left shows a wave just as it formed below the first vertical curve, the center photo shows a close-up of a wave as it passed down the steep chute just before it hit the pool, while the last picture shows the disturbance in the pool caused by an impinging wave and two other waves approaching the pool. They are traveling so fast that only a fleeting glance is obtained of them. An idea of their speed can be obtained from the fact that the pictures were made with a shutter speed of 1/300 second. In this particular case this peculiarity of flow might be said to be of no significance, but the same condition was found by Thomas and Wilsey on the Kittitas wasteway, and Mr. Fred C. Scobey during a recent visit to the laboratory described a similar condition in California where a flow of 20,000 second-feet could be discharged in a chute but because of this wave condition 2,000 second-feet could not be handled. The cause or probability of this occurrence is vague as yet. Additional study may disclose the mechanics.

CANAL SIPHONS

14. The flow conditions at the following canal siphons were either examined personally or discussed with the operating staff:

(a) Owyhee - Specifications no. 559, drawing no. 48-D-950.
(b) Sniveley - Specifications no. 559, drawing no. 48-D-585.
(c) Kingman Lateral - Specifications no. 577, drawings nos. 48-D-852 and 853.
(d) Malheur - Specifications no. 598, drawing no. 48-D-958.
(e) Dead Ox - Specifications no. 598, drawing no. 48-D-981.
(f) Yakima River - Specifications no. 484.
(g) Weed-swallower type on Tieton Main Canal.
(h) King Hill.

15. The chief complaint on the Owyhee project was the difficulty in operating the needle valves which drain the siphon barrels. The worst case was that of the Malheur Siphon where the connections for the conduits leading to the needle valves are on the bottom of the siphon barrel. Debris of every description, such as dead jack rabbits, sage brush, tumble weeds, sand and gravel, is dragged along the bottom of the siphon by the current and is deposited in these openings. When it is necessary to operate the valves, the debris is matted over the upstream end of the needle and cannot be dislodged except by removing the valve. One of the needle valves at Malheur Siphon has been replaced by a gate valve through which trash can be flushed. Similar trouble was experienced at the Kingman Lateral Siphon where the outlet is on the top of the barrel and at the Sniveley Siphon where the outlet is 45 degrees from the bottom of the barrel. Little or no trouble has occurred at the Owyhee Siphon where the opening is 45 degrees from the top. This leads to the conclusion that there are two types of transporta-

tion causing the clogging; (1) the dragging of heavy material along the bottom of the pipe, and (2) the flotation of light material along the top of the pipe. The latter seems to predominate and causes the most trouble as at Malheur, while at Owyhee apparently neither type of material is deposited. If that is the correct conclusion, then the valve openings should be placed on the side of the pipe with a horizontal center line. If that is done, an additional valve, preferably of the slide-gate type, can be placed on the bottom of the pipe to operate under low head to flush the deposited material and complete the draining of the pipe after the head has been lowered by the main valves. The opening on the Yakima River Siphon is on top and is a source of trouble from the large volume of entrained air caught as it passes the opening. It is possible that the air would not be such a problem if the opening would have been on the side as the air has a tendency to travel along the top of the pipe in bubbles.

16. Practically all of the siphons studied and particularly the long ones had a difficulty of operation which is common knowledge in the canal sections. A siphon barrel is designed for a maximum capacity using a conservative value of Kutter's "n". Then an allowance of 10 percent is made for contingencies. The siphon seldom flows at capacity and during the first years of operation if it does flow at capacity, the friction factor is actually less than assumed in the design. As a result there are long periods of operation when there is an excess of head between the inlet and outlet ends of the siphon and the water surface in the inlet barrel is a considerable distance below the grade of the approach canal. This condition causes disturbance in the pipe, resulting in vibration and violent entrainment of air.

17. The worst case of this vibration and air entrainment was seen at the Glenn's Ferry Siphon across the Snake River on the King Hill project. The water flows into the wood-stave pipe above critical velocity and passes through the critical stage from 100 to 150 feet downstream from the entrance. Four $1\frac{1}{2}$-inch vents have been installed at approximately 25-foot intervals beginning about 100 feet below the entrance. The piping to these vents has been extended up to the siphon entrance as shown in figure 18. As observed on this particular occasion, no. 2 vent (numbering from the top down) blew air about 80 percent of the time. After a lull during which all vents were quiet, no. 4 belched practically solid water, then no. 2 resumed blowing, first air and water, then air only during the 80 percent period. There is a very noticeable vibration of the conduit in the region of vents 3 and 4 which can be seen by the eye or felt by the hand. Air was escaping through cracks at vent 3 and water was squirting through cracks below vent 4. Vents 1 and 3 did not function during my visit. A turnout valve about 150 feet below

Flow in Approach Channel

Vents at Inlet to Siphon

Vents at Inlet to Siphon

FIGURE 18 - ENTRANCE CONDITIONS AT GLENN'S FERRY SIPHON ON KING HILL PROJECT

vent 4 blows air occasionally and becomes badly clogged with weeds. Weeds also occasionally clog the vents which may have been the reason they were not working. A surge tank has been constructed about 150 feet back of the outlet of the siphon (figure 19). According to

Surge Tank About 150 Feet From Outlet

Close-up of Surge Tank

Flow Conditions at Siphon Outlet

FIGURE 19 - OUTLET OF GLENN'S FERRY SIPHON ON KING HILL PROJECT

the ditch rider who has been on that job for eight years, a great improvement was made in the flow conditions at the entrance. Prior to that the inlet had acted like a bellows. Conditions similar to these exist at other siphons but are not so obvious because of the more rugged construction as, for instance, the steel pipe and concrete conduit at Malheur and Dead Ox Siphons.

18. A possible solution of this excess head problem, especially on the longer structures, would be the inclusion of a regulating device near the outlet end of the siphon. This device would be a variable hump installed in a rectangular section of the outlet leg of the siphon and its variation would be controlled remotely at the inlet end to raise the water surface in the approach canal above the intake portal. The ditch rider could regulate this adjustable hump as part of his routine duties. The hump itself should have slopes sufficiently flat to pass any entrained debris. An automatic mechanism controlled by a float in the approach canal could be installed to lower this hump in case of excess flow conditions such as a cloudburst in a contributing drainage area. This idea is embryonic but it is believed to have possibilities.

19. A siphon with a weed-swallower entrance has been used to replace metal flumes across low points on the Tieton division of the Yakima project. The entrance (figure 20) has been used on highway culverts where weeds are blown into the ditch in large quantities

Figure 20 - Entrance to Weed-Swallower
Siphon on Tieton Canal

and are carried into the culvert. The shape of the entrance prevents the collection of the weeds by rolling them into the swift part of the stream and literally swallowing them. The action of the structure has been very satisfactory.

SPILLWAYS AND OUTLET WORKS

20. The following dams were visited during the trip. The inflow into the storage reservoirs has been sufficient to fill them and as a result several spillways were seen in action.

(a) Owyhee
(b) Black Canyon
(c) Arrowrock
(d) Tieton
(e) Tieton Diversion
(f) Wapato Diversion
(g) Sunnyside Diversion
(h) Cle Elum
(i) Kachess
(j) Keechlus
(k) Bumping Lake
(l) Grand Coulee
(m) Bull Lake
(n) Alcova

21. At Owyhee Dam the reservoir was sufficiently filled to allow a flow of 3,000 second-feet to be released either through the glory-hole spillway or needle valves. It has been realized for some time that the behavior of a jet of water from a model needle valve was quite radically different from the prototype. The disintegration of the jet from the prototype valve as it strikes the air has to be seen to be realized. The action of the Owyhee valves was observed both from a vantage point immediately beneath them and from the end of the observation gallery in the left abutment. From the first point the "rain" beneath the jets equalled in intensity the downpour during a severe thunderstorm and it fell all along the area beneath the jets. From the second point the impact of the remnants of the jet could be seen as it reached the surface of the stilling pool. As the jet strikes the surface it appears to ricochet and strike a second time farther downstream rather than plunge into the pool. This is due to the lesser density of the air-water mixture in the jet as compared to the solid water in the stilling pool. So far as the dissipation of energy is concerned the absorption of air causes the jet to impinge over a wider area and with less force than a jet of solid water. The ring gate in the glory-hole spillway was manipulated sufficiently to give discharges from 1,000 to 3,000 second-feet. With a discharge of 1,000 second-feet, spray was intermittently ejected sufficiently high to be carried by the wind onto the operating platform. As the gate was lowered and the discharge increased the ejections ceased. Outside of the inconvenience,this spray is causing no damage. With the 1,000 second-foot discharge, the flow into the stilling pool below was undisturbed, but as the flow is increased an unexpected disturbance occurs which, so far as is known, was not detected on the model. The stream of water from the spillway tunnel creates waves on the surface of the stilling pool. These waves travel across the canyon, reflect, and return. As they strike the oncoming high-velocity stream from the tunnel an incident occurs which for lack of a better term is called an "explosion.". With this particular flow the spray from the explosion is thrown two-thirds the distance up the adjacent cliff. The caretaker says

that with larger discharges this spray is thrown to the top of the cliff. Figure 21 shows three different explosions.

FIGURE 21 - DISTURBANCE DUE TO SURFACE WAVES IN STILLING POOL COLLIDING WITH HIGH-VELOCITY STREAM FROM OWYHEE SPILLWAY TUNNEL. DISCHARGE 3,000 SECOND-FEET

21. At Black Canyon Dam particular interest was paid to the question of vibration at certain gate-operating conditions. As described by Mr. George R. Larson, Assistant Engineer, the vibration occurs when about one foot of water is flowing over the gate. This vibration problem has been studied in the Fort Collins laboratory on the 1:40 model of the Grand Coulee and Shasta spillway crests and the cause is believed to be the lack of aeration at very low discharges. At certain flows the path of the sheet of water is practically vertical and of sufficient thickness to seal against the piers forming an air chamber between the downstream face of the drum gate and the sheet of falling water. The air is evacuated by the falling water and the pressure is lowered in this chamber. The sheet of water is pulled back toward the face of the drum gate until the surface tension of the water can no longer support this low pressure. The surface of the water is broken, air rushes in to relieve the low pressure, and the sheet of water springs quickly back to its true trajectory. The vibration evidently is caused by the latter. Since the air space is relatively small, this evacuation of air and relief occurs at short intervals. Mr. Larson could not estimate the frequency of this vibration but the intensity was sufficient to be felt in his home some distance below the dam. When the gate setting is such that the vibration occurs, a slight change of position by either raising or lowering eliminates it. Figure 22 shows the conditions at which vibration occurs on the model of the Grand Coulee and Shasta spillway crests. The vibration can be stopped by admitting air to replace that carried away by the overflow. On the model this could

FIGURE 22 - AIR ZONE UNDER DRUM GATE IN RAISED POSITION ON
1:40 MODEL OF GRAND COULEE AND SHASTA SPILLWAY CRESTS

be done by breaking the water surface with a pipe or stick or by inserting vents through the piers. It is believed that a complete cure of the vibration at Black Canyon Dam could be obtained by air vents through the piers into the zone beneath the gate in its raised position. The flow conditions with the gate partly lowered are shown in figure 23.

22. Eight of the 10 sluiceways at Arrowrock Dam were discharging a total of about 8,000 second-feet (figure 24). As at Owyhee, the jets from these sluiceways start to ravel as soon as they strike the air and by the time the jet strikes the water surface below very little remains of what might be termed a jet. The inflow of air into the sluiceway vents, the entrances of which are below the balustrade near the top of the dam, causes a disturbing noise similar to several large trucks backfiring or machine guns

FIGURE 23 - TWO LEFT DRUM GATES AT BLACK CANYON DAM HALF LOWERED

FIGURE 24 - EIGHT SLUICEWAYS AT ARROWROCK DAM DISCHARGING 8,000 SECOND-FEET

in action. While it may not be causing any trouble besides the annoyance to the workmen and visitors, its elimination would be desirable. It is possible that a change in shape of the entrance would eliminate the noise and at the same time admit more air into the sluiceways which would be desirable as a means of reducing the low pressure and consequent cavitation at the needle control valves.

time of this visit, it was seen in operation two years previously during an unofficial visit. At that time the air vent near the downstream end of the conduit was ejecting an air-water mixture at least 100 feet into the air. This vent has since been plugged. The chief difficulty with the structure is the lack of sufficient consideration of the effect of air on the operation. The streams of water from the portals of the ring gates in the tower fall toward the center of the tower and because of their high velocity, ravel and absorb large amounts of air so that the flow at the bottom of the tower is highly saturated with air. The only place from which air can flow to replace that carried away by the stream is from the top of the tower. When the structure was first operated, the doors and windows in the control house were pulled inward due to the vacuum. Subsequently, air vents around the side of the building have been provided to eliminate this trouble but the operation is not completely satisfactory. Before a similar design is prepared, a model should be studied to eliminate excessive vibration at the gates. In fact it is probable that effective studies on a model of the Cle Elum outlet works could be made with a view toward eliminating the present difficulties.

26. The flow conditions in the Kachess Dam spillway channel were very similar to those in the Cle Elum spillway except that there was only one control gate instead of five as at Cle Elum. This gate was raised to provide a flow of about 3,000 second-feet in the channel. The distribution of flow across the stilling pool was uniform and the severe disturbance due to energy absorption was confined to the pool. The outlet works were not in operation.

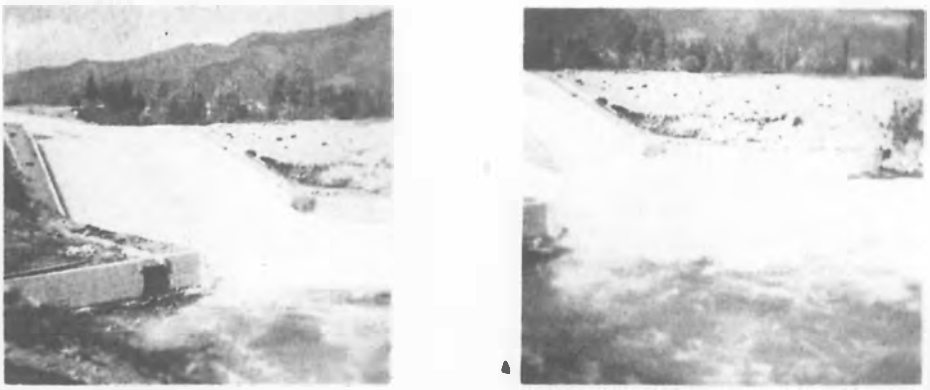


FIGURE 30 - FLOW IN KACHESS DAM SPILLWAY, DISCHARGE ABOUT 3,000 SECOND-FEET

27. The flow over the spillway at Keechlus Dam was not sufficient to show the behavior with quantities approaching maximum. Photographs of the conditions are shown in figure 31.

Spillway as Seen From Top of Dam

Spillway as Seen From Lower End of Side Channel

FIGURE 31 - KEECHLUS DAM SIDE-CHANNEL SPILLWAY

28. A small flow was passing through Bumping Lake spillway (figure 32) and one gate in the outlet works was opened completely to demonstrate the action of the discharge channel below. Although a previous flood filled the spillway channel to within 12 inches of the top of the frame channel, no damage was done and the natural

Flow in Spillway Channel

Flow From End of Spillway Channel

Flow Conditions in Outlet Works Channel

FIGURE 32 - BUMPING LAKE SPILLWAY AND OUTLET WORKS

stilling pool below functioned satisfactorily. The outlet-works tunnel now discharges into a trapezoidal-lined channel which extends about 1,000 feet to the old creek bed. The velocity in this channel is above critical and the conditions may be classed as good, as seen in figure 32. When the dam was first built, a series of baffles were built across the channel at a point below the tunnel to retard the velocity and allow the water to flow away with a low velocity and prevent scour of the channel. The seats for these baffles can be seen in the photograph. So much trouble was experienced with clogging that it was finally decided to pave the channel to the river and allow the high velocity to prevail. The conditions in the channel are now very satisfactory.

29. A stop was made at Grand Coulee Dam on the return trip. The river discharge was 361,700 second-feet and was increasing slightly. The similarity of the flow conditions to those in the model was very pronounced, the principal difference being the entrainment of large amounts of air in the prototype structure where the water surface is broken by flow over obstructions. The magnitude of the structure makes it difficult to get photographs comparable to those made on the model but three are included which show the conditions insofar as possible (figure 33).

From Roadway Above Pumping Plant Site

From Top of Block 40

From West Vista House

FIGURE 33 - CONDITIONS AT GRAND COULEE DAM WITH FLOW OF 361,700 SECOND-FEET (June 7, 1938)

30. The outlet works at Bull Lake Dam (figure 34) were operated to demonstrate the behavior of the stilling pool. The reservoir was at elevation 5765.0, giving a head of 27 feet as compared to a maximum of 67 feet. The hump in the stilling pool de-

All Gates One-quarter Open. Discharge Approx. 650 Second-Feet

All Gates One-Half Open Discharge Approximately 1,300 Second-Feet

All Gates Full Open Discharge Approximately 2,600 Second-Feet

FIGURE 34 - CONDITIONS IN BULL LAKE DAM OUTLET WORKS - RESERVOIR ELEV. 5765.0

signed to spread the flow from the two conduits regardless of the number of gates operating functions as designed in the model giving a uniform distribution of flow across the pool with the hydraulic jump forming immediately downstream from the hump. The two gates in one conduit were fully opened presenting a very unbalanced flow condition. Although there was considerable disturbance near the portal of the conduit it did not carry over the hump.

31. The reservoir at Alcova Dam was at elevation 5466.41, or 6.41 feet above the fixed crest, and the gates were discharging 4,000 second-feet and the outlet works 460 second-feet. As had been previously seen at Cle Elum and Kachess Dams, the flow in the spillway was entraining a large amount of air. At this particular flow the entrainment begins near the lower end of the first vertical curve below the gate. According to Superintendent Austin as the discharge increases this point of air entrainment moves gradually down the channel. This subject of entrainment and its possible retardation of velocity is being studied in connection with the design of Shasta Dam spillway and a progress report on it has been recently completed by Assistant Engineer C. W. Thomas, under the title "Studies of the Flow of Water in Open Channels with High Gradients." The writer,

however, attempted to collect such fragments of information as available on the subject during this trip. The discharge of 400 second-feet through the needle valves was not sufficient to give any indication of its behavior. However, Assistant Engineers C. W. Thomas and E. F. Wilsey had visited the structure on May 18 while enroute from Cle Elum, Washington, to Denver at which time 3,800 second-feet were being discharged through the needle valves. The action in the outlet-works stilling pool was quite rough with a severe wave breaking over the top of the wall at the break in alinement. The extent

Spillway as Seen from the Highway Bridge

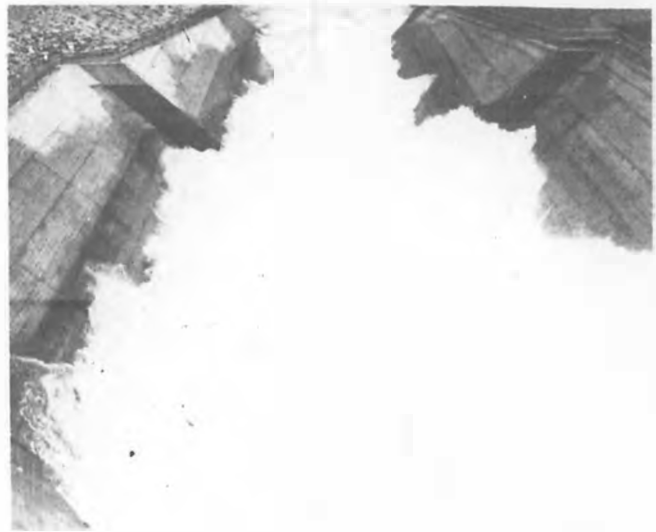
Flow Conditions with Discharge of 4,000 Second-Feet

Flow in Spillway Channel Entering Stilling Pool

FIGURE 35 - CONDITIONS IN ALCOVA SPILLWAY CHANNEL

of the splash is indicated by the wetted area in figure 36. A hole eroded by the waves can be seen in the upper right-hand corner. The splash is more severe on the right side of the pool due to the concentration of flow on that side caused by the bend in the tunnel above. The design of the entire outlet works is not considered as satisfactory. In the first place, the needle valves discharging into the tunnel create a flow condition which is unsatisfactory. Furthermore, the combination of the bend in the tunnel and the stilling pool with sloping sides creates excessive turbulence in the stilling pool. In fact, there seems to be no definite dissipating action in the pool beyond that of literally "wearing itself out." It is suggested that the behavior of this outlet works be watched rather closely and frequent inspections be made to detect any destructive action by the turbulent flow caused by the needle valves.

Tunnel Outlet



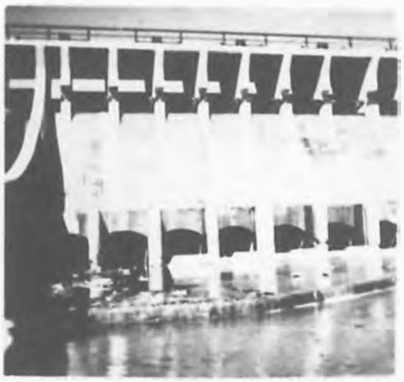
Conditions in Stilling Pool

FIGURE 36 - CONDITIONS IN ALCOVA OUTLET WORKS STILLING POOL WITH DISCHARGE OF 3,800 SECOND-FEET

FISHWAYS AND FISH SCREENS

32. During the course of the trip, fishways were inspected at Willamette Falls near Oregon City, Oregon; Easton Diversion Dam; Bonneville Dam; Rock Island Dam and Jackson Lake Dam. Fish screens were seen in operation at Tieton Canal Intake Dam and Sunnyside Main Canal Intake Dam. The general design of the fishways or fish ladders was of particular interest to the writer because of the lack of previous contact with that type of hydraulic problem. The contrast between the elaborate layout at Bonneville Dam and the crude design at Willamette Falls was very striking. However, the ladders at Willamette Falls have been in operation many years and the passage of the fish upstream each spring has been entirely satisfactory. The manipulation of the pondage above this dam by the paper mills at Oregon City has afforded an excellent opportunity for the study of the migration. The mills operate intermittently and the flow over the dam varies over a wide range in a short time. When the turbines are using the water, the flow through the fish ladders is small and is attractive to the fish. When the mills are not operating all the water is flowing over the dam and the fish ladders are flooded. When the latter occurs during migration season, a large number of salmon collect at the foot of the falls and make no attempt to go over the dam. Within a few minutes after the turbines are started and the flow in the ladders is reduced to normal,

the salmon start through in such manner as to practically fill each pool in the ladder with fish. The period of actual operation at Bonneville Dam has been so short that little data were available as to the actual efficiency of the ladders. In fact, those in charge of the fish handling were more concerned with the fingerling migration downstream than with the fish migration upstream. The mechanical fish screens below the entrance to the Sunnyside Main canal and the Tieton Main canal have not been entirely satisfactory particularly because of the poor distribution of velocity of approach to the screens. At Jackson Lake Dam (figure 37) the only water being released was the flow through the fishway. Apparently the stream



View Showing Lack of
Tail Water

Close-up of Flow From
Fish Ladder

FIGURE 37 - CONDITIONS AT FOOT OF JACKSON LAKE DAM

below had been dredged for some purpose and as a result the tail water was too low to afford a continuous passage for fish from the river into the fishway. Several dead fish were lying on the concrete deck below the sluiceways where they had perished in their attempt to pass the dam. Either sufficient water should be released or a barrier should be placed below to provide sufficient tail water for passing the fish. This suggestion is based on the premise that cooperation is being given to those interested in the preservation of fish in the State of Wyoming.

MISCELLANEOUS

33. Several items were called to my attention which have not been previously discussed and which should be of interest in

future designs. They will each be covered in the following discussion.

34. In the Kittitas Main canal, there is a transition from lined to unlined earth section at station 710+50. The turbulence and return eddies caused by the change of velocity due to the increase of area and reduction of slope has cut into both banks. This is a condition prevailing wherever there is a transition from lined to unlined section, but it is aggravated at this particular point by a curve in the channel immediately above the change of section which causes a concentration of the turbulence on the right bank. According to Superintendent J. S. Moore this condition is worse at fractional capacities than at maximum. The riprap necessary to stabilize the bank at this particular point is shown in figure 38. If the lining was carried through the transition the turbulence would occur in the lined section and the scour would be avoided. It is suggested that the lined transition be used in future designs.

FIGURE 38 - TRANSITION FROM LINED TO UNLINED SECTION AT STATION 710+50 - KITTITAS MAIN CANAL

35. Considerable trouble has been found in the operation of turnout gates in lined sections of canals where the gate is mounted vertically in a recess. The condition is even worse where the bottom of the recess is in the same horizontal plane as the bottom of the canal. A typical example is shown on drawing no. 33-D-258, a copy of which is attached. The whirl or eddy caused by the recess draws material into the gate clogging it. Where the bottom of the gate recess is in the same plane as the bottom of the canal, gravel and sand transported by the canal are also drawn into the gate and held by the mat of floating debris already collected. In the

more severe cases, it has been necessary to fasten logs along the canal lining above the gate to divert the floating debris. A solution to this clogging would be to place the turnout gates flush with the sloped lining in an inclined position and place the bottom of the gates from eight inches to one foot above the bottom of the canal. The first change should make the gates self-cleaning so far as floating debris is concerned and the second will prevent the entrapping of sand and gravel.

36. The exposure of the concrete barrels of the siphons was called to my attention by Manager V. W. Russell of the Yakima-Kittitas project and the suggestion was made that ribs be placed around the outside of the barrel particularly on the exposed side to support an earth cover which would reduce the temperature variation from sun exposure. The suggestion is believed to have much merit.

37. In the Naneum Creek Wasteway at station 886+06.0 on the Kittitas North Branch Canal (Dwg. 33-D-496, Spec. 496) a 2-foot 6-inch by 2-foot 10-inch rectangular culvert was provided to carry the normal flow of Naneum Creek under the canal. This culvert has right-angle bends near the entrance and outlet. Floating bits of timber catch in the outlet bend and cannot be removed until the end of the season. Much better flow conditions would have been obtained with an improvement of the alinement particularly at the outlet. The flow from the culvert is shown in figure 39.

FIGURE 39 - FLOW FROM BYPASS CULVERT UNDER
NANEUM CREEK WASTEWAY - KITTITAS NORTH BRANCH CANAL

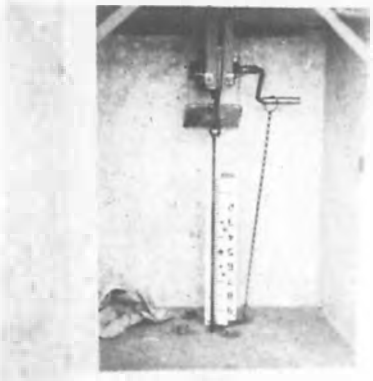
37. The question of reservoir gages was discussed at some length with Superintendent John C. Austin at Alcova Dam. The gage installed during the construction of Alcova Dam is a mercury

column with an air line to the reservoir. In its operation the air line is pumped full of air and the pressure due to elevation of the reservoir balances the column of mercury. This same type of gage has been installed at other reservoirs and it is understood that they are not satisfactory. While at Alcova, the writer operated that gage several times to study its faults. In the first place, the length of air pipe is so extensive that it is a major task to fill the line with the pump provided. Several successive operations produced no like readings. Actually the operators prefer to use a staff gage in the reservoir rather than attempt to operate the mercury gage. One cause for the inconsistency of the readings may be condensation due to the lower temperature in the long air line. The temperature of the line is much lower than the air in the control house and the temperature of the air pumped into the line is raised by the pumping. Leaks in the air line may be another cause but in any case the difficulty of operation is present. A possible solution, if condensation is the cause, would be the use of compressed air from a tank so located as to have the temperature of the material surrounding the air line. Another solution and one which seems more logical would be the installation of an entirely different type of gage - a tape gage in a well with an electrical contact to indicate the position of the water surface. A home-made affair of this type is giving very good service and with some modifications could be used to advantage elsewhere. At Pathfinder Dam, wells consisting of galvanized pipe with flanges on top have been installed on the granite rocks at various positions so as to cover the entire range of reservoir fluctuation. A metal box containing a reel and standard metal tape is bolted to the flange of the well which is appropriate for the elevation of the reservoir. A specially built brass case attached to the free end of the tape contains a flashlight, standard in every detail except the switch. Instead of the ordinary switch, two contact points project through the bottom of the case. As the flashlight indicator is lowered in the well the contact points touch the water surface switching on the light in the top of the case. The beam of light is reflected by a mirror placed above the top of the well in the case. Two photographs of the apparatus are shown in figure 40. The incorporation of the well in the dam would be one improvement and the use of a neon glow light in the gage box with the steel tape as one side of the circuit and the water and well casing as the other would produce a more sensitive instrument.

SUMMARY

38. In conclusion the following features bear emphasis:

(1) Many of the earlier designs of chutes and drops in canals have a trapezoidal section and are not functioning satisfactorily. More



Gage Box with Light Case
Lowered in Well

Brass Light Case Raised
from Well

FIGURE 40 - RESERVOIR GAGE AT PATHFINDER DAM

recent designs have incorporated the rectangular section in which a hydraulic jump provides adequate dissipation of energy. After inspecting these structures with flows approaching capacity, the opinion is reached that savings in cost could be made by shortening the structures and changing the proportions slightly. The study on that problem as applied to canal drops is now in progress in the laboratory and is producing the desired results. It is intended to continue this study into the field of chutes. It is also planned to attempt further savings in cost by using sloping sides to reduce the amount of concrete needed for stability. Previous hydraulic studies have not, however, produced much encouragement along that line.

(2) The design of long siphons such as Malheur and Yakima seems to be a subject for considerably more study such as can only be given in a laboratory. The range of operating conditions to which a siphon is subjected seems to indicate the necessity of a control device near the outlet end to maintain better flow conditions at the entrance. Also further study needs to be given to the location of the drains at the lowermost point of the siphon as present difficulties with clogging and air bleeding are a source of maintenance expense and annoyance.

(3) Those structures on which model studies have been made or which have been designed using data from other model studies are functioning as desired. Little has been accomplished in the coordination between model results and prototype performances principally

because of the lack of adequate equipment and the infrequency of the occurrences of maximum flow conditions. Visual observations are, however, reliable criteria in certain cases both in the laboratory and the field. Coordination of visual observation shows a remarkable similarity in all phases except the entrainment of air. The phenomenon, as seen in lesser discharges, has its advantage in that there is a resulting retardation of velocity of the air-water mixture. The disadvantage, of course, is the need for greater freeboard, particularly on canal chutes, to handle the designed capacity. This subject is included in that of flow of water in open channels with high gradients about which little is known at the present. Because of the very nature of the subject, the only approach known at the present time is that of obtaining pertinent data by field measurements. Mathematical analyses can be made but the results contain empirical coefficients obtainable only by actual measurements. Some progress in this line has been made recently but a great deal more will be needed to complete the story.

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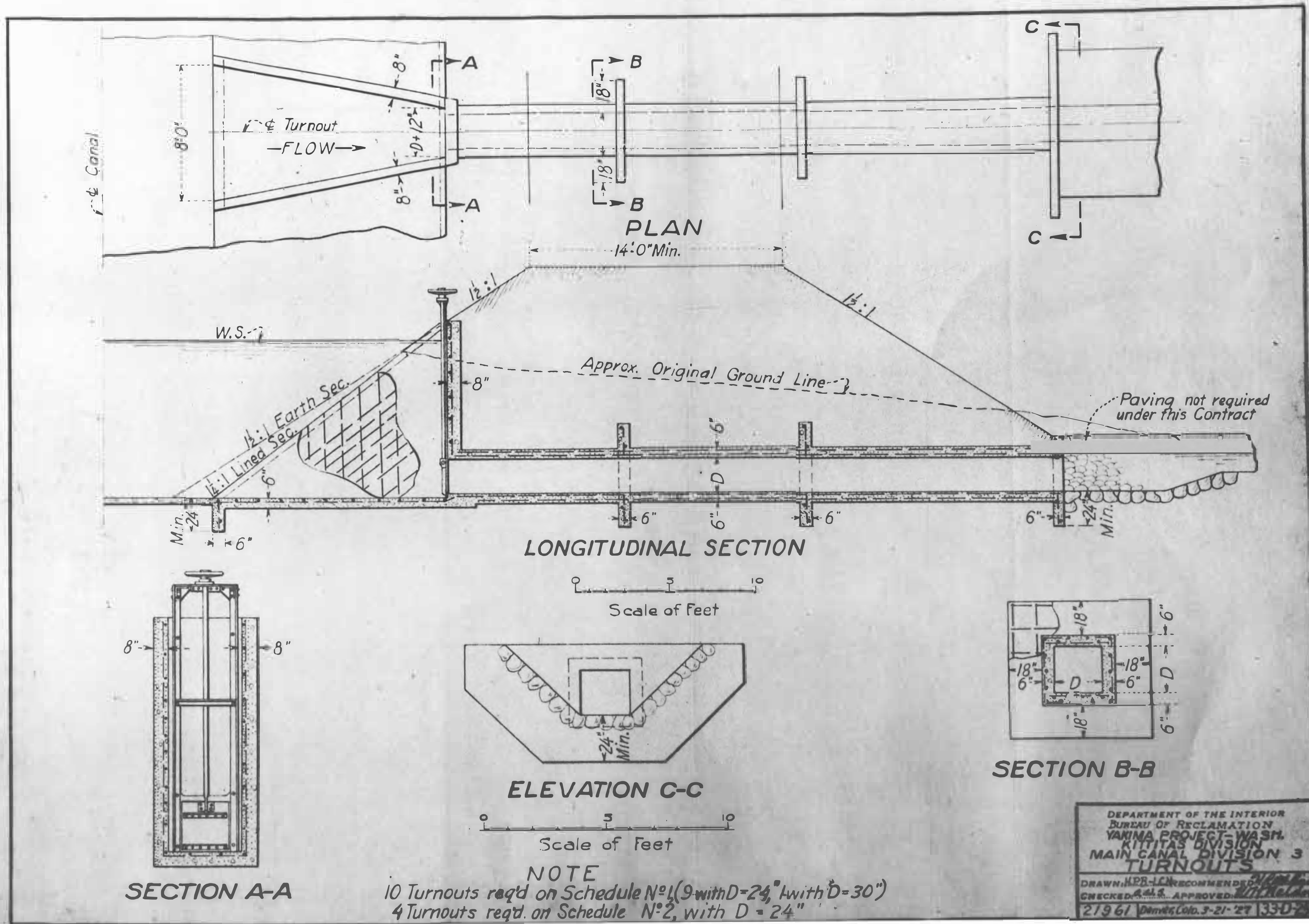

¢ Canal
8'-0"
¢ Turnout
FLOW
8"
D+12"
A
B
C
18"
PLAN
14'-0" Min.
1½:1
W.S.
8"
Approx. Original Ground Line
Paving not required under this Contract
1½:1 Earth Sec.
1¼:1 Lined Sec.
6"
D
Min. 24"
LONGITUDINAL SECTION
Scale of Feet
SECTION A-A
ELEVATION C-C
24" Min.
SECTION B-B
NOTE
10 Turnouts req'd on Schedule No. 1 (9 with D=24", 1 with D=30")
4 Turnouts req'd on Schedule No. 2, with D = 24"
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
YAKIMA PROJECT-WASH.
KITTITAS DIVISION
MAIN CANAL DIVISION 3
TURNOUTS
DRAWN: H.P.B.-L.C.N. RECOMMENDED:
CHECKED: A.A.S. APPROVED:
21961
Denver, Colo. 3-21-'27