INLET AND OUTLET TRANSITIONS FOR CANALS AND CULVERTS

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SYNOPSIS

This paper presents results of model studies of variations in open-type inlet and outlet transitions for small canals and culverts. The studies indicated that lower losses and better performance resulted when closed-conduit sections were added between the pipelines and transitions. Best results were obtained with a 6-diameter-long closed-conduit transition that terminated in a headwall normal to the canal centerline.

INTRODUCTION

Large numbers of transition structures are needed in irrigation distribution systems, drains, and other water conveyances to direct canal flows into pipelines and siphon barrels, and back into canal sections again. When these transitions are small, as for example with 36-inch or smaller pipes, the special forming required to construct conventional warped transitions is usually not justified. In these cases, the less expensive and easier to construct broken-back-type transitions made entirely of plane surfaces are used (Figure 1A).

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In early designs of canal systems using broken-back transitions as outlets from pipelines to canals, a loss value of $0.3 \left(\frac{V_p^2 - V_c^2}{2g} \right)$ was frequently used. In this expression V_p is flow velocity in the pipeline and V_c is velocity in the canal. This 0.3 loss factor was derived intuitively and is apparently not supported by direct experimental data. A similarly derived loss of $0.1 \ \Delta h_v$ (difference in velocity head in pipeline and canal) was used when the transitions served as inlets from canals to pipelines.

In recent years there has been concern about the actual loss factors being greater than 0.3 and 0.1. If the losses were appreciably greater, the structures could be restrictions in distribution systems where head is limited and reduce the carrying capacity to less than the design values.

This would have serious effect upon operation of the irrigation system when the lands were fully developed. Therefore, it was important to determine the actual losses and to make any necessary changes in the design values. Such tests were made in the Denver laboratories of the Bureau of Reclamation, and the investigation was later extended to studies of other designs to obtain equal or better performance with lower losses.

The amount of scour or erosion produced in the canal immediately downstream from transitions was important due to maintenance cost and/or the need for riprap or other armor protection in the canal. The effect on canal bank erosion of changes in the upward slope of the transition invert, in the entering pipeline,

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and in the rate of divergence of the transition sidewalls were not known. Evaluation of these variables was necessary before design decisions could be made as to optimum outlet shape and canal bank protection requirements.

The many different operating conditions and design modifications involved in the testing program dictated that the studies be conducted in a laboratory where such changes could be made easily and quickly. To fill this need, studies were inaugurated and are continuing on an intermittent basis in the Bureau's laboratories. This paper discusses the equipment and procedures used in the tests and the results obtained to date.

TEST EQUIPMENT

Water Model

Most of the studies were made using a canal section supported about 5 feet above the laboratory floor (Figures 1B and 2). The canal was formed of loose plastering sand that eroded easily and showed scour effects within a short time. Canal invert widths of 12 and 18 inches were used, and the canal sides were on 1-1/2:1 slopes. The canal invert was level in the direction of flow. A template that rode on the top rails of the box was used as a guide for reshaping the canal bed between runs, assuring that a constant starting geometry would be obtained in the canal.

At first the transitions were tested only as outlet structures with the flow passing from the pipeline, through the transition, and into the canal. The 12-inch-diameter pipe that supplied water to the transition was placed level in part of the tests, and on a 2:1 upslope to the transition for other tests. The depth of flow in the canal was regulated by an adjustable tailgate at the downstream end of the model.

In later studies the transitions were studied both as inlets and outlets. The piping was modified so that in addition to the flow described above, water could be introduced into the canal from the tailgate end of the box to produce inlet flows into the transition and pipeline (Figure 2).

When a transition was used as an outlet, the pressure head in the 12-inch-diameter pipeline was measured at a station 1 foot (one-conduit diameter) upstream from the transition. When the transition was used as an inlet, the pipeline head was measured at a station 15 feet (15D) downstream from the junction of the transition with the pipeline. The pressures were obtained by two piezometers, one on each side of the pipe. The pressure leads were connected to 1-1/2-inch-diameter stilling wells, and point gage measurements were made of the free water surfaces within the wells. The water surface elevations in the canal were measured by point gages 15 feet downstream from the junction of the transition with the canal for outlet flows, and 4 feet upstream from this junction for inlet flows.

Air Model

Studies of closed-conduit expanding outlet transitions were also made with a test facility using air as the flowing fluid

(Figure 3). Air was drawn from the atmosphere through a 12-inch-diameter pipe into the centrifugal blower. It then passed through a 10.14-inch-diameter pipeline into the expanding transition being tested, and back into the atmosphere. The 10.14-inch-diameter pipeline was 63 inches long (6.2D) for most of the tests, and was lengthened to 207 inches (20.4D) for the remaining tests. A piezometer located 4-1/2 inches from the outlet was used with the 6.2D pipe, and two diametrically opposed wall taps located 1 diameter from the outlet were used with the 20.4D pipe.

INVESTIGATION

Open-channel Transitions

A number of open, broken-back transitions were tested to determine the effect of upward slope of the invert, rate of sidewall divergence, degree of submergence over the outlet pipe crown, and slope of the incoming pipeline on energy losses and scour in the canal channel (Figures 4 through 13). In addition, the effect of placing humps on the transition invert to aid in spreading the flow, and the effects of other modifications such as changing the sidewalls to modified warped walls were tested. For convenience these designs, operating conditions, and test results are briefly summarized in Table 1. Loss factors for all the broken-back transitions, including the ones modified with warped surfaces, were about 0.5 to 0.7 Δh_v for outlet flows. The term Δh_v equals the velocity head in the pipeline 1 diameter upstream from the transition, minus the velocity head in the canal 15 feet downstream from the transition.

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The flow patterns through all the open transitions were generally similar. If the inlet pipe entered the transition horizontally, the stream issuing from it tended to move straight through the transition into the canal, and large eddies moved upstream well up into the transition along either side of the jet (Figure 5A). Scour on the canal bottom and on the side slopes was appreciable in the loose sand and a sandbar was built up across the canal 6 to 12 feet downstream from the canal entrance (Figure 5B).

If the inlet pipeline was sloped, the issuing stream rose in the transition to the water surface to cause higher surface velocities and waves that scoured the canal slopes (Figure 6A). Flow was nearly stagnant at the bottom of the transition and, in some cases, sand was deposited in the transition. A wide sandbar built up several feet downstream from the canal entrance (Figure 6B).

Changes in the slope of the transition invert from a minimum of 1:13.1 to a maximum of 1:5.5 had no apparent effect on the losses encountered or on the scour produced (Table 1 and Figures 5 through 13). Likewise, changes in divergence angles of the outer walls of the transitions from the minimum of 16° per side to a maximum of 30° per side had no appreciable effect, although limited data show a slightly lower loss for a 25° angle. Even altering the outer walls by constructing warped surfaces within the confines of the broken-back walls was not significantly effective.

Different submergences above the crown of the pipe at its juncture with the transition showed little effect in early tests.

More detailed investigations with the 20°, 25°, and 30° broken-back transitions showed lowest losses with small submergences, and progressively higher losses with submergences exceeding about 0.1 pipe diameter (Figure 33A).

Several "humps" were placed on the transition invert a short distance downstream from the pipe exit to help spread the flow and obtain smoother conditions with more uniform velocities at the canal entrance (Figures 4, 5C). Improvements in flow conditions and reductions in scour occurred, but the losses were either unaffected or increased. The usefulness of humps in these transitions appeared to be restricted to reducing scour in the canal.

A qualitative measurement of riprap needed for controlling scour in the canal was obtained by placing a 4-inch-thick layer of 1-1/2-inch gravel in the first 6 feet of the model canal. Tests were made with the 1:8 slope, 6-inch rise transition with warped walls and a horizontal inlet pipeline (Figure 13). A flow velocity of 3 feet per second in the pipeline failed to move any gravel or any appreciable amount of sand in the bed downstream. A velocity of 4 feet per second also failed to move the rock and moved only a very small amount of sand. At a 6-foot-per-second pipeline flow velocity, the rock remained stable but considerable erosion occurred in the sand farther downstream (Figure 13C). It was apparent that this 1-1/2-inch rock was capable of protecting the model canal from scouring tendencies. By geometric scaling this rock is equivalent to 0.125 times the pipe diameter. No tests were made with other sized rocks, but information on required prototype riprap sizes is available from other sources.1/

Noticeable reductions in head loss, improvements in flow distribution, and reduction in scour were achieved when closed-conduit expanding sections were used in conjunction with the open transitions. A short submerged shelf projecting downstream from the transition headwall just above the pipeline crown in a 1:8 sloping transition cut the loss factor from about 0.6 to less than 0.5 (Table 1). A longer hood that created a 4D-long closed-conduit within a 1:8 transition and had a maximum divergence rate of 8-1/2° per side reduced the loss factor to 0.21 (Figure 7C). A short closed-conduit transition from the 12-inch circular pipe to a 12-inch square section, inserted in the pipeline just ahead of the rectangular 1:8 broken-back transition, reduced the 0.6 loss factor to less than 0.4. It was apparent that the best opportunities for improving transition performance lay in closed-conduit, gradually expanding sections.

Closed-conduit Transitions--Air Model Tests

To determine the performance of a series of expanding closed-conduit transitions, air model tests were made (Figures 3 and 4). The shapes of the transitions were selected after considering design problems involved in coupling them with open-type, but shortened, transitions. To avoid excavations deeper than for present

1/"Stilling Basin Performance Studies as an Aid in Determining Riprap Sizes," USBR Hydraulic Laboratory Report No. HYD-409, by A. J. Peterka, February 23, 1956.

structures, no downward divergence relative to the centerline was used. Similarly, to avoid lowering the structure to maintain submergence over the crown of the conduit, no upward divergence relative to the centerline was used. Thus, the height of the transition at the outlet was the same as at the inlet and equal to the diameter of the pipeline. All divergence in the closed-conduit transitions occurred through divergence of the sidewalls and through the change in section from circular inlets to square or rectangular outlets.

Each transition was first tested on the 6.2-diameter-long approach pipe, and velocity traverses were taken horizontally and vertically at the inlet and outlet (Figure 15). There was a slight distortion in the inlet velocity profile with the round-to-square transition, and the distortion became progressively greater as transition expansion increased. The outlet profiles showed that the flow expanded well and followed the diverging walls in the 0°, 2-1/2°, and 5° transitions and to a lesser extent in the 7-1/2° transition. The 10° diverging section was too abrupt, and flow broke away from the right side and the upper and lower right corners so that reverse flow occurred.

It was believed that the somewhat distorted velocity distribution at the transition inlets had appreciable effect upon the ability of the flow to follow the expanding boundaries. A 12-foot extension was added to the approach pipe to produce a section 20.4 diameters long and obtain a more fully developed and uniform

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distribution. Tests with the 0° divergence transition showed nearly symmetrical velocity distributions at both the inlet and outlet (Figure 16A). However, tests with the 10° transition showed noticeable velocity distortion in the horizontal traverse at the inlet, apparently due to the severe separation along the right side of the outlet. This separation was greater than the separation that occurred with the short approach pipe. It was concluded that regardless of the uniformity of approach conditions, the 10° transition was too abrupt to control the discharging flow.

Pressures were subatmospheric at the approach pipe wall taps just upstream from the transitions. This was expected and is due to recovery of head wherein velocity head of the entering stream is converted into pressure head as the flow expands and slows. The pressure level into which the transitions discharge is atmospheric, and hence the pressures in the approach conduit and upstream parts of the transitions where the flow is fast will be less than atmospheric. The extent of the subatmospheric pressure level is a direct measure of the amount of head recovery or effectiveness of the expanding transition. The pressure head at the inlet, divided by the inlet velocity head, produced dimensionless parameters which were plotted against degrees of sidewall divergence (Figure 17A). The greatest head recovery occurred in a transition with a divergence of 7° to 8° and was 55 percent of the inlet velocity head.

The loss in total head from the transition inlet to the atmosphere, divided by inlet velocity head, was similarly plotted against sidewall divergence (Figure 17B). This loss factor, K, was lowest for a divergence of 7.5° to 8° and was 44 percent of the inlet velocity head. The pressures on the transition walls were negative with respect to the outlet head (atmospheric) in all cases except near the outlet of the 0° transition (Figure 18). The pressures at a given station became generally more negative as the rate of transition divergence increased, until the 10° transition was approached and the trend reversed. Flow separation occurred in this transition, and the effectiveness and efficiency dropped below that of the 7-1/2° transition. In all cases, the lowest pressures were obtained on the transition element leading from a 45° point on the circular inlet to an outlet corner. These elements diverge more rapidly than any others in the transitions.

For comparative purposes, plots of cross-sectional areas versus distance along the transition are presented for the transitions tested and for conic transitions (Figure 19).

Loss coefficients, K, for conic expanding transitions of 2-1/2° and 7-1/2° relative to the centerline, and discharging directly into the atmosphere, were found in previous tests to be 0.273 and 0.499, respectively, based on the inlet velocity heads.2/ These values show a trend of greater loss with greater divergence to 7-1/2°, instead of the decreasing loss shown by the round-to-rectangular transitions. This difference is explained by a comparison

2/"Hydraulic Model Studies of the San Jacinto-San Vicente Turnout and Metering Structure, San Diego Aqueduct Project, California," USBR Hydraulic Laboratory Report No. HYD-365 by W. P. Simmons, January 1953.

of the area curves (Figure 19) that show that conic sections enlarge much more rapidly than the round-to-rectangular transitions of the present study, and indicates that considerable separation, and hence loss, occurred in the 7-1/2° cone. This separation was found to exist in the turnout structure conic transition.

Combination Closed-conduit and Open-channel Transitions

The relatively high efficiency of the closed-conduit expanding transitions was partially exploited by placing 2D-long, round-to-rectangular transitions between the end of the circular pipeline and a shortened and modified broken-back transition (Figure 20). The height of the closed transition was kept the same as the diameter of the pipe and the sides diverged 7-1/2° relative to the centerline. The length was 2D and the outlet measured 12 inches high by 18-3/8 inches wide with an area 2.8 times greater than at the inlet. A 5.5D-long, upwardly sloping open-channel transition adapted the rectangular section to the trapezoidal section of the canal.

The loss coefficient for outlet flows was about 0.4 with the inlet pipe horizontal, and about 0.2 with it rising on a 2:1 slope (Table 1). With the pipe horizontal, waves were smaller and less powerful than in previous transitions, but scour remained appreciable (Figure 21). This was apparently due to flow from the closed pipeline continuing straight through the open transition along the floor without appreciable spreading or slowing. Large back eddies were present at the sides in the open transition.

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Several humps were placed on the floor to "lift" this flow stream and help spread it. Scour was decreased when a 6-3/8-inch-high wedge-shaped hump was used, but remained almost unchanged with a 3-3/8-inch one (Figures 20 and 22). Better flow conditions occurred when the inlet pipe was placed on a 2:1 upslope (Figure 23). Wave action persisted, but flow was distributed more uniformly across the section upon reaching the canal. Considerable flow was present along the broken-back transition invert, although the greater part of the flow was near the surface. The scour was moderate and the energy loss coefficient decreased to 0.21.

Additional tests were made with an open transition having a horizontal invert (Figures 20B and 24). The submergence over the crown of the closed-conduit outlet for a 15-inch (1.3D) flow depth in the canal was 0.3D, as compared with 1.3D for the sloped, open transition. The tests were made with a 2:1 sloping pipeline. The water surface was somewhat choppy and waves carried into the canal to produce moderate bank erosion. The flow moving downstream extended completely across the water prism at the canal entrance, and from the water surface downward to 4 or 5 inches above the canal invert. The lowest layers of water were not in significant motion and bottom scour was not apparent. The loss coefficient decreased to 0.15, possibly due to the greatly decreased submergence at the outlet of the closed conduit.

Closed-conduit Transitions--Hydraulic Tests

The losses of the combined closed-conduit and open-channel transitions were significantly lower than for the usual open ones, and scouring was reduced. Consequently, longer round-to-rectangular closed-conduit transitions that terminated in a headwall normal to the canal were studied (Figure 25). The water discharged directly through the headwall into the canal section for outlet flow tests, and through the headwall into the transition for inlet flow tests. No further transitioning was used. The closed-conduit transitions exploited the fact that more orderly and complete expansion, and hence slowing of the flow, can be obtained in closed conduits than can be obtained in the usual open-type transitions. Ideally, based on the areas of the inlet and outlet, a two-thirds velocity reduction can be achieved and about 90 percent of the velocity head can be recovered in a closed-conduit transition 6 diameters long and with a moderate rate of divergence.

12- by 28-inch Transition. A closed-conduit transition with a 12-inch-diameter inlet, a 12-inch-high by 28-inch-wide rectangular outlet, and a length of 72 inches (6D) was constructed and tested (Figures 2 and 25A). The transition sloped upward 4 inches and the top of the exit was level with or slightly beneath the normal canal water surface. The transition terminated in a vertical headwall placed normal to the canal and the 12-inch-diameter inlet pipeline was placed horizontal.

Relatively good flow conditions occurred near the headwall and in the canal. Conditions were similar to those shown in Figure 28. The least desirable conditions were present at a 15-inch flow depth (1.25D) where significant return eddies occurred along the banks at the water surface near the headwall. These eddies eroded the canal bank slopes noticeably (Figures 26B and 26C). At a 12-inch depth (1.00D) these eddies were small enough to be of little consequence and erosion was minor (Figure 26A). At a 10-inch depth (0.82D) the eddies were not significant, but flow velocities along the canal banks and invert were higher than desired and erosion increased. The scours at the 0.83, 1.00, and 1.25D depths compared favorably with those of the open, and the combination open-closed transitions.

Loss coefficients for the 12- by 28-inch transition, when used as an outlet, were quite low and equal to 0.11, 0.09, and 0.11 for canal depths of 0.83, 1.00, and 1.25D, respectively (Table 1 and Figures 27E and 33). Loss coefficients when the transition was used for inlet service were 0.34, 0.37, and 0.40, respectively. It was apparent that very low energy losses were obtained for outlet service, and that no penalty was incurred in erosion in the canal, or in losses for inlet service.

Detailed studies of the flow conditions were made by velocity traverses across the inlet pipeline and the outlet portal (Figure 27). The measurements showed undesirable flow separation along the left side and the corners of the transitions when it

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was used in outlet service. This indicated excessive divergence of the flow passage and a design unnecessarily expensive due to greater than required width.

12- by 24-inch Transition. A 6D-long transition with a 12-inch-diameter inlet and a lesser divergence rate to a rectangular outlet 12 inches high by 24 inches wide was constructed (Figure 25B). When used as an outlet it produced flow in the canal generally similar to that obtained with the previous closed transition (Figure 28). Scour in the canal was relatively small at all flow velocities and water depths and comparable with the best of the other designs (Figures 29 and 30). The loss coefficients decreased to 0.09, 0.07, and 0.11 for the 0.83, 1.00, and 1.25D flow depths (Figures 31 and 33). The reduced scour and lower losses attested to the excellent performance of the transition in expanding the flow, and velocity measurements at the outlet confirmed the conclusion (Figure 31).

The transition performed quite satisfactorily when used as an inlet. Good flow distribution was present in the pipeline, and loss coefficients of 0.35 were determined for canal depths of 1.00 and 1.25D (Figures 31 and 33C). These losses compared very favorably with those of all other designs.

It was recognized that field installations might require transitions so large that the flat tops near the headwall would pose structural problems. This would be less complicated if the span were cut in half by using a center supporting wall or pier.

To determine the effects of such a pier on the flow and losses, tests were made with an 18-inch-long pier in the transition (Figures 25B, 32, and 33). The pier was 0.2D thick and had a rounded upstream end and a blunt face at the downstream end. Its presence increased the outlet loss coefficients to 0.10, 0.12, and 0.17, and the inlet loss coefficients to 0.39 and 0.40. A part of this increased loss is undoubtedly due to the more distorted velocity distribution that occurred in the tests with the pier present (Figure 32). When this increased distortion was first noted the pier was suspected of being out of alinement. A check of the alinement showed it to be satisfactory.

Square Inlet on 12- by 24-inch Transition. Consideration of the cost of forms to make round-to-rectangular transitions led to questioning whether or not simpler square-to-rectangular designs would perform satisfactorily. Therefore, a 6D-long transition with a 12-inch-square inlet instead of a round one, and a 12- by 24-inch rectangular outlet was tested (Figure 25C). The loss coefficients for outlet flows were 0.20, 0.20, and 0.23 for depths of 0.83D, 1.00D, and 1.25D. These values represent about a 100 percent increase over those obtained with the circular entrance design. For inlet-type flows, the loss coefficients were 0.50, 0.50, and 0.51 (Figure 33C). These values are about 25 percent higher than for the circular inlet transition.

In terms of actual head loss in a prototype structure at flow velocities of 8 feet per second, the outlet losses for the square-to-rectangular transition are about 0.10 feet of water more than for the round-to-rectangular design. In many instances this small additional loss may be insignificant, and the lesser construction cost of the square-to-rectangular transition will dictate its use.

CONCLUSIONS

1. The energy losses for conventional, broken-back, open-channel transitions discharging from pipes into small canals is 0.6 to 0.7 times the difference in velocity heads in the pipe and in the canal (Table 1 and Figure 35). This velocity head difference, $\frac{V_p^2}{2g} - \frac{V_c^2}{2g}$, is termed Δh_v.

2. Reasonable changes in angle of divergence of the sidewalls, and/or of the slope of the invert of the open transitions, or of the attitude of the inlet pipeline, had little effect upon energy losses (Figure 4 and Table 1).

3. Outlet losses were reduced to 0.4 Δh_v and less, when short, closed conduit, expanding transitions were placed between the pipeline and modified, broken-back transitions (Figures 20 and 35).

4. Outlet losses were reduced to 0.1 Δh_v with 6D-long, closed-conduit transitions having circular inlets and rectangular outlets, and which discharged directly into the canal through a vertical headwall placed normal to the canal axis (Figures 3A and 35).

5. The addition of a dividing pier to decrease the structural span of the roof near the outlet of the round-to-rectangular transition increased the losses to about 0.13 Δh_v.

6. Changing the 6D-long transition to provide a square instead of the more difficult to form circular inlet increased the outlet losses to 0.20 Δh_v, and the inlet losses to 0.50 Δh_v.

7. Outlet losses of existing broken-back transitions can be materially reduced by installing properly designed hoods within the structures to form controlled, closed-conduit expanding sections (Figure 7C and Table 1).

8. Losses for inlet flows were about 0.4 to 0.5 Δh_v for all transitions tested (Table 1).

9. Scour or erosion in the loose sand of the canal bed was extensive with conventional, broken-back transitions (Figures 5 through 13).

10. Selected humps or flow spreaders on the inverts within open transitions significantly reduced scour (Figures 5 through 13). The humps tested created a slight increase in head loss.

11. Scour was not appreciably affected by changes in the sidewall divergence or invert slopes of the open transitions.

12. Scour with the combination closed-conduit and open-channel transitions was less than for the conventional transitions (Figures 21 through 24).

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13. Scour was reduced, in most cases, when the pipeline to the transition was on a 2:1 slope instead of horizontal.

14. Scour with the 6D-long, closed-conduit transitions was about the same as with the combination transitions, and less than for the conventional transitions (Figures 26, 29, and 30).

15. In general, scour was nominal with flow velocities of 4 fps in the 12-inch-diameter pipe, and severe with velocities of 6 fps. By scaling to larger structure sizes, according to Froude laws, these velocities are equivalent to 5.7 and 8.5 fps for 24-inch pipe, and 8 and 12 fps for 48-inch pipe.

16. A 4-inch-thick layer of 1-1/2-inch gravel extending 4 feet downstream from the transition of the 12-inch test installation provided excellent scour protection at the transition outlet (Figure 13). Erosion occurred beyond this blanket when the velocities were high and/or if waves were appreciable.

17. The optimum divergence of the sides of short, circular-to-rectangular, constant height, closed-conduit transitions is 7-1/2° relative to the centerline (Figures 14, 15, 18, and 19). For longer transitions the divergence should be decreased to about 5° per side.

18. For both inlet and outlet flows submergences up to 0.25D over the crown of the pipeline at its junction with the headwall had only moderate effects upon head losses in the broken-back and the 6D-long closed-conduit transitions (Figure 33). Higher submergences tested in the broken-back transitions further increased

the losses. Negative submergences down to -0.17D, which is tantamount to not having the transition full at the headwall, indicated only minor head loss increases for outlet flows.

Figure 7
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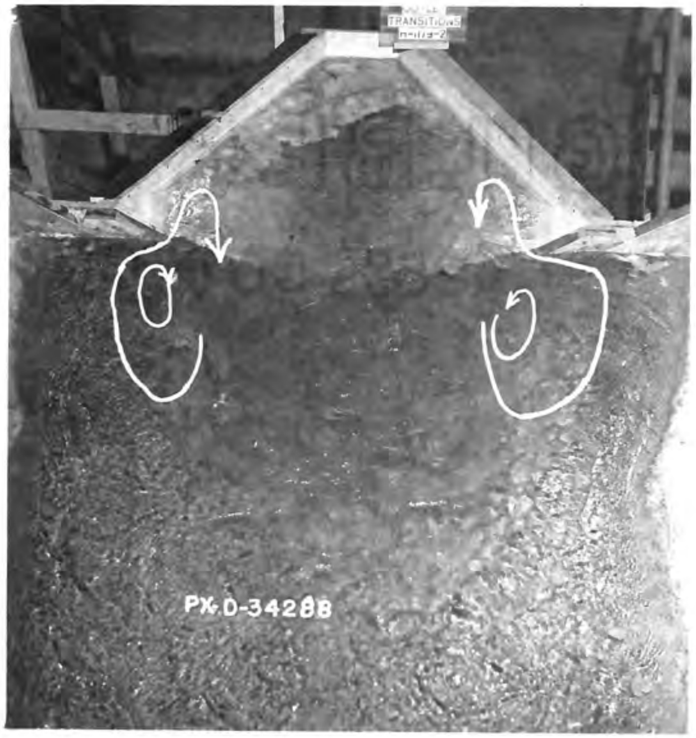


A. Flow is confined mainly to passage center. Eddies occur at sides. Q = 3.0, Vp = 3.8, canal depth = 1.5D.

B. Scour after 45 minutes operation. Q = 3.0, Vp = 3.8, depth = 1.5D.

C. Scour 75 minutes operation with hump. Q = 2.4, Vp = 3.0, depth = 1.5D.

CANAL INLET AND OUTLET TRANSITIONS

Flow Conditions and Scour Patterns--Outlet Flows
Broken-back Transition, 1:8 Slope, 6-inch Rise
Inlet Pipe Horizontal

A. The surface is turbulent with Q = 3.1 cfs, Vp = 4.0 f/s, depth = 1.3D. A boil occurs near the headwall.

B. Scour after 1 hour operation. Q = 2.4 cfs, Vp = 3.0 f/s, depth = 1.3D. Sand was deposited in the transition.

CANAL INLET AND OUTLET TRANSITIONS

Flow Conditions and Scour--Outlet Flows
Broken-back Transition Modified with Warped Surfaces
1:8 Slope, 6-inch Rise. Inlet Pipe on 2:1 Slope

A. The water surface is mildly turbulent.
Q = 4.7 cfs, Vp = 6.0 f/s, depth = 1.3D.

B. Scour after 1 hour operation. Q = 4.
Vp = 6.0, depth = 1.3D.

C. Scour after 45 minutes operation with hood installed in transition. Q = 4.7, Vp = 6.0, depth = 1.3D.

CANAL INLET AND OUTLET TRANSITIONS

Flow Conditions and Scour Patterns--Outlet Flows
Broken-back Transition, 1:8 Slope, 12-inch Rise
Inlet Pipe Horizontal

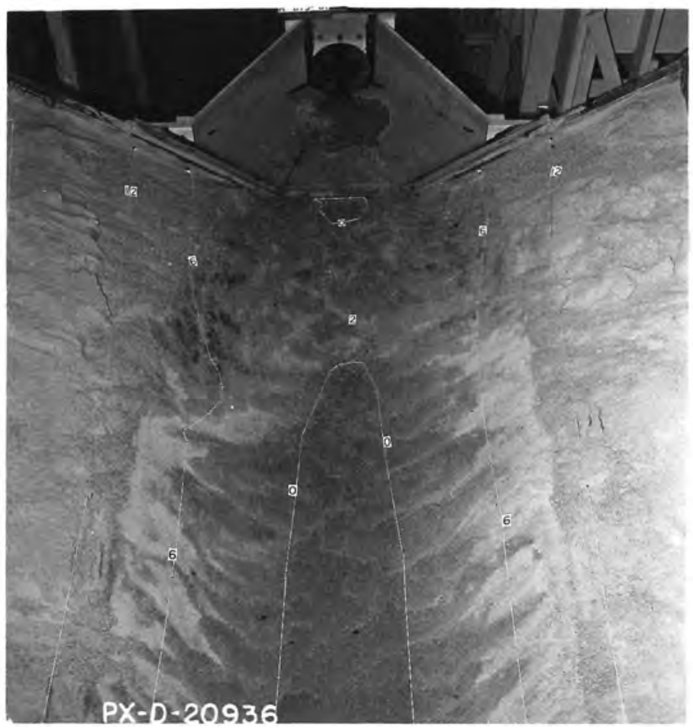
A. The water surface is somewhat rough. Q = 4.7, Vp = 6.0, depth = 1.3D.

B. Scour after 1 hour operation. Q = 4.7, Vp = 6.0, depth = 1.3D.

CANAL INLET AND OUTLET TRANSITIONS

Flow Conditions and Scour Pattern--Outlet Flows
Broken-back Transition, 1:8 Slope, 12-inch Rise
Inlet Pipe on 2:1 Slope

A. Mildly turbulent water surface.
Q = 2.4, Vp = 3.0, depth = 0.8D.

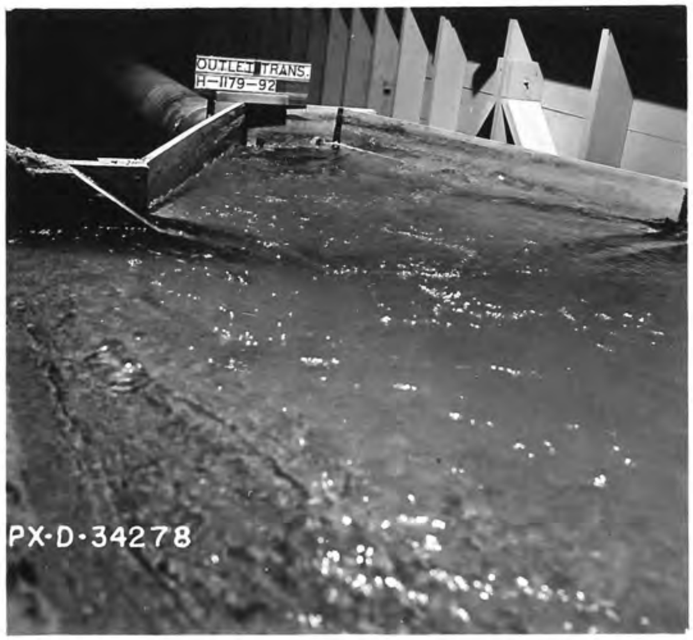


B. Scour after 25 minutes operation each, with flow velocities in pipeline of 2, 2.5, and 3 f/s. Depth = 0.8D.

CANAL INLET AND OUTLET TRANSITIONS

Flow Conditions and Scour Pattern--Outlet Flows
30° Broken-back Transition, 4-inch Rise
Inlet Pipe Horizontal

Figure 12
Report Hyd 492



A. Mildly turbulent water surface.
Q = 2.4, Vp = 3.0, depth = 0.8D.

B. Scour after 30 minutes operation each at flow velocities in pipeline of 2, 2.5, and 3 f/s. Depth = 0.8D.

CANAL INLET AND OUTLET TRANSITIONS

Flow Conditions and Scour Pattern--Outlet Flows
25° Broken-back Transition, 4-inch Rise
Inlet Pipe Horizontal

Figure 13
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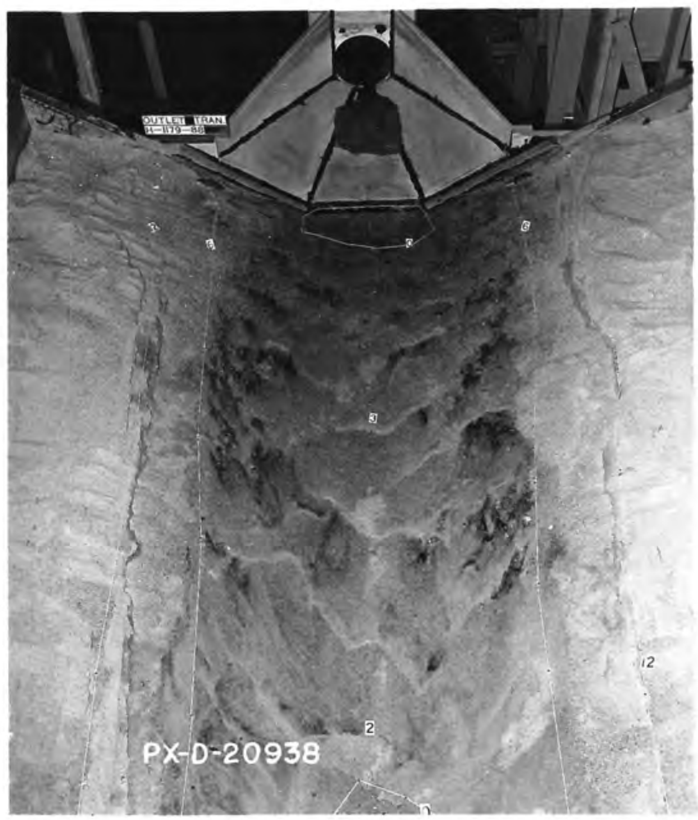
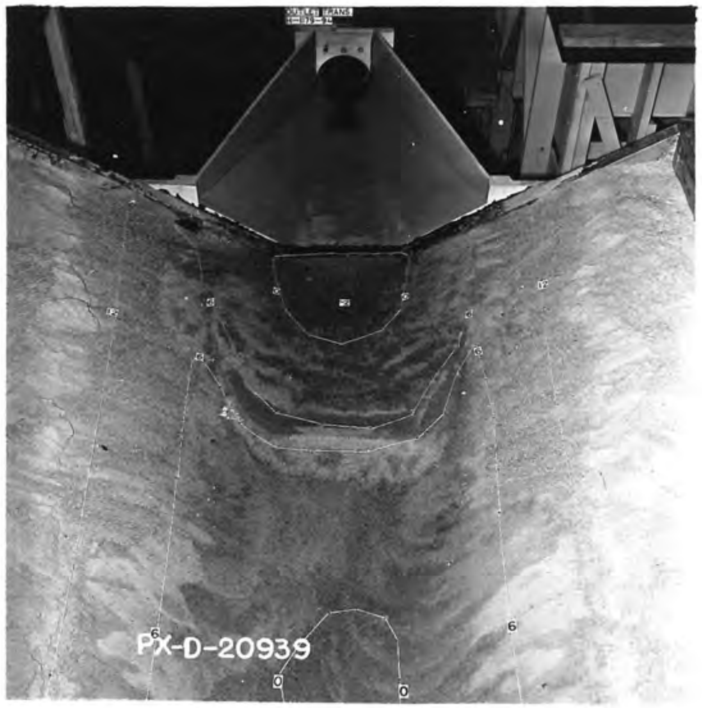
A. Turbulent water surface. Q = 2.4, Vp = 3.0, depth = 0.8D.



B. Scour after 30 minutes operation each at flow velocities in pipeline of 2, 2.5, and 3 f/s. Depth = 0.8D.

CANAL INLET AND OUTLET TRANSITIONS

Flow Conditions and Scour Pattern--Outlet Flows
25° Broken-back Transition, 4-inch Rise
Inlet Pipe on 2:1 Slope



A. Scour after 2-1/2 hours, Vp = 2, 2.5, and 3 f/s; canal depths of 8, 10, and 12 inches. Pipeline horizontal.

B. Scour after 2-1/2 hours, Vp = 2, 2.5, and 3 f/s; canal depths of 8, 10, and 12 inches. Pipeline on 2:1 slope, depth = 0.8D.

CANAL INLET AND OUTLET TRANSITIONS
Scour Patterns--Outlet Flows
20° Broken-back Transition, 4-inch Rise
20-inch Canal Invert

A. Flow conditions. Q = 2.4, Vp = 3 f/s. Scour was negligible.

B. Flow conditions. Q = 4.7, Vp = 6 f/s. Scour occurs at end of riprap.

C. Scour after 1 hour at Q = 3.1 cfs, Vp = 4 f/s and 1 hour at Q = 4.7 cfs, Vp = 6 f/s, canal depth = 1.3D.

CANAL INLET AND OUTLET TRANSITIONS

Flow and Scour in Canal Protected by 4-inch Layer of 1-1/2-inch Gravel. 1:8 Slope, 6-inch Rise Transition with Warped Walls and Horizontal Pipeline--Outlet Flows

Figure 22
Report Hyd 492

A, Water surface is mildly turbulent in transition, but smooth in canal. Q = 4. 7, Vp = 6. 0, canal depth = 1. 3D.

B. Scour after 1 hour operation. Q = 4. 7, Vp = 6. 0, canal depth = 1. 3D.

CANAL INLET AND OUTLET TRANSITIONS

Flow Conditions and Scour Pattern--Outlet Flows
Combination Closed-conduit and Broken-back Transition
1:5. 5 Slope, 12-inch Rise. Inlet Pipe Horizontal

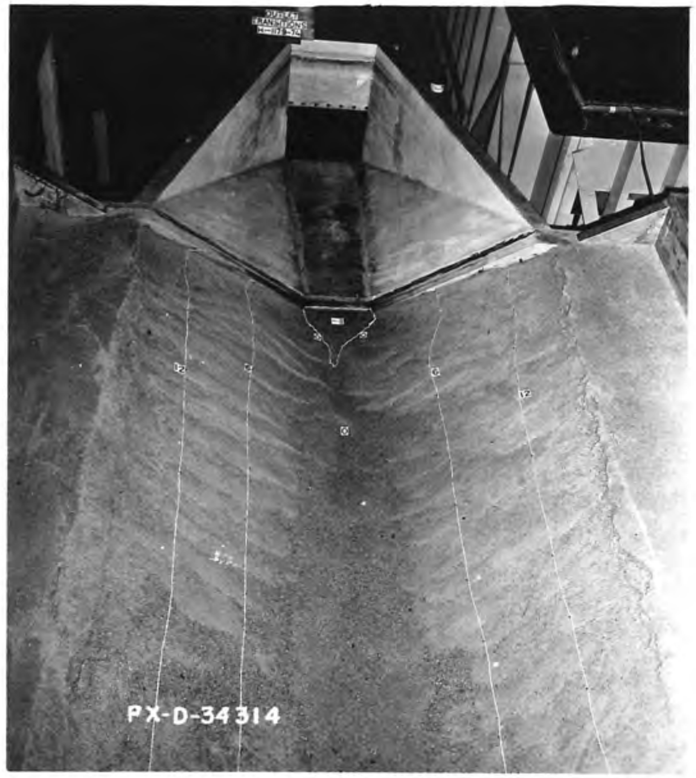
A. A hump occurs in the water surface above the Design 2, hump-like deflector on the floor. Q = 4. 7, Vp = 6. 0, canal depth = 1. 3D.

B. Scour after 1 hour operation 6-3/8-inch-high deflector. Q = 4. 7, Vp = 6. 0 f/s.

C. Scour after 1 hour operation 3-3/8-inch-high deflector. Q = 4. 7, Vp = 6. 0 cfs.

CANAL INLET AND OUTLET TRANSITIONS

Flow Conditions and Scour Patterns--Outlet Flows
Combination Closed-conduit and Broken-back Transition
With Floor Deflector 1:5. 5 Slope, 12-inch Rise. Inlet Pipe Horizontal



A. Scour after 1 hour. Q = 3.1, Vp = 4.0, canal depth = 1.3D.

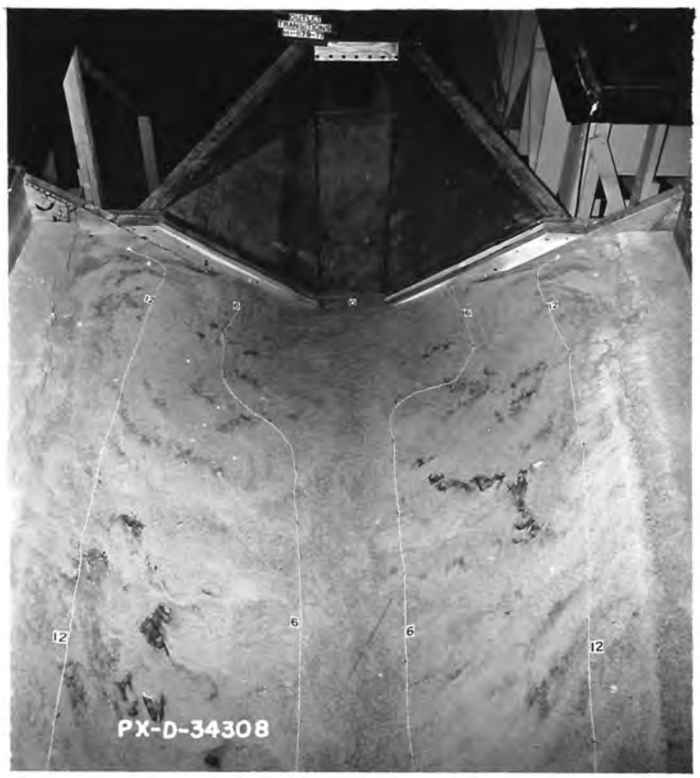
B. Scour after 1 hour. Q = 4.7, Vp = 6.0, **canal depth = 1.3D.**

CANAL INLET AND OUTLET TRANSITIONS

Scour Patterns--Outlet Flows
Combination Closed-conduit and Broken-back Transition
1:5.5 Slope, 12-inch Rise. Inlet Pipe on 2:1 Slope

Figure 25
Report Hyd 492

A. Somewhat turbulent water surfaces occur in the transition and canal. Q = 4.7, Vp = 6.0, canal depth = 1.3D.



B. Scour after 1 hour operation.
Q = 4.7, Vp = 6.0, canal depth = 1.3D.

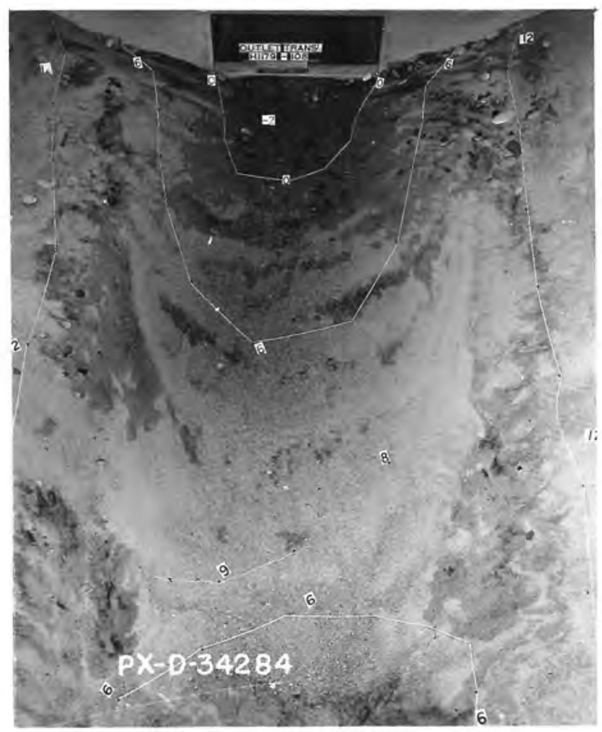
CANAL INLET AND OUTLET TRANSITIONS

Flow Conditions and Scour Pattern--Outlet Flows
Combination Closed-conduit and Broken-back
Transition--Level Invert--Inlet Pipe on 2:1 Slope

Figure 27
Report Hyd 492

A. Scour after 2 hours operation. Q = 3.1, Vp = 4.0, canal depth = 1.0D.

B. Scour after 2 hours operation. Vp = 4.0 f/s, canal depth 1.25D.



C. Scour after 1 hour operation. Vp = 6.0 f/s, canal depth 1.25D.

CANAL INLET AND OUTLET TRANSITIONS

Scour Patterns--Outlet Flows--12- by 28-inch, Closed-conduit Transition--Inlet Pipeline Horizontal

A. 0.83D canal depth.

B. 1.00D canal depth.

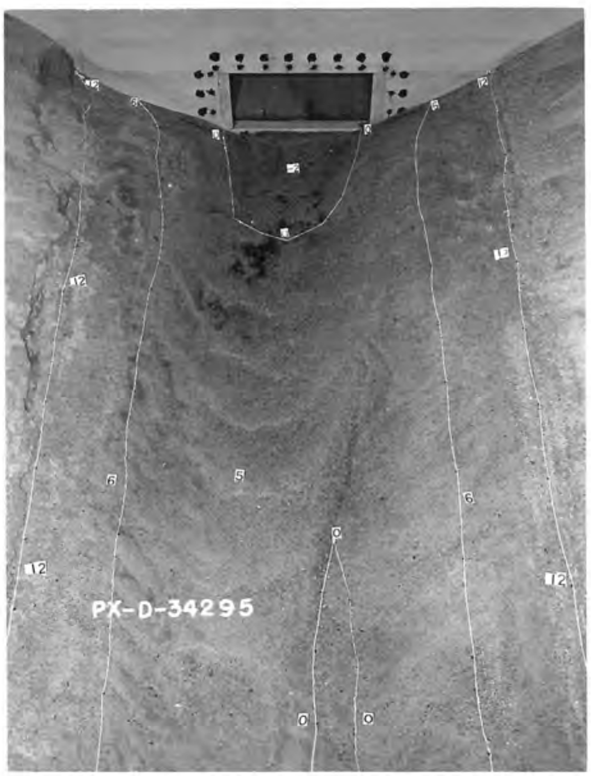
C. 1.25D canal depth.

CANAL INLET AND OUTLET TRANSITION

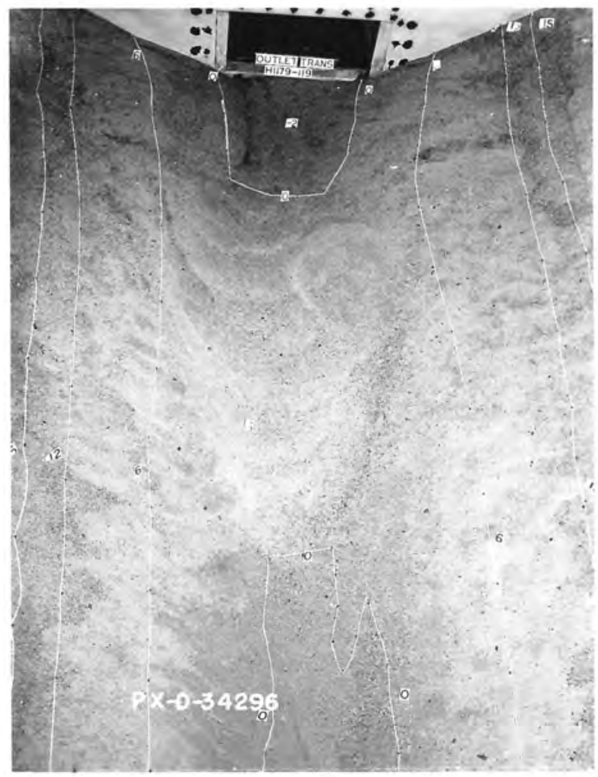
Flow From Outlet Transition--12- by 24-inch Closed-conduit Transition
4 f/s Velocity in Pipeline, Inlet Pipe Horizontal

Figure 30
Report Hyd 492

A. Scour after 1 hour operation.
Canal depth = 0.83D.



B. Scour after 1 hour operation.
Canal depth = 1.00D.



C. Scour after 1 hour operation.
Canal depth = 1.25D.

CANAL INLET AND OUTLET TRANSITIONS

Scour Patterns--Outlet Flows--12- by 24-inch, Closed-conduit Transition
4 f/s Velocity in Pipeline, Inlet Pipe Horizontal

A. 1.00D canal depth.

B. 1.25D canal depth.

C. Erosion after 1 hour, 1.25D depth.

CANAL INLET AND OUTLET TRANSITIONS

Flow Conditions and Scour Patterns--Outlet Flows--12- by 24-inch Transition
6 f/s Velocity, Inlet Pipe Horizontal