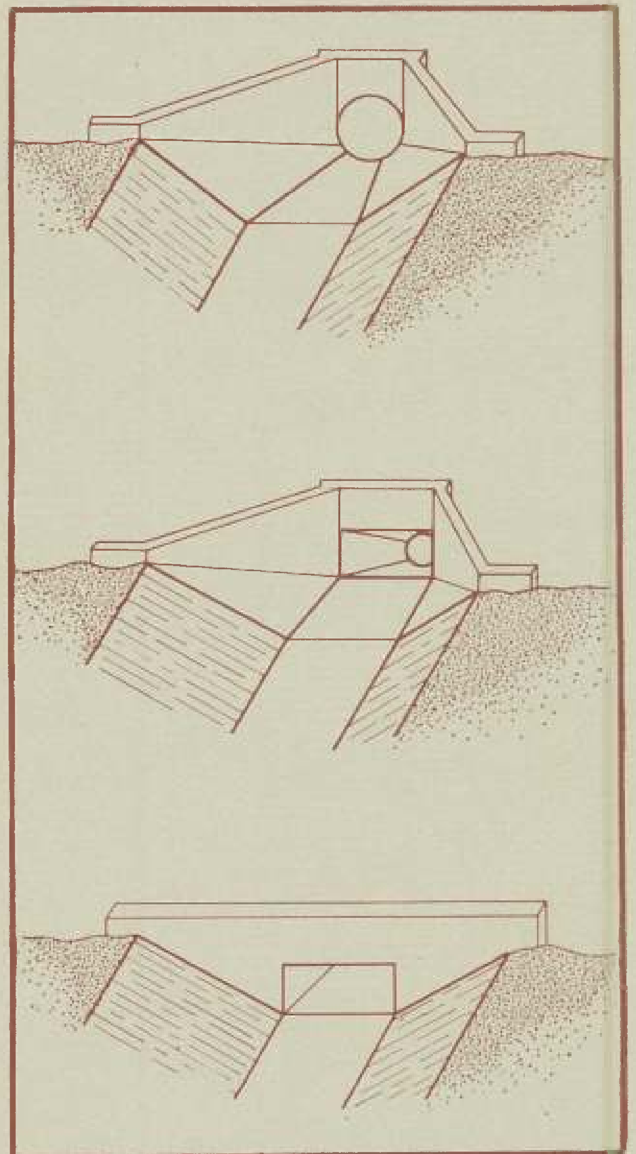
A WATER RESOURCES TECHNICAL PUBLICATION
ENGINEERING MONOGRAPH NO. 33



# Hydraulic Design of Transitions for Small Canals

UNITED STATES DEPARTMENT
OF THE INTERIOR
BUREAU OF RECLAMATION

A WATER RESOURCES TECHNICAL PUBLICATION

Engineering Monograph No. 33

# Hydraulic Design of Transitions for Small Canals

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United States Department of the Interior • Stewart L. Udall, *Secretary*

BUREAU OF RECLAMATION

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***In its assigned function as the Nation's principal natural resource agency, the Department of the Interior bears a special obligation to assure that our expendable resources are conserved, that renewable resources are managed to produce optimum yields, and that all resources contribute their full measure to the progress, prosperity, and security of America, now and in the future.***

ENGINEERING MONOGRAPHS are published in limited editions for the technical staff of the Bureau of Reclamation and interested technical circles in Government and private agencies. Their purpose is to record developments, innovations, and progress in the engineering and scientific techniques and practices that are employed in the planning, design, construction, and operation of Reclamation structures and equipment.

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# Preface

THIS MONOGRAPH is the Bureau of Reclamation's first progress report on methods used and results obtained in determining energy losses and flow characteristics of transitions for moderate and small size canals. The transitions are used to connect pipelines to canals and canals to pipelines. The testing techniques and the conclusions reached in evaluating variables affecting erosion, or scour, in canals adjacent to the transitions are also described. The research studies discussed are part of the Bureau's program of hydraulic research directed toward the development of more efficient and economical designs for water conveyance structures.

The monograph was prepared in the Office of the Chief Engineer, Denver, Colo. It is based on information originally reported in the Bureau's Hydraulics Branch Laboratory Report No. Hyd-492, "Progress Report 1—Research Studies on Inlet and Outlet Transitions for Small Canals," dated July 31, 1962. The author of the monograph presented the paper "Inlet and Outlet Transitions for Canals and Culverts" at the Twelfth Annual Hydraulics Division Conference of the American Society of Civil Engineers, at University Park, Pa., August 6–9, 1963. The paper embraces essentially the same information contained in the laboratory report.

The results achieved through the studies described in this monograph were obtained by the close cooperation between the staffs of the Canals Branch, Division of Design, and the Hydraulics Branch, Division of Research. The data were compiled over a period of several years. Many engineers assisted in the performance of the tests and in analyzing the data obtained.

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## LIST OF FIGURES

# Introduction

THE BUREAU OF RECLAMATION water resource development projects embracing irrigation distribution systems and related structures require large numbers of reinforced concrete transitions for pipelines which discharge into canals, as well as transitions for canals that discharge into pipelines. When the transitions are small—for example, for 36-inch or smaller pipes—the special forming of concrete required for warped transitions is usually not justified. For these small transitions, the broken-back type of transition made entirely of plane surfaces is used, as illustrated in Figure 1.

In early designs of Bureau of Reclamation canal systems incorporating broken-back transitions as outlets from pipelines to canals, a loss value of $0.3\left(\frac{V_p^2}{2g}-\frac{V_c^2}{2g}\right)$ was used. In this expression, $V_p$ is flow velocity in the pipeline, $V_c$ is velocity in the canal, and $g$ is the acceleration due to gravity (approximately 32 feet per second per second). This 0.3 loss factor was derived intuitively and is apparently not supported by experimental data. A similarly derived loss of $0.1\left(\frac{V_p^2}{2g}-\frac{V_c^2}{2g}\right)$ was used when the transitions served as inlets from canals to pipelines.

FIGURE 1.—*Typical field installation of a broken-back transition. Siphon outlet at station 521, West Lateral, Rogue River Basin Project, Oreg. November 1961.*

In recent years, there has been concern about the possibility of actual losses being greater than



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the 0.3 and 0.1 values used in the early designs. If the losses were appreciably greater, the structures could be restrictions in the distribution systems 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. Bureau engineers therefore believed it important to conduct tests to determine the actual losses and to make any necessary changes in the design values. The investigations would be extended, as necessary, to obtain designs with lower losses.

A second important factor was the amount of scour or erosion in the canal immediately downstream from transitions when they were used as outlets. The effect of changes in the upward slope of the transition invert, in the entering pipeline, or in the rate of divergence of the transition sidewalls on canal erosion 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 Hydraulics Branch of the Bureau's engineering laboratories in Denver, Colo. This monograph discusses results that have been obtained thus far, and the equipment and procedures used in the tests.

# Test Equipment

MOST OF THE STUDIES were made using a canal section contained within a wooden structure supported about 5 feet above the laboratory floor, and equipped with suitable piping and instrumentation (Figs. 2 and 3A). The canal bed 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 lay on 1½ to 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 (Fig. 3A).

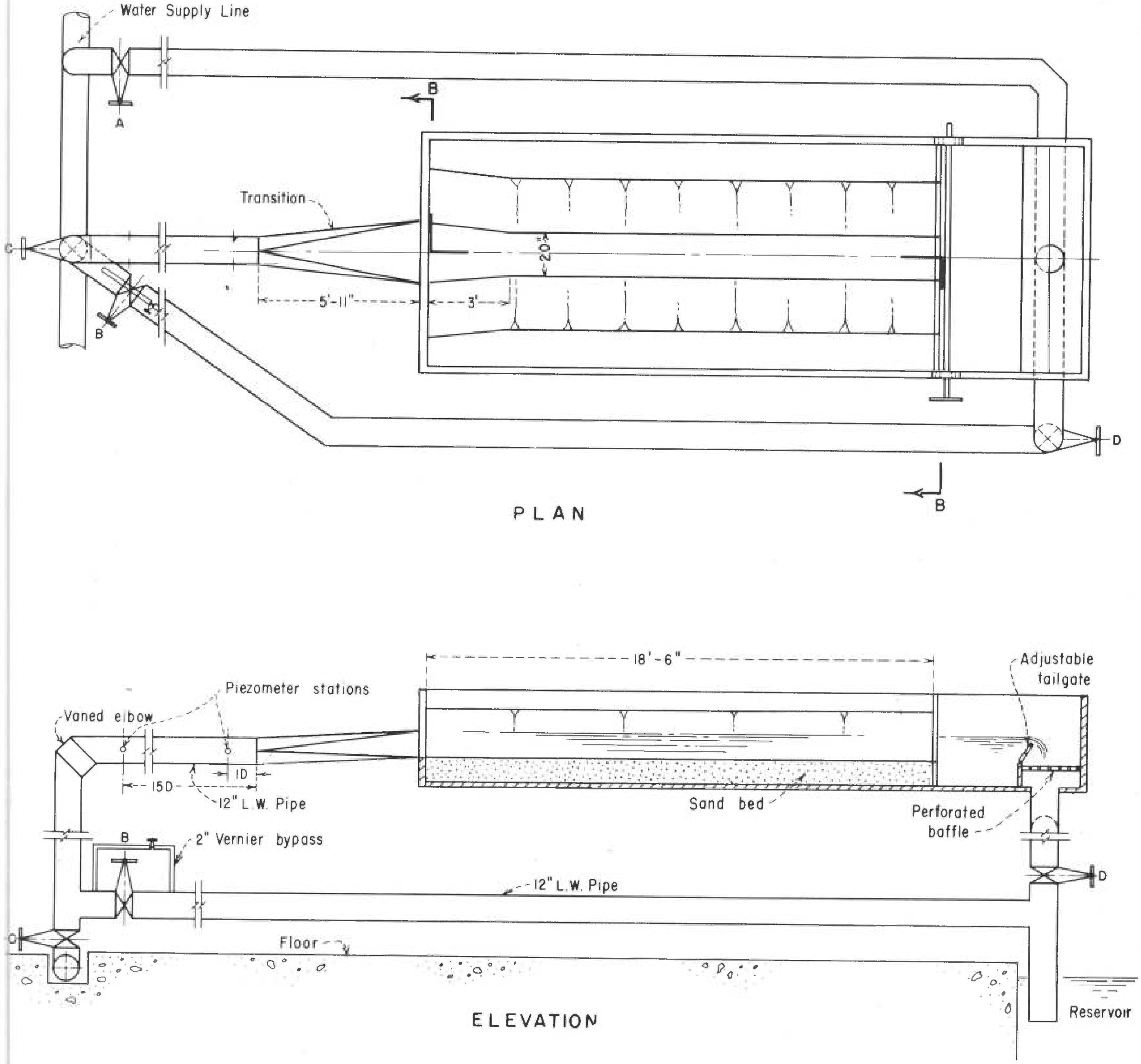
In early studies, the transitions were tested only as outlet structures with the flow passing from the pipeline, through the transition, and into the canal. The 12-inch-diameter pipe that supplied water to the transition was placed level in part of the tests, and on a 2 to 1 upslope to the transition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

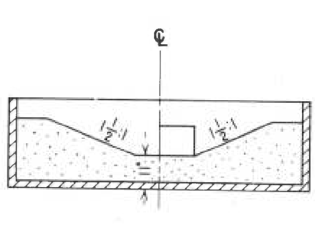
In later studies, the transitions were studied both as inlets and outlets. The piping was modified so that, in addition to the flow described above, water could be introduced into the canal from the tailgate end of the box to produce inlet flows into the transition and pipeline (Fig. 2).

Water leaving the test section was controlled by the tailgate when outlet flow tests were made, and by appropriate valves in the piping system when inlet tests were made. The desired canal water surface elevations could therefore be maintained.

The broken-back transitions, Figure 4, were constructed of ¾-inch plywood and were treated to avoid excessive water absorption. In some cases, warped sections made of concrete were constructed within the confines of broken-back transitions (Fig. 5). The closed-conduit transitions were usually made of 16-gage sheet steel with external reinforcement, as required, and with ⅜-inch-thick steel flanges upstream and downstream.

The rate of water flow supplied to the model was measured by calibrated permanently installed Venturi meters in the laboratory's central water supply system. Water was taken from the laboratory's reservoir, pumped through the meters and

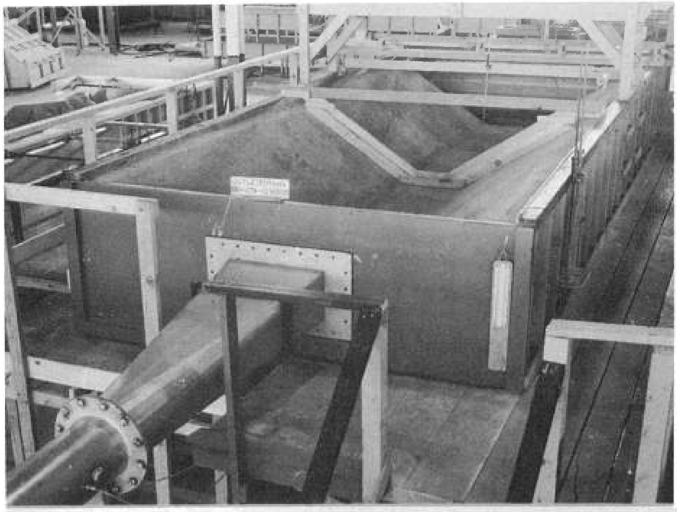


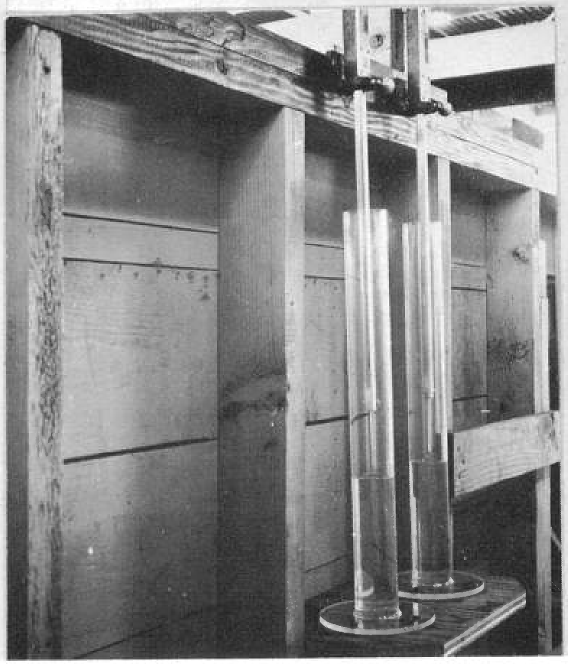

| | TO OPERATE AS AN | |
|---|---|---|
| | INLET TRANSITION | OUTLET TRANSITION |
| CLOSE | C, D | A, B |
| OPEN | A, B | C, D |

TABLE OF VALVE POSITIONS FOR INLET AND OUTLET FLOWS

FIGURE 2.—*Schematic views of test facilities.*



A. Canal model with template in place for shaping sand bed. Closed conduit transition installed with horizontal approach pipe.



B. Stilling wells and point gages for determining hydraulic grade in 12-inch pipeline.

C. Point gage for determining water surface elevation in canal.

FIGURE 3.—*Hydraulic model and instrumentation.*

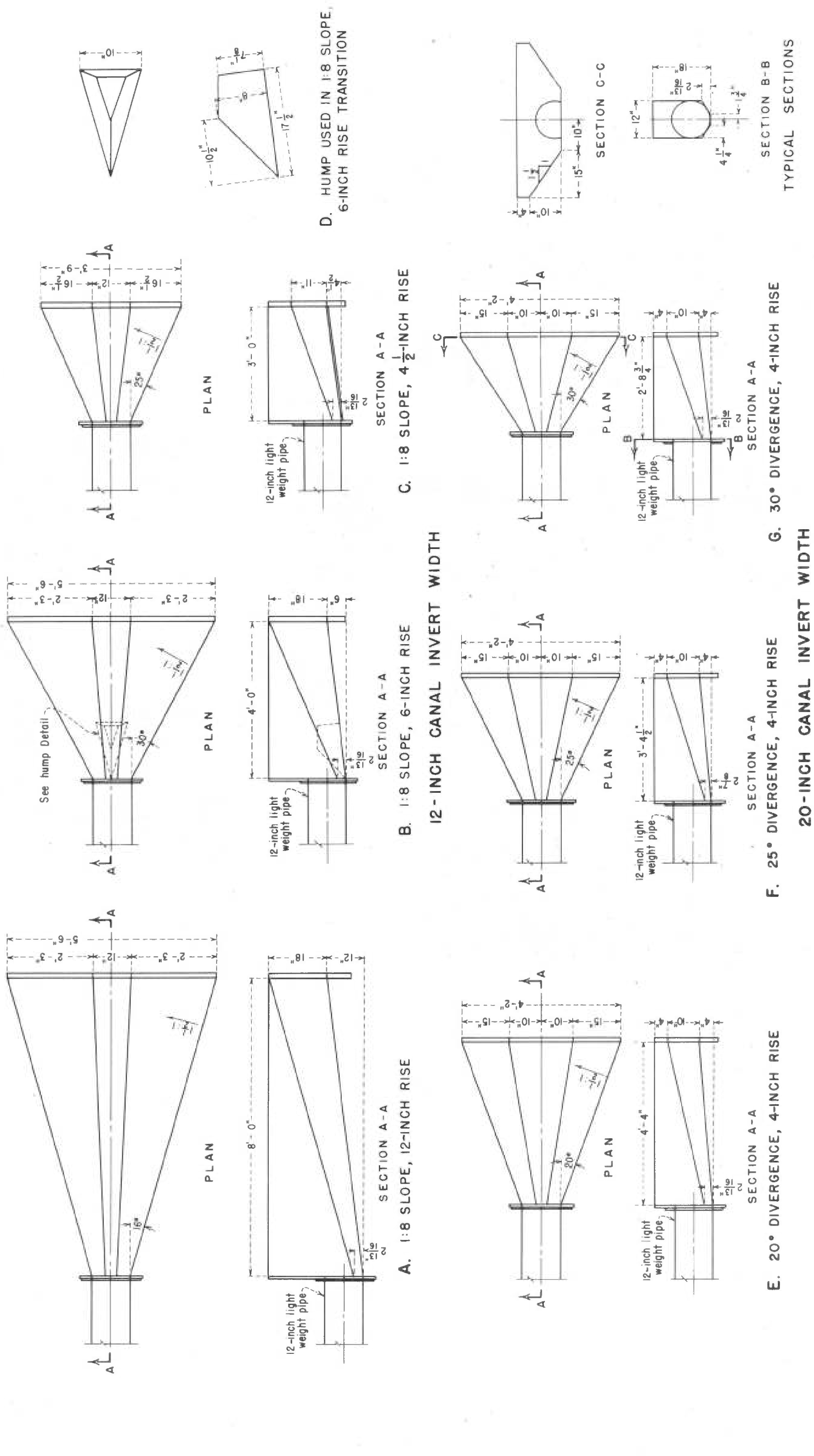
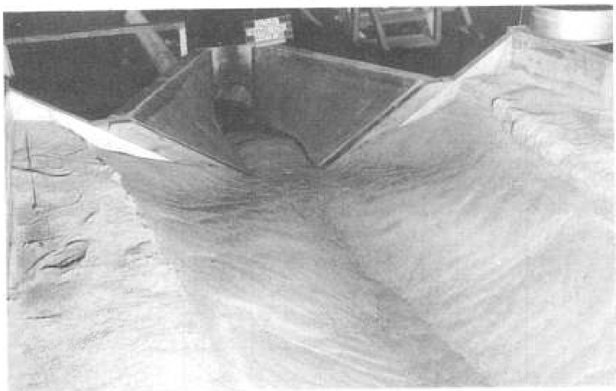



FIGURE 4.—*Broken-back transitions and flow-spreading hump.*

A. The surface is turbulent with Q=3.1 c.f.s., $V_p$=4.0 f.p.s., depth=1.3 D. A boil occurs near the headwall.



B. Scour after 1 hour operation. Q=2.4 c.f.s., $V_p$=3.0 f.p.s., depth=1.3 D. Sand was deposited in the transition.

FIGURE 5.—*Flow conditions and scour. Outlet flow, broken-back transition modified with warped surfaces. 1 to 8 slope, 6-inch rise. Inlet pipe on 2 to 1 slope.*

the model, and returned to the reservoir for recirculation.

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 (15 D) downstream from the junction of the transition with the pipeline. Two piezometers, one on each side of the pipe on the horizontal centerline, were used to obtain the pressures. The pressure leads were connected to 1½-inch-diameter stilling wells, and point gage measurements were made of the free water surfaces within the wells (Fig. 3B). The water surface elevations in the canal were measured with point gages 15 feet downstream from the junction of the transition with the canal for outlet flows, and 4 feet upsteam from this junction for inlet flows (Fig. 3C).

Throughout the test program difficulty was experienced in obtaining consistent data because the quantities being determined were small compared to the possible errors. Establishing water surface elevations was of primary importance and several procedures were used to relate accurately the reading of one gage to another. Best results were obtained by filling the model to a 12-inch canal depth with no normal flow occurring, and after allowing considerable time for turbulence and oscillations to cease, obtaining the gage relationships.

During test runs, data were taken as soon as proper conditions were established and before extensive canal erosion occurred. Accurately determining the canal water surface was complicated by the fact that submerged instruments could not be used because it was necessary to move the canal template up and down the model to reshape the bed. A water surface point gage was used instead, and repeated readings were made during a test run to obtain a good average figure for the undulating, wavy, or choppy water surfaces. Small stilling wells worked satisfactorily for the piezometer readings for the pipeline.

Operator technique had considerable influence on the observed data and with training and experience the accuracy and consistency improved greatly. Despite the efforts and precautions taken, the basic problem remained of seeking small values among relatively large potential errors. Therefore, the data presented herein may be accepted as representative, but minor variations and scatter can be expected.

In the closed-conduit outlet transition tests, velocity measurements were made of the flow in the pipeline 1.3 D upstream from the transition inlet and at the transition exit (Figs. 6, 7, and 8). For inlet flows, velocity traverses were made in the pipeline 1.1 D downstream from the junction of the transition with the pipeline. A 3/16-inch-diameter total head tube was used for measurements in the pipeline, and a ¼-inch-diameter Prandtl-type pitot-static tube was used for measurements at the canal end of the transition.

Studies of closed-conduit expanding-outlet transitions were also made with a test facility using air as the flowing fluid (Fig. 9). 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

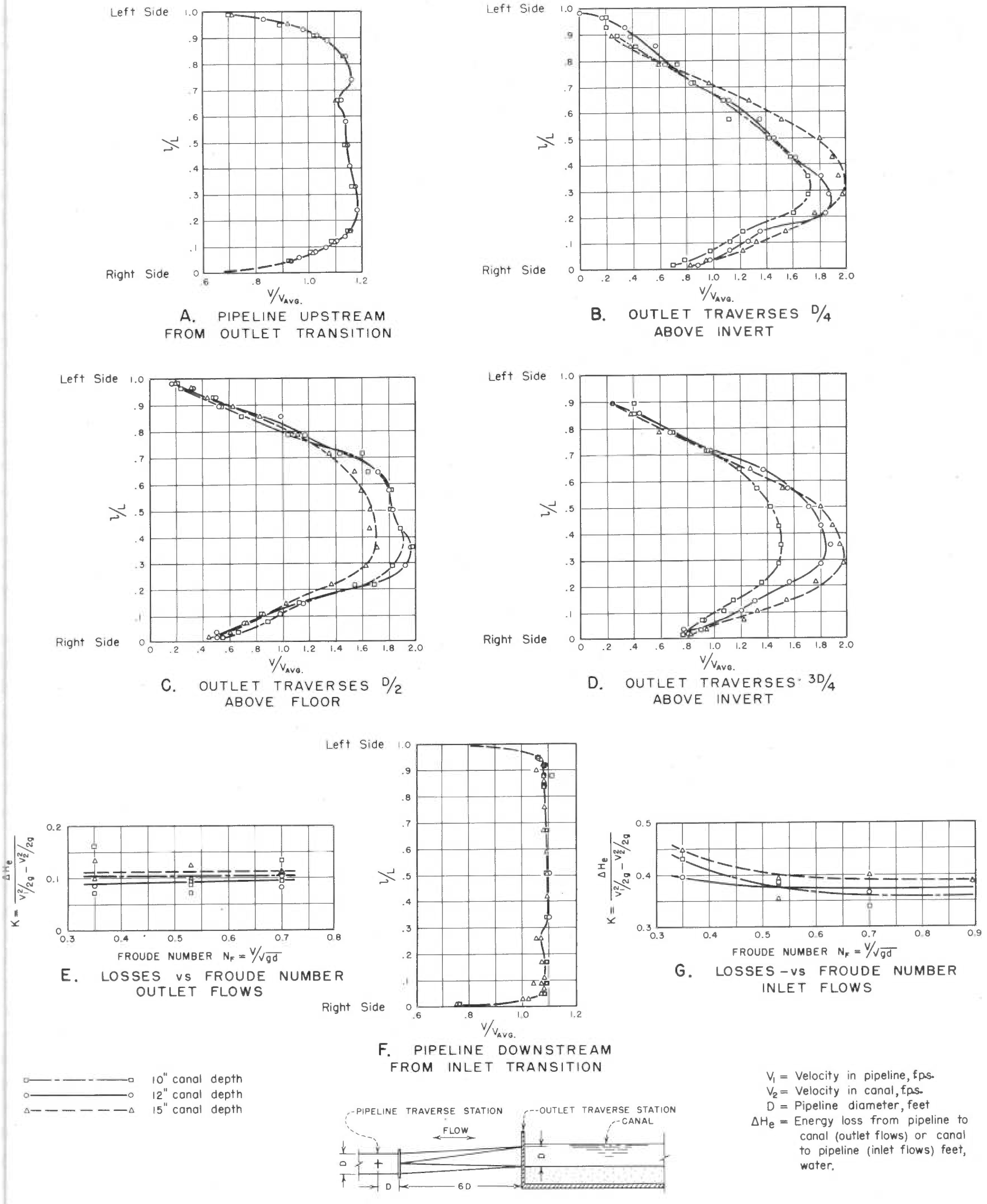



FIGURE 6.—*Velocity distributions and loss factors, 12- by 28-inch closed-conduit transition, horizontal pipeline.*

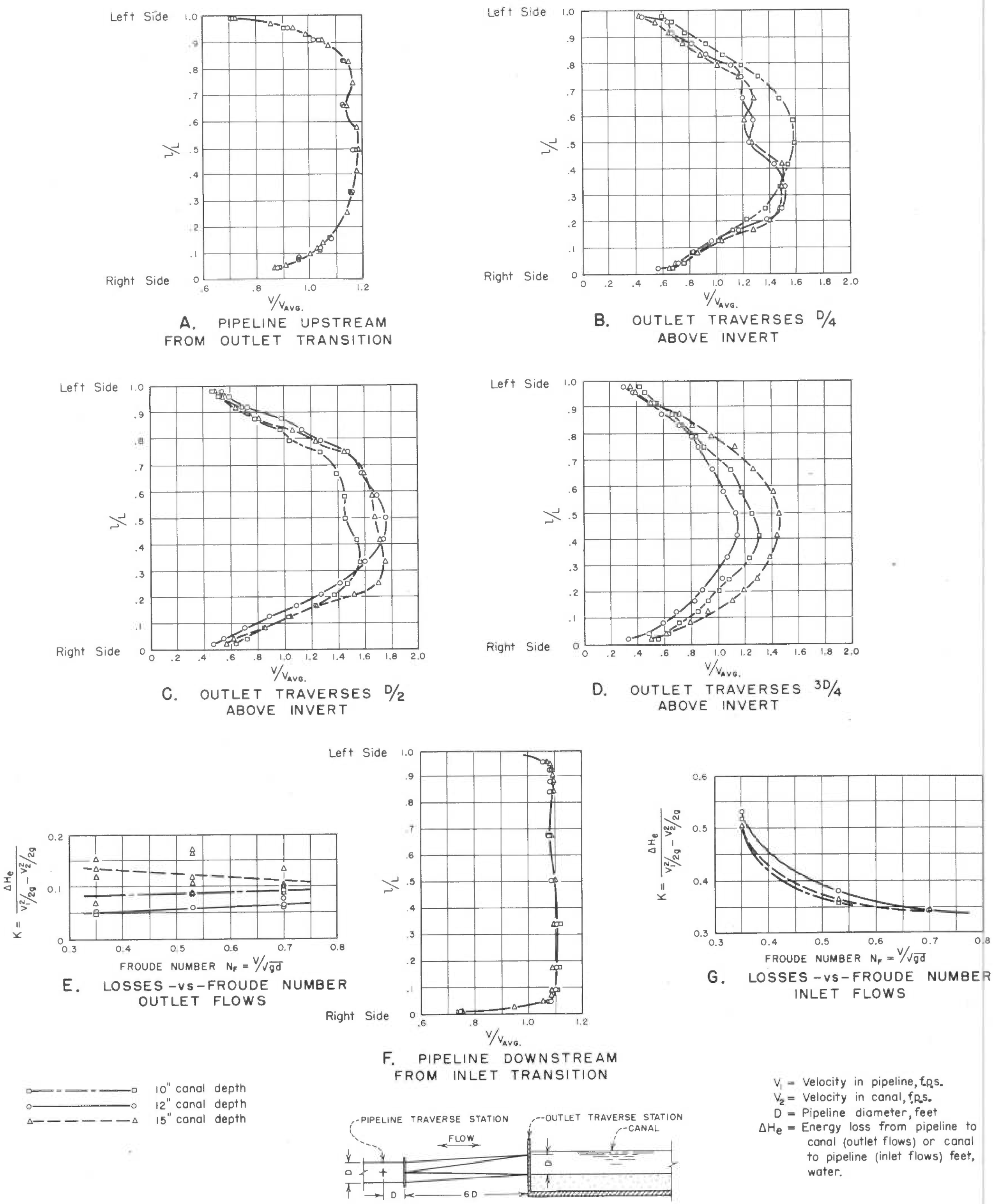



FIGURE 7.—*Velocity distributions and loss factors, 12- by 24-inch closed-conduit transition, horizontal pipeline.*

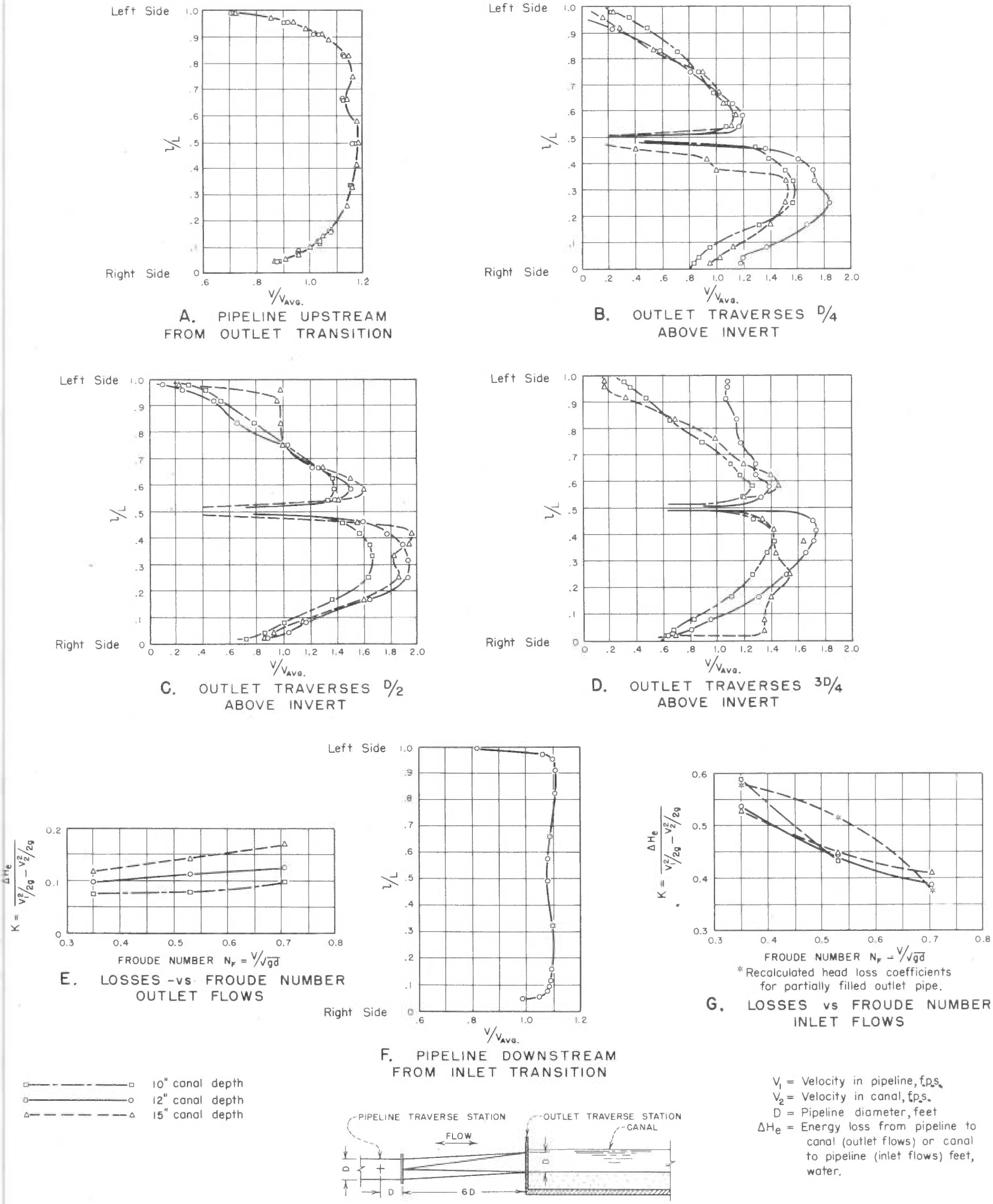



FIGURE 8.—*Velocity distributions and loss factors, 12- by 24-inch closed-conduit transition with divider pier, horizontal pipeline.*

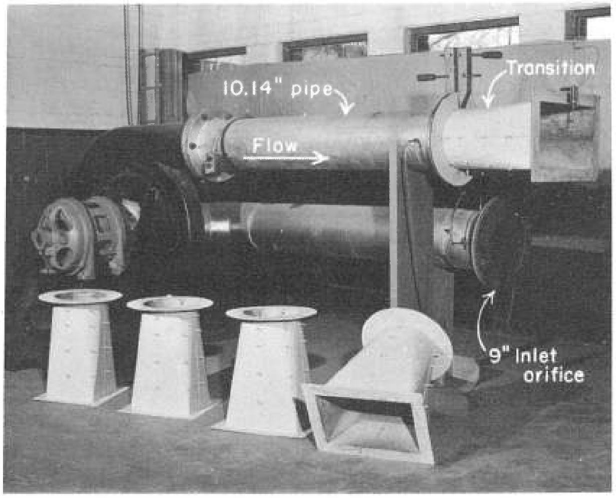



FIGURE 9.—*Air model facilities for testing closed-conduit transitions. Air was drawn from the atmosphere, through the measuring orifice, and then through the outlet transition.*

into the expanding transition being tested, and back into the atmosphere. The 10.14-inch-diameter pipeline was 63 inches long (6.2 D) for most of the tests, and was lengthened to 207 inches (20.4 D) for the remaining tests. A piezometer located 4½ inches from the outlet was used with the 6.2 D-long pipe, and two diametrically opposed wall taps located 1 diameter from the outlet were used with the 20.4 D-long pipe.

Five expanding transitions made of light-gage sheet metal were tested (Figs. 9 and 10). All had inlets 10.14 inches in diameter, and all were 10.14 inches high at the outlet. The sidewalls expanded at the rates of 0°, 2½°, 5°, 7½°, and 10° relative to the centerline, and the lengths were 20.28 inches, or 2 D. Piezometers were placed along the centerline of the right sidewall and along the invert, and also along the diverging transition element from the 45° point above the invert of the circular inlet to the lower righthand corner at the rectangular outlet (Fig. 11F). The piezometers were at stations 2, 5, 10, and 15 inches from the transition inlet.

Vertical and horizontal centerline traverses were obtained near the transition inlets and at the outlets with a ⅛-inch-diameter Prandtl-type pitot-static tube. Pressures were measured with water-filled U-tubes, and the readings were recorded in tenths and hundredths of an inch. Readings were taken after sufficient time had elapsed for conditions to stabilize after starting the flow. The pitot-static tube was set at the desired position, the pressures read, and the tube moved to the next position. This process was repeated until the full effective length of the relatively short tube was within the conduit. The tube was then removed and inserted in the diametrically opposite station so the full length of each traverse could be covered. In addition to readings obtained with the pitot-static tube, readings were taken of the head differential across the 9-inch-diameter inlet orifice on the 12-inch inlet line to the blower, and at the wall taps in the 10.14-inch supply pipe. The barometric pressure and temperature were also measured so atmospheric densities could be computed.

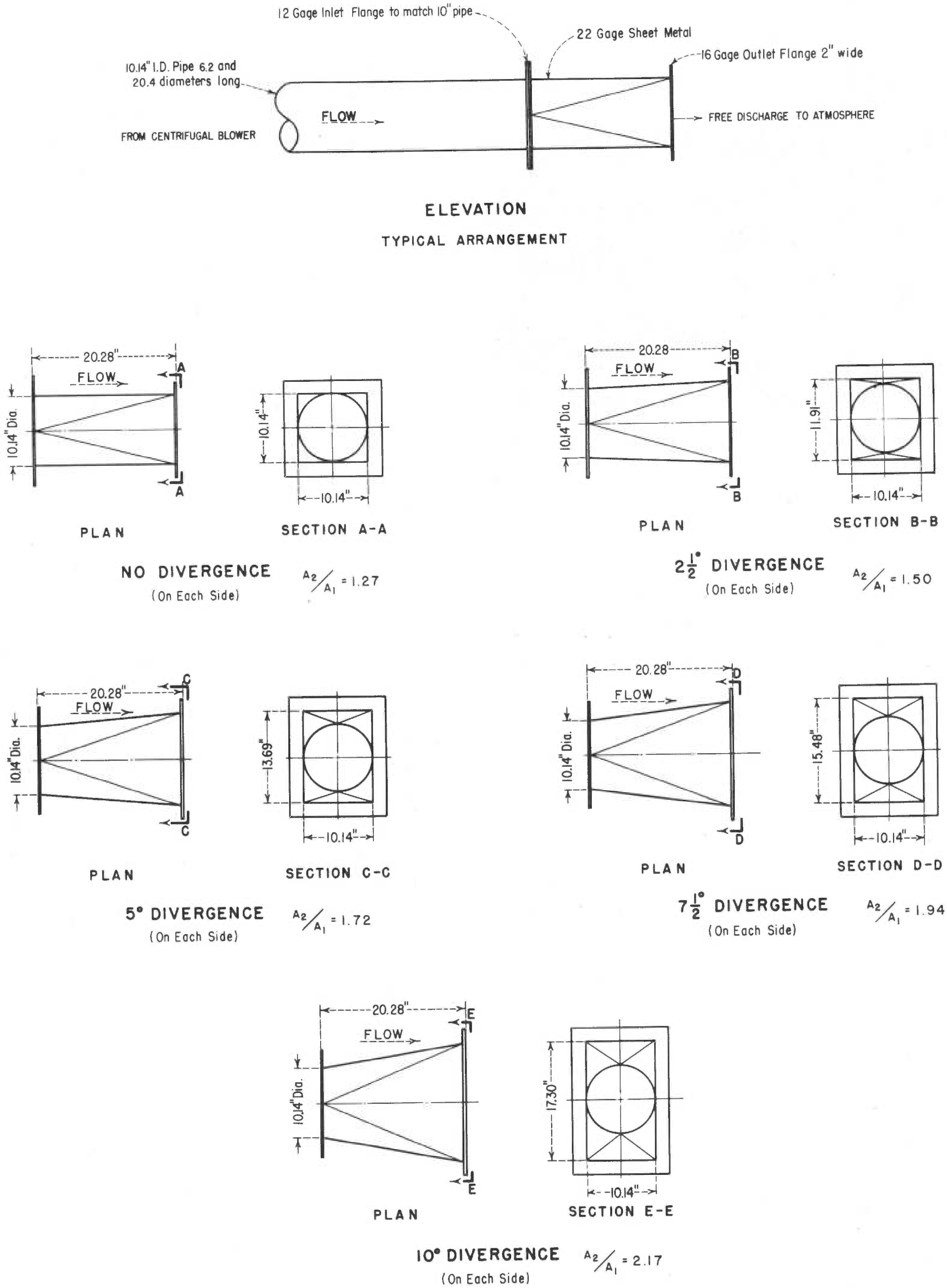



FIGURE 10.—*Closed-conduit transitions tested on air model.*

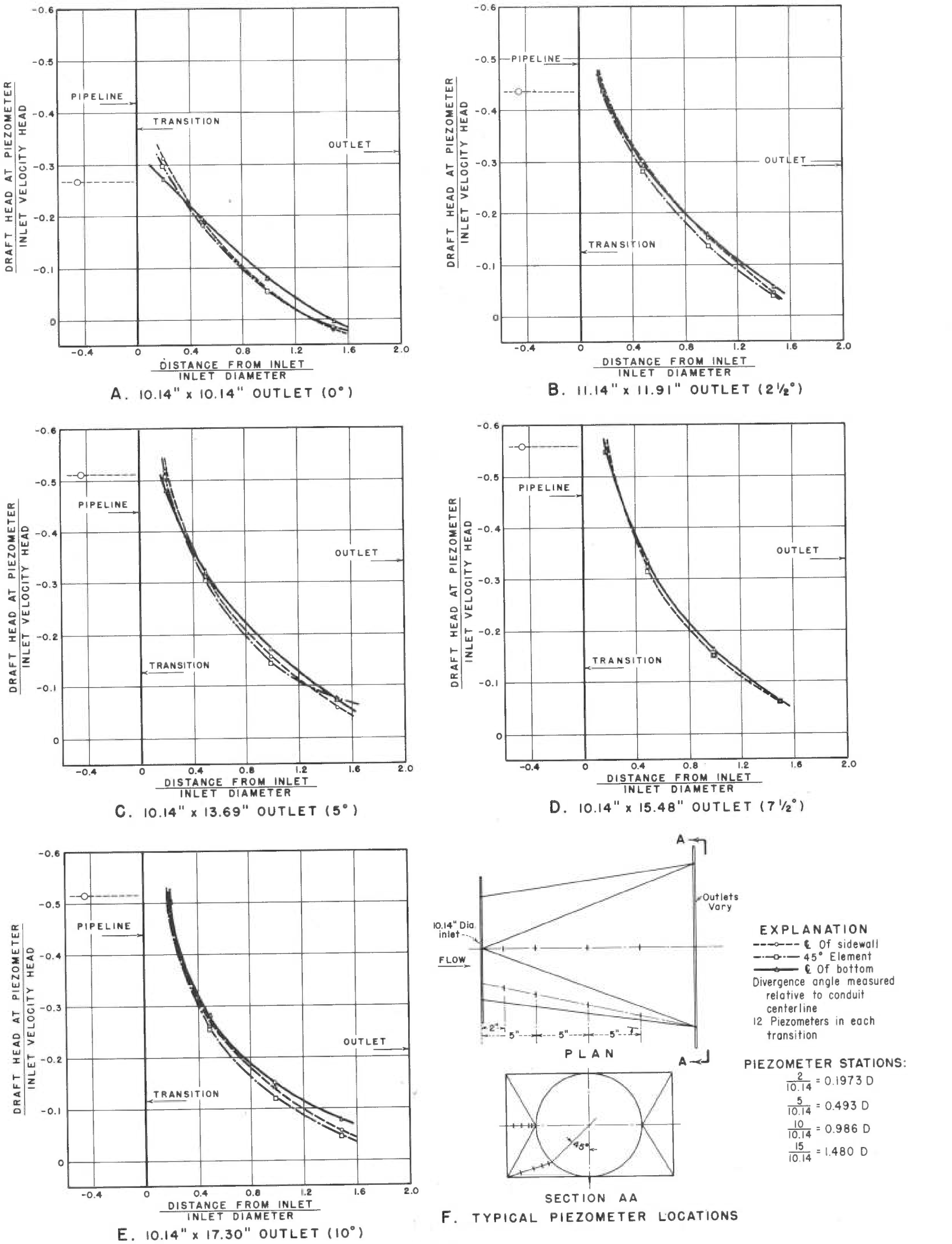



FIGURE 11.—*Wall pressures on closed-conduit transitions used as outlets. Approach pipe 6.2 D long. Air model tests.*

# Investigation

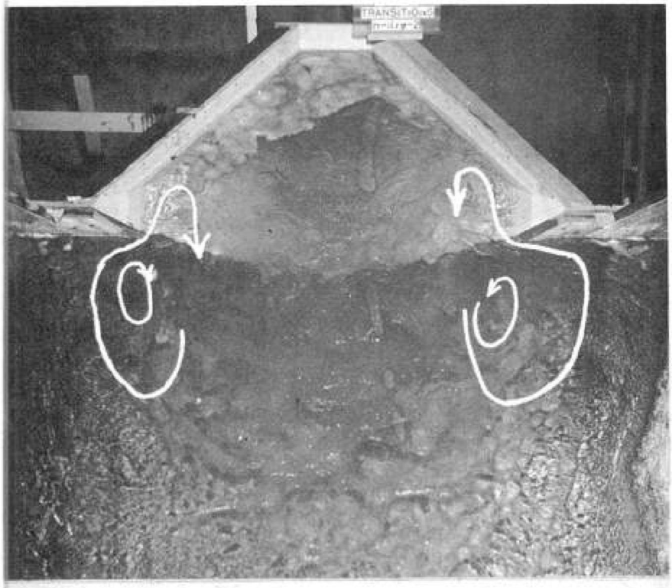
## Open-Channel Transitions

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 (Figs. 4, 5, and 12 through 19). 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 Figure 20. Loss factors for all the broken-backed transitions, including the ones modified with warped surfaces, were about 0.5 to 0.7 $\Delta h_v$ for outlet flows. The term $\Delta h_v$ 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.

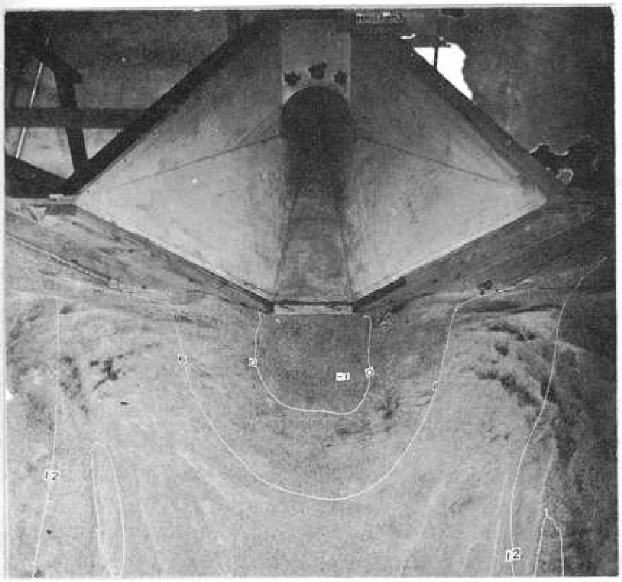
The flow patterns through all the open transitions were generally similar. If the inlet pipe entered the transition horizontally, the stream issuing from it tended to move straight through the transition into the canal, and large eddies moved upstream well up into the transition along either side of the jet (Fig. 12A). 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 (Fig. 12B).

If the inlet pipeline was sloped, the stream issuing from it rose in the transition to the water surface to cause higher surface velocities and waves that scoured the canal slopes (Fig. 5A). 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 (Fig. 5B).

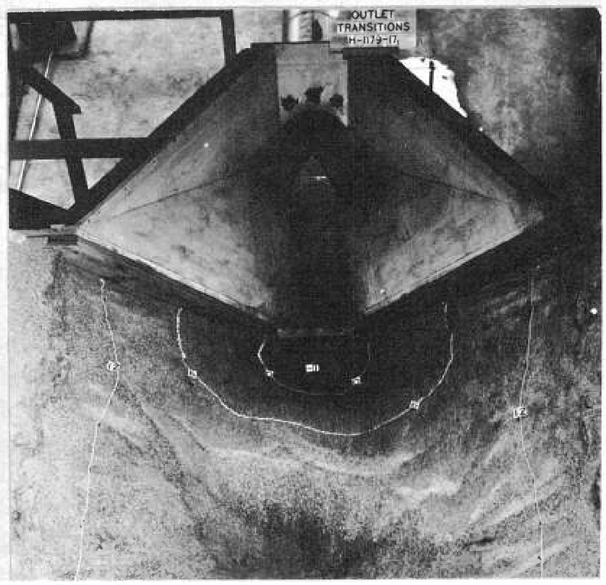
Changes in the slope of the transition invert from a minimum of 1 to 13.1 to a maximum of 1 to 5.5 had no apparent effect on the losses encountered or on the scour produced (Figs. 5, 12 through 19, and 20). Likewise, changes in divergence angles of the outer walls of the transitions from the minimum of 16° per side to a maximum of 30° per side had no appreciable effect, although



A. Flow is confined mainly to passage center. Eddies occur at sides. Q=3.0 c.f.s., $V_D$=3.8 f.p.s., canal depth=1.5 D.

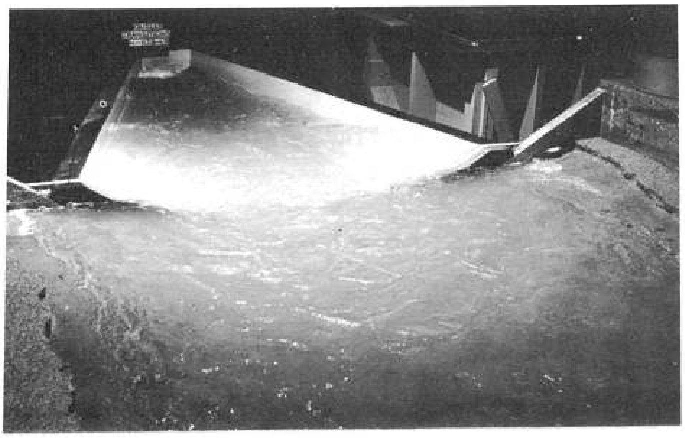


B. Scour after 45 minutes operation. Q=3.0 c.f.s., $V_D$=3.8 f.p.s., depth=1.5 D.

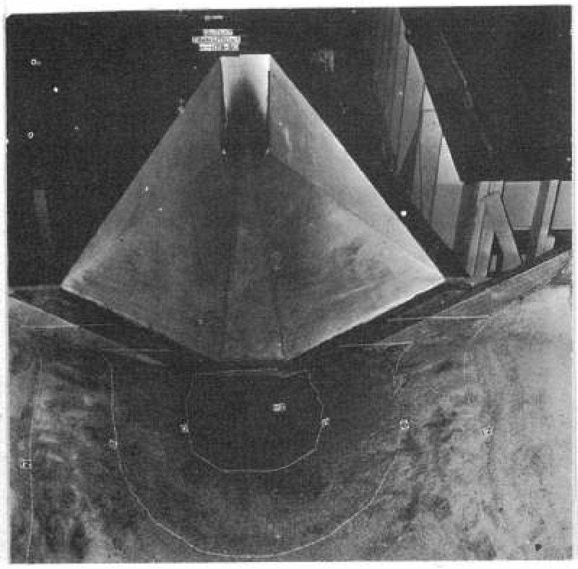



C. Scour after 75 minutes operation with hump. Q=2.4 c.f.s., $V_D$=3.0 f.p.s., depth=1.5 D.

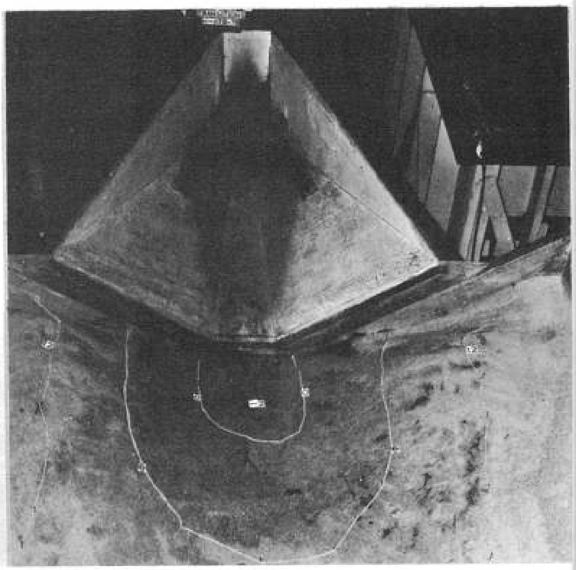
FIGURE 12.—*Flow conditions and scour patterns, outlet flows, broken-back transition, 1 to 8 slope, 6-inch rise, inlet pipe horizontal.*



A. The water surface is mildly turbulent. Q=4.7 c.f.s., $V_p$=6.0 f.p.s., depth=1.3 D.

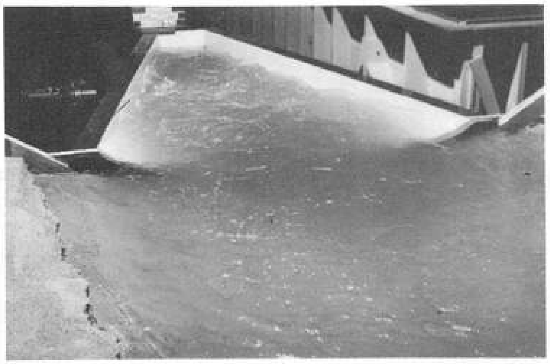


B. Scour after 1 hour operation. Q=4.7 c.f.s., $V_p$=6.0 f.p.s., depth=1.3 D.

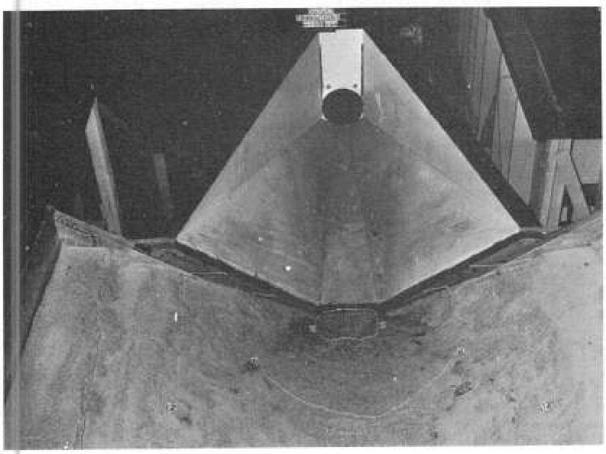


C. Scour after 45 minutes operation with hood installed in transition. Q=4.7 c.f.s., $V_p$=6.0 f.p.s., depth=1.3 D.

FIGURE 13.—*Flow conditions and scour patterns, outlet flows, broken-back transition, 1 to 8 slope, 12-inch rise, inlet pipe horizontal.*



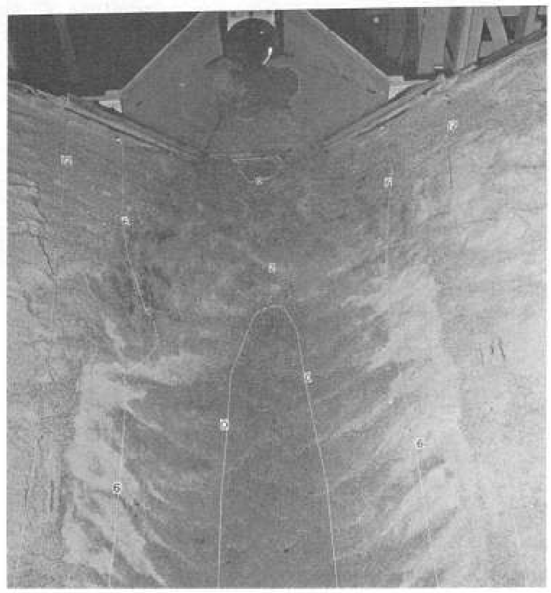
A. The water surface is somewhat rough. $Q=4.7$ c.f.s., $V_p=6.0$ f.p.s., depth=1.3 D.



B. Scour after 1 hour operation. $Q=4.7$ c.f.s., $V_p=6.0$ f.p.s., depth=1.3 D.

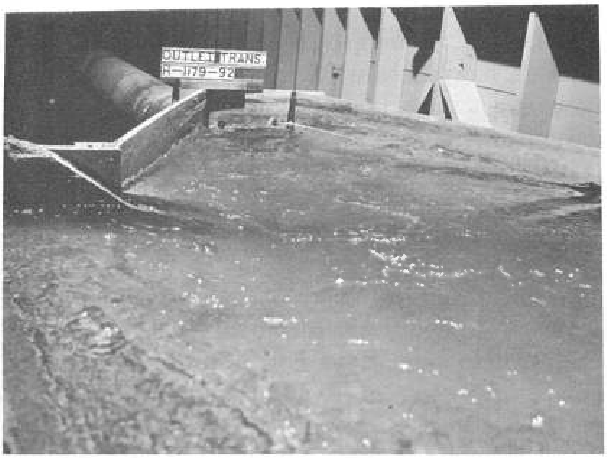
FIGURE 14.—*Flow conditions and scour pattern, outlet flows, broken-back transition, 1 to 8 slope, 12-inch rise inlet pipe on 2 to 1 slope.*

A. Mildly turbulent water surface. $Q=2.4$ c.f.s., $V_p=3.0$ f.p.s., depth=0.8 D.



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

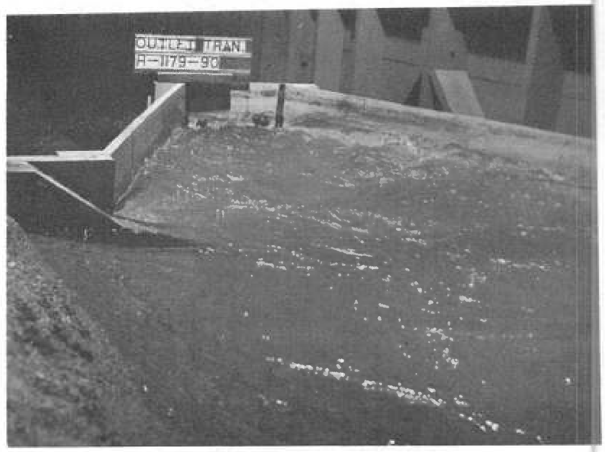
FIGURE 15.—*Flow conditions and scour pattern, outlet flows, 30° broken-back transition, 4-inch rise, inlet pipe horizontal.*



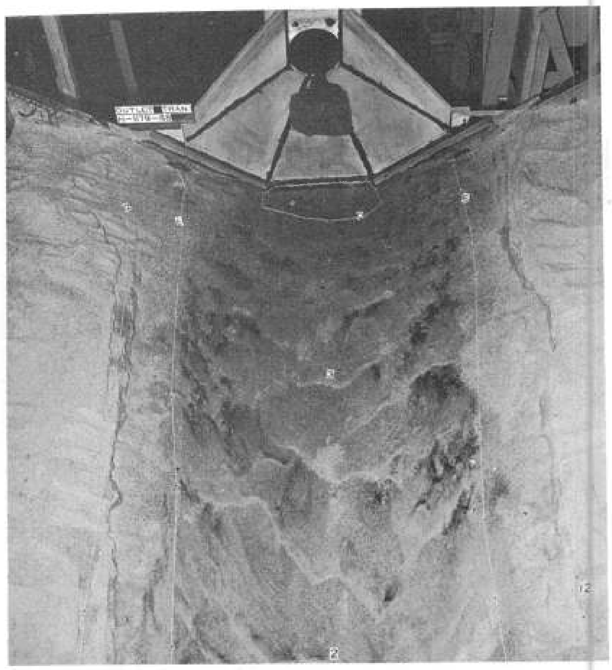

A. Mildly turbulent water surface. Q=2.4 c.f.s., $V_p$=3.0 f.p.s., depth=0.8 D.

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

FIGURE 16.—*Flow conditions and scour pattern, outlet flows, 25° broken-back transition, 4-inch rise, inlet pipe horizontal.*

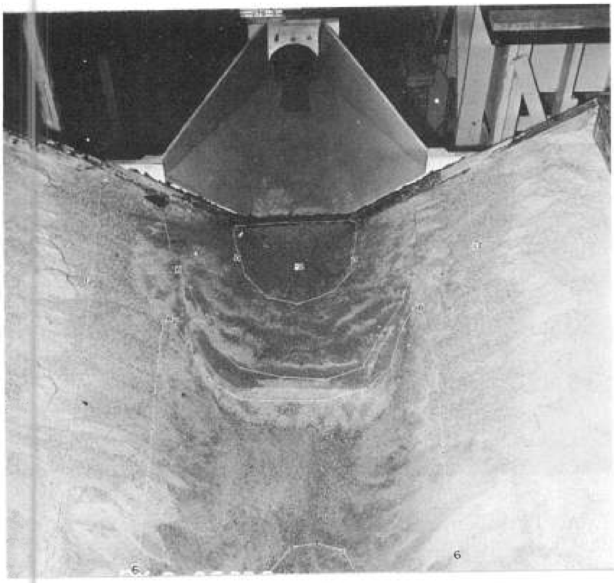



A. Turbulent water surface. Q=2.4 c.f.s., $V_p$=3.0 f.p.s., depth=0.8 D.

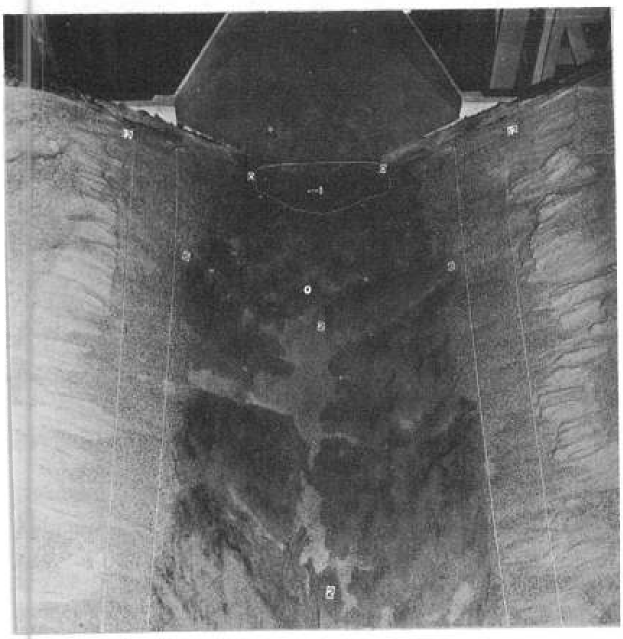


B. Scour after 30 minutes operation each at flow velocities in pipeline of 2, 2.5, and 3 f.p.s., depth=0.8 D.

FIGURE 17.—*Flow conditions and scour pattern, outlet flows, 25° broken-back transition 4-inch rise, inlet pipe on 2 to 1 slope.*



A. Scour after 2½ hours, $V_p$=2, 2.5, and 3 f.p.s., canal depths of 8, 10, and 12 inches. Pipeline horizontal.



B. Scour after 2½ hours, $V_p$=2, 2.5, and 3 f.p.s., canal depths of 8, 10, and 12 inches. Pipeline on 2 to 1 slope, depth=0.8 D.

FIGURE 18.—*Scour patterns, outlet flows, 20° broken-back transition, 4-inch rise, 20-inch canal invert.*

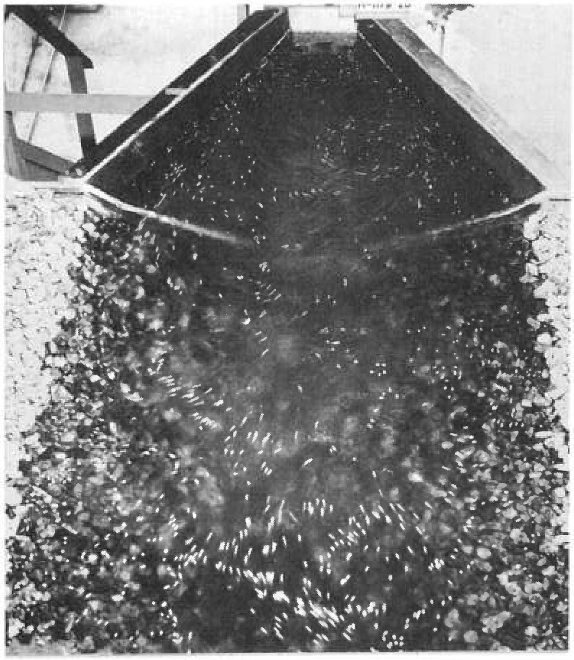
limited data show a slightly lower loss for a 25° angle. Even altering the outer walls by constructing warped surfaces within the confines of the broken-back walls was not significantly effective.

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 (Fig. 21A).

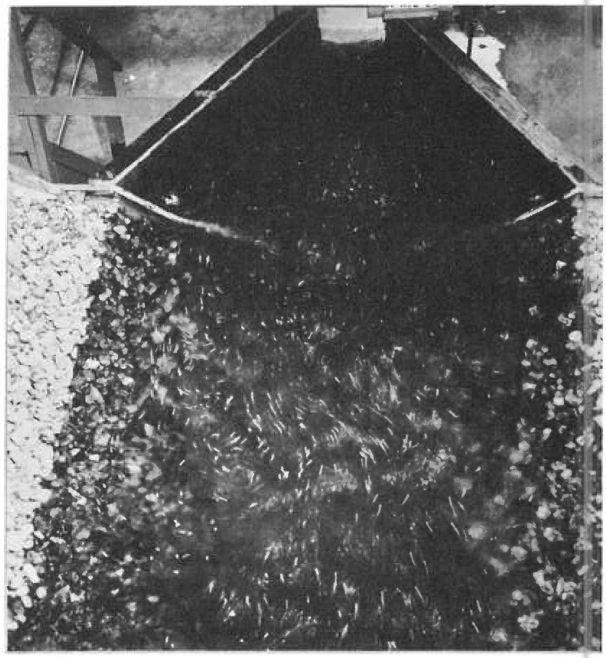
Several "humps" were placed on the transition invert a short distance downstream from the pipe exit to help spread the flow and obtain smoother conditions with more uniform velocities at the canal entrance (Figs. 4, 12C, 22B, and 22C). Improvements in flow conditions and reductions in scour occurred, but the losses were either unaffected or increased. The usefulness of humps appeared to be restricted to reducing scour in the canal.

A qualitative measurement of riprap needed to control scour in the canal was obtained by placing a 4-inch-thick layer of 1½-inch gravel in the first 6 feet of the model canal. Tests were made with the 1 to 8 slope, 6-inch rise transition with warped walls, and a horizontal inlet pipeline (Fig. 19). 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 pipeline velocity of 6 feet per second, the rock remained stable, but considerable erosion occurred in the sand farther downstream (Fig. 19C). It was apparent that this 1½-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 rocks of other sizes.

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 to 8 sloping transition (Fig. 20) cut the loss factor from about 0.6 to less than 0.5. A longer hood that created a 4 D-long closed conduit within a 1 to 8 transition (Fig. 13C) and had a maximum divergence rate of 8½° per side reduced the loss factor to 0.21. A



A. Flow conditions. $Q=2.4$ c.f.s., $V_p=3$ f.p.s. Scour was negligible.



B. Flow conditions. $Q=4.7$ c.f.s., $V_p=6$ f.p.s. Scour occurs at end of riprap.

C. Scour after 1 hour at $Q=3.1$ c.f.s., $V_p=4$ f.p.s., and 1 hour at $Q=4.7$ c.f.s., $V_p=6$ f.p.s., canal depth=1.3 D.

FIGURE 19.—*Flow and scour in canal protected by 4-inch layer of 1½-inch gravel, 1 to 8 slope, 6-inch rise transition with warped walls and horizontal pipeline, outlet flows.*

| DESCRIPTION | RISE | SUBMERGENCE OF OUTLET CROWN | FLOW DEPTH IN CANAL | CANAL INVERT WIDTH | CLOSED CONDUIT SECTION | TRANSITION LENGTH | PIPE LINE | INLET LOSS FACTOR K' | OUTLET LOSS FACTOR K | SCOUR |
|---|---|---|---|---|---|---|---|---|---|---|
| Broken-Back, 1:8 upward slope | 1.00 D | 1.30 D | 1.30 D | 1.00 D | — | 8.00 D | HORIZONTAL | — | 0.66 | EXTENSIVE |
| Same trans., with long hood to confine flow | " | " | " | " | YES | " | " | — | 0.21 | EXTENSIVE |
| *Modified Warp, 1:8 upward slope | " | " | " | " | — | " | " | — | 0.67 | EXTENSIVE |
| Broken-Back, 1:8 upward slope | " | " | " | " | — | " | 2:1 SLOPE | — | 0.66 | MODERATE |
| Broken-Back, 1:8 upward slope | 0.50 D | 0.80 D | 1.30 D | 1.00 D | — | 4.00 D | HORIZONTAL | — | 0.66 | EXTENSIVE* |
| Same trans., pyramid hump on floor | " | " | " | " | — | " | " | — | 0.76 | MODERATE |
| *Modified Warp, 1:8 upward slope | " | " | " | " | — | " | " | — | 0.56 | EXTENSIVE |
| Same trans., short hood over pipe outlet | " | " | " | " | YES | " | " | — | 0.47 | EXTENSIVE |
| Same trans., 12" round to 12" square pipe trans. | " | " | " | " | YES | (4.0 + 1.5) D | " | — | 0.34 | MODERATE |
| Same trans., 12" round to 12" square pipe trans. | " | " | " | " | YES | (4.0 + 3.0) D | | — | 0.37 | MODERATE |
| *Modified Warp, 1:8 upward slope | " | " | " | " | — | 4.00 D | 2:1 SLOPE | — | 0.67 | EXTENSIVE |
| Broken-Back, 1:8 upward slope | 0.38 D | 0.68 D | 1.30 D | 1.00 D | — | 3.00 D | 2:1 SLOPE | 0.34 | 0.87† | EXTENSIVE |
| 20° Broken-Back, 1:13.1 upward slope | 0.33 D | 0 | 0.67 D | 1.67 D | — | 4.35 D | HORIZONTAL | — | 0.59 | EXTENSIVE |
| 20° Broken-Back, 1:13.1 upward slope | " | 0.17 D | 0.83 D | " | — | " | " | 0.43 | 0.61 | EXTENSIVE |
| 20° Broken-Back, 1:13.1 upward slope | " | 0.33 D | 1.00 D | " | — | " | " | 0.47 | 0.75 | EXTENSIVE |
| 20° Broken-Back, 1:13.1 upward slope | " | 0 | 0.67 D | " | — | " | 2:1 SLOPE | 0.79† | 0.62 | EXTENSIVE |
| 20° Broken-Back, 1:13.1 upward slope | " | 0.17 D | 0.83 D | " | — | " | " | 0.65 | 0.63 | EXTENSIVE |
| 20° Broken-Back, 1:13.1 upward slope | " | 0.33 D | 1.00 D | " | — | " | " | 0.66 | 0.67 | EXTENSIVE |
| 25° Broken-Back, 1:10.2 upward slope | 0.33 D | 0 | 0.67 D | 1.67 D | — | 3.39 D | HORIZONTAL | — | 0.44 | EXTENSIVE |
| 25° Broken-Back, 1:10.2 upward slope | " | 0.17 D | 0.83 D | " | — | " | " | 0.40 | 0.49 | EXTENSIVE |
| 25° Broken-Back, 1:10.2 upward slope | " | 0.33 D | 1.00 D | " | — | " | " | 0.47 | 0.65 | EXTENSIVE |
| 25° Broken-Back, 1:10.2 upward slope | " | −0.17 D | 0.50 D | " | — | " | 2:1 SLOPE | 0.22† | — | EXTENSIVE |
| 25° Broken-Back, 1:10.2 upward slope | " | 0 | 0.67 D | " | — | " | " | 0.51 | 0.45 | EXTENSIVE |
| 25° Broken-Back, 1:10.2 upward slope | " | 0.17 D | 0.83 D | " | — | " | " | 0.52 | 0.47 | EXTENSIVE |
| 25° Broken-Back, 1:10.2 upward slope | " | 0.33 D | 1.00 D | " | — | " | " | 0.53 | 0.59 | EXTENSIVE |
| 30° Broken-Back, 1:8.3 upward slope | 0.33 D | 0 | 0.67 D | 1.67 D | — | 2.75 D | HORIZONTAL | — | 0.61 | EXTENSIVE |
| 30° Broken-Back, 1:8.3 upward slope | " | 0.17 D | 0.83 D | " | — | " | " | 0.30 | 0.63 | EXTENSIVE |
| 30° Broken-Back, 1:8.3 upward slope | " | 0.33 D | 1.00 D | " | — | " | " | 0.37 | 0.71 | EXTENSIVE |
| 30° Broken-Back, 1:8.3 upward slope | " | 0 | 0.67 D | " | — | " | 2:1 SLOPE | 0.75† | 0.62 | EXTENSIVE |
| 30° Broken-Back, 1:8.3 upward slope | " | 0.17 D | 0.83 D | " | — | " | " | 0.62 | 0.63 | EXTENSIVE |
| 30° Broken-Back, 1:8.3 upward slope | " | 0.33 D | 1.00 D | " | — | " | " | 0.55 | 0.70 | EXTENSIVE |
| B-B, 1:5.5 slope, with 12" round to 12"x 18$\frac{3}{8}$" rect. | 1.00 D | 1.30 D | 1.30 D | 1.00 D | YES | (5.5 + 2.0) D | HORIZONTAL | — | 0.39 | EXTENSIVE |
| Same trans., with 6$\frac{3}{8}$" hump on floor | " | " | " | " | YES | " | " | — | 0.42 | LIGHT |
| Same transition, no hump | " | " | " | " | YES | " | 2:1 SLOPE | — | 0.21 | MODERATE |
| B-B, level, with 12" round to 12"x 18$\frac{3}{8}$" rect. | 0 | 0.30 D | " | " | YES | " | " | — | 0.15 | LIGHT |
| Closed conduit, 12" round to 12"x 28" rect. | 0.33 D | −0.17 D | 0.83 D | 1.67 D | YES | 6.00 D | HORIZONTAL | 0.38 | 0.10 | MODERATE |
| Closed conduit, 12" round to 12"x 28" rect. | " | 0 | 1.00 D | " | YES | " | " | 0.39 | 0.10 | MODERATE |
| Closed conduit, 12" round to 12"x 28" rect. | " | 0.25 D | 1.25 D | " | YES | " | " | 0.41 | 0.11 | MODERATE |
| Closed conduit, 12" round to 12"x 24" rect. | 0.33 D | −0.17 D | 0.83 D | 1.67 D | YES | 6.00 D | HORIZONTAL | 0.36 | 0.08 | MODERATE |
| Closed conduit, 12" round to 12"x 24" rect. | " | 0 | 1.00 D | " | YES | " | " | 0.38 | 0.06 | MODERATE |
| Closed conduit, 12" round to 12"x 24" rect. | " | 0.25 D | 1.25 D | " | YES | " | " | 0.37 | 0.12 | MODERATE |
| Closed conduit, with center pier | " | −0.17 D | 0.83 D | " | YES | " | " | 0.43 | 0.08 | MODERATE |
| Closed conduit, with center pier | " | 0 | 1.00 D | " | YES | " | " | 0.44 | 0.11 | MODERATE |
| Closed conduit, with center pier | " | 0.25 D | 1.25 D | " | YES | " | " | 0.45 | 0.14 | MODERATE |
| Closed conduit, 12" square to 12"x 24" rect. | 0.33 D | 0.25 D | 1.25 D | 1.67 D | YES | 6.00 D | HORIZONTAL | 0.51 | 0.23 | MODERATE |
| Closed conduit, 12" square to 12"x 24" rect. | " | 0 | 1.00 D | " | YES | " | " | 0.50 | 0.20 | MODERATE |
| Closed conduit, 12" square to 12"x 24" rect. | " | −0.17 D | 0.83 D | " | YES | " | " | 0.50 | 0.20 | MODERATE |

* Warped surfaces constructed within confines of broken back transition using straight wall top and straight intersection of floor as screed guides.

D = Pipeline diameter = 12"

$\Delta h = {V_p}^2/_{2g} - {V_c}^2/_{2g}$ where $V_p$ and $V_c$ are the $Q/_A$ velocities in the pipeline and canal, respectively

$K = \text{Loss}/_{\Delta h}$ For outlets, Loss is $\left(h_p + {V_p}^2/_{2g}\right) - \left(h_c + {V_c}^2/_{2g}\right)$

For inlets, Loss is $\left(h_c + {V_c}^2/_{2g}\right) - \left(h_p + {V_p}^2/_{2g}\right)$ – pipeline loss to pipe measuring station

† Doubtful value

FIGURE 20.—*Table of operating conditions and performance characteristics of transitions.*

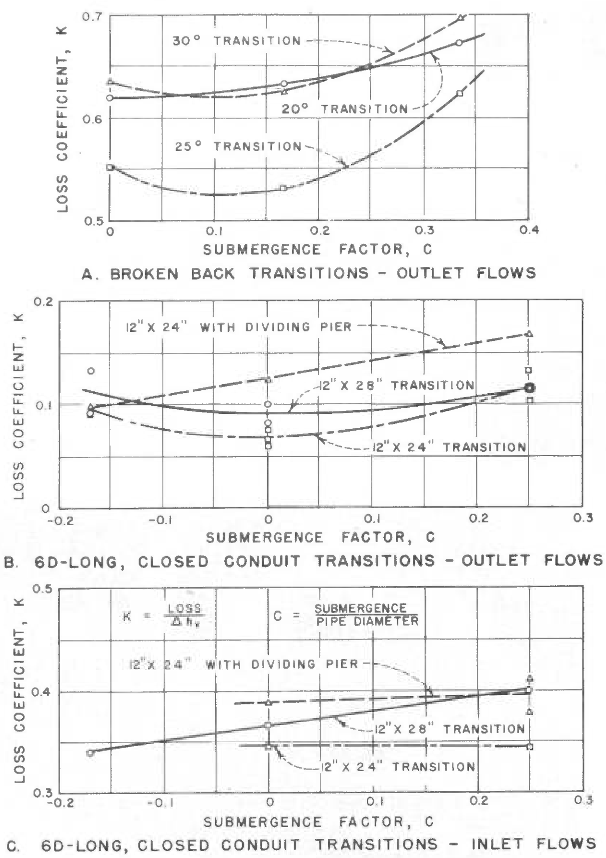



FIGURE 21.—*Effect of submergence on loss coefficients—* $N_f = 0.71$, $V_p = 4.0$ *f.p.s.*

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 to 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.

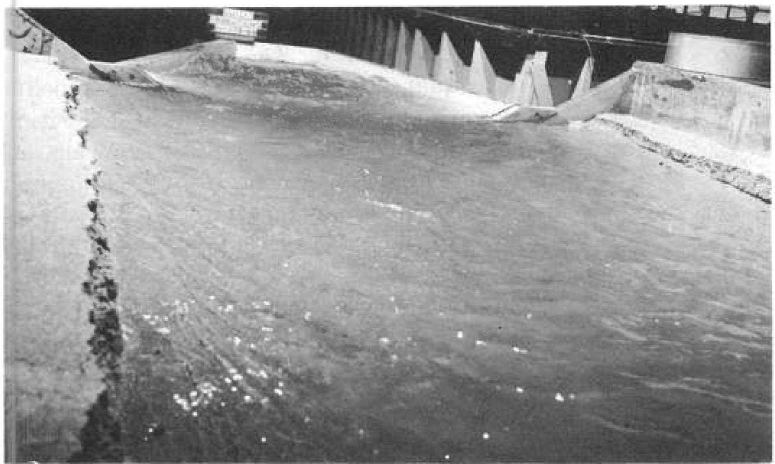
## Closed-Conduit Transitions—Air Model Tests

To determine the performance of a series of expanding closed-conduit transitions, air model tests were made (Figs. 9 and 10). 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 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.

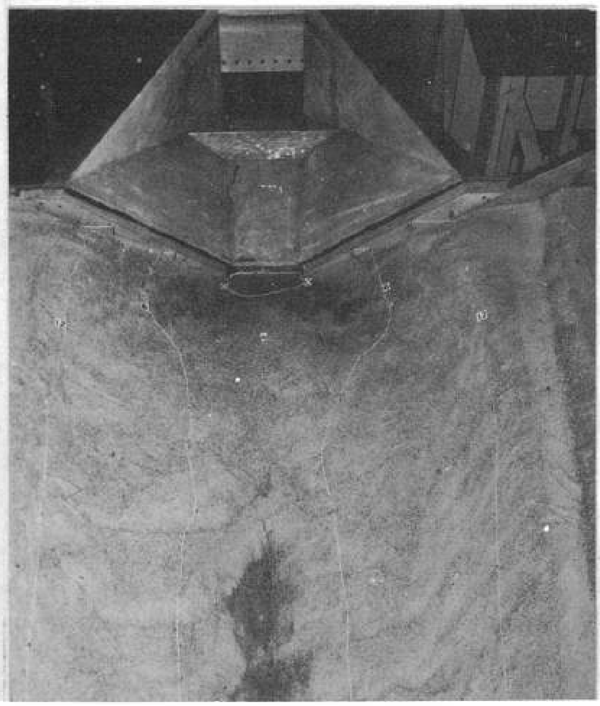
Each transition was first tested on the 6.2-diameter-long approach pipe, and velocity traverses were taken horizontally and vertically at the inlet and outlet (Fig. 23). There was a slight distortion in the inlet velocity profile with the round-to-square transition, and the distortion became progressively greater as transition expansion increased. The outlet profiles showed that the flow expanded well and followed the diverging walls in the 0°, 2½°, and 5° transitions and also followed the walls, but to a lesser extent in the 7½° 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.

The somewhat distorted velocity distribution at the transition inlets apparently 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 distribution. Tests with the 0° divergence transition showed nearly symmetrical velocity distributions at both the inlet and outlet (Fig. 24A). 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.

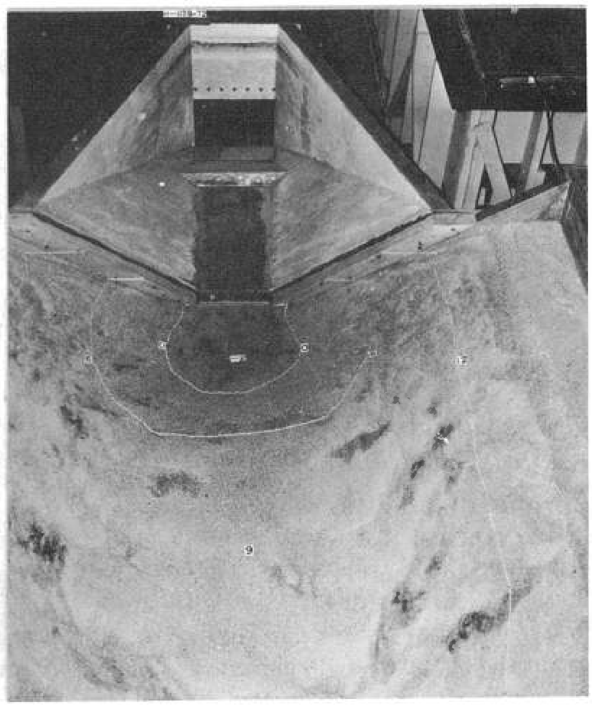
Pressures were subatmospheric at the approach pipe wall taps just upstream from the transitions. This was expected and is due to recovery of head, wherein the velocity head of the entering stream is converted into pressure head as the flow expands and slows. The pressure level into which the transitions 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 sub-



A. A hump occurs in the water surface above the Design 2, hump-like deflector on the floor. Q=4.7 c.f.s., $V_p$=6.0 f.p.s., canal depth=1.3 D.



B. Scour after 1 hour operation $6\frac{3}{8}$-inch-high deflector. Q=4.7 c.f.s., $V_p$=6.0 f.p.s.



C. Scour after 1 hour operation $3\frac{3}{8}$-inch-high deflector. Q=4.7 c.f.s., $V_p$=6.0 f.p.s.

FIGURE 22.—*Flow conditions and scour patterns, outlet flows, combination closed-conduit and broken-back transition with floor deflector, 1 to 5.5 slope, 12-inch rise, inlet pipe horizontal.*

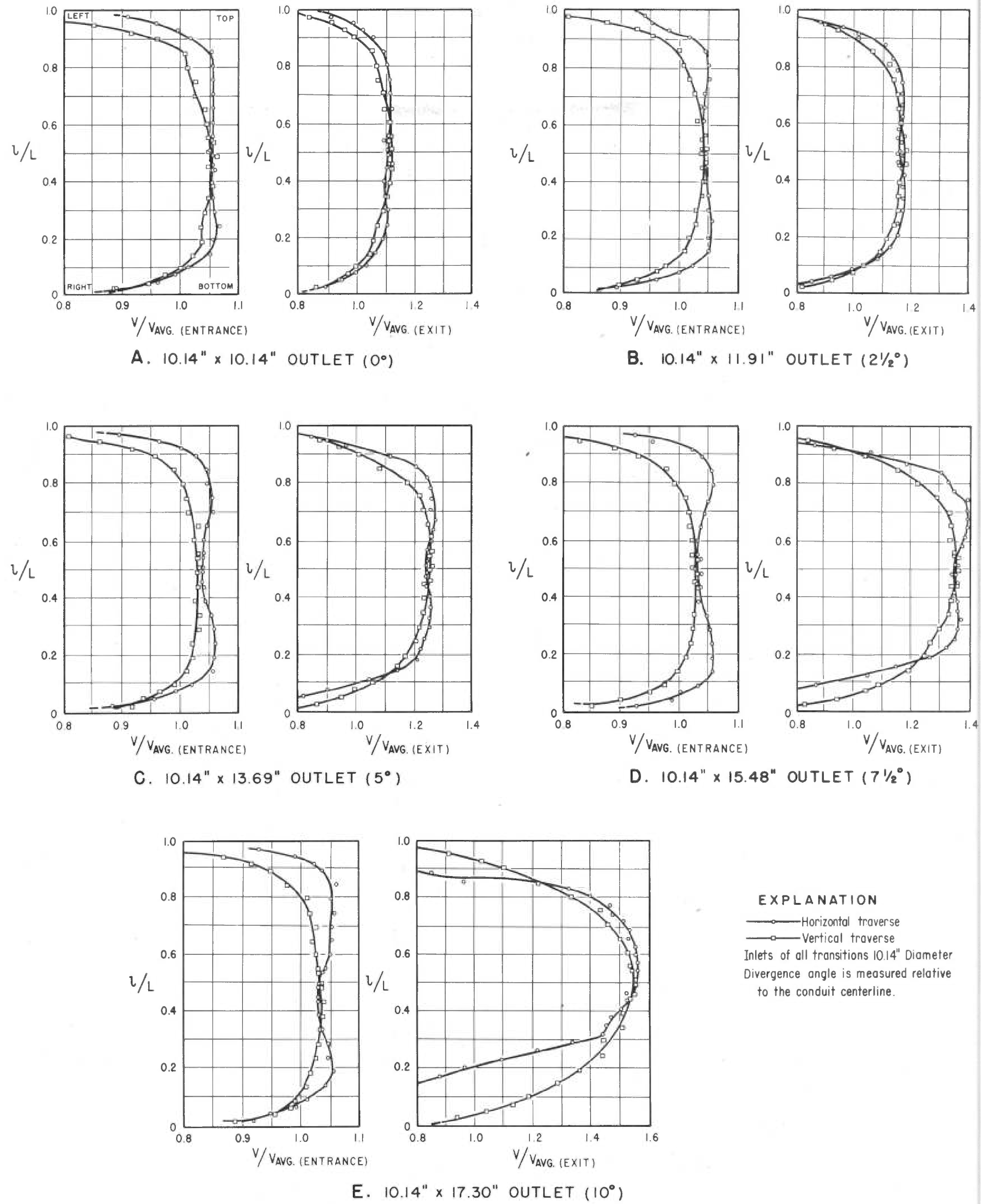



FIGURE 23.—*Velocity distribution for closed-conduit transitions used as outlets, approach pipe 6.2 D long. Air model tests.*

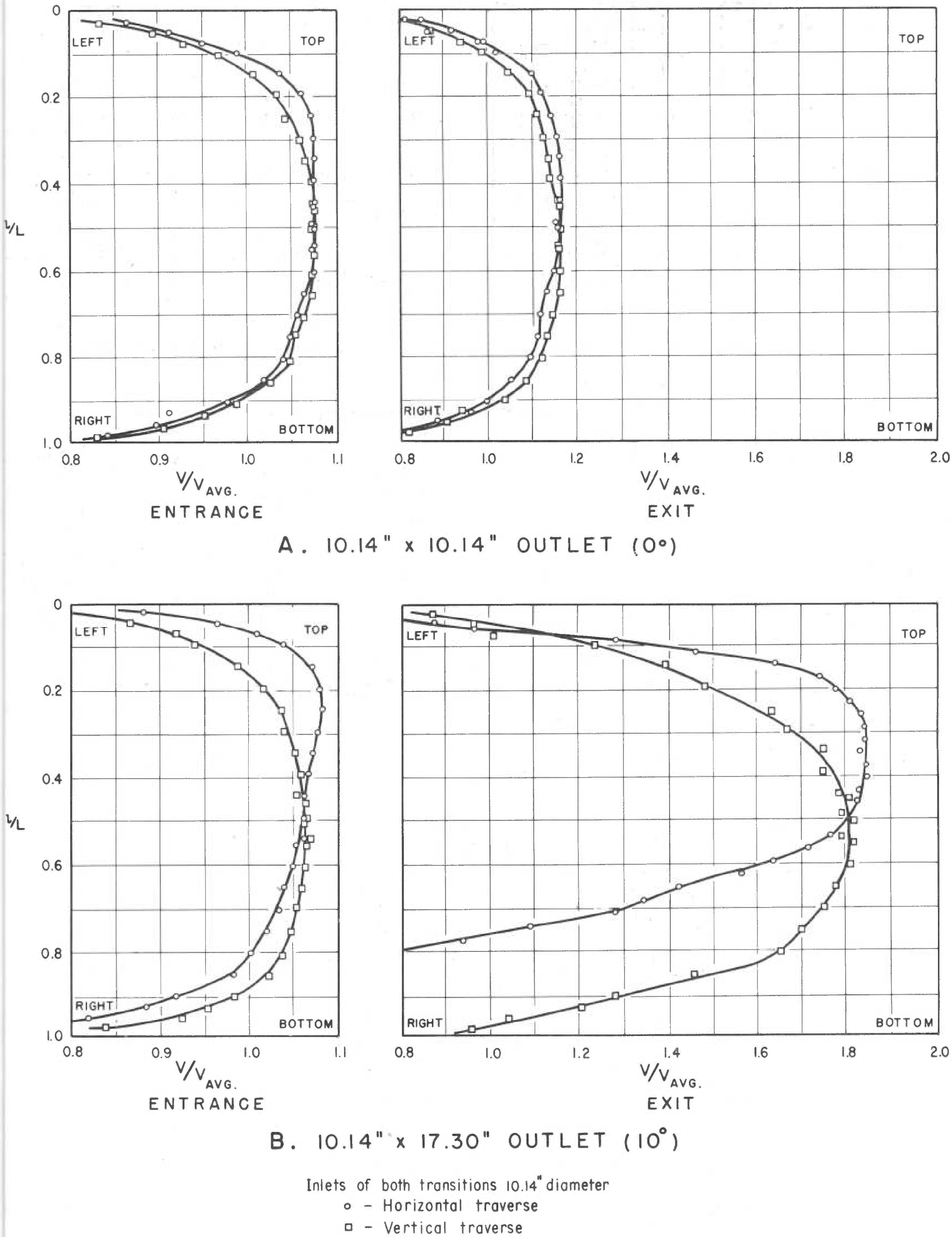



FIGURE 24.—*Velocity distribution for closed-conduit transitions used as outlets, approach pipe 20.4 D long. Air model tests.*

atmospheric 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 (Fig. 25A).

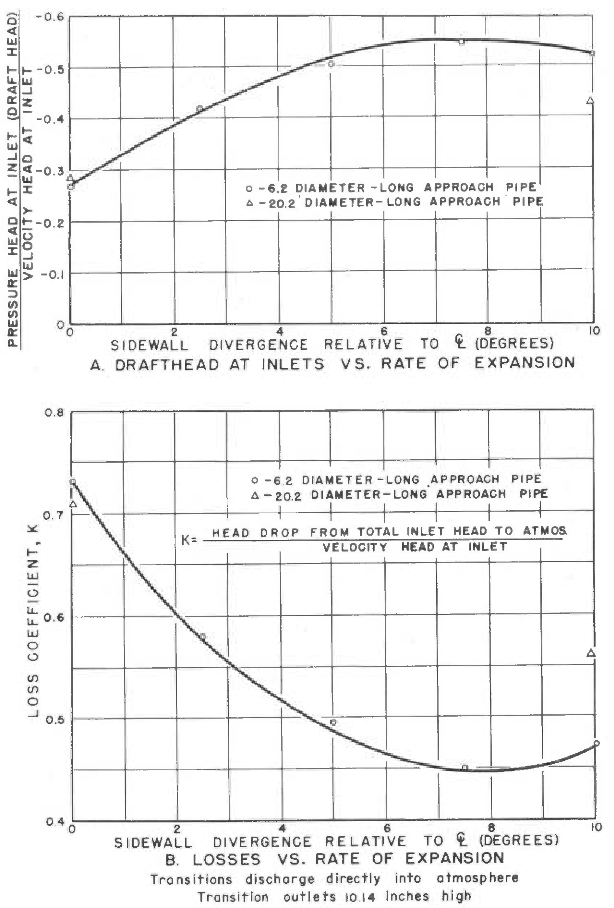



FIGURE 25.—*Draft head at inlet and loss coefficients for closed-conduit transitions used as outlets. Air model tests.*

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 (Fig. 25B). 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 (Fig. 11). 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 7½° 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 (Fig. 26).

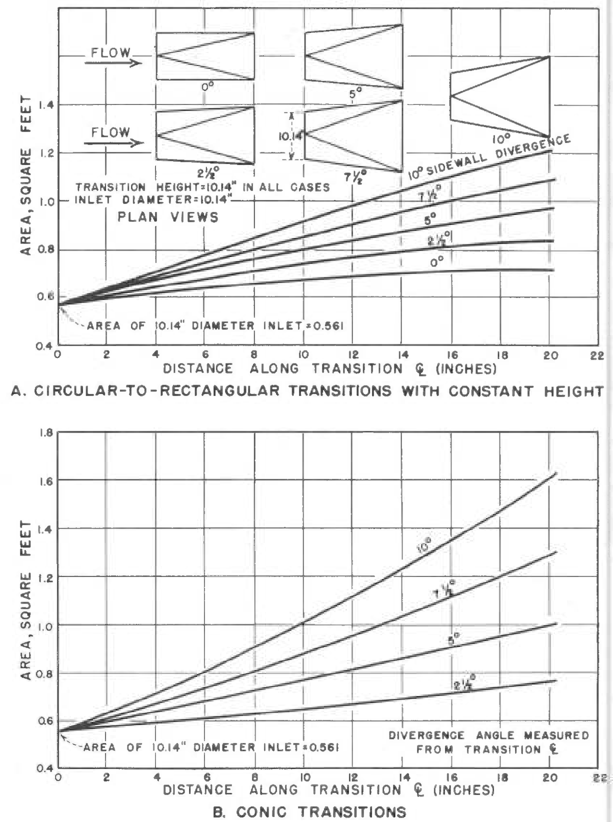



FIGURE 26.—*Area curves for constant height, circular-to-rectangular transitions and for conic transitions.*

Loss coefficients, K, for conic expanding transitions of 2½° and 7½° relative to the centerline, and discharging directly into the atmosphere, were found in previous tests to be 0.273 and 0.499

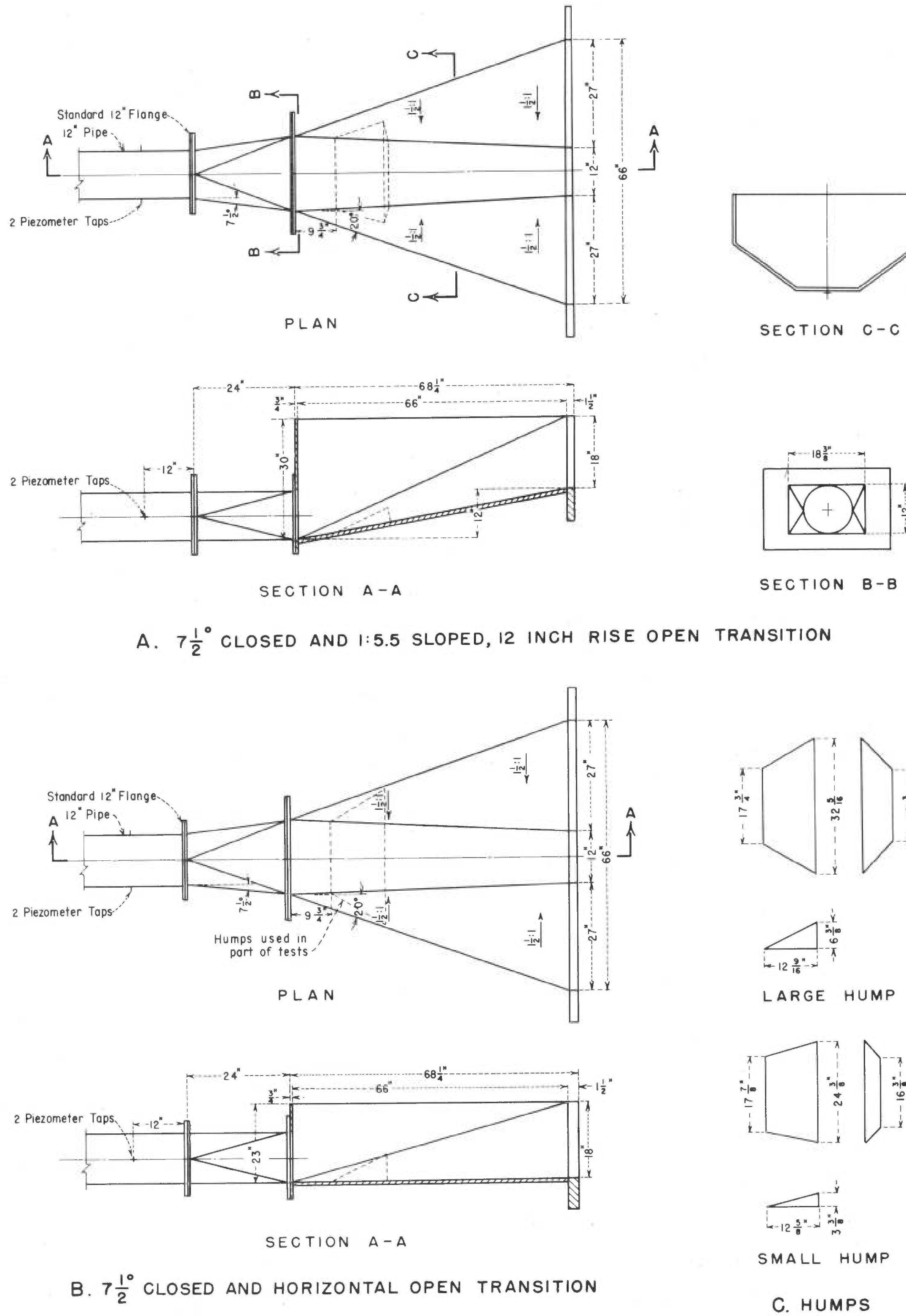



FIGURE 27.—*Combination transition using closed-conduit and open-channel broken-back section, with and without humps.*

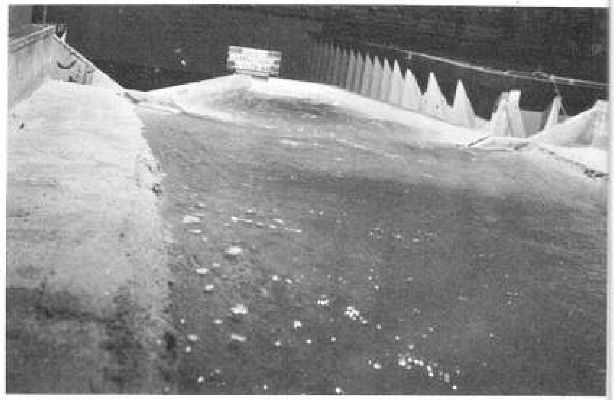
respectively, based on the inlet velocity heads.[1] These values show a trend of greater loss with greater divergence to 7½°, instead of the decreasing loss shown by the round-to-rectangular transitions. This difference is explained by a comparison of the area curves (Fig. 26) that show that conic sections 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 7½° cone. This separation was found to exist in the turnout structure conic transition.

## Combination Closed-Conduit and Open-Channel Transitions

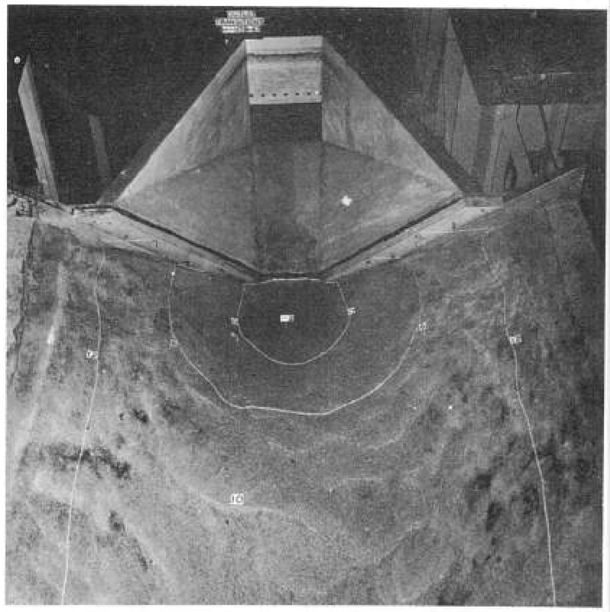
The relatively high efficiency of the closed-conduit expanding transitions was partially exploited by placing 2 D-long, round-to-rectangular transitions between the end of the circular pipeline and a shortened and modified broken-back transition (Fig. 27). The height of the closed transition was kept the same as the diameter of the pipe and the sides diverged 7½° relative to the centerline. The length was 2 D and the outlet measured 12 inches high by 18⅝ inches wide, with an area 2.8 times greater than at the inlet. A 5.5 D-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 to 1 slope (Fig. 20). With the pipe horizontal, waves were smaller and less powerful than in previous transitions, but scour remained appreciable (Fig. 28). 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. Several humps were placed on the floor to "lift" this flow stream and help spread it. Scour was decreased when a 6⅝-inch-high wedge-shaped hump was used, but remained almost unchanged with a 3⅝-inch one (Figs. 22 and 27). Better flow conditions occurred when the inlet pipe was placed on a 2 to 1 upslope (Fig. 29). 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 (Figs. 27B and 30). The submergence over the crown of the



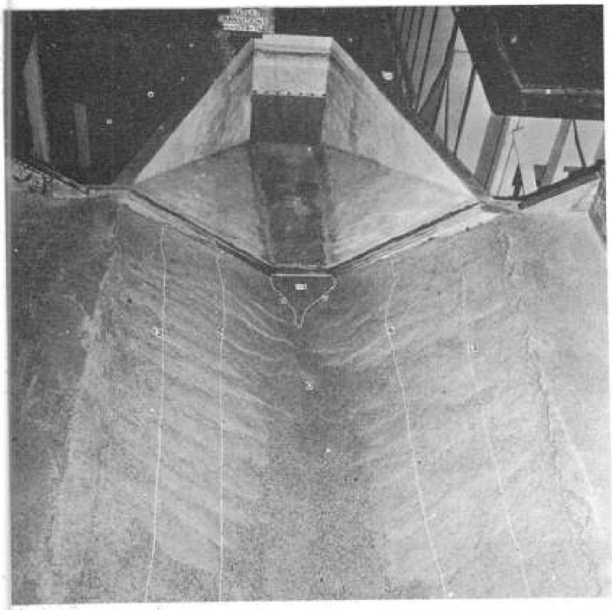
A. Water surface is mildly turbulent in transition, but smooth in canal. Q=4.7 c.f.s., $V_D$=6.0 f.p.s., canal depth=1.3 D.



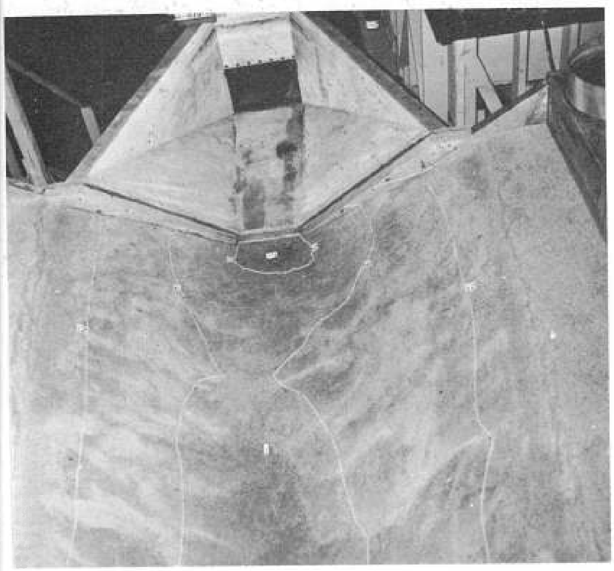
B. Scour after 1 hour operation. Q=4.7 c.f.s., $V_D$=6.0 f.p.s., canal depth=1.3 D.

FIGURE 28.—*Flow conditions and scour pattern, outlet flows, combination closed-conduit and broken-back transition, 1 to 5.5 slope, 12-inch rise, inlet pipe horizontal.*

[1] Bureau of Reclamation, "Hydraulic Model Studies of the San Jacinto-San Vicente Turnout and Metering Structure, San Diego Aqueduct Project, California," Hydraulic Laboratory Report No. Hyd-365, January 26, 1953.



A. Scour after 1 hour. Q=3.1 c.f.s., $V_p$=4.0 f.p.s., canal depth=1.3 D.



B. Scour after 1 hour. Q=4.7 c.f.s., $V_p$=6.0 f.p.s., canal depth=1.3 D.

FIGURE 29.—*Scour patterns, outlet flows, combination closed-conduit and broken-back transition, 1 to 5.5 slope, 12-inch rise, inlet pipe on 2 to 1 slope.*

closed-conduit outlet for a 15-inch (1.3 D) flow depth in the canal was 0.3 D, as compared with 1.3 D for the sloped, open transition. The tests were made with a 2 to 1 sloping pipeline. The water surface was somewhat choppy, and waves that were carried into the canal produced 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 (Fig. 31) were studied. 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 having a 12-inch-diameter inlet, a 12-inch-high by 28-inch-wide rectangular outlet, and an overall length of 72 inches (6 D) was constructed and tested (Figs. 2 and 31A). The transition sloped upward 4 inches and the top of the exit was to be level with or slightly beneath the normal canal water surface. The transition terminated in a vertical headwall placed normal to the canal; 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 32. The least desirable conditions were present at a 15-inch flow depth (1.25 D), where significant return eddies occurred along the banks at the water surface near the headwall. These eddies eroded the canal bank slopes noticeably (Figs. 33B and 33C). At a 12-inch depth (1.0 D), these eddies were small enough to be of little consequence and erosion was minor (Fig. 33A). At a 10-inch depth (0.83 D), 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 1.25 D depths compared favorably with those of the open and the combination open-closed transitions.

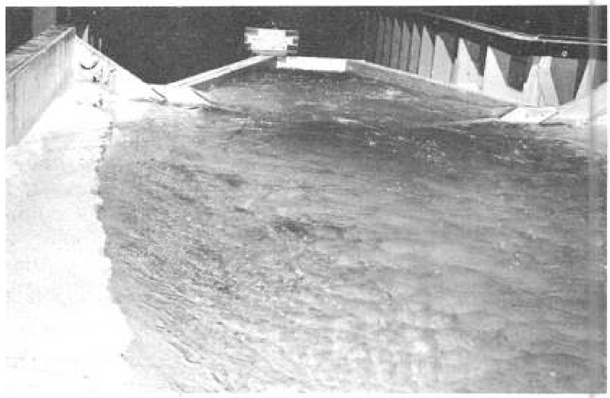
Loss coefficients for the 12- by 28-inch transition, when it was used as an outlet, were quite low and equal to 0.11, 0.09, and 0.11 for canal depths of 0.83, 1.00, and 1.25 D, respectively (Figs. 6, 20, and 21). Loss coefficients when the transition was used for inlet service were 0.34, 0.37, and 0.40, 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 (Fig. 6). The measurements showed undesirable flow separation along the left side and the corners of the transition when it was used in outlet service. This indicated excessive divergence of the flow passage and a design unnecessarily expensive due to greater than required width.

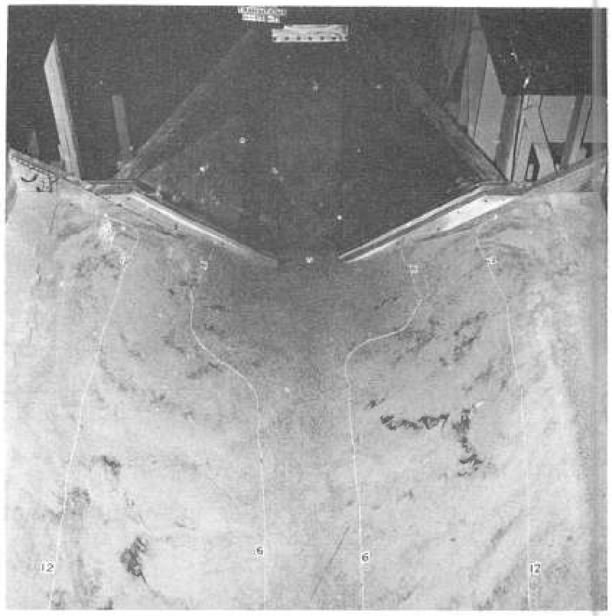
*12- by 24-inch Transition.*—A 6 D-long transition with a 12-inch-diameter inlet and a lesser divergence rate to a rectangular outlet 12 inches high by 24 inches wide was constructed (Fig. 31B). When used as an outlet it produced flow in the canal generally similar to that obtained with the previous closed transition (Fig. 32). Scour in the canal was relatively small at all flow velocities and water depths and comparable with the best of the other designs (Figs. 34 and 35). The loss coefficients decreased to 0.09, 0.07, and 0.11 for the 0.83, 1.00, and 1.25 D flow depths (Figs. 20 and 21). 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 (Fig. 7).

The transition performed 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 1.25 D (Figs. 7, 20, and 21). These losses compared very favorably with those of all other designs.

Field installations might require transitions so large that the flat tops near the head wall 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,



A. Somewhat turbulent water surfaces occur in the transition and canal. Q=4.7 c.f.s., $V_p$=6.0 f.p.s., canal depth=1.3 D.



B. Scour after 1 hour operation. Q=4.7 c.f.s., $V_p$=6.0 f.p.s., canal depth=1.3 D.

FIGURE 30.—*Flow conditions and scour pattern, outlet flows, combination closed-conduit and broken-back transition, level invert, inlet pipe on 2 to 1 slope.*

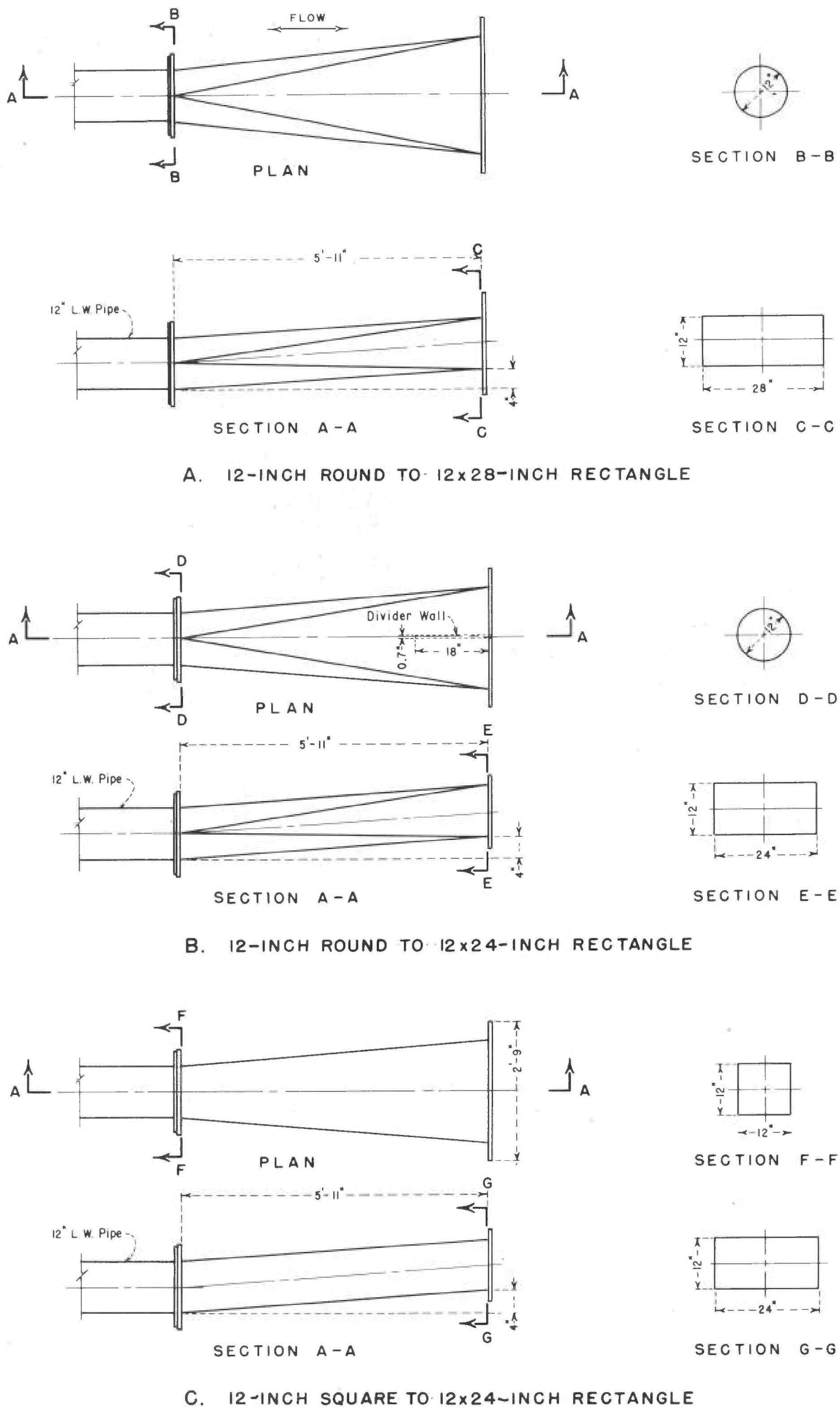
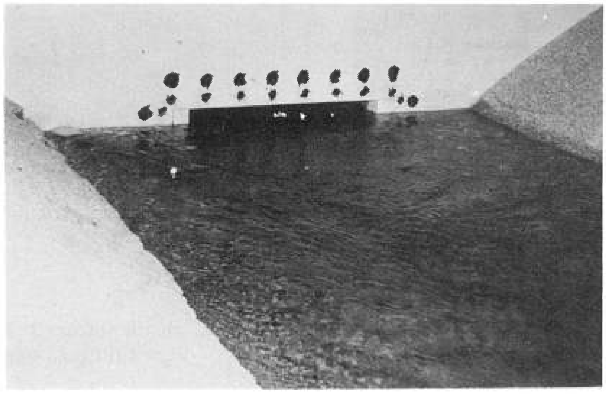
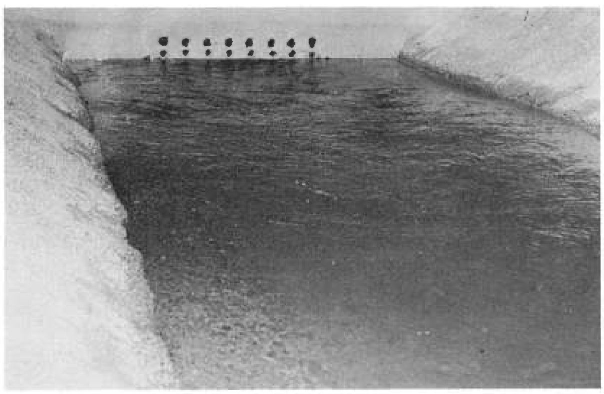


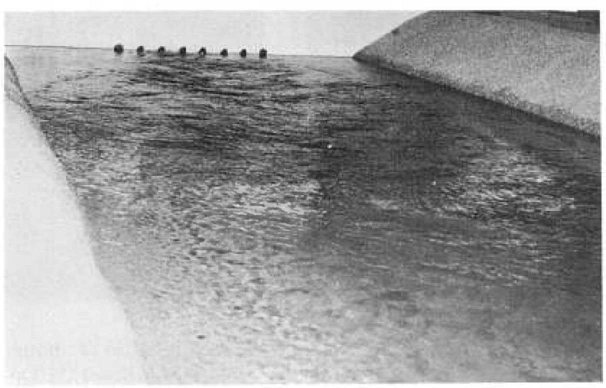

FIGURE 31.—*Closed-conduit round-to-rectangular and square-to-rectangular transitions.*



A. 0.83 D canal depth.

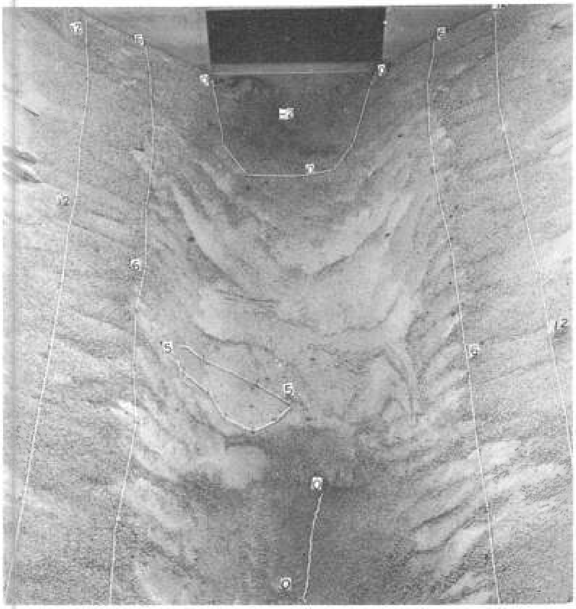


B. 1.00 D canal depth.



C. 1.25 D canal depth.

FIGURE 32.—*Flow conditions, 12- by 24-inch closed-conduit transition, 4 f.p.s. velocity in pipeline, inlet pipe horizontal.*

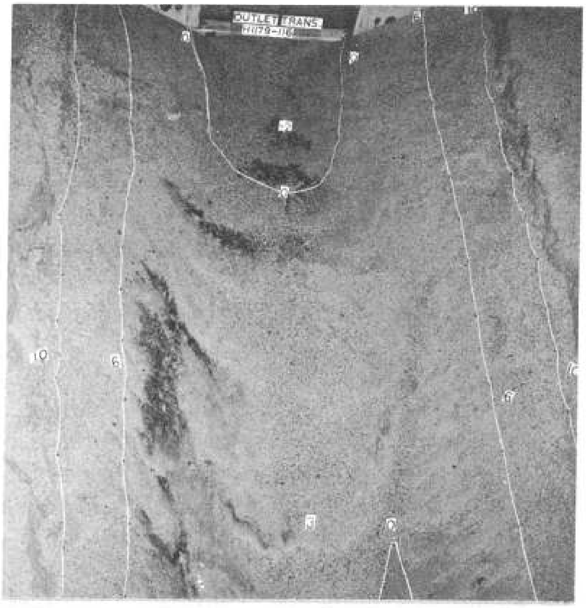


A. Scour after 2 hours operation. Q=3.1 c.f.s., $V_p$=4.0 f.p.s., canal depth=1.0 D.

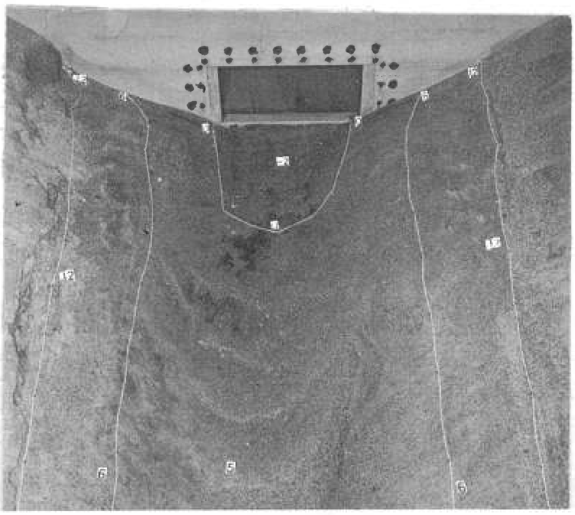
B. Scour after 2 hours operation. $V_p$=4.0 f.p.s., canal depth=1.25 D.

C. Scour after 1 hour operation. $V_p$=6.0 f.p.s., canal depth=1.25 D.

FIGURE 33.—*Scour patterns, outlet flows, 12- by 28-inch, closed-conduit transition, inlet pipe horizontal.*




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



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

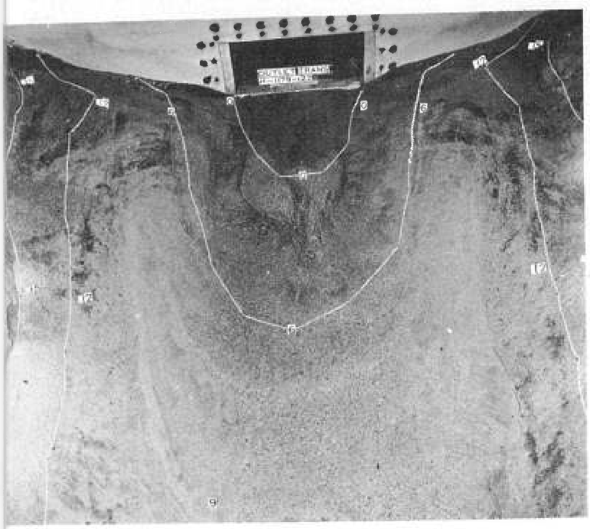

C. Scour after 1 hour operation. Canal depth = 1.25 D.

FIGURE 34.—*Scour patterns, outlet flows, 12- by 24-inch, closed-conduit transition, 4 f.p.s. velocity in pipeline, inlet pipe horizontal.*

tests were made with an 18-inch-long pier in the transition (Figs. 8, 20, 21, and 31). The pier was 0.2 D 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 (Fig. 8). 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.

A. 1.00 D canal depth.

B. 1.25 D canal depth.

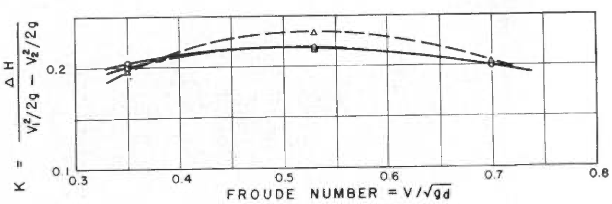


C. Erosion after 1 hour, 1.25 D depth.

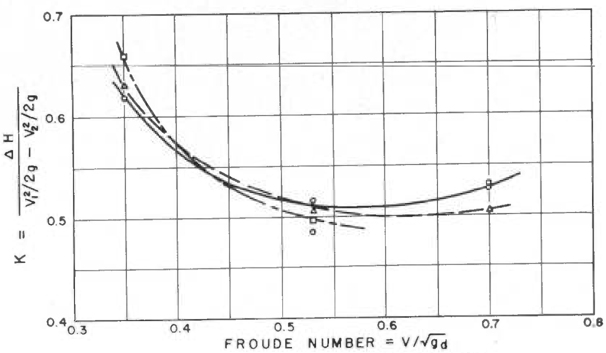
FIGURE 35.—*Flow conditions and scour patterns, outlet flows, 12- by 24-inch transition, 6 f.p.s. velocity, inlet pipe horizontal.*

*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 6 D-long transition with a 12-inch-square inlet instead of a round one, and a 12- by 24-inch rectangular outlet was tested (Fig. 31C). The loss coefficients for outlet flows were 0.20, 0.20, and 0.23 for depths of 0.83 D, 1.00 D, and 1.25 D. 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 (Fig. 36). 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.




A. LOSSES – VS. FROUDE NUMBER OUTLET FLOWS




B. LOSSES VS. FROUDE NUMBER INLET FLOWS

□— — —□ 10" canal depth
○———○ 12" canal depth
△— — — —△ 15" canal depth
$V_1$ = Velocity in pipeline, f.p.s.
$V_2$ = Velocity in canal, f.p.s.
$\Delta H$ = Energy loss from pipeline to canal (outlet flows) or canal to pipeline (inlet flows), feet of water.

FIGURE 36.—*Loss factors, 12-inch square to 12- by 24-inch rectangular transition, inlet pipe horizontal.*

# Conclusions

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 (Fig. 20 and Fig. 37). This velocity head difference, $\frac{V_p^2}{2g}-\frac{V_c^2}{2g}$, is termed $\Delta h_v$.

Reasonable changes in angle of divergence of the sidewalls, of the slope of the invert of the open transitions, or of the attitude of the inlet pipeline, had little effect upon energy losses (Figs. 4 and 20).

Outlet losses were reduced to 0.4 $\Delta h_v$ and less when short, closed-conduit, expanding transitions were placed between the pipeline and modified, broken-back transitions (Fig. 27 and Fig. 37).

Outlet losses were reduced to 0.1 $\Delta h_v$ with 6 D-long closed-conduit transitions having circular inlets and rectangular outlets, and which discharged directly into the canal through a vertical headwall placed perpendicular to the canal axis (Fig. 3A and Fig. 37).

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 $\Delta h_v$.

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

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 (Figs. 13C and 20).

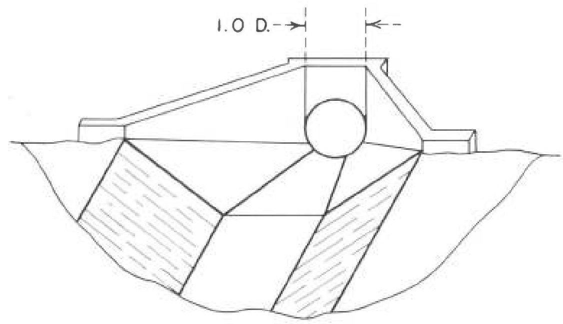
Losses for inlet flows were about 0.4 to 0.5 $\Delta h_v$ for all transitions tested (Fig. 20).

Scour or erosion in the loose sand of the canal bed was extensive with conventional, broken-back transitions (Fig. 5 and Figs. 12 through 19).

Selected humps or flow spreaders on the inverts within open transitions significantly reduced scour (Fig. 5 and Figs. 12 through 19). The humps tested created a slight increase in head loss.

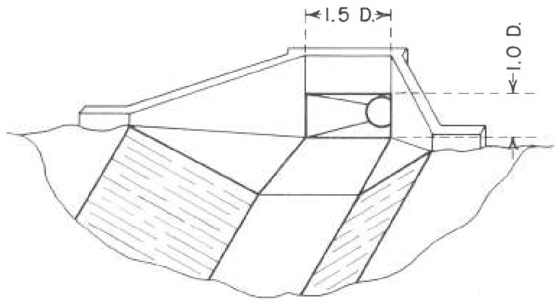
Scour was not appreciably affected by changes in the side-wall divergence or invert slopes of the open transitions.

Scour with the combination closed-conduit and open-channel transitions was less than for the conventional transitions (Fig. 22 and Figs. 28 through 30).



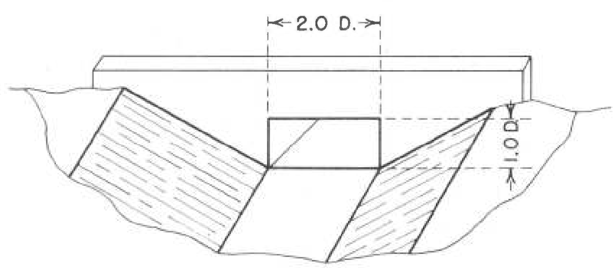

Barrel of pipeline attached to transition:
Loss as an inlet = $0.50 \Delta h_v$
Loss as an outlet = $0.65 \Delta h_v$
Scour — moderate to extensive

A. CONVENTIONAL BROKEN - BACK TRANSITION




Pipeline barrel connects to transition with round - to - rectangular pipe transition:
Loss as an inlet = $0.40 \Delta h_v$
Loss as an outlet = $0.40 \Delta h_v$
Scour — moderate

B. MODIFIED BROKEN - BACK WITH ROUND - TO - RECTANGULAR TRANSITION BETWEEN STRUCTURE AND PIPELINE




6D - long pipe transition connects pipeline to headwall across canal:
Loss as an inlet = $0.40 \Delta h_v$
Loss as an outlet = $0.10 \Delta h_v$
Scour — moderate

C. ROUND - TO - RECTANGULAR PIPELINE TRANSITION TERMINATING IN HEADWALL

D = Pipeline diameter

$\Delta h$ = $V_P^2/2g - V_C^2/2g$, where $V_P$ and $V_C$ are the $Q/A$ velocities in the pipeline and canal, respectively.

K = $\text{Loss}/\Delta h$

For outlets, loss is $\left(h_P + V_P^2/2g\right) - \left(h_C + V_C^2/2g\right)$

For inlets, loss is $\left(h_C + V_C^2/2g\right) - \left(h_P + V_P^2/2g\right)$ − pipeline loss to measuring station.

FIGURE 37.—*Design sheet for small canal transitions.*

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

Scour with the 6 D-long, closed-conduit transitions was about the same as with the combination transitions, and less than for the conventional transitions (Figs. 32, 33, 34, and 36).

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

A 4-inch-thick layer of 1½-inch gravel extending 4 feet downstream from the transition of the 12-inch test installation provided excellent scour protection at the transition outlet (Fig. 19). Erosion occurred beyond this blanket when the velocities were high, waves were appreciable, or both.

The optimum divergence of the sides of short, circular-to-rectangular, constant height, closed-conduit transitions is 7½° relative to the centerline (Figs. 10, 11, 23, 24, and 25). For longer transitions the divergence should be decreased to about 5° per side.

For both inlet and outlet flows submergences up to 0.25 D 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 6 D-long closed-conduit transitions (Fig. 21). Higher submergences tested in the broken-back transitions further increased the losses. Negative submergences down to −0.17 D, which is tantamount to not having the transition full at the headwall, indicated only minor head loss increases for outlet flows.

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