HYDRAULIC MODEL STUDIES

FOR

WHITING FIELD NAVAL AIR STATION

PART V . . . . Studies of Open-Channel Junctions

Project Report No. 24

Prepared by
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Conducted by
SOIL CONSERVATION SERVICE - RESEARCH
United States Department of Agriculture
in cooperation with
Minnesota Agricultural Experiment Station
and the
St. Anthony Falls Hydraulic Laboratory

PREFACE

The Naval Auxiliary Air Station, Whiting Field, is located near Milton, Florida. The surface of the plateau on which the airfield is located is about 130 feet above the surrounding terrain. Prior to the work described here the runoff from the paved runways and the surface area has been carried down the sides of the plateau in unpaved ditches. Although numerous structures have been used to control the grade of the ditches, severe scour of the bed and banks has occurred because the sandy-clay soil is readily erodible. The maintenance problem has become so acute that it was decided to design an entirely new system to convey the water down the sides of the plateau. Parts of the proposed drainage system involved new and untried methods of handling the flow, and these designs were developed by means of hydraulic models. Other structures involved designs on which it was felt that model tests were expedient.

The model studies are reported in five parts. Each part covers one general type of structure. Parts I to IV, covering studies on a straight drop spillway, a cantilevered ditch outlet, pipe-ditch transition structures, and a detention-type box-inlet drop spillway, are presented in Project Report No. 23. Part V, covering the channel junction studies, is presented in Project Report No. 24. The model studies were authorized by Mr. Lewis A. Jones, Chief, Division of Drainage and Water Control, Soil Conservation Service - Research, on September 20, 1948. Dr. M. L. Nichols is chief of Research for the Soil Conservation Service. Each specific model study was requested by Mr. Arthur F. Moratz, Head, District Operations Design and Construction Section, who was responsible for the structural design under the direction of Mr. Edwin Freyburger, Regional Engineer, Upper Mississippi Region, Soil Conservation Service. The tests reported in Parts I to IV were performed by Mr. Charles A. Donnelly, Hydraulic Engineer on the Soil Conservation Service staff, as Project Leader, while the tests reported in Part V were performed by Mr. C. E. Bowers, Research Fellow on the St. Anthony Falls Hydraulic Laboratory staff, as Project Leader. All model studies were conducted under the supervision of Mr. Fred W. Blaisdell, Project Supervisor of the Soil Conservation Service research work on soil conservation structures at the St. Anthony Falls Hydraulic Laboratory. All research conducted by the Soil Conservation Service at this Laboratory is in cooperation with the Minnesota Agricultural Experiment Station and the St. Anthony Falls Hydraulic Laboratory.

Acknowledgment should be made here of the fine cooperation exhibited by all members of the Laboratory staff concerned with these studies. Without this cooperation it would not have been possible to complete the large volume of difficult work within the short time available.

CONTENTS

LIST OF ILLUSTRATIONS

Figure Page

U. S. Department of Agriculture, Soil Conservation Service–Research
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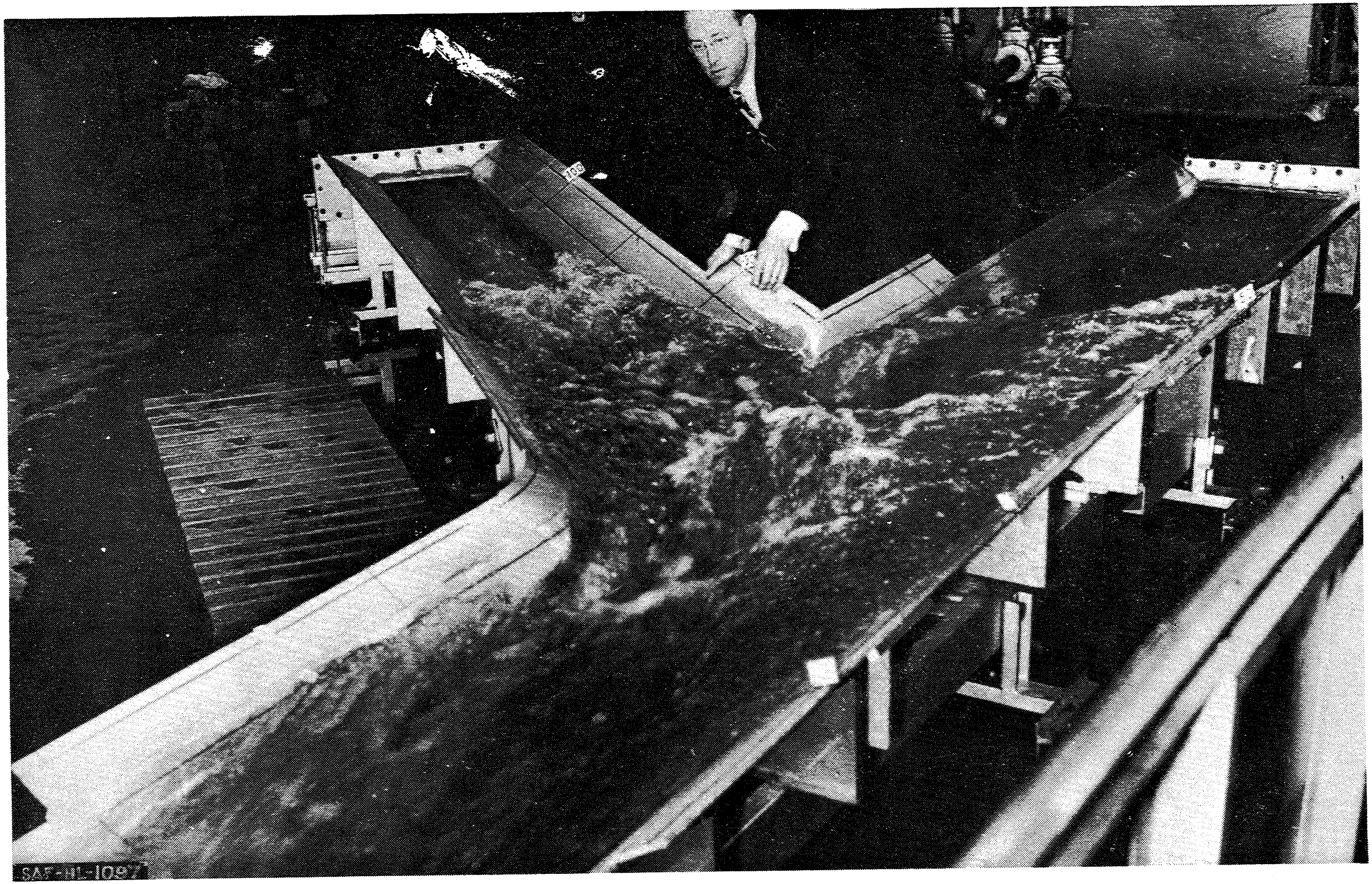

At Structure P-7 Froude numbers are low so that flows in both channels pass through the hydraulic jump and join at subcritical velocities.

Flow at Junction of Two Channels

PART V

STUDIES OF OPEN-CHANNEL JUNCTIONS[*]

INTRODUCTION

General

The Naval Auxiliary Air Station, Whiting Field, is to have a storm-water disposal system in which the existing pipes and terraces under and in the vicinity of the runways and building area will discharge into paved trapezoidal open channels. Many of the channels join other channels as they pass down the sides of the plateau on which the air-field is located. The grades of the main channels and of many of the lateral channels are such that water flows at supercritical velocities or at velocities greater than that of a gravity wave ($V > \sqrt{gd}$). The difficulties anticipated in joining two streams of water, one or more of which is flowing at supercritical velocities, led to the request for model studies of several of the channel junctions.

The primary objectives in the present study include (1) the development of junction designs for specified operating conditions which would result in reasonably smooth flow downstream of the junction and (2) the determination of the necessary wall heights in the vicinity of the junction. Economic and structural considerations involved in the junction designs were considered in the final selection.

Dependent upon the junction design, the discharges, velocities, and related phenomena of the flow in the vicinity of the junction, a hydraulic jump may form in one or both of the inlet channels. This may necessitate a large increase in the height of the sidewalls in the vicinity of the junction. On the other hand, if the flow passes through the junction at velocities greater than the critical, standing waves may form which have a height greatly in excess of a normal freeboard and which continue to oscillate back and forth across the channel for a considerable distance downstream from the junction before being damped

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[*] Soil Conservation Service Report No. MN-R-3-41.

by frictional forces. These standing waves necessitate higher sidewalls not only in the vicinity of the junction but for a considerable distance downstream. As available information on junctions of this type is almost nonexistent, it was necessary to resort to model studies in order to determine the flow conditions and the minimum sidewall heights.

Two general types of junctions were studied. One type consists of the junction of two large channels in which the lateral and inlet main have comparable discharges. The other type, called terrace outlets, consists of a junction between a main channel and a terrace channel having a relatively small discharge.

The maximum discharge ranges from 380 to 960 cfs in the main channels and from 25 to 70 cfs in the terrace channels. The maximum velocity of flow encountered is approximately 30 fps.

Apparatus

The general test setup used in the model studies is illustrated in Figures 1 and 2. It consists of a trapezoidal channel section approximately 25 feet long representing the main channel, and an 8-foot trapezoidal section representing the lateral, plus the supporting structures and the water supply system. The apparatus was designed to permit variation in the slope, location, and elevation of the component channels. Water was supplied to the setup from the main laboratory supply channel through 4-inch flexible pipes. The pipes discharged into special headboxes which in turn discharged into the test channels. The depth of flow at the exit of the headbox was regulated by a nozzle and a surface lip.

The main channel had a bottom width of 7.2 inches and a side slope of $1\frac{1}{2}$ on 1. With the exception of the junction section, the same channel was used for all studies; thus, it was necessary to vary the scale ratio from 6.65 to 11.63 to simulate the various prototype channels. The lateral and junction sections were changed for each study.

The channel sections were constructed of either aluminum or painted plywood. Experiments indicated that slope computations based on an

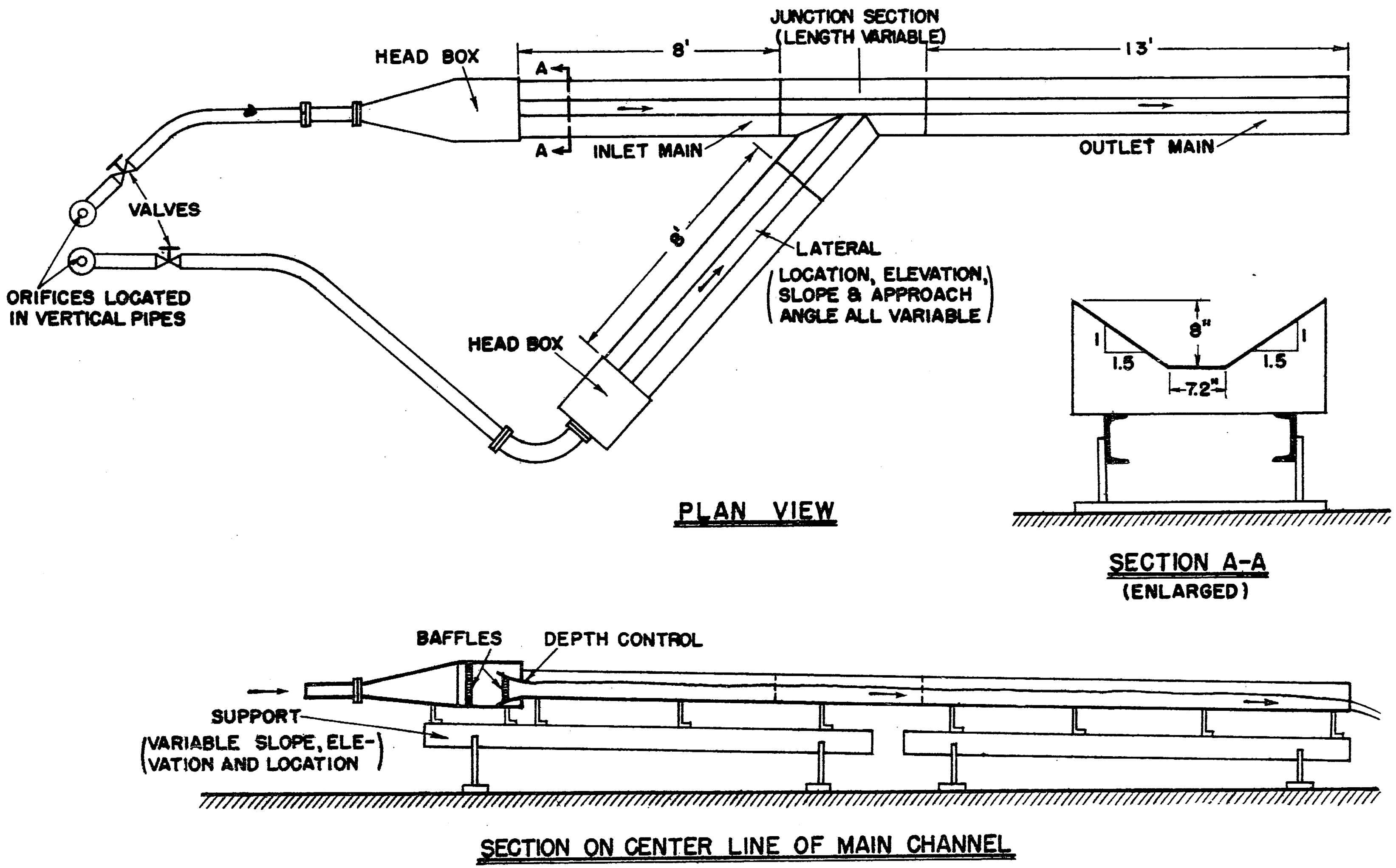

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Figure 1. Sketch of Experimental Arrangement

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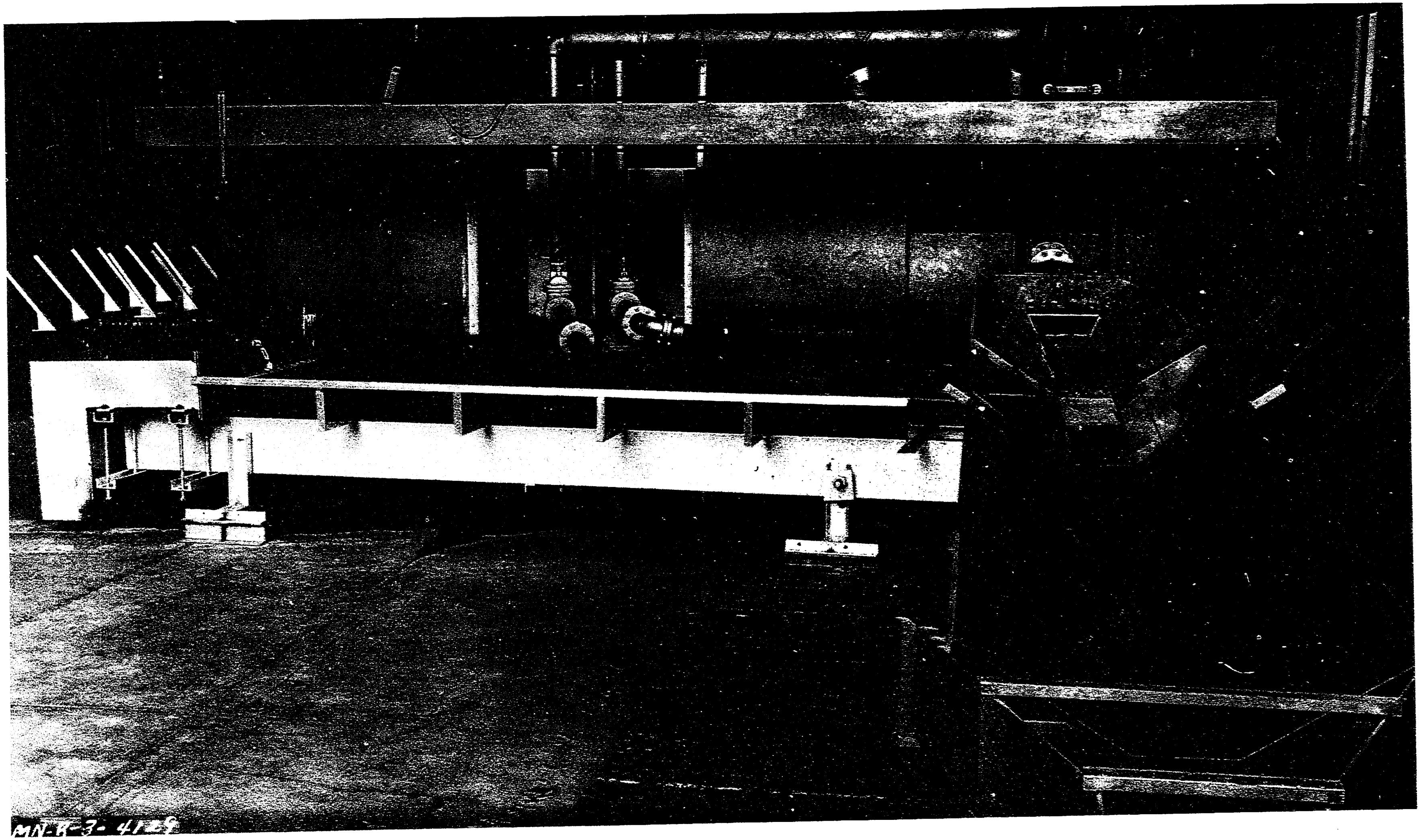

The main channel is at the right; the lateral, making an angle of 85° with the main channel, enters from the left. In the background is the piping system which supplies water to the model.

Figure 2. General View of Test Apparatus

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n value of 0.009 in Manning's formula resulted in uniform flow in the channels.

Froude's law was used to relate flow conditions in the model and prototype.

MODEL TESTS

Model tests were made of only four specific channel junctions which will be used at Whiting Field. In addition, tests were made on a typical terrace junction structure. The selection of the junctions to be studied was made by the Region 3 Engineering Division of the Soil Conservation Service. An attempt was made to study those junctions posing the most difficult design problems since the time available for making the studies limited the number of junctions that could be tested. The model tests are described in the chronological order of their performance.

Structure C-5

Initial tests were made on Structure C-5. Here the Owens Court Terrace Channel, which flows at subcritical velocities, joins C Ditch, which flows at supercritical velocities. Since this was the first junction tested, five different junction designs were subjected to exploratory tests before attempting to develop a final design. A sixth design was not tested due to lack of time. Each of these designs is discussed below.

General

The design conditions for Structure C-5 were supplied by the Region 3 Engineering Division and are listed in Table I in prototype dimensions. As mentioned earlier, the main channel has the same width (7 feet) both above and below the junction. The lateral, with a bottom width of 20 feet, intersects the main channel at an angle of 85 degrees, with permissible variation in angle of plus 5 or minus 10 degrees. It was stipulated that the lateral could intersect the main channel at an elevation up to 2 feet above that of the main channel; ground configurations at the site necessitated this limitation.

TABLE I

DESIGN CRITERIA FOR STRUCTURE C-5

	Inlet Main	Lateral	Outlet Main
Discharge (cfs)	0-414	0-181	0-595
Bottom Width (ft)	7.0	20.0	7.0
Side Slope	1.5:1	3:1	1.5:1
Slope	0.044	0.0095	0.056
Normal Depth (ft)*	1.75	1.53	2.00
Normal Velocity (fps)*	24.4	4.82	29.8
Froude Number*	10.6	0.47	13.8
Manning's n	0.015**	0.035	0.015**

*Based on design discharge.

**Additional tests were run on the final design for n = 0.013.

On the basis of computed flow conditions in the main channel, normal velocity was greater than the critical both upstream and downstream from the junction for the design discharges. An n value of 0.015 was used in Manning's formula for computing flow conditions in the main channel, which was paved. An n value of 0.035 was used for the unpaved lateral. Flow in the lateral was at less than critical velocity.

The scale ratio for all studies of Structure C-5 was 11.63.

Design 1 (Initial Proposal)

Figure 3 illustrates an initial proposal for the design of Structure C-5, first of a series of five which were tested. It consists of a simple intersection of two trapezoidal channels with the bottom of the lateral 2 feet above that of the main.

The performance, as indicated by model tests, was very unsatisfactory. Large waves were created at the junction which continued to oscillate back and forth across the channel downstream from the junction. The maximum height of the waves was 6 feet or approximately three times the normal depth of the stream. Figure 4 illustrates this

	INLET MAIN							LATERAL							OUTLET MAIN							
	SIDE SLOPE	BOTTOM WIDTH	DEPTH	MAX. Q CFS	AV. VEL. FPS	F	SLOPE	BOTTOM WIDTH	DEPTH	SIDE SLOPE	MAX. Q CFS	AV. VEL. FPS	F	SLOPE	BOTTOM WIDTH	DEPTH	SIDE SLOPE	MAX. Q CFS	AV. VEL FPS	F	SLOPE	RELATIVE SCALE
PROTOTYPE	1.5:1	7.00'	1.75"	414	24.40	10.6	.044	20.00'	1.53	3:1	181	4.82	.47	.0095	7.00'	2.00'	1.5:1	595	29.8	13.8	.056	11.63
MODEL	1.5:1	7.22"	1.81"	.898	7.16	10.6	.036	20.62"	1.58	3:1	.393	1.41	.47	.0014	7.22"	2.06"	1.5:1	1.28	8.74	13.8	.047	1.00

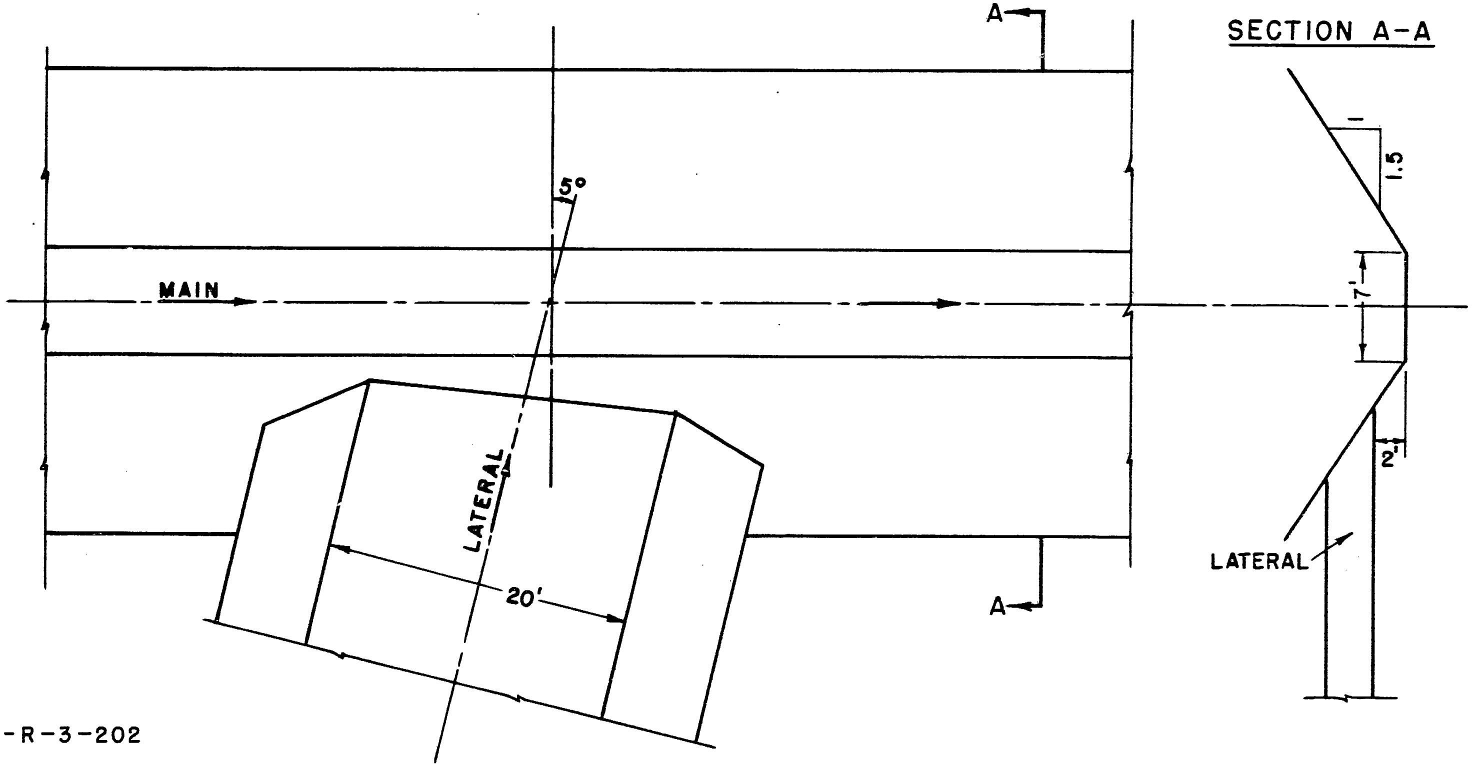

Figure 3. Structure C-5, Design 1 - Initial Design

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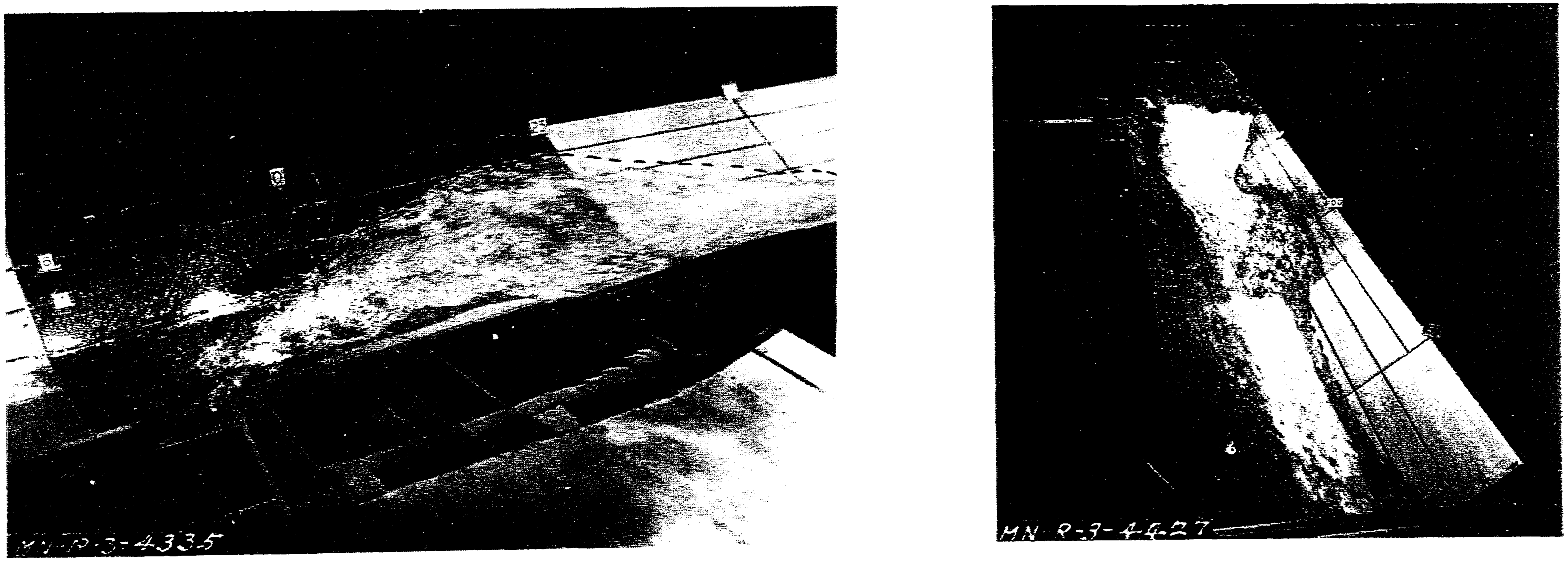

The condition shown above is equivalent to discharge of 414 and 181 cfs in the inlet main and lateral respectively. The vertical spacing of the longitudinal lines is equivalent to 2 feet.

Figure 4. Structure C-5, Design I - Maximum Discharge

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condition for the maximum or design discharge. The disturbance at the junction might be described as a shock wave caused by the high-velocity flow in the inlet main striking the relatively slow flow issuing from the lateral. The wave front extended diagonally across the main channel.

With the design discharge of 414 cfs in the inlet main, a decrease in the lateral flow from 181 to 90 cfs resulted in a wave height of approximately 5 feet at the junction.

With a maximum discharge of 181 cfs in the lateral, a decrease in the inlet main discharge from 414 to 207 cfs resulted in the formation of a hydraulic jump at the upstream edge of the junction (Figure 5b). Downstream of the junction the flow was considerably better than when a jump did not form.

At the conclusion of the preceding tests, several modifications of Design 1 were tested in which the lateral flow was confined to a narrower channel and turned so that it entered the main at angles of 30 to 45 degrees. No appreciable improvement of flow conditions was noted. It was concluded that a serious disturbance would still exist if the lateral flow were turned to enter almost parallel to the main flow unless the lateral flow were accelerated to a velocity comparable to that of the main channel.

Design 2 (Vertical Sidewalls)

In an attempt to suppress the waves formed at the junction, vertical sidewalls were added as shown in Figures 6 and 7. While there was no change in the wave height at the junction, flow conditions downstream were considerably improved provided the walls extended at least 60 to 80 feet downstream from the center of the junction.

Design 3 (Transverse Weir)

A third design was proposed in which the lateral would approach the main channel at a high elevation, be supported over the main channel, and the flow turned through 90 degrees before discharging over a weir onto the water surface in the main channel. Figure 8 illustrates the general principle. Figure 9 shows a modification of the above

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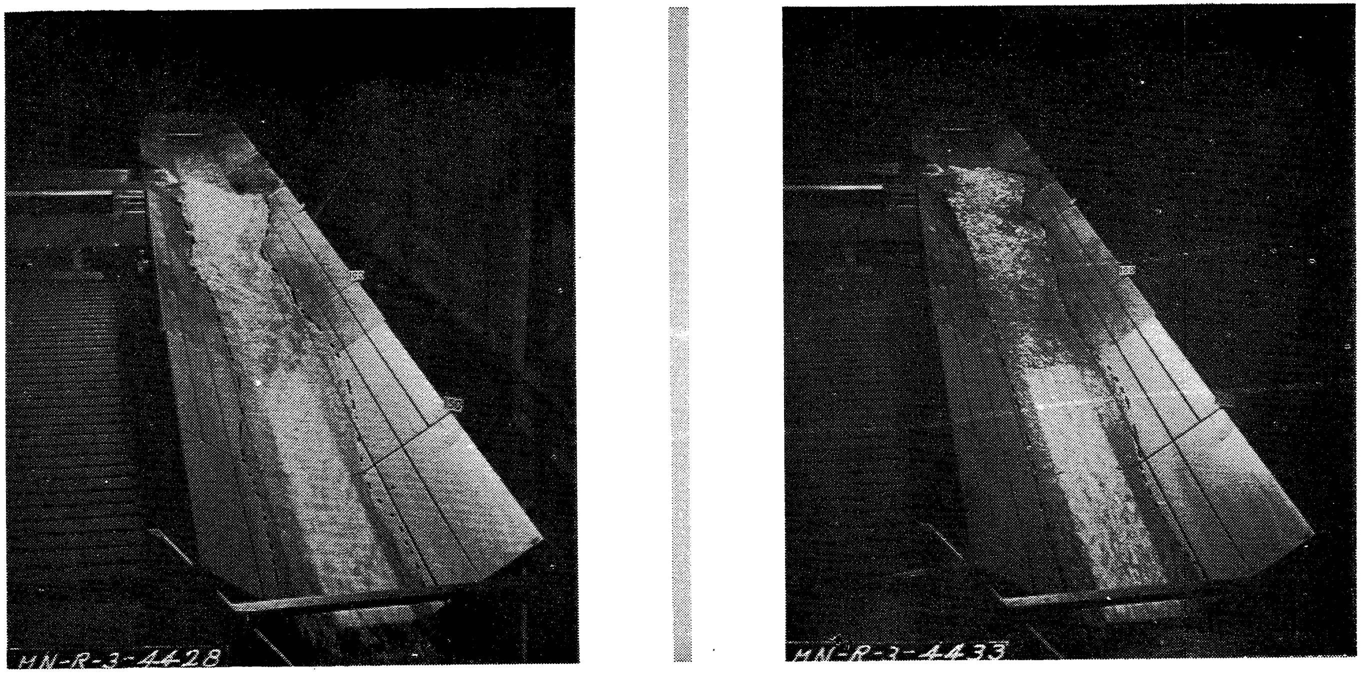

(a) This represents conditions corresponding to prototype flows of 414 cfs in the inlet main and 90 cfs in the lateral.

(b) This represents conditions corresponding to prototype flows of 207 cfs in the inlet main and 181 cfs in the lateral.

Figure 5. Structure C-5, Design I Modified Discharges

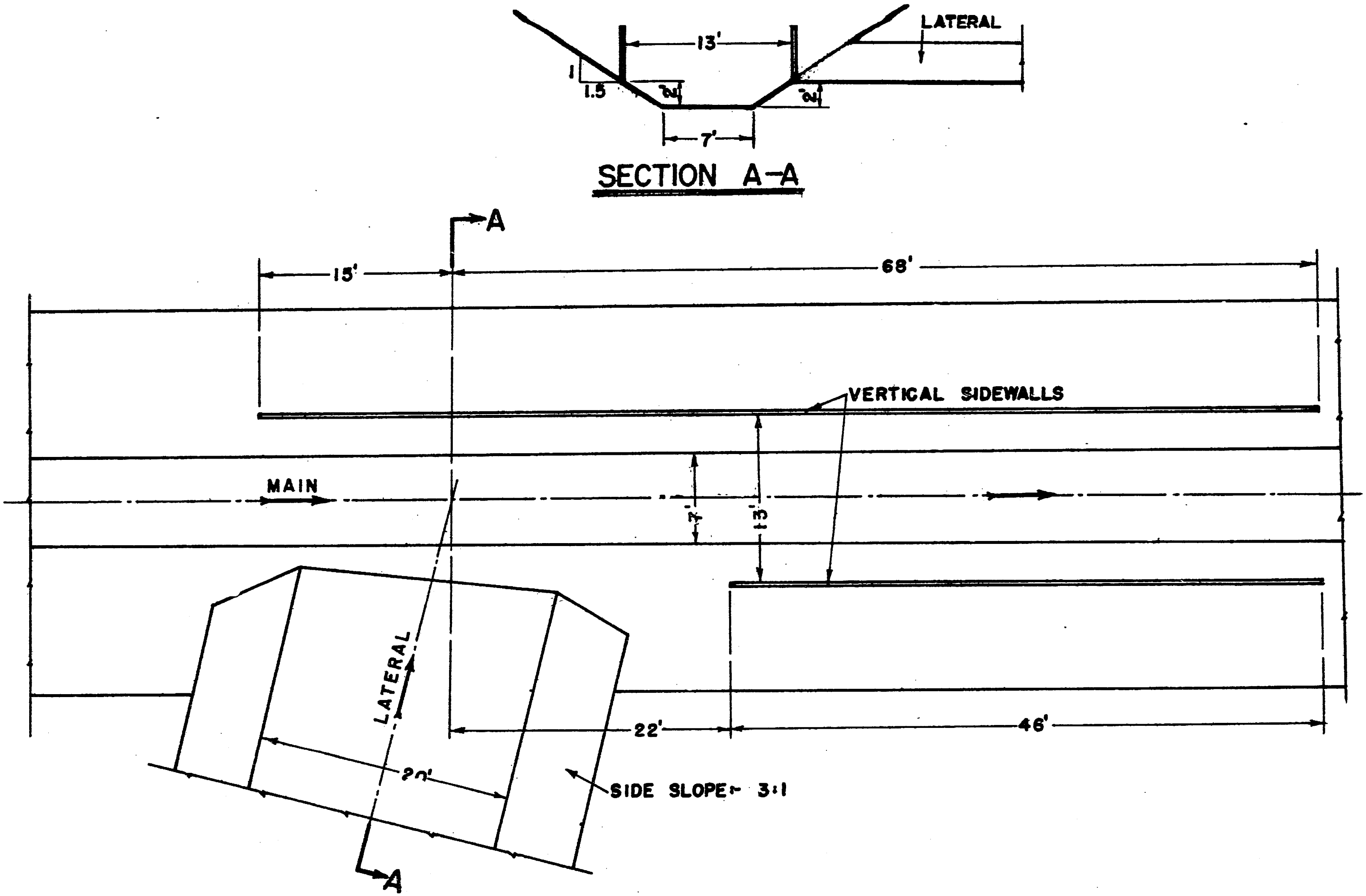

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Figure 6. Structure C-5, Design 2 - Vertical Sidewalls

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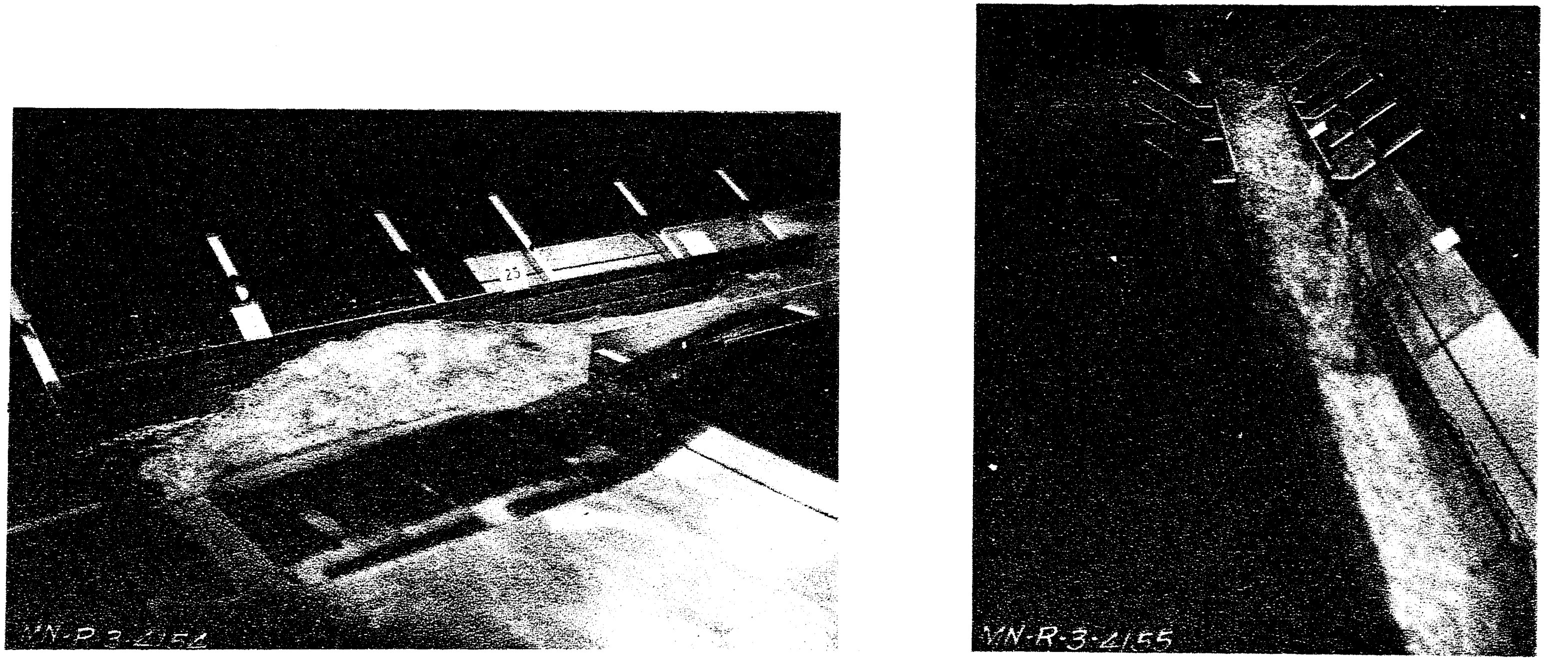

The above design is similar to Design 1 except for addition of vertical sidewalls at the junction.

Figure 7. Structure C-5, Design 2 - Maximum Discharge

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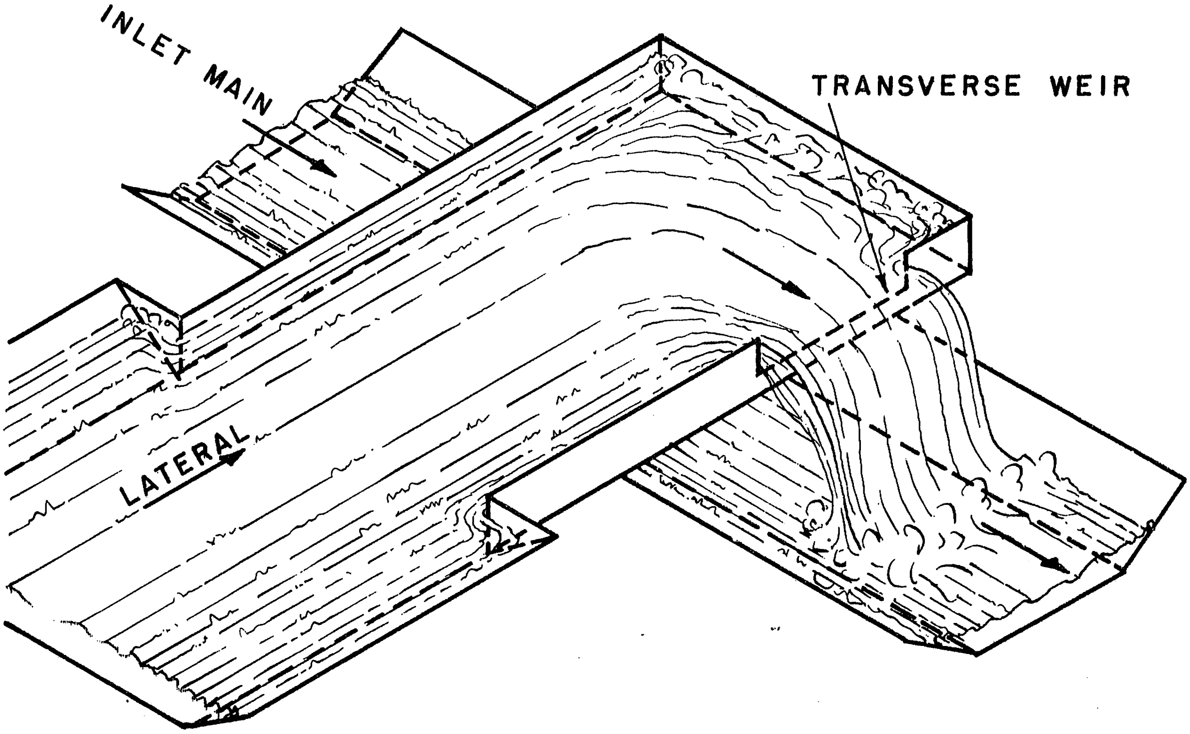
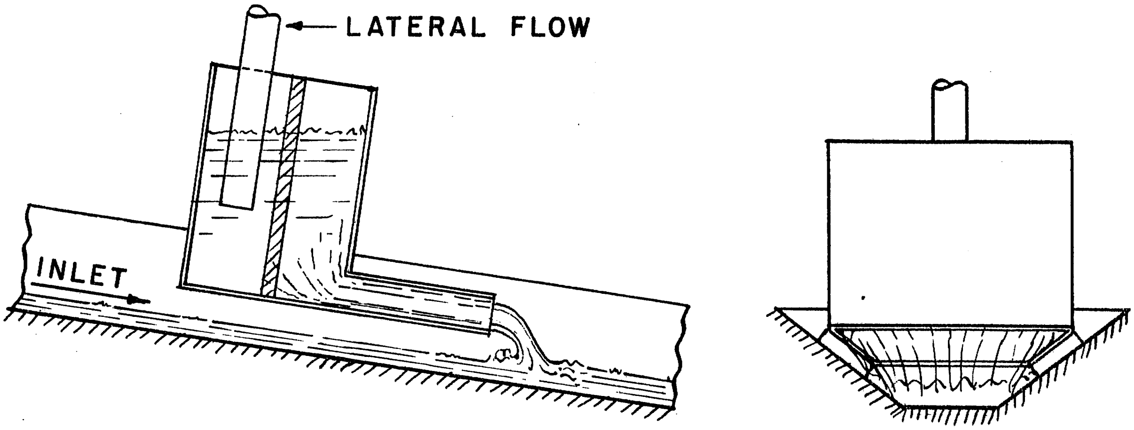


Figure 8. Structure C-5, Design 3 - Proposed Design



This design was a modification of the proposed Design 3 to permit variations in elevation and velocity of the lateral.

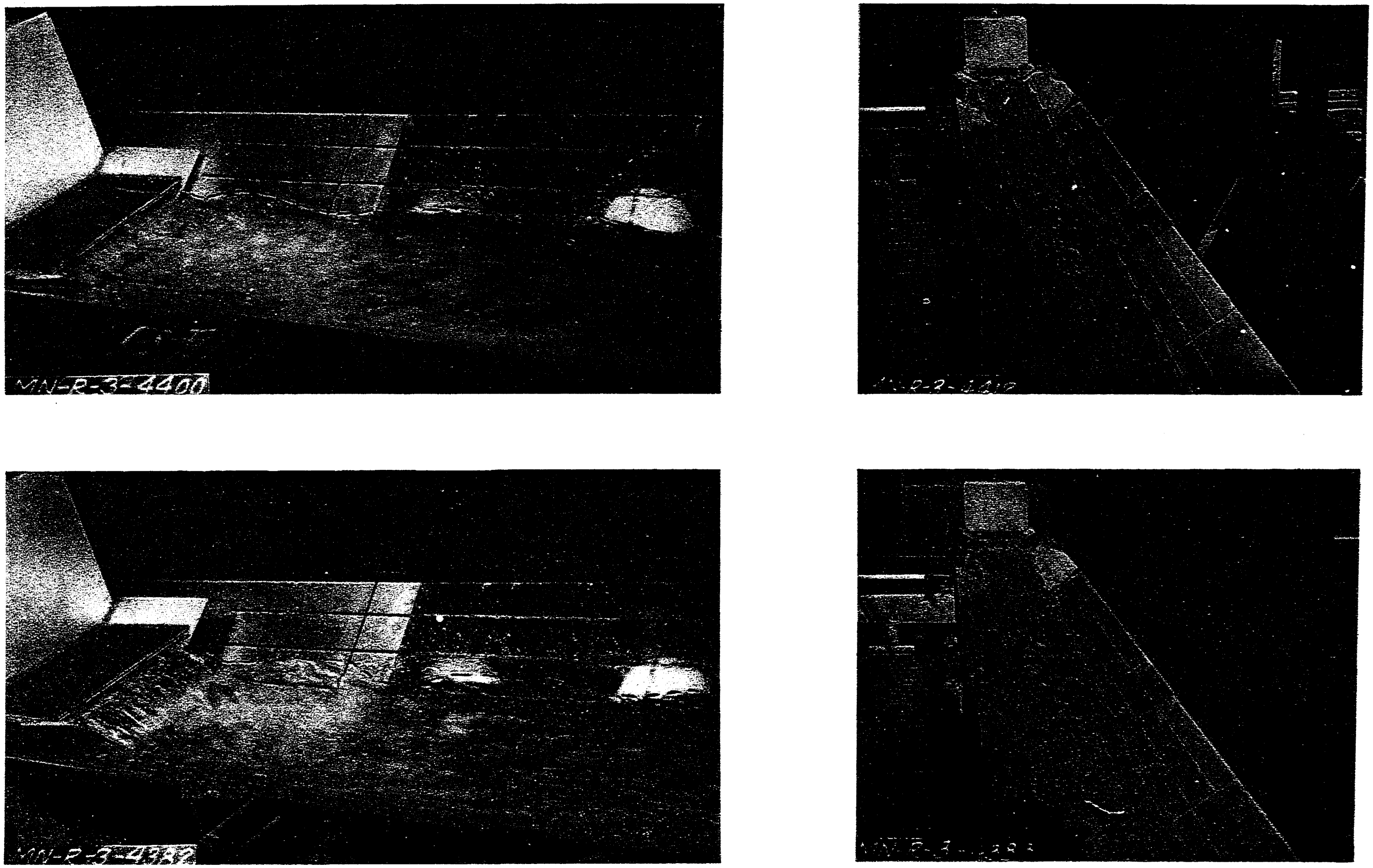
Figure 9. Structure C-5, Modified Design 3 for General Model Tests

proposal that was set up to facilitate model studies on the effect of elevation and velocity of the lateral flow. With this setup it was possible to raise or lower the flow from the lateral with respect to the main stream with a minimum of difficulty. Also, by slight modifications to the headbox it was possible to vary the horizontal velocity of the top or lateral stream from the same velocity as that of the main stream down to a value considerably less. It was assumed that a minimum disturbance would result if the two streams had the same velocity. It should be noted that this arrangement was not intended to simulate the weir of Figure 8 nor to serve as the basis of a prototype design, but merely to furnish qualitative information on the effect of changing some of the variables.

With design discharges in both channels the velocity of the lateral was varied from the same velocity as that in the main channel down to one-half of that amount. No appreciable difference was noted in the downstream flow due to this variation, with the exception of an increase in the amount of spray at the junction for the lower velocity in the lateral.

The vertical spacing between the bottom of the lateral and the bottom of the main was varied from 2.65 feet to 4.6 feet (normal depth of flow in the inlet main was 1.75 feet). Slight surface waves (Figure 10) developed with the latter spacing, but they were not considered objectionable. Waves were created in the downstream channel with a maximum flow in the top (lateral) channel and low flows in the inlet main, but their magnitude was only slightly in excess of the normal depth for a maximum discharge in both channels.

With a vertical spacing of 2.65 feet between the channels, it was found that an occasional surge could cause the water surface of the inlet main to strike the underside of the lateral channel. The result, in some instances, was the formation of a hydraulic jump upstream from the lateral which overtopped the relatively high sidewalls of the model channel. A jump also might form if debris lodged on the upstream side of the lateral. Thus, the tests emphasize the desirability of providing adequate clearance between the surface of the main channel and any structure spanning the channel.



Illustrated is a test setup for a design in which the lateral flow enters the main channel from the top after being turned through 90°. In the top views the vertical spacing between the bottom of the lateral and the bottom of the main corresponds to 2.65 feet, while in the bottom views it corresponds to 4.6 feet.

Figure 10. Structure C-5, Design 3 - Comparative Effect of Lateral Elevation

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Figure 11 illustrates the flow condition downstream from the junction when the top or lateral flow is appreciably narrower than the surface width of the main channel. The discharges, vertical spacing of channels, and related conditions are identical with those of Figure 10, except for the small pieces at the sides of the lateral which cause a horizontal contraction of the lateral flow. It may be noted that with the contracted lateral flow, large waves develop downstream from the junction, illustrating the desirability of spreading the top flow uniformly over the bottom flow.

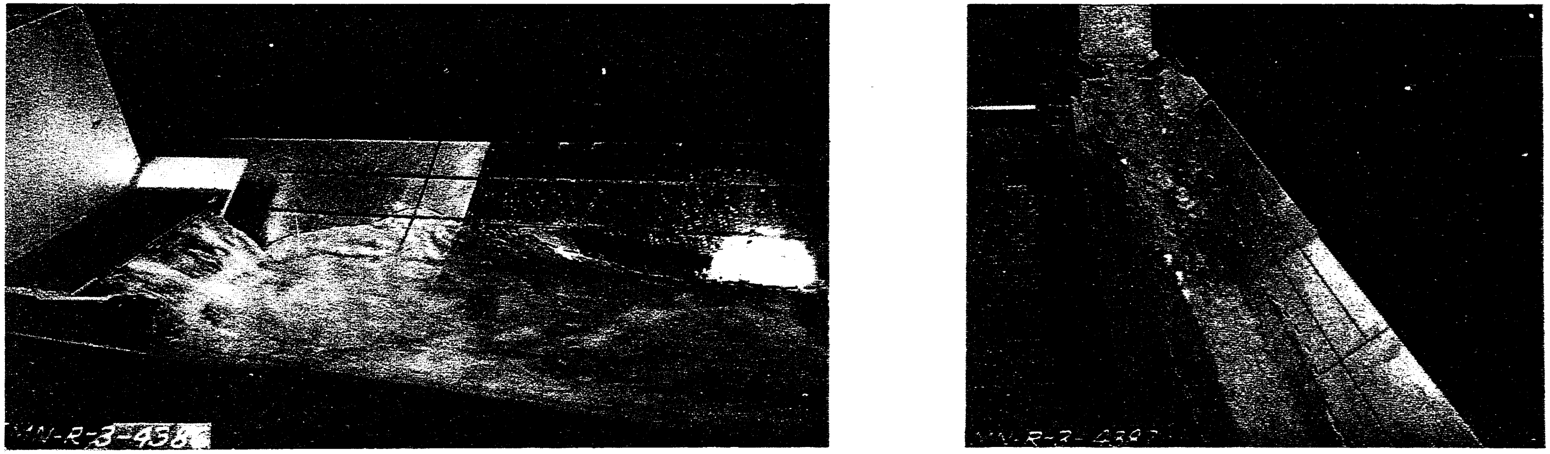
While the above tests indicated that it was feasible to add the lateral flow from the top, the tests of this design were discontinued because the design was considered impractical due to prototype ground configurations. Additional tests were conducted later in connection with the terrace outlets where the ground configuration was more favorable to this type of design.

Design 4 (Undershot)

Another proposal, referred to as Design 4, was similar to Design 3, except that the lateral flow entered the main channel from the bottom. Although this design appeared feasible, no tests were conducted because of time limitations on the study and the development of other designs involving a simpler and more economical construction.

Design 5 (Counterdisturbance)

Figure 12 illustrates a fifth design based on the creation of a disturbance counter to that created by the lateral. An angular wall which diverted part of the flow across the channel was placed upstream from the junction. The diverted flow was reflected off a vertical wall and counteracted the disturbance caused by the lateral. The flow conditions with a maximum discharge in both channels are shown in Figure 13. The method was quite successful, provided the ratio of the main and lateral discharges was not varied too widely.



Small sidepieces have been placed on the top or lateral channel to contract the flow. The resultant waves in the main channel emphasize the desirability of distributing the top flow across the complete width of the main channel.

Figure 11. Structure C-5, Design 3 - Effect of Narrow Lateral

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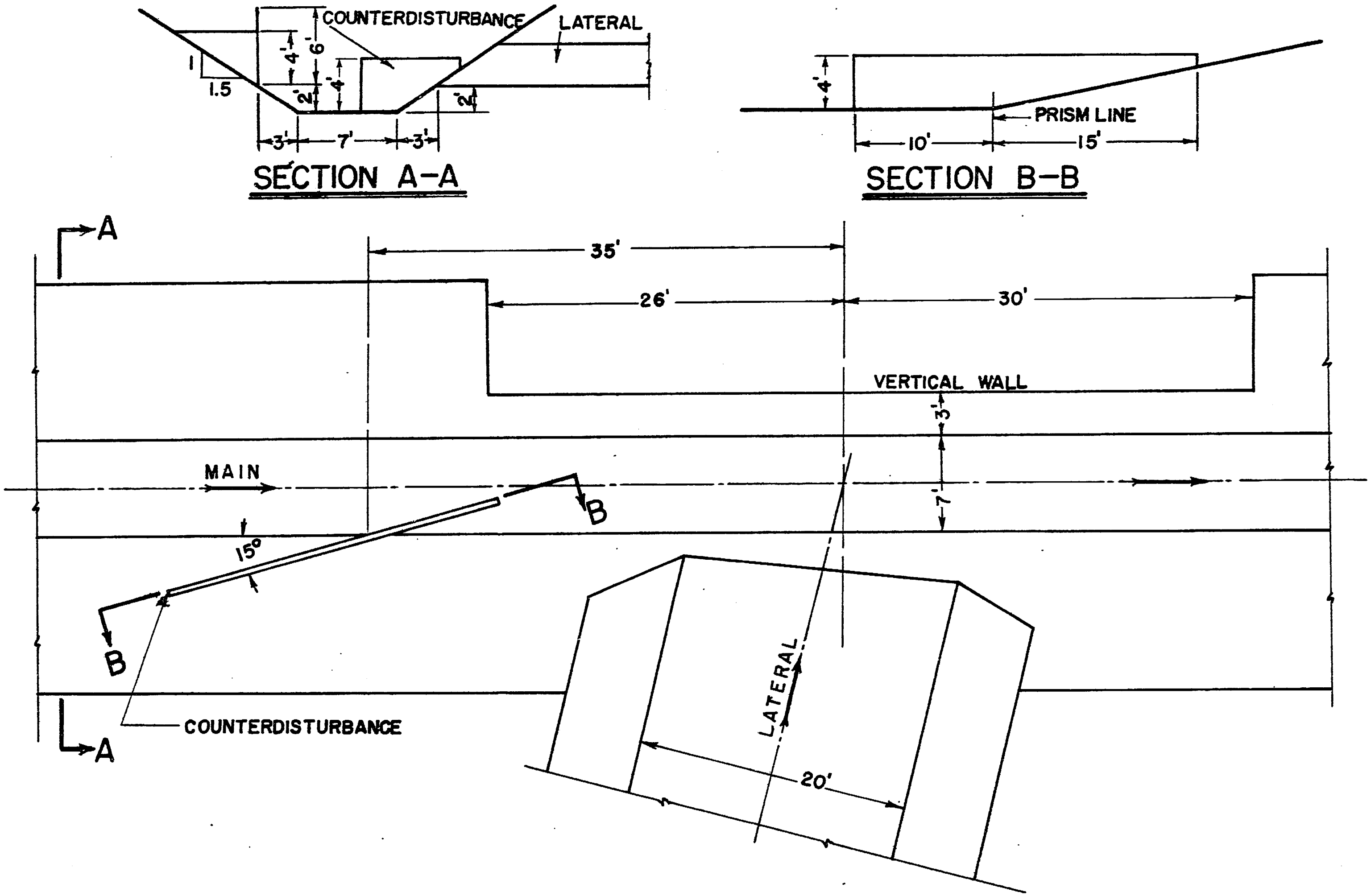

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Figure 12. Structure C-5, Design 5 - Counterdisturbance

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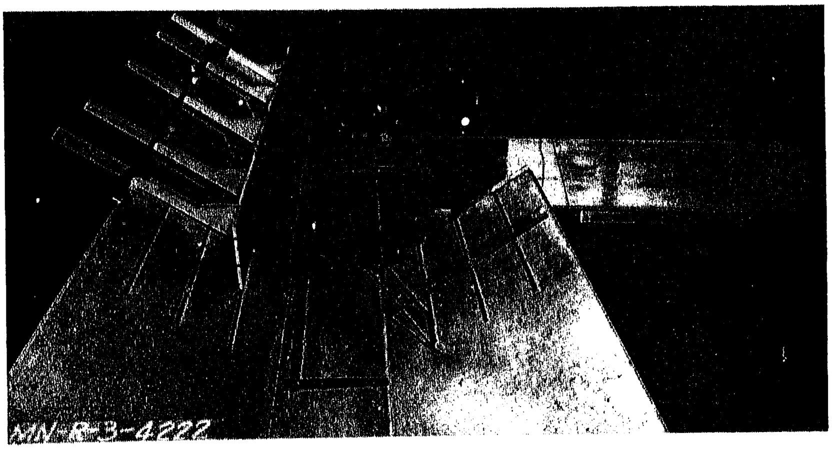
Design 6 (Piers)

Design 6, illustrated in Figure 14, is recommended for the prototype Junction C-5. It is similar to Design 1 with the addition of a vertical wall opposite the lateral and two longitudinal submerged piers downstream from the lateral.

The vertical wall prevents excessive lateral expansion of the flow at the junction, while the longitudinal submerged piers assist in damping the transverse waves generated by the junction of the two flows. Figures 15 and 16 show several flow conditions.

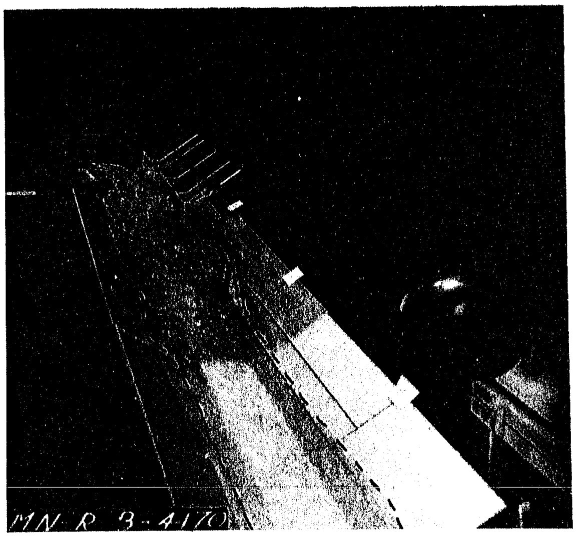
Variations in the position, length, height, and number of piers were studied experimentally. It was found that relatively short piers could be used for a specified combination of discharges in the joining channels, but for other discharges it was necessary to move the piers. This apparently resulted from a variation in the longitudinal position of the cross waves with variations in depth and velocity of the flow. Long piers were necessary to cover the anticipated range of operating conditions. It was also found that an optimum height of pier existed for specified discharges; an average value was selected that is adequate for the anticipated range of operating conditions.

On the basis of visual observations of the flow, it was concluded that for some operating conditions the flow passed through the junction at supercritical velocity, while for others a hydraulic jump was formed. The formation of a jump was dependent upon the discharges of the main and lateral channels. For example, with a discharge of 181 cfs in the lateral, a jump was formed in the main channel for all inlet-main discharges less than approximately 260 cfs. For inlet-main discharges in excess of 260 cfs, a diagonal wave was formed which did not exhibit the appearance of a true jump. Using an analysis based on pressure-momentum relationships, it was possible to predict the approximate range of conditions in which a jump would form. This is discussed in the latter part of this report under the heading, "Pressure-Momentum Relationships." Figures 15b and 16a illustrate the flow with a transverse wave, while Figure 16c illustrates a condition which produces a hydraulic jump.



(a) Downstream View

(b)' Side View with Maximum Discharge in both channels



(c) Upsteam View with Maximum Discharge in both channels

The diagonal Lucite wall in the foreground of the top photograph created disturbance counter to that caused by the lateral.

Figure 13. Structure C-5, Design 5 - Effect of Counterdisturbance

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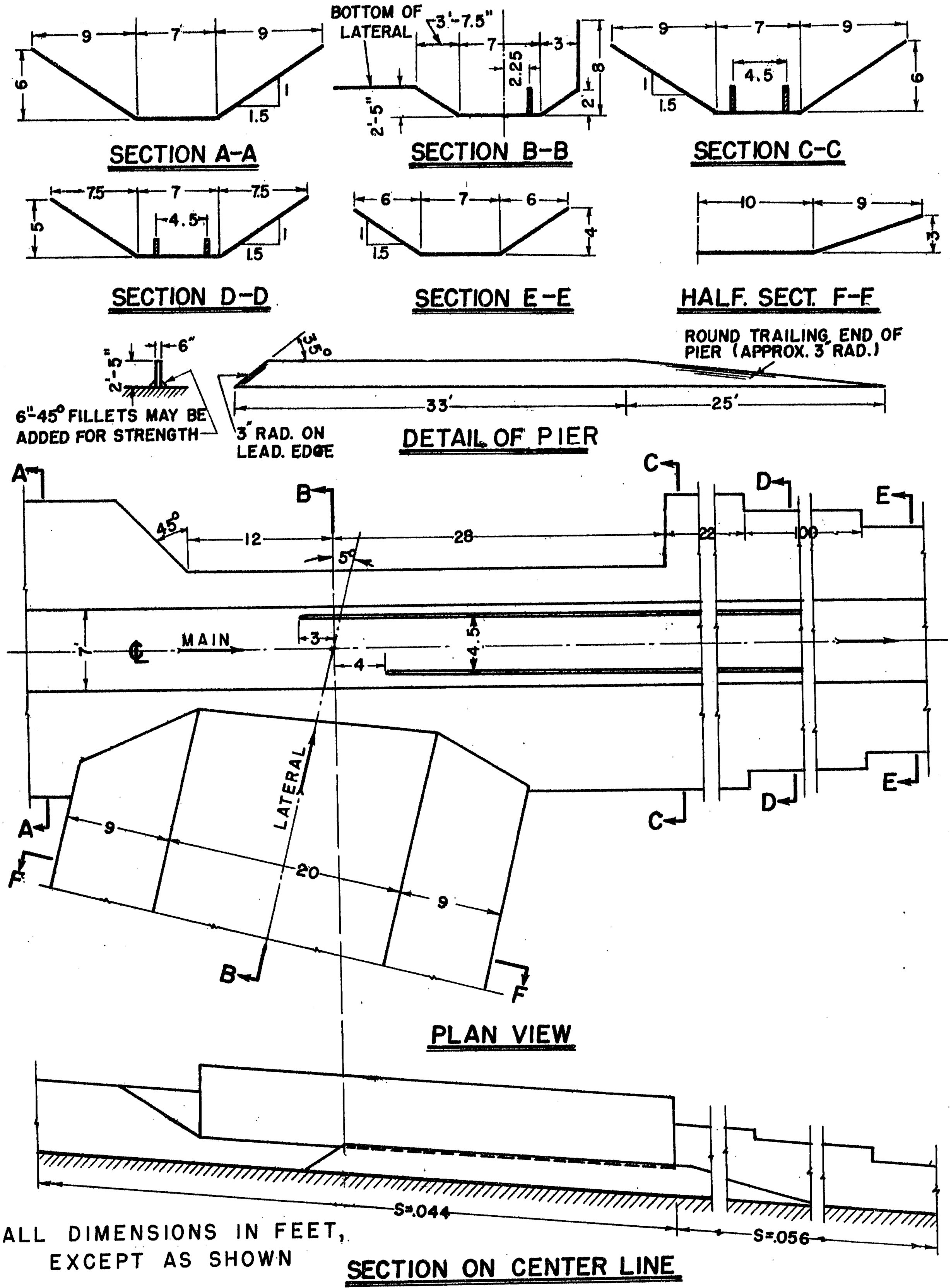

ALL DIMENSIONS IN FEET, EXCEPT AS SHOWN

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This design is recommended for the prototype structure.

Figure 14. Structure C-5, Design 6 - Pier Design

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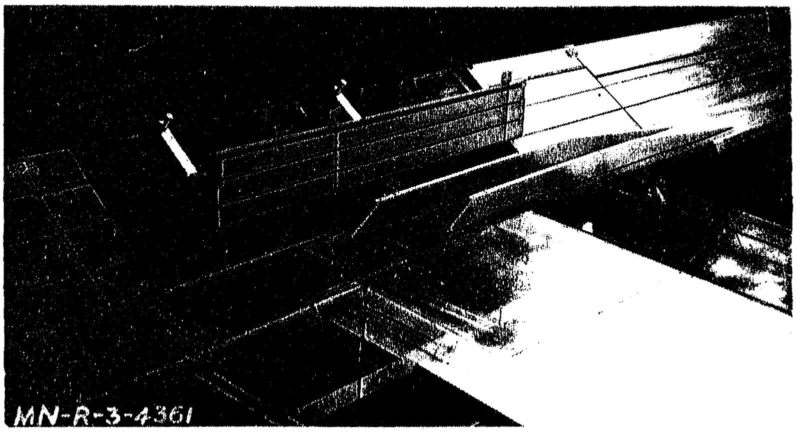
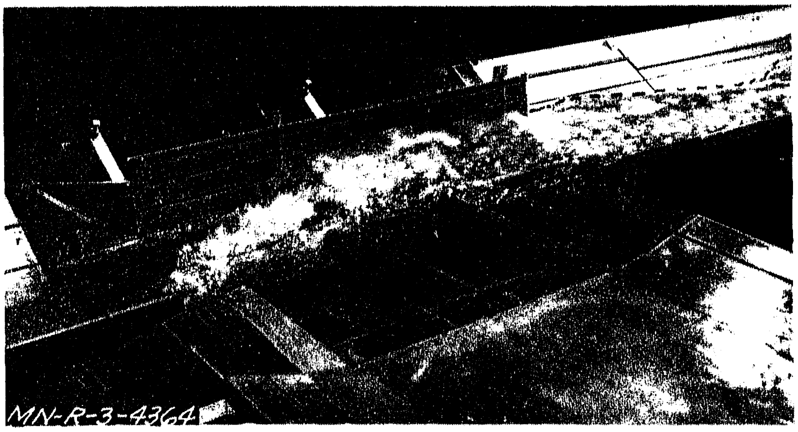
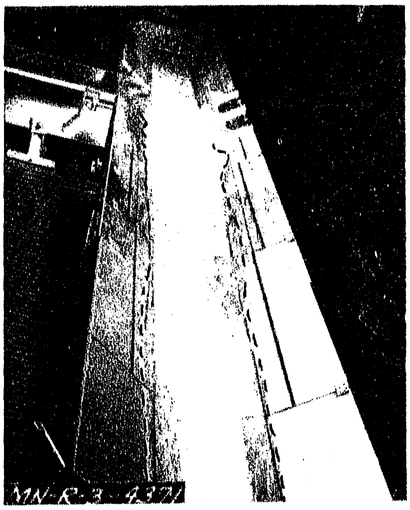


(a) Side View - No Flow
The heavy lines represent the recommended sidewall heights.



(b) Side View with Maximum Discharge in Both Channels



(c) Upstream View with Maximum Discharge in Both Channels

The lower two photographs illustrate the maximum discharge conditions in which $Q_1 = 414$ cfs and $Q_2 = 181$ cfs.

Figure 15. Structure C-5, Design 6 - Pier Design

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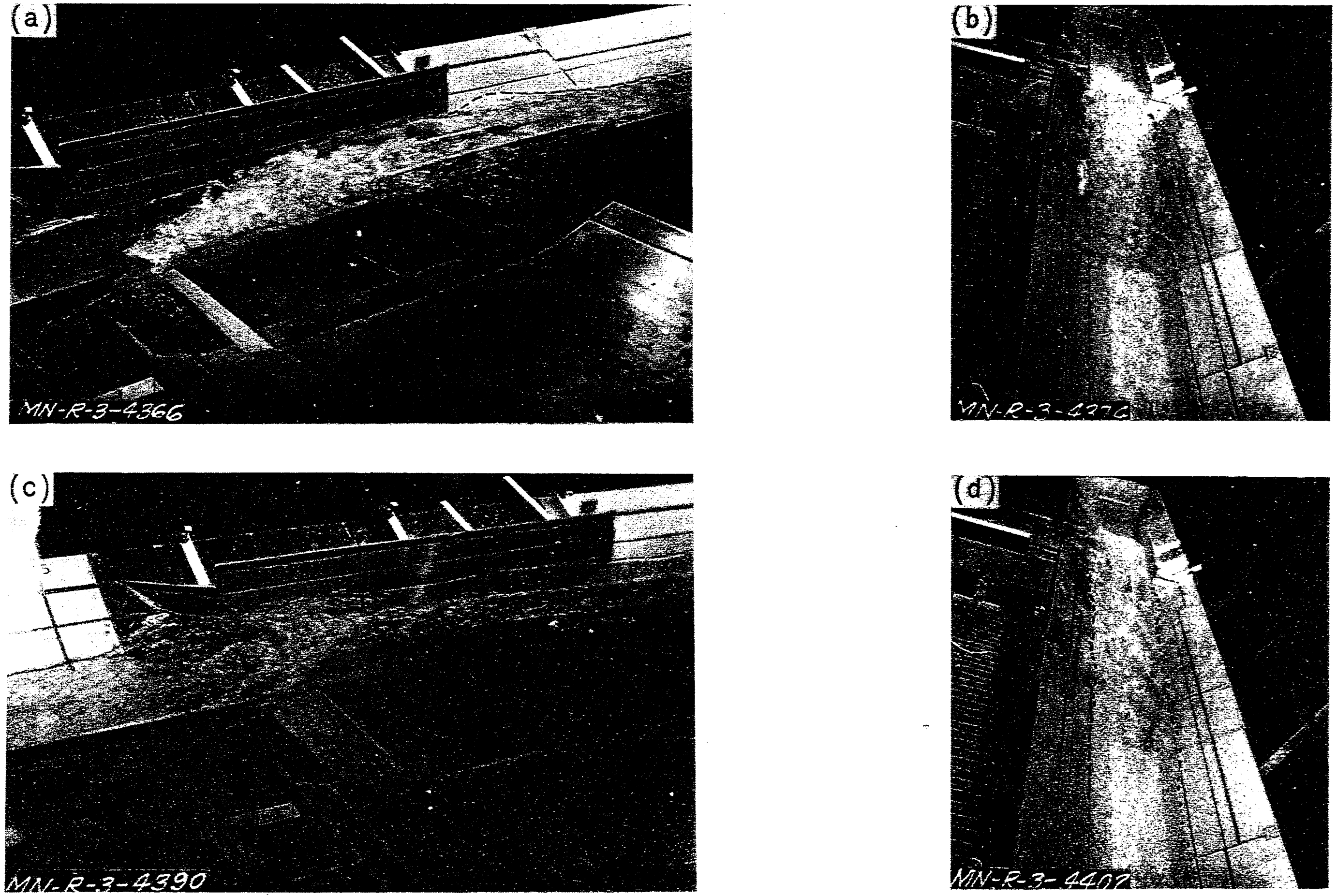

The two top photographs illustrate flows equal to 414 and 90 cfs in the inlet main and lateral respectively. There is a diagonal wave front. In the lower two photographs a jump is formed just upstream of the junction. The discharges are equivalent to 207 cfs in the inlet main and 181 cfs in the lateral.

Figure 16. Structure C-5, Design 6 - Pier Design

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For those conditions in which a jump formed, the position of the jump was dependent upon the discharge of the joining channels. The flow accelerated downstream from the junction, passing through the critical stage within a short distance. Under these conditions the downstream surface was relatively free of surges and waves.

When the flow conditions were such that a diagonal wave formed rather than a jump, the downstream surface was somewhat rough, as is illustrated in Figure 17, but it was considered acceptable.

Figure 18 illustrates the velocity distribution in the main channel.

As noted earlier, the flow in the lateral channel was tranquil. Due to its elevation above the main channel, the flow passed through critical as it entered the main channel; in this respect the junction was the equivalent of a drop-off for the lateral. This prevented the surges and waves of the junction from traveling up the lateral. A minimum vertical spacing of the channel bottom of 2 feet 5 inches is necessary to insure the above conditions.

The recommended wall heights in the vicinity of the junction and related design data are shown in Figure 14.

Recommendations

On the basis of visual observations and photographic records, it was concluded that Design 6 was the most satisfactory of the designs tested; the performance of the junction over the anticipated operating range of discharges and the economic and structural features of the prototype unit were considered in this selection.

Other Designs

In addition to the six designs of Structure C-5 previously discussed, it would be possible to include several other proposals. One of these designs which received some consideration would employ a radius curve in the lateral to turn the lateral flow parallel to the main channel. However, if the lateral flow joined the main flow along one side of the main channel, a shock wave or a hydraulic jump would be created which would still require the use of walls and piers similar to Design 6.

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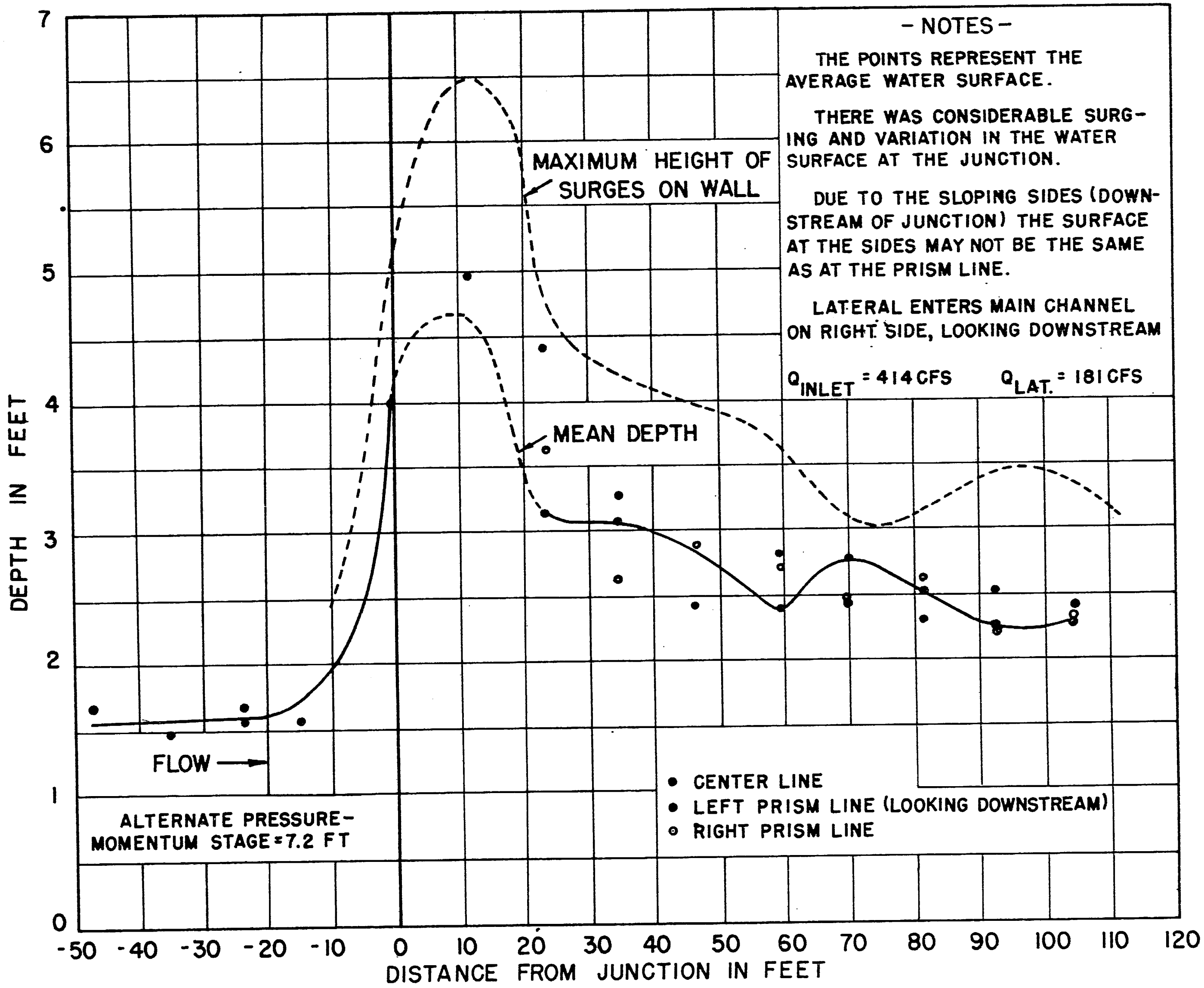

Figure 17. Structure C-5, Design 6 - Depth of Flow at Design Discharge

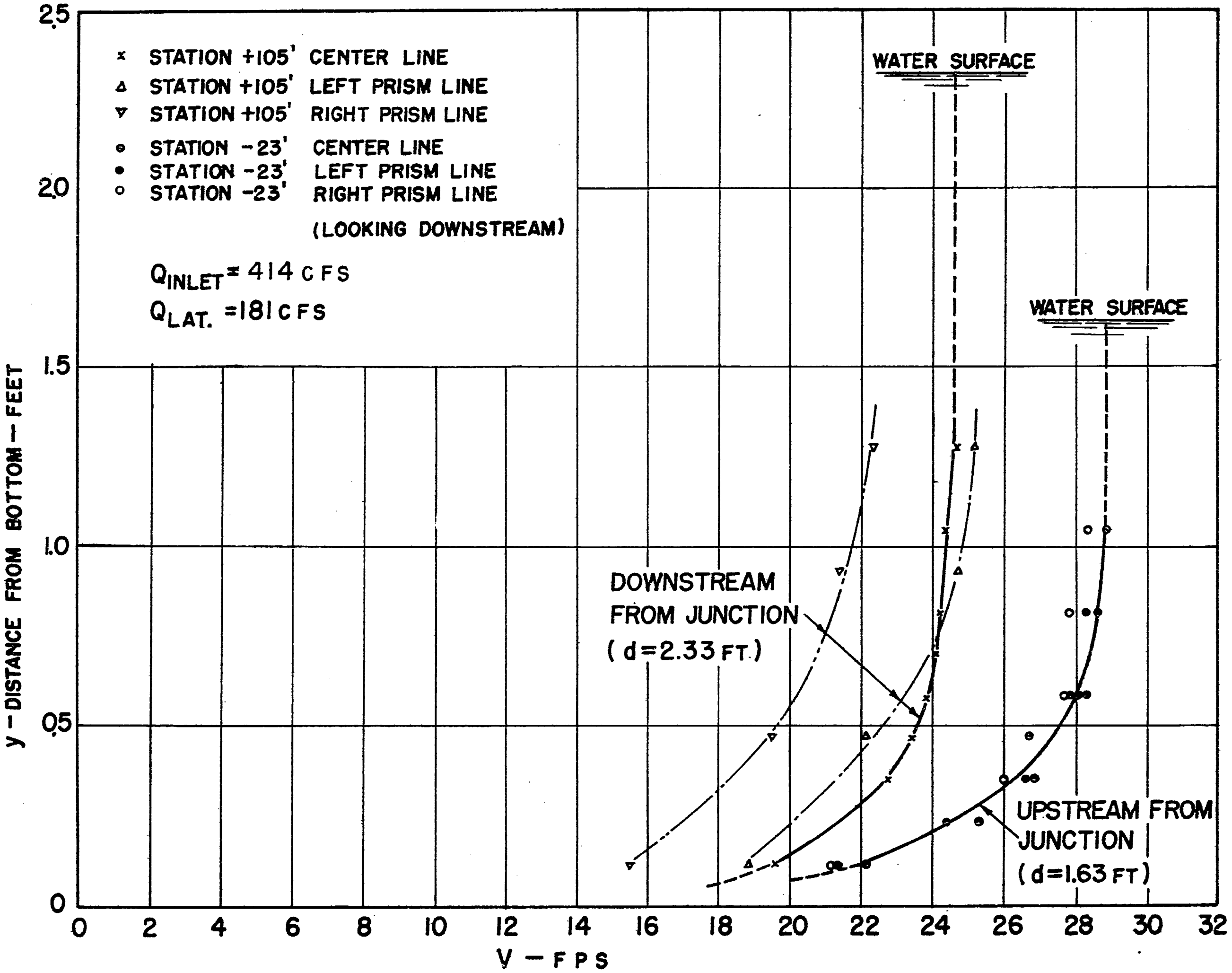

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Figure 18. Structure C-5, Design 6 - Velocity Distribution in the Main Channel

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A second proposal which received some consideration was based on the creation of a hydraulic jump in the main channel for all discharges; the lateral would enter the main channel just downstream from the jump where the flow was tranquil. Sills or other means would be used to force the formation of a jump. As the alternate pressure-momentum stage of the inlet main was 6.8 feet for a discharge of 414 cfs, higher sidewalls would be required than for the recommended design. Also, it would be necessary to raise the bottom of the lateral to an elevation of approximately 6 feet above the main channel. This was not feasible as the original design criteria restricted the vertical spacing between the bottoms of the joining channels to approximately 2 feet because of prototype ground configurations.

Structure C-4

Structure C-4 is a terrace outlet in which local drainage is admitted to C Ditch. The maximum discharge of the lateral is 25 cfs. The design criteria furnished by the Region 3 Engineering Division are listed in Table II.

TABLE II

DESIGN CRITERIA FOR STRUCTURE C-4

	Inlet Main	Lateral	Outlet Main
Discharge (cfs)	384.0	25.0	409.0
Bottom Width (ft)	7.0	8.0	7.0
Side Slope	1.5:1	3:1	1.5:1
Slope	0.0086	0.001	0.020
Normal Depth (ft)*	2.65	1.22	2.20
Normal Velocity (fps)*	13.5	1.75	18.5
Froude Number*	2.14	0.078	4.83
Manning's n	0.015	0.025	0.015

*Based on maximum discharge.

The included angle between the main channel and the lateral was listed as 90 degrees plus or minus 10 degrees. The suggested vertical spacing between the bottom of the main and the bottom of the lateral at the junction was 2 feet 9 inches.

The model was constructed with the lateral at right angles to the main channel. The scale ratio was 11.63.

The recommended design of Structure C-4 is illustrated in Figure 19.

The initial model studies, based on a prototype friction factor for the main channel of 0.015, indicated that with a lateral discharge of 25 cfs, a hydraulic jump formed in the main channel for all discharges up to and including the maximum (Figure 20a). With lateral discharges less than 25 cfs, the formation of a jump was dependent upon the discharge of the inlet main. For those conditions in which a jump formed, flow downstream from the junction was good (Figure 20b). When a jump did not form, waves were created at the junction and the surface downstream from the junction was rough.

In view of the fact that the prototype friction factor of 0.015 was an estimated value and because a decrease in the friction factor would probably be detrimental to flow conditions at the junction, the model was tested for conditions equivalent to a prototype n value of 0.013. It was found that for a lateral discharge of 25 cfs and a maximum inlet main discharge of 384 cfs a hydraulic jump no longer formed (Figures 20c and 20d). As a result, the flow downstream from the junction was characterized by waves which were reflected back and forth across the channel. A decrease in the discharge of the inlet main resulted in the formation of a jump.

The use of a single submerged pier in the center of the channel resulted in good flow conditions for all discharges (Figure 21). The vertical spacing between the bottom of the joining channels was increased to 3.25 feet to prevent surges from traveling up the lateral. Profiles of the water surface are shown in Figure 22 for an inlet-main discharge of 384 cfs and the lateral discharges of 25 and 50 cfs. While the maximum anticipated lateral discharge was 25 cfs, measurements were taken for a discharge of 50 cfs as a matter of general interest.

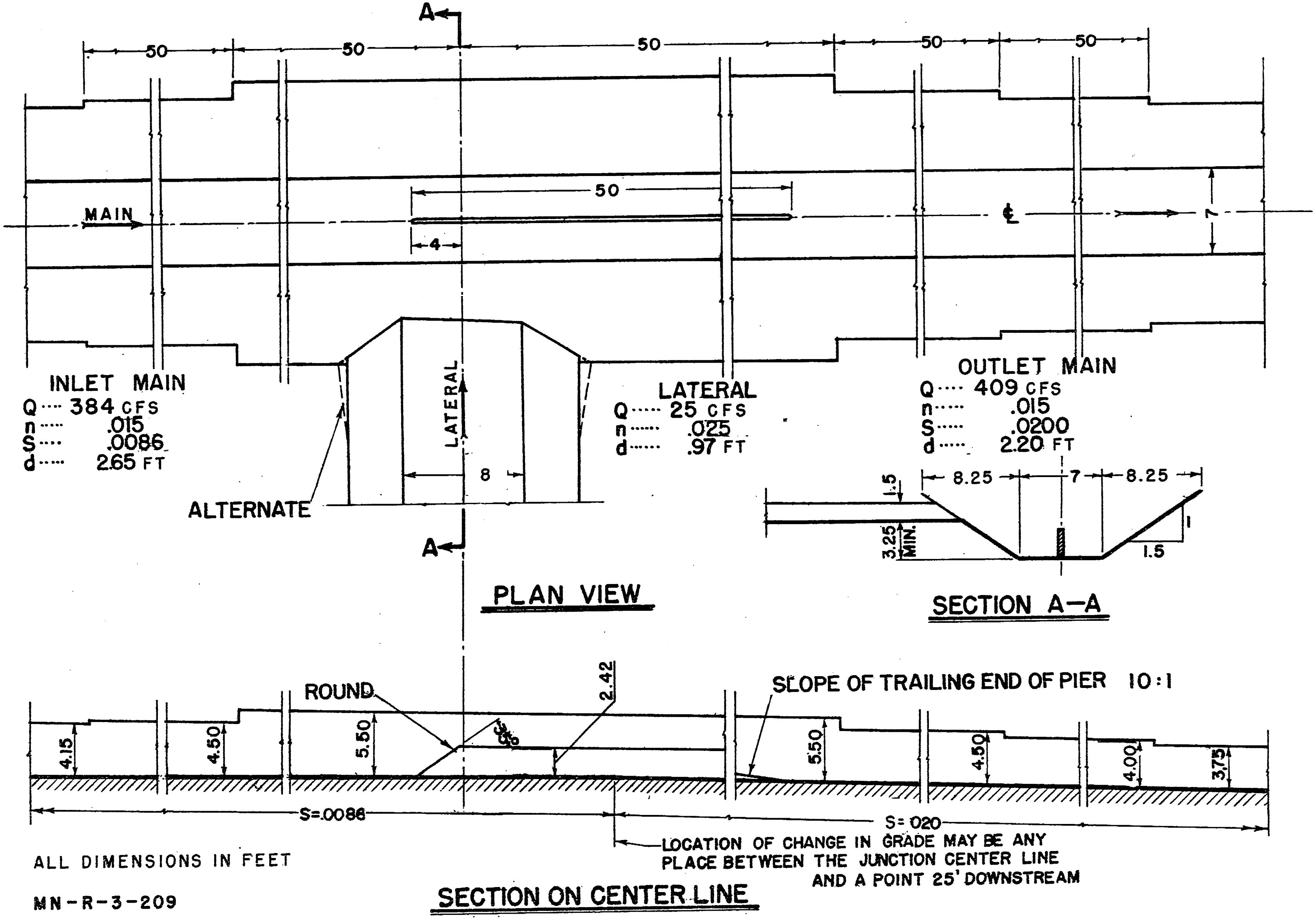

Figure 19. Structure C-4, Design I - Proposed Design

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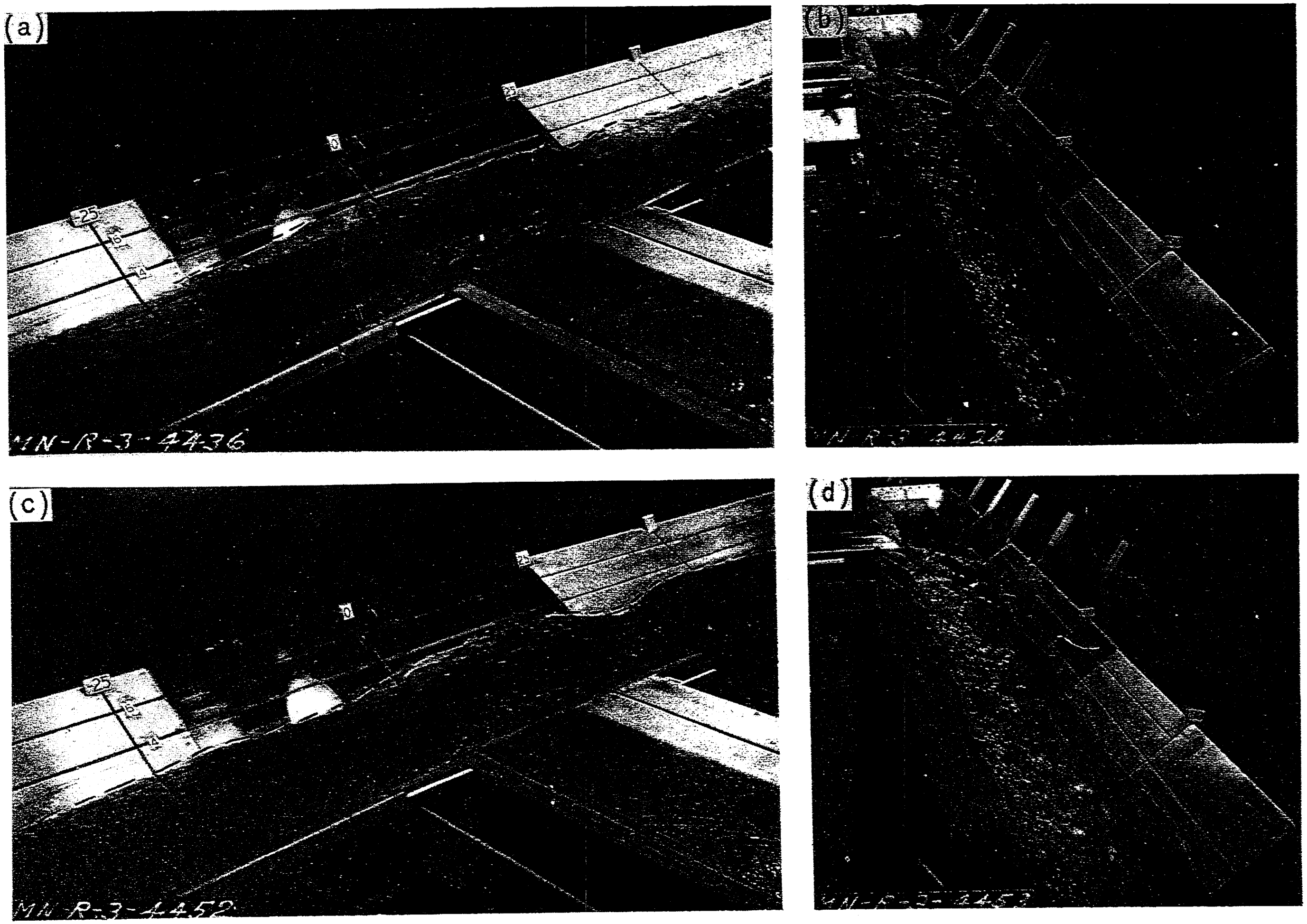

The four photographs illustrate flow conditions corresponding to prototype discharges of 384 and 25 cfs in the inlet main and lateral respectively. The top two photographs illustrate a condition based on a prototype friction factor of 0.015, whereas the condition in the bottom two is based on a factor of 0.013. In the top photograph a hydraulic jump has formed at a point 20 feet upstream of the junction. In the bottom photograph a diagonal wave rather than a jump has been formed.

Figure 20. Structure C-4, Design I - Maximum Discharge Condition

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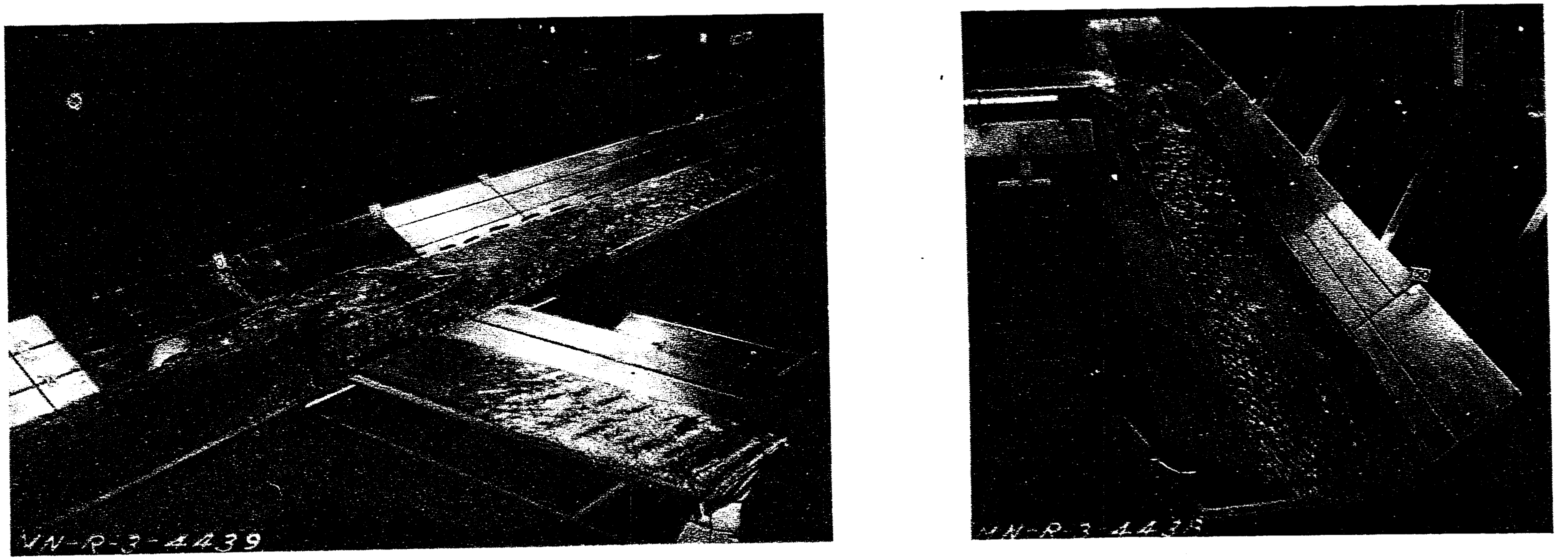

The flow conditions correspond to those of Figures 20c and 20d. The addition of the pier has a beneficial effect.

Figure 21. Structure C-4, Design 2 - Pier Design

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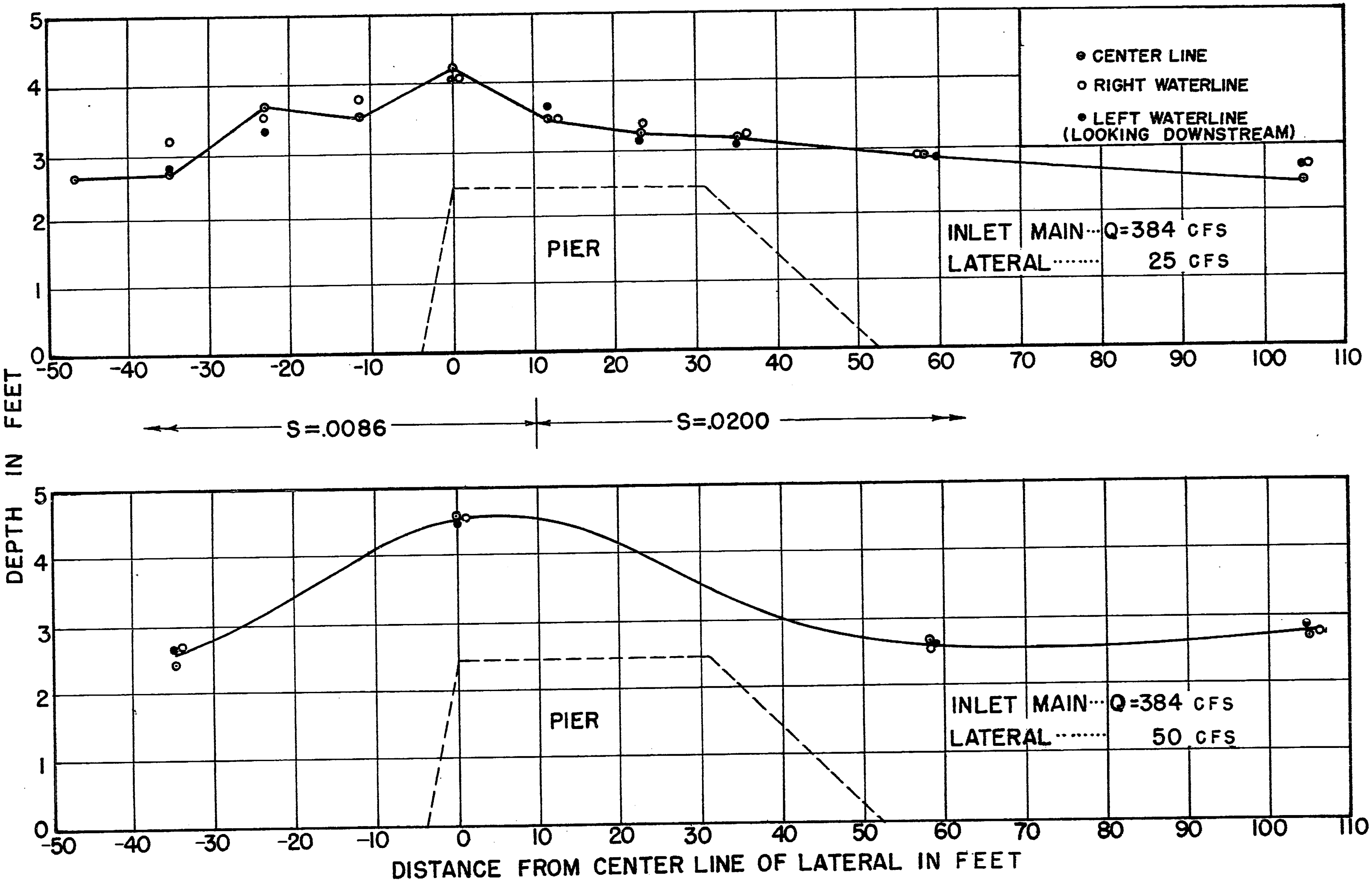

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Figure 22. Structure C-4, Design 2 - Depth of Flow

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The design illustrated in Figure 20 was considered satisfactory and is recommended for the prototype structure.

General Terrace Outlets

Numerous terraces will discharge relatively small quantities of water into A, S, and W Ditches at Whiting Field. If the disturbances produced by a series of terrace outlets located along a ditch are cumulative, they might reach serious proportions. Model studies were desirable, but they could hardly be justified for each terrace outlet. Therefore, it was decided that a general study of terrace outlets would be made which would cover the anticipated range of operating conditions and provide sufficient information for the design of the terrace outlet structures. The Region 3 Engineering Division requested that the studies be conducted on a junction design similar to that shown in Figure 8. The design criteria are shown in Table III.

TABLE III

DESIGN CRITERIA FOR TERRACE OUTLET STRUCTURES

	Inlet Main	Lateral	Outlet Main
Maximum Discharge (cfs)	300-400	5-20	305-420
Bottom Width (ft)	4.0	10.0	4.0
Side Slope	1.5:1		1.5:1
Slope	0.04-0.08	0.005-0.015	0.04-0.08
Manning's n	0.015	0.035	0.015

The lateral was to be at right angles to the main channel. The suggested vertical spacing between the bottom of the main and the bottom of the lateral was 3.0 feet.

The initial tests were conducted with a channel slope of 8 per cent and inlet-main discharges of 0 to 400 cfs. The computed depth of the inlet main for the maximum discharge was 1.88 feet and the Froude number was approximately 16.3.

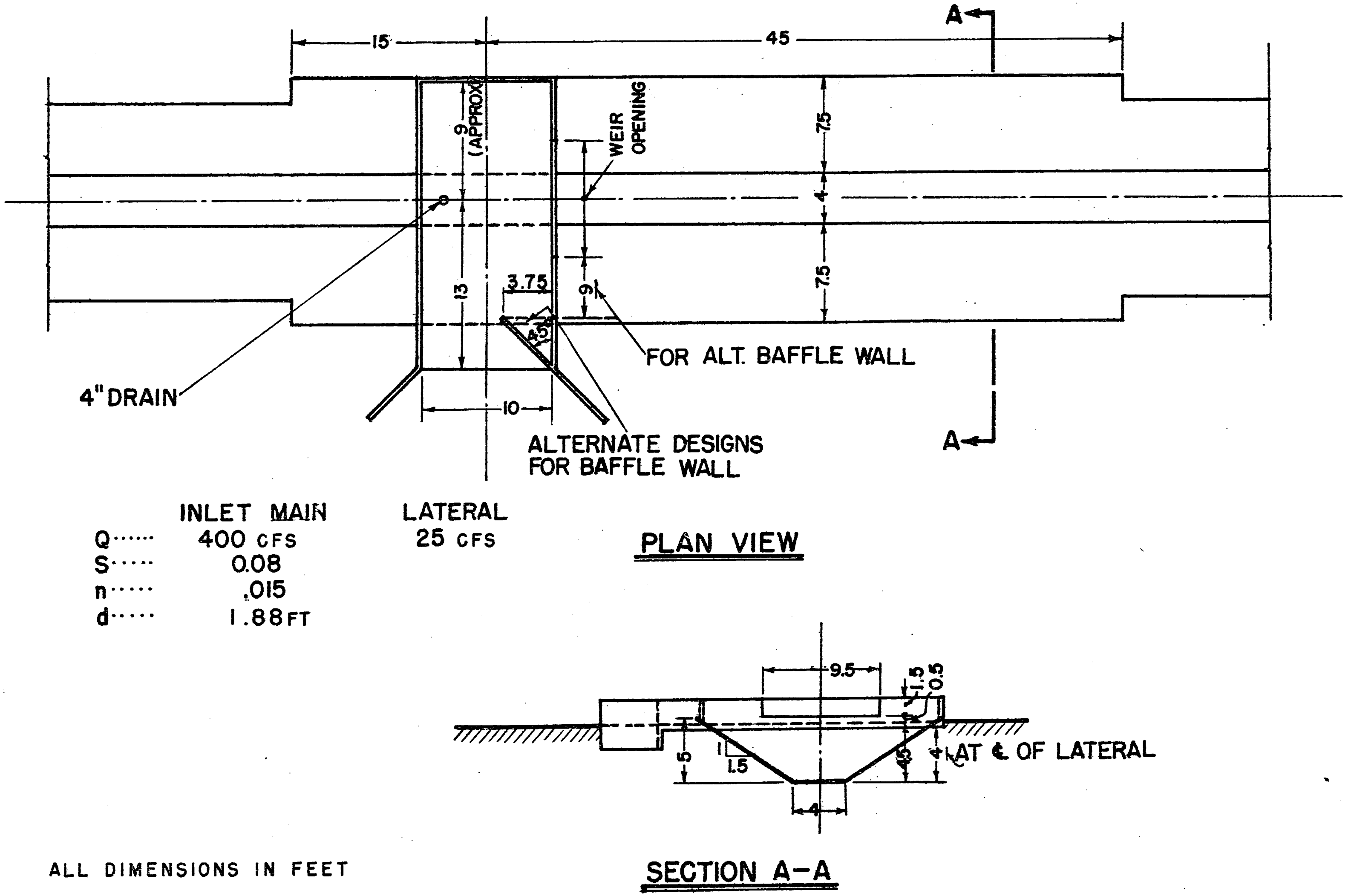
The proposed design for this structure is illustrated in Figure 23. The baffle walls shown in Figure 23 were not installed initially and, with a maximum discharge in the lateral, it was noted that the flow was not evenly distributed across the transverse weir. This resulted because the lateral flow was turned through 90 degrees before flowing over the weir. The addition of a baffle wall to one side of the weir opening greatly improved the flow. It was found that the wall could be placed at right angles to the centerline of the lateral or at 45 degrees as shown in Figure 23.

It was also noted that some surface spray generated by the inlet main was striking the upstream side of the lateral. While this was not necessarily indicative of prototype performance, it was thought desirable to increase the vertical spacing of the channels to 4.5 feet. The greater clearance also reduced the possibility of the formation of a hydraulic jump on the upstream side of the lateral.

Figure 24 illustrates the flow conditions for the recommended design. With large discharges in the main channel there were no appreciable surface waves, but considerable spray was created downstream from the junction. With low discharges in the main channel, as illustrated in Figures 24c and 24d, the water surface downstream was quite irregular, but the maximum height of the waves was less than normal depth for large discharges. It is doubtful whether the model correctly simulates the spray conditions in the prototype; as a result, the recommended wall heights downstream from the junction are only an estimate.

The model tests emphasized the desirability of spreading the top or lateral flow uniformly over the water surface of the main channel. Best results were obtained when the width of the jet was slightly in excess of the water surface width in the main channel.

Due to time limitations on the study, it was not possible to test the complete range of channel slopes and discharges that was initially requested. In addition to the preceding studies only one other test



	INLET MAIN	LATERAL
Q······	400 CFS	25 CFS
S·····	0.08	
n·····	.015	
d·····	1.88 FT	

ALL DIMENSIONS IN FEET

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Figure 23. Terrace Outlet - General Design

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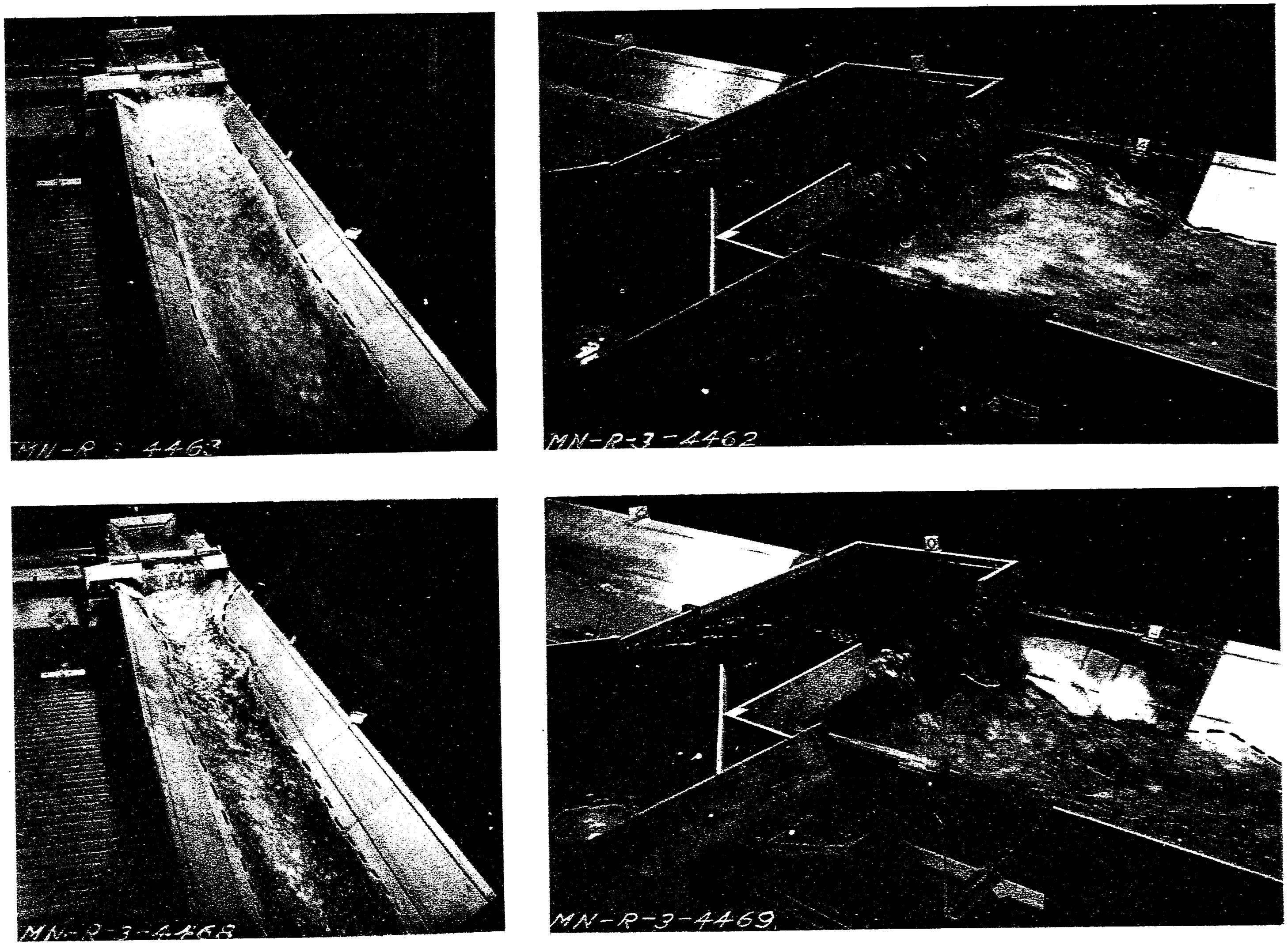

The top two photographs illustrate a typical maximum discharge condition corresponding to 400 and 25 cfs in the inlet main and lateral respectively. The bottom two photographs correspond to discharges of 100 and 25 cfs in the inlet main and lateral respectively.

Figure 24. Terrace Outlet - General Design

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condition was run. It corresponded to a maximum discharge of 300 cfs and the Froude number was 8.2. The appearance of the flow with discharges of 25 and 300 cfs in the lateral and inlet main respectively was similar to the preceding tests. It is probable that for low discharges in the main channel some waves might be formed, but it is doubtful whether they would be serious as long as a generous freeboard is provided.

It may be of interest to note that for the specified channel dimensions, channel slopes of 4 to 8 per cent, a friction factor of 0.015, and inlet-main discharges of 300 to 400 cfs, the minimum computed Froude number was 8.2 and the maximum was 16.3. For a lateral discharge of 25 cfs the ratio of the inlet flow to the lateral flow ranged from 12 to 16. For these conditions it was estimated that, except for spray, the transverse-weir junction would operate satisfactorily. In tests of another junction of this type (P-8) the results were not too satisfactory. In the latter case the discharge ratio for maximum discharge was 13.7, but the Froude number was only 2.9.

Brief tests were conducted with the lateral discharging over a weir at the upstream side of the transverse box. The results were unsatisfactory due to the large amount of spray created and an increased tendency toward the formation of a hydraulic jump.

Structure P-8

Structure P-8 consists of a junction between a channel with a maximum discharge of 70 cfs and P Ditch which has a maximum discharge of 960 cfs. It was requested that tests be conducted on the transverse weir-type junction similar to that shown in Figure 8. The initial design conditions are listed in Table IV.

Due to limitations on the time available for the study, the initial tests were conducted with a maximum discharge in the inlet main of 432 cfs, as opposed to a design maximum of 960 cfs. Subsequent tests were conducted with a maximum of 632 cfs.

TABLE IV

INITIAL DESIGN CRITERIA FOR STRUCTURE P-8

	Inlet Main	Lateral	Outlet Main
Maximum Discharge (cfs)	960.0	70.0	1030.0
Normal Depth (ft)*	4.09		4.23
Normal Velocity (fps)*	19.4		19.8
Bottom Width (ft)	6.0	20.0	6.0
Slope	0.012	0.005-0.015	0.012
Side Slope	1.5:1		1.5:1
Froude Number*	2.86	Tranquil Flow	2.88
Manning's n	0.015	0.035	0.015

*Based on maximum discharge.

Design 1 (Initial Proposal)

With discharges of 432 and 70 cfs in the inlet main and lateral respectively, the downstream water surface was very rough, with large waves developing and continuing downstream. The wave crests were 4 to 4.5 feet above the channel flow and the hollows were 2 feet above the floor (Figure 25a).

Design 2 (Increasing Froude Number)

It was thought that flow conditions could be improved by increasing the Froude number of the inlet main. On the basis of the ground profile of P Ditch, the slope of the ditch upstream from the junction was decreased for a distance of 666 feet and then increased for a distance of 460 feet. The slope data are as follows:

Upstream from Station 43 + 54 - Slope = 0.012
Station 43 + 54 to Station 50 + 20 - Slope = 0.0062
Station 50 + 20 to Station 54 + 80 - Slope = 0.0204
Downstream from Station 54 + 80 - Slope = 0.012
(The junction was located at Station 54 + 70)

Drop-down curves were computed to determine the depths at the junction. The results indicate that normal depth would be obtained.

The computed depths and related data on the inlet main for the above conditions are given in Table V.

TABLE V

DEPTHS AND RELATED DATA ON THE INLET MAIN

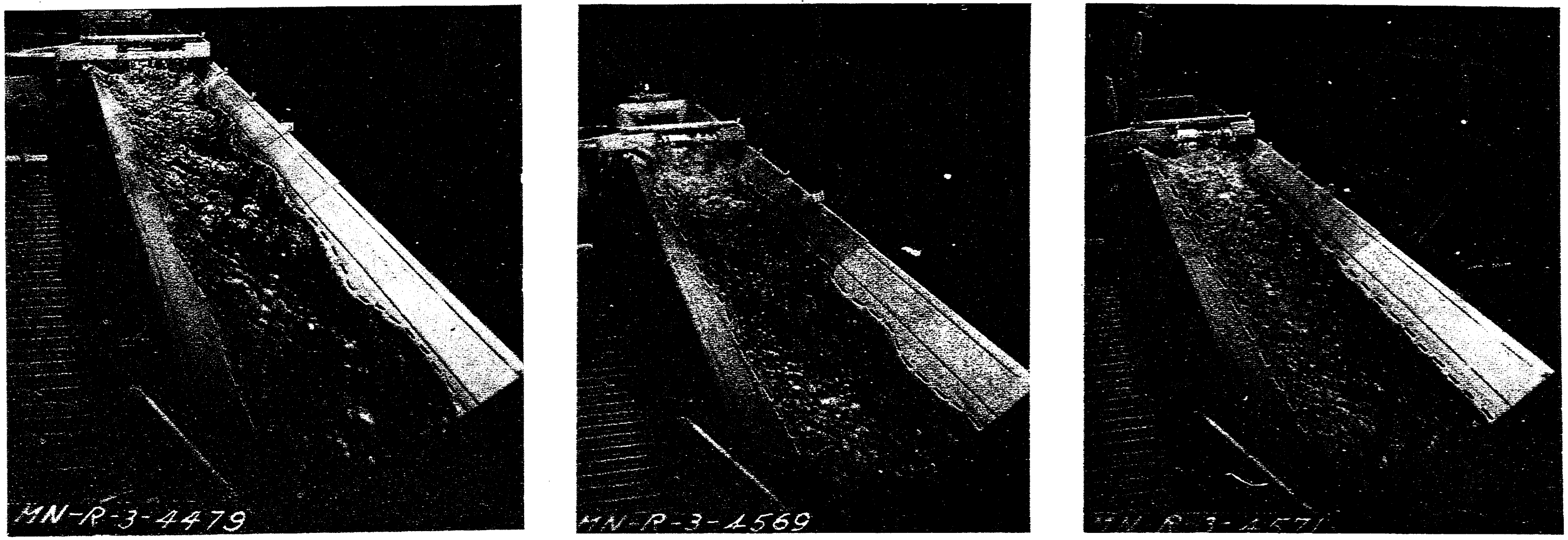
Q (cfs)	d (ft)	V (fps)	F
960	3.58	23.6	4.83
632	2.90	21.1	4.77
432	2.38	19.0	4.71

It may be noted that the slope changes resulted in an increase in the Froude number from 2.86 to 4.71 for a discharge of 432 cfs. The flow condition for discharges of 432 and 70 cfs in the inlet main and lateral respectively are shown in Figure 25b. Some improvement of the flow was noted, but the surface was still considered rough. With a discharge of 632 cfs, the flow was good with only slight waves.

Design 3 (Submerged Piers)

While the flow conditions with an inlet-main discharge in the vicinity of 432 cfs were not satisfactory, no further increase in the Froude number was considered because of limitations imposed by the prototype ground configurations. Instead the use of submerged piers was investigated. It was experimentally determined that two piers located downstream from the junction greatly improved the flow. Figure 25c illustrates the flow conditions for a discharge of 432 cfs. With a discharge of 632 cfs (Figure 28) the flow was likewise improved. At a discharge of 960 cfs in the inlet main, it was estimated that the only objectionable feature of the junction would be spray.

On the basis of the tests, the junction design was considered satisfactory after the addition of the submerged piers. The recommended



(a) Design 1

(b) Design 2

(c) Design 3

The discharge of the inlet main corresponds to 432 cfs (Max. Q_1 = 960 cfs), and the lateral to 70 cfs. The three designs are similar except for difference in slope of the inlet main and the addition of piers in Design 3.

Figure 25. Structure P-8 - Comparison of Three Designs

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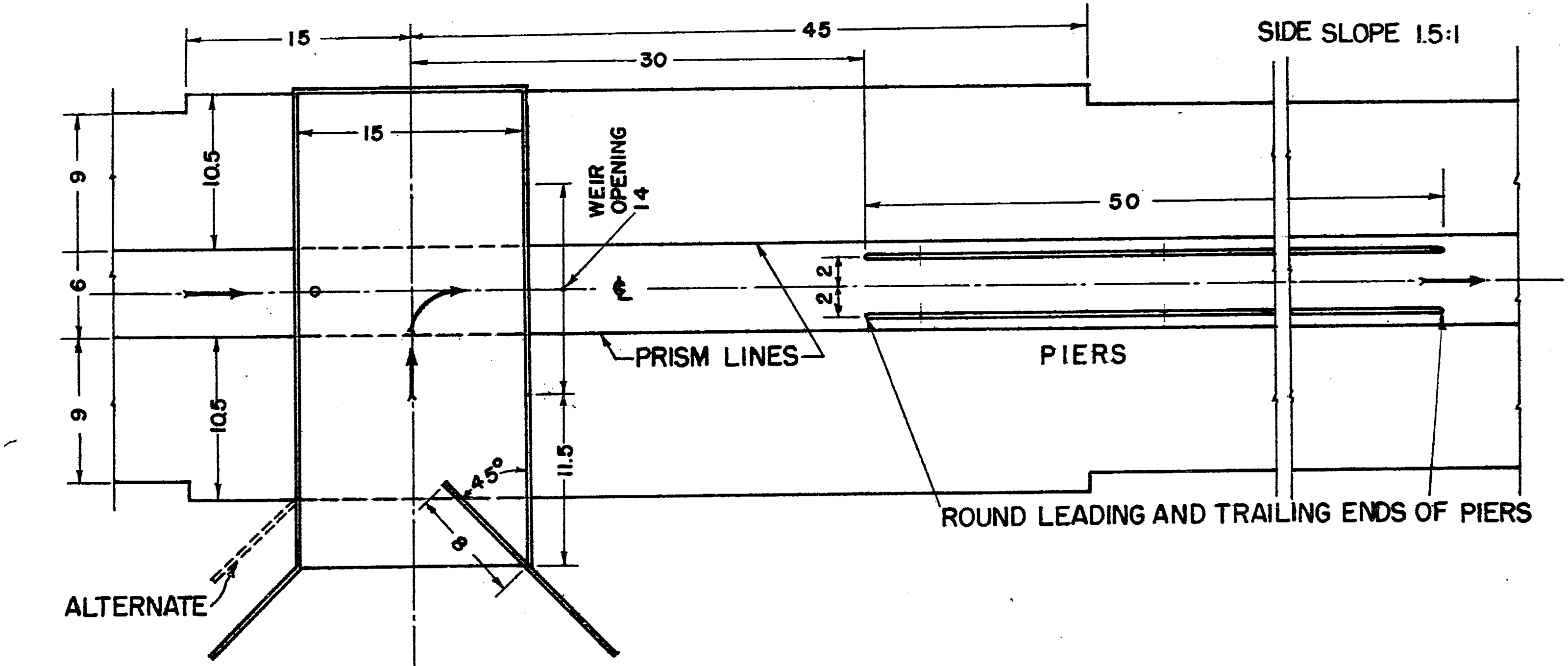
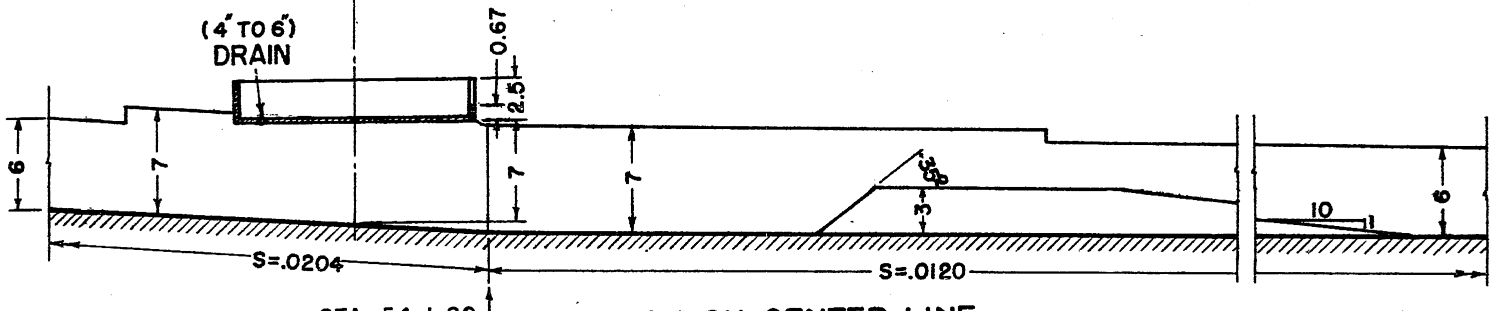


PLAN VIEW



SECTION ON CENTER LINE

ALL DIMENSIONS IN FEET

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Figure 26. Structure P-8, Design 3 - Recommended Design

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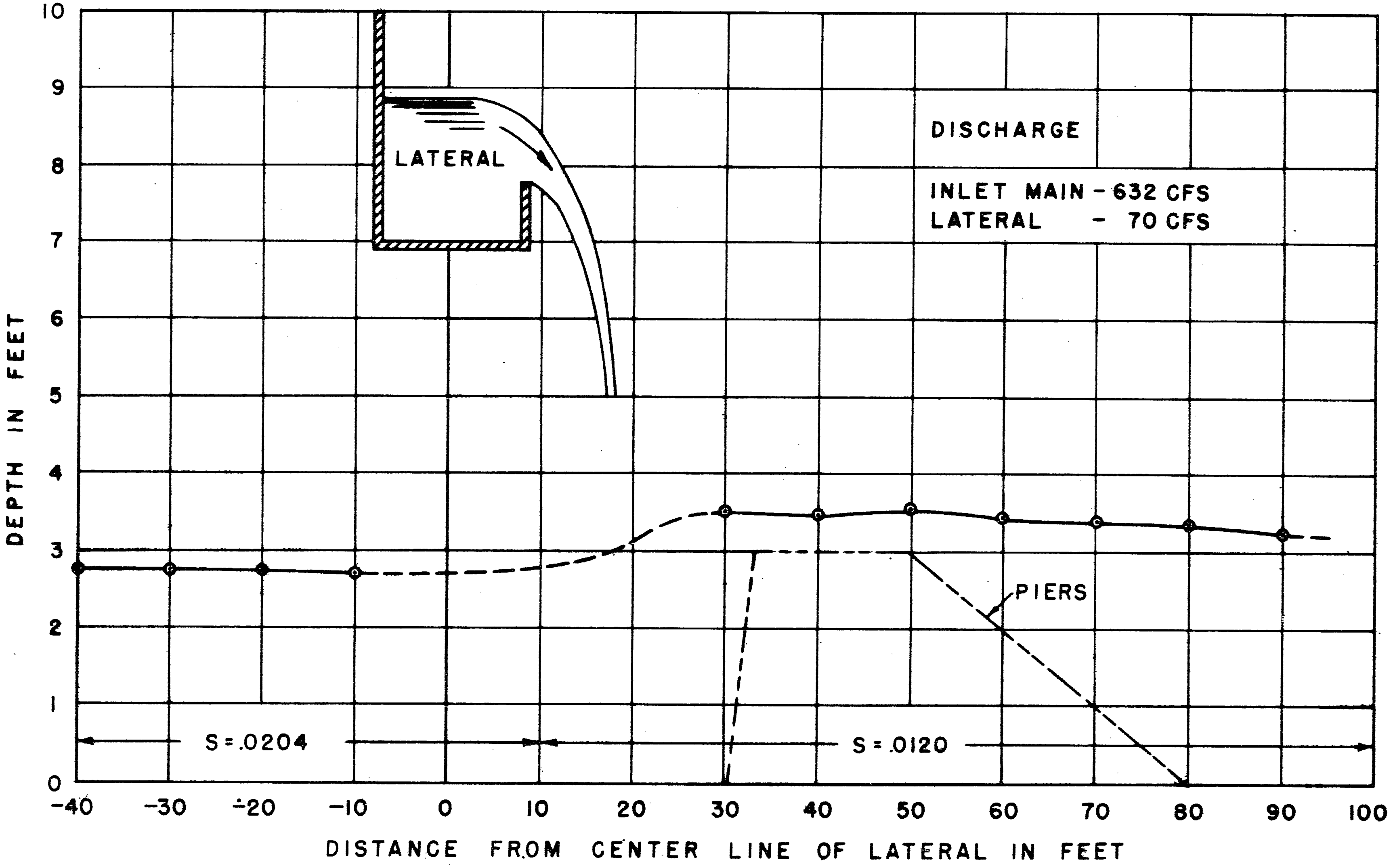

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Figure 27. Structure P-8, Design 3 - Depth of Flow

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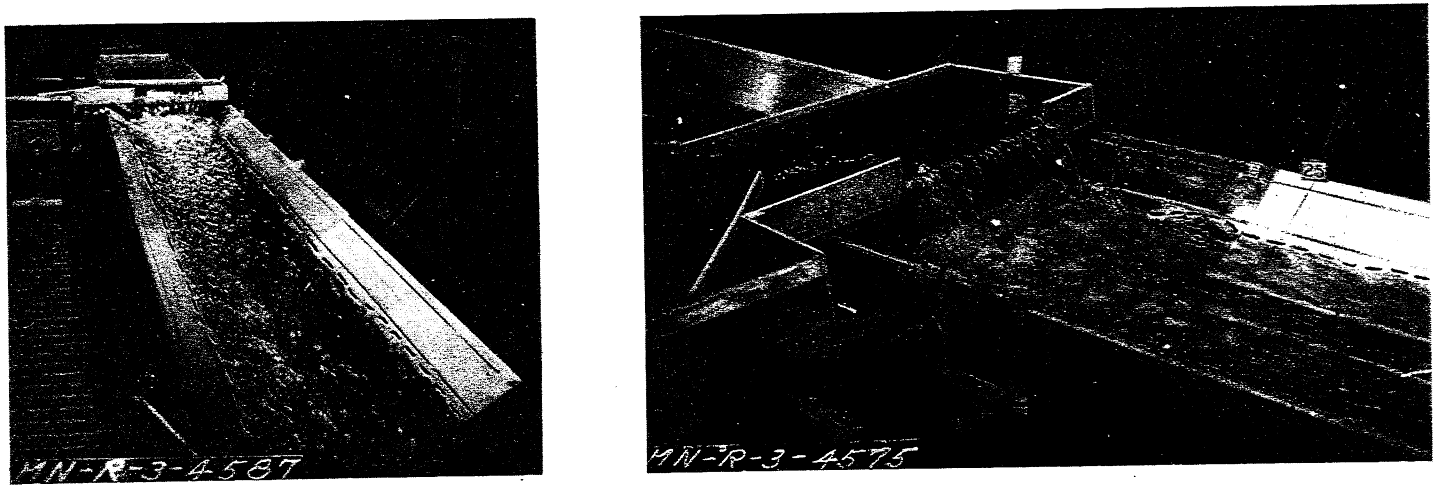

This represents a prototype discharge of 632 cfs in the inlet main and 70 cfs in the lateral. The maximum anticipated discharge of the inlet main is 960 cfs.

Figure 28. Structure P-8, Design 3 - Special Discharge Conditions

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design is shown in Figure 26. The depth of flow for discharges of 632 and 70 cfs in the inlet main and lateral respectively is shown in Figure 27.

It is possible that a junction design similar to that used for Structures C-4 or C-5 may have warranted investigation, but time limitations prevented further tests.

Structure P-7

Structure P-7 consists of the junction of O Ditch and P Ditch, both of which contain flow with velocities greater than the critical. The included angle between the inlet main and lateral could be varied somewhat, but an angle of 51 degrees 2 minutes was considered desirable since this permitted the best topographical location of O Ditch. The design criteria are listed in Table VI.

TABLE VI

DESIGN CRITERIA FOR STRUCTURE P-7

	Inlet Main	Lateral		Outlet Main	
		Initial	Final	Initial	Final
Maximum Discharge (cfs)	630.0	330.0	330.0	960.0	960.0
Normal Depth (ft)*	3.31		2.16	4.08	4.79
Normal Velocity (fps)*	17.3		16.5	19.4	15.2
Bottom Width (ft)	6.0	6.0	6.0	6.0	6.0
Slope	0.012	**	0.017	0.012	0.0062
Side Slope	1.5:1	1.5:1	1.5:1	1.5:1	1.5:1
Froude Number	2.81		3.91	2.86	1.50
Manning's n	0.015	0.015	0.015	0.015	0.015

*Based on maximum discharges.

**Can be varied.

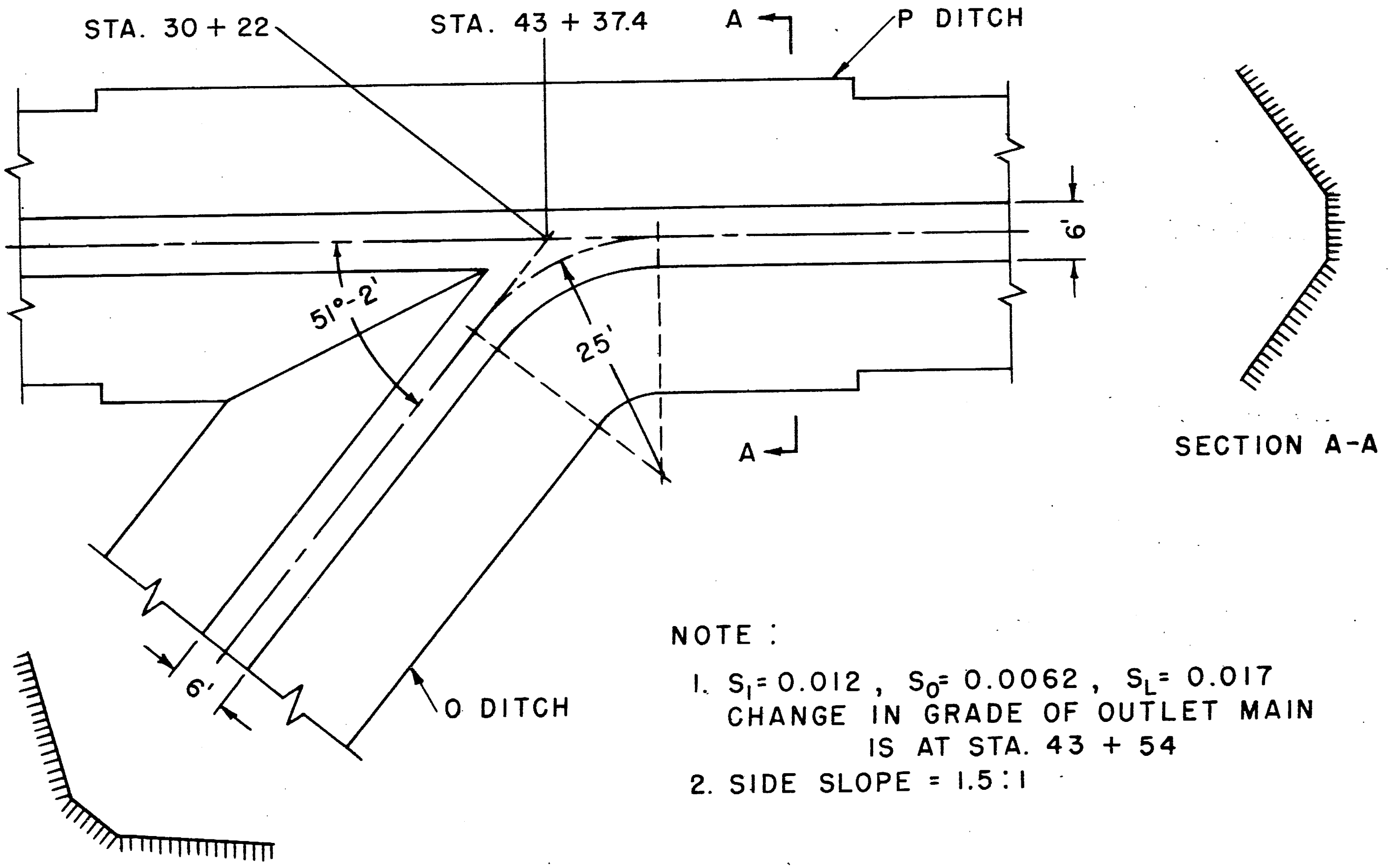
Both the initial design criteria supplied by the Region 3 Engineering Division and the final design criteria developed on the basis of model tests and conferences with the above organization are shown for the lateral and outlet main. The change in slope of the outlet main was made for the purpose of improving flow conditions at Structure P-8 which is located downstream from Structure P-7.

The proposed design of Structure P-7 shown in Figure 29 was based on the assumption that the flow in both channels would pass through a hydraulic jump and join at velocities less than critical. Preliminary computations indicated that this was the simplest and probably the most economical design. Sills or other means would be added to induce the formation of a jump if necessary.

As a first approximation it was assumed that for the maximum discharge condition the depth at the junction would be equivalent to the alternate pressure-momentum depth of the inlet main, with a hydraulic jump forming just upstream of the junction. As the alternate depth of the lateral was considerably less than that of the inlet main, a jump should form at some distance upstream from the junction in the lateral channel. On this basis the computed depth at the junction was 6.9 feet. Model tests subsequently indicated a depth of 7.2 feet at the junction. Figure 30 shows photographs of the flow conditions at the maximum discharge and Figure 31 illustrates the water surface profile based on model tests.

Subsequently an attempt was made to compute the channel depths using the pressure-momentum theory. The results, which are discussed in a later section of this report, were not too successful but did assist in explaining the performance of the junction.

As noted in Table VI, the design discharge of the inlet main was 630 cfs while that of the lateral was 330 cfs. The model tests indicated that for an inlet-main discharge of 630 cfs, hydraulic jumps formed in both channels for all lateral discharges in excess of 167 cfs. With a lateral discharge of 330 cfs, the same condition existed for all inlet-main discharges in excess of 136 cfs. Two views at intermediate flows are shown in Figure 32. The minimum values just cited were dependent on visual observations and are somewhat arbitrary. For those conditions in which the hydraulic jumps formed, the water surface at the junction and downstream therefrom was reasonably smooth and was



NOTE :

1. $S_I = 0.012$, $S_O = 0.0062$, $S_L = 0.017$ CHANGE IN GRADE OF OUTLET MAIN IS AT STA. 43 + 54
2. SIDE SLOPE = 1.5 : 1

MN - R - 3 - 214

Figure 29. Structure P-7 - Proposed Design

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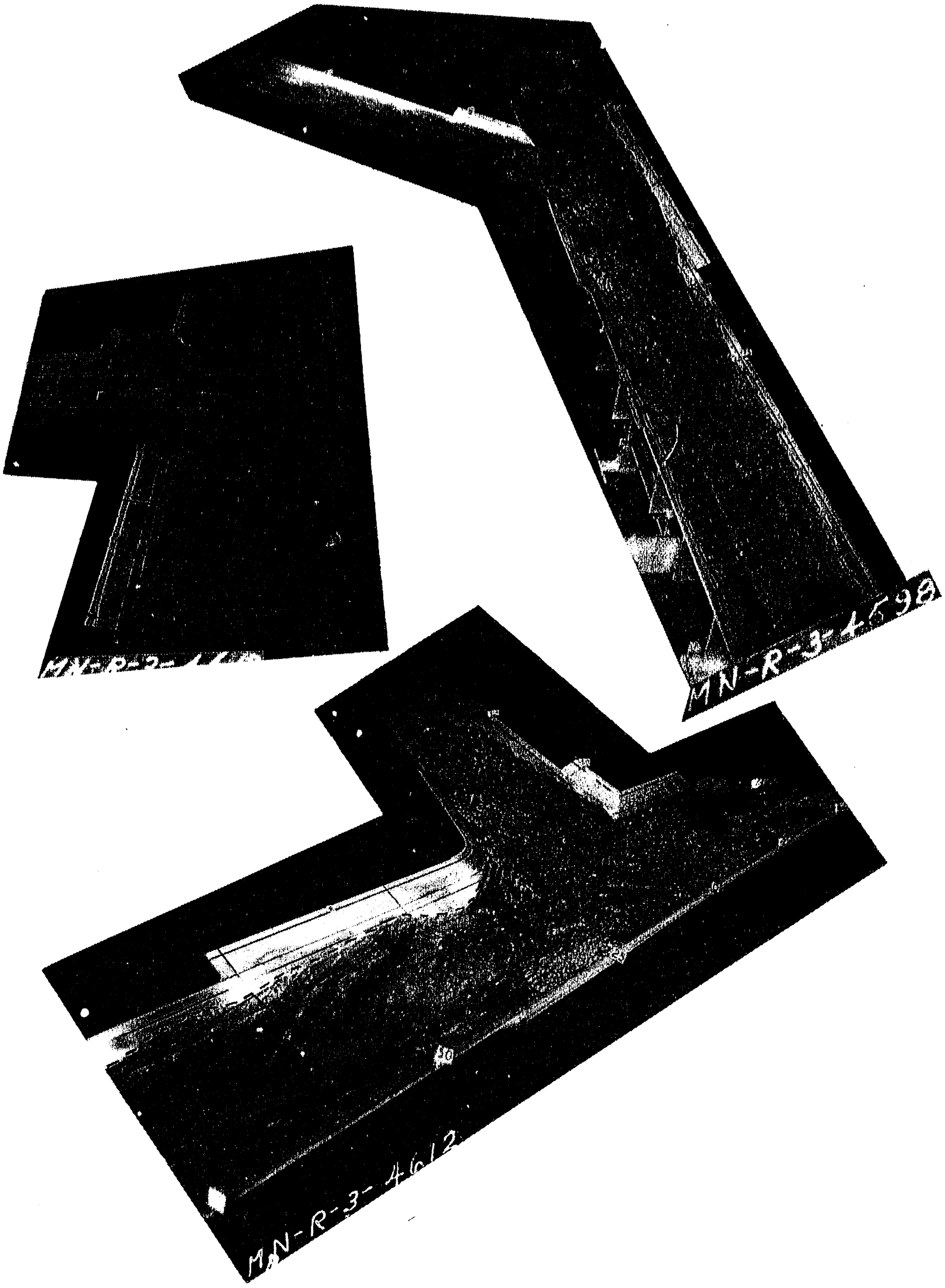

Hydraulic jumps take place upstream from the channel junction.
Flow at the junction is therefore subcritical.

Figure 30. Structure P-7 - Maximum Discharge Conditions

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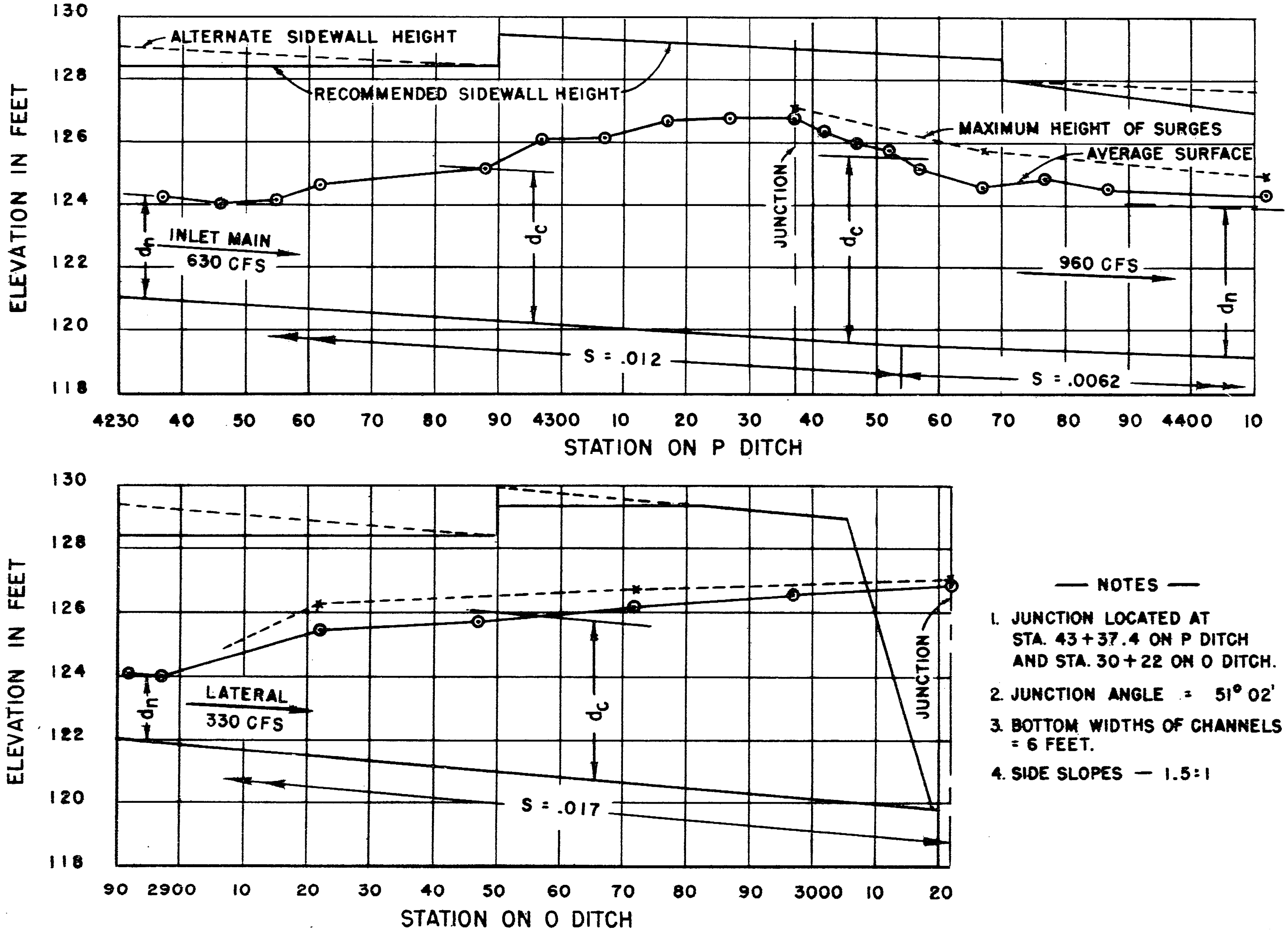

— NOTES —

1. JUNCTION LOCATED AT STA. 43 + 37.4 ON P DITCH AND STA. 30 + 22 ON O DITCH.
2. JUNCTION ANGLE = 51° 02'
3. BOTTOM WIDTHS OF CHANNELS = 6 FEET.
4. SIDE SLOPES — 1.5:1

MN-R-3-215

Figure 31. Structure P-7 - Water Surface Profiles and Sidewall Heights

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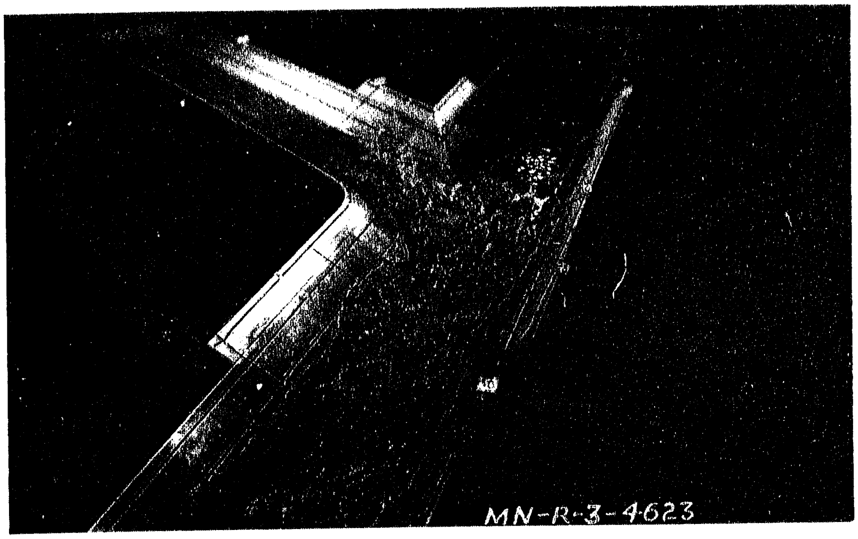
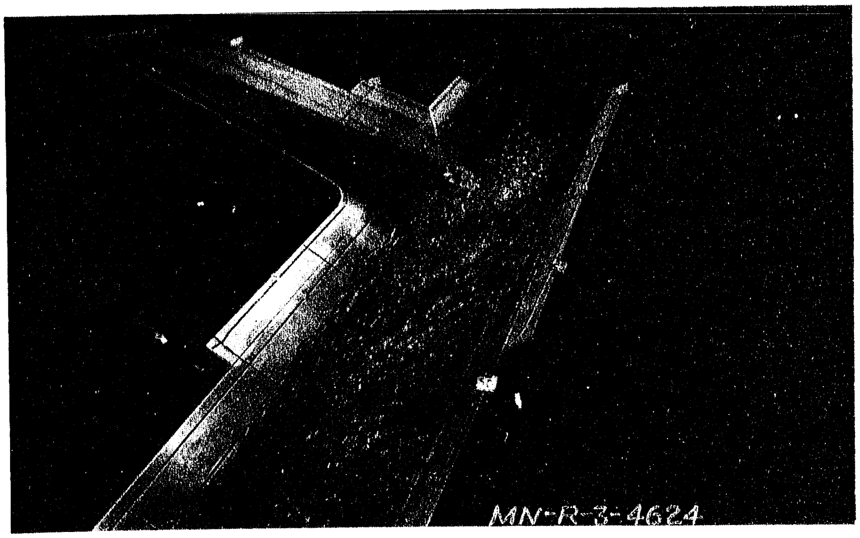


The discharge of the lateral is equivalent to 330 cfs and that of the inlet main to 160 cfs. There is a hydraulic jump in both channels



The lateral has a discharge of 84 cfs, the inlet main a maximum of 630 cfs and there is no hydraulic jump in the inlet main.

Figure 32. Structure P-7 - Intermediate Discharges

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characterized by a minimum of surging. With a maximum discharge in one channel and discharges in the other less than the minimum value just cited, the flow at the junction had velocities greater than critical, and rather large waves developed at the junction and immediately downstream therefrom, as is shown in Figure 33. However, their height was less than the freeboard required for the maximum discharge condition and they were not considered objectionable.

Beginning with a maximum discharge in both channels, a decrease in the discharge of the inlet main caused the jump in that channel to move upstream, caused the jump in the lateral to move downstream, and resulted in a decrease in the depth of flow at the junction. A similar phenomenon resulted if the flow in the main channel were held constant and that of the lateral decreased with the jump in the main channel moving downstream and that of the lateral upstream. Figure 34 illustrates the depth of flow at the junction for various discharges.

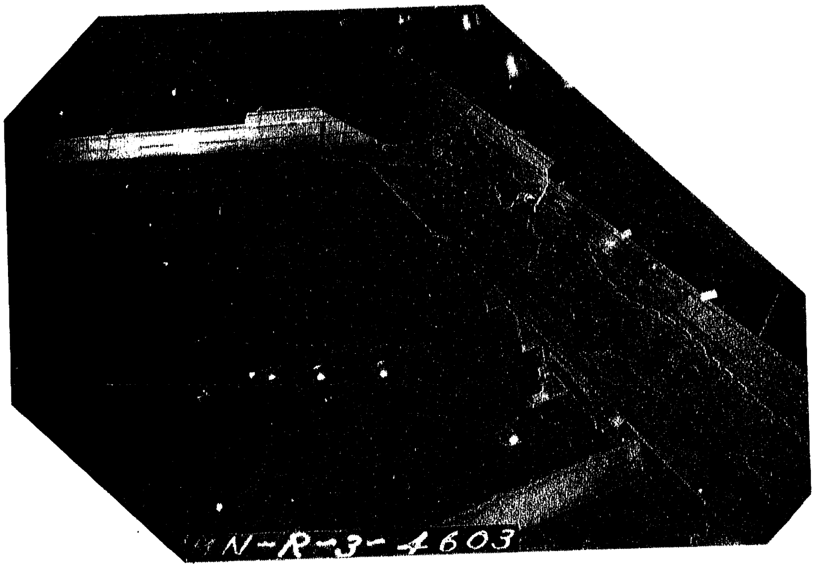
In the tests just described the hydraulic jumps formed naturally without the use of sills. In one series of tests, sills were inserted for the purpose of forcing the formation of a jump for those conditions in which one had not formed previously (large discharge in one channel and a small discharge in the other). The sills were successful in insuring the formation of a jump for all discharges, but they resulted in a serious increase in the depth of flow at the junction with a maximum discharge in both channels. This more than offsets any beneficial effect that they might have, and they were omitted in the recommended design.

The plan of the recommended design for Structure P-7 is illustrated in Figure 29, while the recommended channel wall heights are shown in Figure 31.

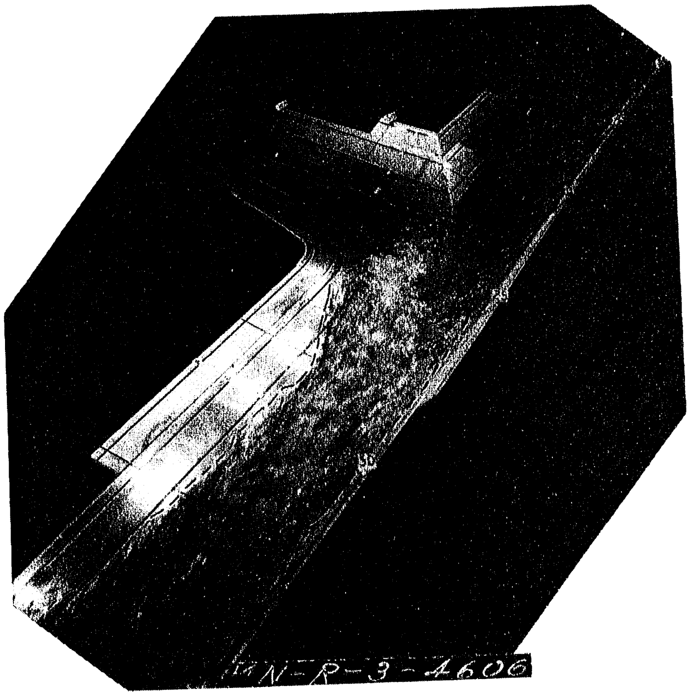
PRESSURE-MOMENTUM RELATIONSHIPS

General

An analysis of the junction of two channels based on pressure-momentum relationships was attempted in an effort to explain and assist



A discharge of 330 cfs in the lateral and no flow in the main.



A discharge of 630 cfs in the main and no flow in the lateral.

Figure 33. Structure P-7- Special Discharge Conditions.

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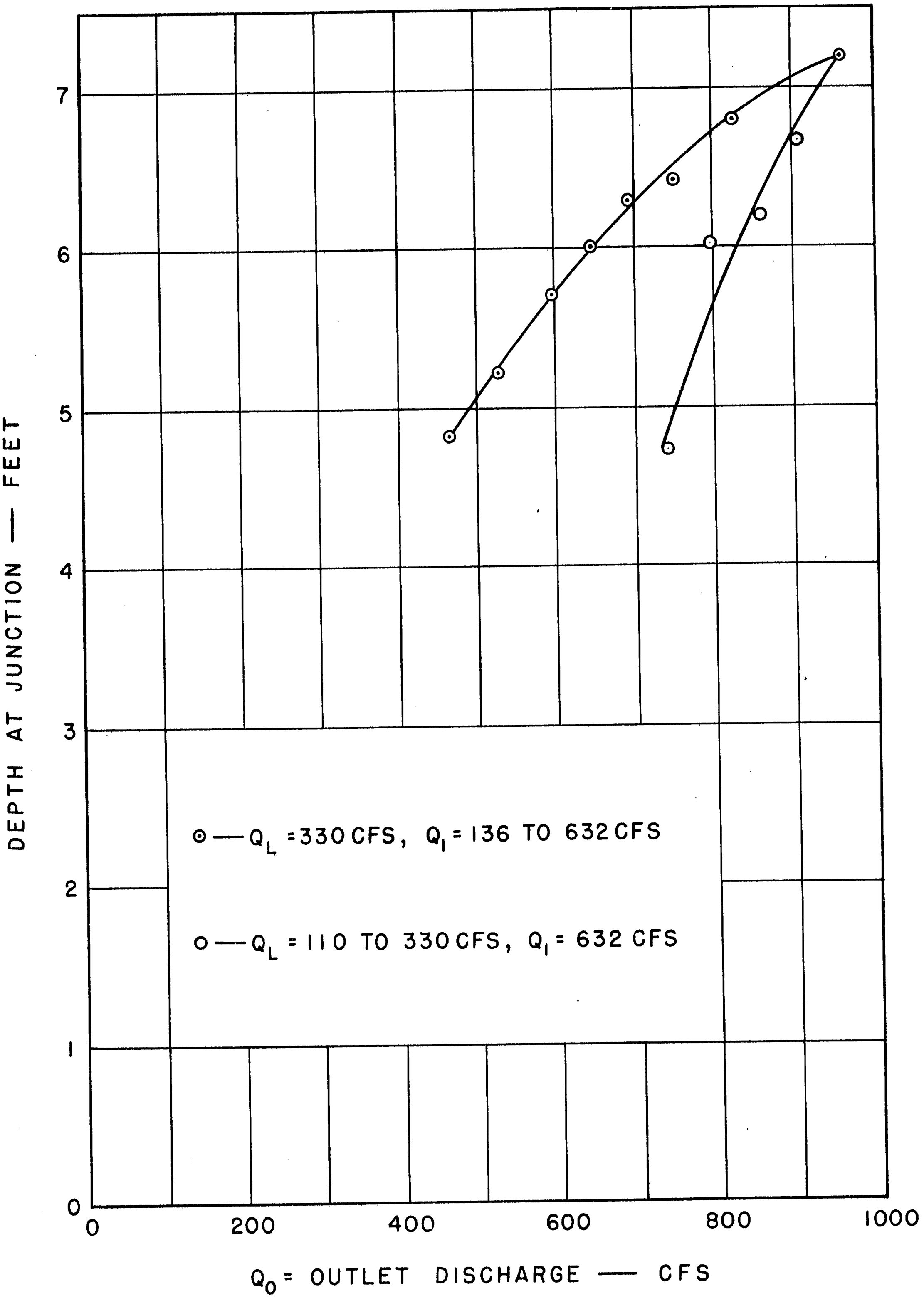

MN-R-3-216

Figure 34. Structure P-7 - Depth of Flow at Junction

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in the prediction of flow conditions in the vicinity of the junction. Basically this analysis consisted of equating vectorially the pressure plus momentum of the incoming stream to that of the outgoing stream.

Considering first the pressure-momentum relationships between two stations in a straight channel with zero slope, the difference in hydrostatic pressure exerted on the two ends of the segment of water between the stations is equal to change of momentum per unit time, or

$$P_1 - P_2 = \frac{Qw}{g} (V_2 - V_1)$$

and

$$P_1 + \frac{QwV_1}{g} = P_2 + \frac{QwV_2}{g} = w\, F_m$$

where P = the total hydrostatic pressure in the end of the segment,

M = the momentum flux, $\frac{QwV}{g}$,

F_m = the pressure plus momentum divided by the unit weight of fluid or $\frac{P + M}{w}$,

Q = the discharge,

V = the average velocity across the section,

w = the unit weight of fluid, and

y = the depth of flow.

If the stations are an appreciable distance apart, it is necessary to include a term for the frictional drag in the above equation, and if the channel has a slope, it is necessary to add a term for the component of gravity.

In applying the same considerations to a junction, the sums of the pressure plus momentum of the inlet main and lateral are equated vectorially to the pressure plus momentum of the outlet main. The reference stations for these computations are taken at the upstream and downstream edges of the junction. For the case in which the inlet main and outlet main have the same cross section and the same alignment, as in the present study, the hydrostatic pressure force exerted by the flow in the lateral is counteracted by the pressure on the opposite wall, provided the water surface in the junction is essentially flat. Thus, the only force the lateral flow can contribute to the main flow is its component of the momentum parallel to the main channel.

It is necessary to know the depth of flow at some point in the vicinity of the junction to provide a starting point or control for the subsequent computations. This control may be either upstream or downstream from the junction depending on the flow conditions. If the flow in all channels is tranquil, the control will be at the downstream edge of the junction (the depth at this point will be determined by flow conditions downstream from the junction). Presumably it is possible to equate the pressure plus momentum at this point to that of the incoming channels and so determine their depth and velocity, provided the discharge of all channels is known. It is usually necessary to make the assumption that the depth of flow is the same in both the inlet main and lateral for tranquil flow.

If the flow in all channels, including the junction, has a velocity greater than the critical, conditions upstream from the junction will presumably determine the depth of the inlet main and lateral immediately upstream from the junction. The depth downstream from the junction can then be computed. However, if hydraulic jumps form upstream from the junction with tranquil flow at the junction, the problem becomes more complex. For example, assuming that the control is at the upstream side of the junction, if the hydraulic jump in the lateral is a considerable distance upstream from the junction, either its position must be known or the depth in the lateral at the edge of the junction must be known in order to compute the momentum contributed by the lateral. Likewise, if the jump in the main channel is a considerable distance upstream from the junction, the pressure plus momentum at that point is not the same as at a point immediately upstream from the junction, and it is necessary to know either the position of the jump or the depth of flow at the junction in order to compute the pressure plus momentum contributed by the inlet main. During the course of the present studies it was noted that in those instances where hydraulic jumps formed (and where <u>normal</u> flow in all channels had a velocity greater than the critical) the flow accelerated and passed through critical at the downstream edge of the junction. Thus it was possible to compute the pressure plus momentum at this point and use this value in determining the depth of flow and the position of the hydraulic jumps in the inlet main and lateral channels. While the computed results were in fairly close agreement with the model performance, the data were quite limited and do not constitute an adequate confirmation of the theory. It should be noted that even though the above theory is accepted, it is first necessary to determine whether or not flow at the junction is tranquil. If shooting flow exists at the junction, the control or known depth is at the upstream edge of the junction and the preceding theory cannot be applicable.

An attempt was made to apply pressure-momentum theory to the analysis of the performance of Structures C-5, P-7, and P-8. The primary objective in the case of Structure C-5 was to obtain an explanation of the conditions under which a hydraulic jump would form in the junction as a check on the model performance. With Structures P-7 and P-8 the same information was desired plus computed values of the depth at various points.

Structure C-5

As noted earlier, the lateral at Structure C-5 intersects the main channel with an included angle of 85 degrees. As an approximation it was assumed that the lateral contributed neither pressure nor momentum. This assumption was made because the velocity in the lateral was relatively low, which was indicative of a low value for the momentum; in order to compute the momentum contributed by the lateral it would be necessary to multiply this low quantity by the cosine of 85 degrees, giving a much smaller value to be added to the momentum in the outlet main. While the water surface at the junction was quite uneven, it was considered expedient to disregard any pressure component of the lateral.

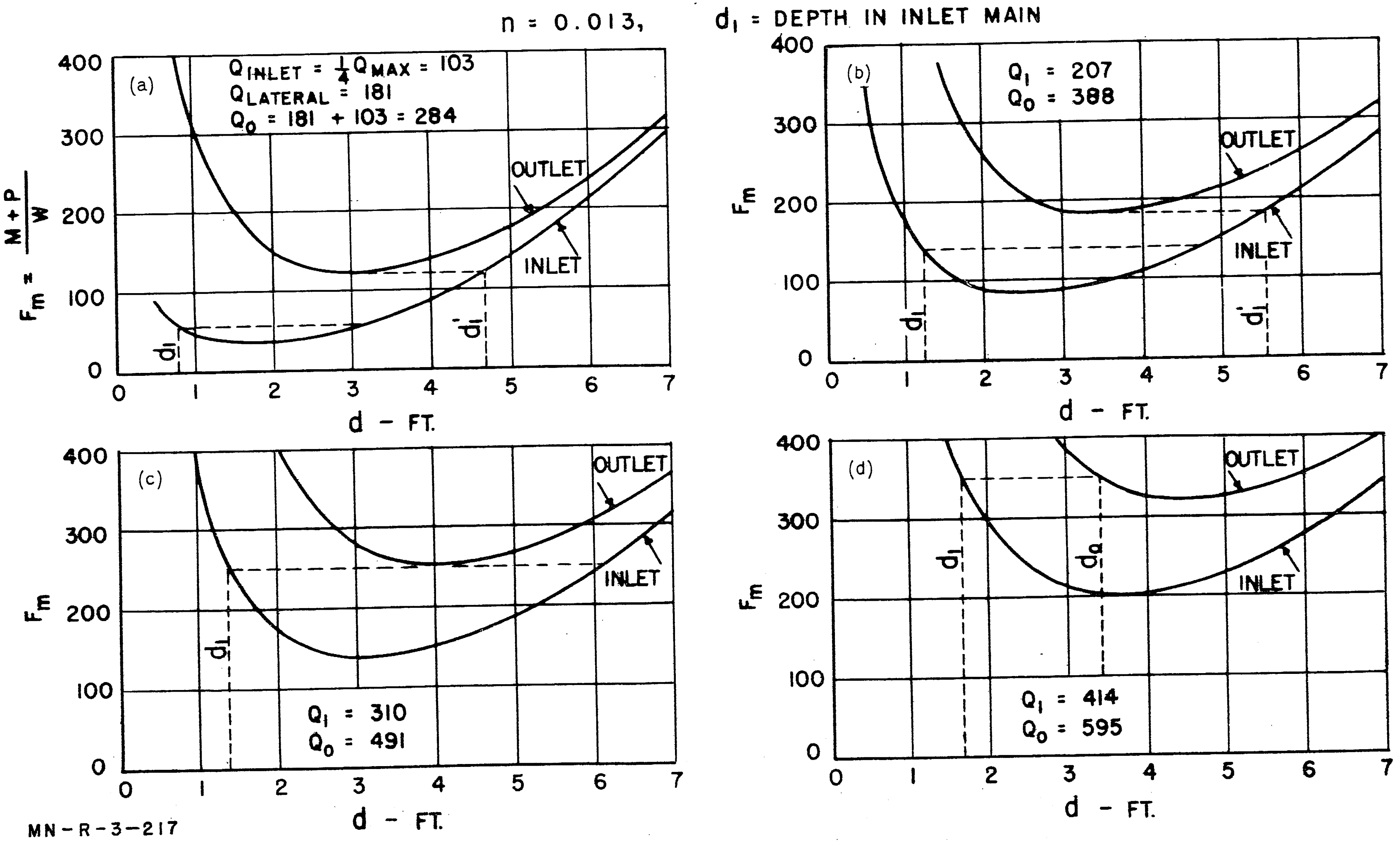
The problem was greatly simplified by the above assumptions and consisted of equating the pressure plus momentum at two stations in the main channel, one above the junction and the other below. The discharge at the lower station was larger than that of the upstream station by the amount contributed by the lateral.

Using the maximum lateral discharge of 181 cfs, the pressure-momentum curves of Figure 35 were computed for four inlet-main discharges. The basic curves represent the pressure plus momentum of the inlet main and the outlet main as a function of the channel depth for Design 6 of Structure C-5. The values of d noted in Figure 35 are the computed normal depths of the inlet main for the specified inlet discharges.

Referring to Figure 35a, it may be noted that the inlet value for F_{m1} of 65 is less than the minimum value that must exist in the outlet channel. The only way in which the inlet main may have the minimum value for F_m of 120 computed for the outlet main in order to equate the values of F_m of the inlet and outlet channels is for a hydraulic jump to form in the main channel at some point upstream from the junction. When this occurs, a force acting downstream will be created which will be equal to the difference between the frictional drag (acting upstream) and the component of gravity (acting downstream) on the segment of water between the hydraulic jump and the upstream edge of the junction. The result will be a new value of F_m at the upstream edge of the junction which will be equal to the minimum or critical value required at the downstream edge of the junction. In other words, d_1 at the upstream side of the junction will not be the normal depth of flow in the inlet main but will be the depth d'_1 in Figure 35a which has the minimum pressure plus momentum required by the flow in the outlet main.

Referring to Figure 35b, it is apparent also that a hydraulic jump must form for an inlet discharge of 207 cfs if the lateral discharge is 181 cfs.

With an inlet discharge of 310 cfs and the same lateral discharge of 181 cfs, it is noted in Figure 35c that the value for F_m is just equal to the minimum or critical discharge in the outlet channel. This represents the borderline case.



The relationship between inlet and outlet discharges is based on a constant lateral discharge of 181 cfs.

Figure 35. Structure C-5 - Pressure Momentum Curves

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In Figure 35d the value of F_m for the inlet channel is in excess of the minimum required in the outlet channel, thus no jump will occur; there will be a transition from the inlet depth of approximately 1.7 feet to an outlet depth of 3.3 feet. The model studies indicated that the transition was in the form of a shock wave which was quite turbulent.

The essential information of Figure 35 has been replotted in Figure 36. As mentioned in the preceding paragraph, the curves indicate that for a lateral discharge of 181 cfs, a hydraulic jump will occur for all inlet discharges less than 310 cfs (outlet discharges less than 491 cfs). The model studies indicated that the above is true for all inlet discharges less than 260 cfs (outlet discharges less than 441 cfs); this figure is based on visual observations and is somewhat arbitrary.

No special effort was made to compute the depth of flow in the vicinity of the junction, but it is thought that for those instances in which the flow at the junction was tranquil the assumption could be made that critical depth occurs at the downstream edge of the junction; it should then be possible to compute the depth at the upstream edge of the junction and thereafter the position of the hydraulic jump. When shooting flow exists at the junction, it is accompanied by a shock wave and a very turbulent surface; it is doubtful whether depth computations would be of much practical value for this condition.

It is thought that the primary value of the preceding computations was an explanation and conformation of the model behavior. The model studies were the primary basis for the selection and design of the prototype junction.

Structure P-8

With regard to Structure P-8 pressure-momentum computations were made for discharges of 632 and 70 cfs in the inlet main and lateral respectively. In this structure the lateral flow passes over a transverse weir, entering the main channel from the top. While the lateral flow has a small downstream component at the point where it strikes the surface of the main stream, it was assumed that the lateral

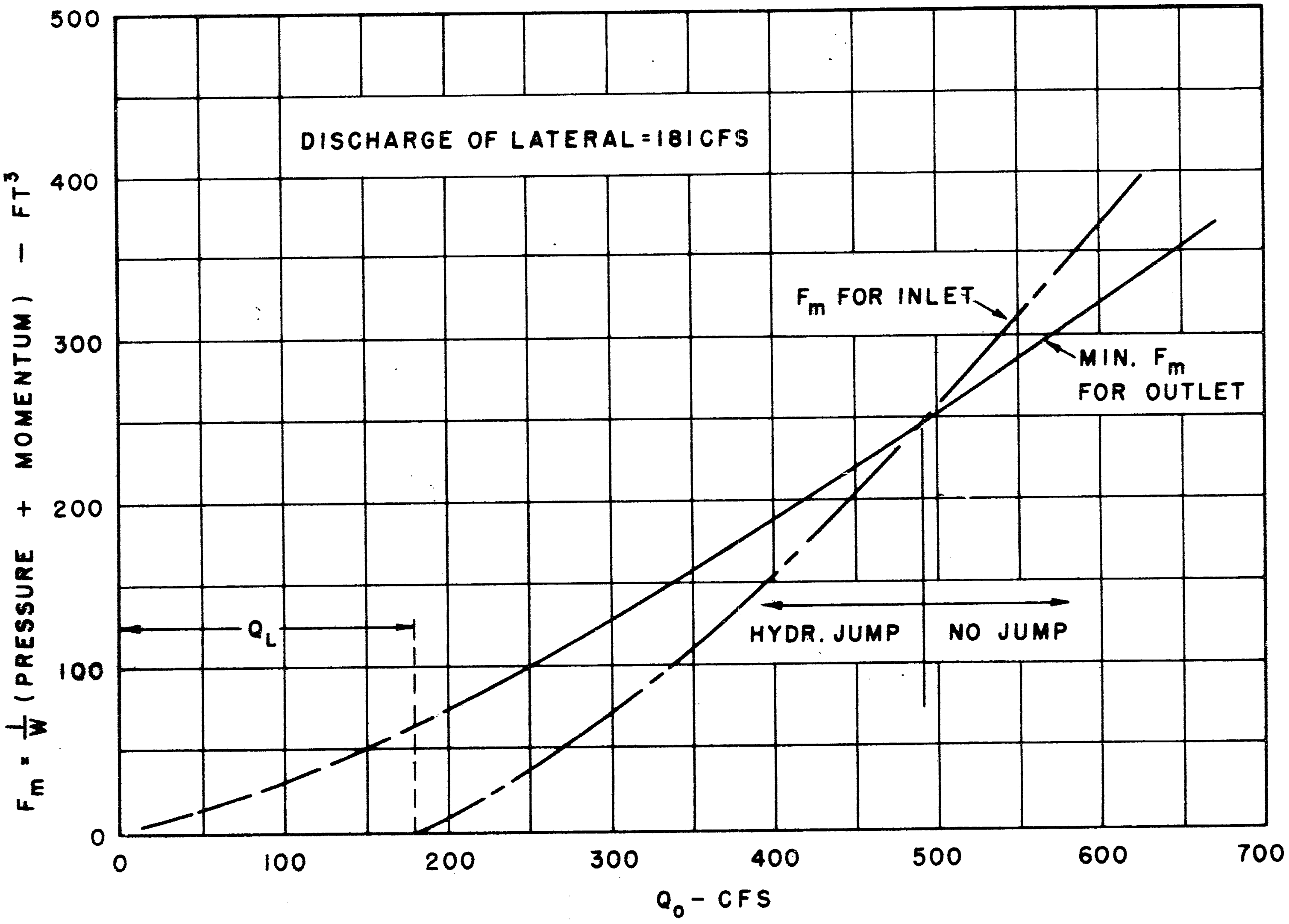

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Figure 36. Structure C-5 - Pressure-Momentum Relationships for Various Inlet Main Discharges

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contributed neither pressure nor momentum to the main stream. The computations were quite simple; the results indicated that there was little possibility of a jump forming. Assuming that the above was true, the control or known depth would be on the upstream edge of the junction. Equating the pressure plus momentum at this point to that downstream from the junction, it was determined that the downstream depth should be 3.4 feet. This may be compared with the results of the model tests (Figure 27) which indicated a value of 3.5 feet.

Structure P-7

The lateral at Structure P-7 intersects the main channel with an included angle of 51 degrees 2 minutes; thus it was necessary to include the momentum contributed by the lateral in the pressure-momentum calculations.

An attempt was first made to determine analytically the operating conditions for which a hydraulic jump would occur in the vicinity of the junction. The momentum of the lateral at normal depth was multiplied by cosine 51 degrees 2 minutes and added to the pressure plus momentum of the inlet main. Whenever this sum was less than the critical or minimum pressure plus momentum of the outlet main, it was assumed that a jump would occur. The computed results agreed with the model performance for approximately one-half of the proposed operating range. One possible explanation for the lack of better agreement is the failure to consider the velocity distribution in the analysis. A uniform velocity distribution was assumed. If the velocity distribution were to be considered, it would be necessary to include a momentum correction factor in the above calculations.

An effort was also made to compute the depth of flow in the vicinity of the junction for several cases in which the flow at the junction was tranquil. Fair results were obtained, but the computations were discontinued when the model studies were completed. The latter indicated that the proposed design was acceptable.

COMMENTS

The present study was undertaken for the specific purpose of obtaining information that would assist in the design of open-channel junctions in the drainage system at Whiting Field. Due to severe time limitations imposed on the study and the numerous structures requiring investigation, it was necessary to arrive at satisfactory designs for the various junctions as expeditiously as possible.

In view of the limited amount of information available on the design of junctions of this type, it would have been very interesting to conduct a more extensive investigation with the objective of obtaining sufficient data to assist in the general design of high-velocity open-channel junctions. While this was not possible, it is thought that in addition to supplying information on the specific junctions being investigated, the studies reported herein may be of some value as an indication of some of the problems which may be encountered in junctions involving shooting flow.

During the course of the studies it became increasingly apparent that model studies of junctions of this type are necessary until more information is available to assist in their design. Pressure-momentum relationships were utilized in an attempt to analyze the behavior of the junctions; while the results were of considerable interest, particularly in the case of Structures C-5 and P-8, they gave only a partial solution to the problem. With additional background information on which to base some of the assumptions employed in the analysis and additional time to make the necessary computations, particularly in the case of Structure P-7, it is thought that closer agreement with the model performance could have been obtained.