FINAL PROJECT REPORT

HYDRAULIC MODEL STUDY

NEORSD HEIGHTS INTERCEPTOR CONTRACT 7A CONTROL STRUCTURE

Report UMCEE 96-08

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INTRODUCTION

The NEORSD Heights Interceptor Contract 7A control structure is to be constructed for the purpose of utilizing the capacity of the Contract 7A interceptor to store stormwater flows by limiting the flow into the downstream Contract 6 interceptor, which has a smaller flow capacity. The proposed design utilizes two 6 feet wide by 8 feet high sluice gates to control the flow. Only one of the gates will be in operation at times where storage is required. Under certain flow conditions, the flow velocity downstream of these gates may reach up to 50 ft/s and a hydraulic jump will occur in order to reduce the velocity to what is required in the downstream Contract 6 interceptor. A stilling basin is included in the design for the purposes of containing the hydraulic jump within the structure and alleviating potential problems with air entrainment. A physical model study was performed, which examined the flow conditions within the control structure downstream of the sluice gate including a short length of the entrance into the Contract 6 interceptor.

The purpose of the model was to study the ability of the proposed stilling basin to confine the location of the hydraulic jump to within the control structure under a range of flow rates up to a maximum of 243 cfs, as well as the ability of the stilling basin to remove the air entrained in the hydraulic jump prior to entering the Contract 6 interceptor. Testing of the proposed design was necessary due to the fact that design calculations were based on the assumption of 2-dimensional flow. Since only one of the two sluice gates will be in operation at a time, the flow in the stilling basin may not be horizontally uniform and therefore may not behave properly due to variations in the flow across the width. The physical model was also used to examine and test modifications to the original design if preliminary testing indicated that such modifications were necessary. This report documents the testing procedures and modifications to the proposed design that were implemented in the physical model study.

GENERAL SYSTEM DETAIL

The control structure is located in a 20 feet diameter tunnel construction shaft with a center dividing wall in which the sluice gates for controlling the flow into the downstream interceptor are located. The top of the divider wall is at an elevation of 670 feet, which is intended to be the maximum hydraulic grade line (HGL) under any given flow condition. Flow enters into the control structure from the Contract 7A and 7C interceptors, which are of 10 feet diameter and 6 feet diameter, respectively. Under peak wet weather conditions, the Contract 7A interceptor is to be used to store excess flows.

A SWMM model of the Contract 7A, 7B, and 7C interceptors prepared by Montgomery Watson determined that for the 25 year, 1 hour storm, the maximum HGL reached at the downstream end of the Contract 7A interceptor at the control structure would be 654.9 feet with the flow restricted to 243 cfs (157 mgd).

Two 6 feet wide by 8 feet high sluice gates were selected for use in controlling the flow to the downstream Contract 6 interceptor. It is envisioned that only one of the gates is to be throttled while the other gate remains closed for this purpose. Four different control structure alternatives were considered for the purpose of controlling the location of the jump and providing sufficient removal of air in the flow at the downstream interceptor.

Alternative 1 involved a 15 feet wide stilling basin downstream of the sluice gates. The floor of the stilling basin was to be 1 foot below the invert of the Contract 6 interceptor in order to provide the necessary tailwater for the hydraulic jump to occur within the basin. This alternative also included chute blocks, baffle blocks, and an end sill to provide additional energy dissipation and control the location of the jump.

Alternative 2 involved the installation of the sluice gates in a stilling well. The stilling well was to be a deep chamber with the bottom elevation at 8 feet below the invert of the Contract 6 interceptor. It is intended that the sluice gates will always be completely submerged in the stilling well.

Alternative 3 involved a stilling basin with a weir in the downstream channel to increase tailwater. The channel was to be 10 feet wide and the floor elevation was to be at the invert of the Contract 6 interceptor.

Alternative 4 involved a stilling basin with a downstream baffle wall located downstream of the control structure. The downstream baffle wall was designed to provide the necessary tailwater for a hydraulic jump to occur in the stilling basin. The baffle wall is raised in order to provide an opening at the bottom of the baffle wall to allow solids to pass through. This design included chute blocks, baffle blocks, and an end sill to provide additional energy dissipation upstream of the baffle wall.

Design calculations for these 4 alternatives were performed and Alternative 4 was recommended. Figure 1 presents the suggested Alternative 4 design.

MODEL DESCRIPTION

Modeling Criteria

The physical hydraulic model was constructed according to Froude scaling principles for dynamic similarity, which fixes the relation between model and prototype conditions for a selected model scale. Dynamic similarity requires that the Froude number, defined by $\frac{V}{\sqrt{gL}}$, remain equal in both the model and prototype, where V refers to any characteristic fluid velocity, g refers to the gravitational acceleration, and L refers to any characteristic system length. The relationships between the prototype and model parameters are directly related to the scale ratio L_r, which is defined as the geometric ratio between any length in the prototype and the corresponding one in the model, $L_r = \frac{L_{prototyp}}{L_{model}}$. For a Froude scaled model, assuming the same fluid in model and prototype, the following ratios must hold true:

Parameter	**Ratio**
Length (L_r)	$L_r = 6$
Velocity (V_r)	$L_r^{1/2} = 2.44$
Discharge (Q_r)	$L_r^{5/2} = 88.18$
Time (T_r)	$L_r^{1/2} = 2.44$

add Δp here

Both the model size and discharge are the critical factors with respect to model facilities. The scale ratio can be determined by either the space available in the laboratory facility or the installed pumping capacity. Consideration is also given to ease of construction and availability of materials when selecting an appropriate scale ratio. An effort is generally made to make the model as large as feasible to avoid scaled effects due to the fact that viscous effects are over represented in a reduced scale Froude model. This consideration generally suggests appropriate model sizes required to avoid distortion of the model flow due to the effects of viscosity. As long as the characteristic model Reynolds number remains in the range of 100,000 to 500,000, viscous effects are considered negligible and the lack of complete dynamic similarity is unimportant.

Model Construction

The physical hydraulic model was constructed at a scale ratio of 1:6. This model scale was selected due to the pumping capacity in the laboratory facility as well as the availability of proper pipe sizes for the model. At this scale, the model Reynolds numbers are in the appropriate range and viscous effects are therefore considered to be negligible. As discussed previously, all relevant model and prototype parameters are related through the length scale ratio, L_r.

The model included an inflow box representing the 10 feet diameter Contract 7A interceptor, the tunnel construction shaft, the divider wall with one sluice gate (due to symmetry of the system), the stilling basin, and a 6 feet model length section of the downstream interceptor.

Drawings provided by Applied Science, Inc. (ASI) gave the detailed dimensions to which the model was originally constructed. These dimensions were in accordance with the Alternative 4 design specified in the ASI memorandum dated January 11, 1996 to Montgomery Watson with minor modifications to the downstream baffle wall. These modifications involved a gradual transition to an 8 foot baffle opening width, and removal of the triangular pier at the center of the wall. Figure 2 presents the revised Alternative 4

(Alternative 4R) design. The model was constructed primarily of plywood, which was painted to provide a smooth finish. One side of the model was constructed of Plexiglas for visualization purposes. The downstream Contract 6 Interceptor was modeled with a PVC pipe to a 6 feet model length. All essential design detail was modeled at the correct scale and was constructed of Plexiglas and plywood as required. Figure 3 presents an overview of the upstream section of the physical model in the initial design. The top of the basin was not included in the model since the basin is not intended to flow in a surcharged condition. The absence of the top of the structure allowed for better inspection of the flow conditions within the stilling basin. The top of the divider wall was constructed to the proper model height, however, as there was concern expressed about overtopping of the wall under extreme throttling conditions.

The original Alternative 4R design specified the diameter of the construction shaft to be 18 feet. This dimension was then increased to 20 feet after model construction began. Under these circumstances and following discussion with ASI, the diameter of the construction shaft in the model study remained at 18 feet. This is only relevant with respect to the area upstream of the divider wall since fillets were to be placed downstream to guide the flow and these were properly reproduced in the model. The lack of exact detail on upstream geometry was relatively unimportant due to the significant throttling of the flow through the sluice gate which diminished any upstream effects.

The required flow conditions were provided through the use of a constant head supply reservoir. Water was pumped from a sump into a piping system comprised of a 12 inch supply line. Flow from the 12 inch line was reduced through an 8 inch valve, which regulated the flow to the model and entered through an 8 inch supply line. The flow was metered with an installed venturi meter upstream of the valve.

INSTRUMENTATION

The flow supplied to the model was metered through the use of a venturi meter located on the 12 inch supply line. A differential mercury manometer was utilized to measure the head difference in the venturi meter. The relationship between the head difference and the discharge through the meter has been previously determined through careful calibration and was used for determining flows in the model study.

The majority of the examination of flow conditions in the control structure and stilling basin was done visually and has been recorded on videotape and still photographs. A videotape recording of the nature of the flow under the various testing conditions was created and an edited version has been provided. Still photographs are discussed and presented in this report.

TEST CONDITIONS

Two different flow cases were examined in the testing procedure. These cases included:

1.) Restricting the flow into the Contract 6 interceptor to 243 cfs (157 mgd), with the HGL at the control structure at its maximum of 670 feet.
2.) Restricting the flow into the Contract 6 interceptor to 155 cfs (100 mgd), with the HGL at the control structure at its maximum of 670 feet.

The 25 year, 1 hour flow of 243 cfs was tested at an HGL of 670 feet rather than the calculated maximum HGL of 654.9 feet for the purpose of representing a worst case flow condition with respect to the flow concerns previously discussed. The 155 cfs flow was tested to represent a lower flow condition in which the gate was throttled for a maximum HGL at the control structure of 670 feet. These flow conditions were established in the model by adjusting the gate opening at a given flow rate until the water level on the upstream side was just below the top of the divider wall.

TEST RESULTS

Initial Design

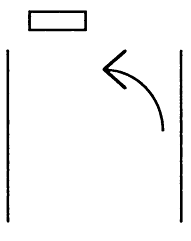
The model was initially constructed in accordance with the Alternative 4R design and was tested under the two flow cases mentioned previously. In this configuration, with the 243 cfs flow, the design was functional in that a hydraulic jump formed, however the entire flow cross-section at the entrance to the Contract 6 interceptor was frothy with entrained air. Figures 4a and 4b present visual results of the testing of this initial design at the higher flow rate of 243 cfs. With the lower flow of 155 cfs, there was no control on the jump inside the stilling basin, which can be seen in Figures 4c and 4d. Both conditions resulted in highly turbulent flows entering the downstream interceptor. Due to the converging side wall on the downstream side of the sluice gate and the high velocities under the gate, an oblique jump was formed which led to highly non-uniform conditions along the entire length of the basin. With such high velocities exiting the gate structure, the chute blocks, baffle blocks, and end sill, originally designed to dissipate the energy from the high velocity flow did not prove to serve their desired purpose. These problems associated with the turbulent nature of the flow under the two cases can also be seen on the videotape which has been provided.

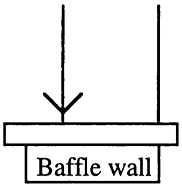
Modifications

As a result of the flow conditions that were observed in the testing of the initial design, a decision was made to increase the width of the basin in an attempt to avoid the oblique jump associated with the width constriction, as well as to slow down the downstream velocities to permit air detrainment. The length of the basin from the downstream side of the gate to the entrance to the downstream interceptor was increased to 57 feet. Due to the ineffectiveness in energy dissipation, as well as to simplify the design, the chute blocks and end sill were removed. It was decided that it was appropriate to use the baffle wall to control the jump directly instead of with the assistance of the end sill. The baffle wall was moved to a location 35 feet downstream of the divider wall which then provided a length of 22 feet to the entrance to the Contract 6 interceptor, and allowed more distance for air to escape. Also, it was decided to modify the baffle wall opening to 1 foot, as well as adjust the baffle wall dimensions to an opening width of 13 feet in order to match the fillets of the initial design, and a top height of 4.5 feet. The dimensions of the baffle blocks were increased to 18 inches high by 14 inches wide. The baffle blocks were moved to a location 12.5 feet downstream of the divider wall. A drop in the floor elevation was located 6 inches upstream of the baffle blocks as an artifact of the way the model was put together, however it served to lift the high velocity jet off the floor, similar to what was attempted by the chute blocks, and was therefore left unchanged. These modifications were made to the model and are hereafter referred to as Revision 1. Figures 5a and 5b present the modifications which comprise Revision 1.

Testing of the Revision 1 model design was performed under the two flow cases. The design proved to be functional in controlling the jump under both flow cases, however some air remained in the flow at the entrance to the Contract 6 interceptor. The flow was still non-uniform downstream of the gate, but became more uniform across the width of the channel after the baffle wall. Testing results are presented in Figures 5c and 5d. In addressing the concern over the high velocity coming through the sluice gate, the possibility of restricting the HGL upstream of the gate to 660 feet was considered, although this design was estimated to work for the maximum HGL of 670 feet. The design proved to be functional for the range of upstream heads at a flow of 243 cfs, however, air still remained at the entrance to the downstream interceptor.

Minor modifications were made to the downstream baffle wall which included increasing the height of the wall by 4.5 inches. There was a small improvement in air entrainment observed at the entrance to the Contract 6 interceptor. There was also minimal submergence of the jump observed as a result of this modification. The high velocity flow through the gate resulted in an upstream flow along the opposite half of the stilling basin as indicated in the schematic below. This upstream recirculation was at a greater depth than the flow beneath the gate and tended to be entrained into it. This gave the appearance of a partial submergence of the gate under the flow conditions observed and it was difficult to define exactly when the jump submerged the sluice gate.





This phenomenon can be easily viewed on the videotape that has been provided. A further adjustment to the baffle wall height was made in which the original height was increased by a total of 9 inches. In this configuration, the jump was definitely submerged at the sluice gate.

The results of the modifications to the Revision 1 design suggested that flow would never be uniform upstream of the hydraulic jump. Therefore, the baffle blocks and baffle wall were moved even closer to the gate to allow for more room for air entrained in the jump to escape. The baffle blocks were moved to a location 10 feet downstream of the gate opening, while the baffle wall was moved to a distance of 30 feet from the gate. These modifications also included replacing the drop in floor elevation upstream of the baffle blocks with a gradually uniform downward slope, increasing the length of the basin by 3 feet, and increasing the width of the baffle blocks to 15 inches. These modifications to the model are hereafter referred to as Revision 2. Figures 6a-6c present the modifications which comprise the Revision 2 design.

Testing of the Revision 2 design proved that there was no problem with air remaining in the flow at the entrance to the downstream interceptor. All the air was removed from the flow before the entrance to the Contract 6 interceptor. There proved to be sufficient energy dissipation under both flow conditions and the flow seemed to be more uniformly distributed across the width of the channel. Figures 6d and 6e show the performance of this configuration at a flow rate of 243 cfs. The baffle blocks were then removed, and under this configuration, the design was ineffective. There was insufficient energy dissipation which resulted in much greater velocities hitting the baffle wall. Because of the more turbulent flows at the baffle wall, more air remained in the flow at the entrance to the downstream interceptor, thus determining the necessity of the baffle blocks for energy dissipation purposes.

With the baffle blocks replaced, the opening under the baffle wall was increased to 2 feet due to concerns with possible obstruction with the proposed 1 foot opening. Under this configuration, some air remained in the flow at the entrance to the Contract 6 interceptor. With this larger opening, a higher velocity is associated with a more significant portion of the flow passes under the baffle wall. The higher velocity caused more rapid transport of the air bubbles downstream. Due to the non-uniform flow upstream of the baffle wall, more air remained in the flow on the side of the basin where the sluice gate was operating. After a more thorough examination of the flow directly downstream of the baffle wall and further testing, the width of the opening was decreased to 8 feet to force more flow over the top of the baffle wall. This modification is presented in Figures 6f and 6g. The 2 feet by 8 feet opening under the baffle wall was now in accordance with the initial design, which allowed for the passage of dry weather flows. Further testing and observation determined that the amount of air was not significantly decreased by the smaller width, however, the location of the flow and air bubbles was more centered at the entrance to the Contract 6 interceptor. Figures 6h and 6i show results of testing at 243 cfs and 155 cfs, respectively. Again, modifications were made to the baffle wall height and these modifications were tested. With an increased height of 9 inches, the jump was again submerged at the gate and no significant improvement with regards to the amount of air carried by the flow was observed.

Sediment

Upon restoring the height of the baffle wall, sediment was introduced into the modified Revision 2 design. The sediment initially introduced into the flow was originally utilized in a similar study for the Columbus, Ohio wastewater treatment plant (Wright, et al, 1988), and was scaled to provide a dynamically scaled settling velocity from a sediment sample taken from their primary sedimentation tank. Since that model study was performed with a 1:7.5 model, this sediment would be slightly smaller than required for dynamic similarity in the present model for the same prototype sediment. The sediment used in the model study was a 120 grit "#37 Crystolon" silicon carbide powder produced by the Norton Company. This black powder allowed for a suitable size distribution to model an appropriate range of settling velocities and particle sizes, as well as utilize a particle with a color that was suitable for visualization purposes. The specific gravity of the silicon carbide is specified to be 3.2.

A sieve analysis of a representative sample yielded the size distribution indicated in Figure 7. Since most of the material passes the 100 mesh sieve, but is retained on the 120 mesh, the representative diameter of the sediment is in the range of 0.125-0.149 mm. The sediment was introduced into the model under the higher flow condition of 243 cfs. There was no deposition of sediment and all sediment particles were washed through the stilling basin under this flow condition.

A much coarser sediment was then introduced in order to develop a condition with sand much coarser than would be generally expected in the prototype. A graded sand was introduced into the upstream end of the model and sediment deposits were observed at two locations as the flow was shut down, which occurred as soon as all sediment was visually observed to pass beneath the sluice gate. The two locations where sediment deposits were observed were at the immediate entrance to the Contract 6 interceptor and directly downstream of the baffle blocks. About 20 percent of the total sediment introduced was deposited and this was removed and subject to a sieve analysis. Figure 8 from the Sedimentation Engineering ASCE Manual (1977), was used to determine the range of fall velocities and particle sizes given the results of the sieve analysis. The model size diameters determined a corresponding model settling velocity assuming a temperature of 20°C. Model settling velocities were multiplied by a factor of the square root of the length scale ratio (L_r = 6) to determine the prototype settling velocity. The figure was again used to then determine the corresponding prototype diameter. The analysis of the coarser sediment yielded the following results:

Mesh Size	Weight retained (grams)	Sieve size (mm)	Model settling velocity (cm/s)	Prototype settling velocity (cm/s)	Corresponding prototype size (mm)
70	56.1	0.21	2.5	6.12	0.42
50	232.9	0.3	4.0	9.80	0.62
30	179.9	0.6	9.5	23.27	1.8
20	183	0.83	15	36.74	2.8
16	307.4	1.1	18	44.09	3.75
10	310	2	28	68.60	8.0

It should be noted that visual observation of the sediment deposits prior to removal from the stilling basin indicated an armor layer of the coarsest particles. Finer sands were protected from erosion by this armor layer. If the larger sediment were not present to provide the armor layer, it is likely that little deposition would have occurred.

Dynamic Force on the Baffle Wall

Additional measurements were made in order to estimate the maximum force that would occur on the baffle wall due to the impingement of the high velocity jet through the gate. A pitot tube was used to measure the total dynamic head on the baffle wall in the impinging jet under the maximum flow rate of 243 cfs. This was difficult to measure due to the air entrained in the jump and air bubbles continuously entering the pitot tube, thus complicating the interpretation of results. However, a total dynamic head of approximately 0.75 feet above the water level was determined in several independent measurements. Converting this to a velocity and scaling to the prototype indicates a maximum velocity of approximately 18 ft/s impinging on the baffle wall. For the total discharge of 243 cfs, a uniform velocity of 18 ft/s would act over an area of 13.5 ft^2. The total thrust on the baffle wall would thus be 8500 pounds. Since a significant fraction of the flow passes under the baffle wall without impinging on it, this estimate is an absolute upper bound and the total force on the wall should be substantially less than that, and in fact will probably be even less than half.

CONCLUSIONS AND RECOMMENDATIONS

The test results indicated that the flow directly downstream of the sluice gate into the hydraulic jump would never be horizontally uniform. Due to the variation in flow across the width of the channel, it was difficult to estimate the correct amount of initial energy dissipation in a conventional manner, therefore numerous modifications were made to the initial design. The test results determined that a downstream baffle wall provided sufficient tailwater to control the jump within the stilling basin and six large baffle blocks provided necessary energy dissipation downstream of the sluice gate. The flow tended to be higher and more turbulent on the side of the channel where the sluice gate was in operation upstream of the hydraulic jump, however, because of the energy dissipation that occurs as the flow hits the baffle blocks and undergoes the jump, the flow became more uniform on the downstream side.

The baffle wall can be used to directly control the location of the hydraulic jump. A baffle wall height of 4.5 feet at a location 30 feet downstream of the divider wall is functional in controlling a jump in the stilling basin without submergence of the gate. A distance of 30 feet from the baffle wall to the entrance to the downstream interceptor is therefore available so that air entrained in the hydraulic jump has sufficient opportunity to escape. In terms of air remaining in the flow at the entrance to the Contract 6 interceptor, the results were most favorable with a 1 foot high opening with a width of 13 feet. However, due to concerns with obstruction and the inability to easily pass dry weather flows, the final modifications utilized a 2 feet high opening and a width of 8 feet. This design provided acceptable removal of air at the downstream interceptor. Although some air was observed, it is not considered to be problematic due to the fact that the air present is not a significant amount and the Contract 6 interceptor is not intended to flow full for extended periods of time. Further increasing the distance from the baffle wall to the entrance to the Contract 6 interceptor could provide complete removal of air entrained in the jump with a 2 feet by 8 feet opening should this modification be physically feasible at the prototype location. Under both flow cases, the final modified Revision 2 design was successful in both controlling the location of the jump and removing most of the air in the flow at the downstream interceptor. Testing of potential problems with sediment determined that for the majority of particles that will enter the prototype, deposition will not be significant. An analysis of the dynamic force at the upstream side of the baffle wall determined that a very conservative estimate of the total thrust would be 8500 pounds. It is therefore recommended that the final modifications discussed will be able to serve the desired purpose of the NEORSD Heights Interceptor Contract 7A control structure. Figure 6a, which represents the Revision 2 design, shows the general dimensions of this final design, with the exception of a change in the baffle wall opening. The baffle wall opening was changed to 2 feet high by 8 feet wide in order to match the initial design, which allowed for the passage of dry weather flows. A summary of the modified dimensions of the design is as follows:

- Stilling basin width of 15 feet and length of 60 feet to the entrance to the Contract interceptor.
- Six baffle blocks 18 inches high by 15 inches wide located 10 feet downstream of the sluice gate.
- A baffle wall located 30 feet downstream of the sluice gate with a top height of 4.5 feet and a bottom opening of 2 feet high by 8 feet wide dimensions.

REFERENCES

Hydraulic Model Study, Wastewater Influent Splitter Chamber," (S.J. Wright, D. Schlapfer and R. Al-Saigh) Report No. UMCE 88-2, The University of Michigan, Department of Civil Engineering, 1988

Sedimentation Engineering, ASCE Manual 54, V.A. Vanoni, ed., 1977

Figure 1: Alternative 4 design

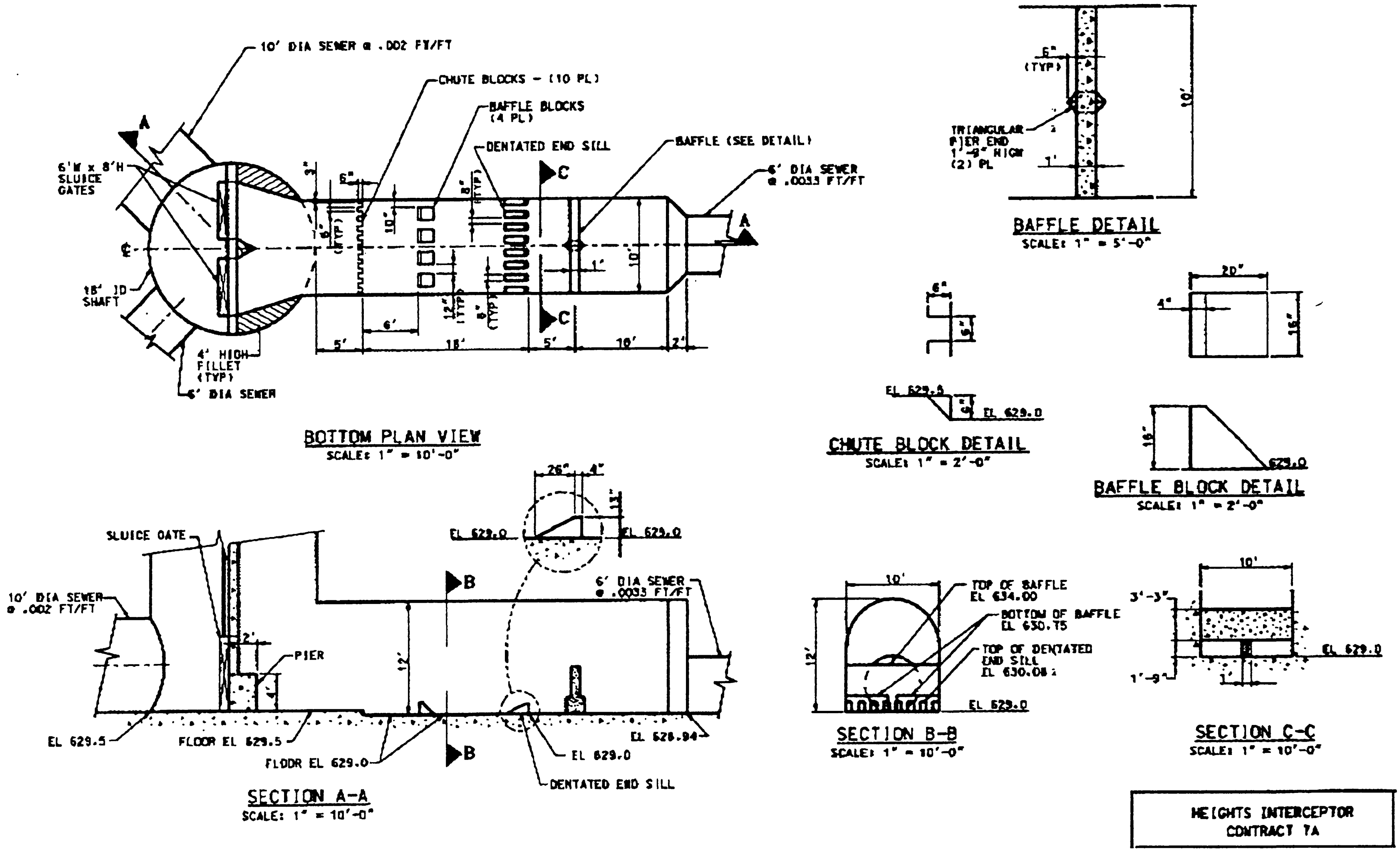
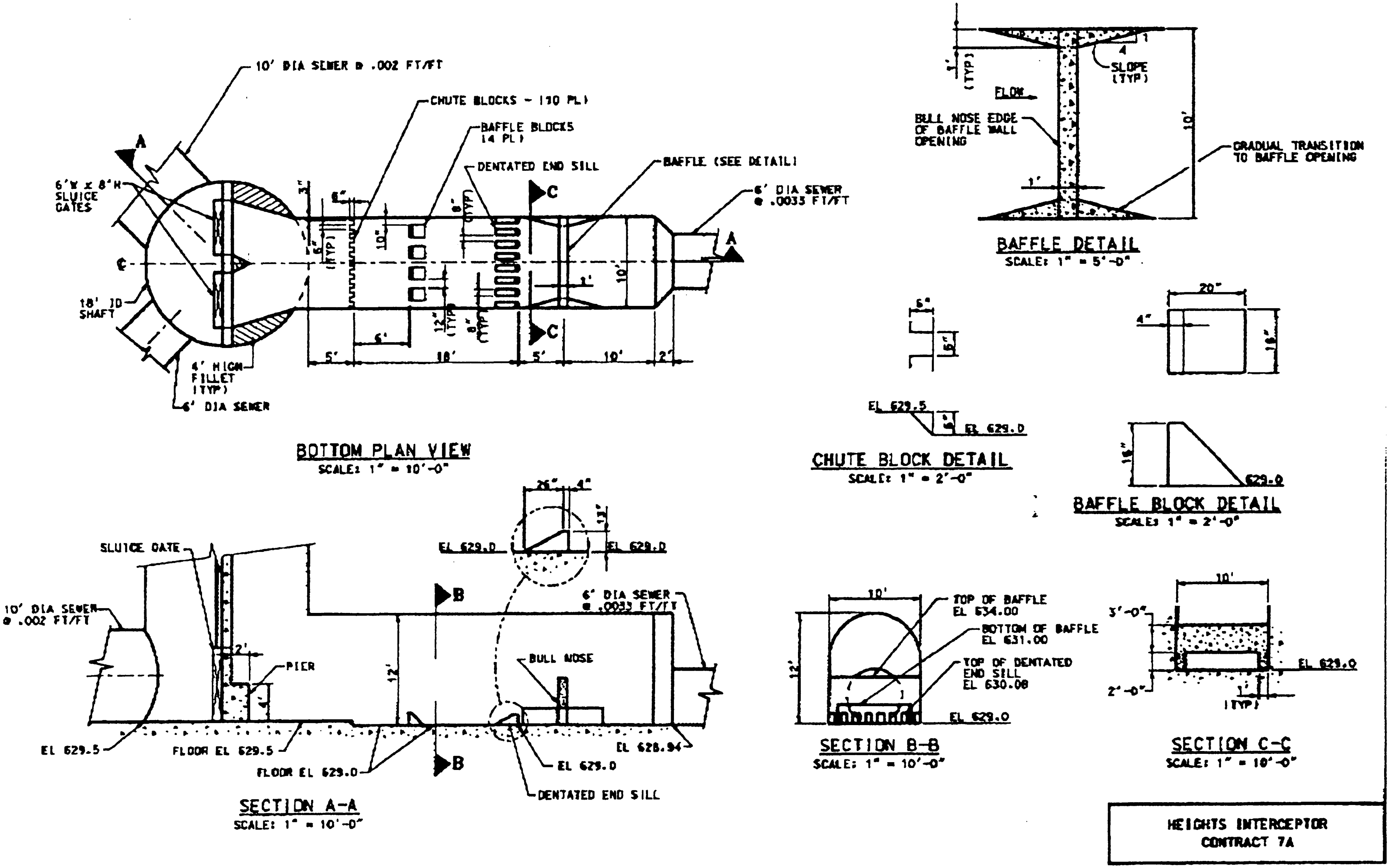


Figure 2: Alternative 4R design



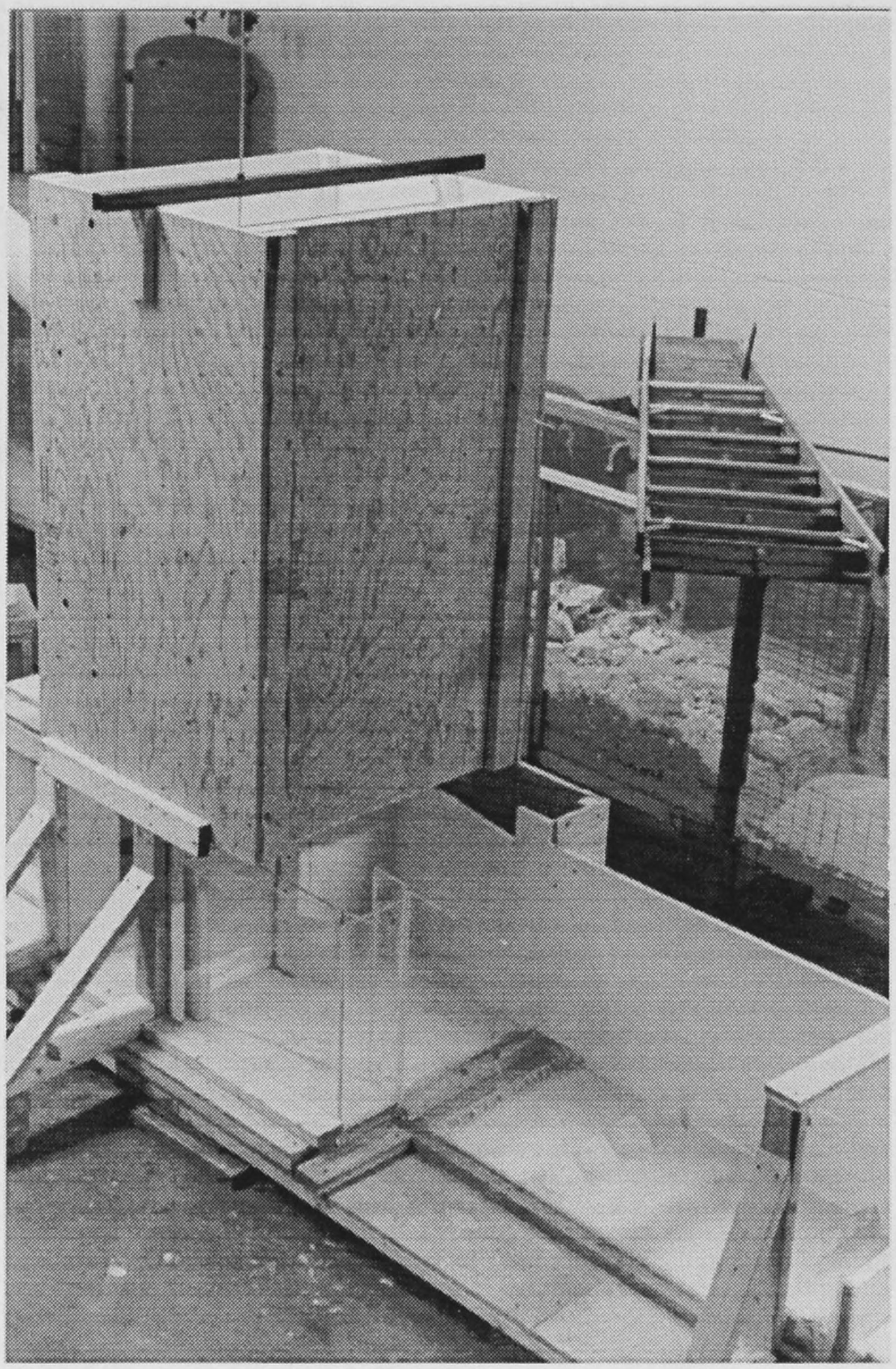


Figure 3: Upstream section of the physical model in initial design configuration.

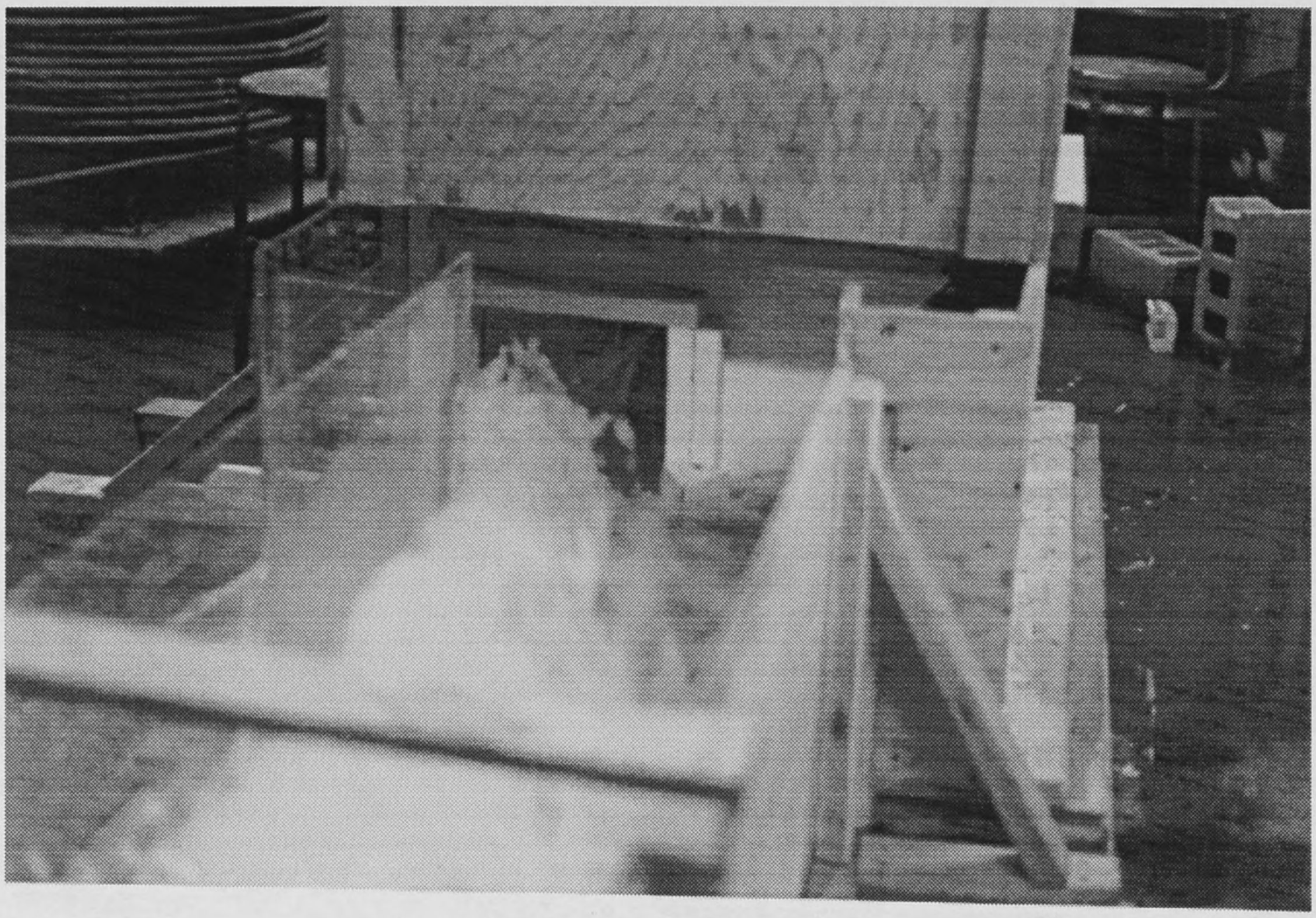


Figure 4a: Hydraulic jump resulting from initial design testing at 243 cfs.

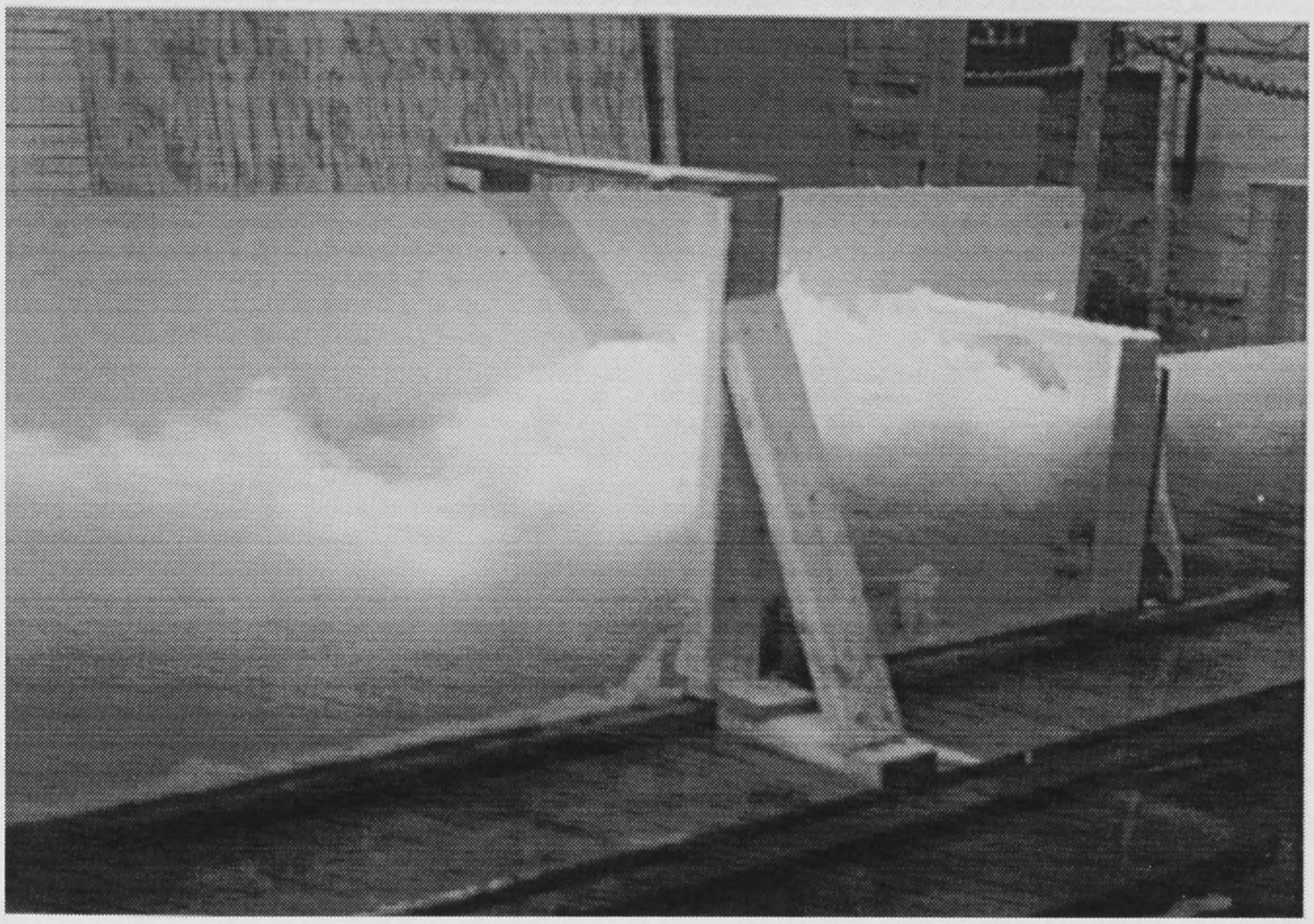


Figure 4b: Side view of stilling basin of the initial design with flow at 243 cfs.

Figure 4c: View of flow eing from sluice gate resulting from initial design testing at 155 cfs.

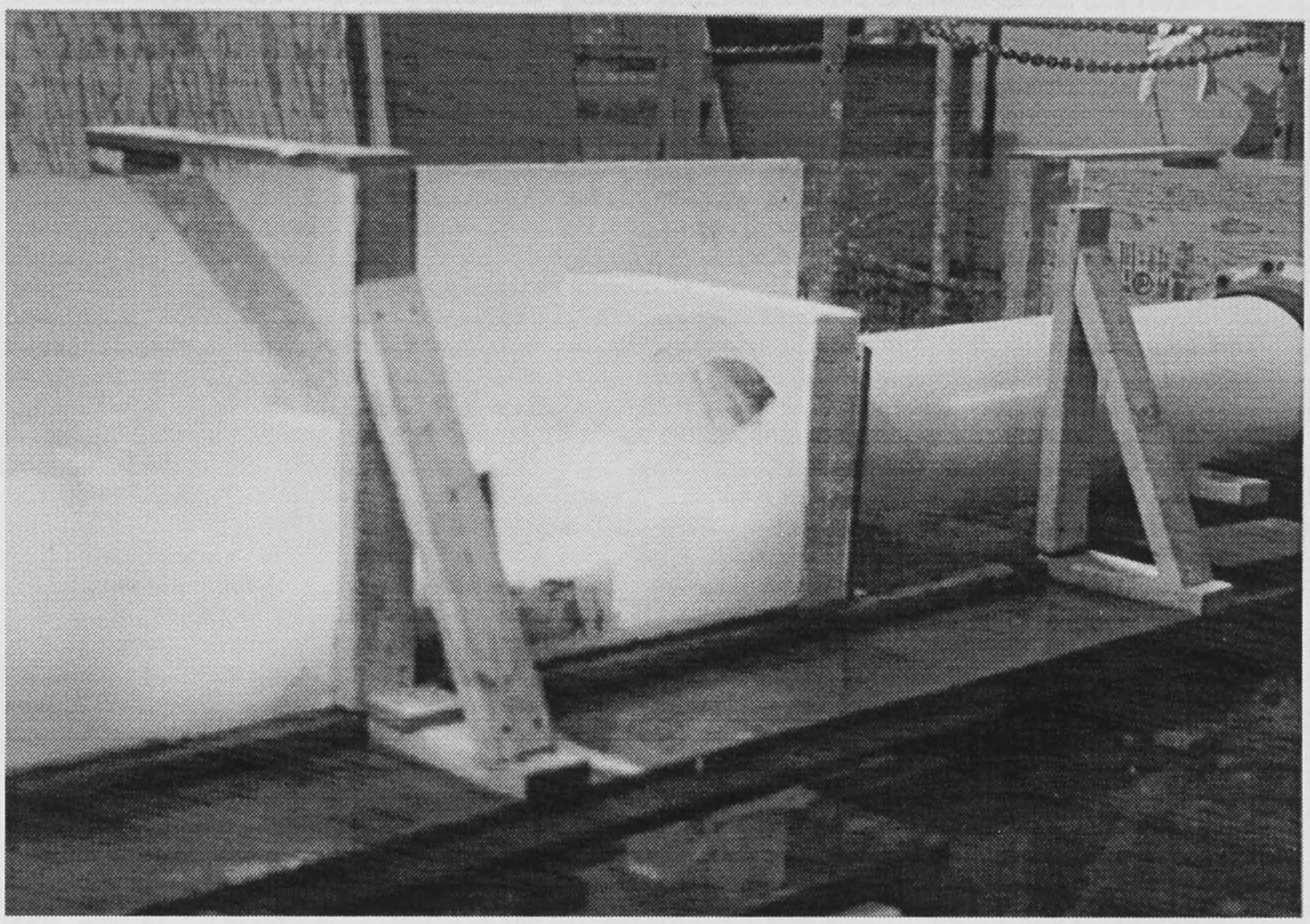


Figure 4d: Downstream end of the stilling basin and the entrance to the Contract 6 interceptor of the initial design at 155 cfs..

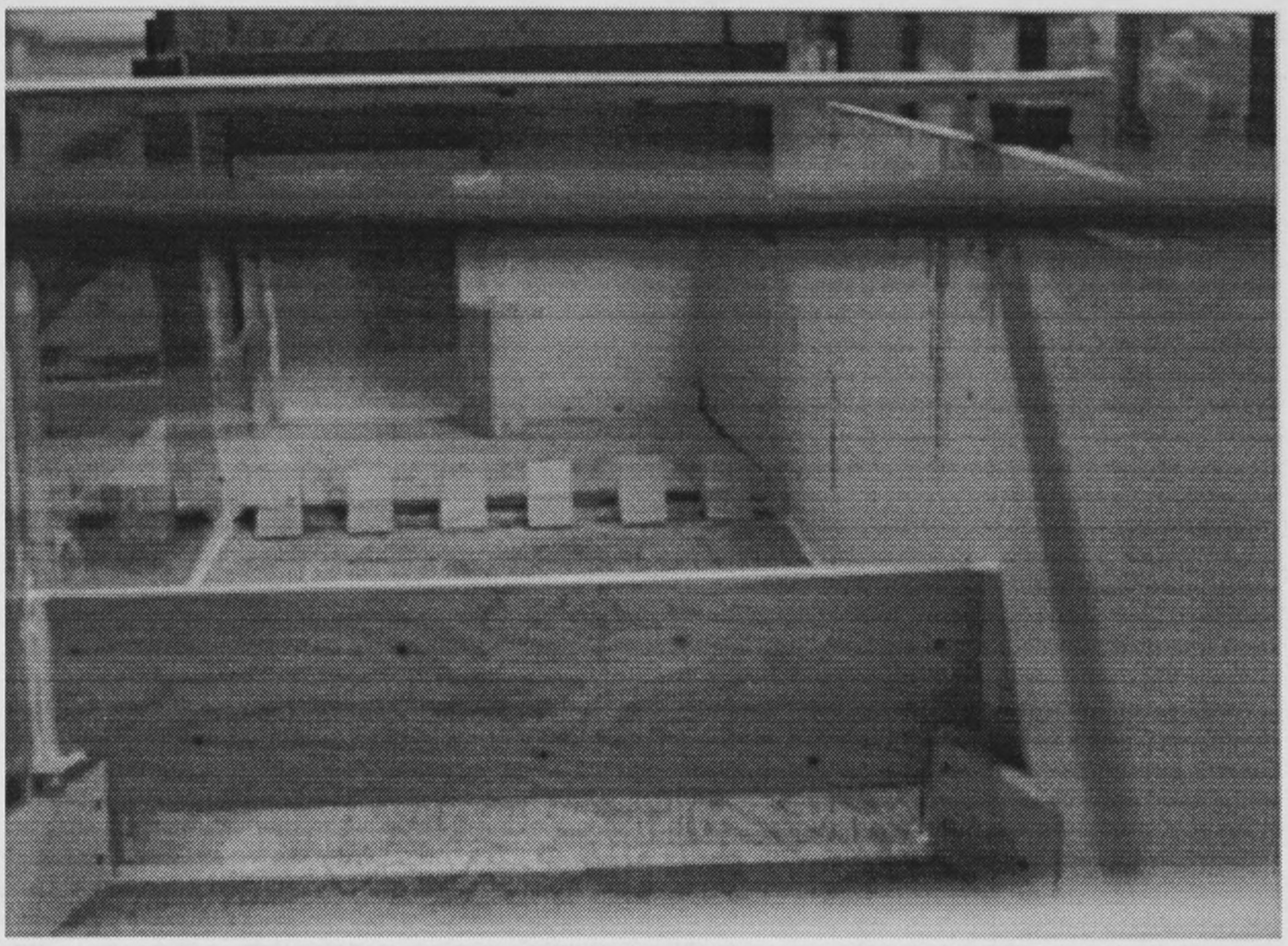


Figure 5a: View of Revision 1 design looking from the downstream end of the channel.

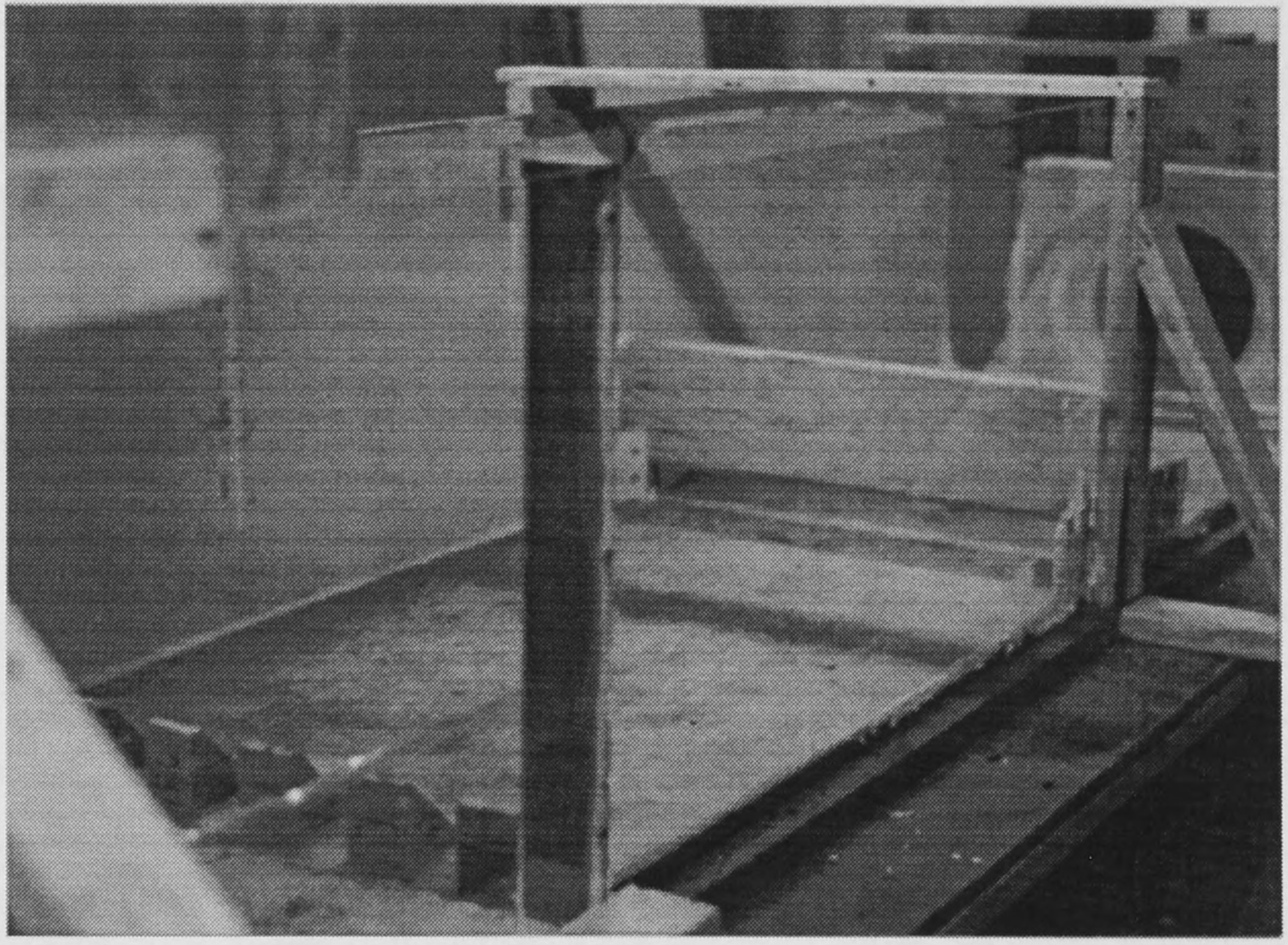


Figure 5b: View of Revision 1 design looking downstream to the entrance to the Contract 6 interceptor.

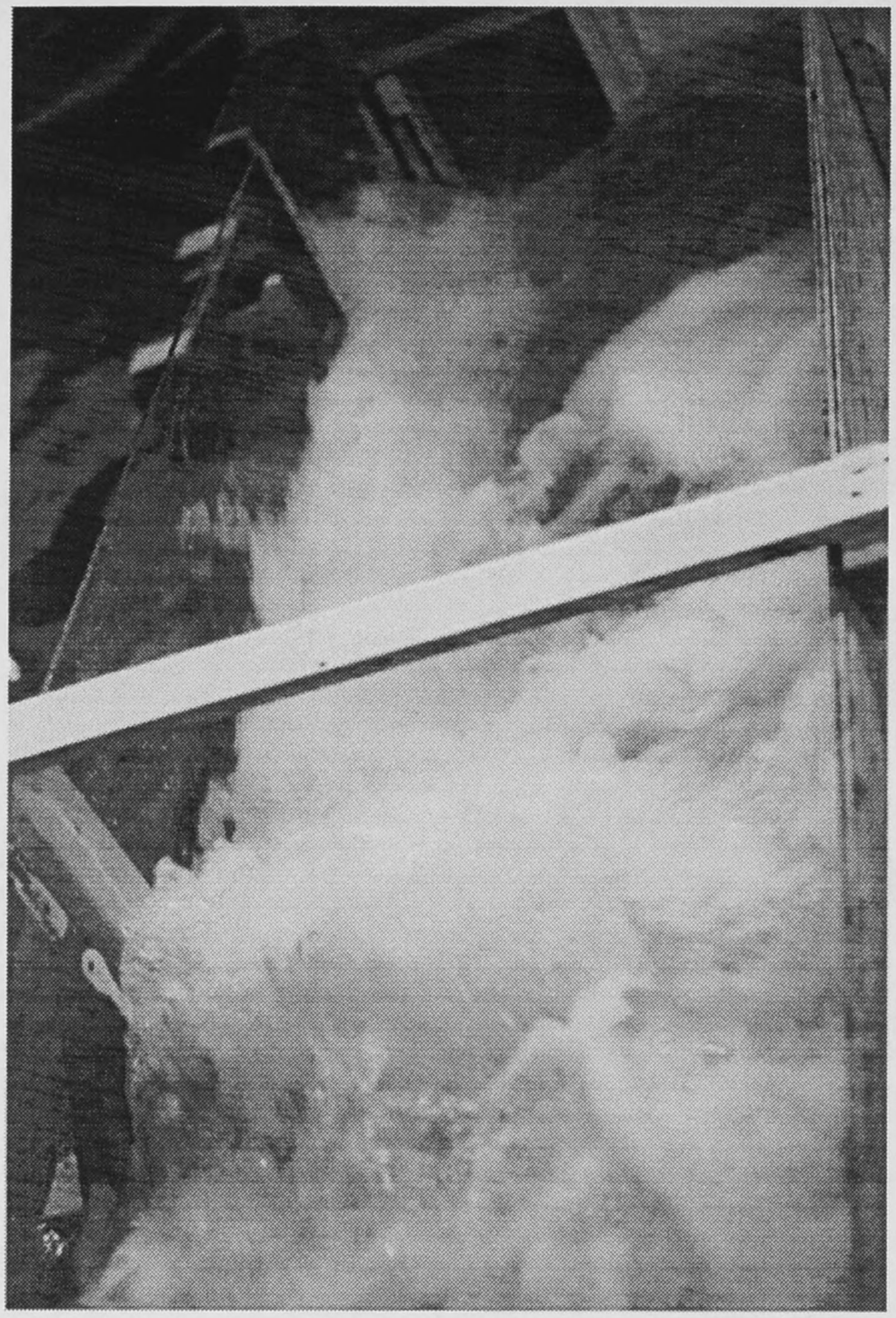


Figure 5c: Top view of testing results of Revision 1 design at 243 cfs.

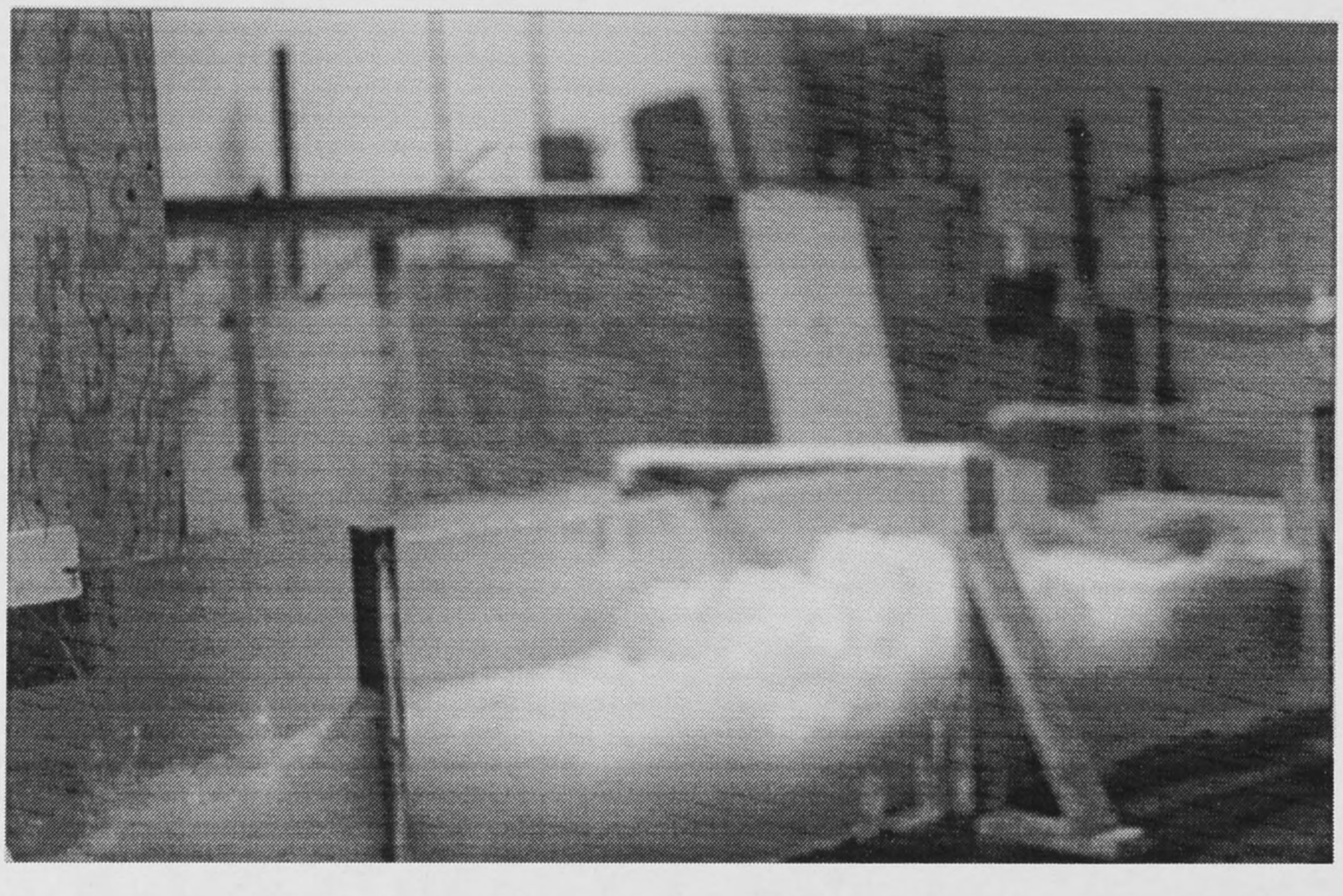
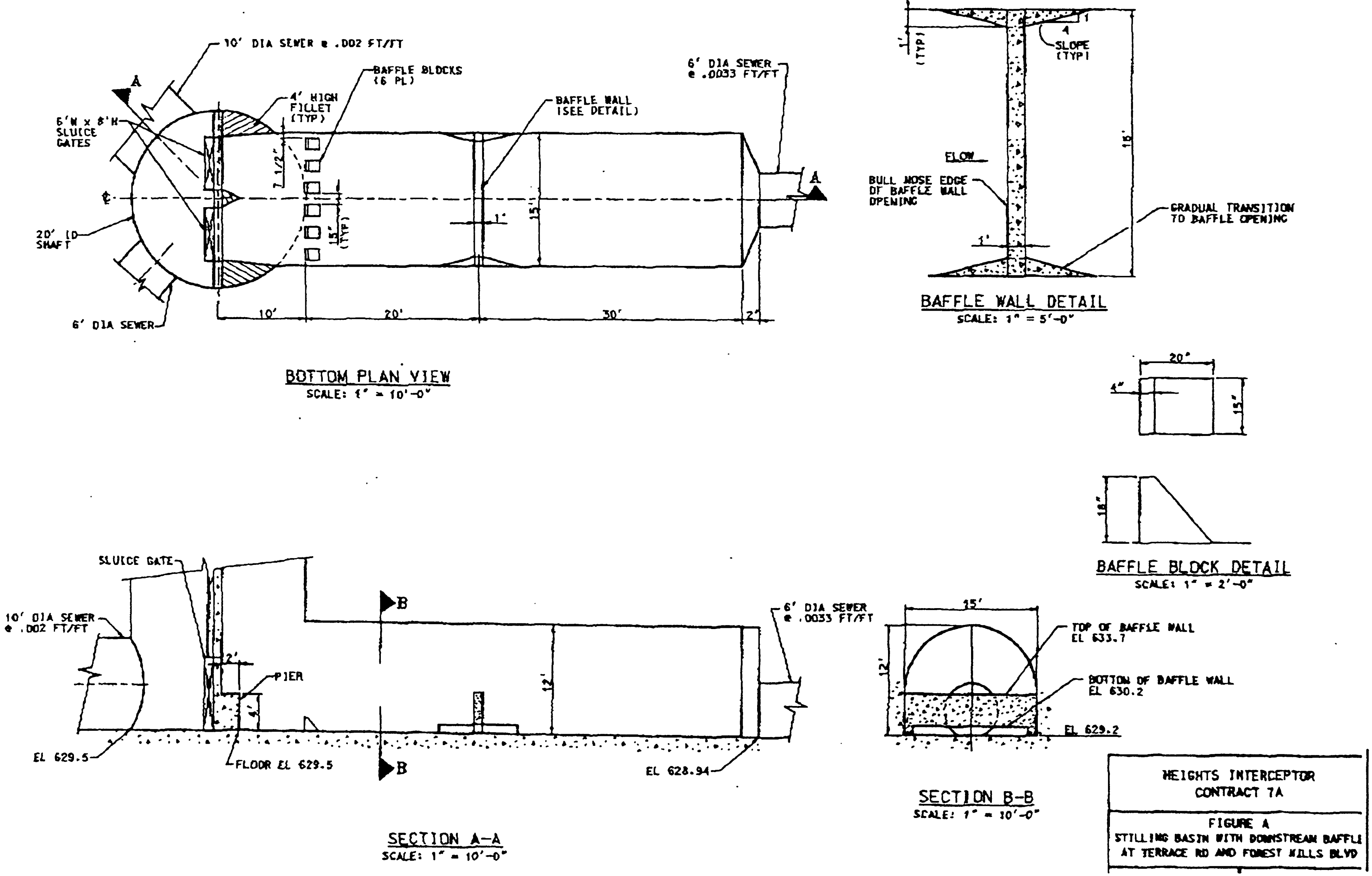


Figure 5d: View of testing results of Revision 1 design along the channel at 243 cfs.

Figure 6a: Revision 2 design



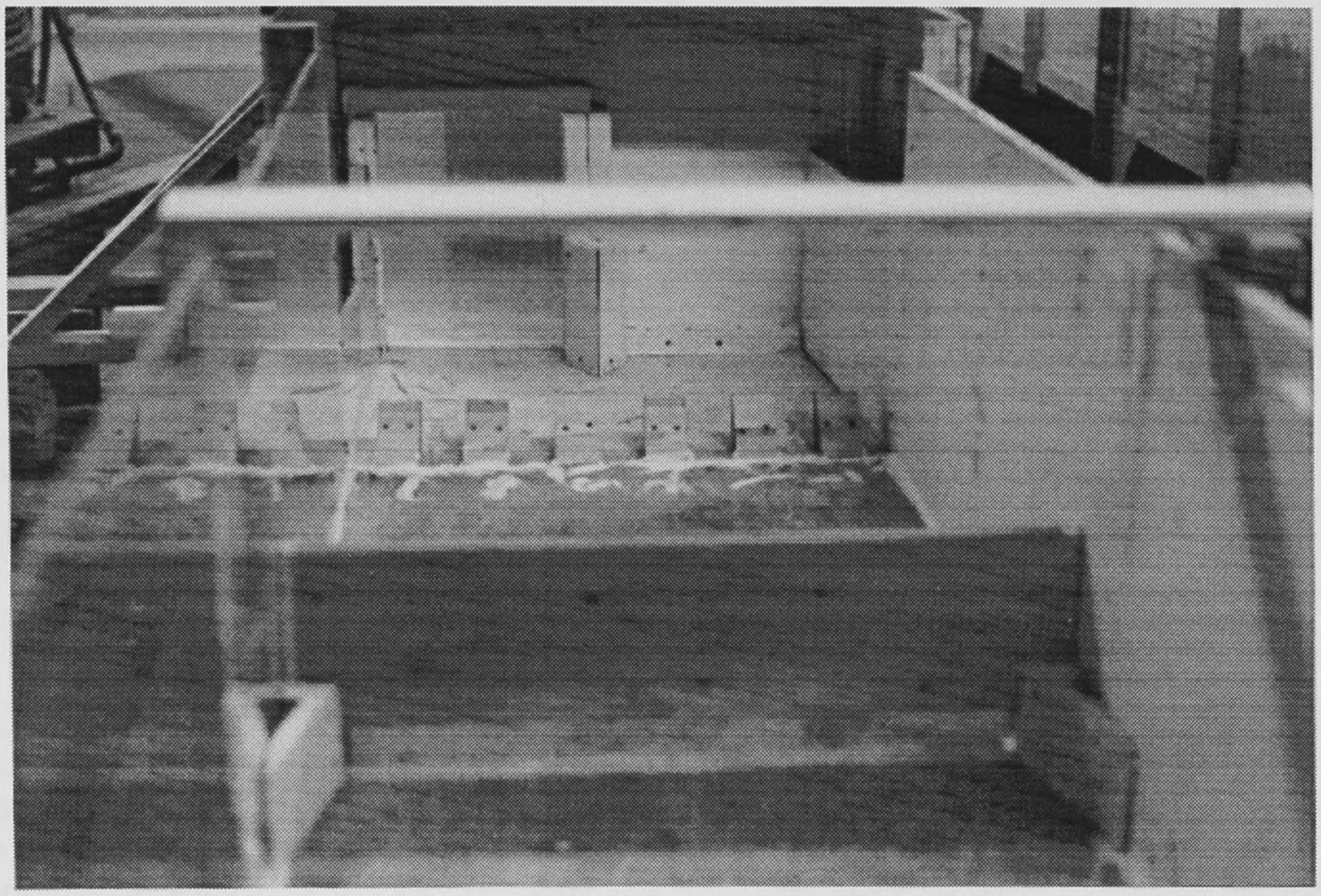


Figure 6b: View of Revision 2 design looking from the downstream end of the channel.

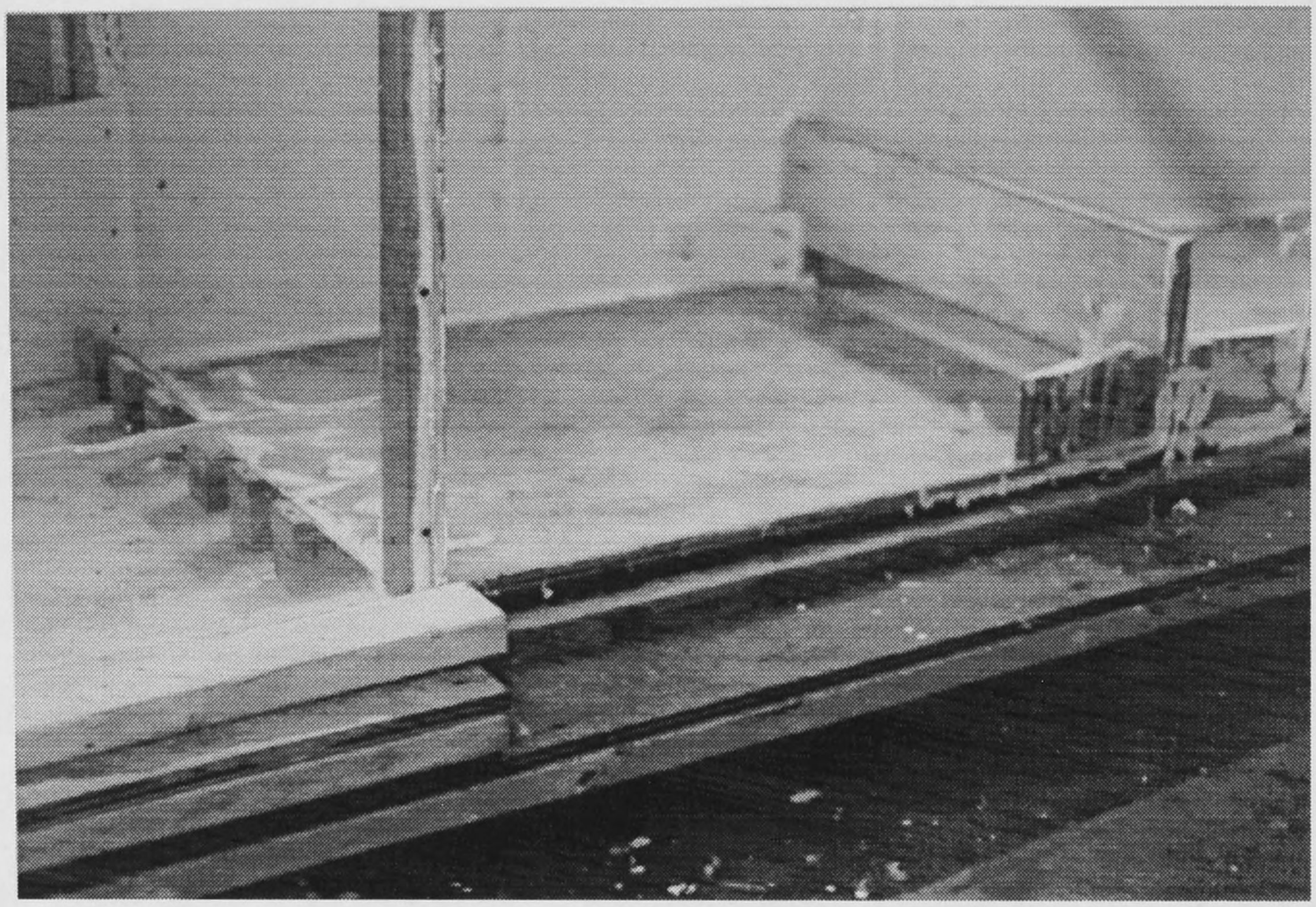


Figure 6c: Side view of Revision 2 design detail involving baffle blocks and the baffle wall.

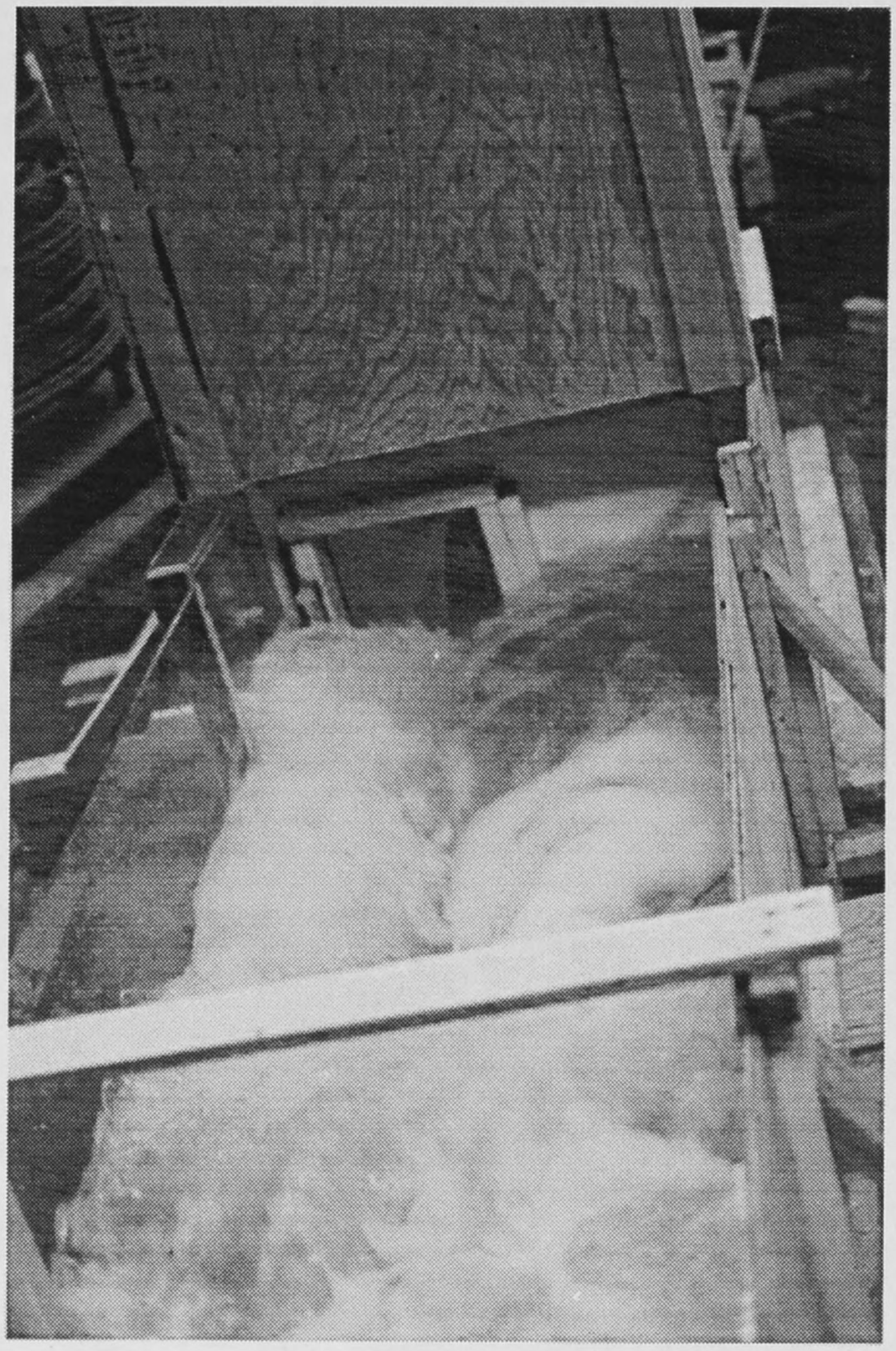


Figure 6d: Top view of testing results of modified Revision 2 design at 243 cfs.

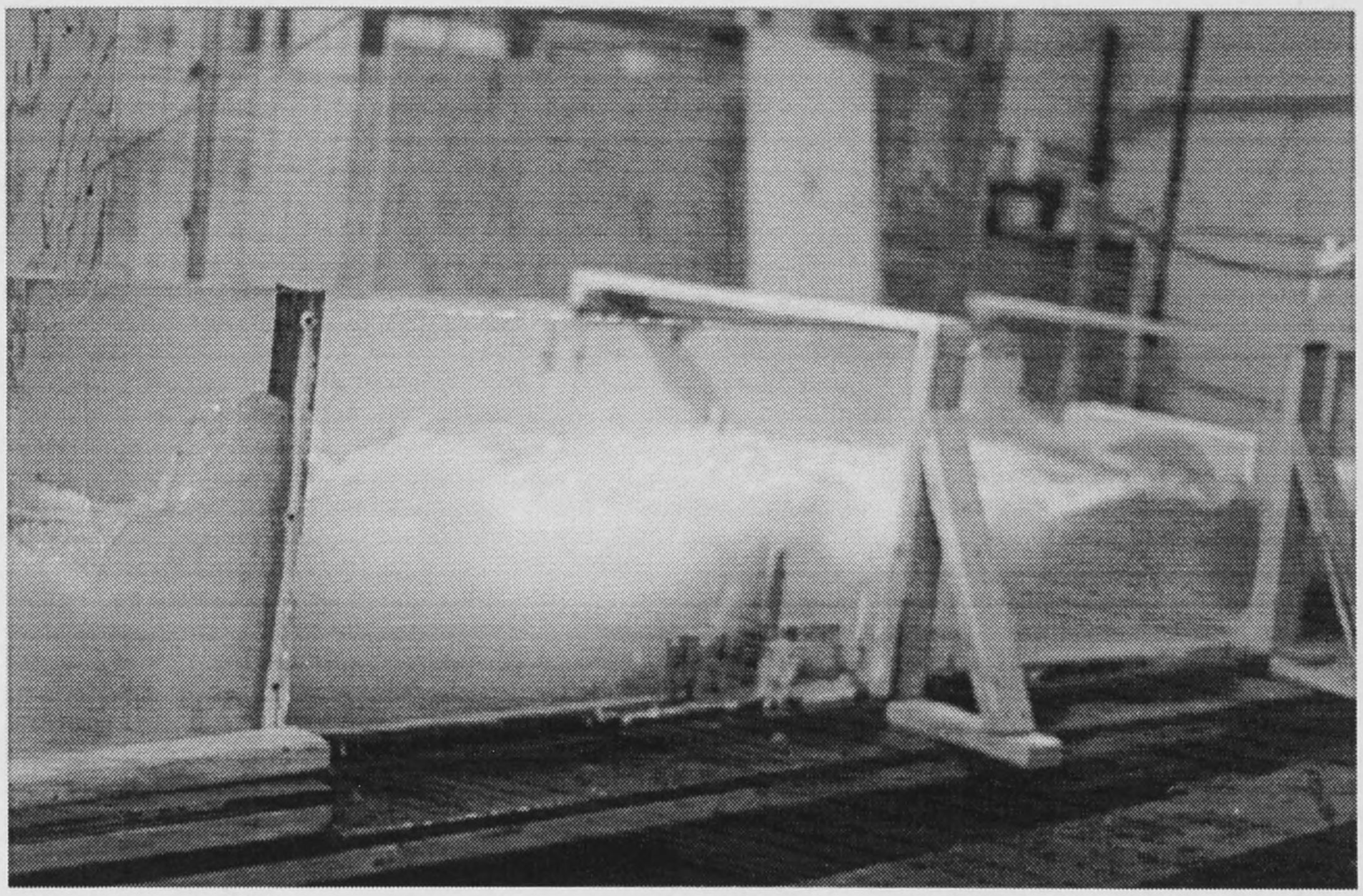


Figure 6e: Side view of testing results of modified Revision 2 design at 243 cfs.

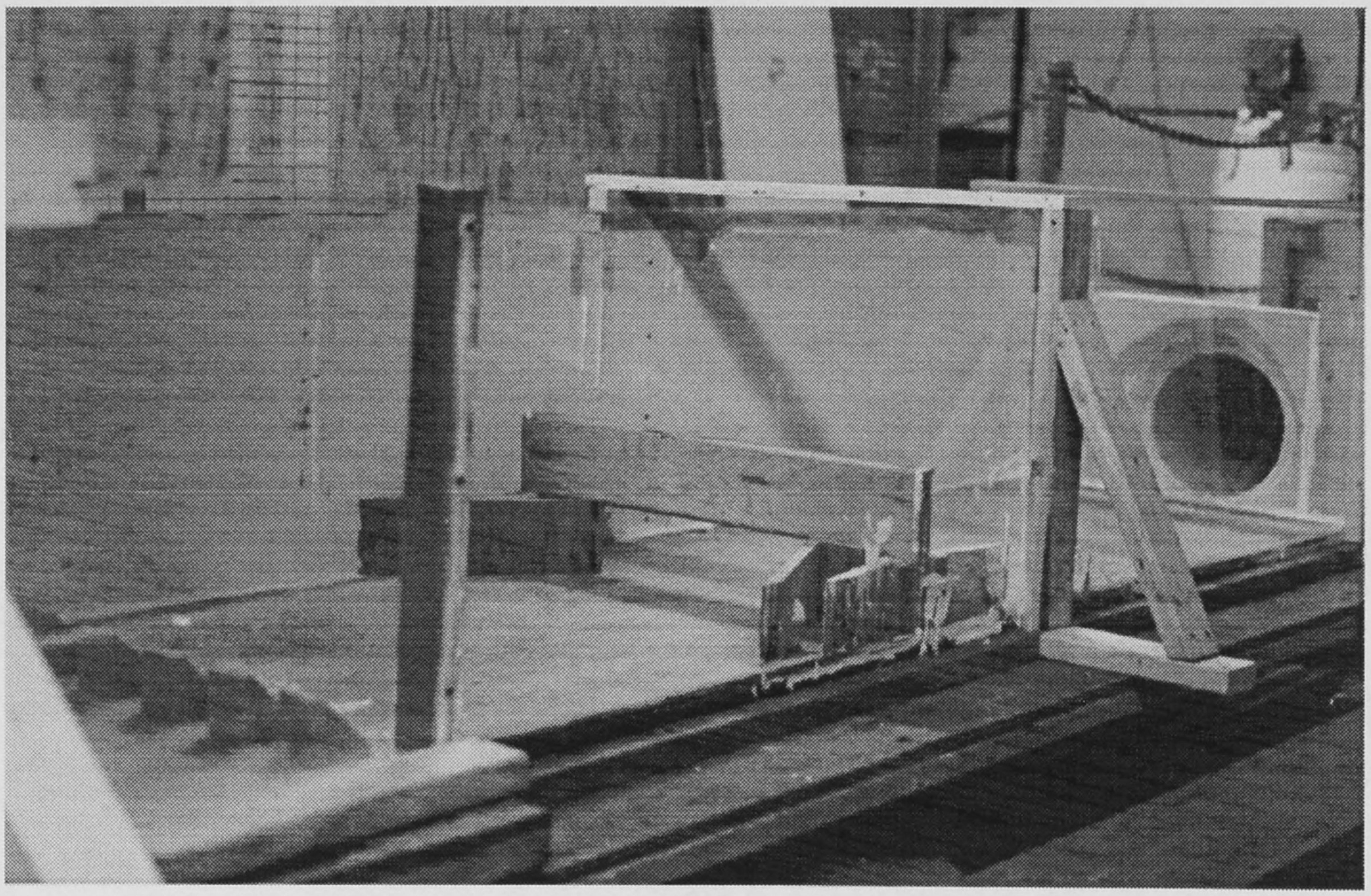


Figure 6f: Modifications to the Revision2 design.

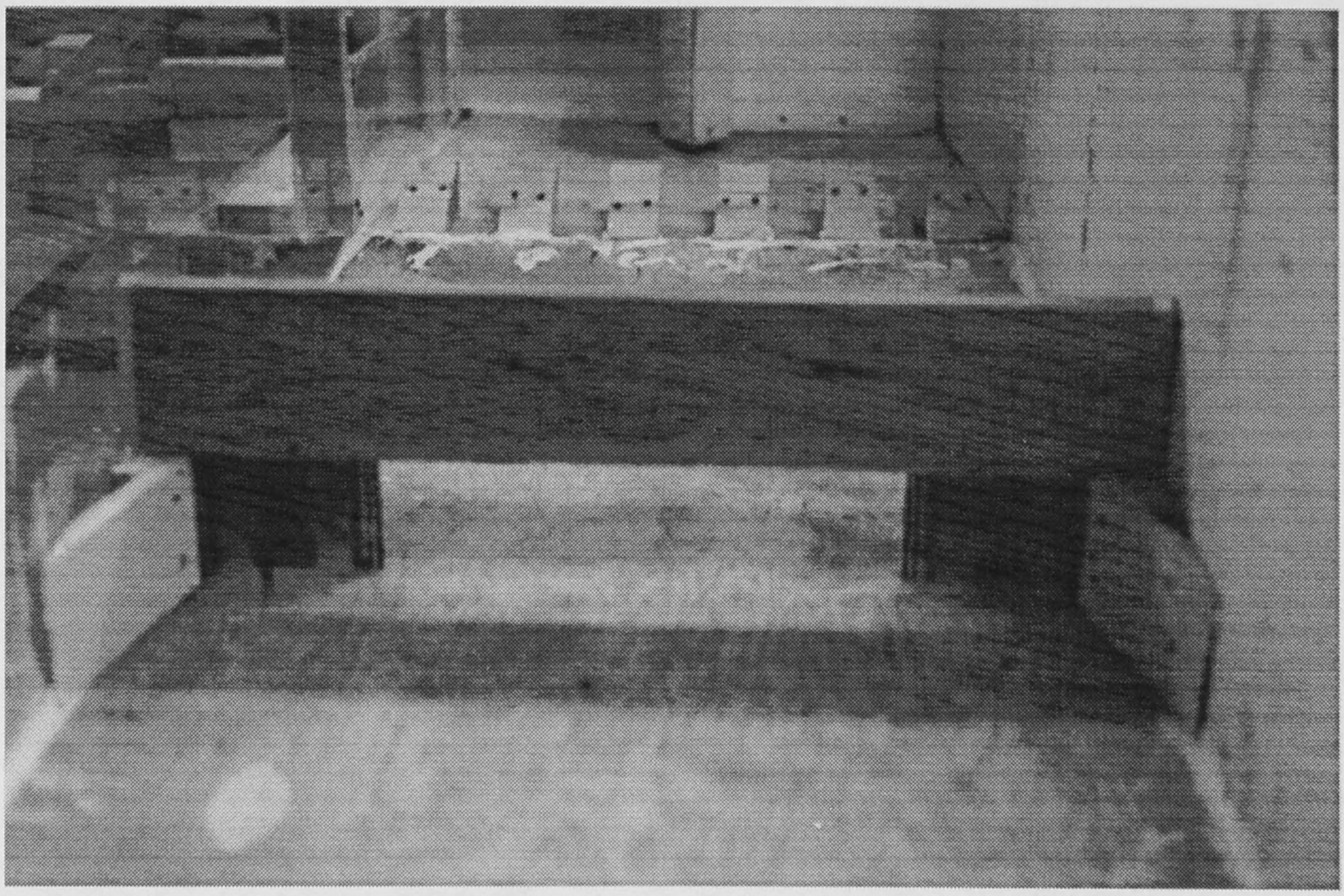


Figure 6g: Decreased 8 foot width of the downstream baffle wall.

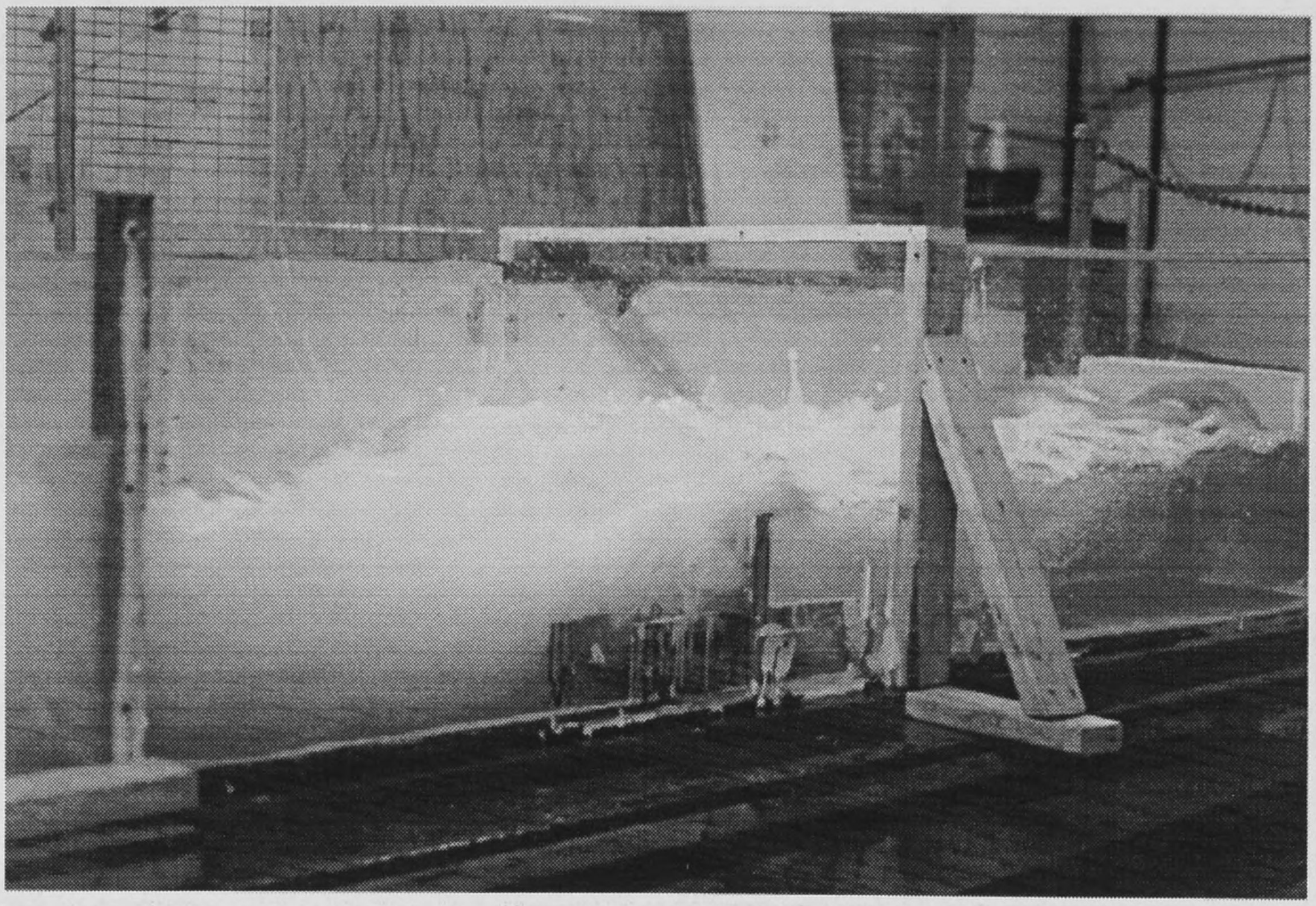


Figure 6h: Results of decreasing baffle width to 8 feet at 243 cfs.

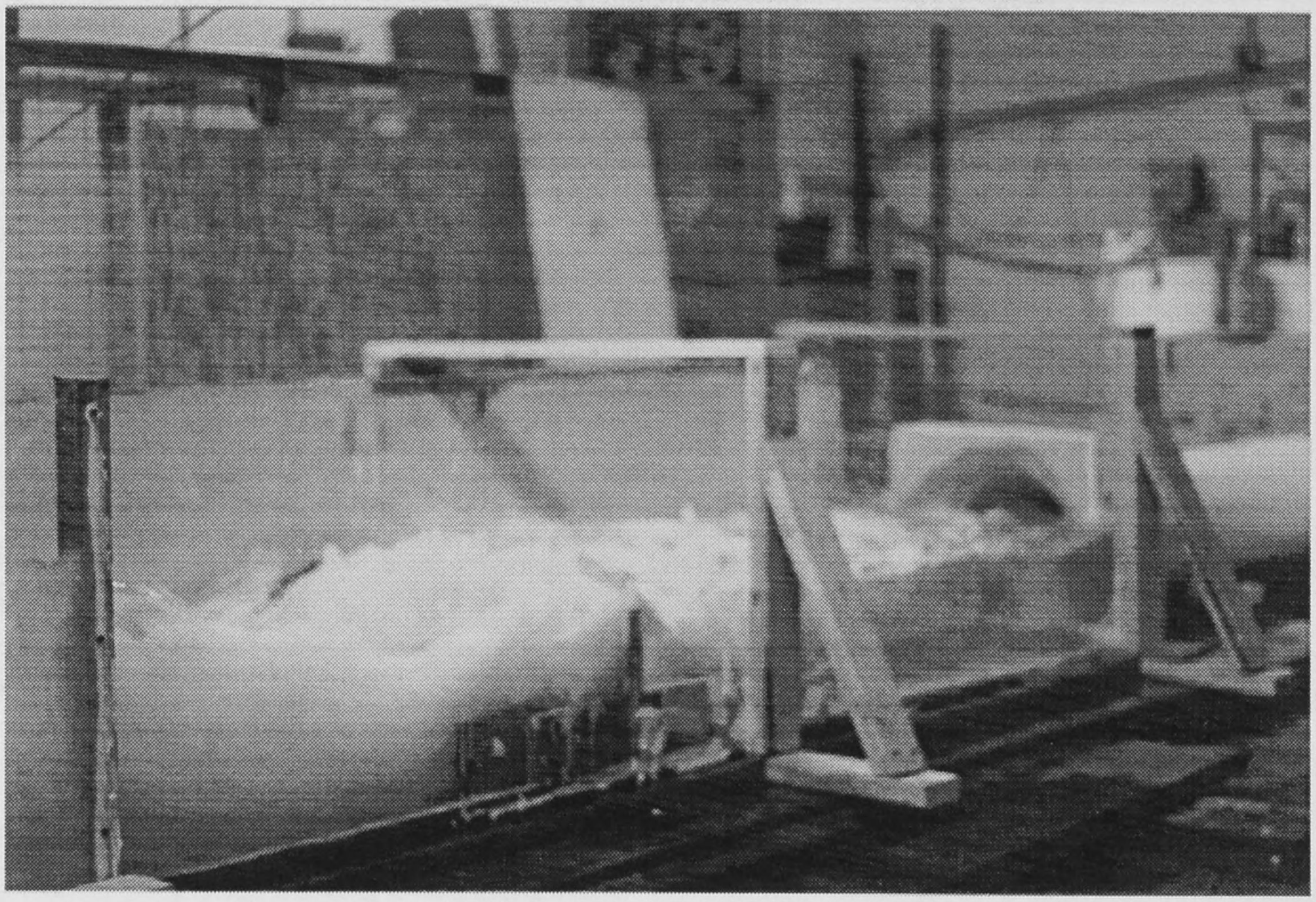


Figure 6i: Results of decreasing baffle width to 8 feet at 155 cfs.

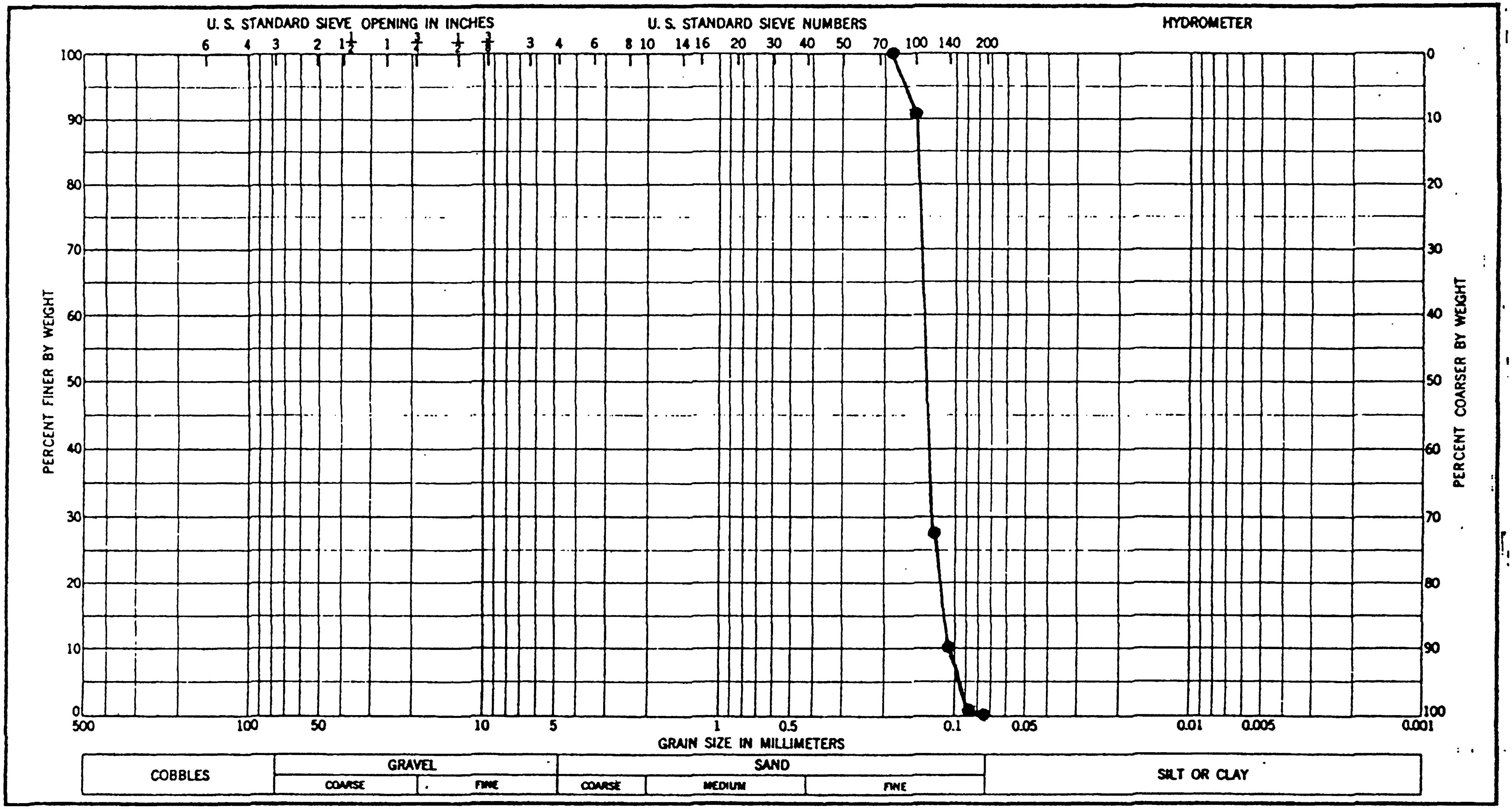
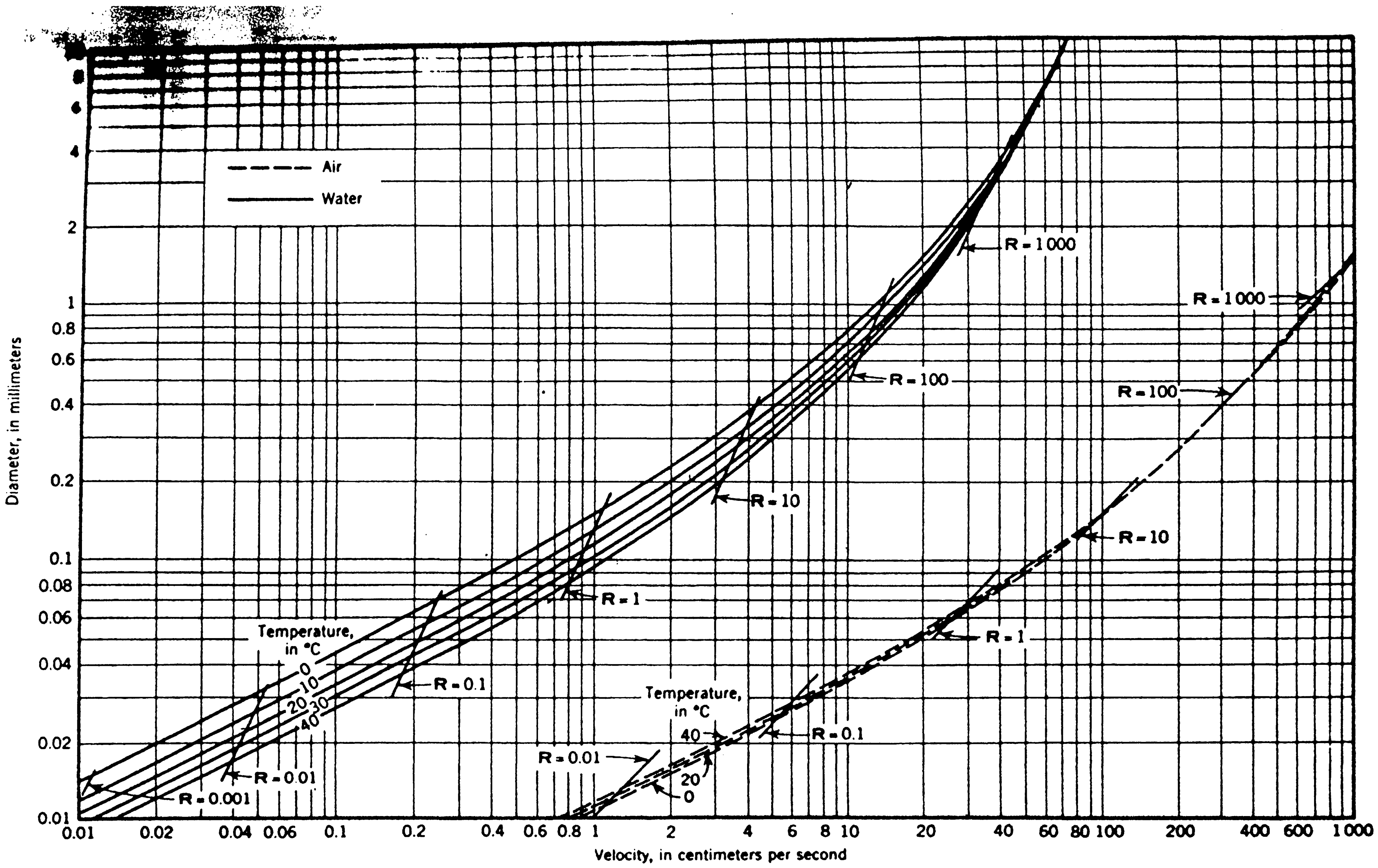


Figure 7: Gradation Curve for Finer Model Sediment
(Silicon Carbide Powder)

Figure 8: Fall Velocity of Quartz Spheres in Air and Water (Rouse, 1937b)



AIIM SCANNER TEST CHART # 2

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Greek and Math Symbols

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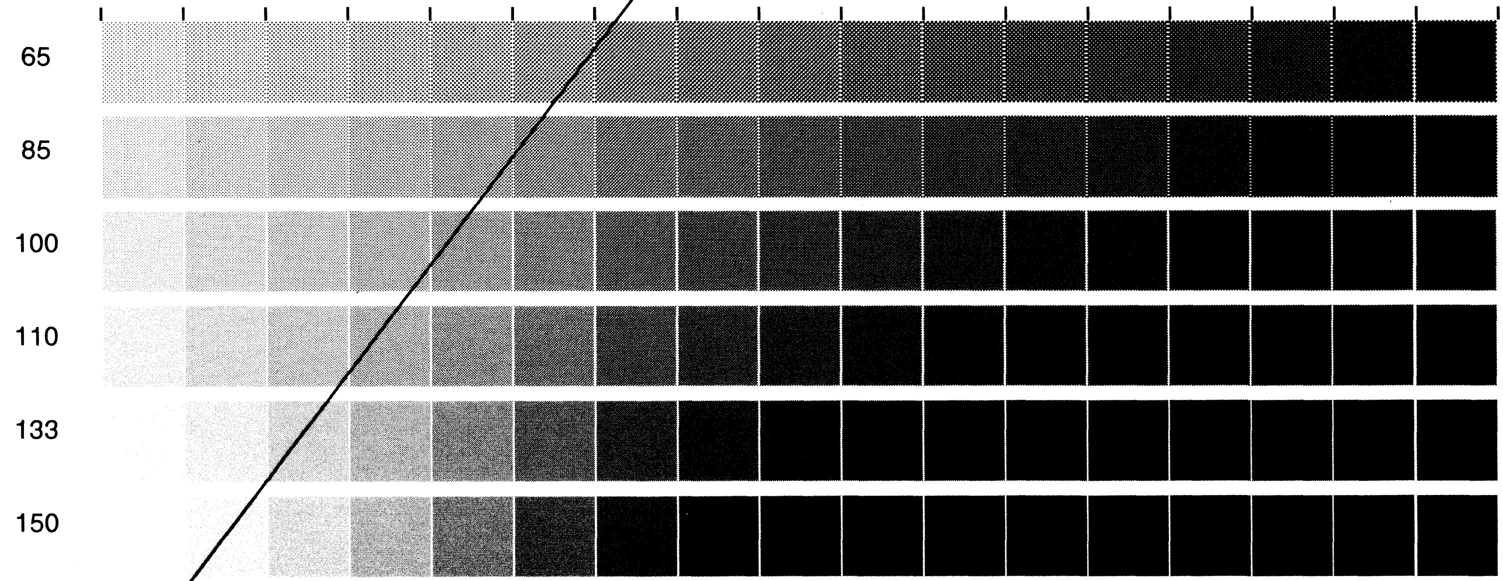

RIT ALPHANUMERIC RESOLUTION TEST OBJECT, RT-1-71

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