University of Minnesota
St. Anthony Falls Hydraulic Laboratory

Project Report No. 197

CULVER-GOODMAN TUNNEL
CONTROL STRUCTURE
MODEL STUDIES

by

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Conducted for

LOZIER ENGINEERS, INC.
Rochester, New York

and

HARZA ENGINEERING COMPANY
Chicago, Illinois

Sponsored by the
DIVISION OF PURE WATERS
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PREFACE

Inherently, most metropolitan areas of the United States have storm water and sanitary sewage handling problems. Due to population growth and ever increasing industrialization, the problems are becoming more severe. Each city has developed a solution unique to its particular problems and topographic features. One of these projects is the combined sewer overflow and abatement plan being developed by the City of Rochester, New York. The Culver-Goodman tunnel control structure is part of the sanitary sewage and storm water runoff collection system in Rochester. The surface flow will be collected by the proposed 16 ft diameter Culver-Goodman tunnel and conveyed to a control structure located at Densmore Creek. The incoming flow enters the distribution chamber of the control structure. Low flows of about 1050 cfs are diverted through sluices to a drop chamber at a lower elevation. As the flow increases, sluice gates are closed limiting the diverted flow. The function of the drop chamber is to dissipate the energy of the falling water and also to provide for effective air removal from the water-air mixture, thus keeping most of the air from entering the 12 ft diameter exit tunnel. The exit tunnel from the control structure conveys the flow to the existing Cross-Irondequoit tunnel, which in turn carries the flow to the treatment plant. As the flow into the distribution chamber increases and some sluice gates are closed to limit the flow to the lower drop chamber, the excess flow fills the distribution chamber and eventually flows over an ogee weir directly into Densmore Creek. The initial control structure was required to handle 8700 cfs. This value was subsequently reduced to about 5,000 cfs based on a mathematical model of the project and more hydrologic information.

The purpose of the control structure model studies was to provide some hydraulic insight as to flow conditions that occur in the distribution chamber, the sluices, the drop chamber, and the outlet pipe. To study these problems a 1:16 scale model was constructed at the St. Anthony Falls Hydraulic Laboratory.

The model tests described in this report were conducted for Lozier Engineers, Inc., of Rochester, New York, represented by Salvatore LaBella, Robert Plecash, and Howard Shapiro; and Harza Engineering Company of Chicago, Illinois, represented by Dr. David Louie, Frank DeFazio, and Wayne Coleman. The model tests were sponsored by the Division of Pure Waters, Monroe County, New York, represented by Gerald McDonald and John Davis. During the course of the model studies, several meetings were held at the St. Anthony Falls Hydraulic Laboratory to demonstrate the model, discuss various aspects of the project, outline the required tests, and discuss the results. Meetings were attended by representatives of the above organizations and the Laboratory. The study was under the immediate direction of Warren Dahlin, Scientist, and various aspects of the project were reviewed

by Joseph Wetzel, Assistant Director. A silent-color motion picture summarizing the pertinent tests was prepared by Warren Dahlin and reviewed by Joseph Wetzel. This final report summarizes the results of the test program.

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CULVER-GOODMAN TUNNEL

CONTROL STRUCTURE MODEL STUDIES

I. INTRODUCTION

The City of Rochester plans to excavate the Culver-Goodman tunnel and connect it to the existing Cross-Irondequoit tunnel through a control structure which will limit the flow diverted for treatment to about 1050 cfs. A 16 ft diameter entrance tunnel with a round to square transition at the downstream end conveys the incoming flow to a distribution chamber. The original design, Type A, distribution chamber is 100 ft long by 76 ft wide, contains 1:1 side slopes, blocks at the upstream end to dissipate some of the energy of the incoming flow, and an ogee crested weir at the downstream end. The floor of the distribution chamber is at elevation 285 ft and the weir crest at elevation 315 ft. Six sluices each 5 ft x 2.5 ft direct the diverted flow downward into the drop chamber. To enter the sluices the incoming flow has to make a 90 degree turn. The 100 ft long by 20 ft wide drop chamber also turns the flow 90 degrees towards the 12 ft diameter exit tunnel. The drop chamber is required to be of sufficient size to dissipate the energy of the falling water and to reduce the flow velocity so that the entrained air in the water-air mixture can rise to the surface and escape. Blocks at the downstream end assist in this process. The floor of the drop chamber is at elevation 216 ft and the top is open to the ground surface. A transition at the entrance to the exit tunnel guides the flow smoothly into the tunnel.

A model including all of these components was fabricated at the St. Anthony Falls Hydraulic Laboratory to a scale of 1:16 and installed in the Laboratory's gravity flow system as shown in Photo 1. This scale was chosen so that 12 inch and 9 inch pipes could be conveniently used in the model to represent the 16 ft diameter entrance tunnel and 12 ft diameter exit tunnel.

This is a "steady-state" model. That is, no flow or head changes are imposed externally during a particular test.

Gravity is the predominant motion-producing force in both the prototype and model. For this kind of system the greatest degree of dynamic similarity is obtained when the model-prototype relationships are established by the Froude Law. The following expressions were used to convert dimensions and hydraulic quantities from model to prototype or vice versa.

Quantity	Ratio	Scale Relation Model:Prototype
Length, L	L_r	1:16
Discharge, Q	$Q_r = L_r^{5/2}$	1:1024
Velocity, V	$V_r = L_r^{1/2}$	1:4
Pressure, P	$P_r = L_r$	1:16
Time, T	$T_r = L_r^{1/2}$	1:4

Complete similarity for the air entrainment and air removal processes in the sluices and drop chamber cannot in general be obtained because the mechanism of entrainment, the sizes of bubbles, and the relative movement of the bubbles through the water are subject to forces other than gravity and depend more on such forces as surface tension and viscosity. However, the processes are qualitatively similar, and it is believed that the observations made in the model regarding the flow characteristics of the aerated mixture will be qualitatively correct.

II. CONCLUSIONS

1. The Type A control structure (Charts 1 and 2) had poor distribution of flow between sluices, poor flow conditions in the sluices, and entrained air was carried into the exit conduit. Type A was judged to be hydraulically unacceptable for the required design functions.

   The Type A-1 control structure (Charts 1 and 2) was hydraulically unacceptable for the design of the structure. Compared to Type A, Type A-1 had poorer distribution of flow between the sluices at lower flows, a stronger counter-clockwise rotation of flow in the distribution chamber for higher flows, and poorer flow conditions in the sluices. Flow conditions in the drop chamber appeared similar for both types with air carried into the exit conduit. It was apparent that the presence of blocks in the distribution chamber improved the flow conditions there, but the blocks in the drop chamber had very little effect.

   The Type A-2 control structure (Charts 1 and 2), the optimum design from the A-series, was judged to be hydraulically unacceptable for the required design functions of the structure. Type A-2 had undesirable flow patterns in the distribution chamber, sluices, and drop chamber, and considerable air was carried into the outlet pipe.

2. The Type B control structure (Charts 16 and 17), which contained an enlarged drop chamber, was effective in keeping most of the air from entering the outlet pipe. The undesirable flow patterns in the distribution chamber and sluices still existed.

   Type B-1 with the spur wall (Chart 16) was ineffective and did very little to improve flow conditions in the drop chamber.

   Type B-2 geometry with the curtain wall (Charts 16 and 17) did reduce the flow velocity along the inside wall and the disturbance of the water surface near the end of the chamber, but some vorticity occurred upstream of the wall. The undesirable flow conditions in the distribution chamber and sluices still existed.

3. The Types C and C-1 control structures (Charts 23 and 24) had very poor flow patterns in the drop chamber and a large quantity of air was carried into the outlet pipe. These designs were hydraulically unacceptable.

4. The Type D control structure (Charts 25 and 26) showed considerable improvement in hydraulic characteristics over previous types tested. However, the upstream corners of the distribution chamber were not fully utilized. An occasional vortex appeared in the sluice structure,

and the flow in the drop chamber was somewhat turbulent with a rough water surface.

The diverging walls in the distribution chamber of the Type D-1 control structure (Charts 25 and 26) noticeably reduced the surface flow back towards the inlet and improved the overall flow pattern in the distribution chamber. The diverging walls also greatly reduced the vorticity in the sluice structure. The vortex suppressors of the Type D-2 control structure (Charts 25 and 26), reduced this remaining vorticity to almost nothing.

The Type D-3 control structure (Charts 25 and 26), the optimum design from the D series, and also the entire model studies were judged to be hydraulically acceptable and is recommended for the final design of the control structure. The flow patterns in the distribution chamber were quite good; vorticity was eliminated in the sluice structure, flow patterns in the drop chamber were good, and practically no air entered the outlet pipe.

The curtain wall of the Type D-3 control structure (Charts 25 and 26) effectively aided in removal of air and reduced the disturbance on the water surface between the wall and the end of the chamber.

5. Pressure fluctuation measurements made on the floor of the drop chamber showed that no negative pressure occurred when the model was operated in the steady state condition and when tailwater elevations were maintained. However, if the drop chamber was empty and the flow started, cavitating pressures did occur until adequate tailwater elevations were reached. If this event happens frequently in the prototype, cavitation may be a problem and should be considered in the structural design.

III. TYPE A CONTROL STRUCTURE

A. Description of Model

The first geometry investigated was designated as a Type A control structure and is shown in Photos 1 and 4. The layout is shown and dimensions specified on Charts 1 and 2. The water supply was obtained from the Mississippi River through the Laboratory's gravity flow supply system. The 12 inch inlet pipes and fittings were assembled and connected to the supply line as shown in Photo 1.

A control valve and calibrated elbow meter were installed in the 12 inch line to measure the higher flows. For lower flows, a 6-inch bypass line containing a control valve and 3-inch diameter calibrated orifice meter was installed.

A wire mesh baffle was inserted at the downstream end of the inlet pipe to provide proper flow conditions into the distribution chamber. The distribution chamber and supporting platform were of wooden construction and supported at the proper elevation on cement block pedestals. The relationship of the various components in the distribution chamber, that is the inlet, blocks, 1:1 side slopes, sluice entrances, and ogee crested weir are shown in Photos 2 and 3. To fabricate the sluice entrances an accurate model was machined and the entrances cast from a pliable plastic putty which when hardened, made a smooth opaque entrance (Photos 2 and 3). The 5 ft by 2.5 ft rectangular sections of the sluices were fabricated from clear lucite, so that the flow conditions inside could be observed and photographed (Photo 4). Gates were provided at the downstream end of the sluices, which in use would be either wide open or completely closed.

The drop chamber shown in Photo 4 was constructed using clear lucite panels reinforced by wooden framing and supported on cement blocks. Baffle blocks were placed at the downstream end of the drop chamber. A mold of the transition to the 12 ft diameter exit pipe was made and the transition cast from fiberglass and resin. For the exit pipe, a 9 inch diameter clear acrylic tube was used to facilitate the observation and photographing of any air bubbles present. At the downstream end of the exit pipe, a valve was installed to control the tailwater in the drop chamber. The flow from the valve was diverted to a wooden box which contained a calibrated V-notch weir at the downstream end. This weir was used to determine the total discharge passing through the sluices (Photo 1).

A removable arrangement of sliding rails was provided over the distribution chamber for supporting an electric point gage used to measure the water surface throughout the chamber and over the ogee weir. Staff gages were placed on the lucite panels of the drop chamber for convenience in recording the water surface inside (Photo 4).

The maximum flow that the type A control structure was required to pass was 8700 cfs. Inlet discharges (Q_I) from 500 to 8700 cfs were observed in the model. The following table lists the flow conditions investigated, where Q_I is the inflow discharge, Q_w the flow over the ogee weir, and Q_D the diverted flow into the drop chamber. The tailwater elevation is that for the drop chamber.

FLOW CONDITIONS INVESTIGATED

Gates Open	Q_I	Q_W	Q_D	T.W.
	cfs	cfs	cfs	ft
All	500	0	500	235
All	1000	0	1000	235
5, 6	1000	0	1000	235
5, 6	2500	1440	1060	250
None	2500	2500	0	--
5, 6	5000	3900	1100	250
None	5000	5000	0	--
5, 6	8700	7580	1120	250
None	8700	8700	0	--

For inflow discharges (Q_I) of 500 and 1000 cfs all flow was diverted through the sluices. With gates 5 and 6 open and inflow of 1000 cfs, the water level in the distribution chamber raised but did not overflow the weir. With gages 5 and 6 open and for the higher inflows of 2500, 5000, and 8700 cfs, the flows diverted (Q_D) to the drop chamber were 1060, 1100, and 1120 cfs, respectively. These flows over the ogee crested weir (Q_w) for these higher flows were not measured but computed by subtracting Q_D from Q_I. The tailwater in the drop chamber was set to either 235 or 250 ft as indicated in the table by using the tailwater control valve.

B. Model Observations

The model was operated with the flow conditions as listed above and observations were made. Flow conditions were observed in the distribution chamber, sluices, drop chamber, and outlet pipe. The major concern in the observations was to detect any undesirable hydraulic phenomenon such as vorticity, presence of air in the sluices and outlet pipe, and unusual turbulence in the flow patterns in the distribution chamber and drop chamber. The flow condition in the sluices was determined by the overall pattern of flow and depth of water in the distribution chamber. For a small water depth, open channel flow occurred in the sluices, with the water not touching the crown. As the stage increased, the flow alternated between open channel and full flow, which resulted in considerable noise. At higher stages, the sluices flowed full constantly.

Photos 5 through 9 show the Type A control structure in operation with all gates open and Q_I = 1000 cfs, Q_W = 0 cfs, Q_D = 1000 cfs, and a tailwater of 235 ft. Photos 5 and 6 show the overall flow pattern in the distribution chamber. Sluices 1 and 2, which are closer to the inlet, have noticeably less flow than the other sluices. This may also be seen in Photos 7 and 8. Photo 7 shows the air entrainment and release processes in the drop chamber. Most of the air rose to the surface in the 100 ft length of chamber as shown in Photo 7, but some was carried into the outlet pipe as indicated in Photo 9. When the inflow was increased beyond 1000 cfs, gates 1 through 4 were closed, leaving only 5 and 6 open. The water level rose eventually filling the chamber, and the surplus water flowed over the ogee weir as shown in Photo 10. In this photo for Q_I = 2500 cfs a noticeable return current develops on the left side over the 1:1 side slopes. At the higher flows this circular flow becomes much stronger. Photo 11 shows the drop chamber for Q_I = 2500 cfs and the tailwater maintained at 250 ft. Although the entrained air rose to the surface in a short distance, air on the surface was drawn down into the outlet pipe as indicated in Photo 12. Photo 12, which has a diverted flow (Q_D) of 1060 cfs and T.W. of 250 ft, may be compared to Photo 9, which has a Q_D of 1000 cfs and T.W. of 235 ft. Although the Q_D is only slightly higher, the air in the outlet pipe is considerably more in Photo 12 than in Photo 9.

C. Water Surface Profiles

Water surface profiles measured in the distribution and drop chambers are presented on Charts 3 through 6. Chart 3 shows the profiles along the centerline in the distribution chamber for all the flow conditions listed in the previous table. To demonstrate the uneven condition in the water surface, Charts 4 and 5 have been plotted with an expanded vertical scale, and profiles along the centerline and on the left and right sides are shown. Chart 4 shows a lower inflow (Q_I) of 1000 cfs and the resulting lower water surface along the right side in the vicinity of sluices 1 and 2. Chart 5 shows the maximum Q_I = 8700 cfs and the resulting uneven water surface in the basin. Chart 6 presents the water surface profiles in the drop chamber for all flow conditions in the table except those specifying that all gates are closed. The readings plot in a uniform manner with a slight slope in the downstream direction as would be expected.

IV. TYPE A-1 CONTROL STRUCTURE

A. Description of Model

The Type A-1 control structure is identical to Type A except that the blocks in both the distribution and drop chambers have been removed (Charts 1 and 2).

B. Model Observations

For low flows and all sluices open, the inflow jet shoots past the number 1 sluice resulting in very little flow in that sluice and sluices 2 and 3 have a reduced flow as shown in Photo 13. For higher flows with only sluice gates 5 and 6 open and the distribution chamber filled to overflowing, the circular motion of the flow is much stronger than for Type A as indicated in Photo 14.

Water surface profiles were recorded in both chambers of the Type A-1 control structure, and the results are presented on Charts 7 through 10. These charts may be compared with charts 3 through 6 for Type A. The flow pattern in the distribution chamber is much rougher and more turbulent for Type A-1 as compared to Type A and is strikingly evident when comparing Chart 8 with 4 and Chart 9 with 5.

Visual observations of flow conditions in the drop chamber and comparison of water surface profiles on Chart 10 (Type A-1) and Chart 6 (Type A) indicate little significant differences between the two types.

V. TYPE A-2 CONTROL STRUCTURE

A. Description of Model

The observations made on Type A-1 resulted in the development of the Type A-2 control structure which has blocks in the distribution chamber and none in the drop chamber (Charts 1 and 2).

B. Model Observations

Observations were made for all the flow conditions listed previously. Since the geometry of the distribution chamber was identical to that for Type A, the flow conditions were quite similar and the information is not repeated here. The flow conditions in the drop chamber for Type A-2 were very similar to the conditions for Type A. Typical patterns in the drop chamber and outlet pipe are shown in Photos 15 through 18. Photos 15 and 16 (Type A-2) may be compared to Photos 7 and 9 (Type A) which have a Q_I = 1000 cfs with all gates open. Photos 17 and 18 (Type A-2) may be compared to Photos 11 and 12 (Type A) which have a Q_I = 2500 cfs with gates 5 and 6 open. The patterns appear strikingly similar. Water surface profiles for Type A-2 are presented on Chart 11 and may be compared to profiles for Type A on Chart 6.

C. Fluctuating Pressures

The Type A-2 control structure was judged to be the optimum design of the A series, and it was decided to investigate the occurrence of pressure fluctuations on the floor of the drop chamber. A pressure tap was located on the drop chamber floor along the centerline of sluice 5 at the wall opposite from the sluice. The pressure transducer assembly containing a 25 psi transducer was connected to the tap with a rigid connector and recordings were made of the pressure fluctuations. The fluctuations were sensed on the diaphragm of the chamber mounted transducer, and the output was transmitted to a Sanborn amplifier. The signal from the Sanborn amplifier was fed into a Tektronic Type 564 storage oscilloscope. The frequency response of the 25 psi pressure transducer used was 5-10 kHZ in the air and flush mounted; the Sanborn Amplifier was 600 HZ, and the storage oscilloscope was 300 kHZ. When the transducer was used in water and chamber mounted as in the model, the frequency response would be lower, but by keeping the chamber and pressure line small, the transducer frequency response should be higher than the response of the amplifier. The scope was adjusted so that the trace would sweep across the screen in one second, flyback, and start another sweep. Each succeeding trace was superimposed and stored over the previous traces. A one minute record was made in this manner, after which a photograph was taken of the stored record on the face of the scope. In some tests with zero tailwater, the time of record was limited to 10 seconds. Typical pressure fluctuations recorded by this method are presented on Charts 12 through 15. Charts 12 through 14 show the pressure fluctuations for the six flow conditions investigated. Maximum fluctuations up to El. 300 and minimum fluctuations down to El. 224.5 occur with an inflow of 1000 cfs, gates 5 and 6 open, and the tailwater maintained at El. 235. (The pressure tap was located at El. 216.0.) With all gates open and inflows of 500 and 1000 cfs, the fluctuations are significantly lower, but this could occur if the jet was not impinging directly on the tap. For higher inflows of 2500, 5000, and 8700 cfs, the fluctuations are lower, but the tailwater was maintained at a higher elevation, 250 ft, and could be absorbing some of the impact forces. It is significant to note that for these normal tailwater conditions no negative pressures were recorded.

The possibility exists that the drop chamber could be empty when the diverted flow impinges on the floor. This condition was investigated by having the model empty, the tailwater valve wide open, and then opening the inflow valve to establish the selected flow as fast as possible. A typical recording made using this procedure is shown on the top of Chart 15. The inflow for this run was 2500 cfs with gates 5 and 6 open. For this situation minimum pressure fluctuations down to El. 190 were detected or a negative pressure head of -26 ft. Two negative spikes down to this value may be seen at the center of the chart. Several spikes reached a minimum elevation of about 200 ft or a negative pressure head of -16 ft. The maximum spike to El. 335 occurs on the right side of the chart. It is to be noted that the time of record for this run was 10 seconds. With the inflow set and the tailwater valve left wide open, the tailwater increased and stabilized at some elevation. With the inflow of 2500 cfs, this elevation was 228.5 ft. Pressure fluctuations for this flow condition are shown on the bottom of Chart 15. The fluctuations are lower with one minimum spike at El. 206 and one maximum spike at El. 326.

When operating the model in the steady state condition, that is setting the discharge to a selected flow and maintaining the tailwater elevation at 235 or 250 ft, cavitation does not appear to be a serious problem. The impact area would have to be designed to withstand the fluctuating pressures shown on the top of Chart 13, which vary from about El. 225 to El. 300. Even with the tailwater uncontrolled and stabilized at El. 228.5, the range of fluctuations is about the same, although single spikes reach up to El. 326 and down to El. 206. These are probably not significant. If the possibility exists in the prototype structure that the drop chamber would be frequently empty and the flow suddenly started, then the pressure fluctuations shown on the top record of Chart 15 should be considered in the design. In this situation the structure should be designed for cavitating pressures as indicated by the low spikes down to a negative pressure head of -16 and -26 ft.

VI. TYPE B CONTROL STRUCTURE

A. Description of Model

Tests on the Type A control structure showed that considerable turbulence occurred in the drop chamber and a significant quantity of air was carried into the outlet pipe. To reduce these undesirable hydraulic conditions, the drop chamber was enlarged from 100 ft by 20 ft (Type A series) to 140 ft by 30 ft and was designated as the Type B control structure. The distribution chamber remains the same as for Types A and A-2. The enlarged drop chamber has no blocks at the downstream end. The Type B control structure model geometry is specified on Charts 16 and 17.

B. Model Observations

As the distribution chamber was unchanged, the flow conditions there were similar to Types A and A-2. Therefore, discussion of observations on Type B will be concentrated on the drop chamber. Photos 19 through 22 show the flow patterns in the drop chamber and outlet pipe for two selected flows. Photos 19 and 20 show the flow patterns for Q_I = 1000 cfs, all gates open, and may be compared to Photos 15 and 16 (Type A-2). The larger size drop chamber is obviously more effective in air removal as there is practically no air in the outlet pipe for Type B (Photo 20), compared to Type A-2 (Photo 16). With inflows up to 5000 cfs and gates 5 and 6 open, the larger chamber is quite effective in removing most of the entrained air as shown in Photos 21 and 22. The water surface profiles recorded in the drop chamber are presented on Chart 18 for the six flow conditions investigated.

C. Fluctuating Pressures

Pressure fluctuations were recorded on the floor of the Type B control structure by the method previously described for Type A-2. The tap was located on the drop chamber floor 20 ft from the inside wall and along the centerline of sluice 5. The tap is actually in the same location as for Type A-2, but the outside wall has been moved 10 ft further out. Charts 19 through 21 show typical pressure fluctuations for the six flow conditions investigated and are similar in nature to those for Type A-2 shown on Charts 12 through 14. With gates 5 and 6 open and inflow of 1000 cfs, the maximum pressure fluctuation reached El. 299 and the minimum was at El. 215 as indicated on the top of Chart 20. For the higher inflow of 2500, 5000, and 8700 cfs the fluctuations were somewhat lower for Type B than for Type A-2. Recordings were also made for the zero tailwater condition. The model was empty, tailwater valve wide open, gates 5 and 6 open, and the flow adjusted rapidly from 0 to 2500 cfs. The 10 second record on the top of Chart 22 shows spikes up to El. 350 and spikes down to El. 174 or a negative pressure head of -42 ft. Several spikes reach about El. 180 or a negative pressure head of -36 ft. With the same inflow of 2500 cfs and the tailwater stabilized at El. 228 without downstream control, spikes up to El. 347 and down to El. 184 or a negative pressure head of -32 ft were recorded as indicated on the bottom of Chart 22. Although the peak values recorded with the tailwater stabilized approach those with zero tailwater, the frequency of occurrence is considerably less.

When operating the Type B model in the steady state condition, cavitation does not appear to be a problem. If the prototype drop structure will be frequently empty and the flow suddenly started, cavitation will be a problem and have to be designed for as spikes down to negative pressure heads of -36 and -42 ft are cavitating pressures. Pressure measured on the model were transposed to prototype values by multiplying the length ratio. In the prototype, negative pressure heads below -34 ft will not occur as cavitation takes place.

VII. TYPES B-1 AND B-2 CONTROL STRUCTURES

The flow in the drop chamber was quite turbulent and in the Type B control structure a relatively high flow velocity was observed along the inside wall. This higher velocity persisted down to the end of the drop chamber resulting in some occasional vorticity at that location. To counteract this, two appurtenances were installed in the model and observations made on their effectiveness. The first was a 2 ft thick spur wall 55 ft from the downstream end protruding out 4.5 ft from the inside wall into the flow and extending from the floor at elevation 216 ft to the top of the chamber. This was designated as Type B-1 control structure (Chart 16). Observations showed that this spur wall was ineffective and did very little to improve flow conditions in the drop chamber. The spur wall was removed and a 1 ft thick curtain wall was placed at the same location across the entire chamber. The bottom of the wall was at elevation 230 ft and extended to the top of the chamber. This geometry was designated as Type B-2 (Charts 16 and 17). The curtain wall had considerable effect on reducing the flow velocity along the inside wall and also reduced the disturbance of the water surface between the wall and the downstream end of the chamber, but some vorticity was observed immediately upstream of the wall.

VIII. TYPE C CONTROL STRUCTURE

Although the Type B control structure was reasonably effective in diverting the flow, it was decided that improvements still could be made, particularly with regard to the flow in the sluices. The Type C control structure evolved and the model revised to conform to this geometry. The layout and specifications are given on Charts 23 and 24. The major revisions necessary to the model were blocking off the six sluices between the distribution and drop chambers, cutting and construction of the upper drop chamber at the downstream end of the distribution chamber, cutting an opening through the 8 ft thick wall, and fabrication and installation of the sluice structure in the drop chamber. The upper drop chamber is 15 ft wide and the floor is at El. 260 ft and continuous from the upper drop chamber to the sluice structure. The number of sluices has been reduced to four, each 2.5 ft by 2.5 ft. The sluices go through a 5 ft thick vertical wall and discharge towards the outlet end of the drop chamber.

The inflow (Q_I) thus travels the full length of the distribution chamber, and for lower flows drops into the upper drop chamber as shown in Photo 23. For higher inflows the water fills the basin, and the diverted flow is drawn off from the bottom with the excess going over the ogee weir. The water in the upper drop chamber passes through an opening in the 8 ft thick wall, makes a 90 degree turn and enters the sluices. The water from the sluices jets into the lower drop chamber towards the outlet end as shown in Photo 24. The impingement of the jets on the water in the chamber entrained considerable air and the water-air mixture was carried to the end of the chamber (Photo 25). The air did not have time to escape and was drawn into the outlet pipe (Photo 26). As the quantity of air entering the outlet pipe was relatively large, the Type C control structure was not acceptable.

IX. TYPE C-1 CONTROL STRUCTURE

To increase the distance from the impingement area of the jets to the outlet pipe, the vertical wall containing the four sluices was tipped forward to a 30 degree angle from the vertical as shown on Chart 24. This geometry was designated as Type C-1 control structure. Typical flow patterns in the drop chamber and outlet pipe are shown in Photos 27 and 28. Various flow conditions were observed and the flow patterns showed definite improvement in hydraulic performance; but as shown in Photo 28, considerable air still entered the outlet pipe. This design was also judged to be not acceptable.

X. TYPE D CONTROL STRUCTURE

A. Description of Model

Following an in-depth review of the previously discussed model studies and the overall layout of the structure, it was decided that in order to develop a hydraulically acceptable structure more major revisions would be necessary. After consideration of the various factors, the Type D control structure as shown on Charts 25 and 26 evolved and the revisions were incorporated into the model. In the distribution chamber, the 1:1 side slopes were eliminated and the side walls were made vertical resulting in a rectangular chamber 100 ft long by 76 ft wide. The upper drop chamber was left unchanged. The two rows of blocks at the inlet were moved further away from the inlet to a distance of 20 ft to the first row of blocks. The lower drop chamber was extended 40 ft upstream, and the sluices which previously faced downstream in the lower drop chamber were turned to face upstream and installed at a 45 degree angle (Chart 26). The water jets from the sluices then impinged on the floor at the extreme upstream end of the drop chamber, and the flow passed underneath the sluice structure. In this arrangement the full length of the drop chamber was utilized for energy dissipation and deaeration.

B. Model Observations

As a result of an extensive mathematical model study using a transient-mixed-flow model, conducted at the St. Anthony Falls Hydraulic Laboratory, and further hydrologic information, the maximum flow that the structure was required to handle was reduced to 5000 cfs (previously 8700 cfs) and the tailwater elevation was to be maintained at El. 235 for all flows. These model studies were conducted for Lozier Engineers, Inc., of Rochester, New York, and sponsored by the Division of Pure Waters, Monroe County, New York. This reduction of maximum flow from 8700 to 5000 cfs does not affect the acceptability of previous designs tested because most of the unacceptable flow characteristics described in this report for earlier designs were for inflows of 5000 cfs and lower. Inlet discharges (Q_I) from 500 to 5000 cfs were observed in the model and the results documented by photography, water surface measurements, piezometric or average pressures, and fluctuating pressures. The following table lists the flow conditions investigated on the Type D model.

FLOW CONDITIONS INVESTIGATED

Gates Open	Q_I	Q_W	Q_D	T.W.
	cfs	cfs	cfs	ft
All	500	0	500	235
All	1000	0	1000	235
2,3,4	1000	0	1000	235
2,3,4	2500	1470	1030	235
2,3,4	5000	3950	1050	235

This program was expanded somewhat during the tests to include other conditions, as it was discovered that for Type D the critical flow for formation of vortices was between discharges of 500 and 1000 cfs. Vortices occurred in most of the previous types but not necessarily of the same form or at the same discharge as for Type D. Also, other combinations of open gates were investigated.

Typical flow patterns in the distribution chamber are shown in Photos 29 through 31. The flow pattern is considerably improved over the patterns for previous types with the 1:1 sloping sides installed. During the test program, it was noticed that a large vortex would occasionally form in the sluice structure for a discharge between 600 and 800 cfs, with the strongest vortex occurring for a discharge of about 650 cfs. Typically the vortex would attach to the wall opposite the sluices and extend through a particular sluice as shown in Photo 32. In most instances the vortex would go through either sluice 2 or 3. This vortex was unique in that it was horizontal and remained subsurface, with the air coming up through the sluice. The flow condition in the drop chamber was also considerably improved, although as one might expect, the flow was turbulent with a somewhat rough water surface.

XI. TYPE D-1 CONTROL STRUCTURE

A. Description of Model

In examining Photos 29 through 31 it can be seen that the upstream corners of the distribution chamber are not being utilized effectively. To improve this condition and also to reduce excavation costs, diverging walls from the inlet to the upper drop chamber were installed as shown on Charts 25 and 26 and in Photos 33 through 36 (Type D-1). These walls follow the approximate outline of the jet shown in Photo 29.

B. Model Observations

Photos 33 through 35 (Type D-1) may be compared to Photos 29 through 31 (Type D) as they show patterns for the same flow conditions. The diverging walls noticeably reduce the surface flow back towards the inlet and the overall flow pattern in the distribution chamber appears improved. It was therefore recommended that these walls be included in the final design.

It was also discovered that with the diverging walls in the distribution chamber, the vorticity was greatly reduced in the sluice structure. Only an occasional small vortex would occur in either sluice 2 or 3 as shown in Photo 36, which may be compared to Photo 32.

XII. TYPE D-2 CONTROL STRUCTURE

A. Description of Model

To reduce this remaining vorticity, several vortex suppressors were fabricated and tested in the sluice structure. Basically three alternate suppressors were made and observations made on each one individually and in combination with the other two. One scheme had three horizontal ribs each 1 ft by 1 ft and spaced 7.5 ft on the floor with the ribs extending from a point between the sluices to the opposite wall. The second scheme had seven vertical ribs each 1 ft by 1 ft spaced 3.75 ft on the wall opposite the sluice entrances. The third scheme had 5 horizontal ribs each 1 ft by 1 ft spaced 3.75 ft in a vertical plane from a point between sluices 2 and 3 to the opposite wall. The ribs were horizontal with the bottom rib on the floor to form a so-called center rack. Observations on each of these suppressors indicated that individually the roughness was not sufficient to effectively reduce the vorticity. Various combinations of these three individual suppressors were examined. Both the combinations of ribs on the back wall and the center rack and the combination of ribs on the back wall and ribs on the floor proved quite effective in reducing vorticity to almost nothing. In consultations with the designing engineers, it was decided that the center rack would probably collect trash and hamper cleaning operations more than with the ribs on the floor. The combination of ribs on the back wall and the floor was judged the optimum design for vortex suppression and is therefore included in the final recommended design. It was designed as Type D-2 control structure, the details of which are specified on Charts 25 and 26.

B. Model Observations

No photos of flow patterns in the sluice structure will be presented at this time as they are quite similar to those presented later for the final design Type D-3 control structure.

Typical photos of the flow patterns in the drop chamber for the Type D-2 control structure are shown in Photos 37 and 38. They show a somewhat turbulent and wavy water surface in the structure, with practically no air entering the outlet pipe. They are presented here to provide a comparison with the final design Type D-3.

XIII. TYPE D-3 CONTROL STRUCTURE

A. Description of Model

The optimum or most effective design resulting from the model studies was designated as Type D-3 control structure, the layout and specifications of which are presented on Charts 25 and 26. The design includes the diverging walls in the distribution chamber and vortex suppression ribs in the sluice structure, both of which have been described previously, and a vertical curtain wall across the drop chamber. This 1 ft thick curtain wall is 40 ft from the outlet end of the drop chamber, and the bottom of the wall is at El. 228 ft and extends to the top of the chamber (Charts 25 and 26). The curtain wall helps to remove air and reduces the disturbance on the water surface between the wall and the outlet end. Observations were made with the curtain wall at various distances from the outlet, that is, 80, 60, and 40 ft. The 80 ft distance brought the wall too close to the highly turbulent region and was not as efficient as the other two locations. Hydraulic conditions appeared quite good with the wall at either the 60 or 40 ft location. Based on these results, the consultants decided to place the wall 60 feet from the exit conduit entrance, and then shifted the conduit entrance 20 feet upstream. This is expected to provide adequate protection for the exit conduit for diversion flows up to 1000 cfs.

B. Model Observations

Photos 39 through 43 show the flow patterns in the distribution chamber for the five flow conditions investigated. This geometry results in the least amount of excavation, and is the optimum design hydraulically. Return currents were minimized, flow towards the weir was fairly uniform, and the water surface was relatively calm.

Photos 44 through 46 show the flow patterns in the sluice structure for the range of flows in which the formation of vorticity was prevalent. The added roughness was very effective in eliminating vorticity. A swirl formed on the water surface infrequently, but this was quickly broken up. It is to be noted in Photo 46 that the streaks appearing on the lucite panel are not vortices, but are associated with leakage due to a high head on a joint in the model.

The flow patterns in the sluices and impact area in the drop chamber are shown in Photos 47 through 52 for the five flow conditions listed in the table. Also, various combinations of gates open for an inflow of 1000 cfs were observed. No significant differences in flow patterns were detected for all possible combinations of gates open. A typical pattern is shown in Photo 50 in which gates 1, 2, and 4 are open. All of these photos show the expected turbulence of the water-air mixture in the impact areas.

Photos 53 through 57 show the flow patterns in the downstream end of the drop chamber for the five flow conditions. The wavy water surface upstream of the curtain wall is to be noted and compared to the relatively calm water surface downstream of the curtain wall, thus showing the effectiveness of the curtain wall. Also, very little vorticity was detected in the region of the wall and at the outlet end.

Photos 58 through 62 show the flow patterns in the outlet pipe for the five flow conditions. Very little air enters the outlet pipe. A trace of air appears in Photo 58, but the other photos indicate an absence of air in the outlet pipe.

C. Water Surface Profiles

Water surface profiles were measured in the distribution and drop chambers. Chart 27 shows the profiles along the centerline in the distribution chamber for the five flow conditions specified in the previous table. Charts 28 through 32 show the profiles for each flow condition separately and include the profiles along the centerline, along the left wall, and along the right wall. The vertical scale has been expanded in these charts so that any variations in the water surface would be more pronounced. Examination of the charts show that the results plot in a regular and consistent manner and show little or no variation across the chamber. The most variation in the water surface across the chamber occurs for an inflow (Q_I) of 500 cfs as seen on Chart 28. For this low flow condition, a pattern of standing waves develop as shown in Photo 39, which probably accounts for most of this variation. On Chart 28 the high water surface point at the front of the pier is the water surface build-up by the center pier. As expected, the water surface is somewhat uneven over the blocks as shown on Charts 28 and 29 for inflows of 500 and 1000 cfs, respectively, with all gates open. For inflows of 1000 and 2500 cfs with gates 2, 3, and 4 open the profiles are fairly uniform as indicated on Charts 30 and 31. Even with an inflow of 5000 cfs, the water surface is fairly uniform in the distribution chamber (Chart 32). The water surface profiles in the drop chamber are shown on Chart 33 for the five flow conditions and are essentially level at the tailwater level of 235 ft with some build-up in the impact area.

D. Piezometric and Fluctuating Pressures

To investigate the pressure on the floor of the drop chamber, 18 pressure taps were installed in the model at the locations shown on Chart 25. Taps 1 through 9 were located on the floor along the upstream wall, and taps 10 through 18 on the floor along the centerline of sluice 3. The 18 taps were connected by flexible plastic tubes to a manometer board where the piezometric or average pressure values were read. The pressure values for the five flow conditions are tabulated on Chart 34 and a plot of these values are presented on Chart 35. Outside of the impact area the pressures are essentially the same as the tailwater elevation of 235 ft. In the impact area the pressures rise slightly as the inflow increases with a maximum elevation of 243.6 ft occurring at taps 8 and 9 for inflows (Q_I) of

2500 and 5000 cfs. The corresponding diverted flows (Q_D) are 1030 and 1050 cfs, respectively.

A survey was also made of fluctuating pressures in the jet impact area. To accomplish this, the flexible plastic tube was disconnected from the selected tap and was replaced with the pressure transducer assembly containing a 25 psi transducer connected with a rigid connection. The equipment and procedure used in recording the pressure fluctuations was previously described in tests on Type A-2. Charts 36 through 51 show some typical pressure fluctuations recorded at selected taps 6, 8, 11, and 13. Recordings were made at other taps but were similar to these and therefore are not presented in this report. Charts 36 and 37 show the pressure fluctuations with $Q_I = Q_D = 500$ cfs and the normal tailwater of 235 ft. Fluctuations are minimal. Charts 38 and 39 show the fluctuations with $Q_I = Q_D = 1000$ cfs, all gates open, and a T.W. elevation of 235 ft. Fluctuations have increased slightly. With $Q_I = Q_D = 1000$ cfs and gates 2, 3, and 4 open, the water head on the sluices builds up resulting in higher jet velocities, and consequently, higher impact fluctuating pressures as shown on Charts 40 and 41. The maximum spike recorded reached El. 300 at tap 6 as seen on Chart 40. Increasing the Q_I to 2500 and 5000 cfs did not increase the pressure fluctuations appreciably because the head on the sluices rose only slightly and the diverted flows (Q_D) increased to only 1030 and 1050 cfs, respectively. Charts 42 through 45 show typical pressure fluctuations for these flows. In all these tests with the normal tailwater elevation of 235 ft, no negative pressures were detected, although one minimum spike approached El. 216 ft (zero datum) at tap 11 as seen on Chart 45.

To simulate starting up conditions, the model was completely drained and then the flow was turned on rapidly to a given discharge. For these tests pressure measurements were made at taps 12 and 13. Charts 46 and 47 show typical pressure fluctuations when the flow was increased from 0 to 500 cfs, and Charts 48 and 49 when the flow was increased from 0 to 1000 cfs. The model time was 10 seconds for the top record and 1 minute for the bottom record on each chart. The maximum pressure fluctuation recorded was a spike to El. 350 (Chart 47), and the minimum was a spike to El. 150 (Chart 49). This is a negative pressure head of -66 ft. As the maximum spike was near the limit of the scale, the range was changed to include elevations above 350 ft and below 150 ft. No fluctuations above El. 350 or below El. 150 were recorded. Charts 50 and 51 show typical pressure fluctuations for inflows of 500 and 1000 cfs with the tailwater control valve wide open and the flow stabilized. The uncontrolled elevation was 223.5 ft for $Q_I = 500$ cfs and 227 ft for $Q_I = 1000$ cfs. The maximum pressure fluctuation for these flow conditions was El. 197 (Chart 50, tap 13), and the minimum fluctuation was El. 195 (Chart 50, tap 12), which is a negative pressure head of -21 ft.

In the steady state tests on the Type D-3 control structure with the tailwater elevation maintained at 235 ft, no negative pressures were detected and therefore no cavitation should occur. Again as in Types A-2 and B, if the possibility exists that the drop chamber could be frequently empty when the flow starts, cavitating pressures will occur as shown in the model studies and should be considered in the design. Negative pressures are consistently below El. 216 (tap elevation or zero datum) and spikes frequently reach El. 182 or a negative pressure head of -34 ft, which is a cavitation pressure head.

LIST OF PHOTOS

PHOTO 1 — Type A Control Structure. All gates open, T.W. = 235 ft, Q_I = 1,000 cfs, Q_w = 0 cfs, Q_D = 1,000 cfs. An overall view of the model layout.

PHOTO 2 — Type A Control Structure. A view of the distribution chamber showing the inlet, blocks, and sluice entrances.

PHOTO 3 — Type A Control Structure. A view of the distribution chamber showing the sluice entrances, side slopes and overflow weir.

PHOTO 4 — Type A Control Structure. A view of the drop chamber and outlet pipe.

PHOTO 5 — Type A Control Structure. All gates open, Q_I = 1,000 cfs, Q_w = 0 cfs, Q_D = 1,000 cfs. The flow pattern in the distribution chamber.

PHOTO 6 — Type A Control Structure. All gates open, Q_I = 1,000 cfs, Q_w = 0 cfs, Q_D = 1,000 cfs. The flow pattern in the distribution chamber.

PHOTO 7 — Type A Control Structure. All gates open, T.W. = 235 ft, Q_I = 1,000 cfs, Q_w = 0 cfs, Q_D = 1,000 cfs. The flow pattern in the drop chamber.

PHOTO 8 — Type A Control Structure. All gates open, Q_I = 1,000 cfs, Q_w = 0 cfs, Q_D = 1,000 cfs. The flow pattern in the sluices.

PHOTO 9 — Type A Control Structure. All gates open, T.W. = 235 ft, Q_I = 1,000 cfs, Q_w = 0 cfs, Q_D = 1,000 cfs The flow pattern in the outlet pipe.

PHOTO 10 — Type A Control Structure. Gates open: 5 & 6, Q_I = 2,500 cfs, Q_w = 1,440 cfs, Q_D = 1,060 cfs. The flow pattern in the distribution chamber.

PHOTO 11 — Type A Control Structure. Gates open: 5 & 6, T.W. = 250 ft, Q_I = 2,500 cfs, Q_w = 1,440 cfs, Q_D = 1,060 cfs. The flow pattern in the drop chamber.

PHOTO 12 — Type A Control Structure. Gates open: 5 & 6, T.W. = 250 ft, Q_I = 2,500 cfs, Q_w = 1,440 cfs, Q_D = 1,060 cfs. The flow pattern in the outlet pipe.

PHOTO 13 — Type A-1 Control Structure. All gates open, Q_I = 1,000 cfs, Q_w = 0 cfs, Q_D = 1,000 cfs. The flow pattern in the distribution chamber.

LIST OF PHOTOS (Cont'd)

LIST OF PHOTOS (Cont'd)

PHOTO 53	Type D-3 Control Structure. All gates open, T.W. = 235 ft, Q_I = 500 cfs, Q_w = 0 cfs, Q_D = 500 cfs. The flow pattern in the drop chamber.
PHOTO 54	Type D-3 Control Structure. All gates open, T.W. = 235 ft, Q_I = 1,000 cfs, Q_w = 0 cfs, Q_D = 1,000 cfs. The flow pattern in the drop chamber.
PHOTO 55	Type D-3 Control Structure. Gates open: 2, 3, 4, T.W. = 235 ft, Q_I = 1,000 cfs, Q_w = 0 cfs, Q_D = 1,000 cfs. The flow pattern in the drop chamber.
PHOTO 56	Type D-3 Control Structure. Gates open: 2, 3, 4, T.W. = 235 ft, Q_I = 2,500 cfs, Q_w = 1,470 cfs, Q_D = 1,030 cfs. The flow pattern in the drop chamber.
PHOTO 57	Type D-3 Control Structure. Gates open: 2, 3, 4, T.W. = 235 ft, Q_I = 5,000 cfs, Q_w = 3,950 cfs, Q_D = 1,050 cfs. The flow pattern in the drop chamber.
PHOTO 58	Type D-3 Control Structure. All gates open, T.W. = 235 ft, Q_I = 500 cfs, Q_w = 0 cfs, Q_D = 500 cfs. The flow pattern in the outlet pipe.
PHOTO 59	Type D-3 Control Structure. All gates open, T.W. = 235 ft, Q_I = 1,000 cfs, Q_w = 0 cfs, Q_D = 1,000 cfs. The flow pattern in the outlet pipe.
PHOTO 60	Type D-3 Control Structure. Gates open: 2, 3, 4, T.W. = 235 ft, Q_I = 1,000 cfs, Q_w = 0 cfs, Q_D = 1,000 cfs. The flow pattern in the outlet pipe.
PHOTO 61	Type D-3 Control Structure. Gates open: 2, 3, 4, T.W. = 235 ft, Q_I = 2,500 cfs, Q_w = 1,470 cfs, Q_D = 1,030 cfs. The flow pattern in the outlet pipe.
PHOTO 62	Type D-3 Control Structure. Gates open: 2, 3, 4, T.W. = 235 ft, Q_I = 5,000 cfs, Q_w = 3,950 cfs, Q_D = 1,050 cfs. The flow pattern in the outlet pipe.

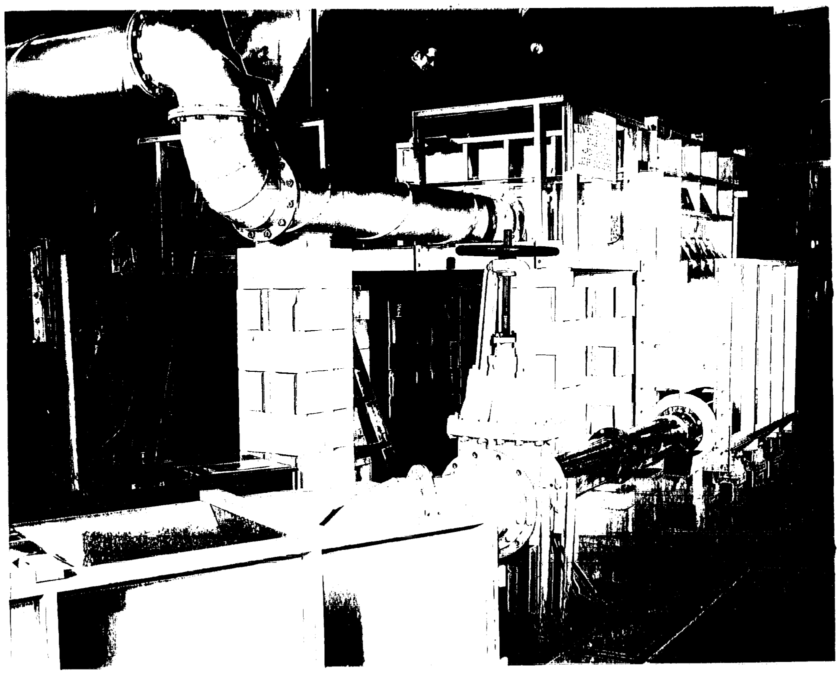


Photo 1 - Type A Control Structure. All gates open, T.W.= 235 ft, Q_I = 1,000 cfs, Q_W = 0 cfs, Q_D = 1,000 cfs. An overall view of the model layout.

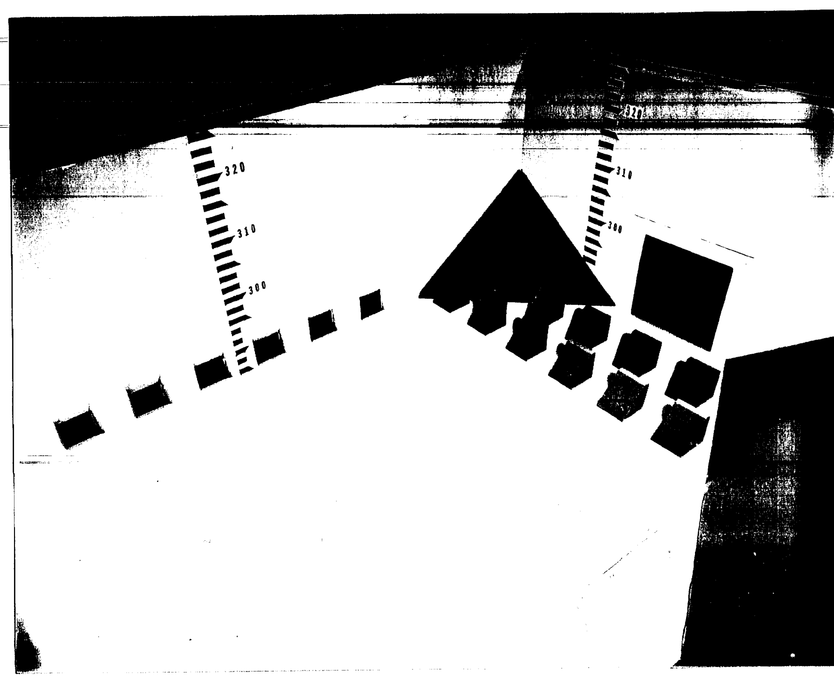


Photo 2 - Type A Control Structure. A view of the distribution chamber showing the inlet, blocks, and sluice entrances.

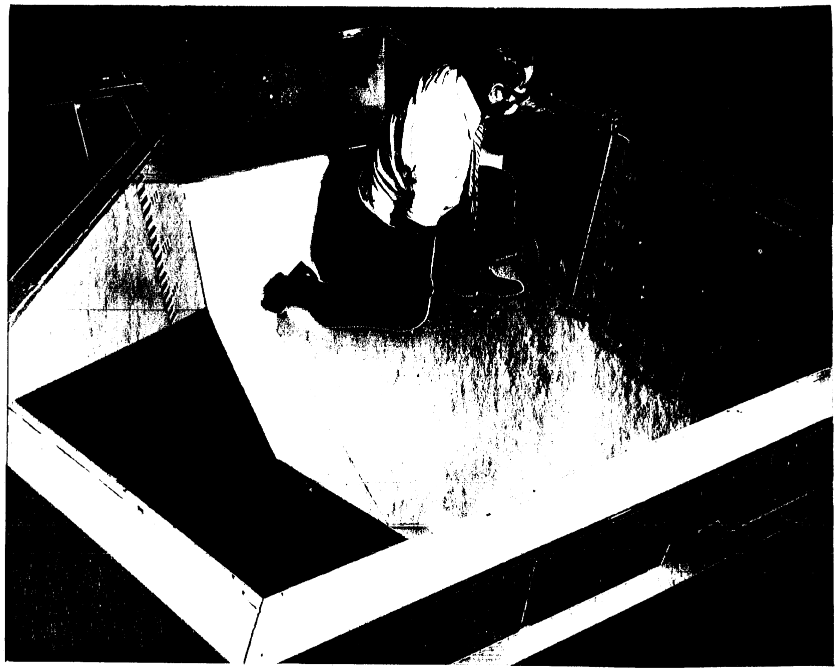


Photo 3 - Type A Control Structure. A view of the distribution chamber showing the sluice entrances, side slopes and overflow weir.

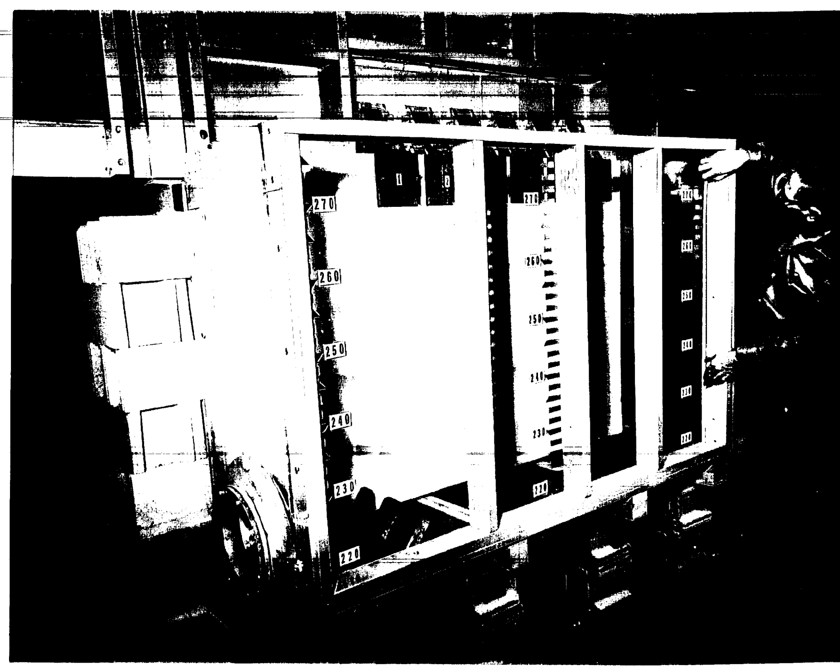


Photo 4 - Type A Control Structure. A view of the drop chamber and outlet pipe.

Photo 5 - Type A Control Structure. All gates open, Q_T = 1,000 cfs, Q_W = 0 cfs, Q_D = 1,000 cfs. The flow pattern in the distribution chamber.

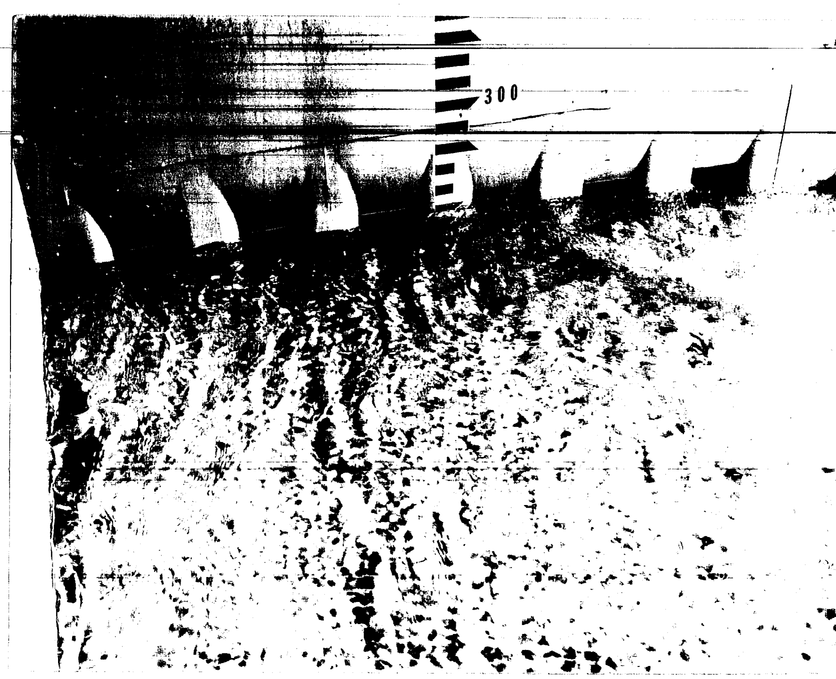


Photo 6 - Type A Control Structure. All gates open, Q_T = 1,000 cfs, Q_W = 0 cfs, Q_D = 1,000 cfs. The flow pattern in the distribution chamber.

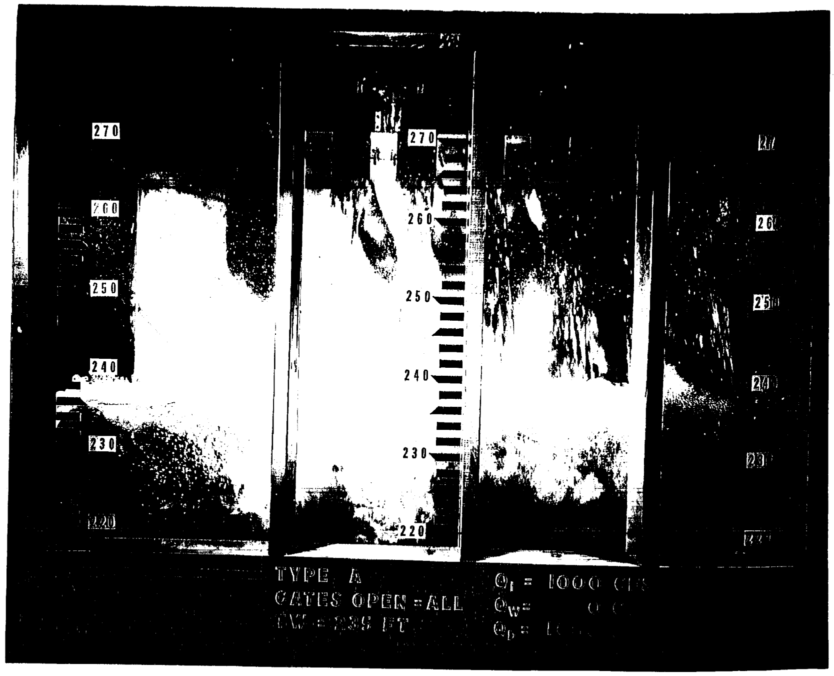


Photo 7 - Type A Control Structure. All gates open, T.W.=235 ft, Q_I = 1,000 cfs, Q_W = 0 cfs, Q_D = 1,000 cfs. The flow pattern in the drop chamber.

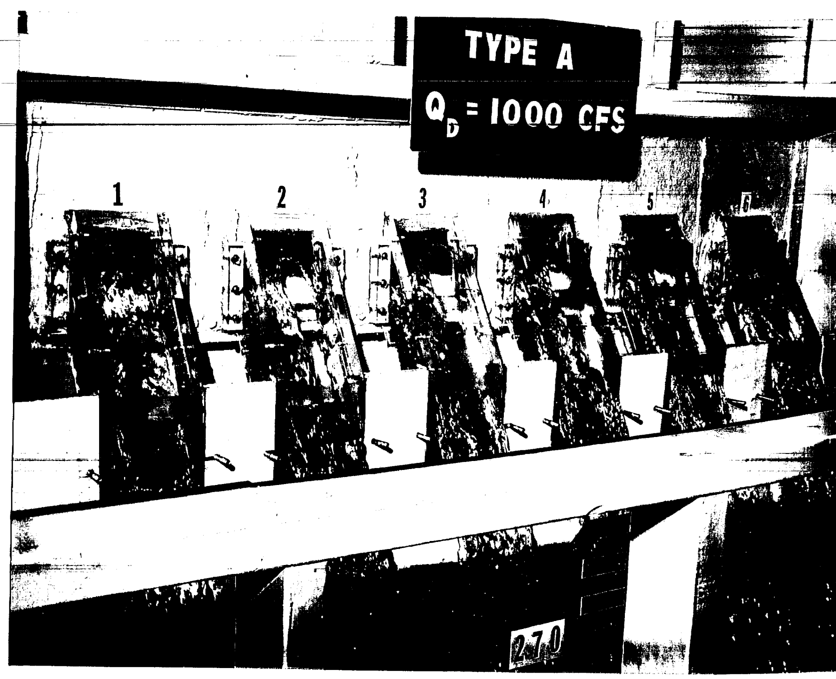


Photo 8 - Type A Control Structure. All gates open, Q_T = 1,000 cfs, Q_W = 0 cfs, Q_D = 1,000 cfs. The flow pattern in the sluices.

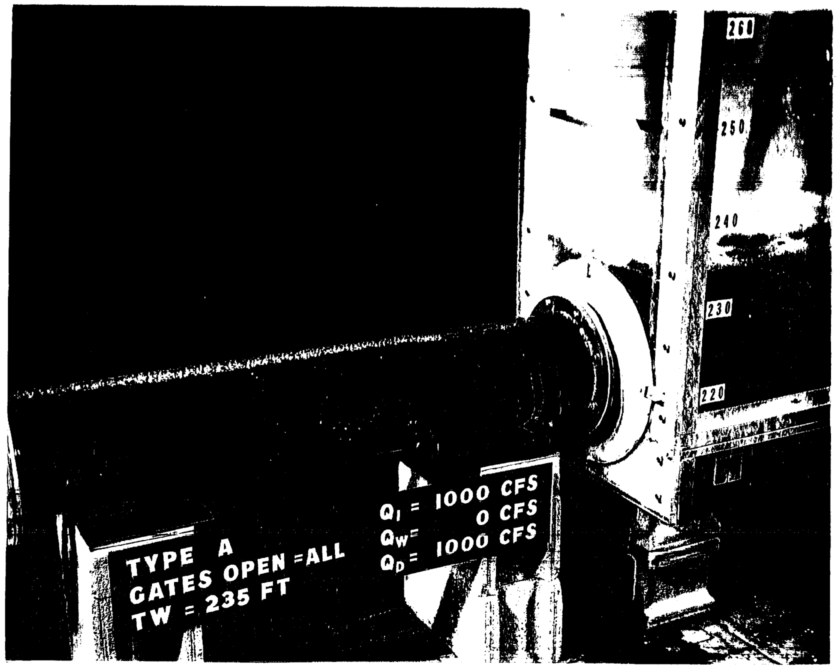


Photo 9 - Type A Control Structure. All gates open, T.W.= 235 ft, Q_I = 1,000 cfs, Q_W = 0 cfs, Q_D = 1,000 cfs. The flow pattern in the outlet pipe.

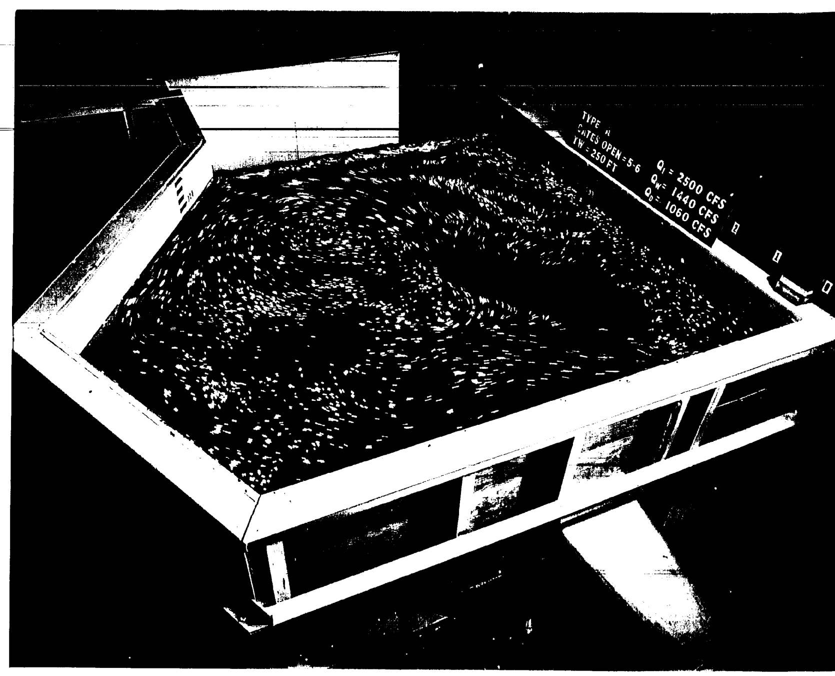


Photo 10 - Type A Control Structure. Gates open: 5 & 6,

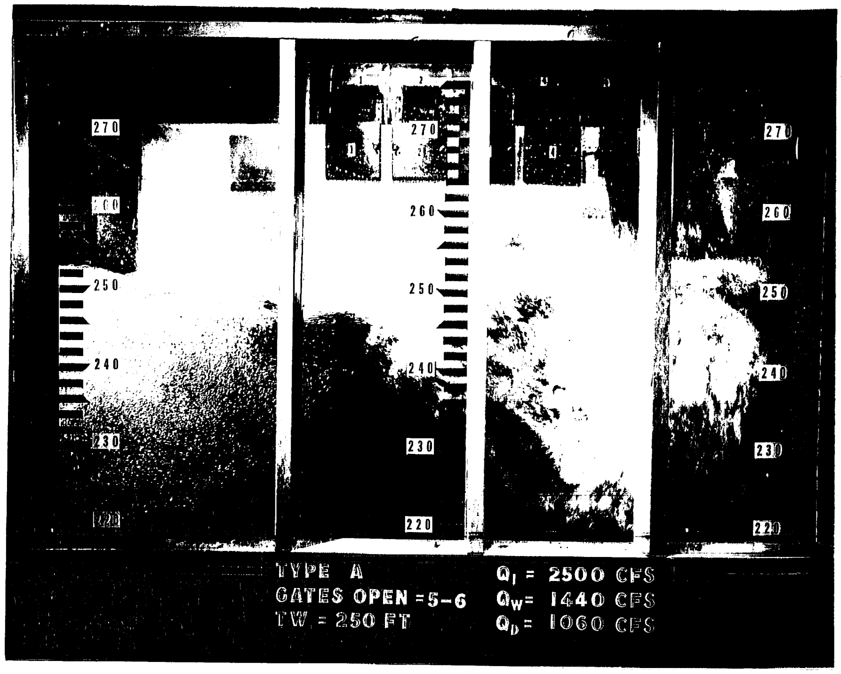


Photo 11 - Type A Control Structure. Gates open: 5 & 6, T.W.= 250 ft, Q_I = 2,500 cfs, Q_W = 1,440 cfs, Q_D = 1,060 cfs. The flow pattern in the drop chamber.

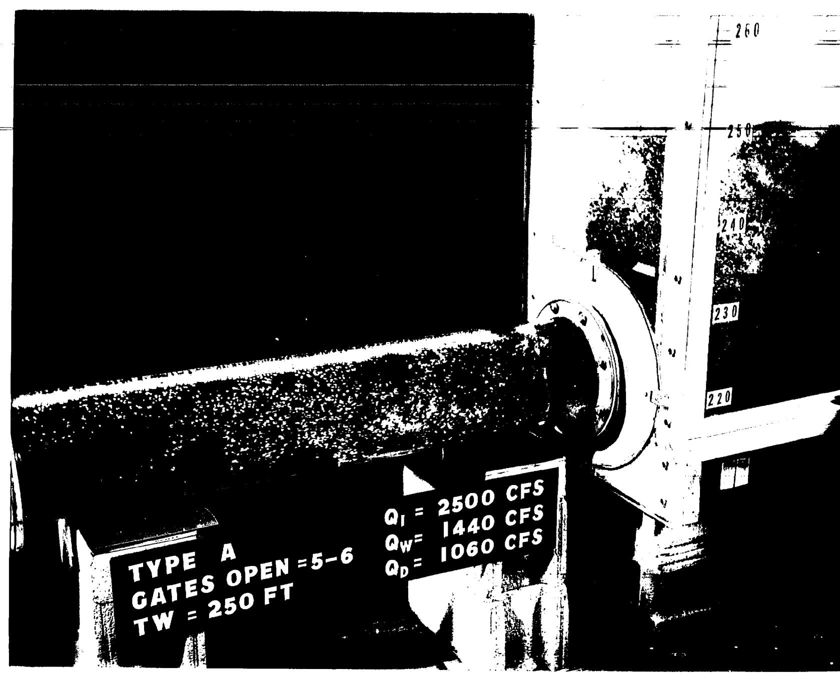


Photo 12 - Type A Control Structure. Gates open: 5 & 6, T.W.= 250 ft, Q_I = 2,500 cfs, Q_W = 1,440 cfs, Q_D = 1,060 cfs. The flow pattern in the outlet pipe.

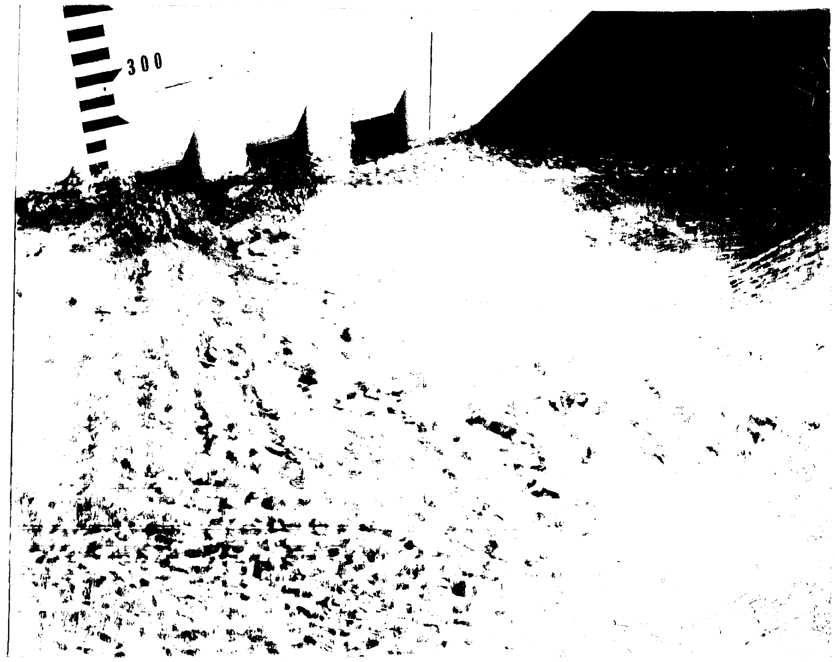


Photo 13 - Type A-1 Control Structure. All gates open, Q_T = 1,000 cfs, Q_W = 0 cfs, Q_D = 1,000 cfs. The flow pattern in the distribution chamber.

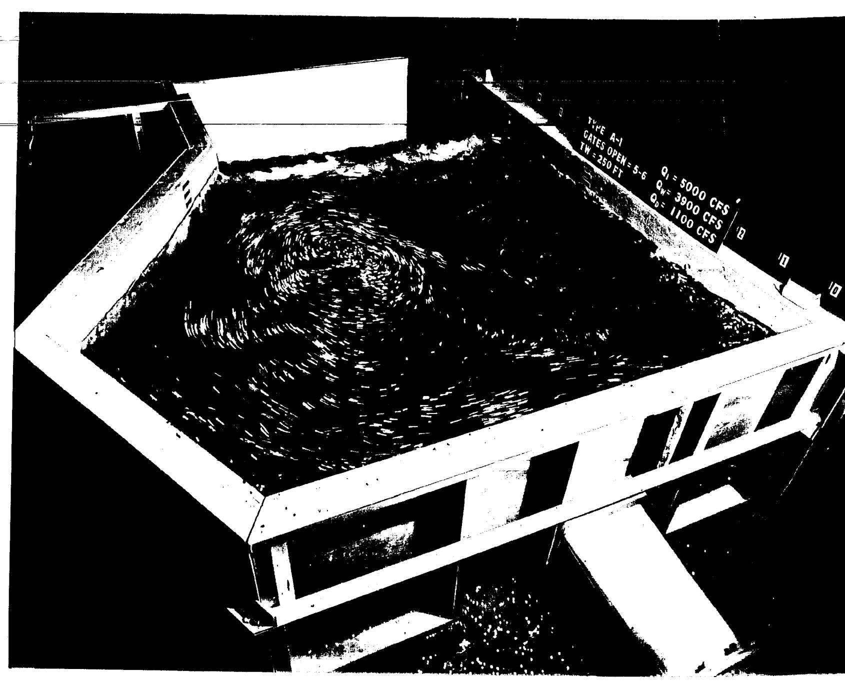


Photo 14 - Type A-1 Control Structure. Gates open: 5 & 6, Q_T = 5,000 cfs, Q_W = 3,900 cfs, Q_D = 1,100 cfs. The flow pattern in the distribution chamber.

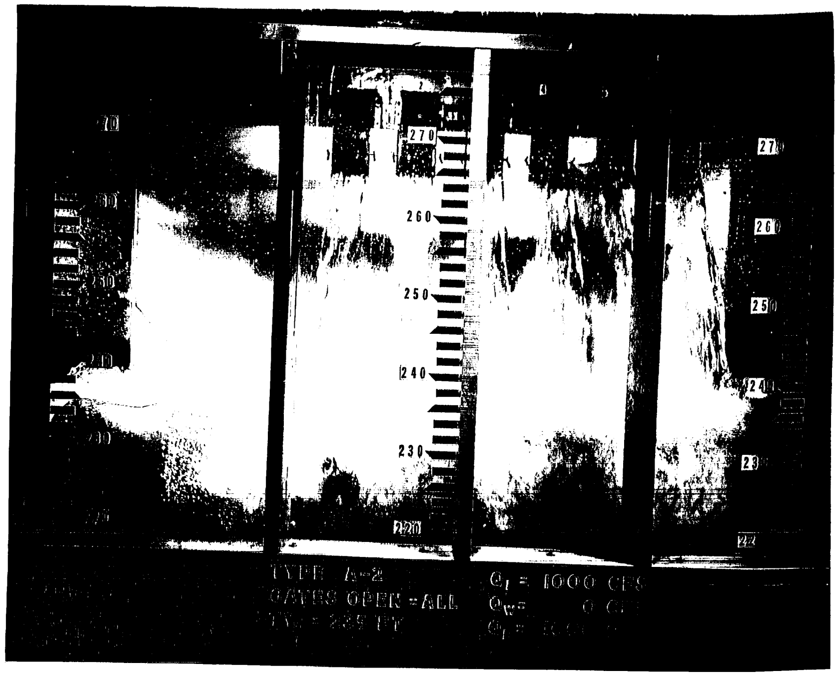


Photo 15 - Type A-2 Control Structure. All gates open, T.W.= 235 ft, Q_I= 1,000 cfs, Q_W= 0 cfs, Q_D= 1,000 cfs. The flow pattern in the drop chamber.

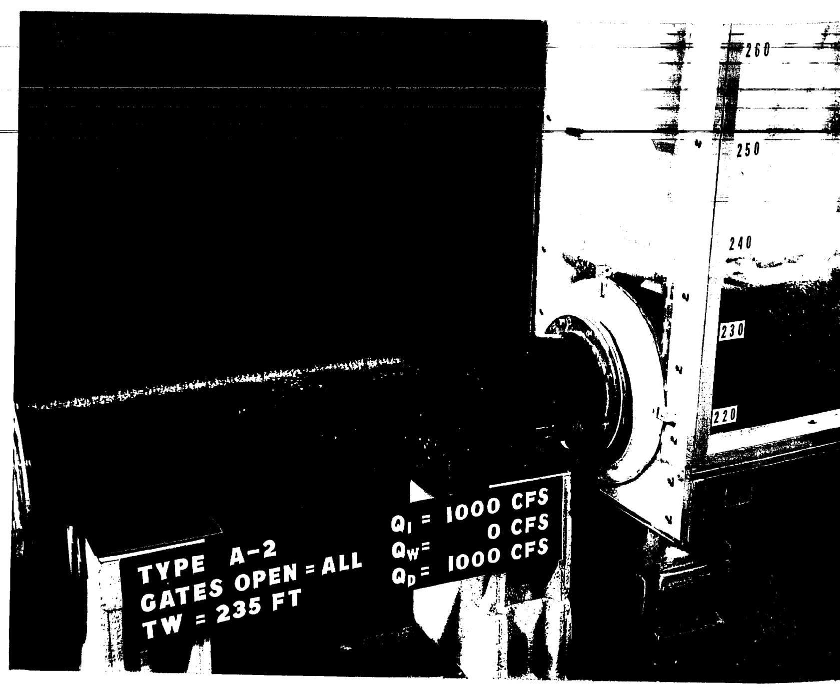


Photo 16 - Type A-2 Control Structure. All gates open, T.W.= 235 ft, Q_I= 1,000 cfs, Q_W= 0 cfs, Q_D= 1,000 cfs. The flow pattern in the outlet pipe.

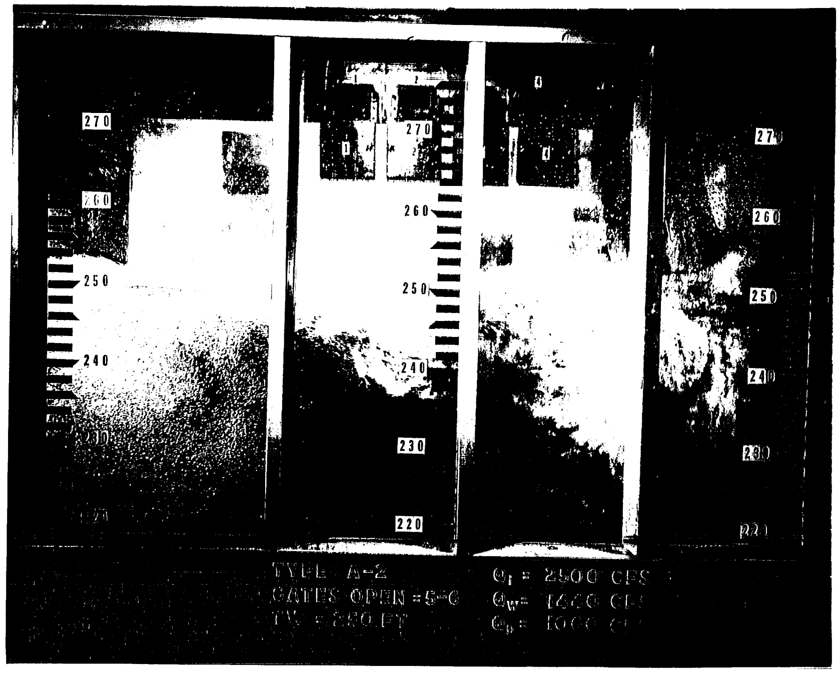


Photo 17 - Type A-2 Control Structure. Gates open: 5 & 6, T.W.= 250 ft, Q_I = 2,500 cfs, Q_W = 1,440 cfs, Q_D = 1,060 cfs. The flow pattern in the drop chamber.

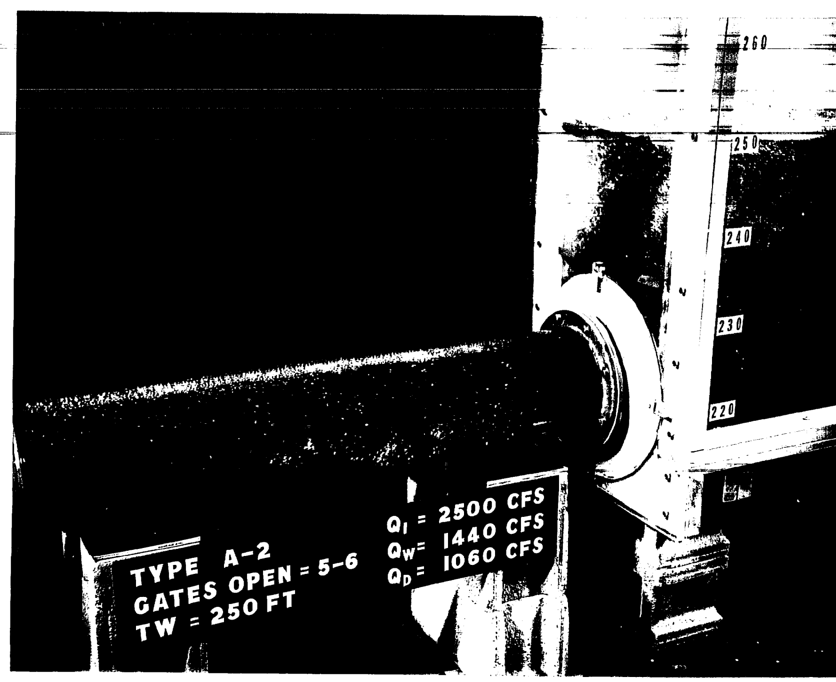


Photo 18 - Type A-2 Control Structure. Gates open: 5 & 6, T.W.= 250 ft, Q_I = 2,500 cfs, Q_W = 1,440 cfs, Q_D = 1,060 cfs. The flow pattern in the outlet pipe.

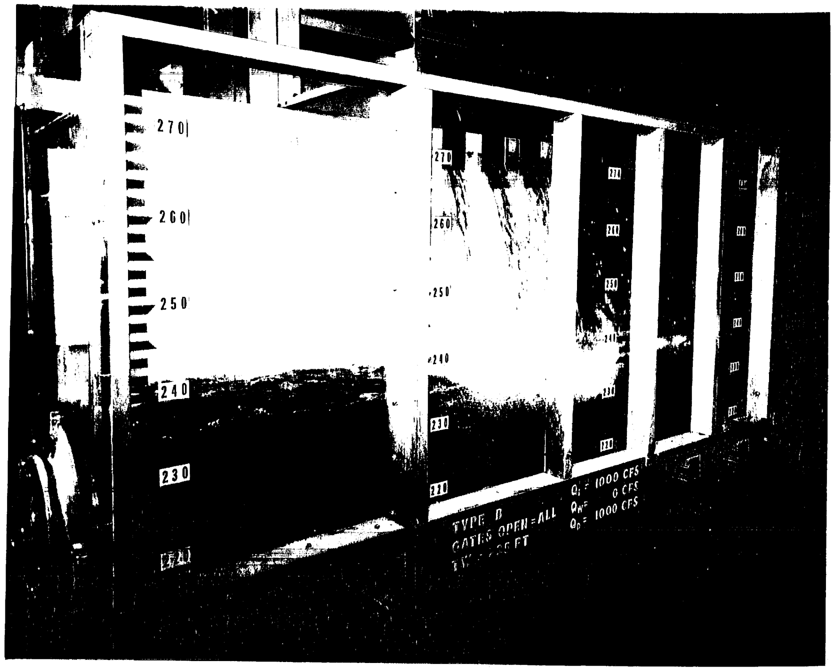


Photo 19 - Type B Control Structure. All gates open, T.W. = 235 ft, Q_I = 1,000 cfs, Q_W = 0 cfs, Q_D = 1,000 cfs. The flow pattern in the drop chamber.

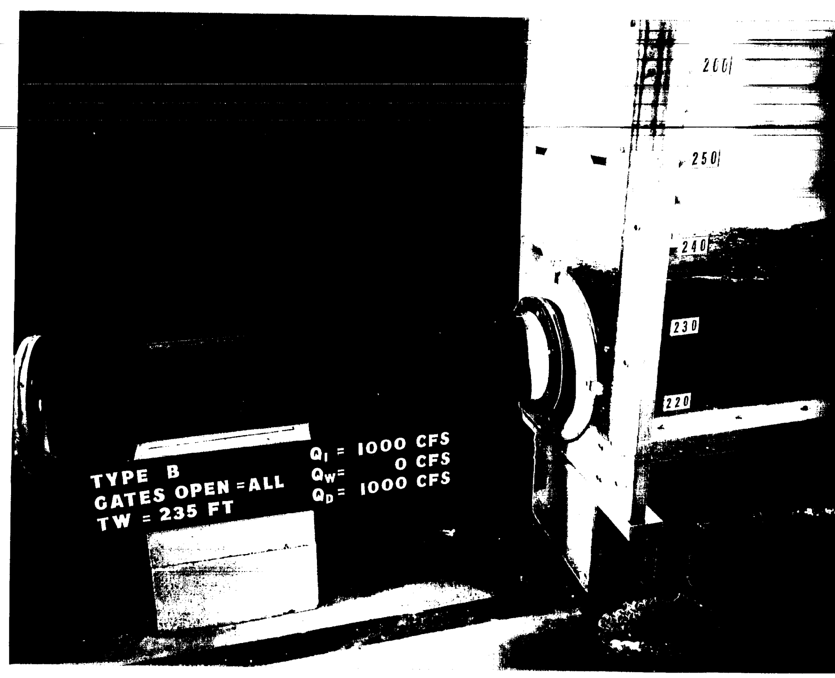


Photo 20 - Type B Control Structure. All gates open, T.W. = 235 ft, Q_I = 1,000 cfs, Q_W = 0 cfs, Q_D = 1,000 cfs. The flow pattern in the outlet pipe.

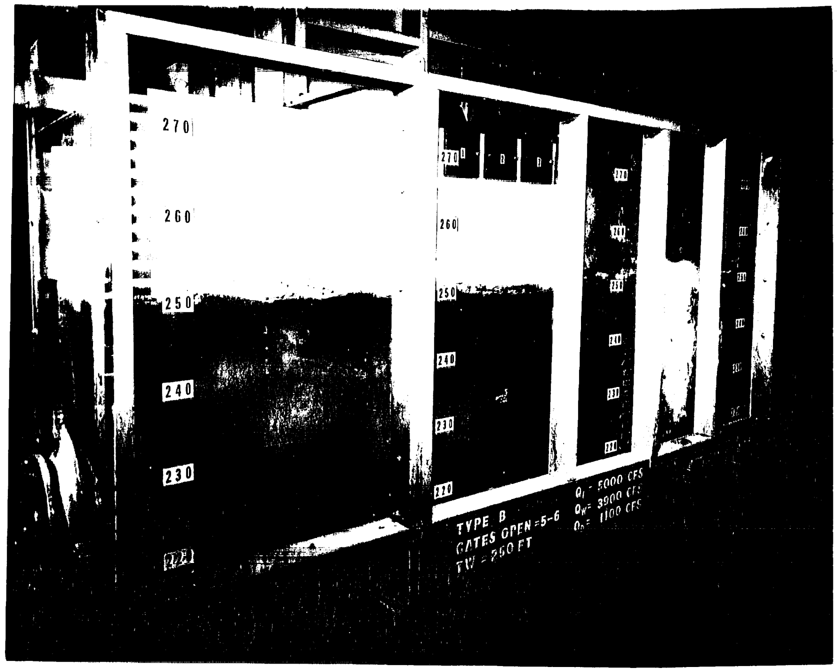


Photo 21 - Type B Control Structure. Gates open: 5 & 6, T.W.= 250 ft, Q_I = 5,000 cfs, Q_W = 3,900 cfs, Q_D = 1,100 cfs. The flow pattern in the drop chamber.

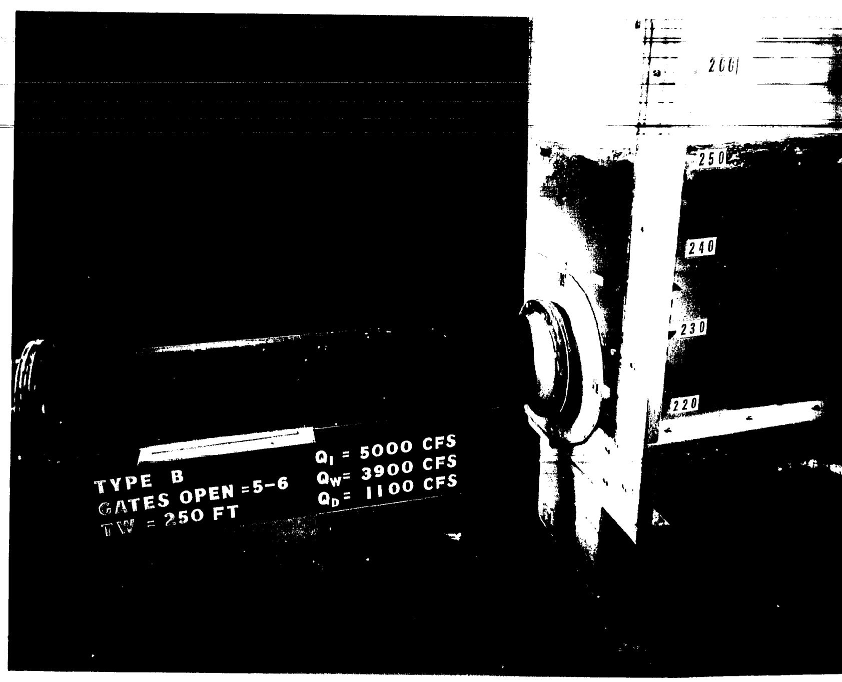


Photo 22 - Type B Control Structure. Gates open: 5 & 6, T.W.= 250 ft, Q_I = 5,000 cfs, Q_W = 3,900 cfs, Q_D = 1,100 cfs. The flow pattern in the outlet pipe.

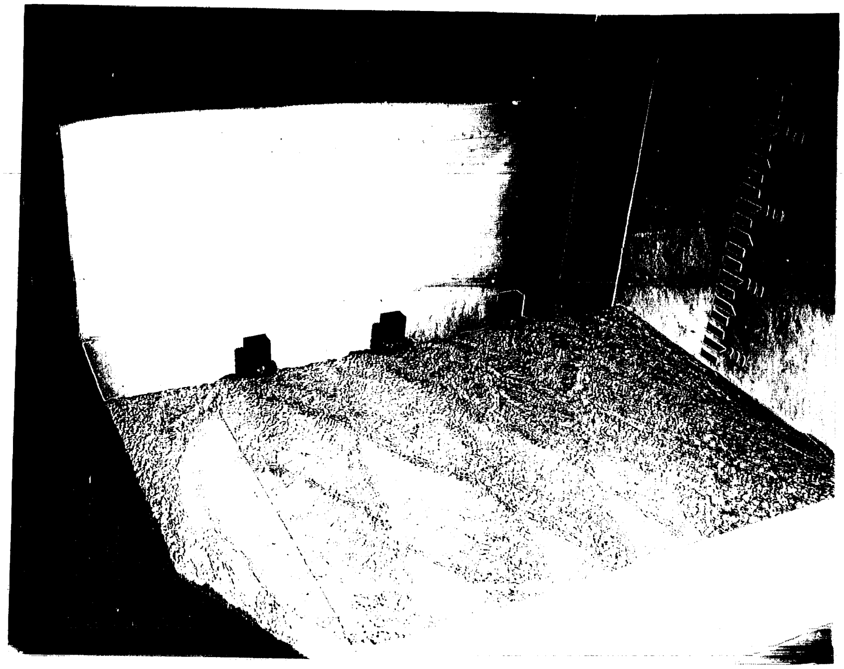


Photo 23 - Type C Control Structure. All gates open, Q_I = 500 cfs, Q_W = 0 cfs, Q_D = 500 cfs. The flow pattern in the distribution chamber.

Photo 24 - Type C Control Structure. All gates open, T.W.= 235 ft, Q_I= 1,000 cfs, Q_W= 0 cfs, Q_D= 1,000 cfs. The flow pattern in the drop chamber.

Photo 25 - Type C Control Structure. All gates open, T.W.= 235 ft, Q_I = 1,000 cfs, Q_W = 0 cfs, Q_D = 1,000 cfs. The flow pattern in the drop chamber.

Photo 26 - Type C Control Structure. All gates open, T.W.= 235 ft, Q_I = 1,000 cfs, Q_W = 0 cfs, Q_D = 1,000 cfs. The flow pattern in the outlet pipe.

Photo 27 - Type C-1 Control Structure. Gates open: 1,2,4, T.W.= 250 ft, Q_I = 2,500 cfs, Q_W = 1,500 cfs, Q_D = 1,000 cfs. The flow pattern in the drop chamber.

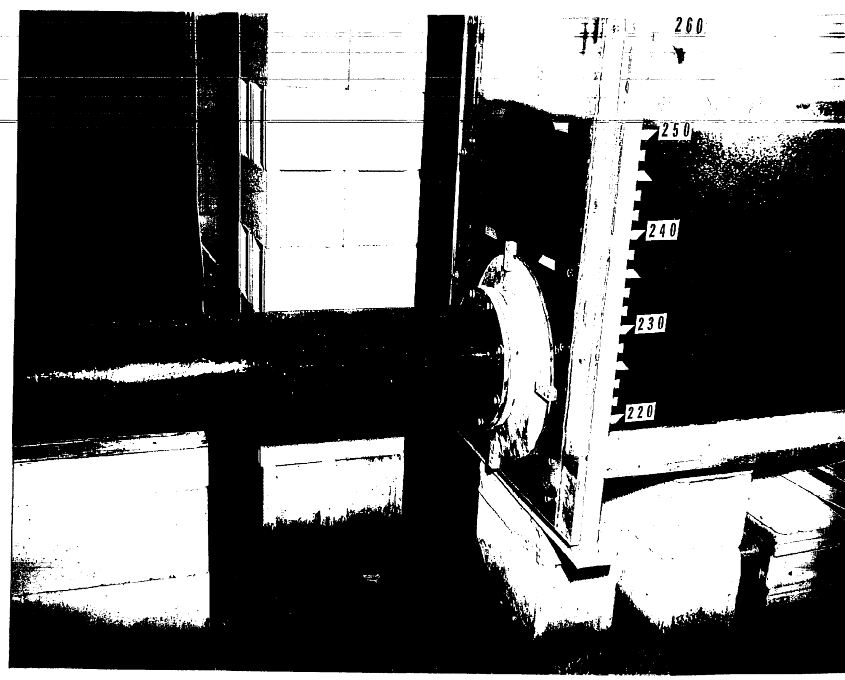


Photo 28 - Type C-1 Control Structure. Gates open: 1,2,4, T.W.= 250 ft, Q_I = 2,500 cfs, Q_W = 1,500 cfs, Q_D = 1,000 cfs. The flow pattern in the outlet pipe.

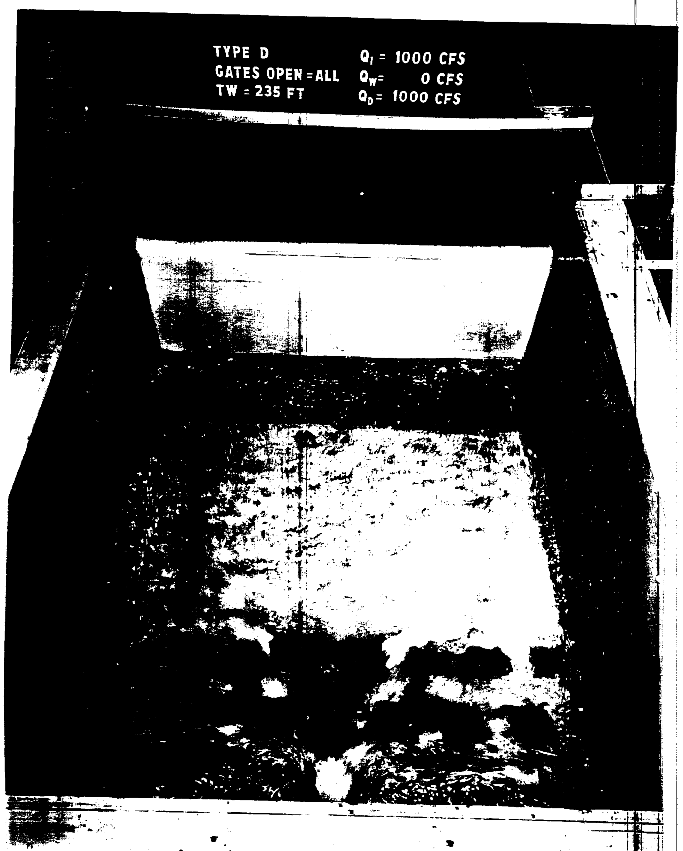


Photo 29 - Type D Control Structure. All gates open, Q_T = 1,000 cfs, Q_W = 0 cfs, Q_D = 1,000 cfs. The flow pattern in the distribution chamber.

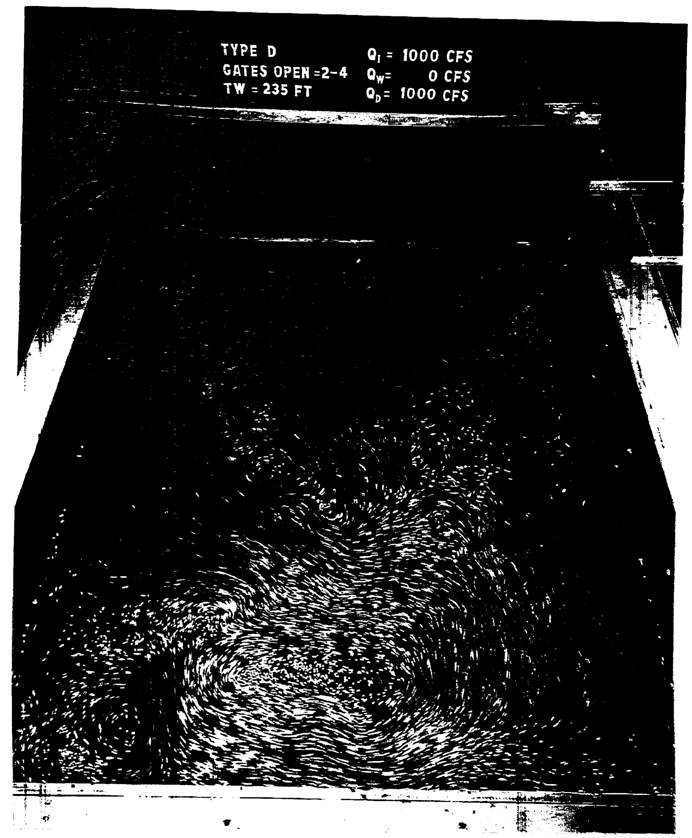


Photo 30 - Type D Control Structure. Gates open: 2,3,4, Q_T = 1,000 cfs, Q_W = 0 cfs, Q_D = 1,000 cfs. The flow pattern in the distribution chamber.

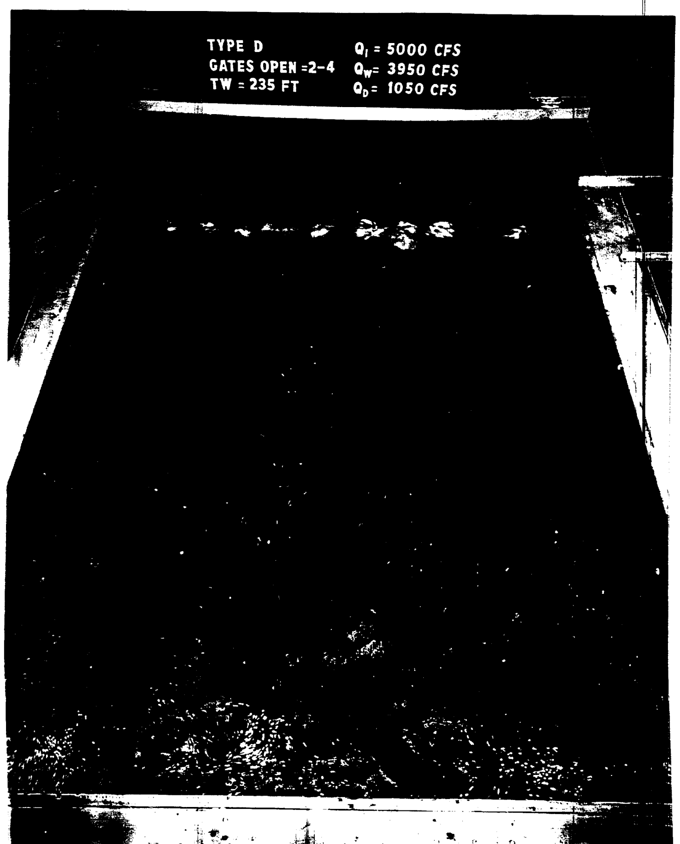


Photo 31 - Type D Control Structure. Gates open: 2,3,4, Q_T = 5,000 cfs, Q_W = 3,950 cfs, Q_D = 1,050 cfs. The flow pattern in the distribution chamber.

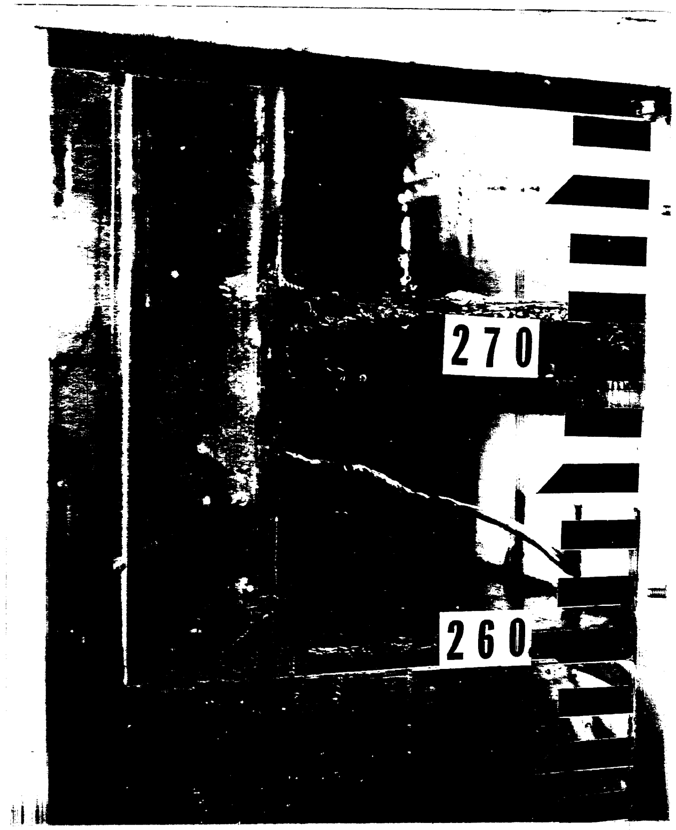


Photo 32 - Type D Control Structure. All gates open, Q_T = 650 cfs, Q_W = 0 cfs, Q_D = 650 cfs. The flow pattern in the upper drop chamber.

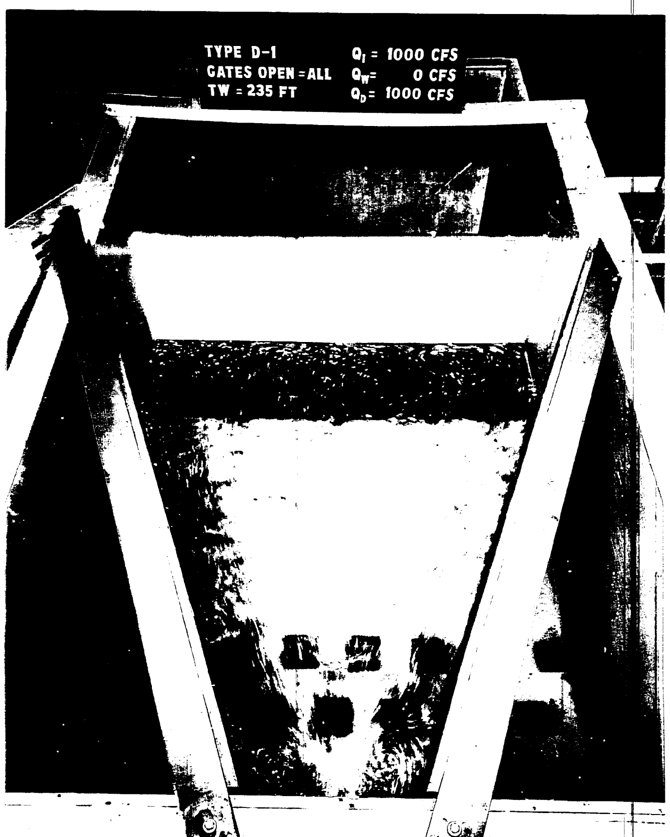


Photo 33 - Type D-1 Control Structure. All gates open, Q_I = 1,000 cfs, Q_W = 0 cfs, Q_D = 1,000 cfs. The flow pattern in the distribution chamber.

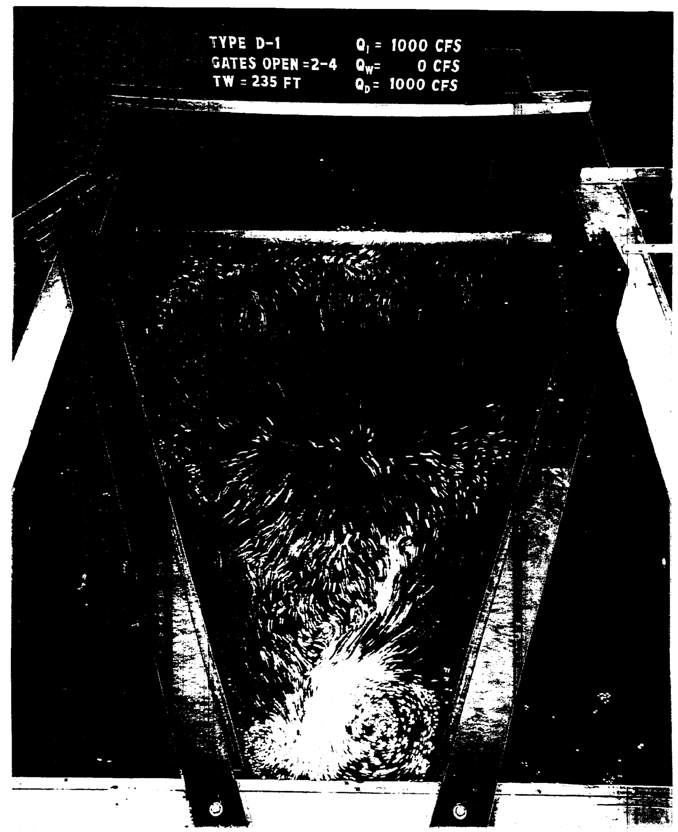


Photo 34 - Type D-1 Control Structure. Gates open: 2,3,4, Q_I = 1,000 cfs, Q_W = 0 cfs, Q_D = 1,000 cfs. The flow pattern in the distribution chamber.

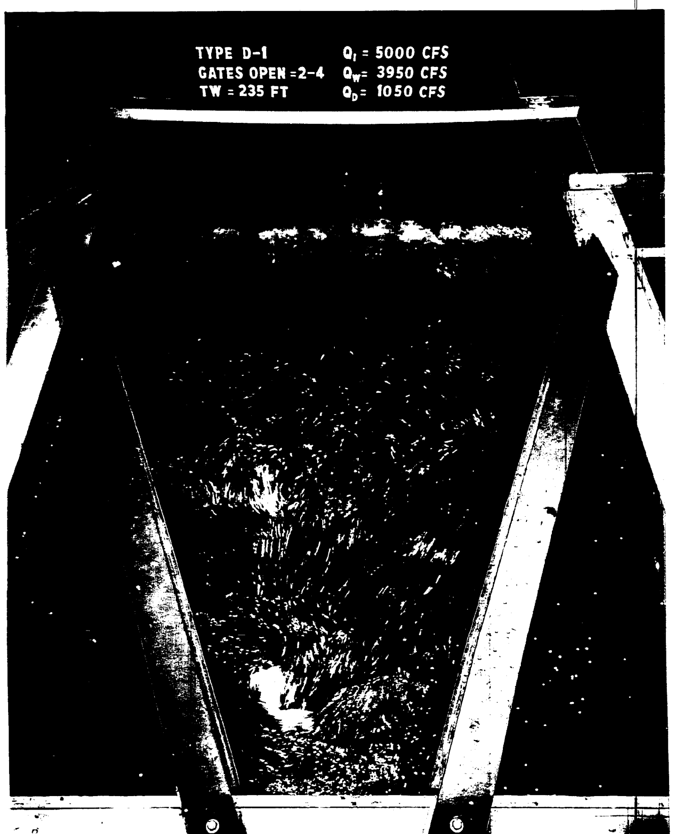


Photo 35 - Type D-1 Control Structure. Gates open: 2,3,4, Q_I = 5,000 cfs, Q_W = 3,950 cfs, Q_D = 1,050 cfs. The flow pattern in the distribution chamber.

Photo 36 - Type D-1 Control Structure. All gates open, Q_I = 650 cfs, Q_W = 0 cfs, Q_D = 650 cfs. The flow pattern in the upper drop chamber.

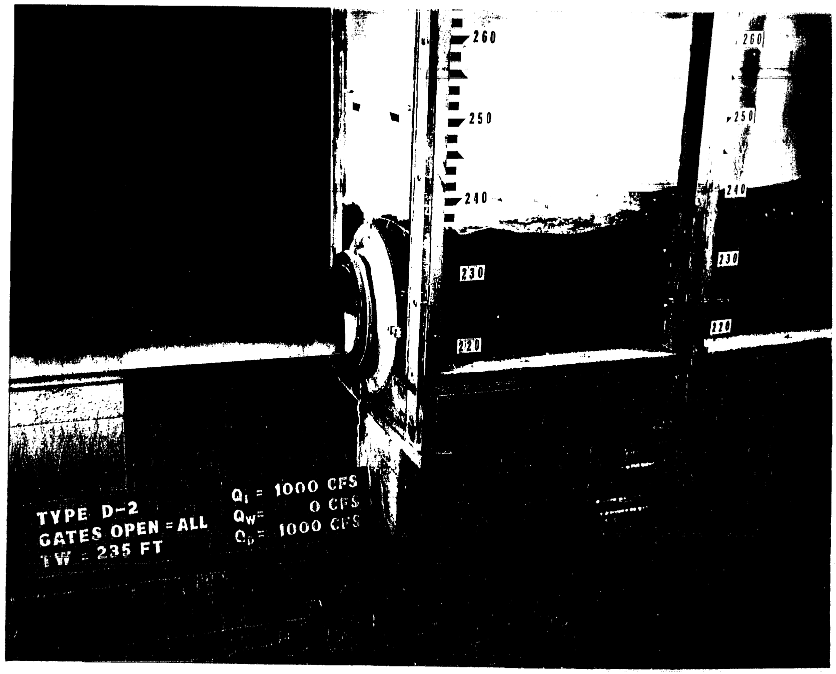


Photo 37 - Type D-2 Control Structure. All gates open, T.W.= 235 ft, Q_I= 1,000 cfs, Q_W= 0 cfs, Q_D= 1,000 cfs. The flow pattern in the outlet pipe.

Photo 38 - Type D-2 Control Structure. Gates open: 2,3,4, T.W.= 235 ft, Q_I= 5,000 cfs, Q_W= 3,950 cfs, Q_D= 1,050 cfs. The flow pattern in the outlet pipe.

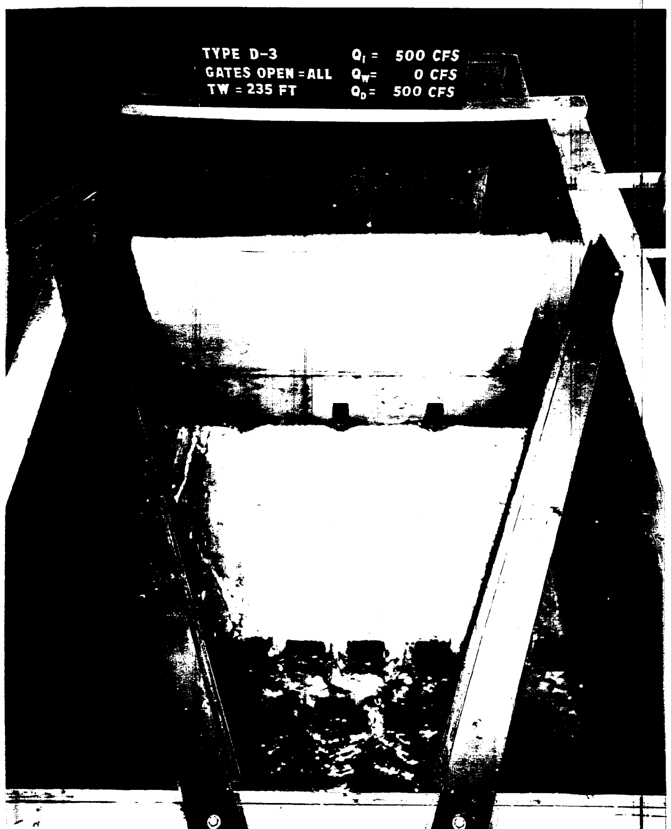


Photo 39 - Type D-3 Control Structure. All gates open, Q_T = 500 cfs, Q_w = 0 cfs, Q_D = 500 cfs. The flow pattern in the distribution chamber.

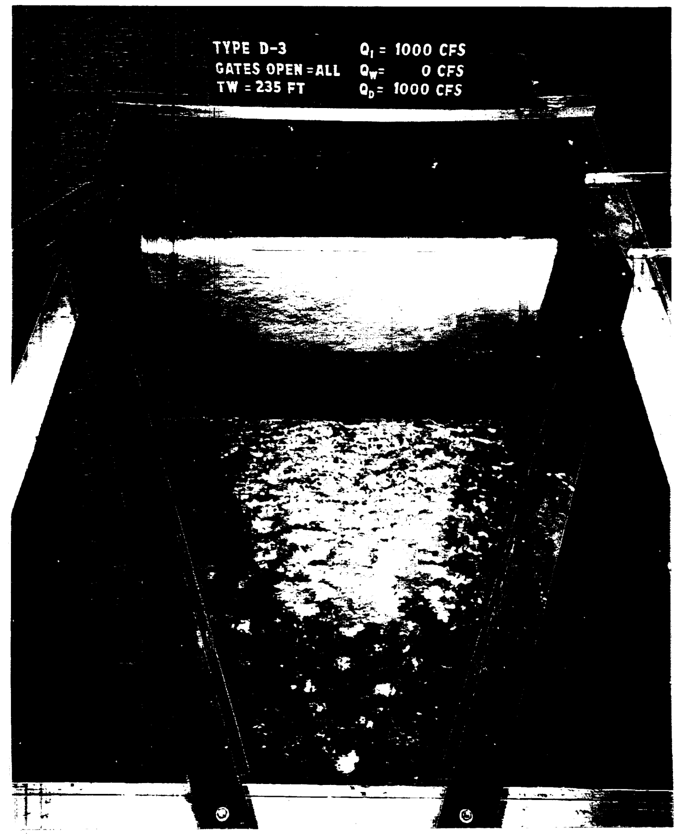


Photo 40 - Type D-3 Control Structure. All gates open, Q_T = 1,000 cfs, Q_w = 0 cfs, Q_D = 1,000 cfs. The flow pattern in the distribution chamber.

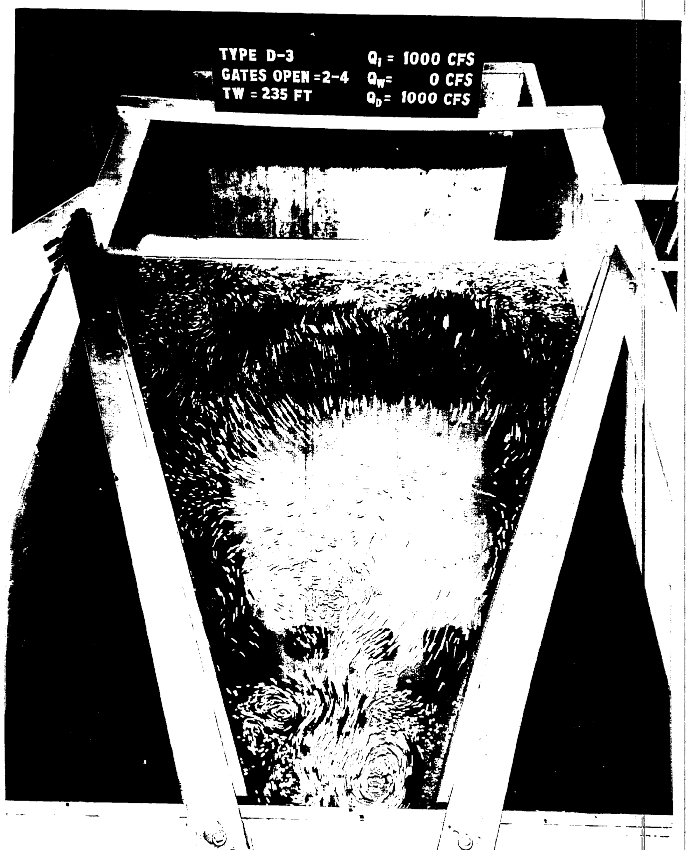


Photo 41 - Type D-3 Control Structure. Gates open: 2,3,4, Q_I = 1,000 cfs, Q_W = 0 cfs, Q_D = 1,000 cfs. The flow pattern in the distribution chamber.

Photo 42 - Type D-3 Control Structure. Gates open: 2,3,4, Q_I = 2,500 cfs, Q_W = 1,470 cfs, Q_D = 1,030 cfs. The flow pattern in the distribution chamber.

Photo 43 - Type D-3 Control Structure. Gates open: 2,3,4, Q_T = 5,000 cfs, Q_W = 3,950 cfs, Q_D = 1,050 cfs. The flow pattern in the distribution chamber.

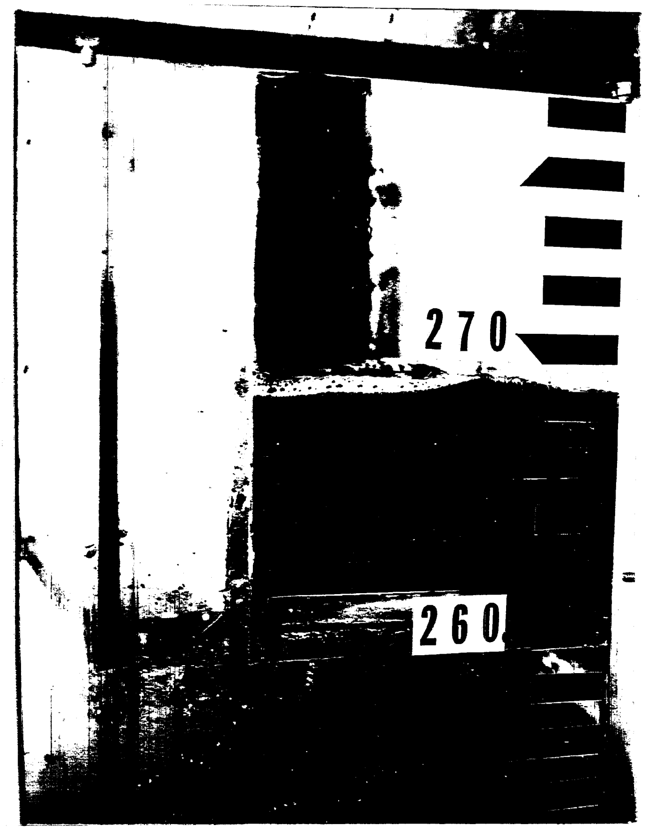


Photo 44 - Type D-3 Control Structure. All gates open, Q_T = 500 cfs, Q_W = 0 cfs, Q_D = 500 cfs. The flow pattern in the upper drop chamber.

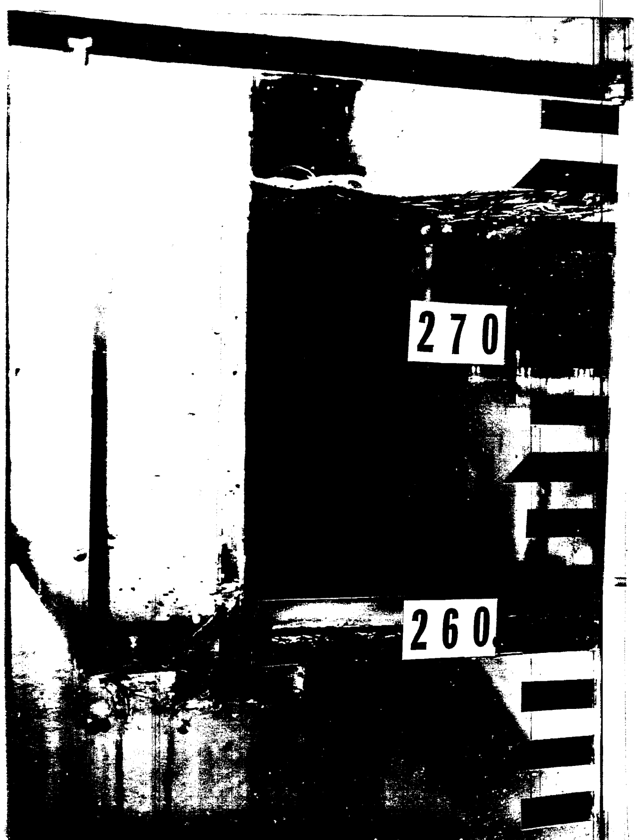


Photo 45 - Type D-3 Control Structure. All gates open, Q_T = 650 cfs, Q_W = 0 cfs, Q_D = 650 cfs. The flow pattern in the upper drop chamber.

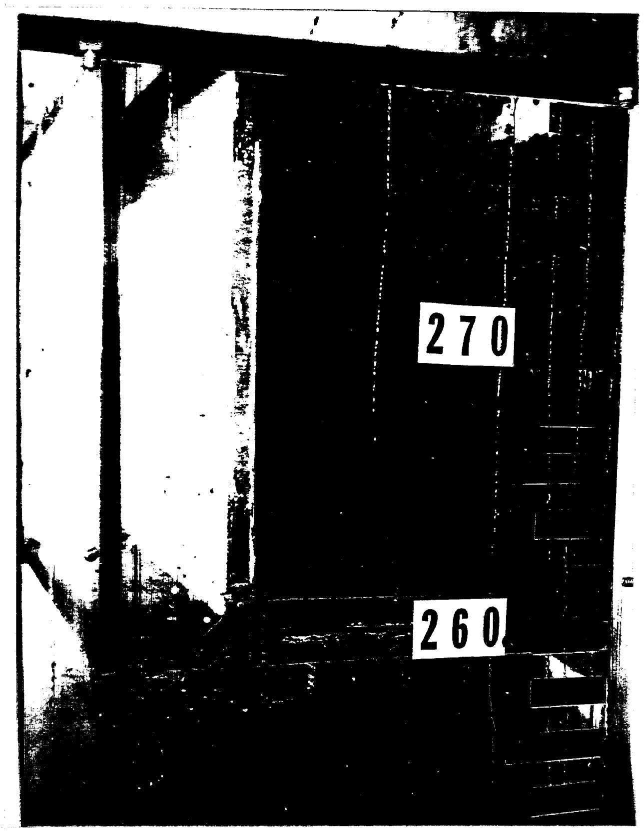


Photo 46 - Type D-3 Control Structure. All gates open, Q_T = 800 cfs, Q_W = 0 cfs, Q_D = 800 cfs. The flow pattern in the upper drop chamber.

Photo 47 - Type D-3 Control Structure. All gates open, T.W. = 235 ft, Q_I = 500 cfs, Q_W = 0 cfs, Q_D = 500 cfs. The flow pattern in the sluices and drop chamber.

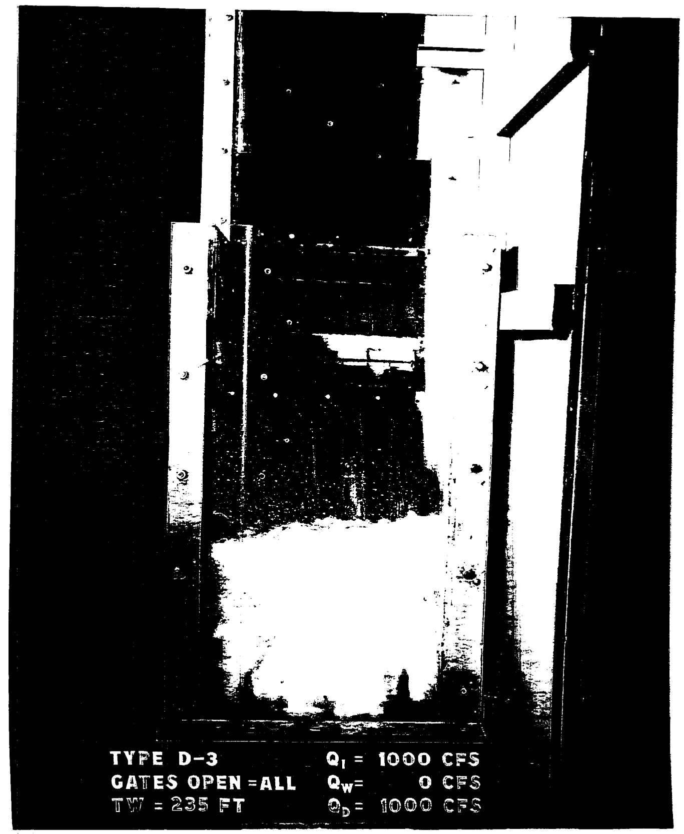


Photo 48 - Type D-3 Control Structure. All gates open, T.W. = 235 ft, Q_I = 1,000 cfs, Q_W = 0 cfs, Q_D = 1,000 cfs. The flow pattern in the sluices and drop chamber.

Photo 49 - Type D-3 Control Structure. Gates open: 2, 3,4, T.W. = 235 ft, Q_T = 1,000 cfs, Q_W = 0 cfs, Q_D = 1,000 cfs. The flow pattern in the sluices and drop chamber.

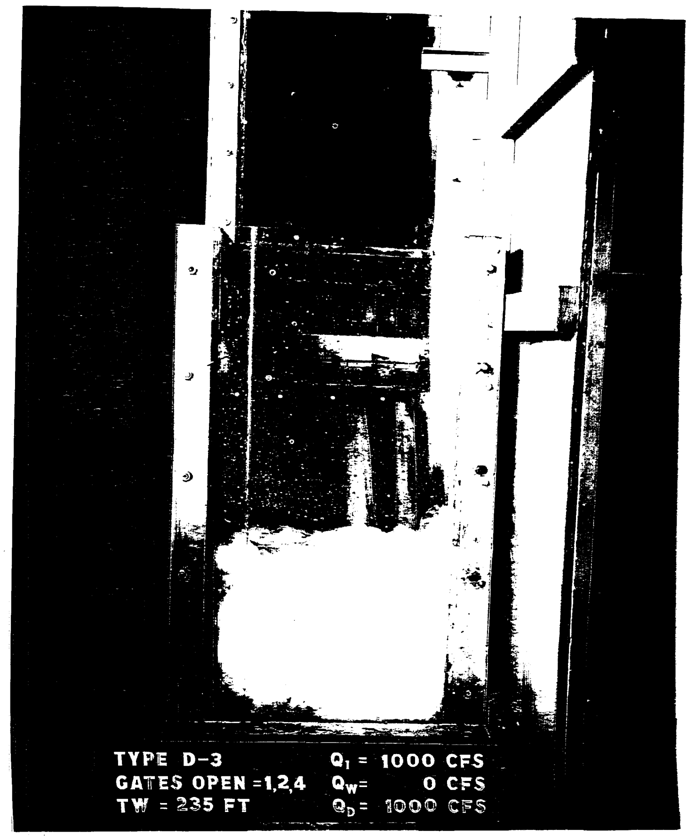


Photo 50 - Type D-3 Control Structure. Gates open: 1, 2, 4, T.W. = 235 ft, Q_T = 1,000 cfs, Q_W = 0 cfs, Q_D = 1,000 cfs. The flow pattern in the sluices and drop chamber.

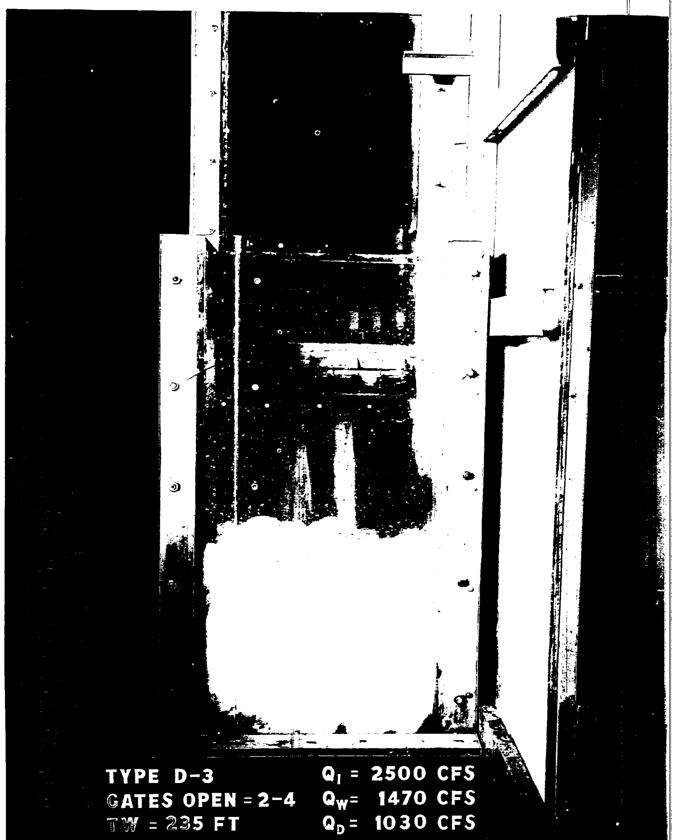


Photo 51 - Type D-3 Control Structure. Gates open: 2, 3,4, T.W. = 235 ft, Q_I = 2,500 cfs, Q_w = 1,470 cfs, Q_D = 1,030 cfs. The flow pattern in the sluices and drop chamber.

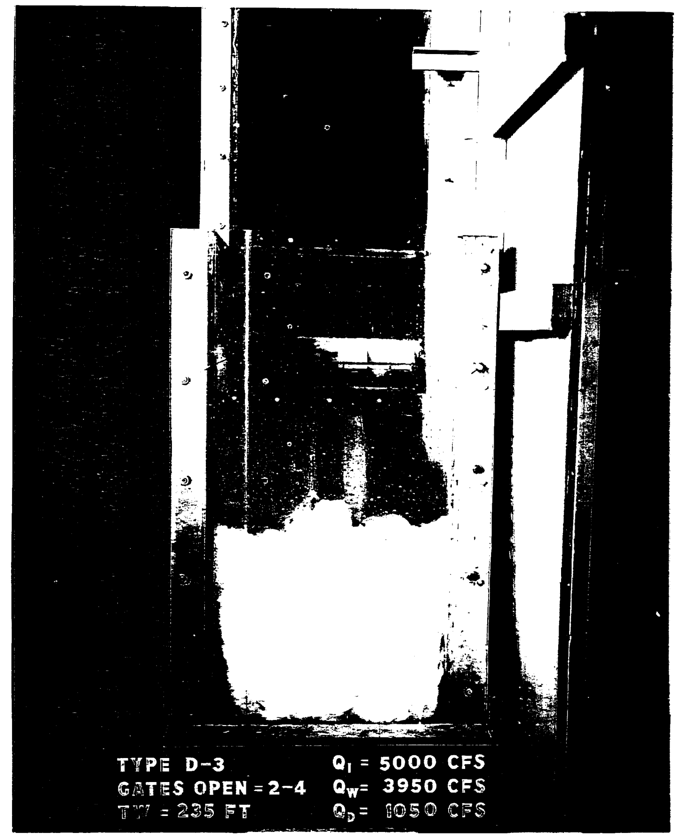


Photo 52 - Type D-3 Control Structure. Gates open: 2, 3,4, T.W. = 235 ft, Q_I = 5,000 cfs, Q_w = 3,950 cfs, Q_D = 1,050 cfs. The flow pattern in the sluices and drop chamber.

Photo 53 - Type D-3 Control Structure. All gates open, T.W.= 235 ft, Q_I = 500 cfs, Q_W = 0 cfs, Q_D = 500 cfs. The flow pattern in the drop chamber.

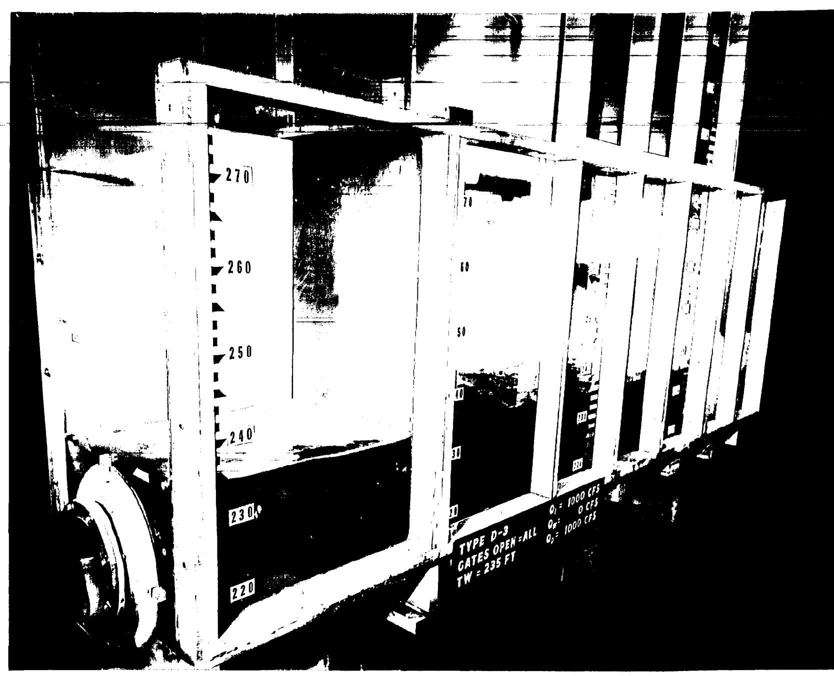


Photo 54 - Type D-3 Control Structure. All gates open, T.W.= 235 ft, Q_I = 1,000 cfs, Q_W = 0 cfs, Q_D = 1,000 cfs. The flow pattern in the drop chamber.

Photo 55 - Type D-3 Control Structure. Gates open: 2,3,4, T.W.= 235 ft, Q_I= 1,000 cfs, Q_W= 0 cfs, Q_D= 1,000 cfs. The flow pattern in the drop chamber.

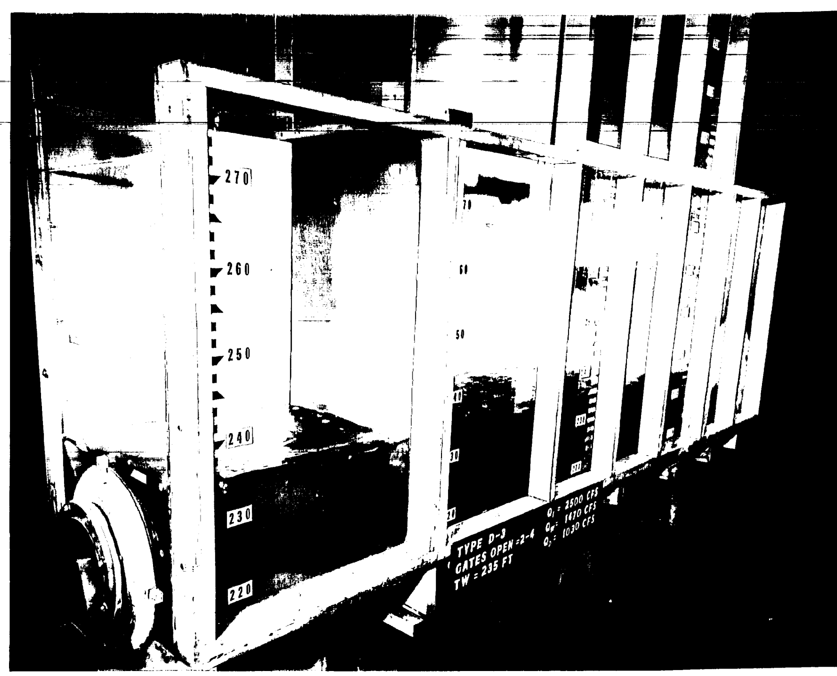


Photo 56 - Type D-3 Control Structure. Gates open: 2,3,4, T.W.= 235 ft, Q_I= 2,500 cfs, Q_W= 1,470 cfs, Q_D= 1,030 cfs. The flow pattern in the drop chamber.

Photo 57 - Type D-3 Control Structure. Gates open: 2,3,4, T.W.= 235 ft, Q_I = 5,000 cfs, Q_W = 3,950 cfs, Q_D = 1,050 cfs. The flow pattern in the drop chamber.

Photo 58 - Type D-3 Control Structure. All gates open, T.W.= 235 ft, Q_I = 500 cfs, Q_W = 0 cfs, Q_D = 500 cfs. The flow pattern in the outlet pipe.

Photo 59 - Type D-3 Control Structure. All gates open, T.W.=235 ft, Q_I = 1,000 cfs, Q_W = 0 cfs, Q_D = 1,000 cfs. The flow pattern in the outlet pipe.

Photo 60 - Type D-3 Control Structure. Gates open: 2,3,4, T.W.= 235 ft, Q_I = 1,000 cfs, Q_W = 0 cfs, Q_D = 1,000 cfs. The flow pattern in the outlet pipe.

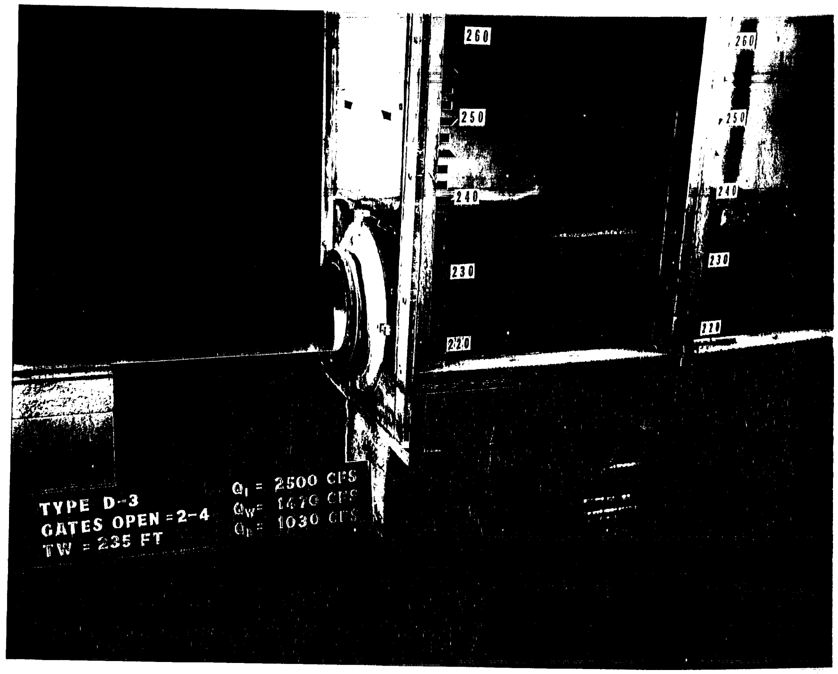
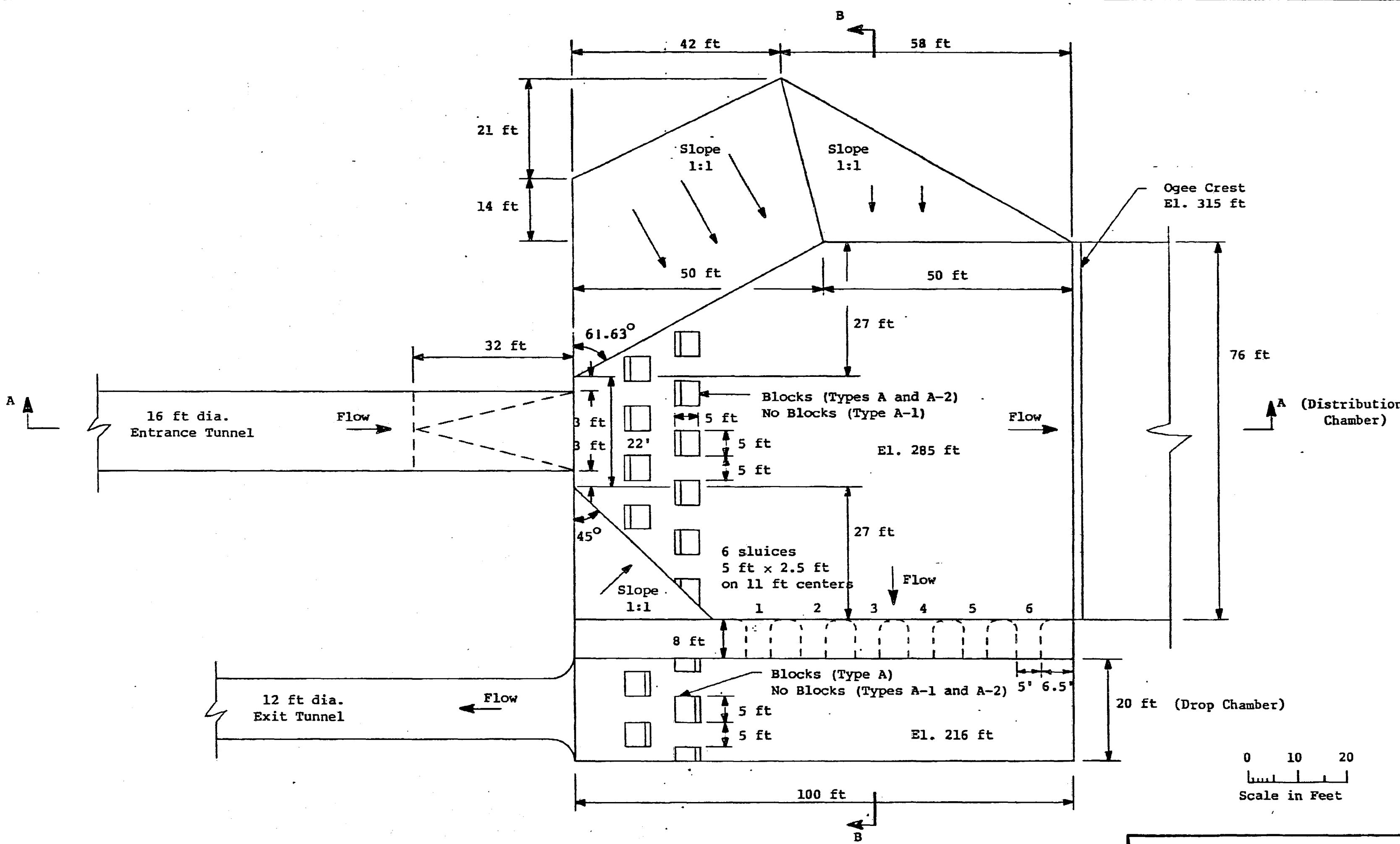


Photo 61 - Type D-3 Control Structure. Gates open: 2,3,4, T.W. = 235 ft, Q_I = 2,500 cfs, Q_W = 1,470 cfs, Q_D = 1,030 cfs. The flow pattern in the outlet pipe.

Photo 62 - Type D-3 Control Structure. Gates open: 2,3,4, T.W. = 235 ft, Q_I = 5,000 cfs, Q_W = 3,950 cfs, Q_D = 1,050 cfs. The flow pattern in the outlet pipe.

LIST OF CHARTS

LIST OF CHARTS (Cont'd.)



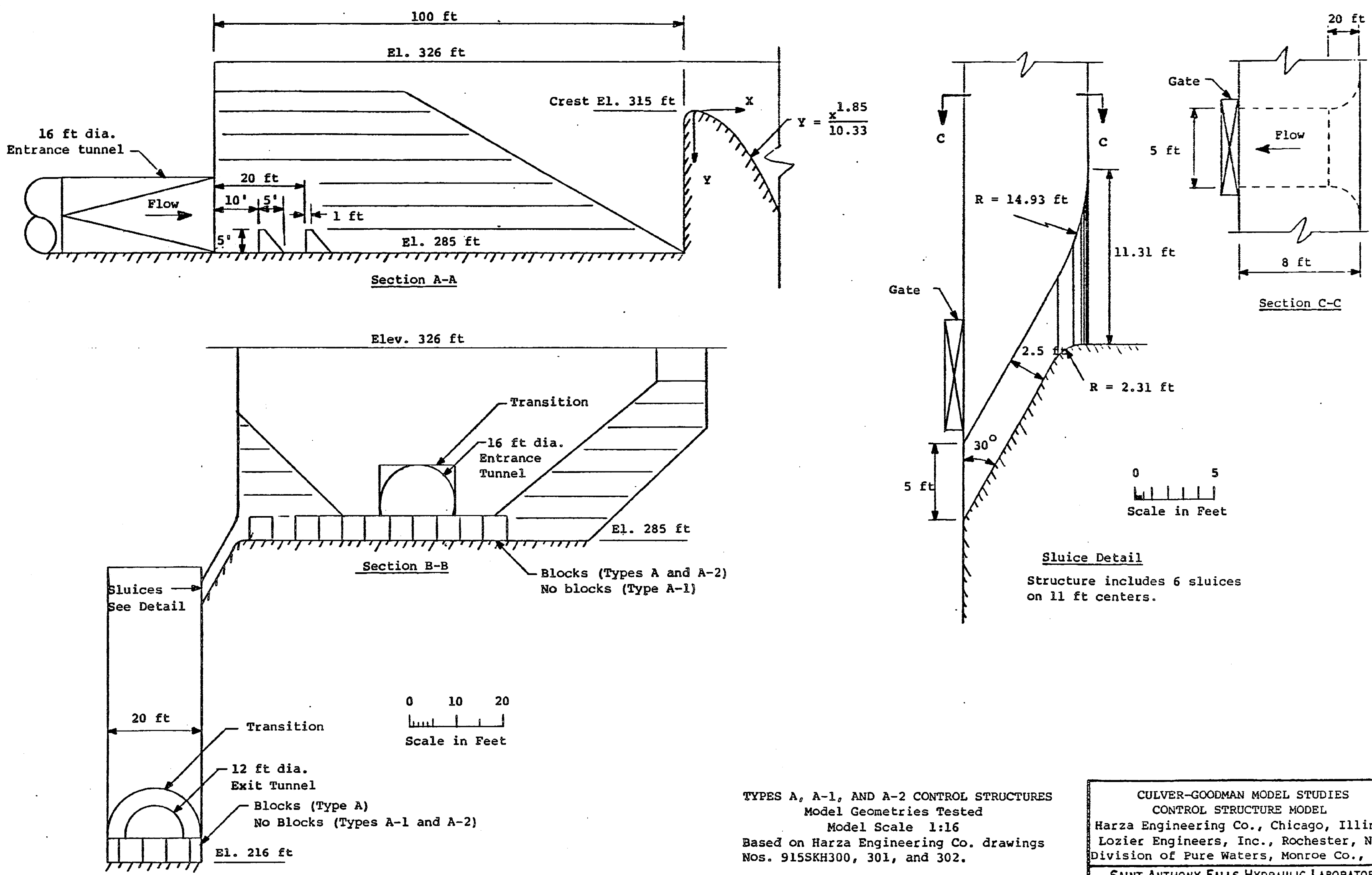
TYPES A, A-1, AND A-2 CONTROL STRUCTURES
Model Geometries Tested
Model Scale 1:16
Based on Harza Engineering Co. drawings
Nos. 915SKH300, 301, and 302.

CULVER-GOODMAN MODEL STUDIES
CONTROL STRUCTURE MODEL
Harza Engineering Co., Chicago, Illinois
Lozier Engineers, Inc., Rochester, N.Y.
Division of Pure Waters, Monroe Co., N.Y.

SAINT ANTHONY FALLS HYDRAULIC LABORATORY
UNIVERSITY OF MINNESOTA

DRAWN DA	CHECKED	APPROVED
SCALE	DATE 3/19/80	NO. 260AB508-19

CHART 1



TYPES A, A-1, AND A-2 CONTROL STRUCTURES
Model Geometries Tested
Model Scale 1:16
Based on Harza Engineering Co. drawings
Nos. 915SKH300, 301, and 302.

CULVER-GOODMAN MODEL STUDIES
CONTROL STRUCTURE MODEL
Harza Engineering Co., Chicago, Illinois
Lozier Engineers, Inc., Rochester, N. Y.
Division of Pure Waters, Monroe Co., N.Y.

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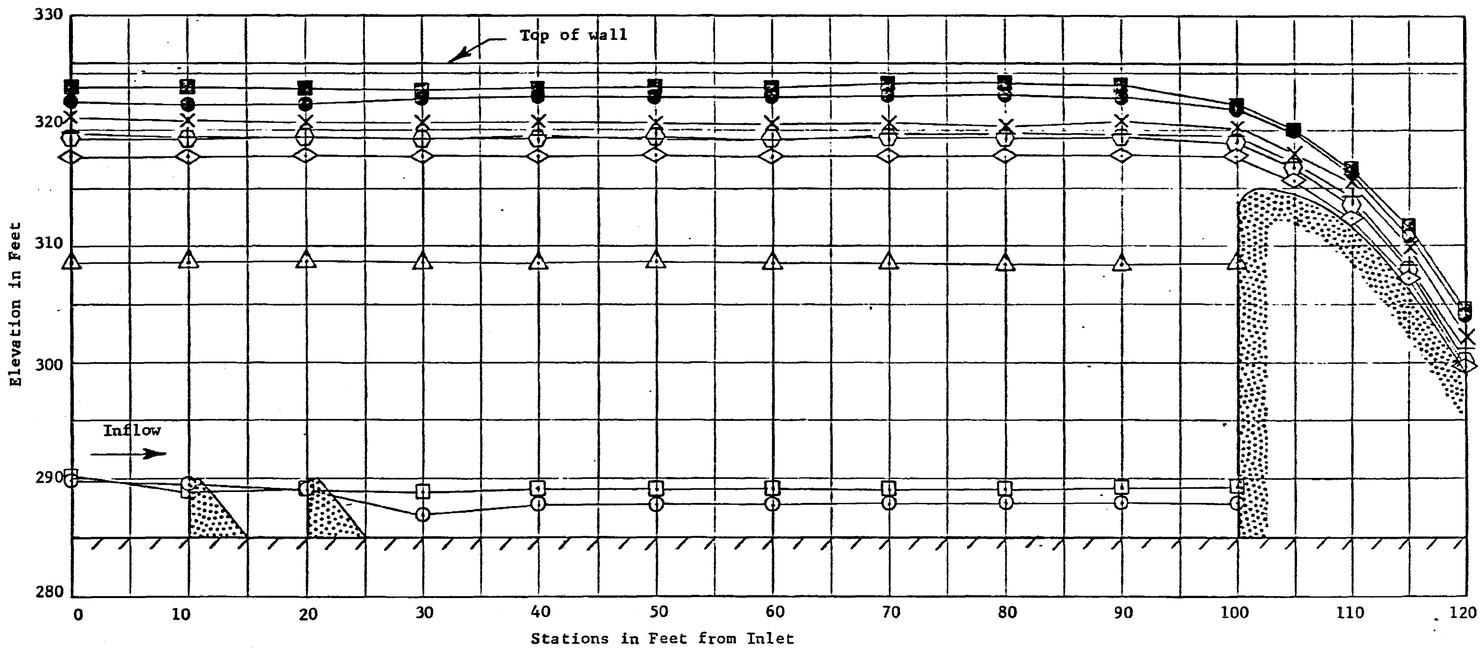
UNIVERSITY OF MINNESOTA

DRAWN DA	CHECKED	APPROVED
SCALE	DATE 3/19/80	NO 260AB509-20

CHART 2



Symbol	Gates Open	T.W. ft	Q_I cfs	Q_W cfs	Q_D cfs
⊙	All	235	500	0	500
⊡	All	235	1000	0	1000
△	5 & 6	235	1000	0	1000
◇	5 & 6	250	2500	1440	1060
⬡	None	--	2500	2500	0
+	5 & 6	250	5000	3900	1100
×	None	--	5000	5000	0
●	5 & 6	250	8700	7580	1120
■	None	--	8700	8700	0

TYPE A CONTROL STRUCTURE
Water Surface Profiles
In Distribution Chamber
Model Scale 1:16

Profiles are on centerline of entrance conduit.

CULVER-GOODMAN MODEL STUDIES
CONTROL STRUCTURE MODEL

Harza Engineering Co., Chicago, Illinois
Lozier Engineers, Inc., Rochester, N.Y.
Division of Pure Waters, Monroe Co., N.Y.

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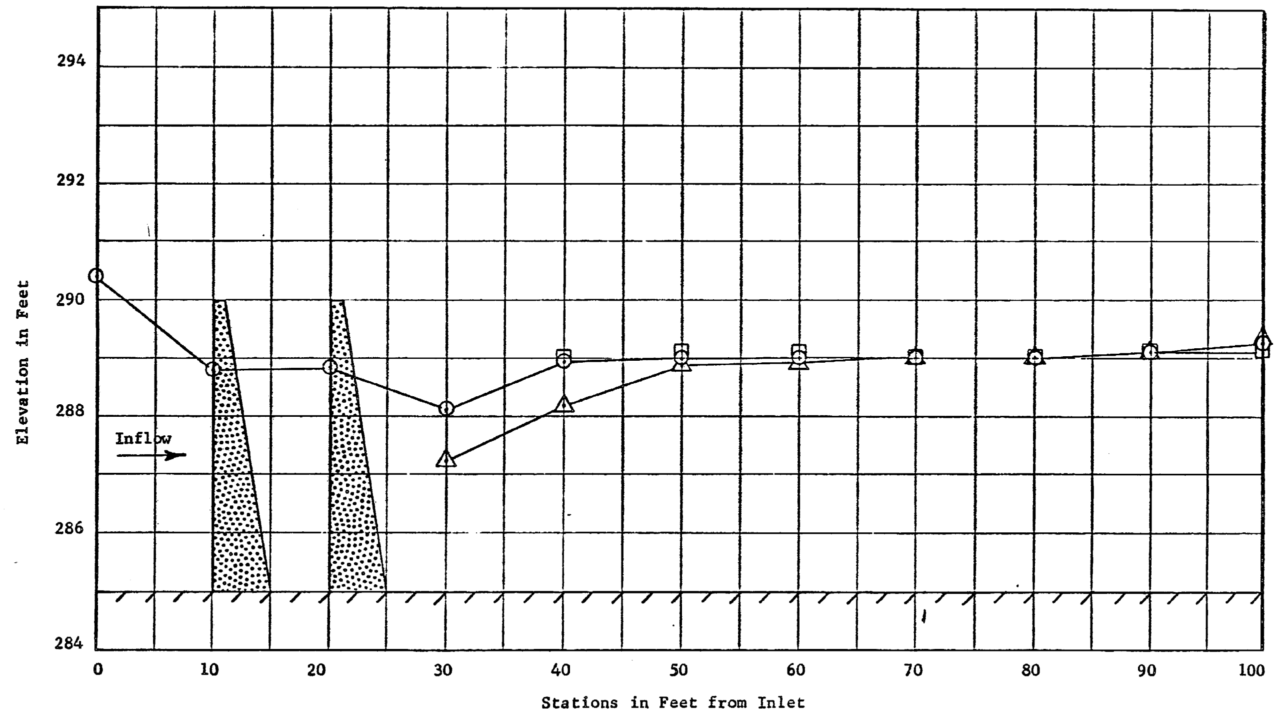
UNIVERSITY OF MINNESOTA

DRAWN DA	CHECKED [illegible]	APPROVED
SCALE	DATE 2/3/78	NO. 260AB508-1

CHART 3



⊙ Profile - centerline

⊡ Profile - 33 ft left of centerline

△ Profile - 33 ft right of centerline

TYPE A CONTROL STRUCTURE
Water Surface Profiles
in Distribution Chamber
Model Scale 1:16
All gates open, T.W. = 235 ft
Q_I = 1000 cfs, Q_W = 0 cfs, Q_D = 1000 cfs

CULVER-GOODMAN MODEL STUDIES CONTROL STRUCTURE MODEL Harza Engineering Co., Chicago, Illinois Lozier Engineers, Inc., Rochester, N.Y. Division of Pure Waters, Monroe Co., N.Y.		
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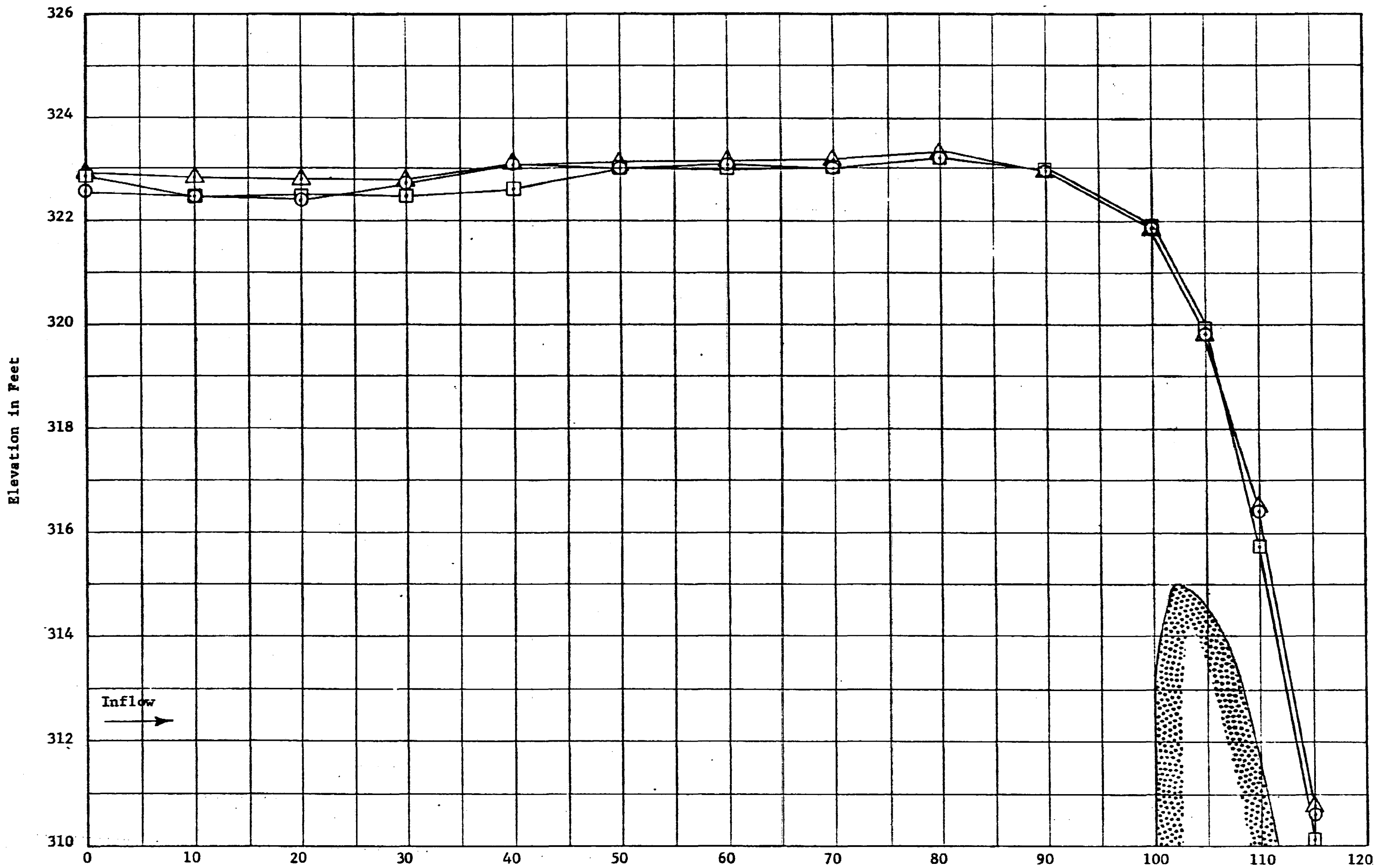
DRAWN DA	CHECKED [signature]	APPROVED
SCALE	DATE 2/3/78	NO. 260AB508-3

CHART 4



⊙ Profile - centerline

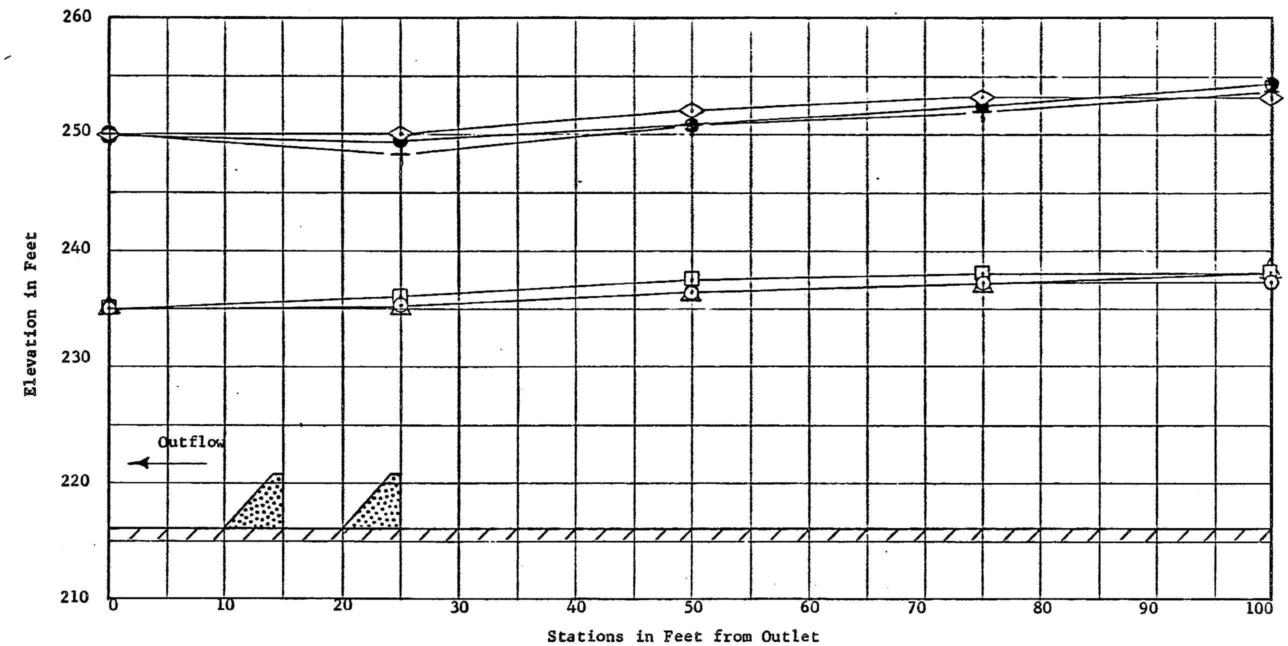
⊡ Profile - 33 ft left of centerline

△ Profile - 33 ft right of centerline

TYPE A CONTROL STRUCTURE
Water Surface Profiles
in Distribution Chamber
Model Scale 1:16
Gates 5 & 6 open, T.W. = 250 ft
Q_I = 8700 cfs, Q_W = 7580 cfs, Q_D = 1120 cfs

CULVER-GOODMAN MODEL STUDIES CONTROL STRUCTURE MODEL Harza Engineering Co., Chicago, Illinois Lozier Engineers, Inc., Rochester, N.Y. Division of Pure Waters, Monroe Co., N.Y.		
SAINT ANTHONY FALLS HYDRAULIC LABORATORY UNIVERSITY OF MINNESOTA		
DRAWN DA	CHECKED [signature]	APPROVED
SCALE	DATE 2/3/78	NO. 260AB508-4

CHART 5



Symbol	Gates Open	T.W. ft	Q_I cfs	Q_W cfs	Q_D cfs
⊙	All	235	500	0	500
⊡	All	235	1000	0	1000
△	5 & 6	235	1000	0	1000
◇	5 & 6	250	2500	1440	1060
+	5 & 6	250	5000	3900	1100
●	5 & 6	250	8700	7580	1120

TYPE A CONTROL STRUCTURE
Water Surface Profiles
in Drop Chamber
Model Scale 1:16

CULVER-GOODMAN MODEL STUDIES
CONTROL STRUCTURE MODEL
Harza Engineering Co., Chicago, Illinois
Lozier Engineers, Inc., Rochester, N.Y.
Division of Pure Waters, Monroe Co., N.Y.

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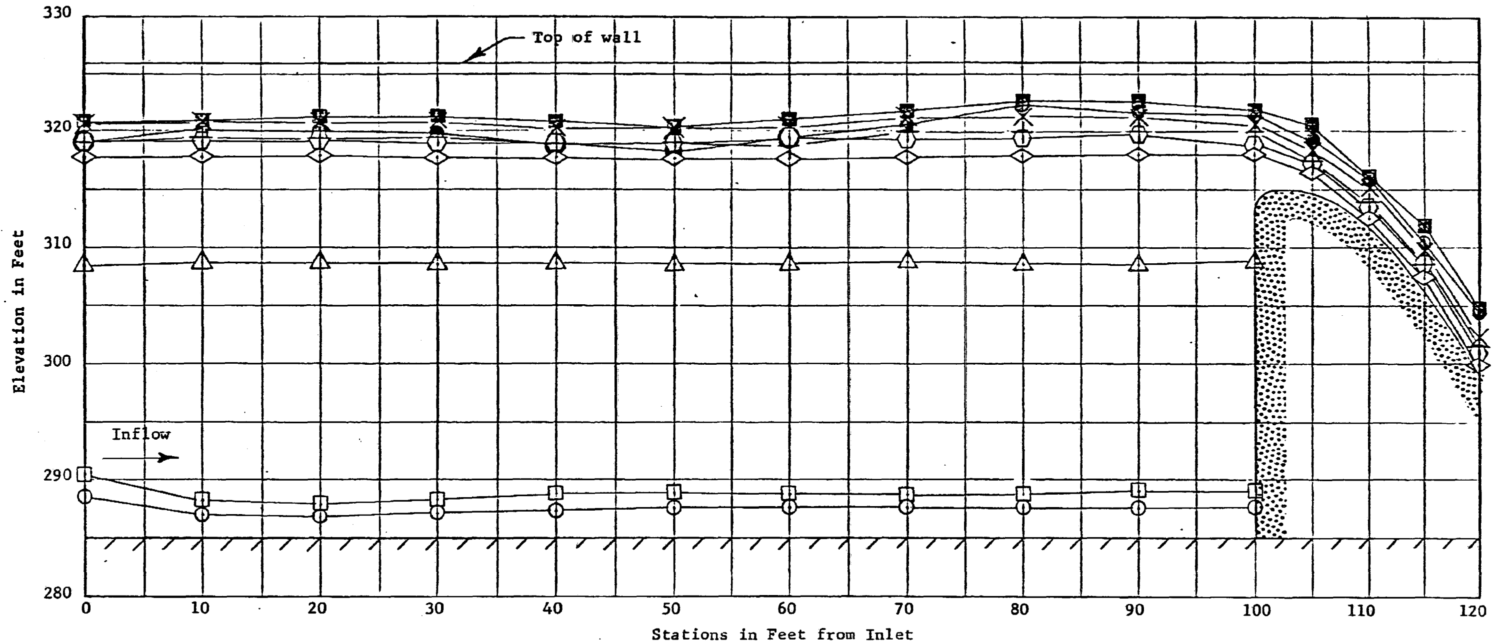
UNIVERSITY OF MINNESOTA

DRAWN DA	CHECKED	APPROVED
SCALE	DATE 2/3/78	NO 260AB508-2

CHART 6



Symbol	Gates Open	T.W. ft	Q_I cfs	Q_W cfs	Q_D cfs
⊙	All	235	500	0	500
⊡	All	235	1000	0	1000
△	5 & 6	235	1000	0	1000
◇	5 & 6	250	2500	1400	1060
⊙	None	-	2500	2500	0
+	5 & 6	250	5000	3900	1100
×	None	-	5000	5000	0
●	5 & 6	250	8700	7580	1120
■	None	-	8700	8700	0

TYPE A-1 CONTROL STRUCTURE
Water Surface Profiles
In Distribution Chamber
Model Scale 1:16

Profiles are on centerline of entrance conduit.

CULVER-GOODMAN MODEL STUDIES
CONTROL STRUCTURE MODEL
Harza Engineering Co., Chicago, Illinois
Lozier Engineers, Inc., Rochester, N.Y.
Division of Pure Waters, Monroe Co. N.Y.

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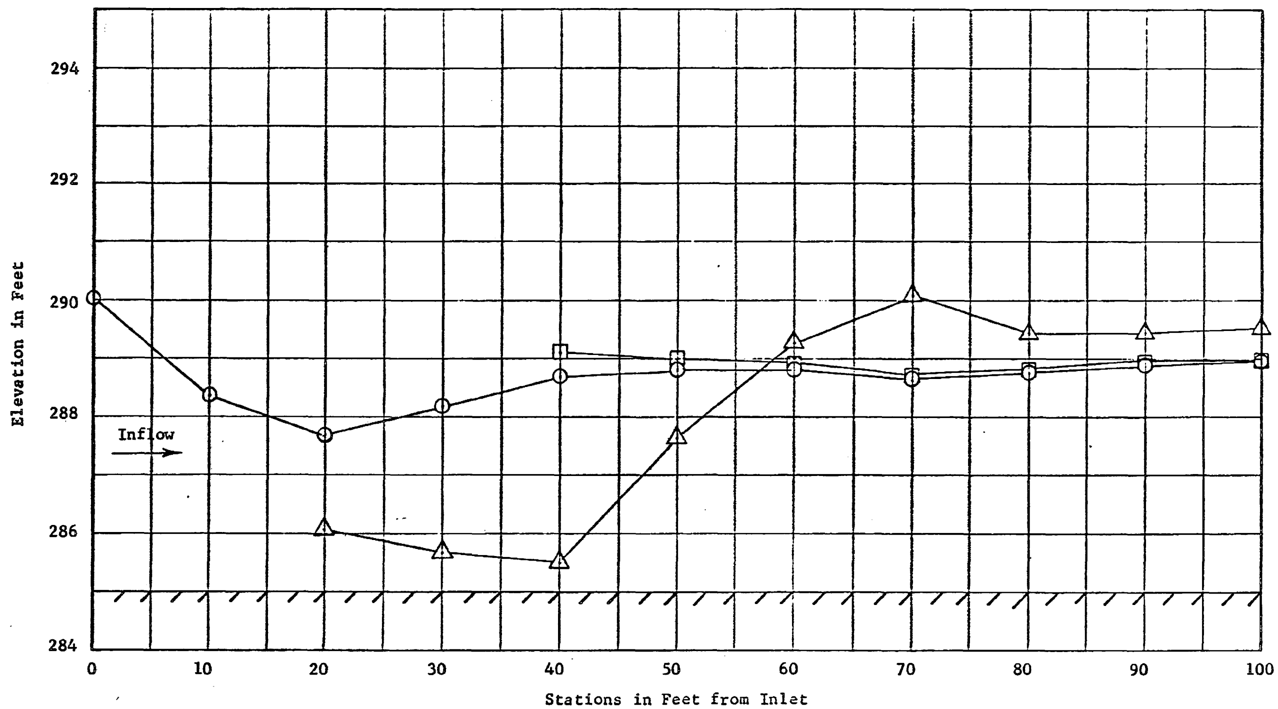
UNIVERSITY OF MINNESOTA

DRAWN DA	CHECKED	APPROVED
SCALE	DATE 2/3/78	NO. 260AB508-5

CHART 7



⊙ Profile - centerline

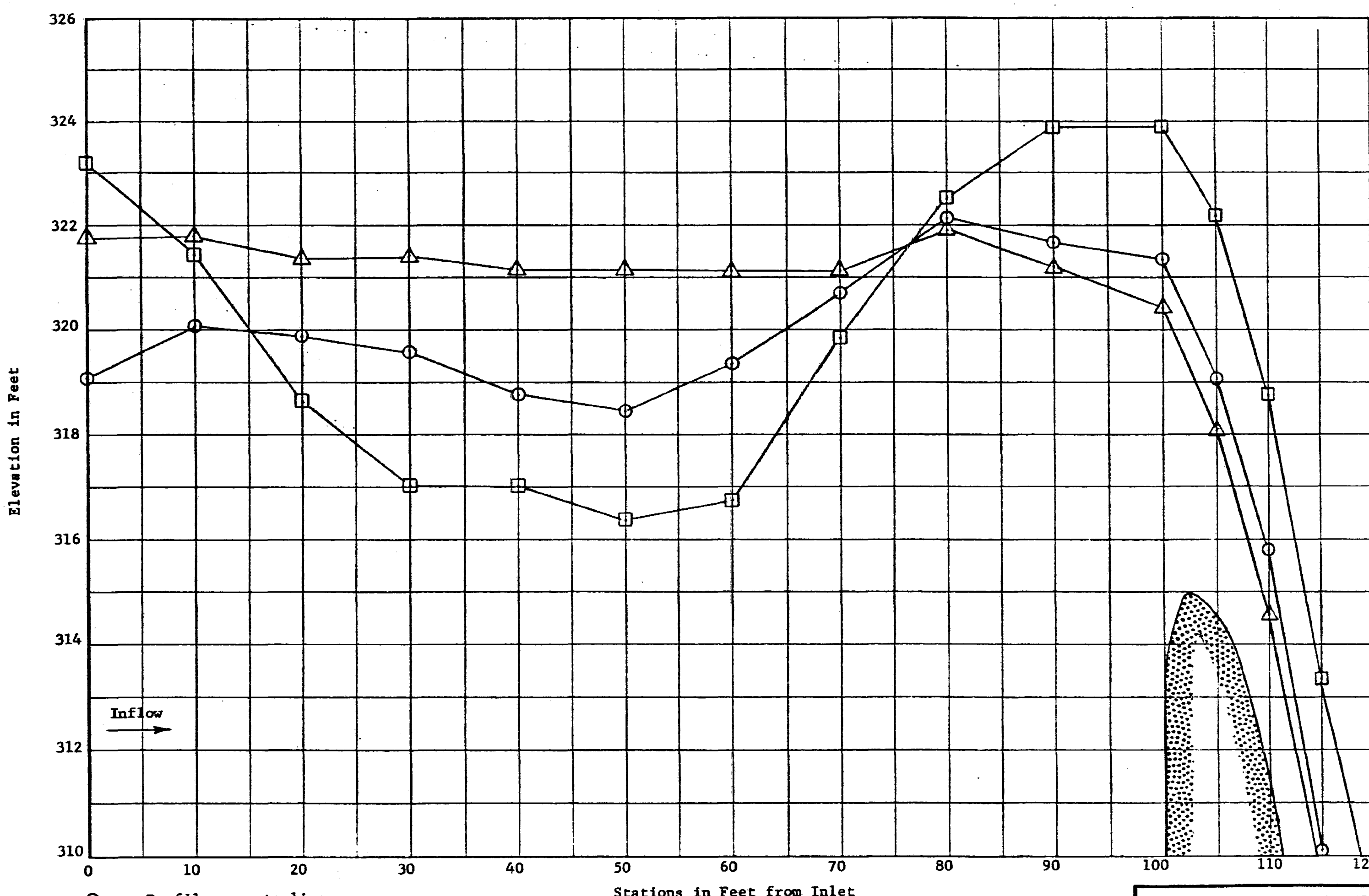
⊡ Profile - 33 ft left of centerline

△ Profile - 33 ft right of centerline

TYPE A-1 CONTROL STRUCTURE
Water Surface Profiles
in Distribution Chamber
Model Scale 1:16
All gates open, T.W. = 235 ft
Q_I = 1000 cfs, Q_W = 0 cfs, Q_D = 1000cfs

CULVER-GOODMAN MODEL STUDIES CONTROL STRUCTURE MODEL Harza Engineering Co., Chicago, Illinois Lozier Engineers, Inc., Rochester, N.Y. Division of Pure Waters, Monroe Co., N.Y.		
SAINT ANTHONY FALLS HYDRAULIC LABORATORY UNIVERSITY OF MINNESOTA		
DRAWN DA	CHECKED [illegible]	APPROVED
SCALE	DATE 2/3/78	NO. 260AB508-7

CHART 8



⊙ Profile - centerline

⊡ Profile - 33 ft left of centerline

△ Profile - 33 ft right of centerline

TYPE A-1 CONTROL STRUCTURE
Water Surface Profiles
in Distribution Chamber
Model Scale 1:16
Gates 5 & 6 open, T.W. = 250 ft
Q_I = 8700 cfs, Q_W = 7580 cfs, Q_D = 1120 cfs

CULVER-GOODMAN MODEL STUDIES
CONTROL STRUCTURE MODEL
Harza Engineering Co., Chicago, Illinois
Lozier Engineers, Inc., Rochester, N.Y.
Division of Pure Waters, Monroe Co., N.Y.
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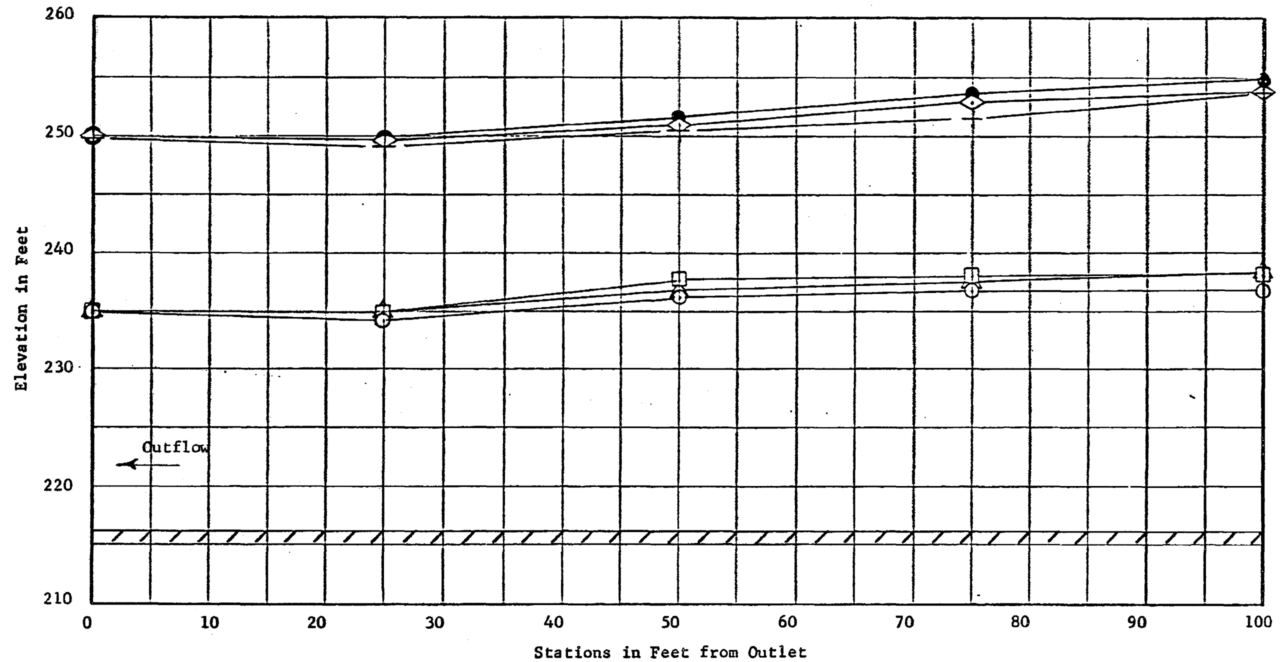
UNIVERSITY OF MINNESOTA

DRAWN DA	CHECKED	APPROVED
SCALE	DATE 2/3/78	NO. 260AB508-8

CHART 9



Symbol	Gates Open	T.W. ft	Q_I cfs	Q_W cfs	Q_D cfs
⊙	All	235	500	0	500
⊡	All	235	1000	0	1000
△	5 & 6	235	1000	0	1000
◇	5 & 6	250	2500	1440	1060
+	5 & 6	250	5000	3900	1100
●	5 & 6	250	8700	7580	1120

TYPE A-1 CONTROL STRUCTURE
Water Surface Profiles
in Drop Chamber
Model Scale 1:16

CULVER-GOODMAN MODEL STUDIES
CONTROL STRUCTURE MODEL
Harza Engineering Co., Chicago, Illinois
Lozier Engineers, Inc., Rochester, N.Y.
Division of Pure Waters, Monroe Co., N.Y.

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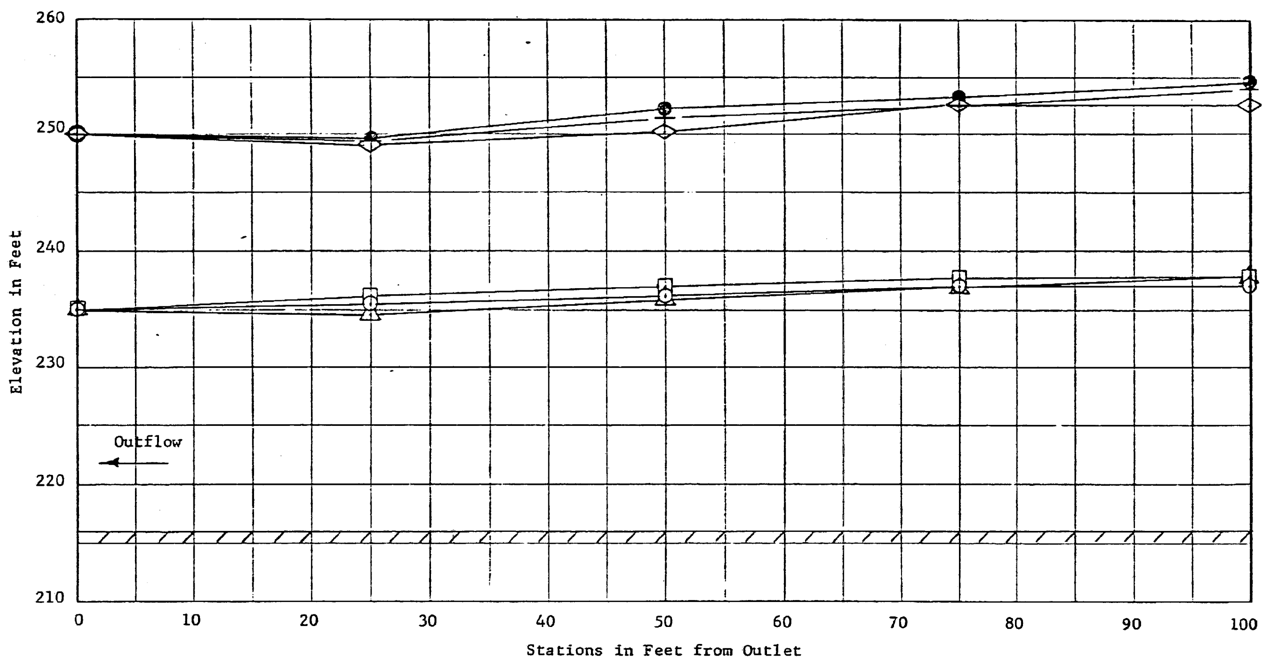
UNIVERSITY OF MINNESOTA

DRAWN DA	CHECKED	APPROVED
SCALE	DATE 2/3/78	NO. 260AR508-6

CHART 10



Symbol	Gates Open	T.W. ft	Q_I cfs	Q_W cfs	Q_D cfs
⊙	All	235	500	0	500
⊡	All	235	1000	0	1000
△	5 & 6	235	1000	0	1000
◇	5 & 6	250	2500	1440	1060
+	5 & 6	250	5000	3900	1100
●	5 & 6	250	8700	7580	1120

TYPE A-2 CONTROL STRUCTURE
Water Surface Profiles
in Drop Chamber
Model Scale 1:16

CULVER-GOODMAN MODEL STUDIES
CONTROL STRUCTURE MODEL
Harza Engineering Co., Chicago, Illinois
Lozier Engineers, Inc., Rochester, N.Y.
Division of Pure Waters, Monroe Co., N.Y.

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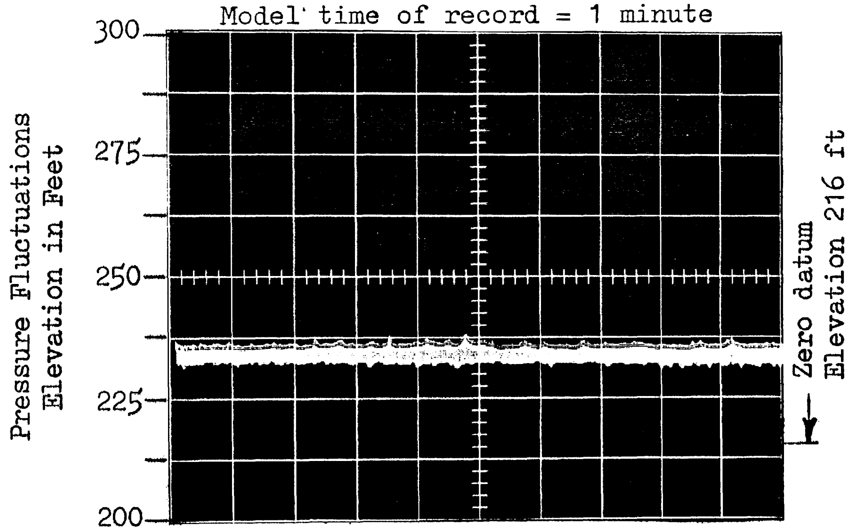
UNIVERSITY OF MINNESOTA

DRAWN DA	CHECKED	APPROVED
SCALE	DATE 2/3/78	NO. 260AB508-9

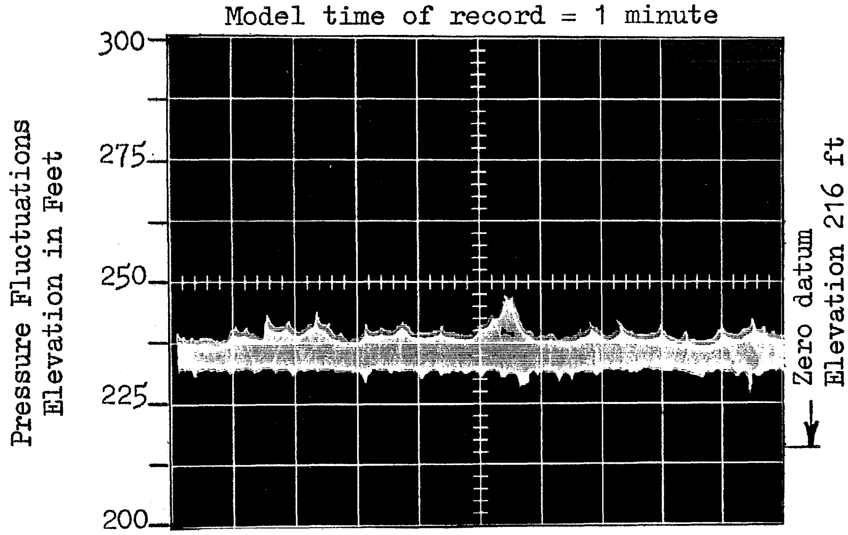
CHART 11

Model time of record = 1 minute



Gates open - all, T.W. = 235 ft
Q_I = 500 cfs, Q_W = 0 cfs, Q_D = 500 cfs

Model time of record = 1 minute



Gates open - all, T.W. = 235 ft
Q_I = 1000 cfs, Q_W = 0 cfs, Q_D = 1000 cfs

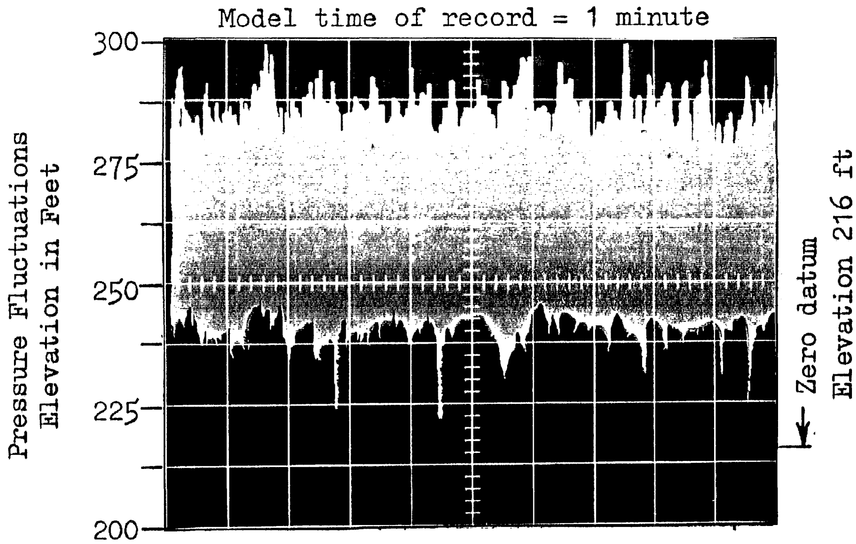
TYPE A-2 CONTROL STRUCTURE
Typical Pressure Fluctuations - Tap 1
Model Scale 1:16

The tap was located on the drop chamber floor along the centerline of sluice 5 at the wall opposite from the sluice. The fluctuations were recorded with a chamber mounted 25 psi transducer.

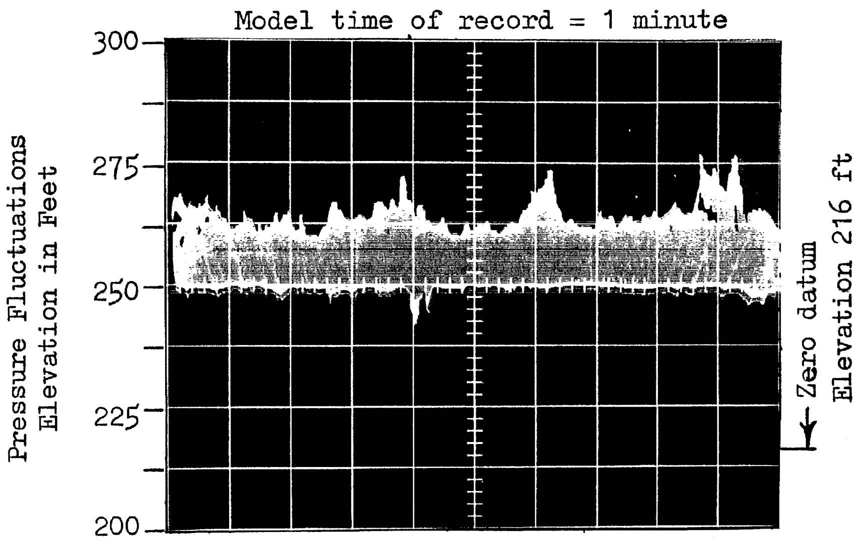
CULVER-COODMAN MODEL STUDIES
CONTROL STRUCTURE MODEL
Harza Engineering Co., Chicago, Illinois
Lozier Engineers, Inc., Rochester, N.Y.
Division of Pure Waters, Monroe Co., N.Y.

SAINT ANTHONY FALLS HYDRAULIC LABORATORY
UNIVERSITY OF MINNESOTA

DRAWN WQD	CHECKED WQD	APPROVED
SCALE	DATE 2/7/78	NO. 260AA2317-7



Gates open - 5 & 6, T.W. = 235 ft
Q_I = 1000 cfs, Q_W = 0 cfs, Q_D = 1000 cfs

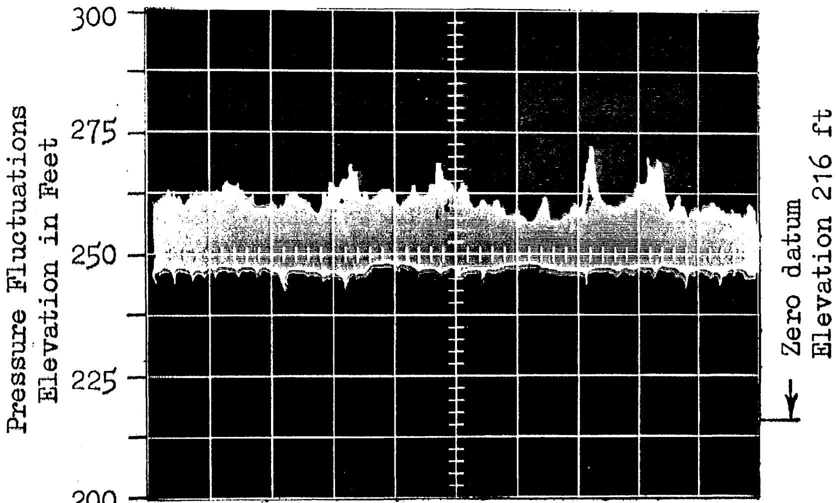


Gates open - 5 & 6, T.W. = 250 ft
Q_I = 2500 cfs, Q_W = 1440 cfs, Q_D = 1060 cfs

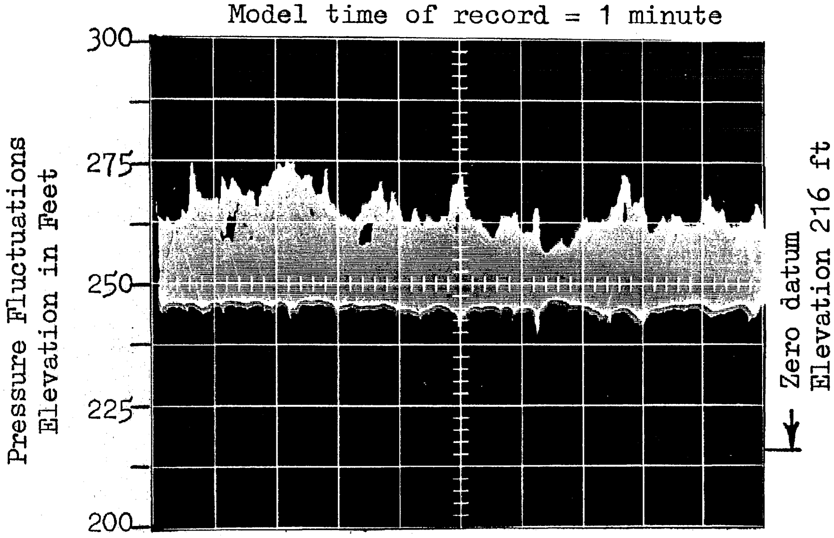
TYPE A-2 CONTROL STRUCTURE
Typical Pressure Fluctuations - Tap 1
Model Scale 1:16

The tap was located on the drop chamber floor along the centerline of sluice 5 at the wall opposite from the sluice. The fluctuations were recorded with a chamber mounted 25 psi transducer.

CULVER-GOODMAN MODEL STUDIES CONTROL STRUCTURE MODEL Harza Engineering Co., Chicago, Illinois Lozier Engineers, Inc., Rochester, N.Y. Division of Pure Waters, Monroe Co., N.Y.		
SAINT ANTHONY FALLS HYDRAULIC LABORATORY UNIVERSITY OF MINNESOTA		
DRAWN WQD	CHECKED [signature]	APPROVED
SCALE	DATE 2/7/78	NO. 260AA2317- 8



Gates open - 5 & 6, T.W. = 250 ft
Q_I = 5000 cfs, Q_W = 3900 cfs, Q_D = 1100 cfs



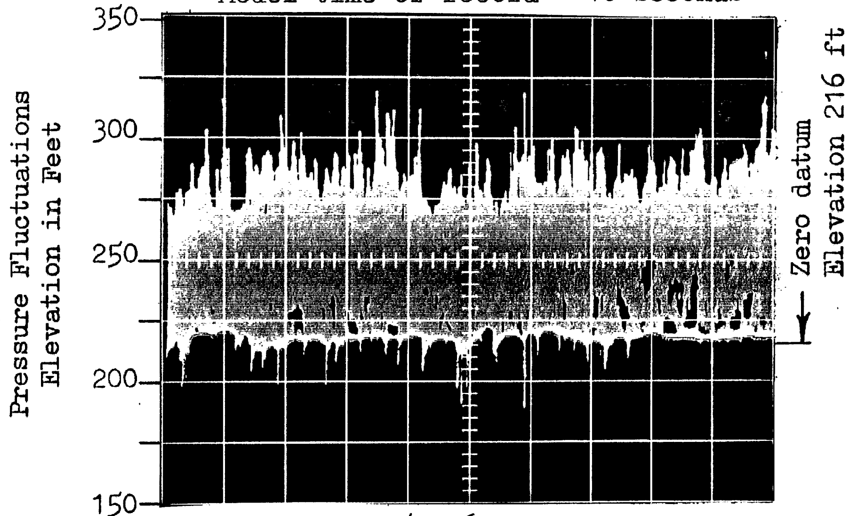
Gates open - 5 & 6, T.W. = 250 ft
Q_I = 8700 cfs, Q_W = 7580 cfs, Q_D = 1120 cfs

TYPE A-2 CONTROL STRUCTURE
Typical Pressure Fluctuations - Tap 1
Model Scale 1:16

The tap was located on the drop chamber floor along the centerline of sluice 5 at the wall opposite from the sluice. The fluctuations were recorded with a chamber mounted 25 psi transducer.

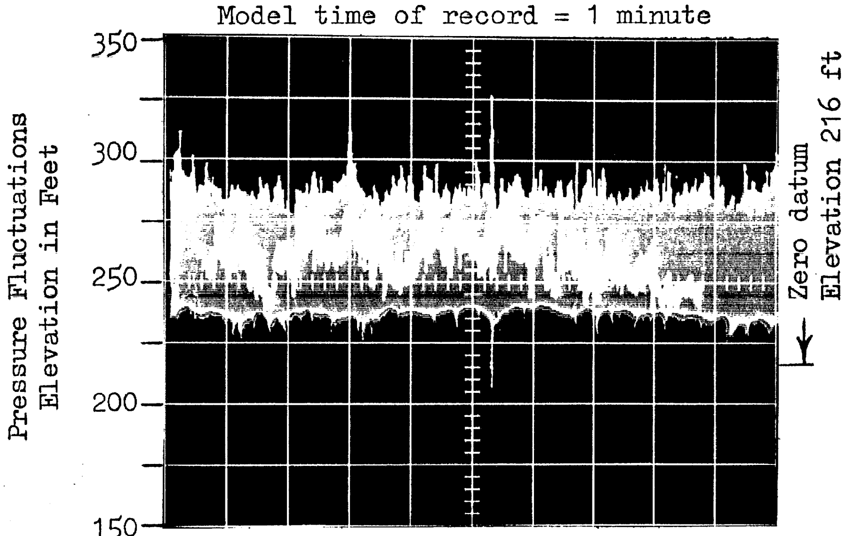
CULVER-GOODMAN MODEL STUDIES CONTROL STRUCTURE MODEL Harza Engineering Co., Chicago, Illinois Lozier Engineers, Inc., Rochester, N.Y. Division of Pure Waters, Monroe Co., N.Y.		
SAINT ANTHONY FALLS HYDRAULIC LABORATORY UNIVERSITY OF MINNESOTA		
DRAWN WQD	CHECKED WQD	APPROVED
SCALE	DATE 2/7/78	NO. 260AA2317- 9

Model time of record = 10 seconds



Gates open - 5 & 6 , T.W. = 0 ft
Q_I = 0-2500 cfs, Q_D = 0-1060 cfs

Model time of record = 1 minute



Gates open - 5 & 6 , T.W = 228.5 ft
Q_I = 2500 cfs, Q_W = 1440 cfs, Q_D = 1060 cfs

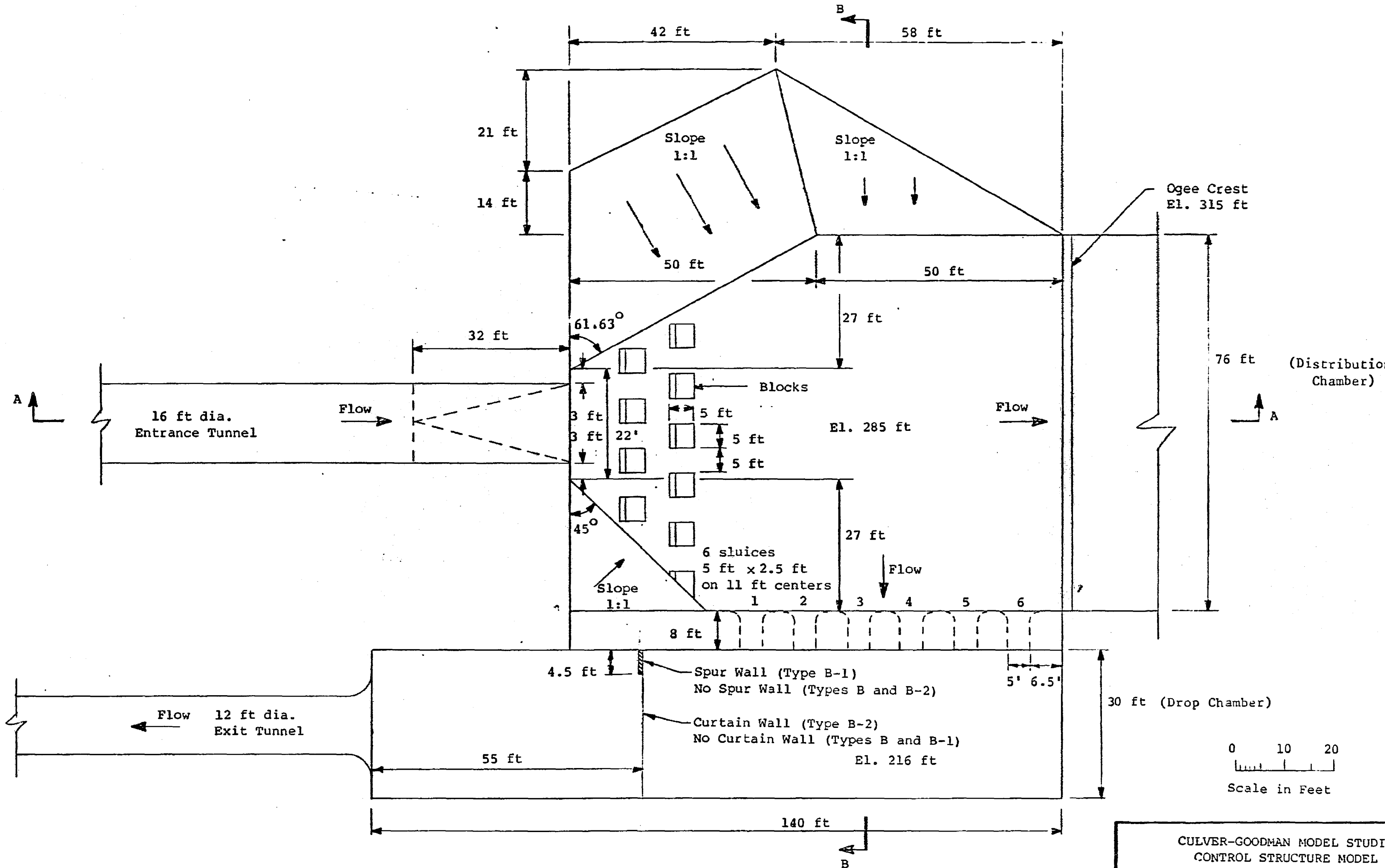
TYPE A-2 CONTROL STRUCTURE
Typical Pressure Fluctuations - Tap 1
Model Scale 1:16

The tap was located on the drop chamber floor along the centerline of sluice 5 at the wall opposite from the sluice. The fluctuations were recorded with a chamber mounted 25 psi transducer.

CULVER-GOODMAN MODEL STUDIES
CONTROL STRUCTURE MODEL
Harza Engineering Co., Chicago, Illinois
Lozier Engineers, Inc., Rochester, N.Y.
Division of Pure Waters, Monroe Co., N.Y.

SAINT ANTHONY FALLS HYDRAULIC LABORATORY
UNIVERSITY OF MINNESOTA

DRAWN WQD	CHECKED	APPROVED
SCALE	DATE 2/7/78	NO. 260AA2317-19



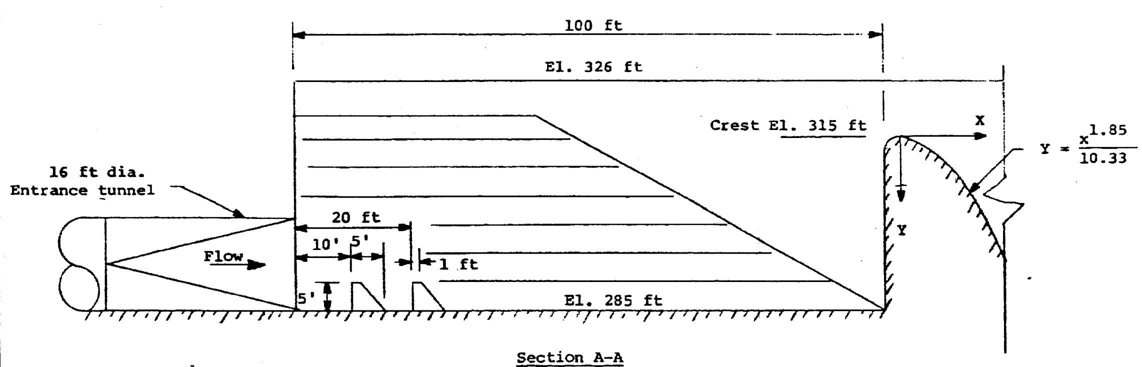
TYPES B, B-1 AND B-2 CONTROL STRUCTURES
Model Geometries Tested
Model Scale 1:16
Based on Harza Engineering Co. drawings
Nos. 915SKH300 R3 and 301 R3.

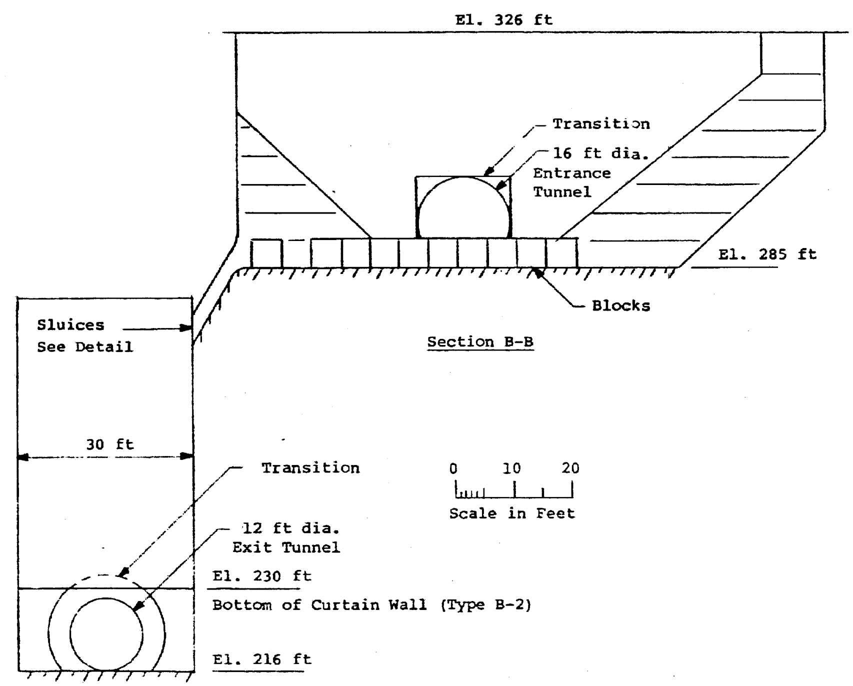
CULVER-GOODMAN MODEL STUDIES
CONTROL STRUCTURE MODEL
Harza Engineering Co., Chicago, Illinois
Lozier Engineers, Inc., Rochester, N.Y.
Division of Pure Waters, Monroe Co., N.Y.

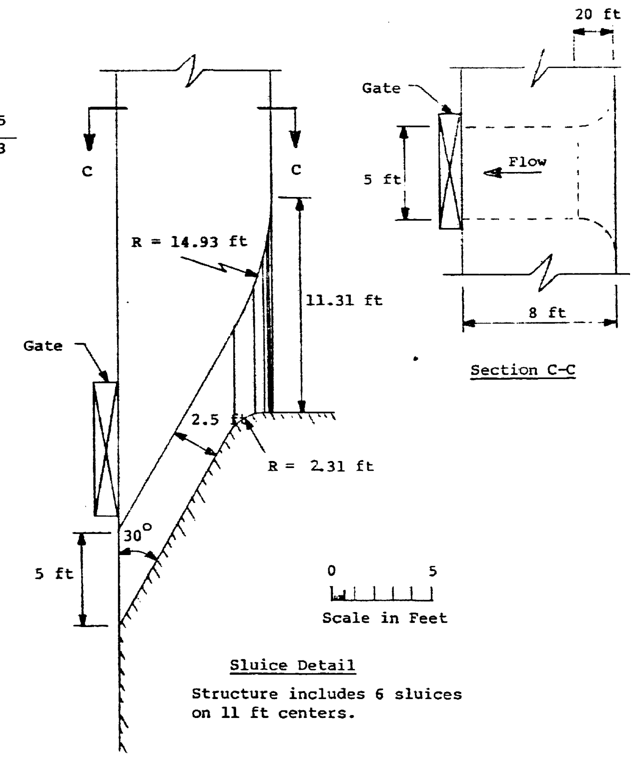
SAINT ANTHONY FALLS HYDRAULIC LABORATORY
UNIVERSITY OF MINNESOTA

DRAWN DA	CHECKED	APPROVED
SCALE	DATE 3/19/80	NO 260-B503-21

CHART 16







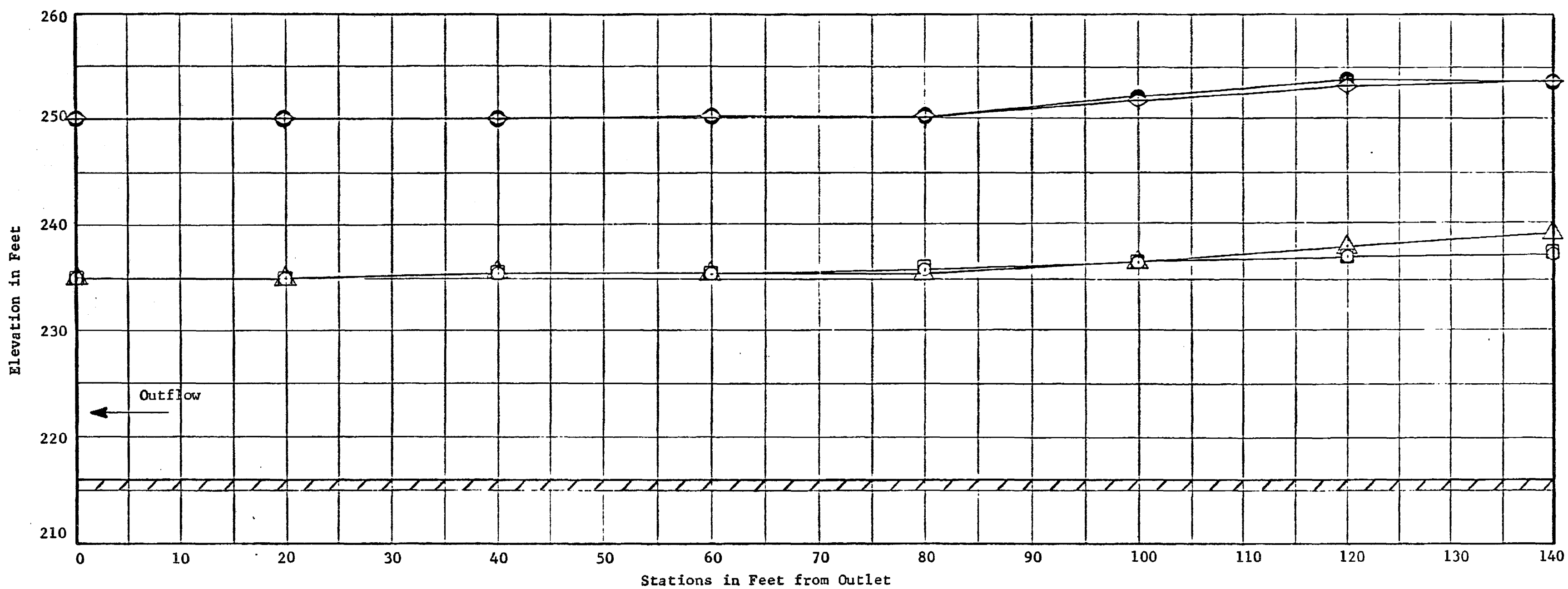
TYPES B, B-1, AND B-2 CONTROL STRUCTURES
Model Geometries Tested
Model Scale 1:16
Based on Harza Engineering Co. drawings
Nos. 915SKH300 R3 and 301 R3

CULVER-GOODMAN MODEL STUDIES
CONTROL STRUCTURE MODEL
Harza Engineering Co., Chicago, Illinois
Lozier Engineers, Inc., Rochester, N. Y.
Division of Pure Waters, Monroe Co., N.Y.

SAINT ANTHONY FALLS HYDRAULIC LABORATORY
UNIVERSITY OF MINNESOTA

DRAWN DA	CHECKED [signature]	APPROVED
SCALE	DATE 3/19/80	NO 26?A3538-22

CHART 17



Symbol	Gates Open	T.W. ft	Q_I cfs	Q_W cfs	Q_D cfs
⊙	All	235	500	0	500
⊡	All	235	1000	0	1000
△ (with dot)	5 & 6	235	1000	0	1000
◇ (with dot)	5 & 6	250	2500	1440	1060
+	5 & 6	250	5000	3900	1100
●	5 & 6	250	8700	7580	1120

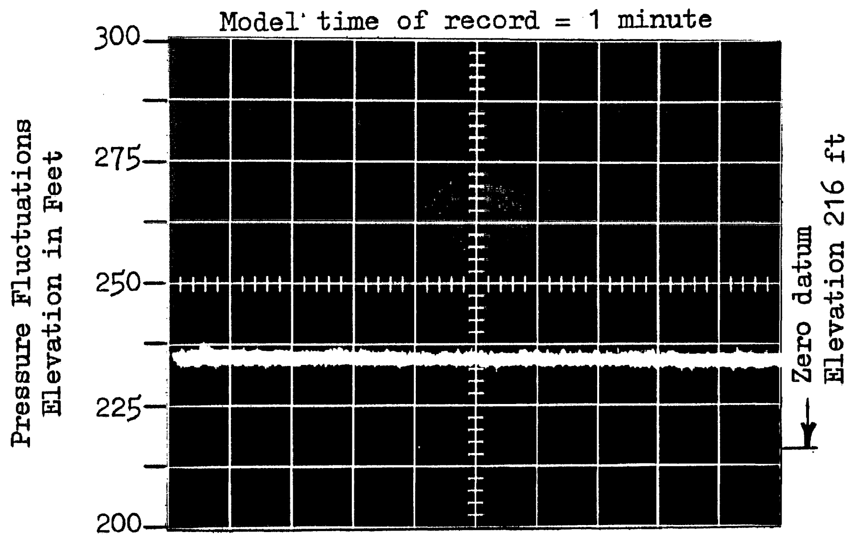
Type B CONTROL STRUCTURE
Water Surface Profiles
in Drop Chamber
Model Scale 1:16

CULVER-GOODMAN MODEL STUDIES
CONTROL STRUCTURE MODEL
Harza Engineering Co., Chicago, Illinois
Lozier Engineers, Inc., Rochester, N. Y.
Division of Pure Waters, Monroe Co., N.Y.

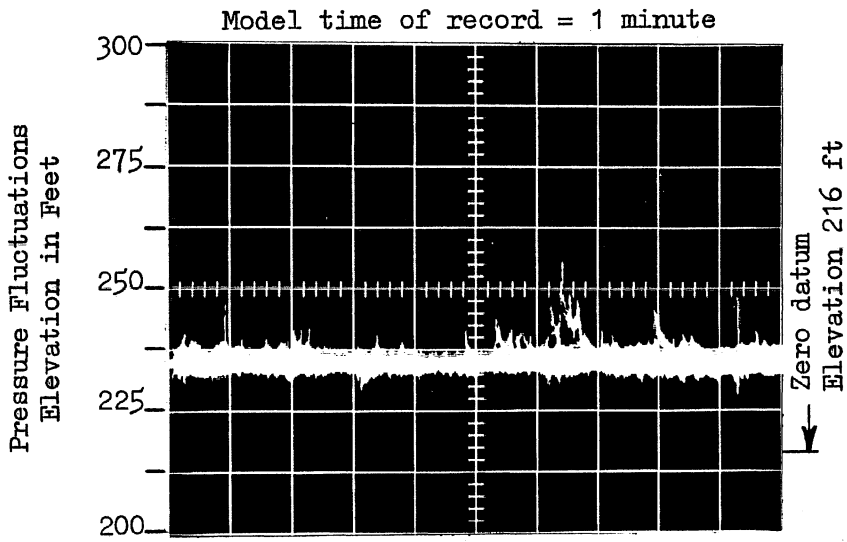
SAINT ANTHONY FALLS HYDRAULIC LABORATORY
UNIVERSITY OF MINNESOTA

DRAWN DA	CHECKED	APPROVED
SCALE	DATE 3/17/78	NO 260AB508-10

CHART 18



Gates open - all, T.W. = 235 ft
Q_I = 500 cfs, Q_W = 0 cfs, Q_D = 500 cfs



Gates open - all, T.W. = 235 ft
Q_I = 1000 cfs, Q_W = 0 cfs, Q_D = 1000 cfs

TYPE B CONTROL STRUCTURE
Typical Pressure Fluctuations - Tap 1
Model Scale 1:16

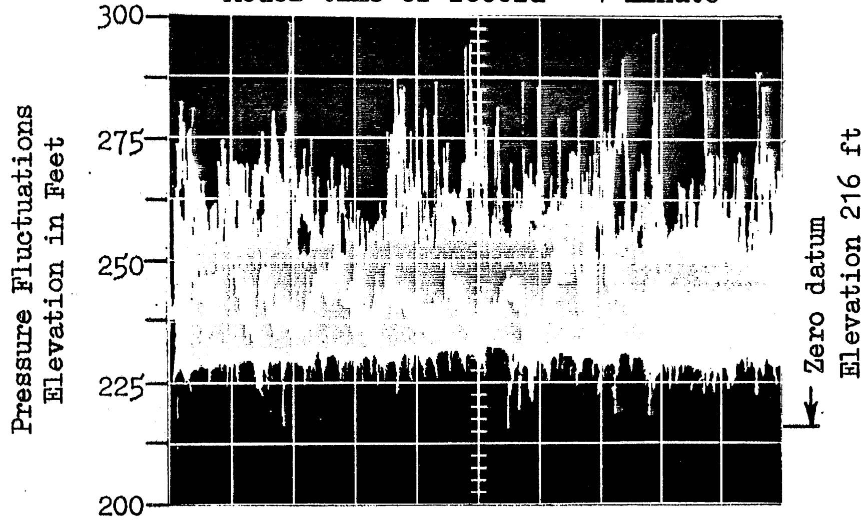
The tap was located on the drop chamber floor 20 ft from the inside wall and along the centerline of sluice 5. The fluctuations were recorded with a chamber mounted 25 psi transducer.

CULVER-COODMAN MODEL STUDIES
CONTROL STRUCTURE MODEL
Harza Engineering Co., Chicago, Illinois
Lozier Engineers, Inc., Rochester, N.Y.
Division of Pure Waters, Monroe Co., N.Y.

SAINT ANTHONY FALLS HYDRAULIC LABORATORY
UNIVERSITY OF MINNESOTA

DRAWN WQD	CHECKED DAA	APPROVED
SCALE	DATE 2/7/78	NO. 260AA2317-22

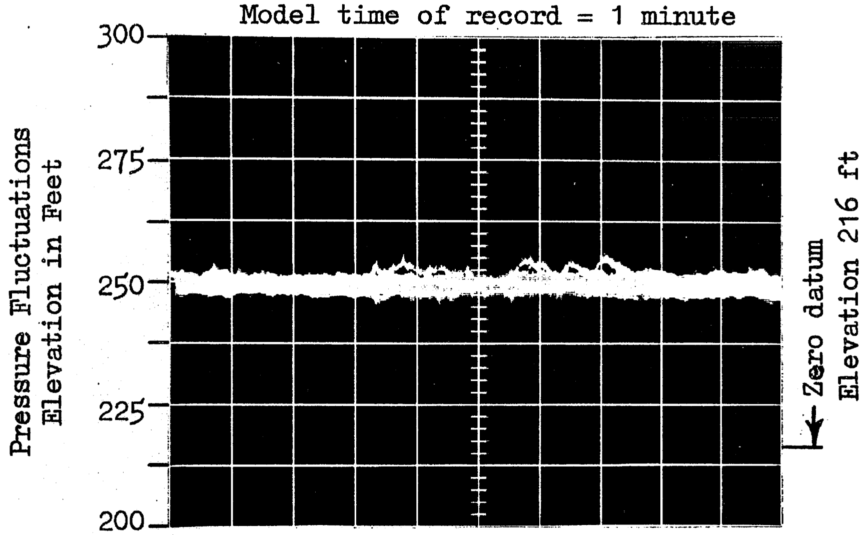
Model time of record = 1 minute



Gates open - 5 & 6, T.W. = 235 ft

Q_I = 1000 cfs, Q_W = 0 cfs, Q_D = 1000 cfs

Model time of record = 1 minute



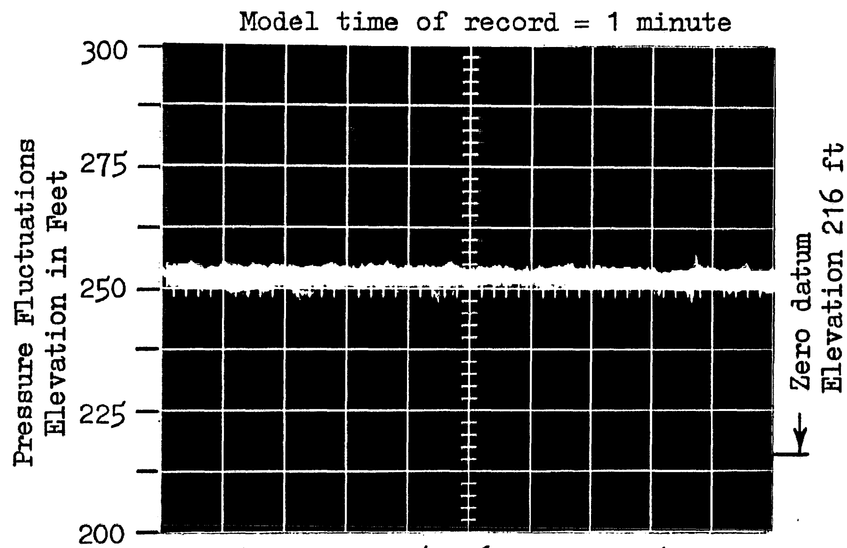
Gates open - 5 & 6, T.W. = 250 ft

Q_I = 2500 cfs, Q_W = 1440 cfs, Q_D = 1060 cfs

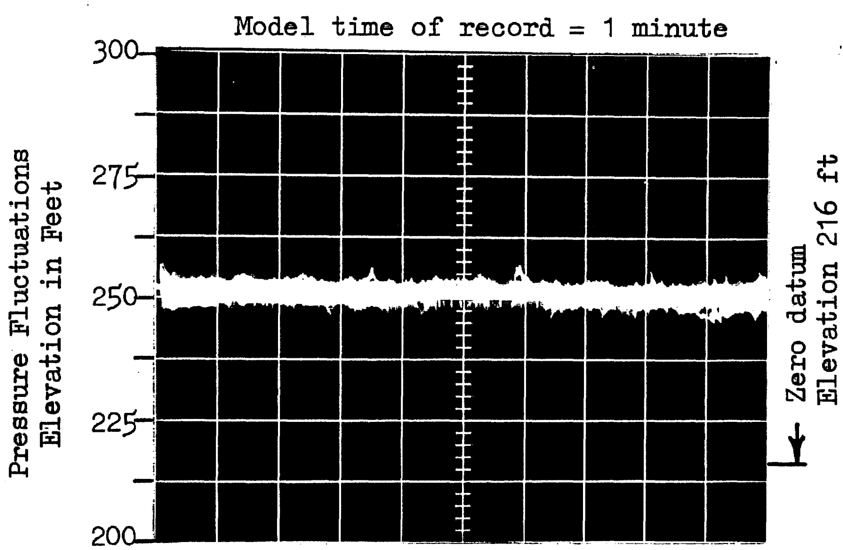
TYPE B CONTROL STRUCTURE
Typical Pressure Fluctuations - Tap 1
Model Scale 1:16

The tap was located on the drop chamber floor 20 ft from the inside wall and along the centerline of sluice 5. The fluctuations were recorded with a chamber mounted 25 psi transducer.

CULVER-GOODMAN MODEL STUDIES CONTROL STRUCTURE MODEL Harza Engineering Co., Chicago, Illinois Lozier Engineers, Inc., Rochester, N.Y. Division of Pure Waters, Monroe Co., N.Y.		
SAINT ANTHONY FALLS HYDRAULIC LABORATORY UNIVERSITY OF MINNESOTA		
DRAWN WQD	CHECKED DAA	APPROVED
SCALE	DATE 2/7/78	NO. 260AA2317-23



Gates open - 5 & 6, T.W. = 250 ft
Q_I = 5000 cfs, Q_W = 3900 cfs, Q_D = 1100 cfs



Gates open - 5 & 6, T.W. = 250 ft
Q_I = 8700 cfs, Q_W = 7580 cfs, Q_D = 1120 cfs

TYPE B CONTROL STRUCTURE
Typical Pressure Fluctuations - Tap 1
Model Scale 1:16

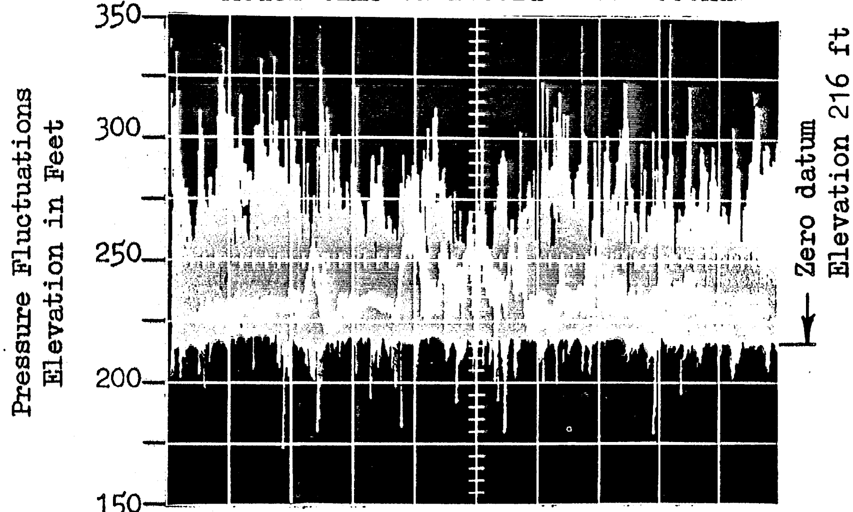
The tap was located on the drop chamber floor 20 ft from the inside wall and along the centerline of sluice 5. The fluctuations were recorded with a chamber mounted 25 psi transducer.

CULVER-GOODMAN MODEL STUDIES
CONTROL STRUCTURE MODEL
Harza Engineering Co., Chicago, Illinois
Lozier Engineers, Inc., Rochester, N.Y.
Division of Pure Waters, Monroe Co., N.Y

SAINT ANTHONY FALLS HYDRAULIC LABORATORY
UNIVERSITY OF MINNESOTA

DRAWN WQD	CHECKED DAA	APPROVED
SCALE	DATE 2/7/78	NO. 260AA2317-24

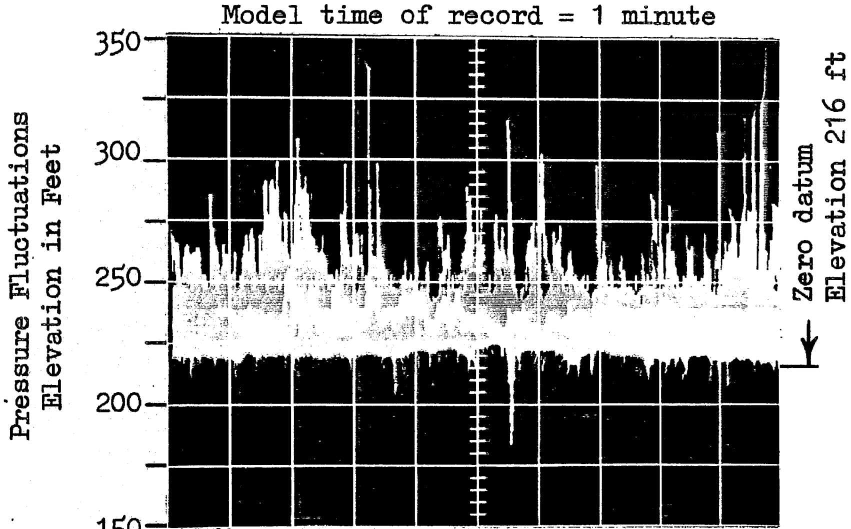
Model time of record = 10 seconds



Gates open - 5 & 6 , T.W. = 0 ft

Q_I = 0-2500 cfs, Q_D = 0-1060 cfs

Model time of record = 1 minute



Gates open - 5 & 6 , T.W = 228 ft

Q_I = 2500 cfs, Q_W = 1440 cfs, Q_D = 1060 cfs

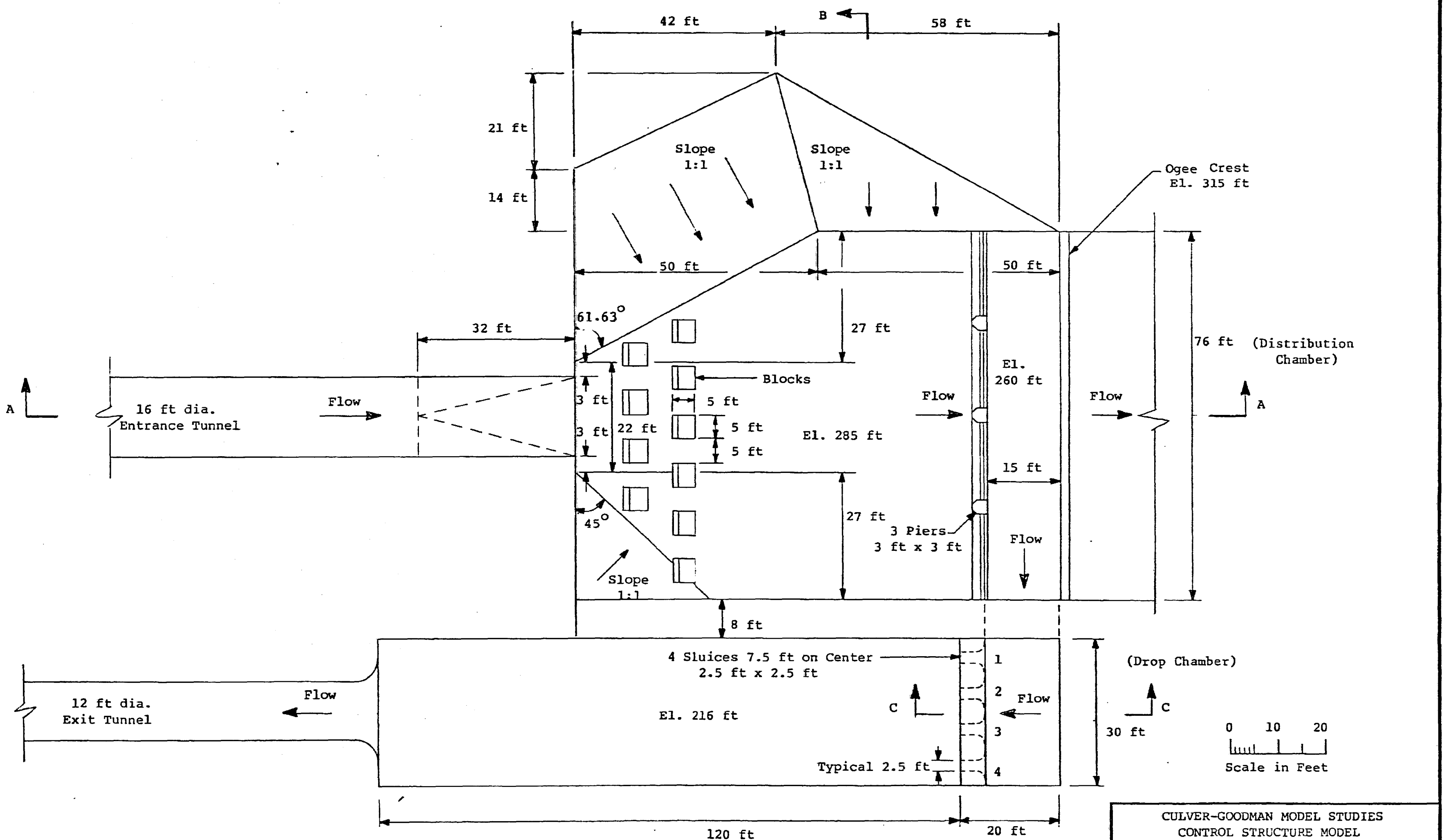
TYPE B CONTROL STRUCTURE
Typical Pressure Fluctuations - Tap 1
Model Scale 1:16

The tap was located on the drop chamber floor 20 ft from the inside wall and along the centerline of sluice 5. The fluctuations were recorded with a chamber mounted 25 psi transducer.

CULVER-GOODMAN MODEL STUDIES
CONTROL STRUCTURE MODEL
Harza Engineering Co., Chicago, Illinois
Lozier Engineers, Inc., Rochester, N.Y.
Division of Pure Waters, Monroe Co., N.Y.

SAINT ANTHONY FALLS HYDRAULIC LABORATORY
UNIVERSITY OF MINNESOTA

DRAWN WQD	CHECKED DAA	APPROVED
SCALE	DATE 2/7/78	NO. 260AA2317- 28



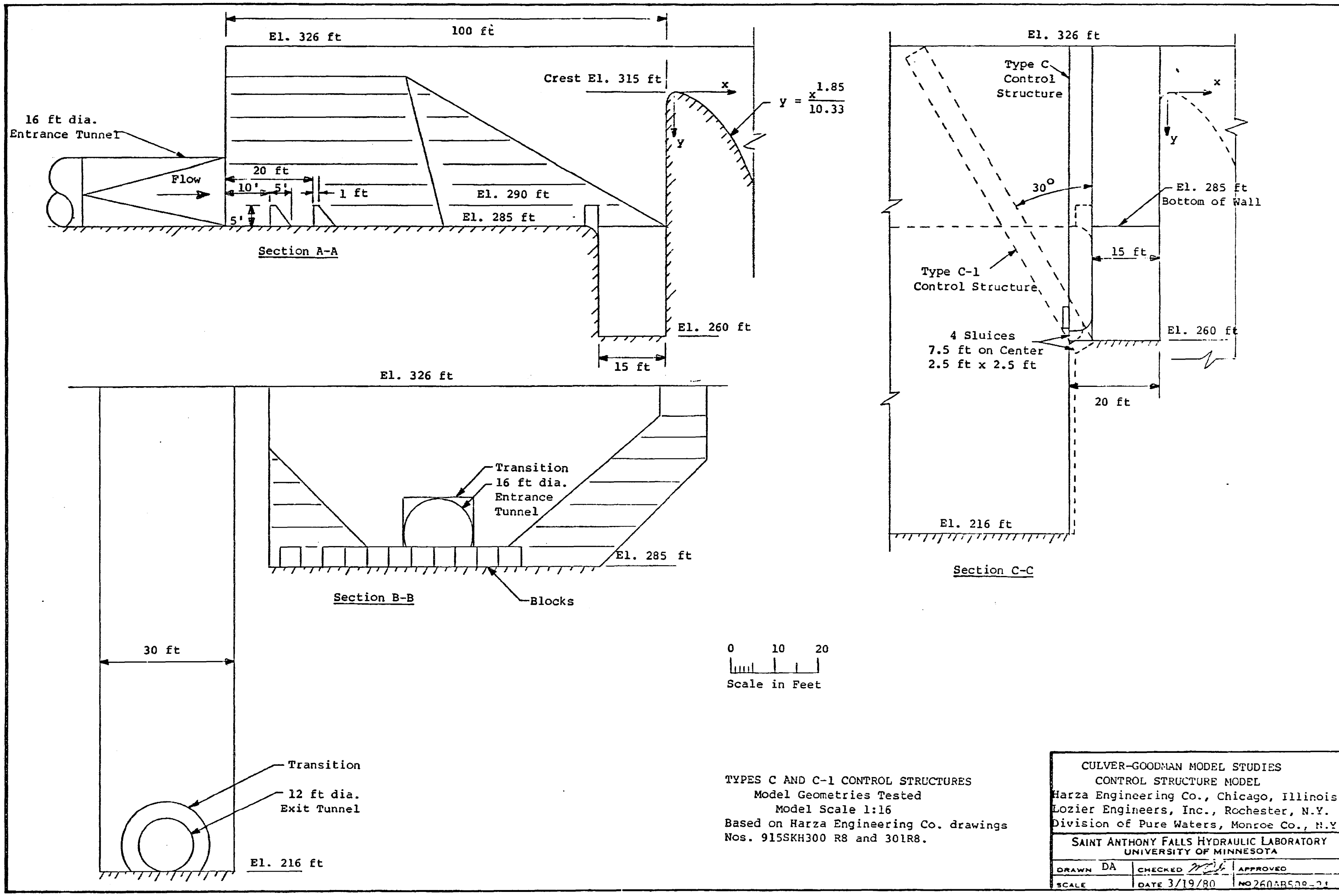
TYPES C AND C-1 CONTROL STRUCTURES
Model Geometries Tested
Model Scale 1:16
Based on Harza Engineering Co. drawings
Nos. 915SKH300R8 and 301R8.

CULVER-GOODMAN MODEL STUDIES
CONTROL STRUCTURE MODEL
Harza Engineering Co., Chicago, Illinois
Lozier Engineers, Inc., Rochester, N.Y.
Division of Pure Waters, Monroe Co., N.Y.

SAINT ANTHONY FALLS HYDRAULIC LABORATORY
UNIVERSITY OF MINNESOTA

DRAWN DA | CHECKED [signature] | APPROVED
SCALE | DATE 3/19/80 | NO 260AB508-23

CHART 23



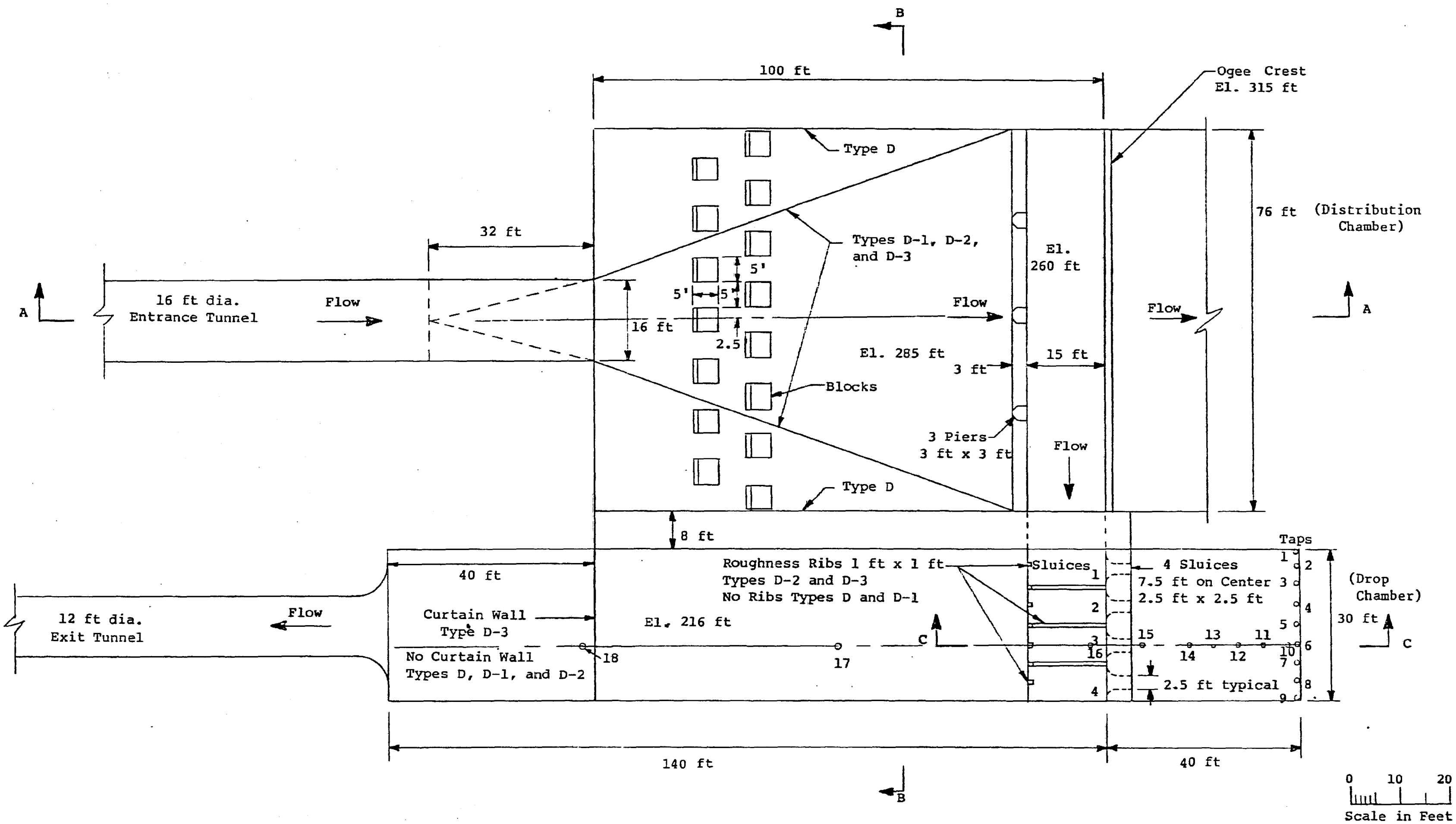
TYPES C AND C-1 CONTROL STRUCTURES
Model Geometries Tested
Model Scale 1:16
Based on Harza Engineering Co. drawings
Nos. 915SKH300 R8 and 301R8.

CULVER-GOODMAN MODEL STUDIES
CONTROL STRUCTURE MODEL
Harza Engineering Co., Chicago, Illinois
Lozier Engineers, Inc., Rochester, N.Y.
Division of Pure Waters, Monroe Co., N.Y.

SAINT ANTHONY FALLS HYDRAULIC LABORATORY
UNIVERSITY OF MINNESOTA

DRAWN DA	CHECKED	APPROVED
SCALE	DATE 3/19/80	NO 2604B508-21

CHART 24



TYPES D, D-1, D-2, AND D-3 CONTROL STRUCTURES
Model Geometries Tested
Model Scale 1:16
Based on Harza Engineering Co. drawings Nos. 915SKH300 R9 and 301 R9.

CULVER-GOODMAN MODEL STUDIES
CONTROL STRUCTURE MODEL
Harza Engineering Co., Chicago, Illinois
Lozier Engineers, Inc., Rochester, N.Y.
Division of Pure Waters, Monroe Co., N.Y.

SAINT ANTHONY FALLS HYDRAULIC LABORATORY
UNIVERSITY OF MINNESOTA

DRAWN DA	CHECKED	APPROVED
SCALE	DATE 3/19/80	NO. 260AB508-25

CHART 25

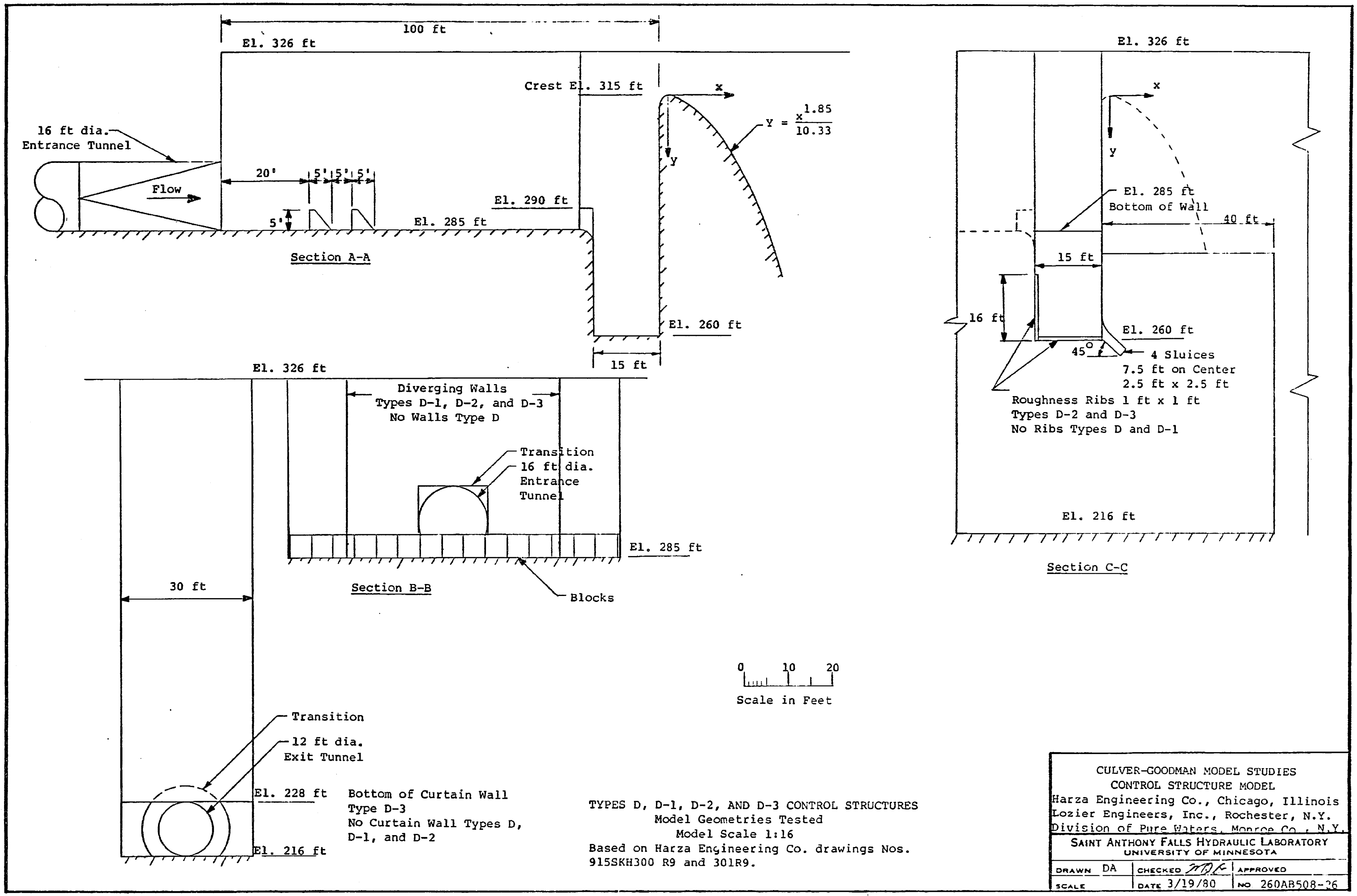
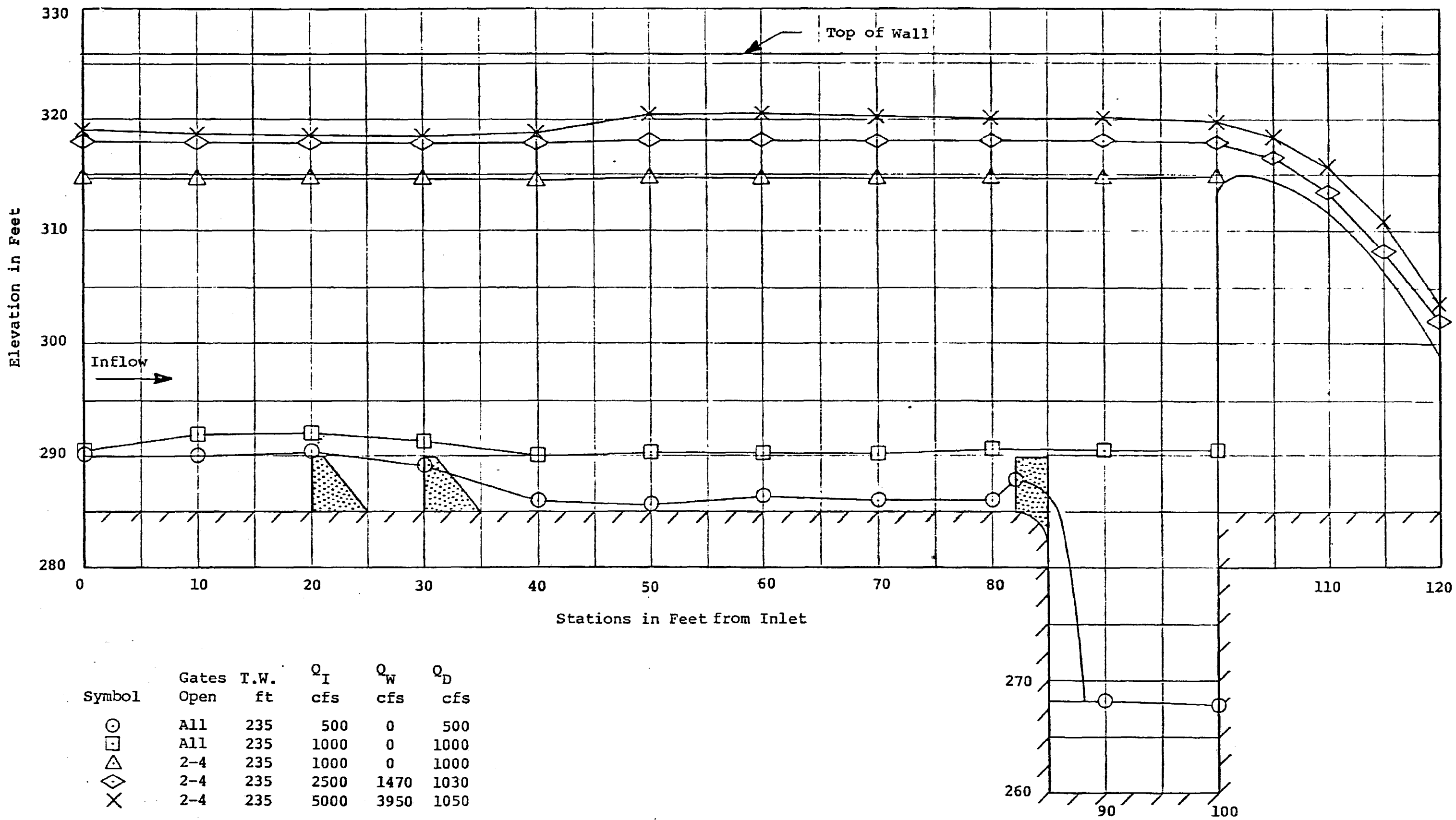

100 ft
El. 326 ft
Crest El. 315 ft
x
$Y = \frac{x^{1.85}}{10.33}$
y
16 ft dia.
Entrance Tunnel
20'
5' 5' 5'
Flow
5'
El. 290 ft
El. 285 ft
Section A-A
El. 260 ft
15 ft
El. 326 ft
Diverging Walls
Types D-1, D-2, and D-3
No Walls Type D
Transition
16 ft dia.
Entrance
Tunnel
El. 285 ft
Section B-B
Blocks
30 ft
Transition
12 ft dia.
Exit Tunnel
El. 228 ft
El. 216 ft
Bottom of Curtain Wall
Type D-3
No Curtain Wall Types D,
D-1, and D-2
El. 326 ft
x
y
El. 285 ft
Bottom of Wall
40 ft
15 ft
16 ft
El. 260 ft
45°
4 Sluices
7.5 ft on Center
2.5 ft x 2.5 ft
Roughness Ribs 1 ft x 1 ft
Types D-2 and D-3
No Ribs Types D and D-1
El. 216 ft
Section C-C
0 10 20
Scale in Feet
TYPES D, D-1, D-2, AND D-3 CONTROL STRUCTURES
Model Geometries Tested
Model Scale 1:16
Based on Harza Engineering Co. drawings Nos.
915SKH300 R9 and 301R9.
CULVER-GOODMAN MODEL STUDIES
CONTROL STRUCTURE MODEL
Harza Engineering Co., Chicago, Illinois
Lozier Engineers, Inc., Rochester, N.Y.
Division of Pure Waters, Monroe Co., N.Y.
SAINT ANTHONY FALLS HYDRAULIC LABORATORY
UNIVERSITY OF MINNESOTA
DRAWN DA
CHECKED
APPROVED
SCALE
DATE 3/19/80
NO 260AB508-26

CHART 26



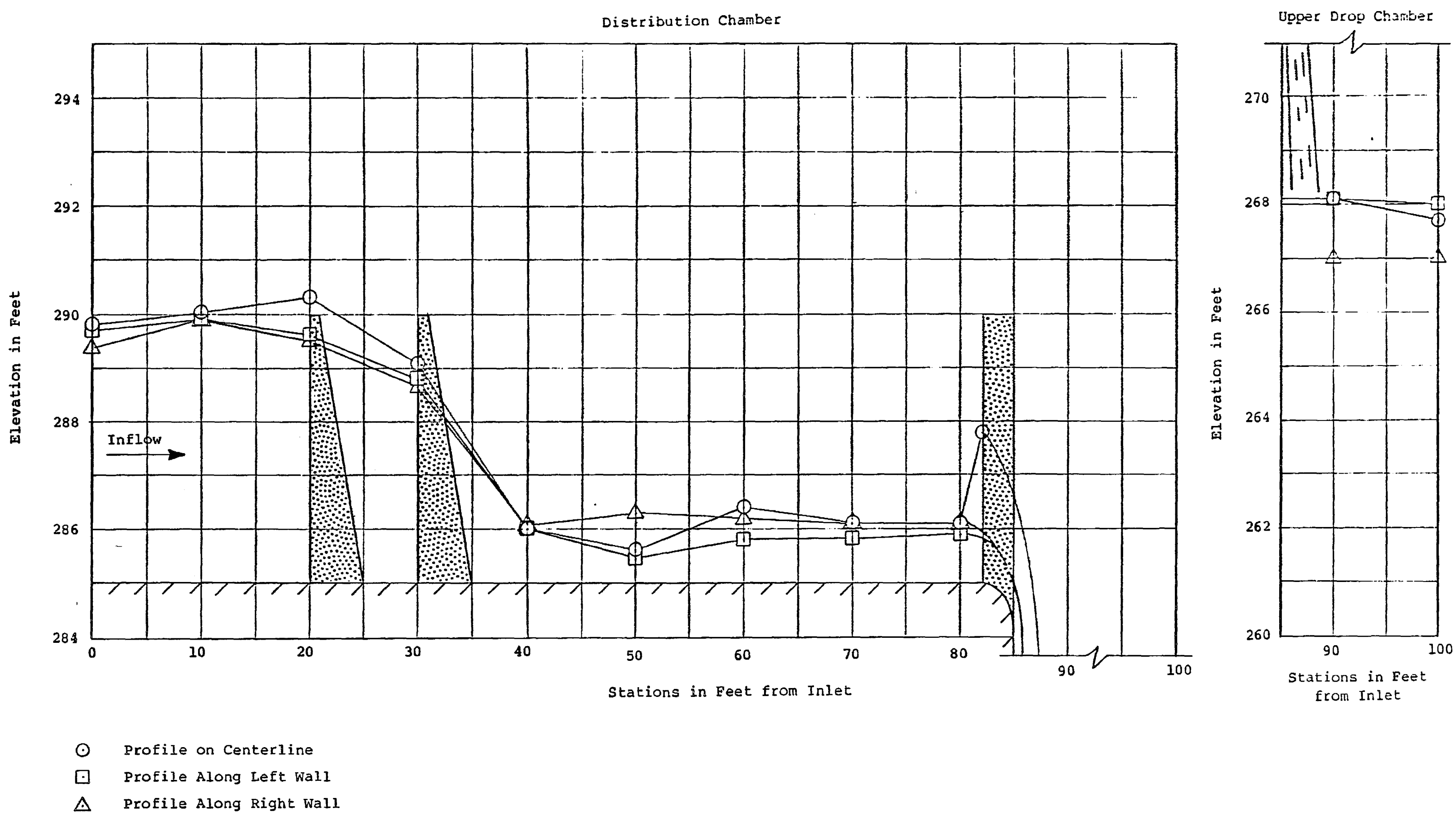
Symbol	Gates Open	T.W. ft	Q_I cfs	Q_W cfs	Q_D cfs
⊙	All	235	500	0	500
⊡	All	235	1000	0	1000
△	2-4	235	1000	0	1000
◇	2-4	235	2500	1470	1030
×	2-4	235	5000	3950	1050

Type D-3 CONTROL STRUCTURE
Water Surface Profiles
in Distribution Chamber
Model Scale 1:16

CULVER-GOODMAN MODEL STUDIES
CONTROL STRUCTURE MODEL
Harza Engineering Co., Chicago, Illinois
Lozier Engineers, Inc., Rochester, N.Y.
Division of Pure Waters, Monroe Co., N.Y.
SAINT ANTHONY FALLS HYDRAULIC LABORATORY
UNIVERSITY OF MINNESOTA

DRAWN DA	CHECKED	APPROVED
SCALE	DATE 6/19/79	NO 260AB508-11

CHART 27



Type D-3 CONTROL STRUCTURE
Water Surface Profiles
in Distribution Chamber
and Upper Drop Chamber
Model Scale 1:16

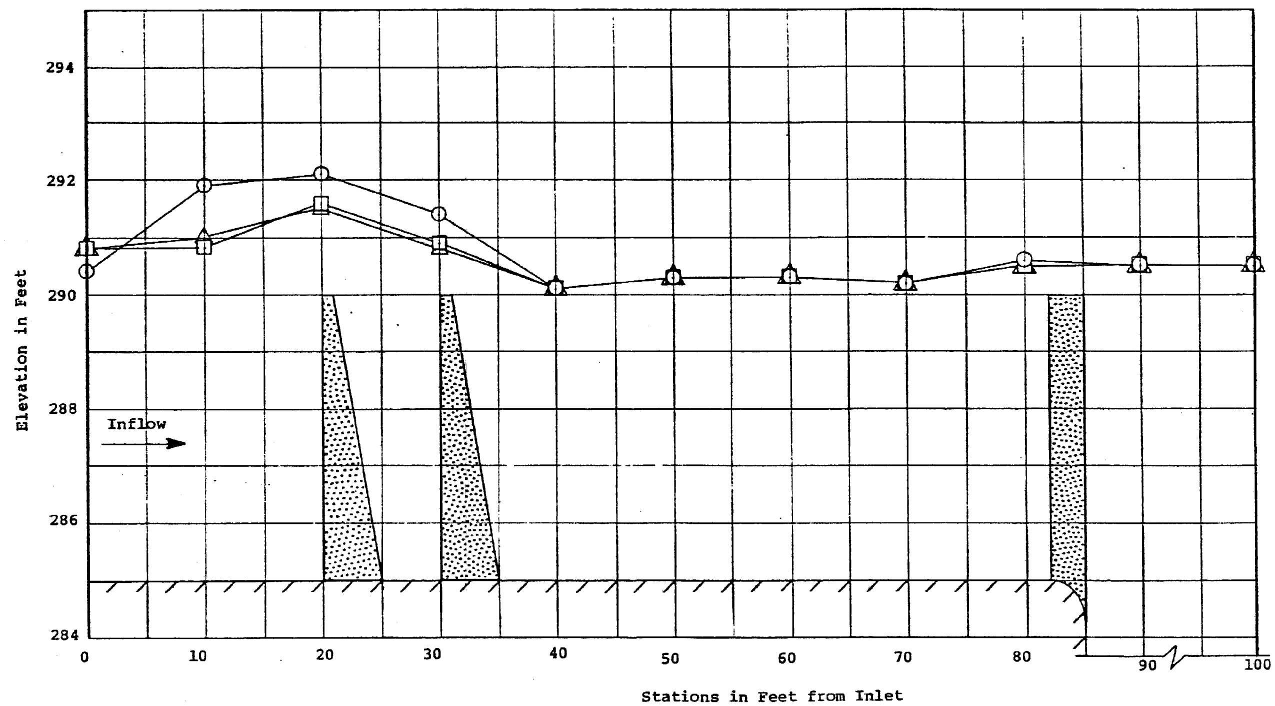
All Gates open, T.W. = 235 ft
Q_I = 500 cfs, Q_W = 0 cfs, Q_D = 500 cfs

CULVER-GOODMAN MODEL STUDIES
CONTROL STRUCTURE MODEL
Harza Engineering Co., Chicago, Illinois
Lozier Engineers, Inc., Rochester, N.Y.
Division of Pure Waters, Monroe Co., N.Y.

SAINT ANTHONY FALLS HYDRAULIC LABORATORY
UNIVERSITY OF MINNESOTA

DRAWN DA	CHECKED	APPROVED
SCALE	DATE 6/19/79	NO 260AB508-13

CHART 28



⊙ Profile on Centerline

⊡ Profile Along Left Wall

△ Profile Along Right Wall

Type D-3 CONTROL STRUCTURE
Water Surface Profiles
in Distribution Chamber
Model Scale 1:16

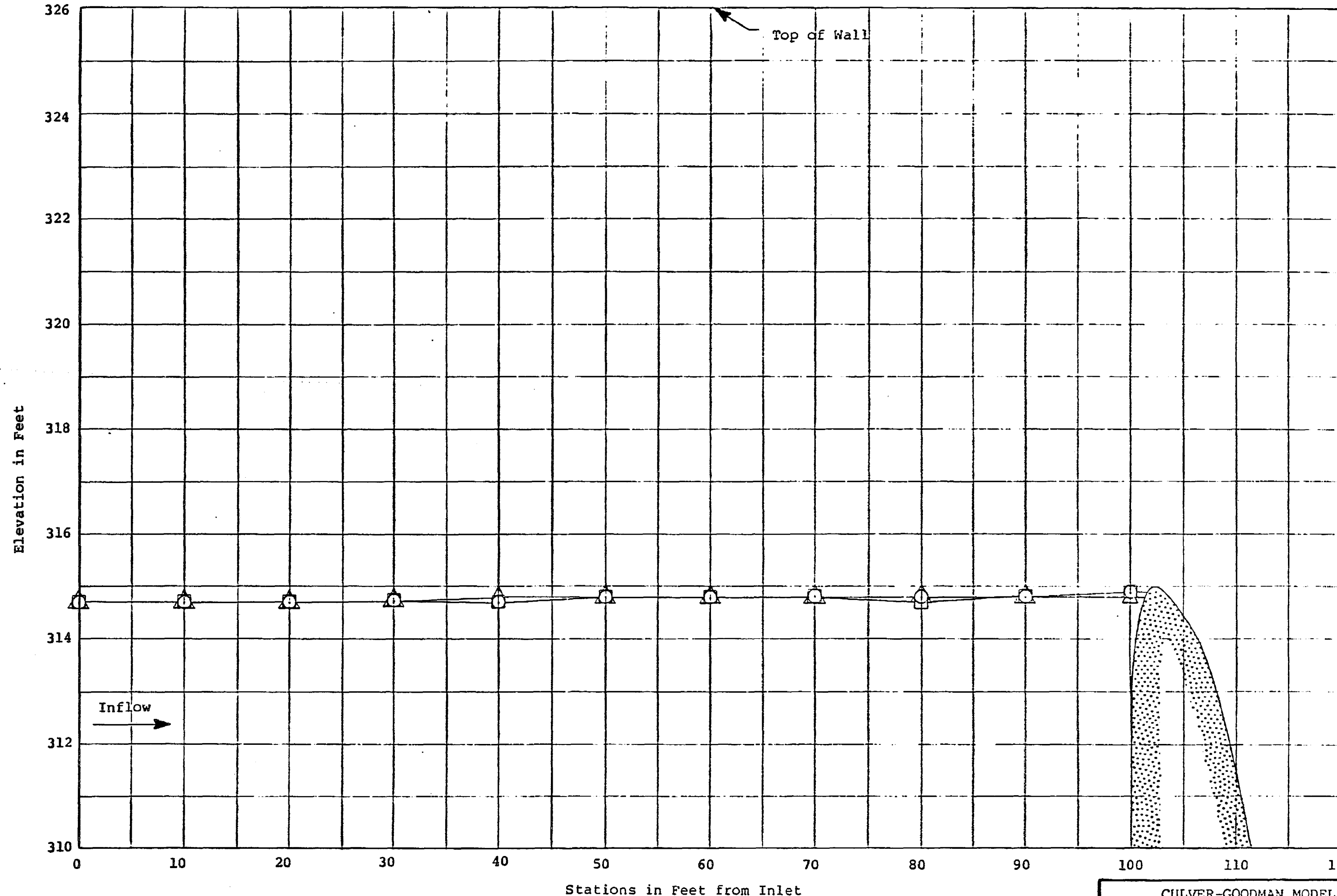
All Gates open, T.W. = 235 ft
Q_I = 1000 cfs, Q_W = 0 cfs, Q_D = 1000 cfs

CULVER-GOODMAN MODEL STUDIES
CONTROL STRUCTURE MODEL
Harza Engineering Co., Chicago, Illinois
Lozier Engineers, Inc., Rochester, N.Y.
Division of Pure Waters, Monroe Co., N.Y.

SAINT ANTHONY FALLS HYDRAULIC LABORATORY
UNIVERSITY OF MINNESOTA

DRAWN DA	CHECKED [illegible]	APPROVED
SCALE	DATE 6/19/79	NO. 260AB508-14

CHART 29



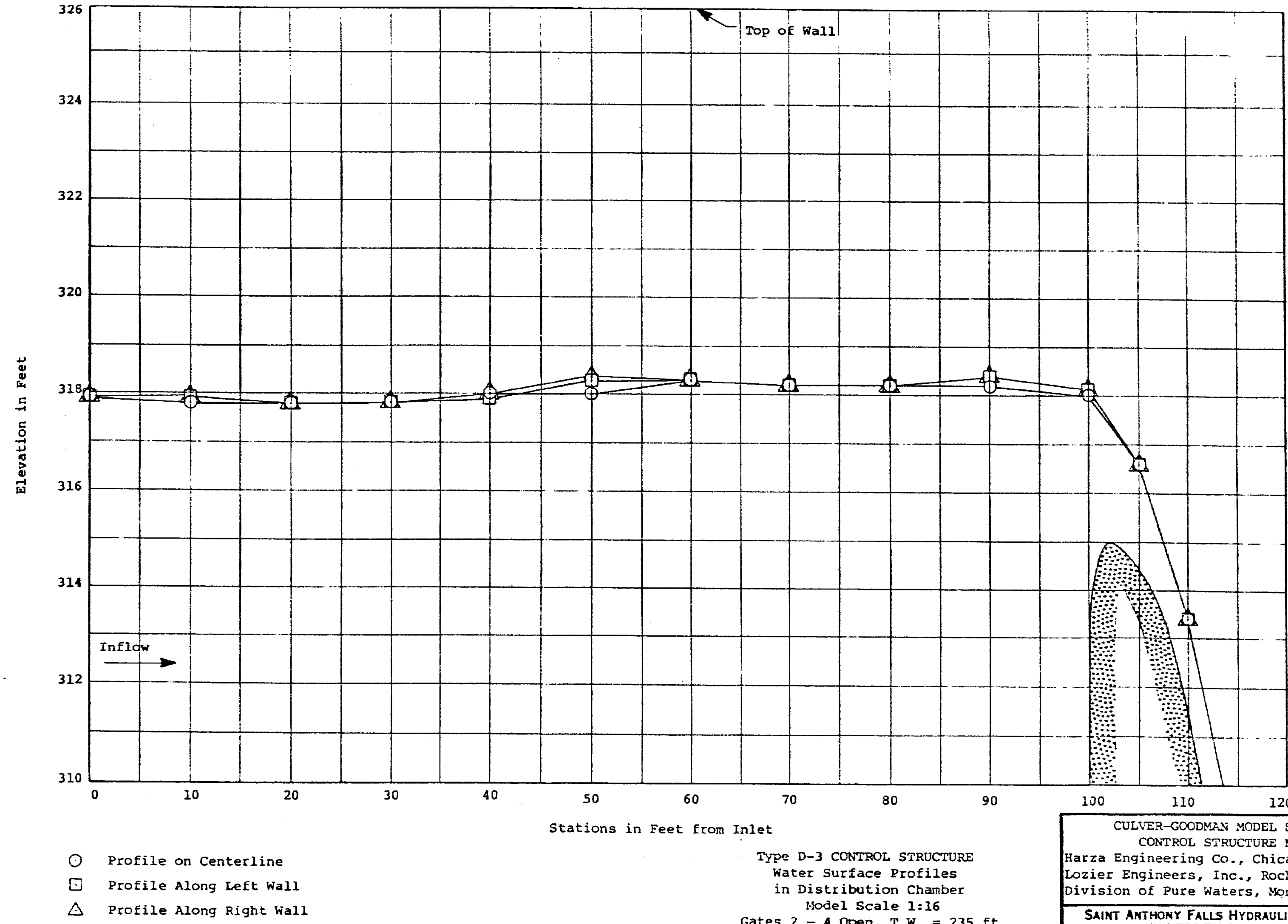
⊙ Profile on Centerline
⊡ Profile Along Left Wall
△ Profile Along Right Wall

Type D-3 CONTROL STRUCTURE
Water Surface Profiles
in Distribution Chamber
Model Scale 1:16

Gates 2 - 4 Open, T.W. = 235 ft
Q_I = 1000 cfs, Q_W = 0 cfs, Q_D = 1000 cfs

CULVER-GOODMAN MODEL STUDIES CONTROL STRUCTURE MODEL Harza Engineering Co., Chicago, Illinois Lozier Engineers, Inc., Rochester, N.Y. Division of Pure Waters, Monroe Co., N.Y.		
SAINT ANTHONY FALLS HYDRAULIC LABORATORY UNIVERSITY OF MINNESOTA		
DRAWN DA	CHECKED	APPROVED
SCALE	DATE 6/19/79	NO 260AB508-15

CHART 30



Type D-3 CONTROL STRUCTURE
Water Surface Profiles
in Distribution Chamber
Model Scale 1:16
Gates 2 – 4 Open, T.W. = 235 ft
Q_I = 2500 cfs, Q_W = 1470 cfs, Q_D = 1030 cfs

CULVER-GOODMAN MODEL STUDIES
CONTROL STRUCTURE MODEL
Harza Engineering Co., Chicago, Illinois
Lozier Engineers, Inc., Rochester, N.Y.
Division of Pure Waters, Monroe Co., N.Y.

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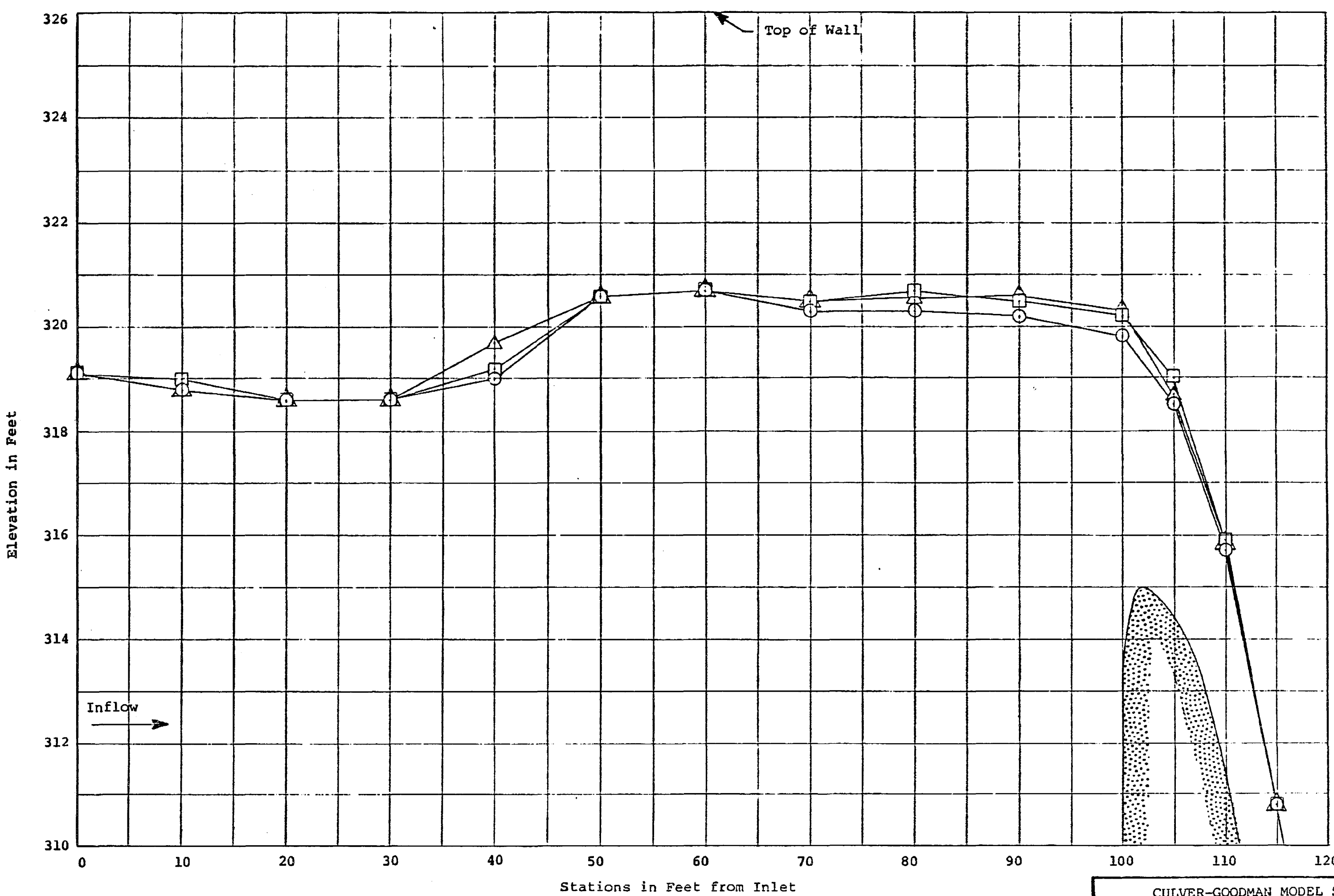
UNIVERSITY OF MINNESOTA

DRAWN DA	CHECKED	APPROVED
SCALE	DATE 6/19/79	NO 260AB508-16

CHART 31



⊙ Profile on Centerline

⊡ Profile Along Left Wall

△ Profile Along Right Wall

Type D-3 CONTROL STRUCTURE
Water Surface Profiles
in Distribution Chamber
Model Scale 1:16

Gates 2 - 4 Open, T.W. = 235 ft

Q_I = 5000 cfs, Q_W = 3950 cfs, Q_D = 1050 cfs

CULVER-GOODMAN MODEL STUDIES
CONTROL STRUCTURE MODEL
Harza Engineering Co., Chicago, Illinois
Lozier Engineers, Inc., Rochester, N.Y.
Division of Pure Waters, Monroe Co., N.Y

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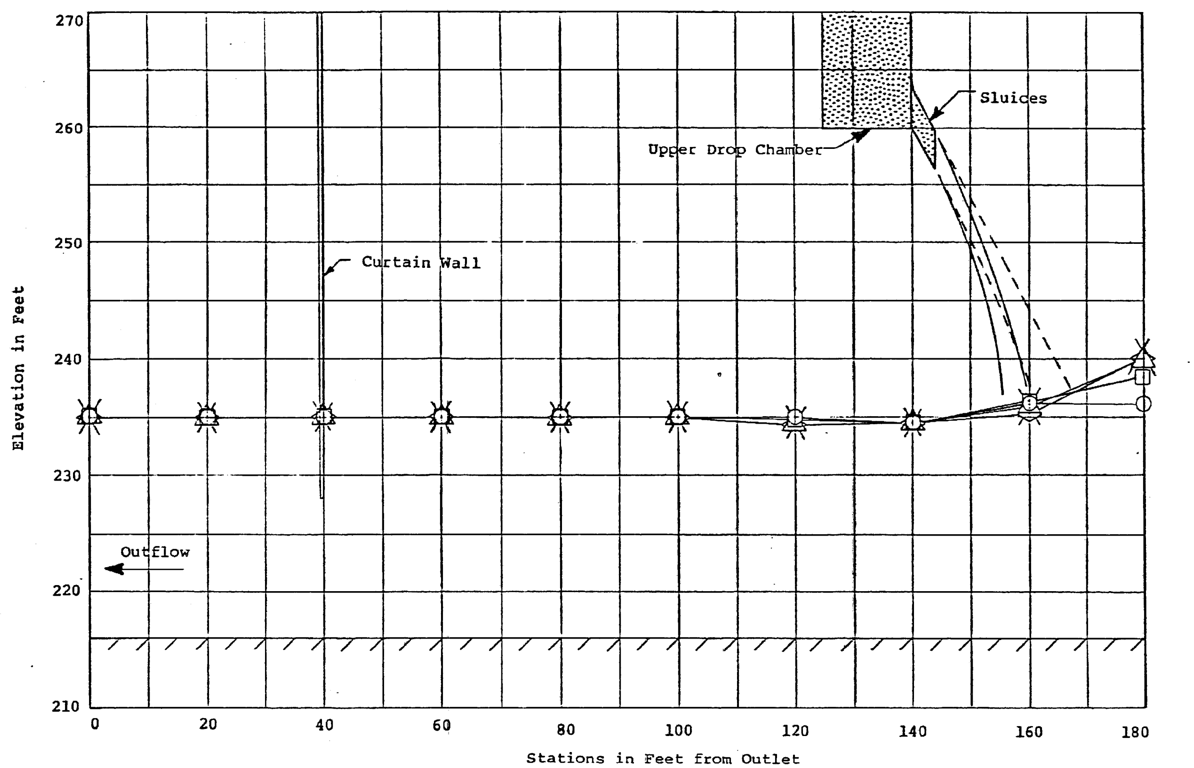
DRAWN DA	CHECKED	APPROVED
SCALE	DATE 6/19/79	NO 260AB508-17

CHART 32



Symbol	Gates Open	T.W. ft	Q_I cfs	Q_W cfs	Q_D cfs
⊙	All	235	500	0	500
⊡	All	235	1000	0	1000
△	2-4	235	1000	0	1000
◇	2-4	235	2500	1470	1030
×	2-4	235	5000	3950	1050

Type D-3 CONTROL STRUCTURE
Water Surface Profiles
in Drop Chamber
Model Scale 1:16

CULVER-GOODMAN MODEL STUDIES
CONTROL STRUCTURE MODEL
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Lozier Engineers, Inc., Rochester, N.Y.
Division of Pure Waters, Monroe Co., N.Y.

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DRAWN DA	CHECKED	APPROVED
SCALE	DATE 6/19/79	NO. 260AB508-12

CHART 33

Piezometric Pressures in Drop Chamber

	Flow Conditions				
Gates Open	All	All	2-4	2-4	2-4
T.W. - FT	235	235	235	235	235
Q_I - CFS	500	1000	1000	2500	5000
Q_W - CFS	0	0	0	1470	3950
Q_D - CFS	500	1000	1000	1030	1050
Tap No.	Piezometric Pressures - Elevation in Ft of Water				
1	235.6	238.3	240.3	240.3	240.3
2	235.6	238.3	237.6	237.6	237.7
3	235.6	237.3	239.6	238.9	239.6
4	235.5	237.2	240.9	240.9	239.9
5	235.5	237.2	240.3	240.3	240.3
6	235.3	237.7	241.6	242.3	242.3
7	235.3	237.3	240.9	240.9	241.6
8	235.5	237.3	242.3	243.6	243.6
9	235.6	237.3	242.3	243.6	243.6
10	235.3	236.3	238.8	239.3	240.0
11	235.3	235.9	235.3	235.2	236.3
12	234.9	235.5	233.7	233.5	233.9
13	235.9	234.8	234.3	234.0	234.0
14	234.8	234.9	234.4	234.1	234.7
15	234.8	234.8	234.5	234.3	234.7
16	234.8	234.8	234.5	234.3	234.3
17	234.9	234.9	234.8	234.7	234.9
18	234.9	234.9	234.8	234.7	234.9

TYPE D-3 CONTROL STRUCTURE
Piezometric Pressures in Drop Chamber
Model Scale 1:16

CULVER-GOODMAN MODEL STUDIES
CONTROL STRUCTURE MODEL
Harza Engineering Co., Chicago, Illinois
Lozier Engineers, Inc., Rochester, N.Y.
Division of Pure Waters, Monroe Co., N.Y.

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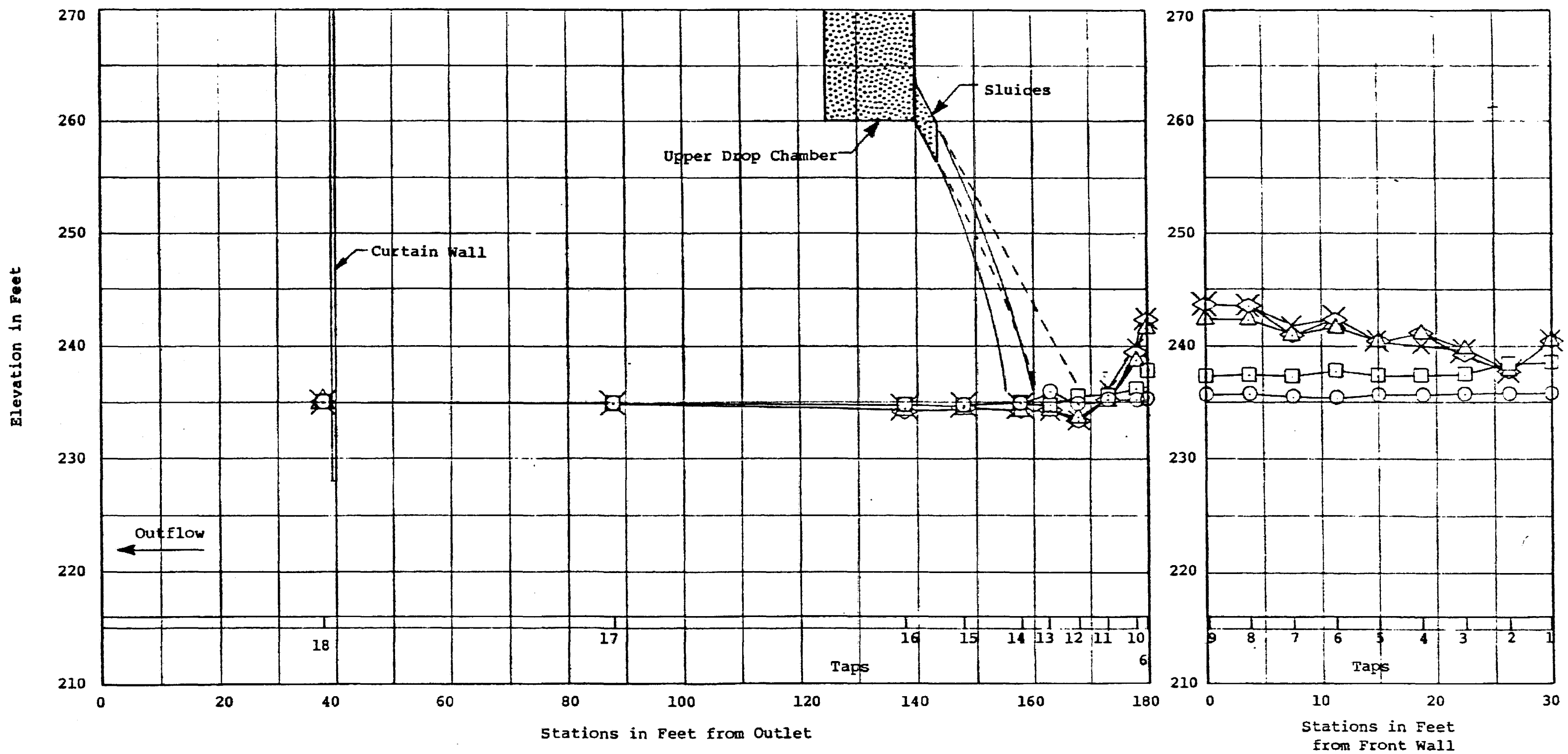
DRAWN WQD	CHECKED [signature]	APPROVED
SCALE	DATE 12/14/79	NO. 260AA2317-47



Symbol	Gates Open	T.W. ft	Q_I cfs	Q_W cfs	Q_D cfs
⊙	All	235	500	0	500
⊡	All	235	1000	0	1000
△	2-4	235	1000	0	1000
◇	2-4	235	2500	1470	1030
×	2-4	235	5000	3950	1050

Type D-3 CONTROL STRUCTURE
Piezometric Pressures
in Drop Chamber
Model Scale 1:16

CULVER-GOODMAN MODEL STUDIES
CONTROL STRUCTURE MODEL
Harza Engineering Co., Chicago, Illinois
Lozier Engineers, Inc., Rochester, N.Y.
Division of Pure Waters, Monroe Co., N.Y.

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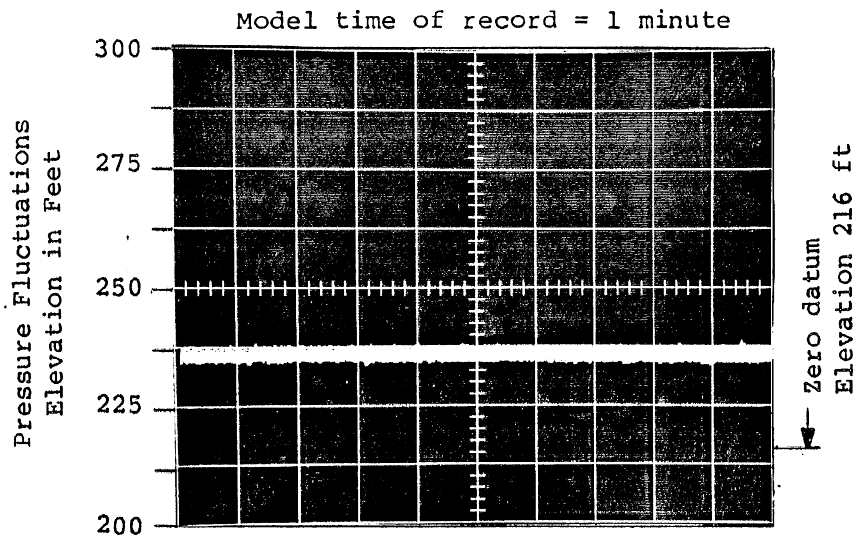
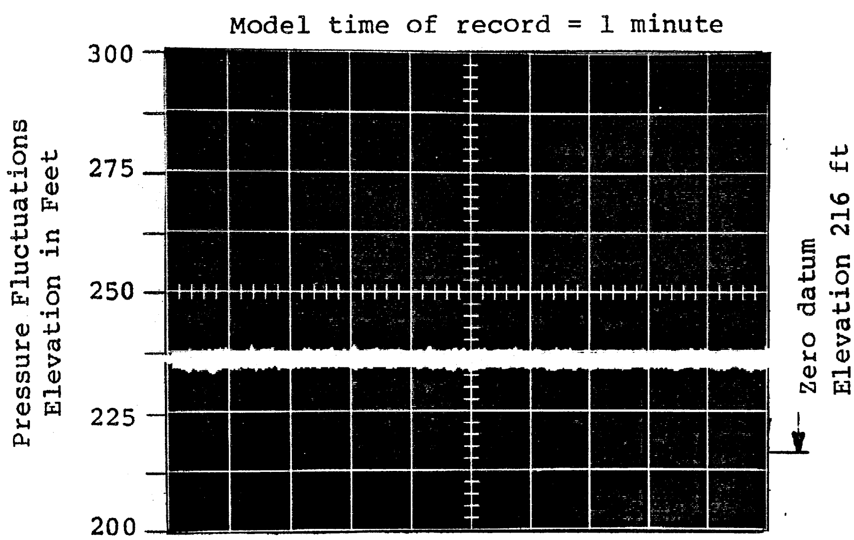
DRAWN DA | CHECKED | APPROVED
SCALE | DATE 6/19/79 | NO 260-3508-18

CHART 35



Tap 6



Tap 8

TYPE D-3 CONTROL STRUCTURE
Typical Pressure Fluctuations
Model Scale 1:16

Gates Open - all , T.W. = 235 ft

Q_I = 500 cfs, Q_W = 0 cfs, Q_D = 500 cfs

The fluctuations were recorded with a chamber mounted 25 psi transducer.

CULVER-GOODMAN MODEL STUDIES
CONTROL STRUCTURE MODEL
Harza Engineering Co., Chicago, Illinois
Lozier Engineers, Inc., Rochester, N.Y.
Division of Pure Waters, Monroe Co., N.Y.

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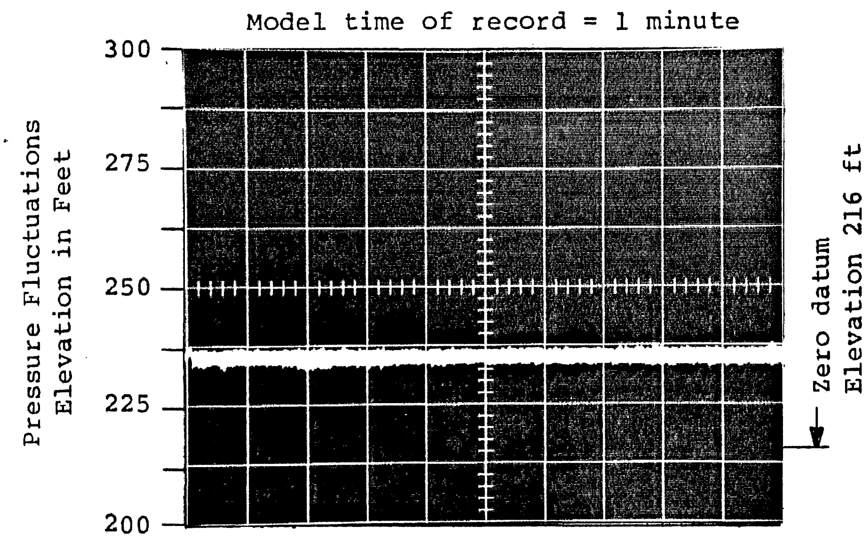
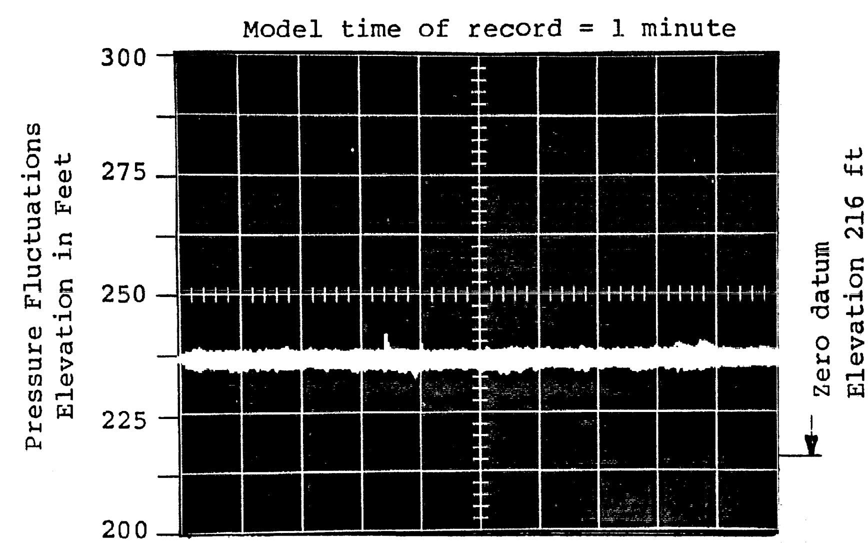
DRAWN DA	CHECKED [signature]	APPROVED
SCALE	DATE 12/14/79	NO. 260AA2317-31



Tap 11



Tap 13

TYPE D-3 CONTROL STRUCTURE
Typical Pressure Fluctuations
Model Scale 1:16

Gates Open - all , T.W. = 235 ft

Q_I = 500 cfs, Q_W = 0 cfs, Q_D = 500 cfs

The fluctuations were recorded with a chamber mounted 25 psi transducer.

CULVER-GOODMAN MODEL STUDIES
CONTROL STRUCTURE MODEL
Harza Engineering Co., Chicago, Illinois
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Division of Pure Waters, Monroe Co., N.Y.

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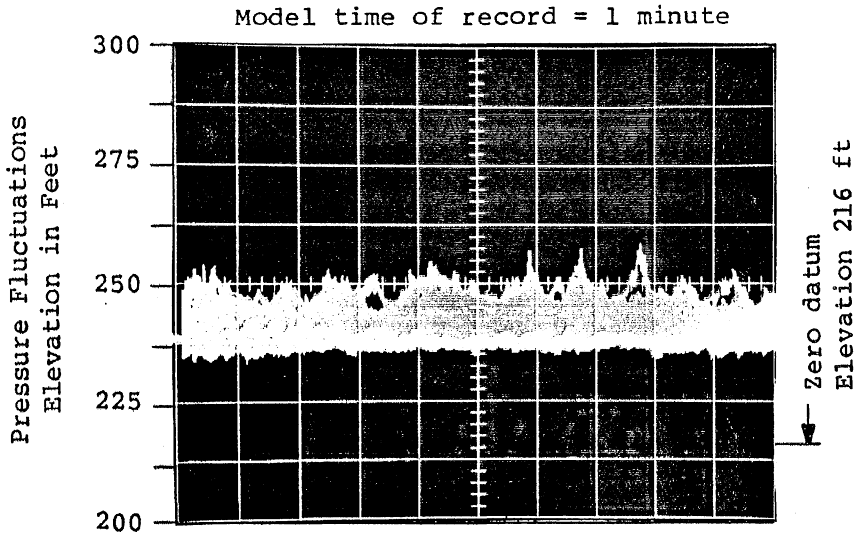
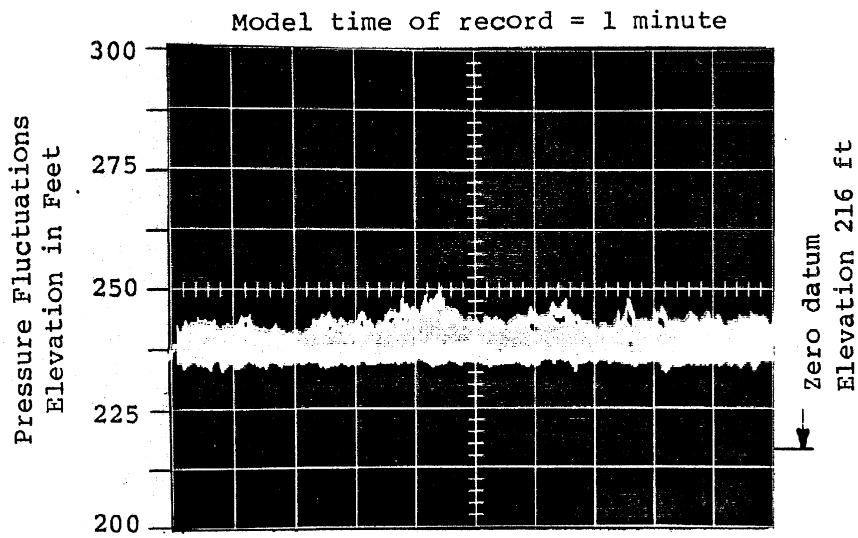
DRAWN DA	CHECKED [signature]	APPROVED
SCALE	DATE 12/14/79	NO. 260AA2317-32



Tap 6



Tap 8

TYPE D-3 CONTROL STRUCTURE
Typical Pressure Fluctuations
Model Scale 1:16

Gates Open - all, T.W. = 235 ft

Q_I = 1000 cfs, Q_W = 0 cfs, Q_D = 1000 cfs

The fluctuations were recorded with a chamber mounted 25 psi transducer.

CULVER-GOODMAN MODEL STUDIES
CONTROL STRUCTURE MODEL
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Division of Pure Waters, Monroe Co., N.Y.

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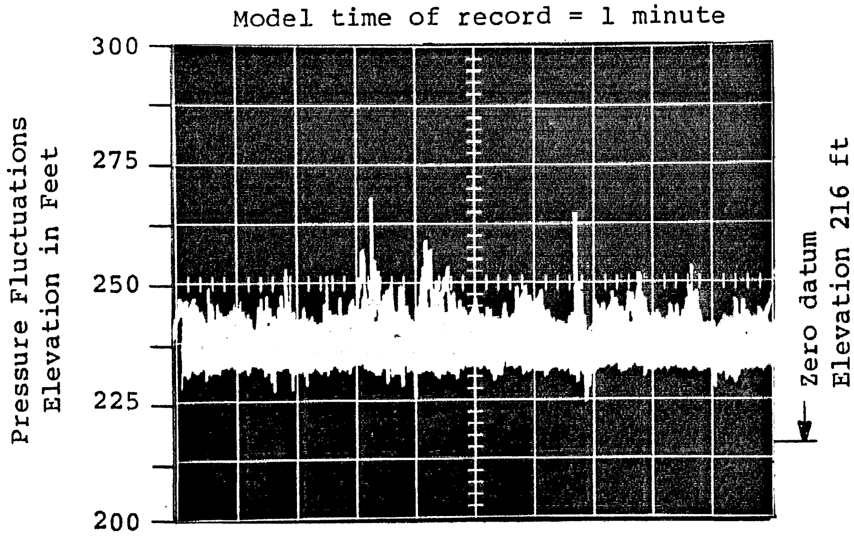
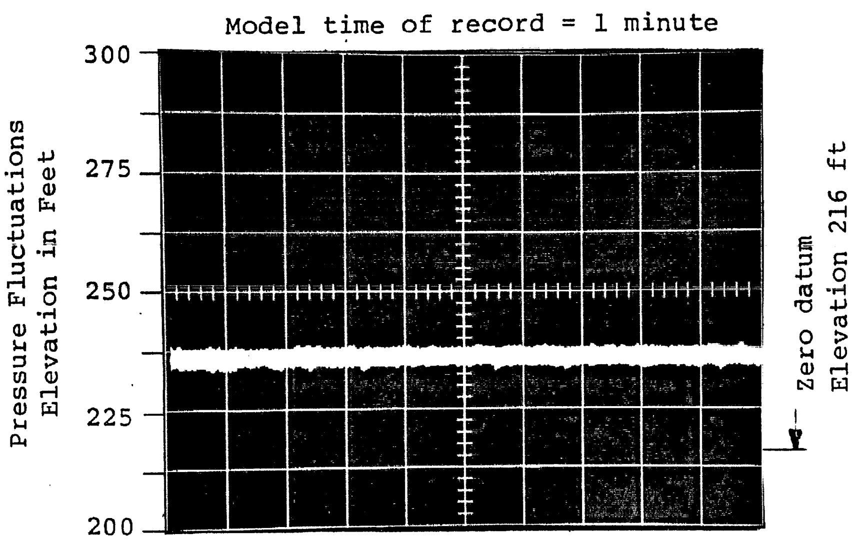
DRAWN DA	CHECKED [signature]	APPROVED
SCALE	DATE 12/14/79	NO. 260AA2317-33



Tap 11



Tap 13

TYPE D-3 CONTROL STRUCTURE
Typical Pressure Fluctuations
Model Scale 1:16

Gates Open - all , T.W. = 235 ft

Q_I = 1000 cfs, Q_W = 0 cfs, Q_D = 1000 cfs

The fluctuations were recorded with a chamber mounted 25 psi transducer.

CULVER-GOODMAN MODEL STUDIES
CONTROL STRUCTURE MODEL
Harza Engineering Co., Chicago, Illinois
Lozier Engineers, Inc., Rochester, N.Y.
Division of Pure Waters, Monroe Co., N.Y.

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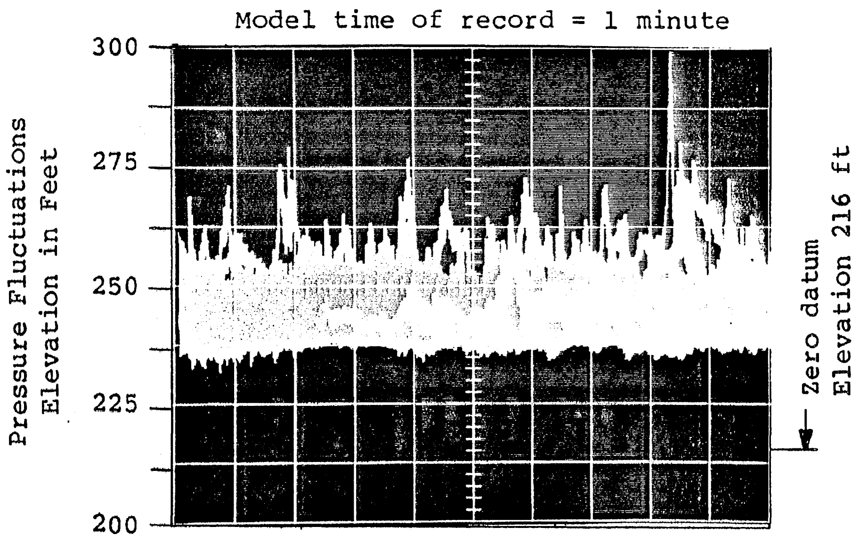
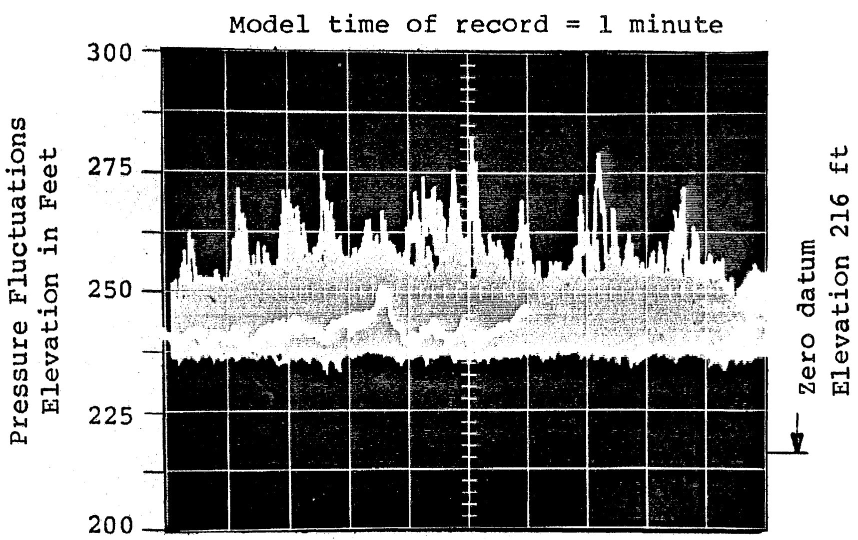
UNIVERSITY OF MINNESOTA

DRAWN DA	CHECKED	APPROVED
SCALE	DATE 12/14/79	NO. 260AA2317-34



Tap 6



Tap 8

TYPE D-3 CONTROL STRUCTURE
Typical Pressure Fluctuations
Model Scale 1:16

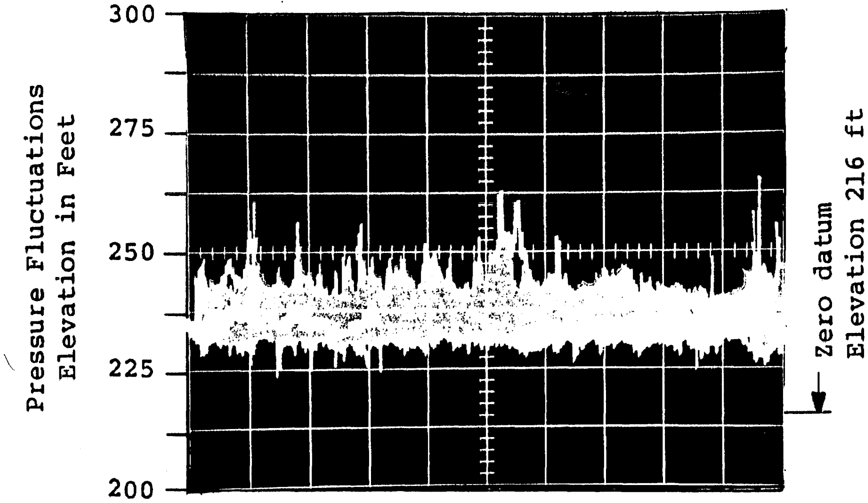
Gates Open - 2-4 , T.W. = 235 ft

Q_I = 1000 cfs, Q_W = 0 cfs, Q_D = 1000cfs

The fluctuations were recorded with a chamber mounted 25 psi transducer.

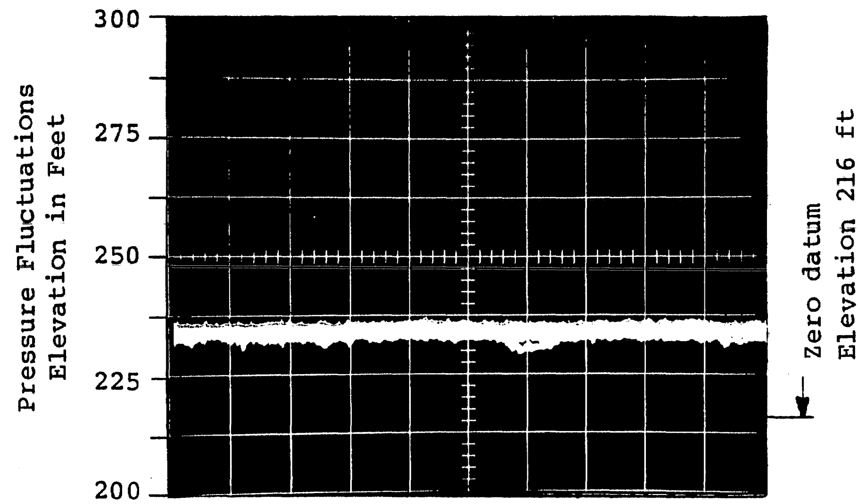
CULVER-GOODMAN MODEL STUDIES CONTROL STRUCTURE MODEL Harza Engineering Co., Chicago, Illinois Lozier Engineers, Inc., Rochester, N.Y. Division of Pure Waters, Monroe Co., N.Y.		
SAINT ANTHONY FALLS HYDRAULIC LABORATORY UNIVERSITY OF MINNESOTA		
DRAWN DA	CHECKED [signature]	APPROVED
SCALE	DATE 12/14/79	NO. 260AA2317-35

Model time of record = 1 minute



Tap 11

Model time of record = 1 minute



Tap 13

TYPE D-3 CONTROL STRUCTURE
Typical Pressure Fluctuations
Model Scale 1:16

Gates Open - 2-4 , T.W. = 235 ft

Q_I = 1000 cfs, Q_W = 0 cfs, Q_D = 1000 cfs

The fluctuations were recorded with a chamber mounted 25 psi transducer.

CULVER-GOODMAN MODEL STUDIES
CONTROL STRUCTURE MODEL
Harza Engineering Co., Chicago, Illinois
Lozier Engineers, Inc., Rochester, N.Y.
Division of Pure Waters, Monroe Co., N.Y.

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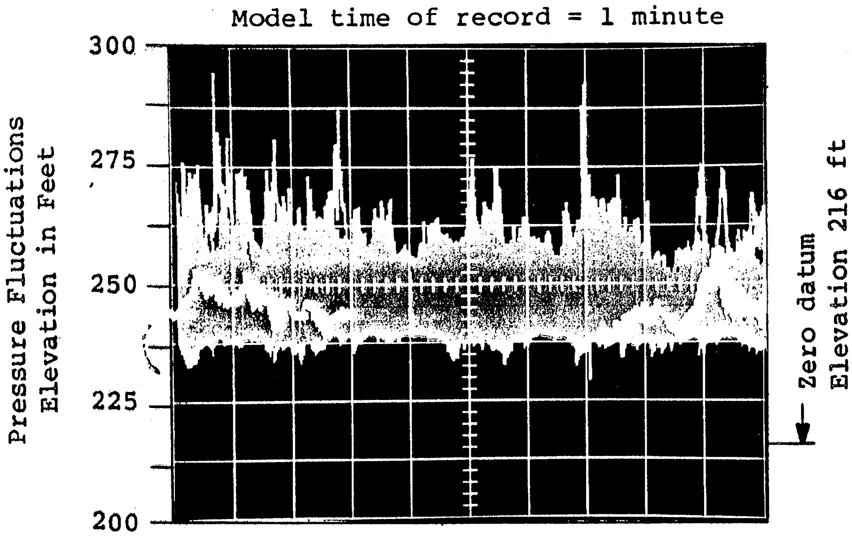
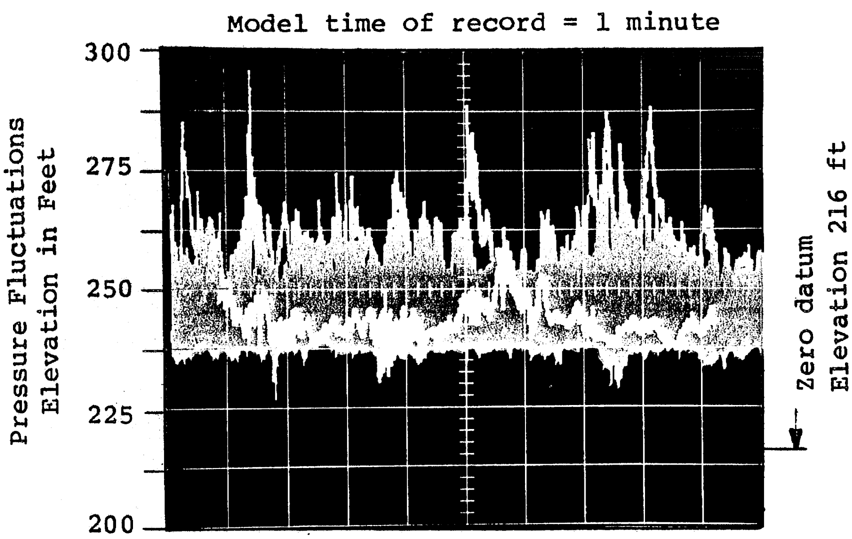
UNIVERSITY OF MINNESOTA

DRAWN DA	CHECKED [signature]	APPROVED
SCALE	DATE 12/14/79	NO. 260AA2317-36



Tap 6



Tap 8

TYPE D-3 CONTROL STRUCTURE
Typical Pressure Fluctuations
Model Scale 1:16

Gates Open - 2-4 , T.W. = 235 ft

Q_I = 2500 cfs, Q_W = 1470 cfs, Q_D = 1030cfs

The fluctuations were recorded with a chamber mounted 25 psi transducer.

CULVER-GOODMAN MODEL STUDIES
CONTROL STRUCTURE MODEL
Harza Engineering Co., Chicago, Illinois
Lozier Engineers, Inc., Rochester, N.Y.
Division of Pure Waters, Monroe Co., N.Y.

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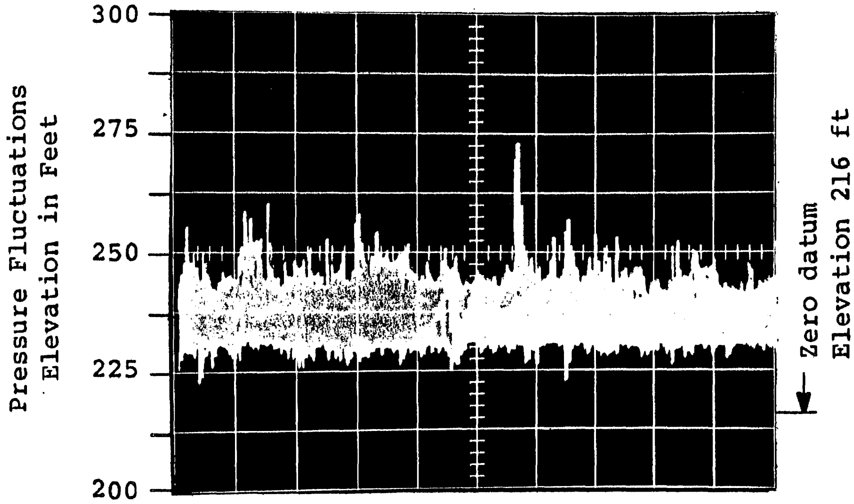
UNIVERSITY OF MINNESOTA

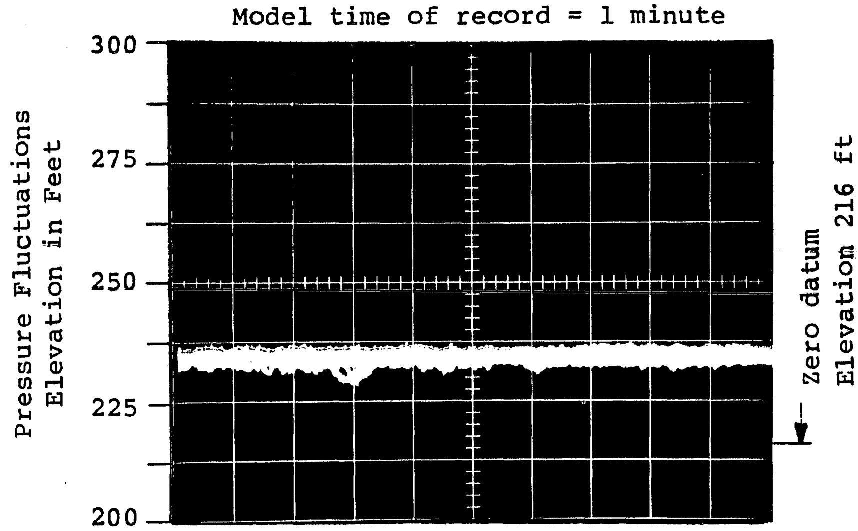
DRAWN DA	CHECKED MQD	APPROVED
SCALE	DATE 12/14/79	NO. 260AA2317-37

Model time of record = 1 minute



Tap 11

Model time of record = 1 minute



Tap 13

TYPE D-3 CONTROL STRUCTURE
Typical Pressure Fluctuations
Model Scale 1:16

Gates Open - 2-4, T.W. = 235 ft

Q_I = 2500 cfs, Q_W = 1470 cfs, Q_D = 1030cfs

The fluctuations were recorded with a chamber mounted 25 psi transducer.

CULVER-GOODMAN MODEL STUDIES
CONTROL STRUCTURE MODEL
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Division of Pure Waters, Monroe Co., N.Y.

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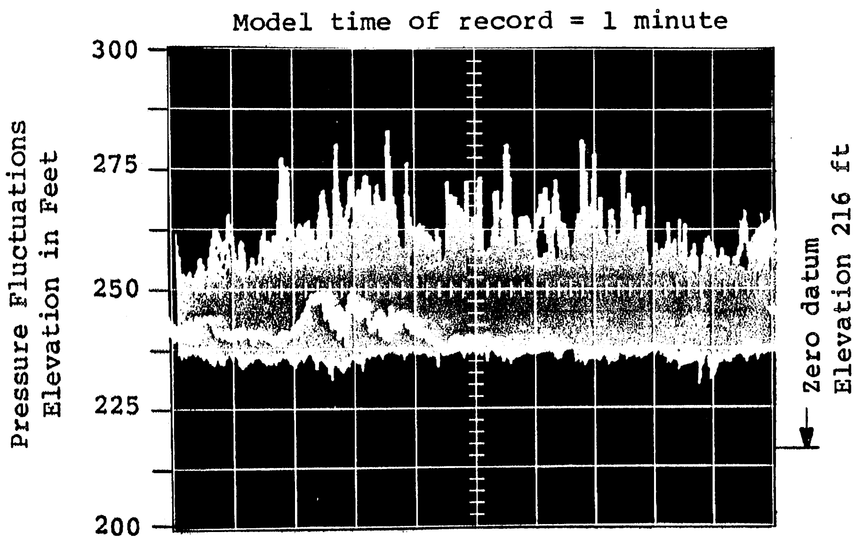
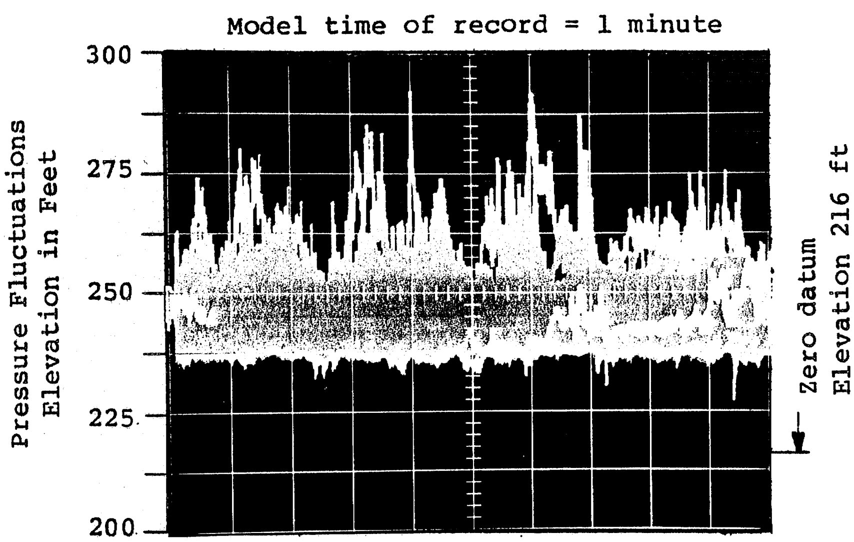
DRAWN DA	CHECKED [signature]	APPROVED
SCALE	DATE 12/14/79	NO. 260AA2317-38



Tap 6



Tap 8

TYPE D-3 CONTROL STRUCTURE
Typical Pressure Fluctuations
Model Scale 1:16

Gates Open - 2-4 , T.W. = 235 ft

Q_I = 5000 cfs, Q_W = 3950 cfs, Q_D = 1050 cfs

The fluctuations were recorded with a chamber mounted 25 psi transducer.

CULVER-GOODMAN MODEL STUDIES
CONTROL STRUCTURE MODEL
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Lozier Engineers, Inc., Rochester, N.Y.
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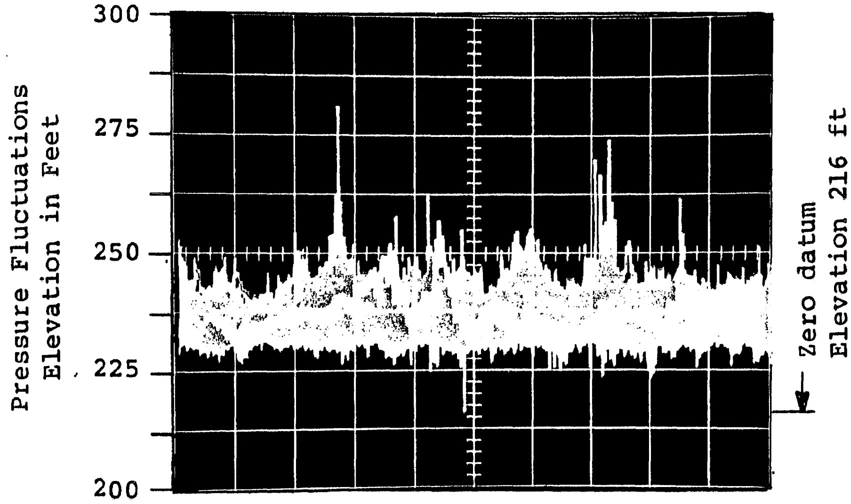
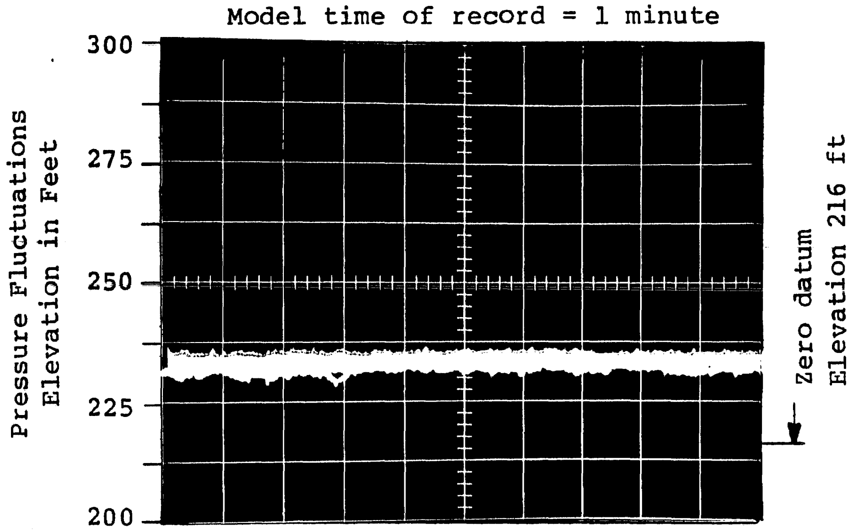
DRAWN DA	CHECKED [signature]	APPROVED
SCALE	DATE 12/14/79	NO. 260AA2317-39

Model time of record = 1 minute



Tap 11

Model time of record = 1 minute



Tap 13

TYPE D-3 CONTROL STRUCTURE
Typical Pressure Fluctuations
Model Scale 1:16

Gates Open - 2-4 , T.W. = 235 ft

Q_I = 5000 cfs, Q_W = 3950 cfs, Q_D = 1050 cfs

The fluctuations were recorded with a chamber mounted 25 psi transducer.

CULVER-GOODMAN MODEL STUDIES
CONTROL STRUCTURE MODEL
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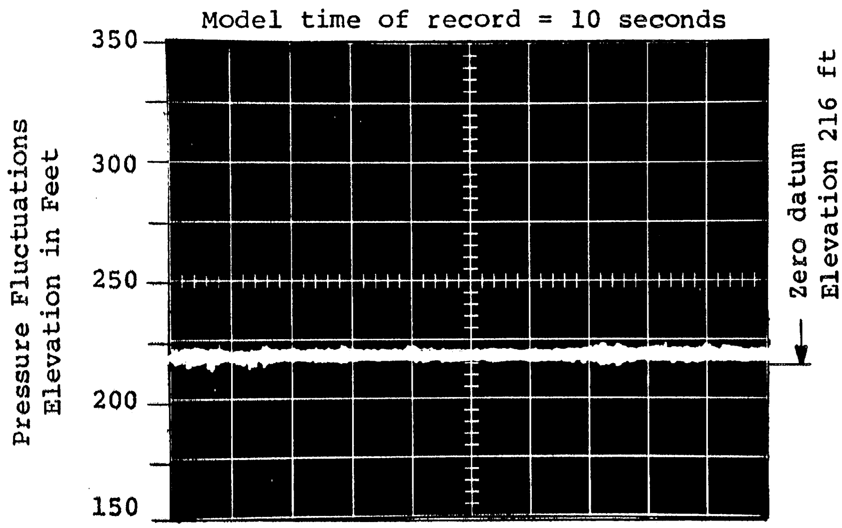
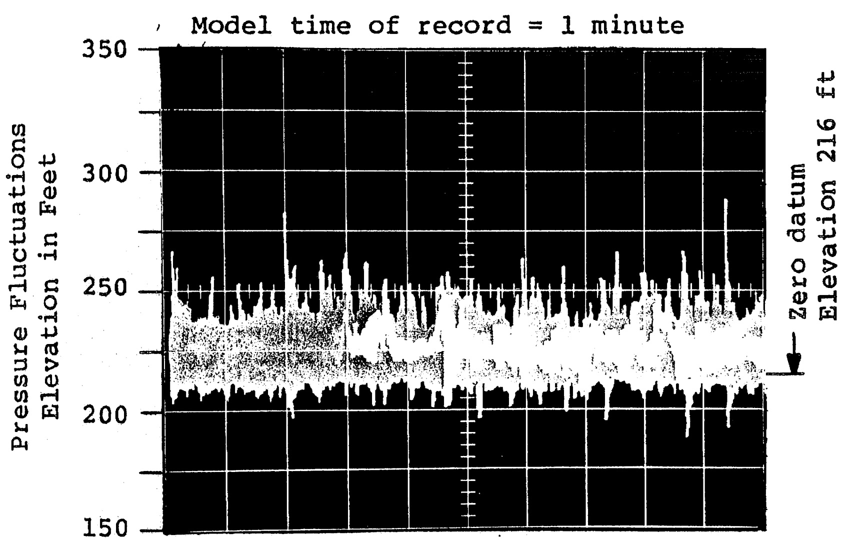
DRAWN DA	CHECKED [illegible]	APPROVED
SCALE	DATE 12/14/79	NO. 260AA2317-40



Tap 12



Tap 12

TYPE D-3 CONTROL STRUCTURE
Typical Pressure Fluctuations
Model Scale 1:16

Gates Open - all, T.W. = 0 ft

Q_I = 500 cfs, Q_W = 0 cfs, Q_D = 500 cfs

The fluctuations were recorded with a chamber mounted 25 psi transducer.

CULVER-GOODMAN MODEL STUDIES
CONTROL STRUCTURE MODEL
Harza Engineering Co., Chicago, Illinois
Lozier Engineers, Inc., Rochester, N.Y.
Division of Pure Waters, Monroe Co., N.Y.

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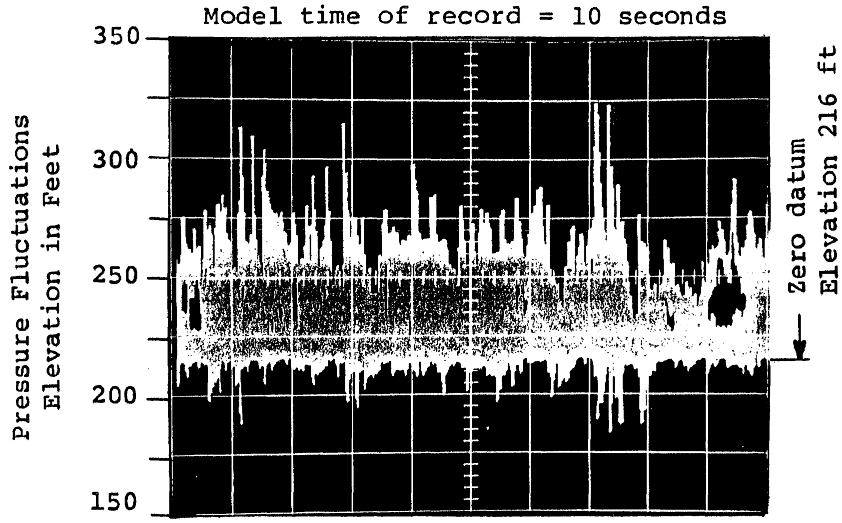
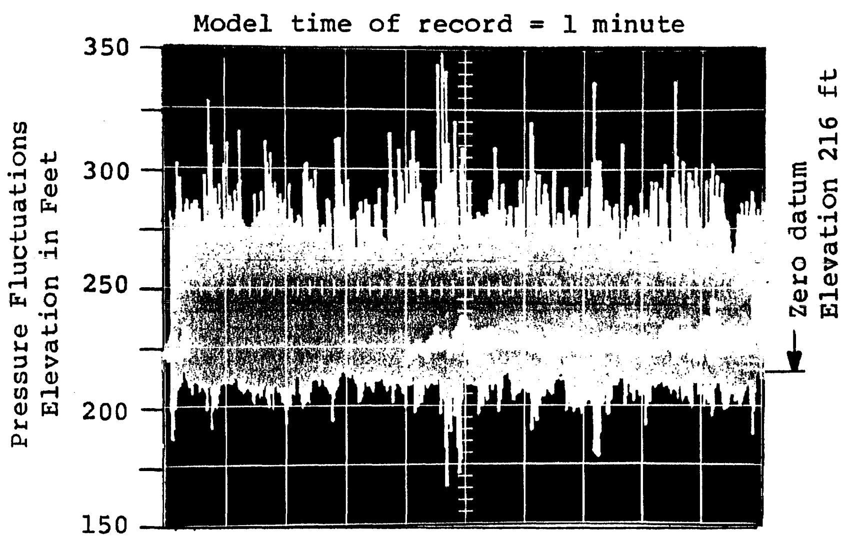
UNIVERSITY OF MINNESOTA

DRAWN DA	CHECKED [signature]	APPROVED
SCALE	DATE 12/14/79	NO. 260AA2317-41

CHART 47



Tap 13



Tap 13

TYPE D-3 CONTROL STRUCTURE
Typical Pressure Fluctuations
Model Scale 1:16

Gates Open - all , T.W. = 0 ft

Q_I = 500 cfs, Q_W = 0 cfs, Q_D = 500 cfs

The fluctuations were recorded with a chamber mounted 25 psi transducer.

CULVER-GOODMAN MODEL STUDIES
CONTROL STRUCTURE MODEL
Harza Engineering Co., Chicago, Illinois
Lozier Engineers, Inc., Rochester, N.Y.
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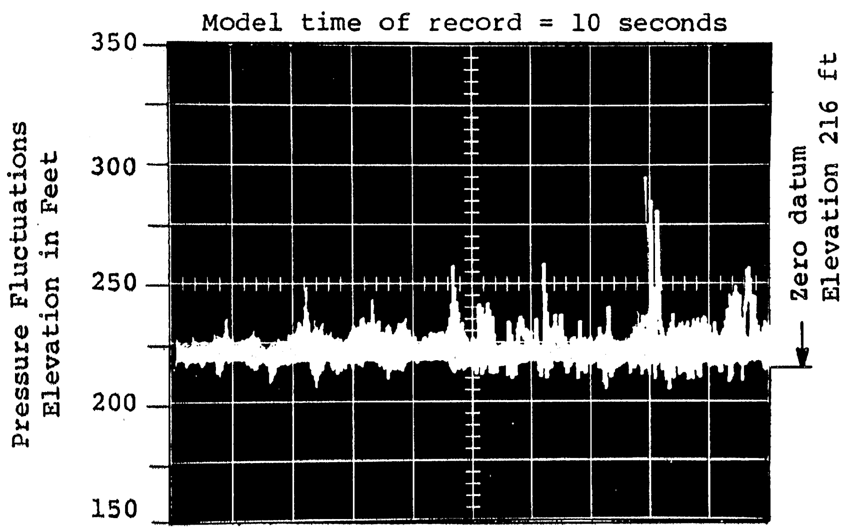
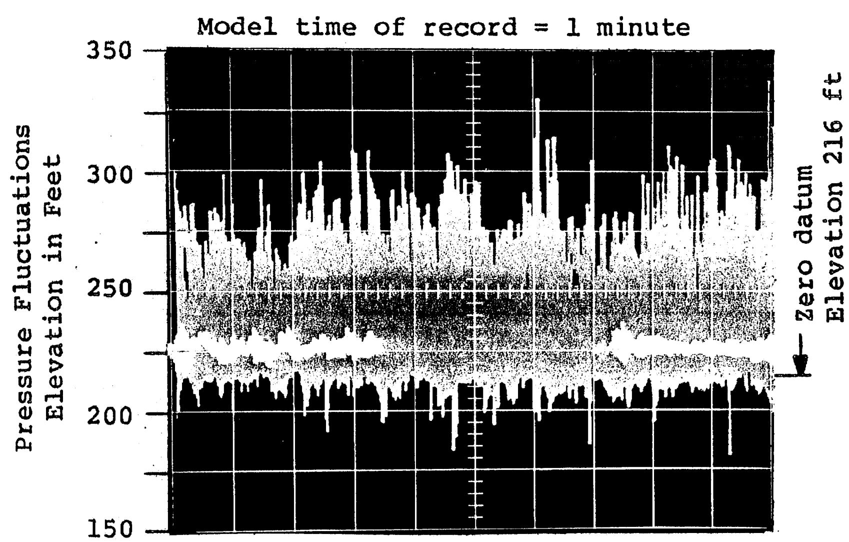
UNIVERSITY OF MINNESOTA

DRAWN DA	CHECKED	APPROVED
SCALE	DATE 12/14/79	NO. 260AA2317-42



Tap 12



Tap 12

TYPE D-3 CONTROL STRUCTURE
Typical Pressure Fluctuations
Model Scale 1:16

Gates Open - all , T.W. = 0 ft

Q_I = 1000 cfs, Q_W = 0 cfs, Q_D =1000 cfs

The fluctuations were recorded with a chamber mounted 25 psi transducer.

CULVER-GOODMAN MODEL STUDIES
CONTROL STRUCTURE MODEL
Harza Engineering Co., Chicago, Illinois
Lozier Engineers, Inc., Rochester, N.Y.
Division of Pure Waters, Monroe Co., N.Y.

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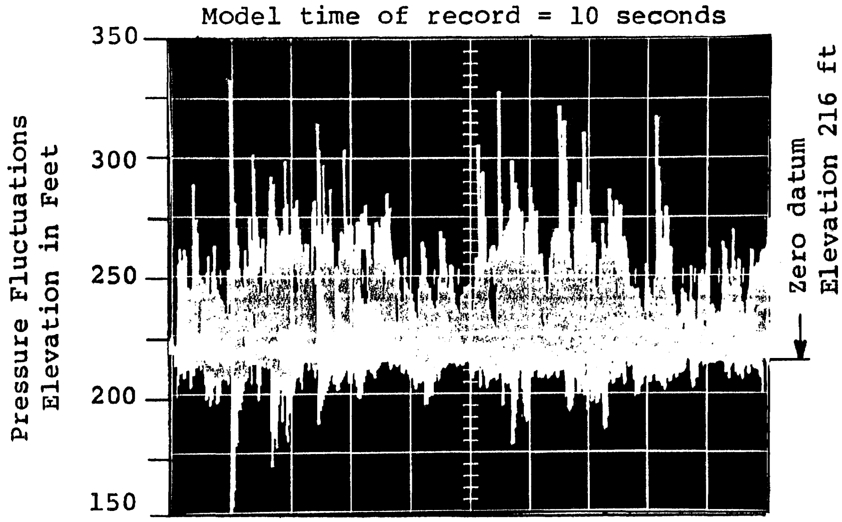
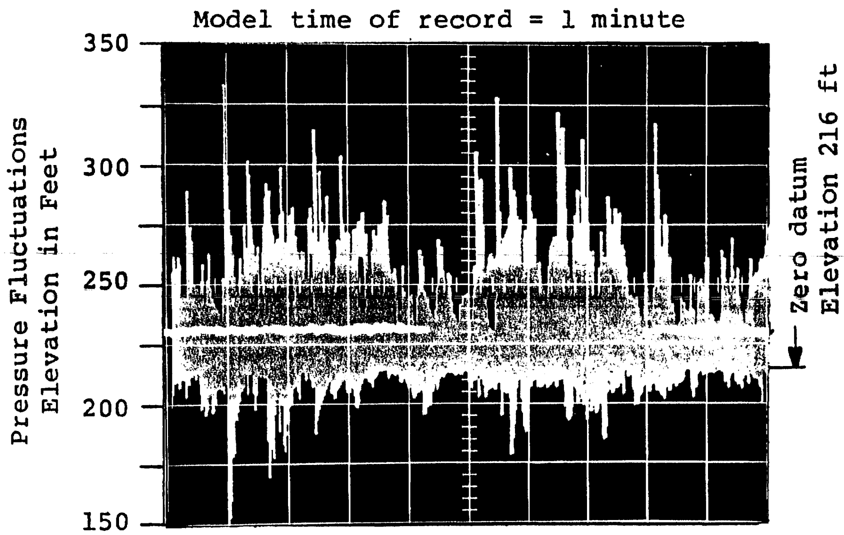
DRAWN DA	CHECKED [signature]	APPROVED
SCALE	DATE 12/14/79	NO. 260AA2317-43



Tap 13



Tap 13

TYPE D-3 CONTROL STRUCTURE
Typical Pressure Fluctuations
Model Scale 1:16

Gates Open - all , T.W. = 0 ft

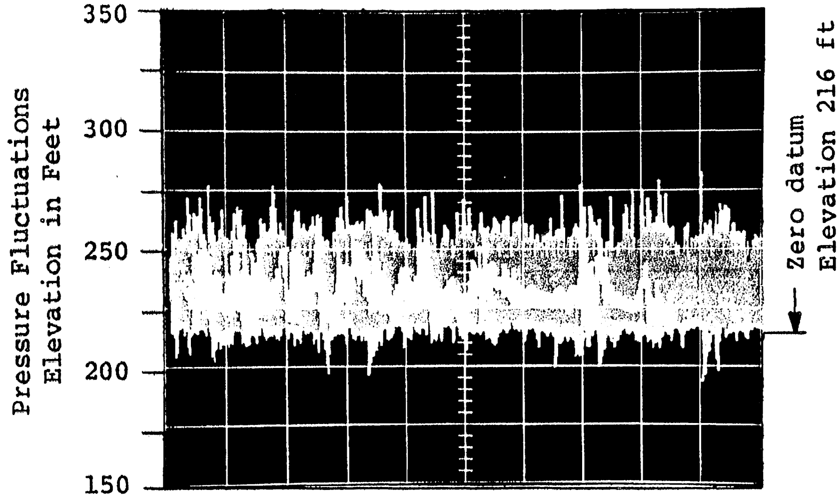
Q_I = 1000 cfs, Q_W = 0 cfs, Q_D = 1000 cfs

The fluctuations were recorded with a chamber mounted 25 psi transducer.

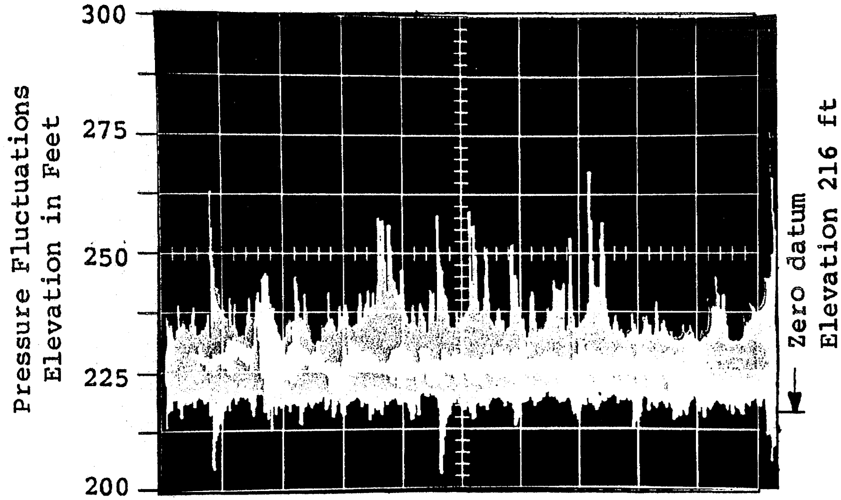
CULVER-GOODMAN MODEL STUDIES
CONTROL STRUCTURE MODEL
Harza Engineering Co., Chicago, Illinois
Lozier Engineers, Inc., Rochester, N.Y.
Division of Pure Waters, Monroe Co., N.Y.

SAINT ANTHONY FALLS HYDRAULIC LABORATORY
UNIVERSITY OF MINNESOTA

DRAWN DA	CHECKED [signature]	APPROVED
SCALE	DATE 12/14/79	NO. 260AA2317-44



Tap 12



Tap 13

TYPE D-3 CONTROL STRUCTURE
Typical Pressure Fluctuations
Model Scale 1:16

Gates Open - all, T.W. =223.5 ft

Q_I = 500cfs, Q_W = 0cfs, Q_D = 500 cfs

The fluctuations were recorded with a chamber mounted 25 psi transducer.

CULVER-GOODMAN MODEL STUDIES
CONTROL STRUCTURE MODEL
Harza Engineering Co., Chicago, Illinois
Lozier Engineers, Inc., Rochester N.Y.
Division of Pure Waters, Monroe Co., N.Y.

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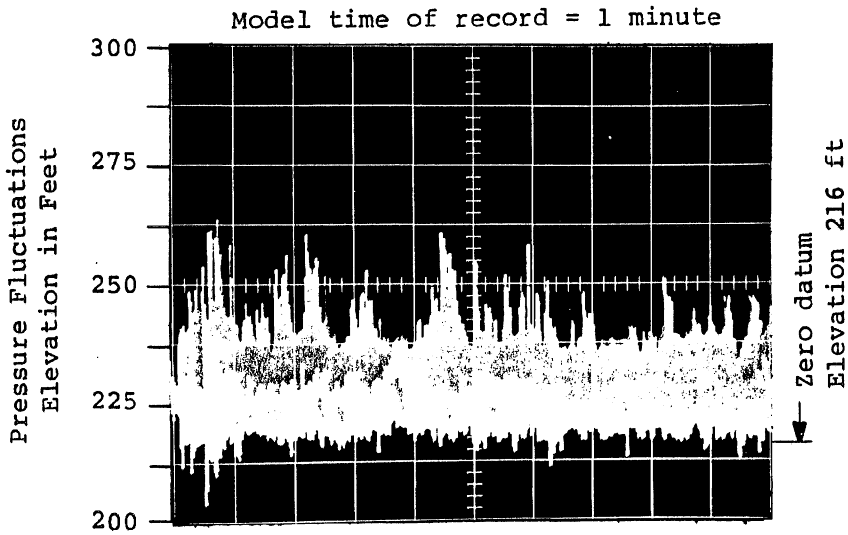
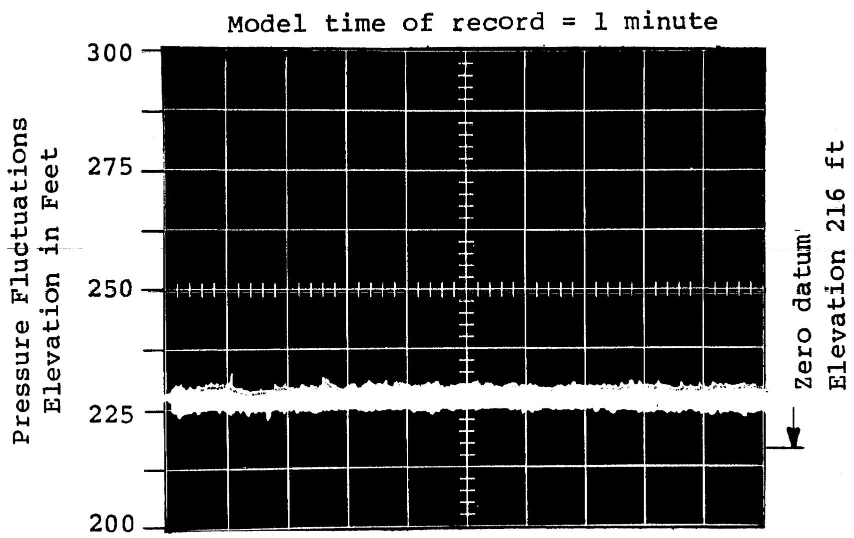
SCALE	DATE 12/14/79	NO 260AA2317-45



Tap 12



Tap 13

TYPE D-3 CONTROL STRUCTURE
Typical Pressure Fluctuations
Model Scale 1:16

Gates Open - all , T.W. = 227 ft

Q_I = 1000 cfs, Q_W = 0 cfs, Q_D = 1000 cfs

The fluctuations were recorded with a chamber mounted 25 psi transducer.

CULVER-GOODMAN MODEL STUDIES
CONTROL STRUCTURE MODEL
Harza Engineering Co., Chicago, Illinois
Lozier Engineers, Inc., Rochester, N.Y.
Division of Pure Waters, Monroe Co., N.Y.

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SCALE	DATE 12/14/79	NO. 260AA2317-46