University of Minnesota
St. Anthony Falls Hydraulic Laboratory

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ROCHESTER COMBINED SURGE AND DROPSHAFT MODEL STUDIES

by

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and

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Conducted for

LOZIER-SEELYE-TONIAS, A JOINT VENTURE
Rochester, New York

and

HARZA ENGINEERING COMPANY
Chicago, Illinois

Sponsored by

ROCHESTER PURE WATERS DISTRICT
Monroe County, New York
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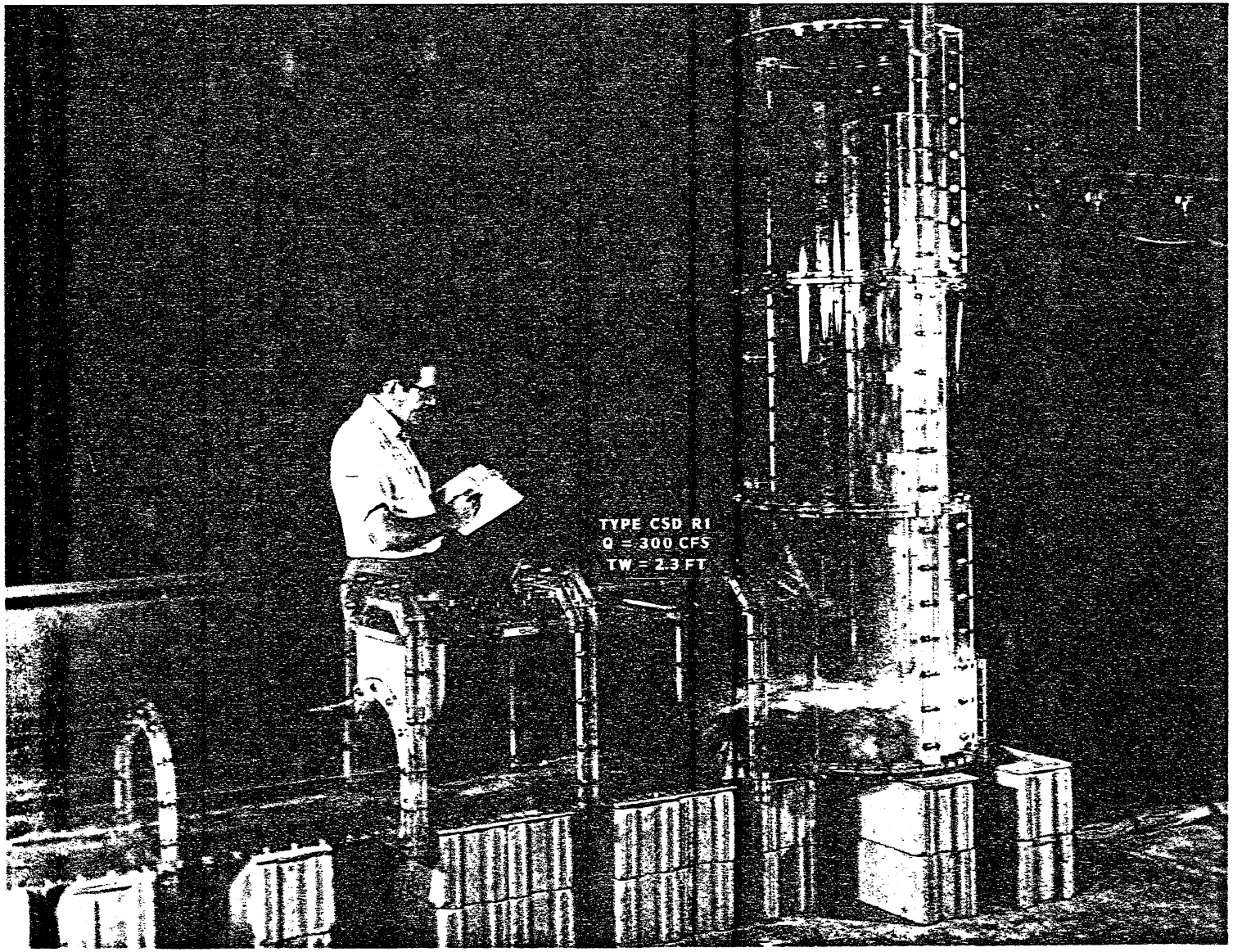

Frontispiece - Type CSD R1 dropshaft, Q = 300 cfs, T.W. = 2.3 ft.
The overall model.

PREFACE

In most large cities the problems of handling storm water and sanitary sewage have increased severely. One concept being developed as a solution to the problem is the use of tunnels beneath the ground surface for conveyance, storage, and purification of the storm water and sanitary sewage. These tunnels are excavated or bored into rock layers beneath the ground surface. The effluent is stored during periods when the capacity of the treatment plant is exceeded and pumped out of storage and treated as the demands on the plants have diminished.

The City of Rochester, New York, has developed a solution unique to its particular problems and topographic features called the combined sewer overflow and abatement plan (CSOAP). Conduits near the surface collect the storm water runoff and sewage and convey it to vertical dropshafts of various diameters and heights. The water drops through the vertical shaft into a sump and deaeration chamber where energy is dissipated and the entrained air removed. The air is returned to the surface through an air vent, and the water is conveyed through an exit conduit to the storage and conveyance tunnel.

At several locations along the tunnel it is proposed to construct surge shafts to attenuate pressure surges in the system. For convenience and cost reduction, it is advantageous to combine the surge shafts with nearby conventional dropshafts. Previous model studies at the St. Anthony Falls Hydraulic Laboratory for Rochester, New York, were concerned with the development of optimum designs for these so-called conventional dropshafts and control structures. A combined structure of this type has not been model tested, although many features developed previously for the design of the dropshafts have been incorporated into the combined structure. The purpose of the "Rochester Combined Surge and Dropshaft Model Studies" was to determine its suitability for use in the CSOAP project and develop optimum designs to satisfy unique requirements at several sites.

Basically a relatively large-cylindrical surge shaft extending to the ground surface replaces the sump of a typical dropshaft structure. Inside the surge shaft is the vertical dropshaft which contains the falling water-air mixture. In the combined structure energy dissipation and air removal takes place in the surge shaft and deaeration chamber. To study the problems associated with this combined structure a 1:12 scale model was constructed at the St. Anthony Falls Hydraulic Laboratory.

The model tests described in this report were conducted for Lozier-Seelye-Tonias, A Joint Venture of Rochester, New York; and Harza Engineering Company of Chicago, Illinois. The model tests were sponsored by the Rochester Pure Waters District, Monroe County, New York, Department of Engineering. During the course of the model studies, several meetings were held at the St. Anthony Falls Hydraulic Laboratory and attended by representatives of the above organizations and the Laboratory. The models were

demonstrated, various aspects of the project discussed, the various tests outlined, and the results reviewed.

Karl Nesbeitt, Senior Hydraulic Engineer of Harza, was the principal coordinator between the Laboratory and the above organizations. The study was under the immediate direction of Warren Dahlin, Scientist, and tests were conducted by Christopher Thompson and Robert Bulleigh, supporting staff members. A silent-color motion picture summarizing the various revisions was prepared by Warren Dahlin and Karl Wikstrom. Various aspects of the project were reviewed by Joseph Wetzel, Assistant Director. This final report summarizes the results of the test program.

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ROCHESTER COMBINED SURGED AND DROPSHAFT

MODEL STUDIES

I. INTRODUCTION

The City of Rochester, New York, is developing the combined sewer overflow and abatement plan (CSOAP) to handle sanitary sewage and storm water. The west side system contains 40 dropshafts along a 26 mile long tunnel. The function of these dropshafts is to transport the water from one elevation and energy level to a lower elevation and energy level. At several locations along the tunnel it is proposed to construct surge shafts to attenuate surge pressures in the system. To minimize construction disturbances at the surface, reduce the amount of boring and excavation, and consequently reduce the construction costs, the surge shafts have been combined with conventional dropshafts. These combined surge and dropshaft structures would have dual functions of conveying water from the ground surface to the underground tunnels and relieving surge pressures in the system.

Conduits at the ground surface collect the water and convey it to a quarter cylinder elbow which deflects the water 90 degrees into a vertical-rectangular shaft. The vertical shaft is located inside and at the upstream side of the surge shaft. One wall of the vertical shaft is slotted to provide for air re-entrainment and also pressure relief in the dropshaft. The surge shaft is a large excavated and lined cylinder which extends from the tunnel level to the ground surface. A boot is attached to the surge shaft just below the dropshaft. Attached to the downstream side of the surge shaft is a deaeration chamber containing a slotted weir, false crown with air slots, and a bellmouth entrance to the exit conduit. An air vent is provided along the downstream side of the surge shaft.

The water falling through the elbow and vertical shaft entrains considerable air while gaining kinetic energy. The falling water-air mixture impinges on the floor of the surge shaft. The boot, surge shaft, and deaeration chamber dissipate some of the energy, remove and collect the entrained air, and direct the water at a reduced velocity into the exit conduit. Some of the entrained air is released in the surge shaft and rises directly to the surface. The remaining air rises to the false crown in the deaeration chamber, passes through the air slots into the chamber above, and returns to the upper part of the surge tank through a vent shaft. Part of this return air is then recirculated via the dropshaft air slots and air ramps. A definition sketch (Chart 1) indicates the various shaft components.

It is desirable to remove most of the entrained air from the water before it enters the tunnels. The entrapped air in the tunnels introduces

the danger of high waterhammer head rise upon its sudden release which could cause damage to the system. The release of high velocity air at ground surface structures could also introduce hazards at these locations. The surge shaft is provided for the purpose of damping system hydraulic transients. The effectiveness of the surge shaft and deaeration chamber in removing the entrained air was one factor considered in the evaluation of the various types tested.

The purpose of the model studies was to determine the feasibility of combining a surge shaft and dropshaft into one structure, develop an optimum combined structure, and test various geometries to satisfy the unique requirements at several locations. During the course of the studies seven variations or revisions were made and the results documented. All of the revisions were documented by visual observations and photography.

Photographic documentation included still photos, motion pictures, color slides, and video tapes. These proved to be excellent methods of recording the overall hydraulic characteristics of the structures and the air entrainment and release mechanisms. On design types that were not hydraulically acceptable, documentation was limited to the visual observations and photography. For hydraulically acceptable designs more detailed documentation was made which included the recording of water surface fluctuations, static pressures, hydraulic gradelines, fluctuating pressures, and air concentrations.

In the prototype the tunnels will most likely be empty or will convey low discharges at the beginning of the storm and gradually fill, and in extreme storms they may fill completely. In the model, observations were made over the entire discharge range from minimum flow to maximum flow and with tailwater elevation range from uncontrolled to maximum. When the system was flowing full, very little air was entrained. The model was operated in a steady-state condition; that is, no flow or tailwater elevation changes were made during a particular test.

In both the prototype and the model, gravity is the predominant motion-producing force. For this type 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. The letter L is the length in ft, Q the discharge in cfs, V the velocity in fps, P the pressure head in ft, T the time, and f the frequency. The subscripts m and p refer to model and prototype, respectively, and the subscript r denotes the ratio of model to prototype.

Quantity	Ratio	Scale Relation
Length, L	$L_r = L_m/L_p$	1:12
Discharge, Q	$Q_r = L_r^{5/2}$	1:498.8
Velocity, V	$V_r = L_r^{1/2}$	1:3.464
Pressure, P	$P_r = L_r$	1:12
Time, T	$T_r = L_r^{1/2}$	1:3.464
Frequency, f	$f_r = 1/L_r^{1/2}$	1:0.2887

For example, if the velocity in the model is 1.0 ft/sec, the corresponding velocity in the prototype will be 3.464 ft/sec.

Complete similarity for the air entrainment and air removal processes cannot in general be obtained because the mechanism of entrainment, the size 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 model is believed to be sufficiently large, such that the processes employed in the model experiments are quite similar to those expected in the prototype. It is believed that the observations made in the model regarding the flow characteristics of the aerated mixture will be qualitatively correct. When the model indicates a large amount of air entrainment in the inlet and vertical shaft and effective air removal in the sump, the prototype behavior is expected to be similar, even though the quantities of air do not obey Froude law scaling.

II. CONCLUSIONS

1. The Type CSD R1 dropshaft (Charts 1 and 8) was quite effective in energy dissipation and air removal. It was judged hydraulically acceptable. Therefore Type CSD R1 dropshaft is recommended for use in the Rochester project.

2. The Type CSD R2 dropshaft (Charts 2 and 8), which is similar to Type CSD R1 with the free trajectory inlet installed and the dropshaft removed, was definitely not as effective and considerable air entered the exit conduit. Also impact pressures are likely to be higher on the invert and the divider wall between the surge shaft and air vent. The Type CSD R2 dropshaft is not recommended.

3. The Type CSD R3 dropshaft (Charts 3 and 8), which is similar to Type CSD R1 without the boot, was not as effective as Type CSD R1 but better than Type CSD R2. The energy previously dissipated in the boot now has to be dissipated at the sides and downstream of the dropshaft. This results in the entrained air being carried further downstream into the deaeration chamber. The boot does improve the effectiveness of the structure and the additional cost would be minimal; therefore, Type CSD R3 is not recommended.

4. The Type CSD R4 dropshaft (Charts 4 and 8), which is similar to Type CSD R1 with the deaeration chamber 20 ft shorter, was definitely not as effective. The deaeration chamber is not long enough to allow time for all the entrained air to escape; considerable quantities are carried to the end of the chamber and into the exit conduit. The Type CSD R4 dropshaft is not recommended.

5. The Type CSD R5 dropshaft (Charts 5 and 8), which is similar to Type CSD R1 with the inlet turned 30 degrees, was quite effective in energy dissipation and air removal and was judged hydraulically acceptable. The Type CSD R5 dropshaft is recommended for use at the necessary sites.

6. The Type CSD R6 dropshaft (Charts 6 and 8) is similar to Type CSD R1 with the deaeration chamber width reduced from 12 to 10 ft and a 10 ft exit conduit replacing the 12 ft exit conduit. This type is quite effective in energy dissipation and air removal. Although some slight vorticity occurred at the entrance to the exit conduit it is hydraulically acceptable. The Type CSD R6 dropshaft is recommended for use where it is needed.

7. The Type CSD R7 dropshaft (Charts 7 and 8) is similar to Type CSD R6 with an 8 ft exit conduit replacing the 10 ft exit conduit and minor revisions to improve the entrance to the exit conduit. This type is also quite effective in energy dissipation and air removal and performs similar to Types CSD R1 and R6. It also has some slight vorticity occurring at the entrance to the exit conduit similar to that observed in Type CSD R6. The Type CSD R7 dropshaft is hydraulically acceptable and recommended for use in the Rochester project.

III. TYPE CSD R1 DROPSHAFT

A. Description of Model

The initial geometry investigated was constructed according to Harza Engineering Company Drawing No. 1329 HYD 201 R1 dated February, 1982, and was designated as Type CSD R1 dropshaft. The dimensions and layout of this type are shown on Chart 1. Chart 8 lists the major components for comparison with later types. The 1:12 model was fabricated from transparent lucite as shown in Photos 1 and 2 so that flow characteristics in the structure could be observed and photographed. The model components were fabricated in the laboratory shops (Photos 1 and 2) and assembled at the model site (Photo 3). The components modeled included a 6 ft diameter entrance conduit, a transition from a round to a square section, and a quarter cylinder elbow with a radius of 12 ft as shown on Chart 1 and in Photo 4. Attached to the elbow is a 6 ft by 8 ft rectangular dropshaft which is located at the upstream side of the surge shaft as shown in Photos 3 through 5. The outer wall of the dropshaft has air ports and ramps to provide for air re-entrainment and pressure relief. The 25 ft diameter surge shaft extends from the tunnel level, designated as elevation 0 ft in the model, to the ground surface. The invert of the inlet conduit is at elevation 70 ft. Attached to the bottom of the surge shaft, just below the dropshaft is a boot as shown in Photo 5. An air vent is provided at the downstream side of the surge shaft (Photo 3). Also connected to the downstream side of the surge shaft is a 52.2 ft long by 12 ft wide deaeration chamber as shown in Photo 6. The dearation chamber contains a 4 ft high slotted weir, a false crown with five-2 ft air slots through it, and a 4 ft radius bellmouth as shown in Photo 6. The air vent and the space between the false crown and the true crown are both 2.5 ft. A 12 ft high by 12 ft wide horseshoe shaped exit conduit is attached to the dearation chamber. For convenience in the fabrication, assembling, and revising of the model, the components were made in flanged sections and bolted together. An example of this is the surge shaft which consists of six-half cylinder sections (Photos 2 and 3). One revision requires that the inlet be turned 30 degrees from the centerline of the deaeration chamber and surge shaft. To facilitate this, 30 degree segments, like that shown on the left side of the surge shaft in Photo 5, were provided in the upstream sections of the surge shaft that needed to be turned. To turn the elbow, dropshaft, and boot these 30 degree segments were removed, the sections containing the elbow, dropshaft, and boot turned clockwise, and the 30 degree segment installed on the other side. By using this technique, the required revisions were made faster and more economically as the need for a duplicate elbow, boot, and surge shaft sections was eliminated. The water supply for the model was obtained from the Mississippi River through the Laboratory supply system. A 6 inch supply line was provided which contained a control valve and a calibrated 4 inch diameter orifice meter for measuring the discharge. A wire mesh baffle was placed in the inlet line just upstream of the model to smoothen out the inflow. To maintain the tailwater at prescribed elevations a butterfly valve was installed at the

end of the exit conduit. The butterfly valve was installed with its axis horizontal so that the valve plate opened at the crown of the tunnel. Thus, any air collecting at the crown in the model would be swept out, simulating air movement in the prototype tunnel. A waste channel was provided to remove the water from the model area and return it to the river.

The design discharge for the 6 ft by 8 ft dropshaft was 300 cfs. Discharges observed in the model were 100, 200, 300, and 400 cfs. For each of these discharges the tailwater elevation was uncontrolled (tailwater valve wide open) and then maintained at the selected elevations of 10, 22, 30, 45, and 70 ft while observations and necessary documentation were made.

For measuring pressures as shown on Chart 1 a number of pressure taps were drilled into the model at selected locations. Normally these taps would be connected by plastic tubes to a bank of piezometer tubes where the hydraulic gradelines would be observed. For measuring instantaneous pressure fluctuations a pressure transducer was connected to the desired tap. Two methods were used. At locations where the fluctuation frequencies were relatively high, a 25 psi Kulite transducer with a sensing area of 0.085 in. diameter was flush mounted and through an electrical circuit connected to a Tektronic T 912 storage oscilloscope where the fluctuations were displayed. The frequency response of the 25 psi Kulite transducer used was 10 kHz in air and flush mounted, and the Tektronic T 912 storage oscilloscope has a frequency response to at least 10 mHz. When the transducer was used in water as in the model, the frequency response would be somewhat lower. For convenience in locations where the fluctuating frequencies are relatively low, a larger 25 psi CEC transducer with a sensing area of about 0.5 in. diameter was mounted in a lucite block and connected to a tap with a short, small diameter tube. The output was transmitted to a Sanborn amplifier and strip chart recorder which utilized a thermo pen to trace the record on heat sensitive paper.

The frequency response of the 25 psi CEC pressure transducer used was 5-10 kHz in air and flush mounted, the Sanborn amplifier 600 Hz, and the thermo pen 125 Hz for one-half scale deflection. 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 and short, the transducer frequency response should be higher than the response of the amplifier.

Air concentration measurements in the models were made with an electrical instrument previously developed at the Laboratory for measuring air concentrations in percent by volume in flowing air-water mixtures. A plastic rod supporting a pair of electrical probes was inserted through ports into the dropshaft so that measurements could be made, not at a point, but in a small region of the flow. The probe was connected to an electrical circuit and read-out meter. The method consists basically of measuring the difference between the conductivity of a mixture of air and water and water alone.

B. Model Observations

Visual Observations and photographs show that the Type CSD R1 dropshaft is quite effective in dissipating energy and removing most of the entrained air. The frontispiece and Photos 7 through 15 show the hydraulic characteristics of this combined structure for the design discharge of 300 cfs and tailwaters of 2.3 (uncontrolled), 14, 22, 45, and 70 ft. The frontispiece shows the overall flow pattern through the structure for the uncontrolled tailwater of 2.3 ft. The water follows the invert of the quarter cylinder elbow (Photo 7), and separates from the boundary as it enters the dropshaft. The main jet shoots across the dropshaft impinging on the opposite wall at a low angle as shown in Photo 7. The jet is broken up when it hits the downstream wall of the dropshaft as shown in Photo 9. Photo 8 shows the pool created by the slotted weir which effectively reduced the impact forces of the falling water-air mixture on the surge shaft invert. Most of the entrained air is released before the flow goes over the weir. When the tailwater is raised to elevation 14 ft so that the entrance to the exit conduit is submerged by 2 ft, most of the air is released in the surge shaft and deaeration chamber and very little air enters the exit conduit as shown in Photos 10 and 11. This demonstrates the effectiveness of the structure in energy dissipation and air removal. At a tailwater elevation of 22 ft, which is the elevation of the deaeration chamber crown, the released air rises to the false crown and passes through the air slots to the chamber above as shown in Photos 12 and 13. The air collects in the chamber, returns to the air vent, which releases it to the ground surface. The major quantities of air are removed in the surge shaft and upstream end of the deaeration chamber as shown in Photo 13. When the tailwater elevation is raised to 45 ft and 70 ft less air is entrained and most of the air is removed in the surge shaft as shown in Photos 14 and 15, respectively.

For discharges lower than the design discharge of 300 cfs, the flow patterns in the structure show decreased turbulence and less air entrainment. Photos 16 and 17 show the flow patterns for a discharge of 200 cfs and tailwater elevations of 2.2 (uncontrolled) and 22 ft, respectively. Increasing the discharge to 400 cfs results in increased turbulence and air entrainment as shown in Photos 18 through 20. More air is entrained and carried further into the deaeration chamber as shown in Photo 20, which also demonstrates the effectiveness of the slots in air removal. Photo 20 showing 400 cfs may be compared to Photo 13 for 300 cfs. Although the air is carried further downstream in the deaeration chamber for a flow of 400 cfs, the major quantity of the air is effectively removed (Photo 20) and very little air enters the exit conduit as shown in Photo 21. These visual observations show that the Type CSD R1 dropshaft was very effective in dissipating energy and air removal.

C. Water Surface Fluctuations

To provide design information for the walls of the dropshaft and the divider wall between the air vent and surge shaft, observations of water surface fluctuations were made at four critical locations shown on Charts 9 and 10. The locations were in the dropshaft (1), in the surge shaft next to the dropshaft (2), in the surge shaft next to the air vent (3), and in

the air vent (4). Observations were made for discharges of 100, 200, 300, and 400 cfs; and tailwater elevations of uncontrolled, 10, 22, 30, 45, and 70 ft for each discharge. The maximum and minimum water surface elevations were determined at each location for a two minute time period. The summary of typical water surface fluctuations observed is presented on Charts 9 and 10. For both the uncontrolled tailwater elevation and 10 ft, the water surface is below the bottom of the rectangular dropshaft and also the water surface has not reached the air vent. For example, with the design discharge of 300 cfs and uncontrolled tailwater elevation of 2.3 ft, the fluctuations varied from El. 8.5 to 11.5 ft at location 2, and 7.0 to 9.0 ft at location 3, both in the surge shaft. No readings were available in the dropshaft, and the air vent was empty. With the discharge of 300 cfs and tailwater elevation raised to 22 ft, fluctuations from El. 18.0 to 21.0 ft occurred at location 1 in the dropshaft and from El. 23.5 to 26.0 ft at location 2 in the surge shaft adjacent to the dropshaft (Chart 9). The water surface was consistently higher outside of the dropshaft for this flow condition. The maximum differential of 8 ft occurred when the water surface inside the dropshaft was at the minimum of 18.0 ft and outside the dropshaft at the maximum of 26.0 ft. When the tailwater elevation was raised to 30 ft the maximum differential was 7.5 ft when the water surface inside the dropshaft was at El. 29.0 ft and 36.5 ft outside. The maximum differential for flow conditions with the water surface higher outside of the dropshaft, and for all discharges up to and including the design discharge of 300 cfs, is the 8.0 ft differential occurring with the flow of 300 cfs and tailwater elevation of 22 ft. For a discharge of 400 cfs and tailwater elevations of 22 and 30 ft, this differential was 10 ft in the same direction. For some flow conditions the water surface was higher in the dropshaft than outside in the surge shaft. The maximum differential in this direction occurred for a flow of 100 cfs and tailwater elevation of 30 ft. The maximum reading to El. 37.0 ft occurred in the dropshaft and minimum reading to El. 29.6 ft outside for a maximum differential of 7.4 ft in that direction. The water surface fluctuations on either side of the divider wall between the surge shaft and the air vent are tabulated on Chart 10. Generally the water surface was higher in the surge shaft with the maximum differential of 4.5 ft occurring for a discharge of 300 cfs and tailwater elevation of 30 ft when the maximum water surface elevation was 34.5 ft in the surge shaft and the minimum of 30.0 ft in the air vent. A differential of 4.0 ft occurred for a flow of 400 cfs and tailwater of 30 ft, and a differential of 3.5 ft for 300 cfs and tailwater of 22 ft, and 400 cfs and tailwaters of 22 and 45 ft. The maximum differential in the other direction, that is when the water surface was higher in the air vent than the surge shaft, were only 1.0 ft for 300 cfs and 1.5 ft for 400 cfs both for a tailwater of 22 ft.

D. Air Concentrations

Air concentration measurements were made in the dropshaft and air vent using the resistance type probe described earlier. The tap locations and elevations along with the readings are presented on Charts 11 through 18. Measurements were made for discharges of 100 cfs (Charts 11 and 12), 200 cfs (Charts 13 and 14), 300 cfs (Charts 15 and 6) and 400 cfs (Charts 17 and 18). For each discharge observations were made for tailwater elevations of uncontrolled, 45 ft, and 70 ft. For the uncontrolled tailwater and all

flows the air vent contains 100 percent air and will remain so until the tailwater is above the deaeration crown elevation of 22 ft.

In the dropshaft at the design discharge of 300 cfs and uncontrolled tailwater of 2.3 ft the percent air at tap 33 near the top varies from 13 at the slotted wall to 82 near the upstream wall for an average of about 55 percent. The 13 and 35 percent reading at the slotted wall indicates a jet in that area which can be seen in Photos 7 and 9. At tap 34 the percent air varies from 83 to 93 and at tap 35 from 48 to 93, the average of each being about 80 percent. These readings indicate that the incoming jet is dispersed reasonably well and additional air is entrained in the dropshaft. With the flow of 200 cfs and tailwater of 2.2 ft the percent air in the dropshaft is slightly higher than for 300 cfs and the averages vary from about 57 at tap 33 to about 85 to tap 35. With the flow of 100 cfs these averages vary from about 89 at tap 33 to about 92 at tap 35. For both of these lower flows dispersion is good at tap 35 near the bottom. With the 400 cfs flow and tailwater of 2.6 ft the average percent air was about 70 at tap 33, 76 at tap 34, and 77 at tap 35. Comparison of these values with those for 300 cfs indicate a higher percent of air at tap 33, and lower at taps 34 and 35.

As the tailwater level was raised, the quantity of air in the system was reduced. This may be seen in Charts 12, 14, 16, and 18 which show air percentages with the tailwater elevation at 45 ft for flows of 100, 200, 300, and 400 cfs, respectively. For this condition the tailwater level is just below tap 33 which is at elevation 48 ft. These reductions in air concentrations are quite noticeable; for example, compare Chart 16 (300 cfs and tailwater of 45 ft) with Chart 15 (300 cfs and tailwater of 2.3 ft). In the air vent, at tap 36 the percent air remains at 100, but at tap 37 reduces to zero. In the dropshaft the average of the percent air values drop from about 55 to 37 at tap 33, 81 to 22 at tap 34, and 79 to 18 at tap 35. Similar reductions in air concentrations occurred for the lower flows of 100 cfs (Chart 12) and 200 cfs (Chart 14), and the higher flow of 400 cfs (Chart 18).

These air concentration measurements indicate good air entrainment and dispersion in the dropshaft.

E. Piezometric Pressures

The piezometric pressures or hydraulic gradelines were recorded from the bank of piezometric tubes on the manometer board for discharges of 100, 200, 300 (design discharge), and 400 cfs; and for tailwater elevations of uncontrolled, 10, 22, 30, 45 and 70 ft. The tap locations are shown on Chart 1. On all these graphs, the abscissa is the distance along the tap location line in feet, and the ordinate is elevation in feet. The baseline shows the tap numbers and distance locations. The main graph on the left shows the pressures along the centerline of the structure, and the smaller graph on the right the pressures perpendicular to the centerline in the impact area beneath the dropshaft. The pressures plot in a consistent manner and all pressures were positive except at taps 7 and 8, which are located on the invert of the quarter cylinder elbow, where the pressures are only slightly negative. Close examination of Charts 20 through 22 for

flows of 200 through 400 cfs show the pressure points slightly below the baseline or boundary and should be of little consequence in the prototype structure. The sudden drop in pressure between taps 24 and 25 show the effect of the impact weir located there. This is caused by the increase in velocity over the weir and the resultant lower depths of flow over the weir and immediately downstream. This effect is essentially drowned out at the 10 ft tailwater elevation. The pool created upstream of the weir is effective in reducing the fluctuating impact pressure beneath the dropshaft.

F. Fluctuating Pressures

Two methods of measuring pressure fluctuations were used as described earlier in Section III-A. The Kulite transducer with a sensing area of 0.085 inch diameter was flush mounted at taps locations 17, 18, and 19 where higher fluctuations and higher frequencies were expected. These taps are located in the impact area on the surge shaft invert beneath the dropshaft as shown on Chart 1. The normal procedure was to store the pressure fluctuation record on the screen of the storage oscilloscope for one minute and photograph it. Charts 23 through 26 show photographs taken of these records for discharges of 100, 200, 300, and 400 cfs, and tailwaters of uncontrolled, 22, 70 ft for each flow. The trace was set to sweep across the scope in 1 second, fly back, and start again. Each succeeding trace was superimposed over the past record until a model time record of 1 minute was reached and the recording stopped. The envelope on the photos is the stored record of all the traces and the lighter narrow trace is the last individual sweep. It was observed that some higher frequency fluctuations were not stored on the screen, and it was decided that they should be recorded and documented in some manner. To accomplish this, the screen was visually watched continually for 5 minutes, and the magnitude of these individual spikes estimated and recorded. This was done separately for both maximum and minimum spikes. These spikes are recorded on Charts 27 and 28 for discharges of 100, 200, 300, and 400 cfs and uncontrolled tailwaters. The hatched areas are the ranges from the oscilloscope photos for a model time of 1 minute. The x's are the visually observed maximum and minimum spikes observed for a model time of 5 minutes. The horizontal time scales shown are for these visually observed readings. If no x's are shown, like for 100 cfs on Chart 27, no spikes occurred outside of the range shown on the oscilloscope photo (Chart 23). Chart 42 shows a tabulated summary of typical pressure fluctuations that occurred at tap 17 on the right side of the impact area for various flow conditions. The chart shows the average piezometric pressures, and the values derived from Charts 23 through 28 including the maximum and minimum ranges from the photos, and the maximum and minimum visually observed readings.

For the design discharge of 300 cfs and uncontrolled tailwater of 2.3 ft the average piezometric pressure was 13.1 ft, with a photo range from El. 58 to -16 ft (Chart 25) and maximum and minimum observed spikes to El. 100 ft and El. -26 ft (Chart 28). Lower minimum spikes were observed for 200 cfs and tailwater of 2.2 ft, and 400 cfs and tailwater of 2.6 ft, and were -40 and -44 ft, respectively. Tap 17 is located at El. 0 ft, so these values represent negative pressure heads of -40 and -44 ft and are cavitating pressures. These pressures are scaled from the model values by multiplying by the length ratio. Actually in the prototype these values

would not occur because when the negative pressure heads approach -34 ft cavitation would occur.

Charts 29 through 35 present the pressure fluctuation data recorded at tap 18, which is located in the center of the impact area for the various discharges from 100 to 400 cfs and tailwaters from uncontrolled to 70 ft. The summary is tabulated on Chart 42. For the design discharge of 300 cfs and tailwater elevation of 2.3 ft the piezometric pressure was 17.1 ft, the photo range from El. 68 to -10 ft (Chart 31), with maximum spikes to El. 90 ft, and minimum spikes to El. -28 ft (Chart 35). This is as negative pressure head of -28 ft and approaches cavitation. When the tailwater was raised to El. 10 ft the photo range was from El. 50 to -2 ft (Chart 31) and no spikes outside of that range were observed. When the tailwater was raised to El. 22 ft the photo range was somewhat greater and was from El. 54 to -12 ft (Chart 31). At this tailwater the fluctuations were of longer duration and in the form of surges. For lower discharges the observed maximum and minimum spikes were greater. For a flow of 100 cfs and tailwater of 1.6 ft, the photo range was from El. 96 to -16 ft (Chart 29) and maximum and minimum spikes were observed to El. 140 ft and -36 ft (Chart 34), or a negative pressure head of -36 ft.

For a higher discharge of 400 cfs and tailwater of 2.6 ft the values were somewhat lower. the piezometric pressure was 18.6 ft, the photo range from El. 60 to -8 ft (Chart 33), and maximum and minimum spikes to El. 84 ft and El. -24 ft (Chart 35) or a negative pressure head of -24 ft.

The pressure fluctuation data at Tap 19 on the left side of the impact area is presented on Charts 36 through 41 for the various discharges from 100 to 400 cfs and tailwaters from uncontrolled to 70 ft. The summary is tabulated on Chart 42. For the design discharge of 300 cfs and tailwater of 2.3 ft, the piezometric pressure was 12.8 ft, the photo range from El. 50 to -8 ft, and maximum and minimum spikes to El. 70 ft and El. -28 ft (a negative pressure head of -28 ft). For a flow of 200 cfs and tailwater of 2.2 ft the piezometric pressure was 6.9 ft, the photo range from El. 50 to -16 ft, and maximum and minimum spikes to El. 50 ft and El. -20 ft. At a higher flow of 400 cfs and tailwater of 2.6 ft the piezometric pressure was 14.1 ft, the photo range from El. 70 to -16 ft, and maximum spikes to El. 82 ft and minimum spikes to El. -48 ft, or a negative pressure head of -48 ft.

The Type CSD R1 design includes the slotted weir. The beneficial effects of the weir in reducing fluctuating impact pressures was demonstrated in previous model studies on Rochester dropshafts; therefore, no tests on the present model were made without the weir. For convenience in areas where the pressure fluctuations and frequencies were expected to be lower, the chamber mounted CEC transducer and Sanborn strip recorder were used. A survey was made of pressure fluctuations in the quarter cylinder elbow at taps 7 and 8, the dropshaft at taps 9 and 11, the surge shaft outside of the impact area at taps 13, 14, 15, 16, 20, 21, 22, and 23, the deaeration chamber at tap 25, and the exit conduit at tap 28. The tap locations are shown on Chart 1. Recordings of typical pressure pressure fluctuations for discharges from 100 to 400 cfs and tailwater elevations from uncontrolled to 70 ft are presented on Charts 43 through 55 and the summary of typical pressure fluctuations at these taps

on Charts 56 and 57. The highest fluctuations were recorded at tap 21 which is located on the surge shaft centerline immediately downstream of the impact area. In this area the deflected flow has a strong horizontal velocity component which results in some high spikes and also some low spikes which reach slightly negative values. For the design discharge of 300 cfs and tailwater of 2.3 ft the maximum pressure fluctuation was to El. 24.6 ft and the minimum to El. -4.0 ft (Chart 48). With lower flows, for 100 cfs and tailwater of 1.6 ft the fluctuations varied from El. 15.0 to -3.2 ft, and for 200 cfs and tailwater of 2.2 ft from El. 18.8 to -4.5 ft (Chart 57). At a high flow of 400 cfs and tailwater of 2.6 ft the maximum fluctuation was to El. 21.2 ft, and the minimum to El. -3.4 ft (Chart 57). Some moderate fluctuations were also recorded at taps 15, 16, and 20 which are also close to the impact area beneath the dropshaft. At the other tap locations fluctuations and surging are minimal. Pressure fluctuations in areas other than the critical impact area appear minimal and should cause no major structural design problems.

IV. TYPE CSD R2 DROPSHAFT

A. Description of Model

The Type CSD R2 dropshaft is similar to Type CSD R1 dropshaft (Chart 1) with the dropshaft removed and the free trajectory inlet installed in the model as shown on Charts 2 and 8. To accomplish this the quarter cylinder in the elbow was replaced by a step, and a chord from the bottom of the step to the tangent point of the removed quarter cylinder at the bottom of the elbow.

B. Model Observations

With the design discharge of 300 cfs and tailwater of 3.0 ft the incoming jet ventilates at the step and shoots through the elbow as a free trajectory jet into the surge shaft as shown in Photos 22 and 23. The bottom of the jet touches the lower end of the chord slightly with most of the jet clearing the corner (Photo 23). The jet shoots completely across the 25 ft diameter surge shaft and impinges on the invert at the junction of the surge shaft and deaeration chamber as shown in Photo 22. The top of the jet touches the divider wall between the surge shaft and air vent. The jet is deflected high over the slotted weir and about halfway through the deaeration chamber. The jet is not dispersed adequately and impact pressures are probably quite high. The surge shaft is not utilized for energy dissipation and air removal. This is more apparent when the tailwater is raised to elevation 22 ft as shown in Photo 24. A large quantity of entrained air is carried through the deaeration chamber and enters the exit conduit. Photo 24 may be compared to Photo 12 which shows the efficient Type CSD R1 design.

At lower flows, 200 cfs for example, the incoming jet separates at the step and then impinges on the chord about three-quarters of the way down (Photo 25). The jet shoots across the surge shaft at a flatter angle and impinges on the divider wall between the surge shaft and air vent. Impact pressures are probably high at this point and again the surge shaft is not utilized. At a flow of 400 cfs the structure is even less efficient and photos are not shown in this report.

The Type CSD R2 dropshaft is not effective in energy dissipation and air removal, and considerable air enters the exit conduit. This type was judged to be hydraulically unacceptable.

V. TYPE CSD R3 DROPSHAFT

A. Description of Model

The Type CSD R3 dropshaft is basically Type CSD R1 without the boot on the upstream side of the surge shaft and below the dropshaft as shown on Charts 3 and 8. Actually in the model it was more convenient to block the boot off with a curved plate the same radius as the surge shaft, as shown in Photo 26, than to remove it.

B. Model Observations

In a structure which has the boot, such as Type CSD R1 dropshaft, the falling water air mixture impinging on the invert spreads out in all directions including the boot as shown in Photo 8. Consequently, some energy is dissipated in the boot. If the boot is not there, as in Type CSD R3 dropshaft, this energy must be directed to the sides and downstream as shown in Photo 26. Comparing Photo 26 (Type CSD R3) with Photo 8 (Type CSD R1), both of which are for the design flow of 300 cfs and tailwater of 2.3 ft, it appears that somewhat more entrained air is carried towards and over the weir for Type CSD R3. Photo 27 of Type CSD R3 may also be compared with Phot 10 of Type CSD R1 where the tailwater elevation is 14 ft. Again, the entrained air is carried further downstream in the deaeration chamber for Type CSD R3. One has to consider that turbulence and surging could be partly responsible for this effect. At a tailwater of 22 ft this effect is not readily discernable when Photo 28 is compared to Photo 12. At higher tailwaters the boot would have less effect on the water-air mixture coming down the dropshaft. Photo 29 shows the flow pattern when the tailwater is 45 ft. Photos 30 and 31 show the flow patterns when the discharge is 400 cfs and tailwaters of 2.6 ft and 22 ft, respectively.

Although the beneficial effects of the boot are not highly visible, the boot does cause some energy dissipation in a critical area, particularly for lower tailwaters where the stage will be the greater part of the time. In a meeting at the Laboratory it was pointed out by Joint Venture personnel that the mole used to bore the tunnel into the surge shaft would in the process overshoot and bore into the boot location. Thus, there would be little, if any, saving in excavation costs. In view of the beneficial effects of the boot on the hydraulic characteristics and the construction procedures, it was mutually decided that the boot should be included in the combined structures. Therefore, the Type CSD R3 dropshaft is not recommended.

VI. TYPE CSD R4 DROPSHAFT

A. Description of Model

The Type CSD R4 dropshaft is similar to Type CSD R1 dropshaft with the deaeration chamber shortened 20 ft (Charts 4 and 8 and Photo 32). This was accomplished by removing a flanged 20 ft section (20 inches in the model) from the downstream end of the deaeration chamber. The end plate and bellmouth were moved upstream to complete the shortened chamber, and a 20 ft section of exit conduit inserted in the gap.

B. Model Observations

Photos 32 through 35 show the Type CSD R4 dropshaft in operation with the design discharge of 300 cfs and tailwater elevations of 2.3, 14, and 22 ft. Photo 32 shows the flow pattern with the uncontrolled tailwater of 2.3 ft. Most of the entrained air is released upstream of the weir and any air carried into the exit conduit would be released there and returned to the ground surface through the deaeration chamber, air vent, and surge shaft. Photos 33 and 34 show the flow pattern when the tailwater is at elevation 14 ft, where the 12 ft high exit conduit is submerged by 2 ft. Considerable entrained air reached the end of the deaeration chamber and is drawn into the exit conduit. It collects at the crown of the exit conduit and is carried downstream, and in the prototype would enter the storage and conveyance tunnel. When the tailwater was raised to 22 ft as shown in Photo 35, minimum amounts of air entered the exit conduit.

It is apparent that a 20 ft shorter deaeration chamber is not as effective in air removal. Also an unknown factor is how quantities of air observed in the model scale up to prototype quantities. Conjecture is that the prototype will have comparatively more air. In consideration of these factors, it was decided that the slightly higher excavation costs were warranted to provide a more effective deaeration chamber. The Type CSD R4 dropshaft is not recommended.

VII. TYPE CSD R5 DROPSHAFT

A. Description of Model

The Type CSD R5 dropshaft is similar to the Type CSD R1 dropshaft with the inlet pipe, elbow, dropshaft, and boot rotated 30 degrees clockwise from the centerline of the surge shaft and deaeration chamber as shown on Charts 5 and 8 and in Photo 36. To accomplish this revision, the 30 degree segments located at the upstream left side of the surge shaft were removed, the components rotated clockwise, and the segments installed at the upstream right side of the surge shaft. The water supply line was revised to connect with the turned inlet pipe.

B. Model Observations

The Type CSD R5 dropshaft appears quite effective in dissipating energy and air removal as shown in Photos 36 through 41. Photos 36 through 39 show the design discharge for tailwater of 2.3, 14, 22, and 45 ft. Photos 40 and 41 show a discharge of 400 cfs and tailwaters of 2.6 ft and 22 ft, respectively. The flow patterns appear similar to those for Type CSD R1 which has the inlet in line with the deaeration chamber. The only noticeable difference is a slightly higher velocity and turbulence for Type CSD R5 at the junction of the surge shaft and right side of the dearation chamber which is opposite from the inlet, dropshaft, and boot. The flow from the dropshaft is deflected across the surge shaft and impinges in this area causing more turbulence there than on the left side. This does not affect the efficiency of the deaeration chamber in air removal and should be of little concern.

C. Piezometric Pressures

Piezometric pressure were recorded on the Type CSD R5 dropshaft for discharges of 100, 200, 300 (design discharge) and 400 cfs, and tailwaters from uncontrolled to 70 ft for each discharge. The plots of pressures are presented on Charts 58 through 61 and may be compared to those for the Type CSD R1 dropshaft on Charts 19 through 22. The pressures for Type CSD R5 plot in a consistent manner and are similar to the plots of pressures for the Type CSD R1 dropshaft. All the pressures are positive except the slightly negative values at taps 7 and 8 which are located on the invert of the quarter cylinder in the elbow.

D. Fluctuating Pressures

Fluctuating pressures were recorded on the Type CSD R5 dropshaft using the same procedures described for Type CSD R1 in Section III-F. The flush mounted Kulite transducer was used in the impact area under the dropshaft

at taps 17, 18, and 19. The chamber mounted CEC transducer was used at all the other taps investigated. Charts 62 through 66 show oscilloscope photos at tap 18 for discharges from 100 to 400 cfs and tailwater from uncontrolled to El. 70 ft. Charts 67 and 68 show the ranges from these photographs and the visually observed readings if any occurred for the various discharges and uncontrolled tailwaters. Charts 69 through 71 show pressure fluctuation data for taps 17 and 19 for the design discharge of 300 cfs and tailwaters from 2.3 to 70 ft. A tabulated summary of the data for taps 17 through 19 is presented on Chart 72. In comparing the data for Type CSD R5 dropshaft with that for Type CSD R1 dropshaft there are some noticeable differences in the pressures, particularly for the uncontrolled tailwater conditions. This is noticeable in the oscilloscope photos, plots of visually observed readings, and in the summaries of typical pressure fluctuations on Chart 72 (Type CSD R5 dropshaft) and Chart 42 (Type CSD R1 dropshaft). For example at Tap 18 with a discharge of 100 cfs and tailwater of 1.6 ft, for Type CSD R5 dropshaft the range from the photos was from El. 72 to -4 ft and the observed maximum and minimum spikes were to El. 120 ft and El. -18 ft. For Type CSD R1 the photo range was from El. 96 to -16 ft and the observed spikes were to El. 140 ft and -36 ft. With the design discharge of 300 cfs and tailwater of 2.3 ft the variations were not as great. For Type CSD R5 the photo range was from El. 68 to 0 ft and the observed spikes were to El. 84 ft and El. -12 ft. For Type CSD R1 the photo range was from El. 68 to -10 ft and the observed spikes were to El. 90 ft and -28 ft. Similar comparisons can be made of pressures at taps 17 and 19.

The reasons for these variations are not readily apparent. The inlet pipe, elbow, dropshaft, and boot are the same, only turned 30 degrees. New taps were intalled in the invert at the same locations relative to the dropshaft and boot. The piezometric pressures are relatively close in values. What is different is the flow pattern in the surge shaft and entrance to the deaeration chamber. In Type CSD R1 the flow approaches the deaeration chamber symmetrically and in Type CSD R5 it does not. One can only speculate that this is the cause.

Samples of typical pressure fluctuations on Type CSD R5 recorded with the chamber mounted CEC transducer are presented on Charts 73 through 79. They are for taps outside of the impact area beneath the dropshaft and for the design discharge of 300 cfs and tailwaters from 2.3 ft to 70 ft. The summary of these pressure fluctuations for Type CSD R5 are presented on Chart 80. At most of the taps the fluctuations are minimal, but some moderate fluctuations were recorded near the impact area at taps 15, 16, 20, and 21. The highest fluctuations were recorded at tap 21 as shown on Chart 76. For the 2.3 ft tailwater the average piezometric pressure was 7.0 ft, the fluctuations reached a maximum elevation of 30.4 ft and minimum of -3.6 ft. This was the only negative reading observed and is a negative pressure head of -3.6 ft. Spikes up to El. 60 ft and down to 46.6 ft were observed at tap 9, which is located at El. 50 ft at the top of the dropshaft, for a tailwater of 45 ft as shown on Charts 74 and 80. The Type CSD R5 dropshaft, which has the inlet turned 30 degrees is quite effective in energy dissipation and air removal and is hydraulically acceptable for use in the Rochester project.

VIII. TYPE CSD R6 DROPSHAFT

A. Description of Model

The Type CSD R6 dropshaft is similar to Type CSD R1 with revisions in the deaeration chamber and the exit conduit. Details of this type are shown on Charts 6 and 8. The inlet angle is 0 degrees, or the inlet pipe, elbow, dropshaft, and boot are in line with the centerline of the surge shaft and deaeration chamber. The deration chamber width was reduced from 12 ft to 10 ft and the false crown including the slots was lowered 1.08 ft. The false crown was lowered to keep the ratio of the distance between the bottom of the false crown and the crown of the exit conduit equal between the two types. The height of the slotted weir was reduced from 4 ft to 3.33 ft, and the bellmouth radius reduced from 4 ft to 3.33 ft. The 12 ft exit conduit was replaced with a 10 ft exit conduit.

B. Model Observations

The Type CSD R6 dropshaft is effective in energy dissipation and air removal as shown in Photos 42 through 47. Photos 42 through 45 show the design discharge of 300 cfs and tailwaters from 2.6 to 45 ft. Lower flows were less turbulent and not shown here. Photos 46 and 47 show a higher flow of 400 cfs and tailwaters of 3.1 and 22 ft. The flow patterns in Type CSD R6 are much like those in Type CSD R1, except some increase in vorticity was observed near the bellmouth for Type CSD R6. The probable cause of this is the increased velocity in the deaeration chamber. The cross-sectional area of the deaeration chamber was reduced by 31 percent and the design discharge kept at 300 cfs resulting in the higher velocity. This vorticity is barely noticeable near the bellmouth in Photo 43 and should be of little concern.

C. Piezometric Pressures

The piezometric pressures for Type CSD R6 dropshaft are presented on Charts 81 through 84 and are for the most part, repetitious of pressures for Type CSD R1. Piezometric pressures were taken for discharges from 100 to 400 cfs and tailwaters from uncontrolled to 70 ft for each flow. Examination and comparison of the pressures for the two types reveal no noticeable differences for discharges of 100 and 200 cfs. For discharges of 300 and 400 cfs the uncontrolled tailwater elevations have increased for Type CSD R6. For a flow of 300 cfs the uncontrolled tailwater increased from 2.3 to 2.6 ft, and for 400 cfs from 2.6 to 3.1 ft. This increase is undoubtedly due to the smaller deaeration chamber and exit conduit. This raises the piezometric pressures slightly for taps downstream of the slotted weir for the uncontrolled tailwater condition.

D. Fluctuating Pressures

Fluctuating pressures for the Type CSD R6 dropshaft were recorded in the impact area at taps 17, 18, and 19 with the flushed mounted Kulite transducer. Flow conditions investigated were discharges from 100 to 400 cfs and tailwaters from uncontrolled to 70 ft for each flow. The procedures used in obtaining data on previous models were followed here also. The photos of records and plots of visually observed readings are presented on Charts 85 through 94 and the summary of typical pressure fluctuations on Chart 95. This data may be compared to the data for Type CSD R1, and it compares reasonably well as would be expected.

For the design discharge of 300 cfs and tailwater of 2.6 ft, at tap 18 the average piezometric pressure was 15.4 ft, the photo range was from El. 66 to -4 ft, and the observed maximum and minimum readings were El. 76 ft and El. -12 ft. At tap 17, the average piezometric pressure was 11.4 ft, the photo range was from El. 60 to -8 ft and the observed readings from El. 84 ft to El. -30 ft. At tap 19, the average piezometric pressure was 11.4 ft, the photo range was from El. 52 to -10 ft, and the observed readings from El. 70 ft to El. -28 ft. The largest variation in the observed readings was from a maximum elevation of 130 ft to a minimum elevation of -32 ft observed at tap 18 for a discharge of 100 cfs and tailwater of 1.6 ft. The fluctuating pressures for Type CSD R6 recorded outside of the impact area with the chamber mounted CEC transducer are presented on Charts 96 through 102. Observations were made for the design discharge of 300 cfs and tailwater from uncontrolled to 70 ft. A summary of typical pressure fluctuations is tabulated on Chart 103. This pressure data is similar to that taken on Type CSD R1. At most taps the pressure fluctuations are minimal with some moderate fluctuations occurring at taps 15, 16, 20, and 21 near the impact area under the dropshaft. For example, with the design discharge of 300 cfs and tailwater of 2.6 ft, at tap 21 on the centerline just downstream of tap 18, the average piezometric pressure was 6.2 ft, and the fluctuations varied from El. 18.4 to -0.2 ft. The lowest fluctuation occurred at tap 16 for the same flow conditions, where the average piezometric pressure was 6.1 ft, and the fluctuations varied from El. 14.0 to -1.2 ft. The slightly negative piezometric pressures observed at taps 7 and 8 on the quarter cylinder elbow also are indicated in the fluctuating pressures as shown on Chart 96. For tailwaters of 22 and 45 ft the pressure fluctuation traces are below the zero datum mark, indicating a slightly negative pressure.

The Type CSD R6 dropshaft is effective in energy dissipation and air removal, with a slight increase in vorticity near the bellmouth, and is hydraulically acceptable for use in the Rochester project. Although the bellmouth tested had a radius of 3.33 ft, it is recommended that the prototype be constructed with a 4 ft radius which would be a slightly more efficient entrance to the exit conduit.

IX. TYPE CSD R7 DROPSHAFT

A. Description of Model

The Type CSD R7 dropshaft is similar to Type CSD R6 with an 8 ft exit conduit replacing the 10 ft exit conduit and the inlet to the exit conduit revised (Charts 7 and 8). A 4 ft radius bellmouth replaced the 3.3 ft radius bellmouth and 45 degree fillets were placed in the downstream corners of the deaeration chamber to provide a smoother transition from the 10 ft wide chamber to the 8 ft exit conduit. These fillets extended from the chamber floor up to the bellmouth. The false crown was left at the same elevation of 15.42 ft above the floor.

B. Model Observations

Photos 48 through 53 show the Type CSD R7 dropshaft in operation with the design discharge of 300 cfs. The overall flow patterns appear quite similar to Types CSD R1 and R6 dropshafts. The only noticeable difference is the slight vorticity at the entrance to the exit conduit for a 14 ft tailwater as shown in Photo 50 which also occurs for Type CSD R6. At a tailwater of 22 ft this vorticity disappears as shown in Photo 52. This vorticity appears insignificant and as it only occurs for a brief time during a transitional stage should present no problems. Lower flows cause less turbulence and the structure easily handles them. At a higher discharge of 400 cfs as shown in Photos 54 and 55, more turbulence occurs but the structure still is effective in dissipating the energy and removing the entrained air.

C. Piezometric Pressures

The piezometric pressures for Type CSD R7 dropshaft are plotted on Charts 104 thorugh 107 for discharges of 100, 200, 300, and 400 cfs and for tailwaters from uncontrolled to 70 ft for each flow. The plots are consistent with previous model types and no problem areas appear. For all flows and tailwaters of 10 ft and above the piezometric pressures are quite similar to the pressures for Types CSD R1 and R6, including the slightly negative pressures at taps 7 and 8 on the invert of the quarter cylinder elbow. For all flows and the tailwater uncontrolled, the tailwater elevation is noticeably higher for Type CSD R7. This is caused by the smaller exit conduit and entrance to it. When compared to Type CSD R6 with the 10 ft exit conduit, the uncontrolled tailwater for Type CSD R7 was 0.2 ft higher at 100 cfs to 1.2 ft at 400 cfs. This has the effect of raising the piezometric pressures in the exit conduit and back to the weir in the deaeration chamber.

D. Fluctuating Pressures

Fluctuating pressures in the impact area for the Type CSD R7 dropshaft were recorded at taps 17, 18, and 19 using the same procedure as for previous types. Oscilloscope photos and plots of visually observed readings are presented on Charts 108 through 117 for discharges of 100, 200, 300, and 400 cfs and tailwaters from uncontrolled to 70 ft. The summary of typical pressure fluctuations is tabulated on Chart 118.

For the design discharge of 300 cfs and uncontrolled tailwater of 3.8 ft, at tap 18, the average piezometric pressure was 17.6 ft, the photo range from El. 64 to -6 ft, and the observed readings reached to a maximum El. of 80 ft and minimum El. of -30 ft. At tap 17 on the right side, the average piezometric pressure was 12.1 ft, the photo range from El. 60 to -10 ft, and the observed readings from El. 80 ft to -44 ft. At tap 19 on the left side, the average piezometric pressure was 12.1 ft, the photo range from El. 80 to -10 ft, and the observed readings from El. 94 to -30 ft.

The maximum fluctuations occurred at tap 18 with a discharge of 100 cfs and tailwater of 1.8 ft. The piezometric pressure was 8.1 ft, the photo range from El. 90 to -20 ft, and the observed readings from El. 140 to -40 ft.

This pressure data on Type CSD R7 is quite similar to data for Type CSD R1. When they are compared to data for Types CSD R5 and R6, the negative pressures are somewhat lower for Types CSD R1 and R7.

Pressure fluctuations outside of the impact areas were recorded at selected taps between 7 and 28 for the design discharge of 300 cfs and tailwaters from uncontrolled to 70 ft. These records are presented on Charts 119 through 125 and the summary of typical pressure fluctuations on Chart 126. Like previous types tested the pressure fluctuations are minimal at most taps, except at taps 15, 16, 20, and 21 near the impact area, which have some moderate fluctuations. The slightly negative fluctuations were again observed at taps 7 and 8 on the invert of the quarter cylinder elbow. The only negative reading occurred at tap 21 for a discharge of 300 cfs and tailwater of 3.8 ft when the average piezometric pressure was 6.6 ft; the maximum spike reached El. 26.2 ft and the minimum spike El. -8 ft. The Type CSD R7 dropshaft was quite effective in dissipating energy and removal of entrained air and judged to be hydraulically acceptable as a design for the Rochester project. The slight vorticity observed at the entrance to the exit conduit should not cause any problems.

LIST OF PHOTOGRAPHS

PHOTO 16 Type CSD R1 dropshaft, Q = 200 cfs, T.W. = 2.2 ft.
The surge shaft and deaeration chamber.

PHOTO 17 Type CSD R1 dropshaft, Q = 200 cfs, T.W. = 22 ft.
The surge shaft and deaeration chamber.

PHOTO 18 Type CSD R1 dropshaft, Q = 400 cfs, T.W. = 2.6 ft.
The overall model.

PHOTO 19 Type CSD R1 dropshaft, Q = 400 cfs, T.W. = 22 ft.
The surge shaft and deaeration chamber.

PHOTO 20 Type CSD R1 dropshaft, Q = 400 cfs, T.W. = 22 ft.
The air passing through the slots.

PHOTO 21 Type CSD R1 dropshaft, Q = 400 cfs, T.W. = 22 ft.
The entrance to the exit conduit.

PHOTO 22 Type CSD R2 dropshaft, Q = 300 cfs, T.W. = 3.0 ft.
The overall model.

PHOTO 23 Type CSD R2 dropshaft, Q = 300 cfs, T.W. = 3.0 ft.
The free trajectory inlet.

PHOTO 24 Type CSD R2 dropshaft, Q = 300 cfs, T.W. = 22 ft.
The overall model.

PHOTO 25 Type CSD R2 dropshaft, Q = 200 cfs, T.W. = 1.8 ft.
The overall model

PHOTO 26 Type CSD R3 dropshaft, Q = 300 cfs, T.W. = 2.3 ft.
The surge shaft and deaeration chamber.

PHOTO 27 Type CSD R3 dropshaft, Q = 300 cfs, T.W. = 14 ft.
The overall model.

PHOTO 28 Type CSD R3 dropshaft, Q = 300 cfs, T.W. = 22 ft.
The surge shaft and deaeration chamber.

PHOTO 29 Type CSD R3 dropshaft, Q = 300 cfs, T.W. = 45 ft.
The overall model.

PHOTO 30 Type CSD R3 dropshaft, Q = 400 cfs, T.W. = 2.6 ft.
The overall model.

PHOTO 31 Type CSD R3 dropshaft, Q = 400 cfs, T.W. = 22 ft.
The overall model.

PHOTO 32 Type CSD R4 dropshaft, Q = 300 cfs, T.W. = 2.3 ft.
The surge shaft and deaeration chamber.

PHOTO 33 Type CSD R4 dropshaft, Q = 300 cfs, T.W. = 14 ft.
The surge shaft and deaeration chamber.

PHOTO 34 Type CSD R4 dropshaft, Q = 300 cfs, T.W. = 14 ft.
The deaeration chamber and exit conduit.

PHOTO 35 Type CSD R4 dropshaft, Q = 300 cfs, T.W. = 22 ft.
The surge shaft and deaeration chamber.

PHOTO 36 Type CSD R5 dropshaft, Q = 300 cfs, T.W. = 2.3 ft.
The overall model.

PHOTO 37 Type CSD R5 dropshaft, Q = 300 cfs, T.W. = 14 ft.
The surge shaft and deaeration chamber.

PHOTO 38 Type CSD R5 dropshaft, Q = 300 cfs, T.W. = 22 ft.
The surge shaft and deaeration chamber.

PHOTO 39 Type CSD R5 dropshaft, Q = 300 cfs, T.W. = 45 ft.
The overall model.

PHOTO 40 Type CSD R5 dropshaft, Q = 400 cfs, T.W. = 2.6 ft.
The overall model.

PHOTO 41 Type CSD R5 dropshaft, Q = 400 cfs, T.W. = 22 ft.
The overall model.

PHOTO 42 Type CSD R6 dropshaft, Q = 300 cfs, T.W. = 2.6 ft.
The overall model.

PHOTO 43 Type CSD R6 dropshaft, Q = 300 cfs, T.W. = 14 ft.
The surge shaft and deaeration chamber.

PHOTO 44 Type CSD R6 dropshaft, Q = 300 cfs, T.W. = 22 ft.
The surge shaft and deaeration chamber.

PHOTO 45 Type CSD R6 dropshaft, Q = 300 cfs, T.W. = 45 ft.
The overall model.

PHOTO 46 Type CSD R6 dropshaft, Q = 400 cfs, T.W. = 3.1 ft.
The overall model.

PHOTO 47 Type CSD R6 dropshaft, Q = 400 cfs, T.W. = 22 ft.
The overall model.

PHOTO 48 Type CSD R7 dropshaft, Q = 300 cfs, T.W. = 3.8 ft.
The surge shaft and deaeration chamber.

PHOTO 49 Type CSD R7 dropshaft, Q = 300 cfs, T.W. = 14 ft.
The surge shaft and deaeration chamber.

PHOTO 50 Type CSD R7 dropshaft, Q = 300 cfs, T.W. = 14 ft.
The entrance to the exit conduit.

PHOTO 51 Type CSD R7 dropshaft, Q = 300 cfs, T.W. = 22 ft.
The surge shaft and deaeration chamber.

PHOTO 52 Type CSD R7 dropshaft, Q = 300 cfs, T.W. = 22 ft.
The entrance to the exit conduit.

PHOTO 53 Type CSD R7 dropshaft, Q = 300 cfs, T.W. = 45 ft.
The overall model.

PHOTO 54 Type CSD R7 dropshaft, Q = 400 cfs, T.W. = 4.7 ft.
The overall model.

PHOTO 55 Type CSD R7 dropshaft, Q = 400 cfs, T.W. = 22 ft.
The overall model.

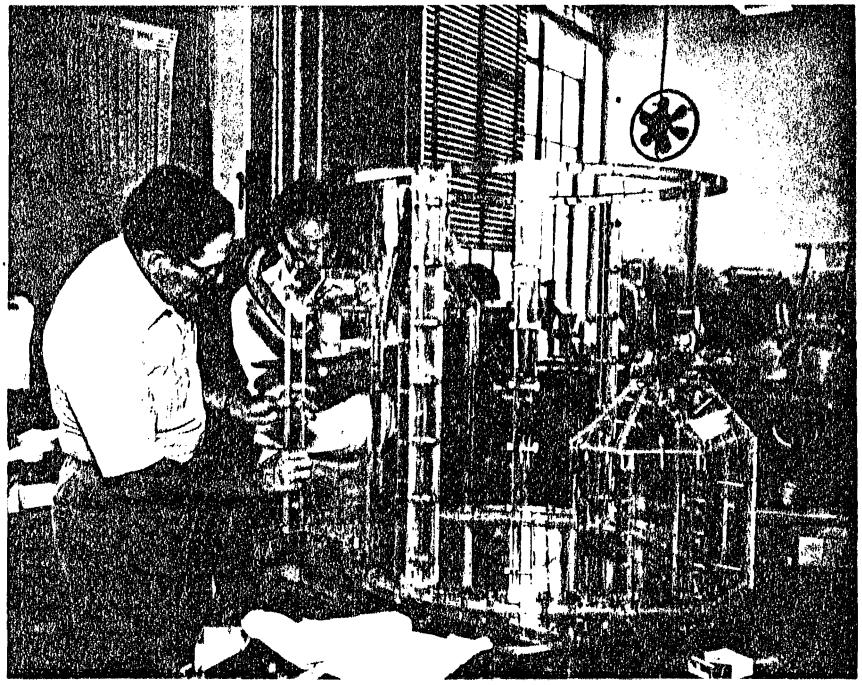


Photo 1 - The surge shaft being fabricated in the Laboratory shop.

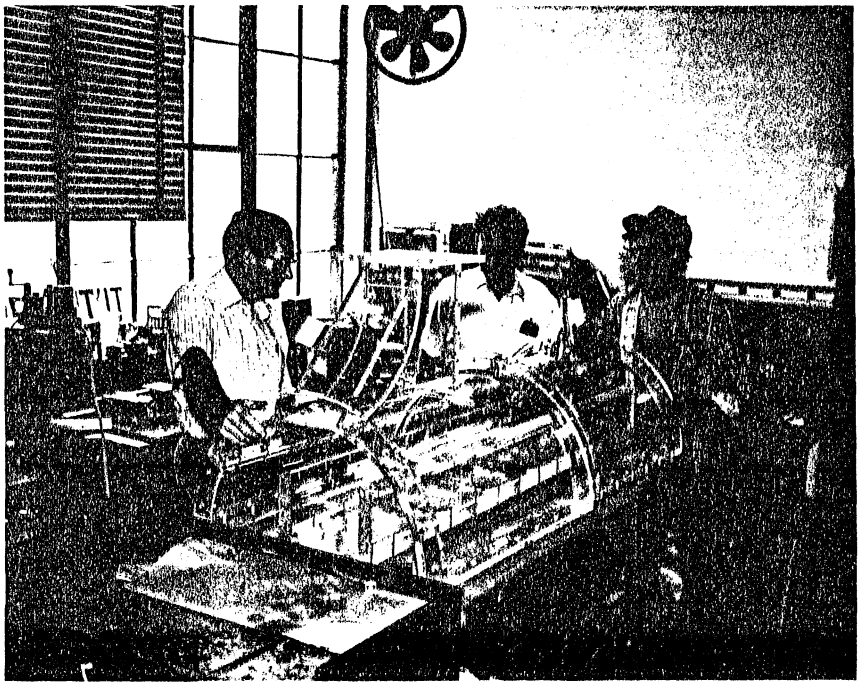


Photo 2 - The dropshaft, elbow, and sections of the surge shaft being fabricated.

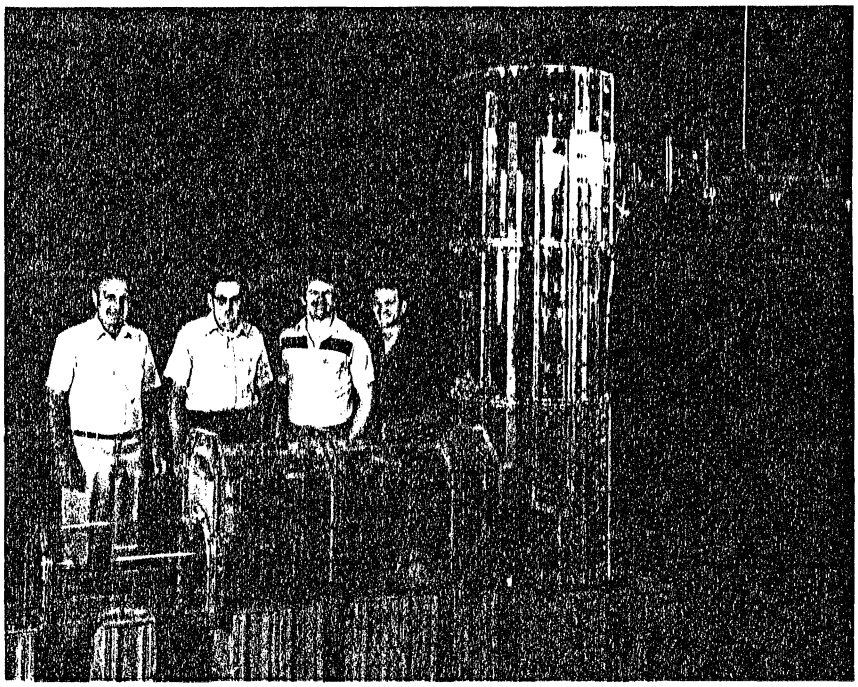


Photo 3 - Type CSD R1 dropshaft. The completed model ready for testing and the personnel responsible for its construction.

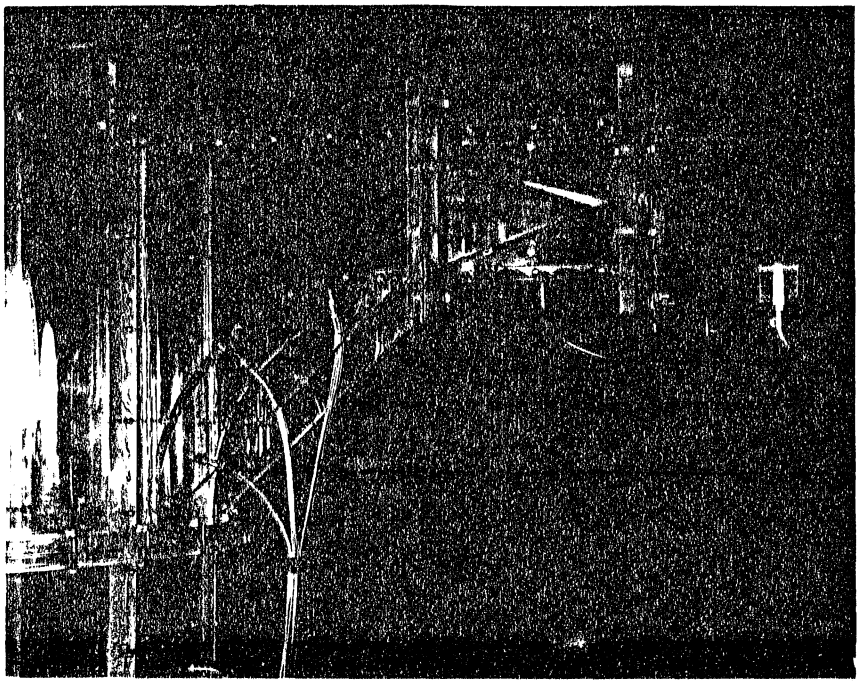


Photo 4 - Type CSD R1 dropshaft. The transition and quarter cylinder elbow.

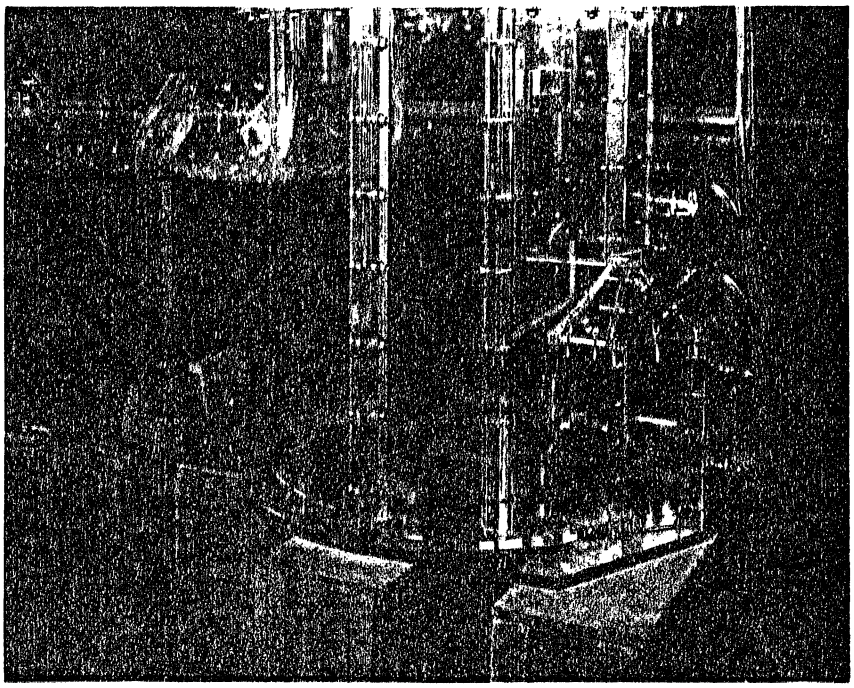


Photo 5 - Type CSD R1 dropshaft. The bottom of the surge shaft with the boot.

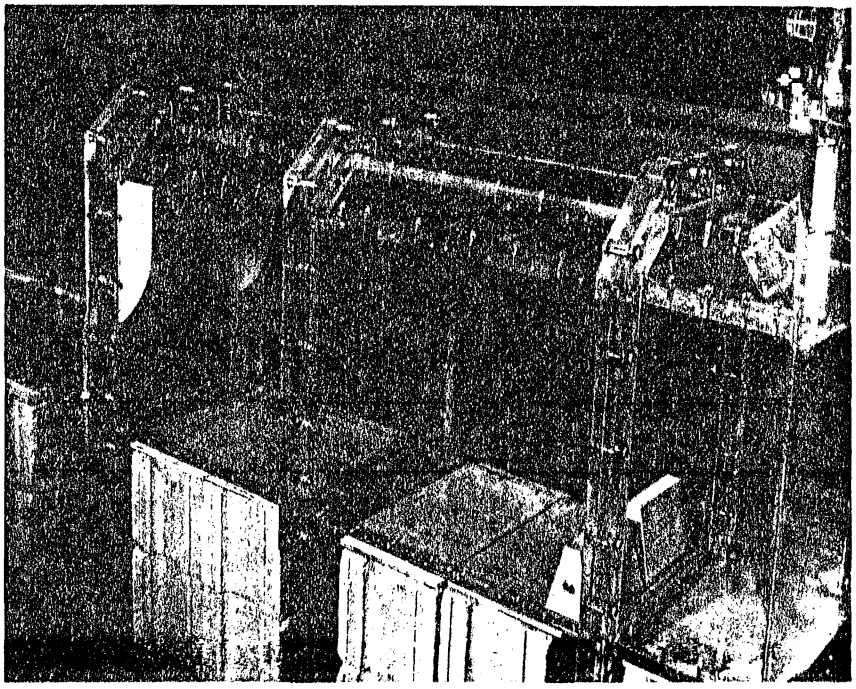


Photo 6 - Type CSD R1 dropshaft. The deaeration chamber with the slotted weir, air slots, and bellmouth.

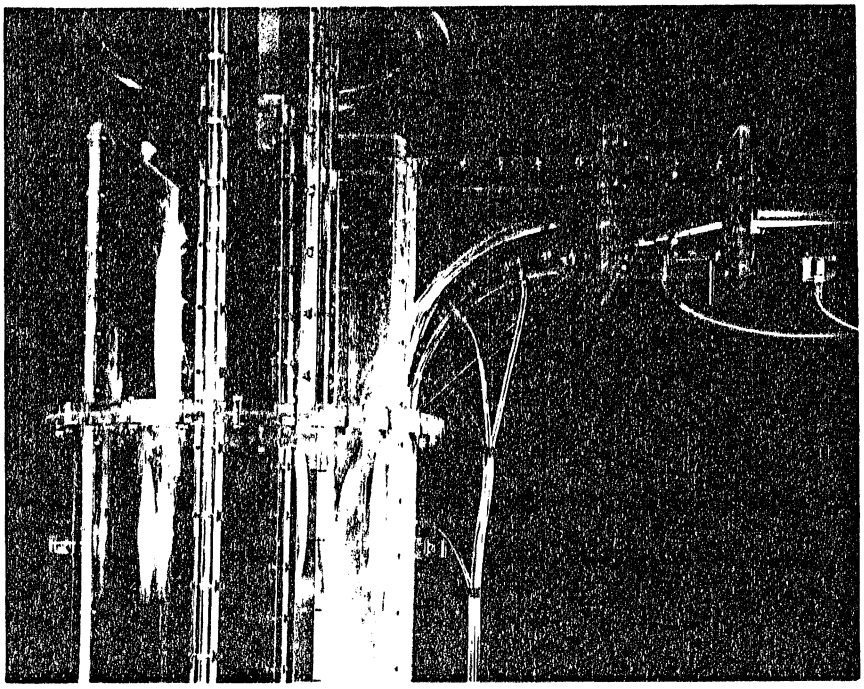


Photo 7 - Type CSD R1 dropshaft, Q = 300 cfs, T.W. = 2.3 ft. The quarter cylinder elbow.

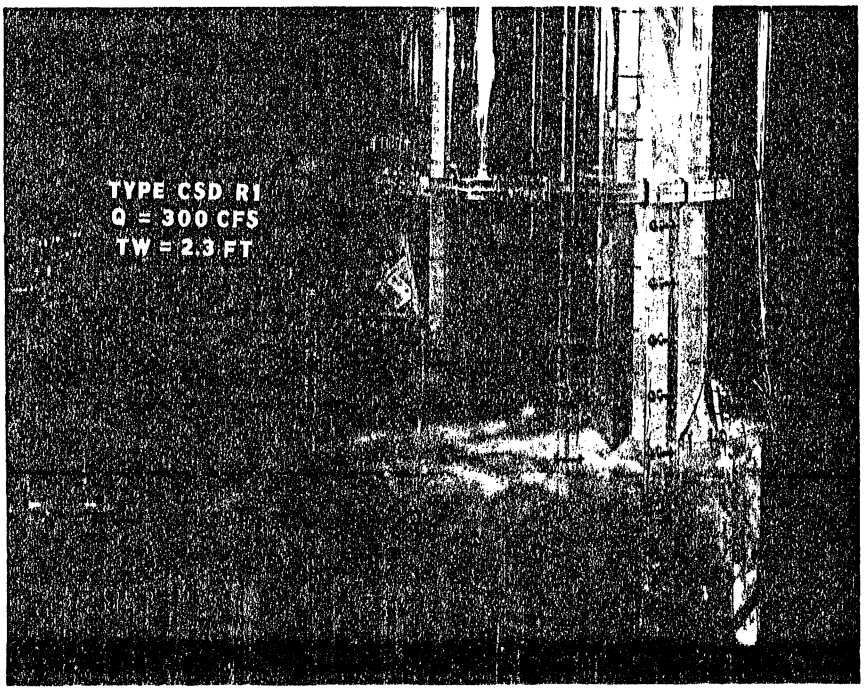


Photo 8 - Type CSD R1 dropshaft, Q = 300 cfs, T.W. = 2.3 ft. The surge shaft and deaeration chamber.

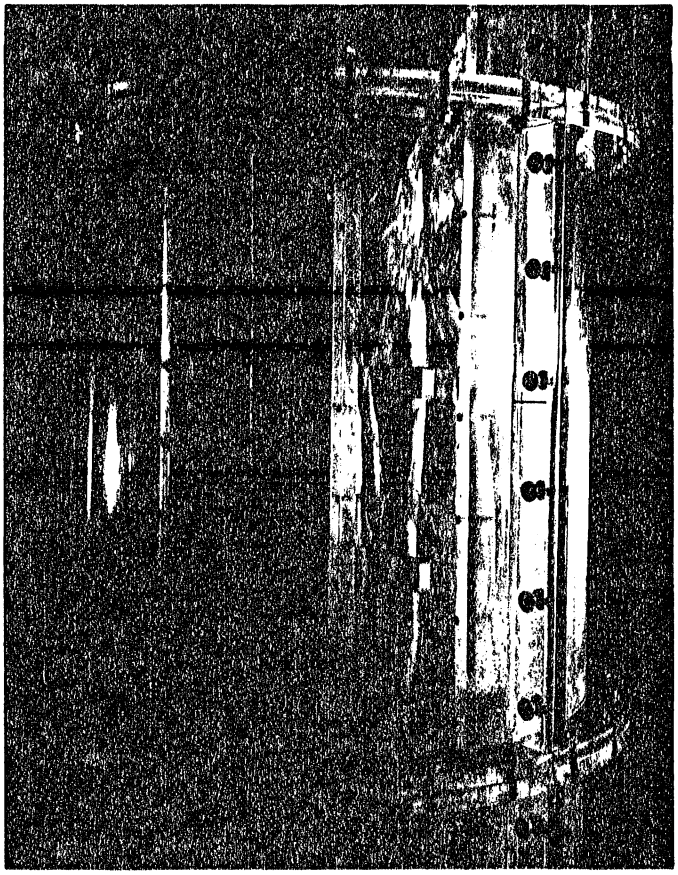


Photo 9 - Type CSD R1 dropshaft, Q = 300 cfs, T.W. = 2.3 ft.
The impact area on the dropshaft wall.

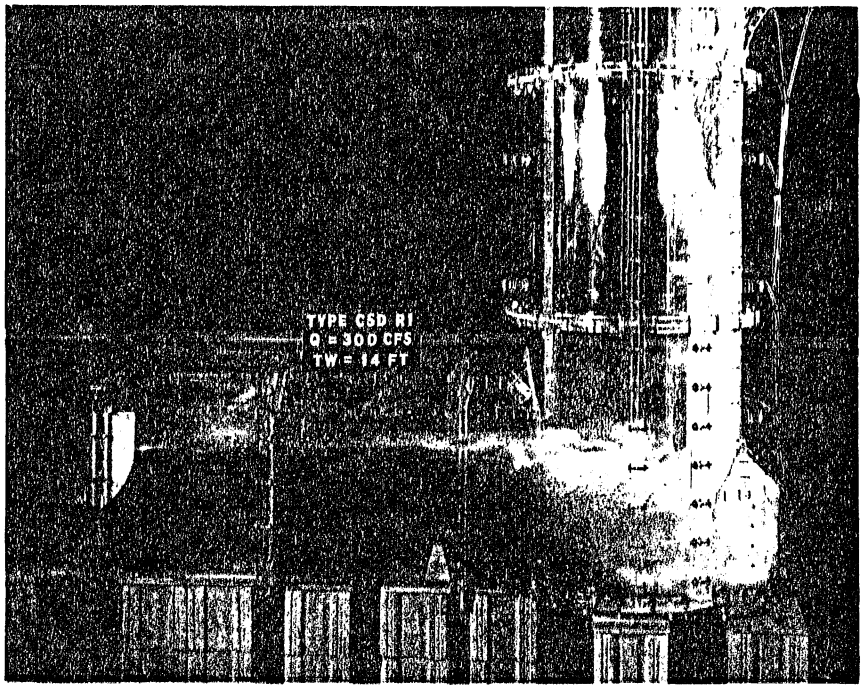


Photo 10 - Type CSD R1 dropshaft, Q = 300 cfs, T.W. = 14 ft. The surge shaft and deaeration chamber.

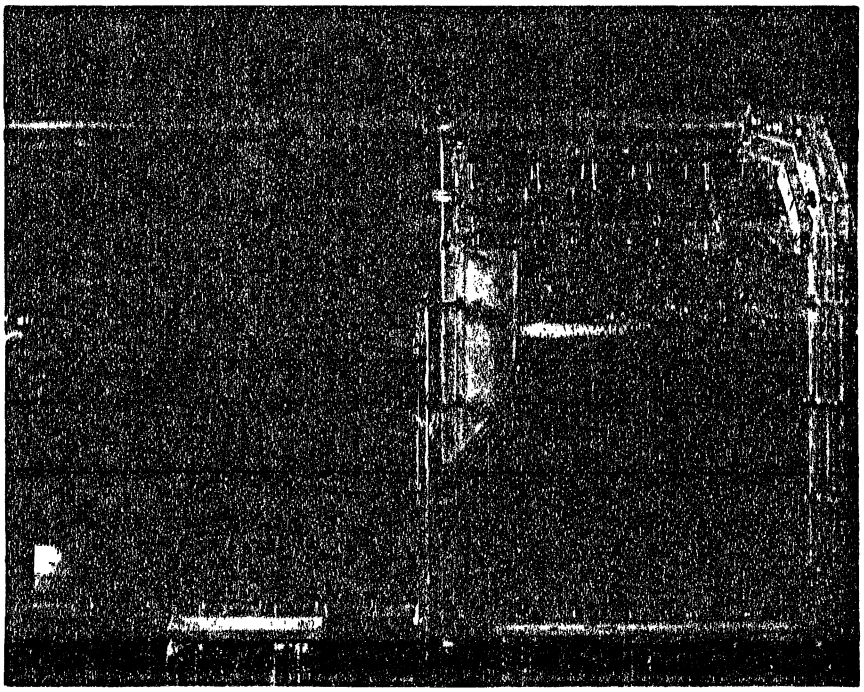


Photo 11 - Type CSD R1 dropshaft, Q = 300 cfs, T.W. = 14 ft. The entrance to the exit conduit.

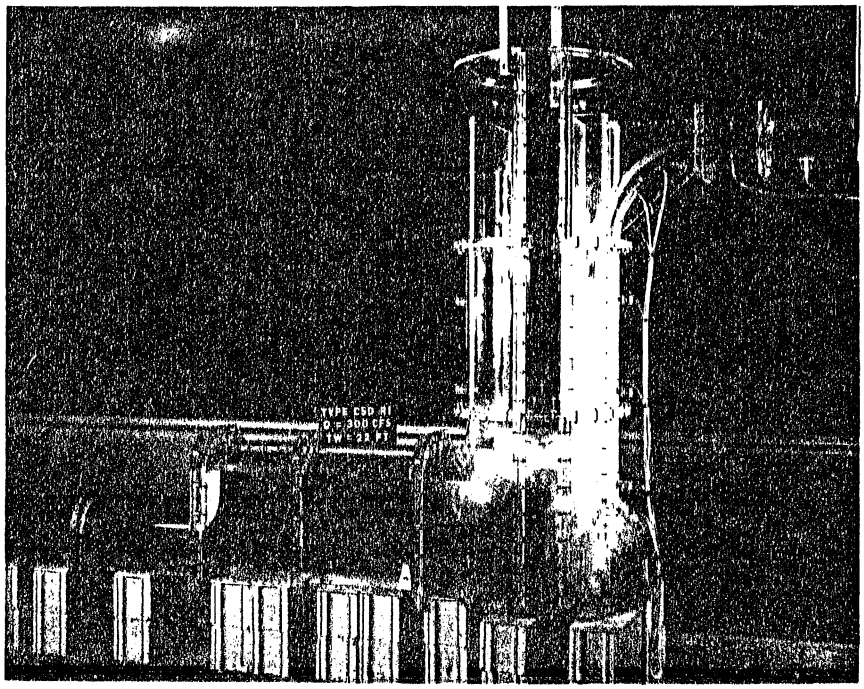


Photo 12 - Type CSD R1 dropshaft, Q = 300 cfs, T.W. = 22 ft.
The overall model.

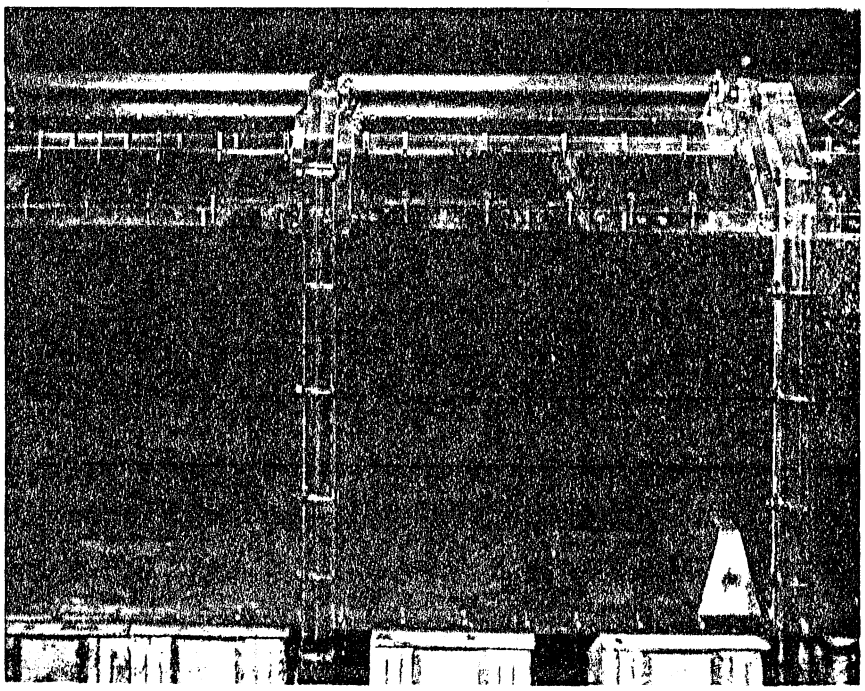


Photo 13 - Type CSD R1 dropshaft, Q = 300 cfs, T.W. = 22 ft.
The air passing through the slots.

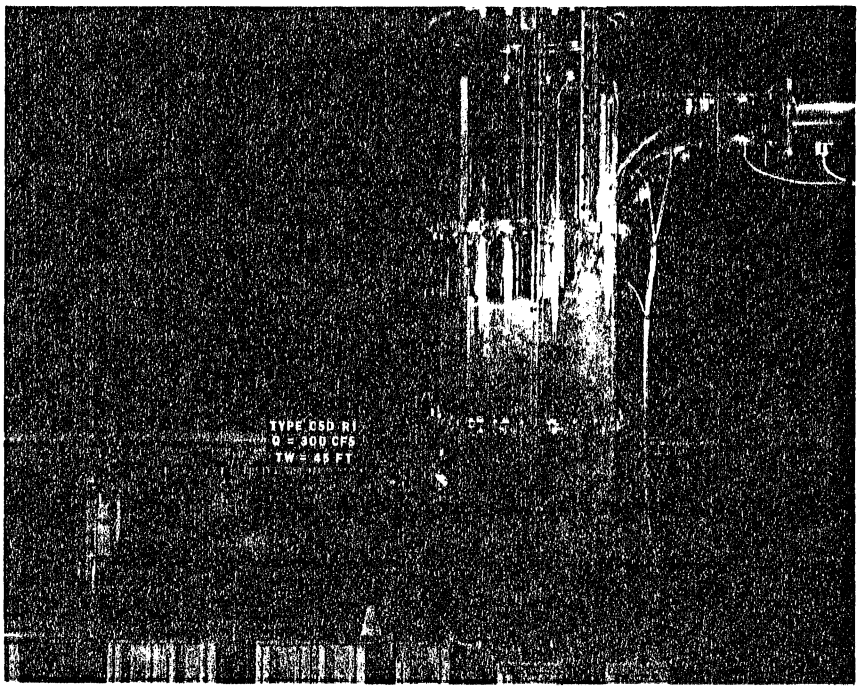


Photo 14 - Type CSD R1 dropshaft, Q = 300 cfs, T.W. = 45 ft. The overall model.

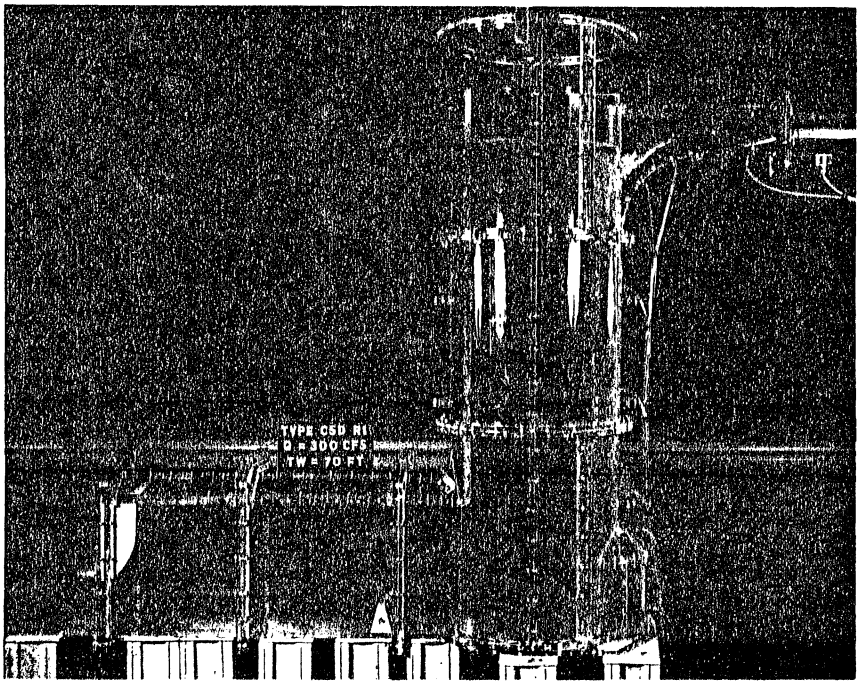


Photo 15 - Type CSD R1 dropshaft, Q = 300 cfs, T.W. = 70 ft. The overall model.

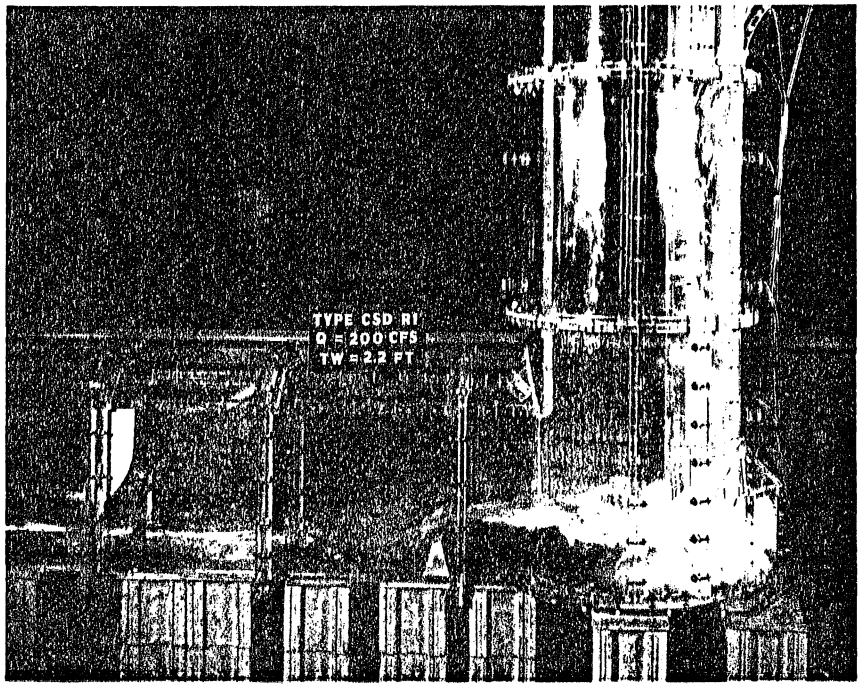


Photo 16 - Type CSD R1 dropshaft, Q = 200 cfs, T.W. = 2.2 ft. The surge shaft and deaeration chamber.

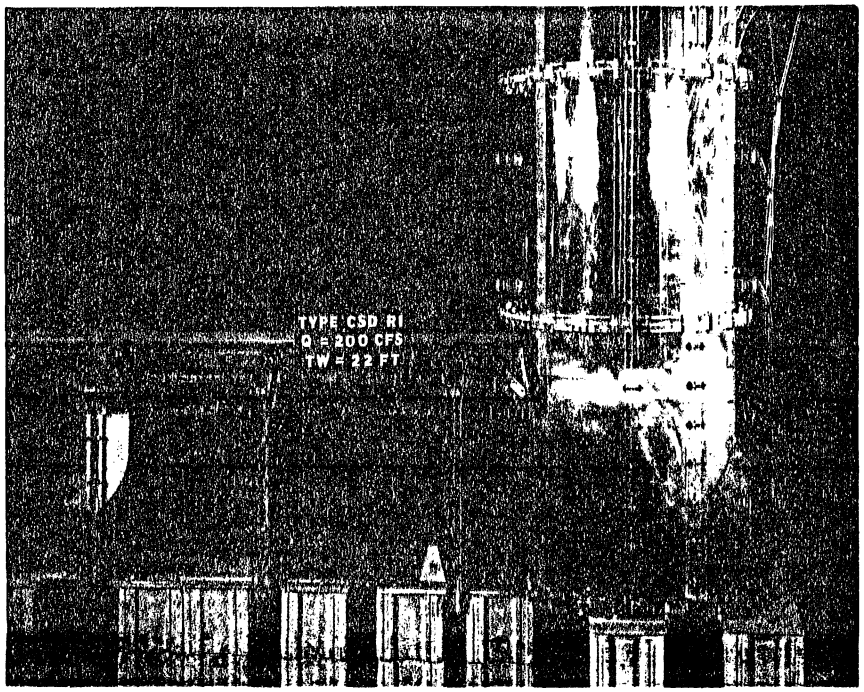


Photo 17 - Type CSD R1 dropshaft, Q = 200 cfs, T.W. = 22 ft. The surge shaft and deaeration chamber.

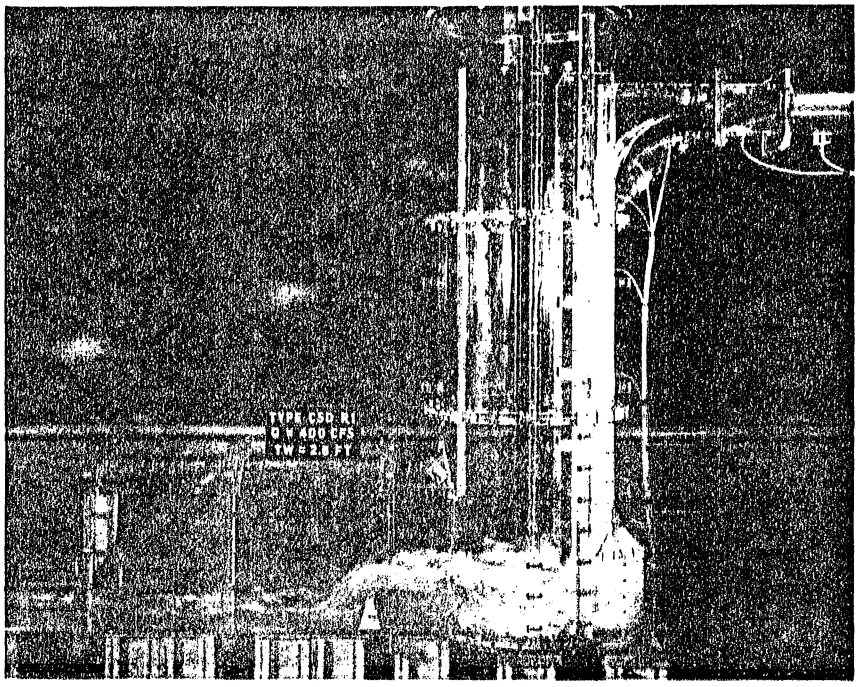


Photo 18 - Type CSD R1 dropshaft, Q = 400 cfs, T.W. = 2.6 ft. The overall model.

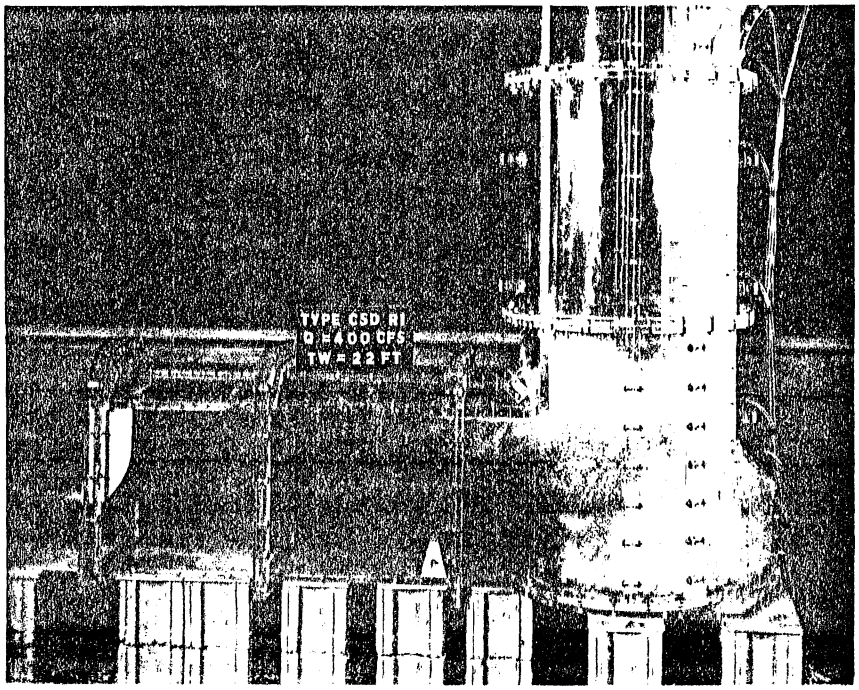


Photo 19 - Type CSD R1 dropshaft, Q = 400 cfs, T.W. = 22 ft. The surge shaft and deaeration chamber.

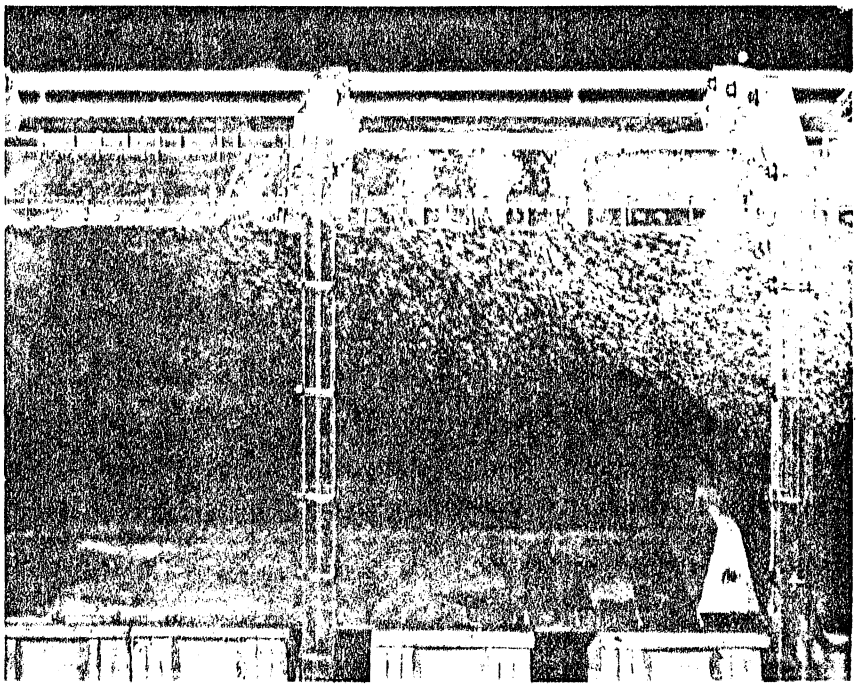


Photo 20 - Type CSD R1 dropshaft, Q = 400 cfs, T.W. = 22 ft.
The air passing through the slots.

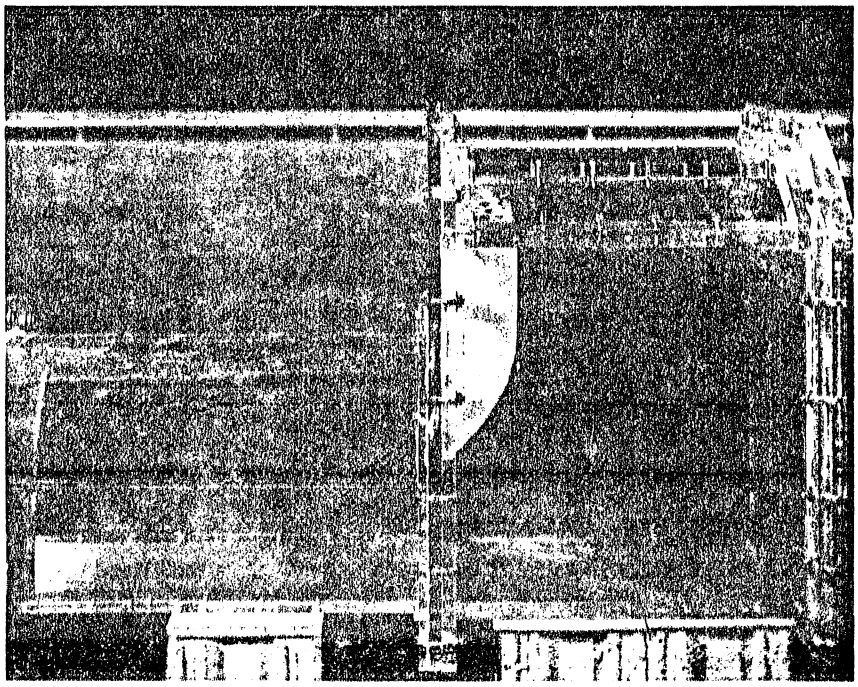


Photo 21 - Type CSD R1 dropshaft, Q = 400 cfs, T.W. = 22 ft.
The entrance to the exit conduit.

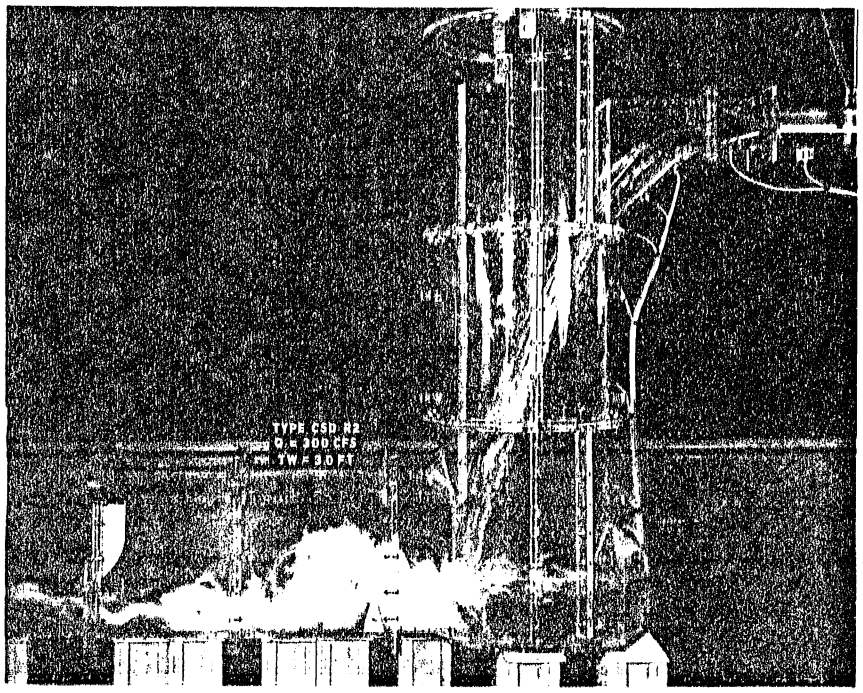


Photo 22 - Type CSD R2 dropshaft, Q = 300 cfs, T.W. = 3.0 ft. The overall model.

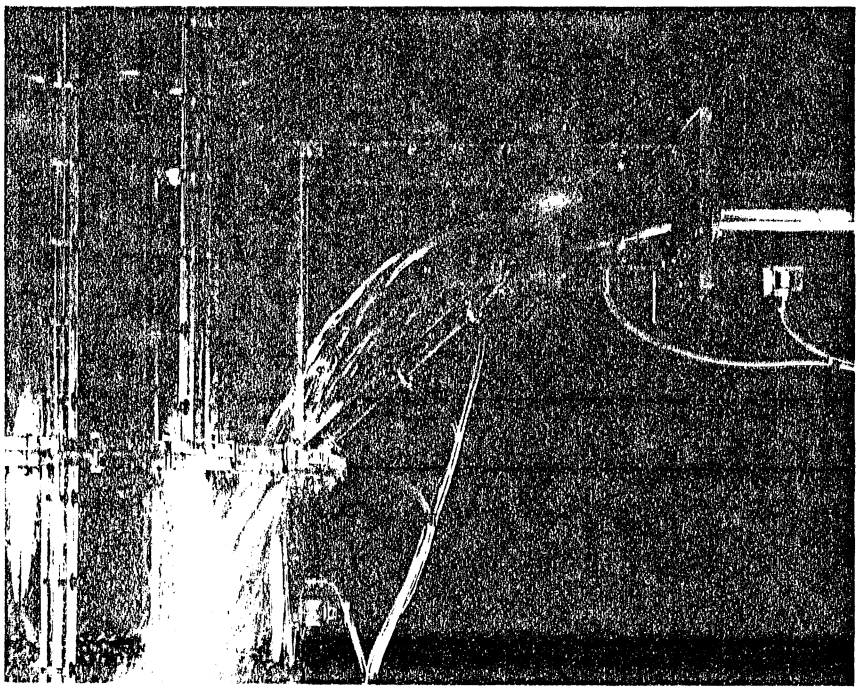


Photo 23 - Type CSD R2 dropshaft, Q = 300 cfs, T.W. = 3.0 ft. The free trajectory inlet.

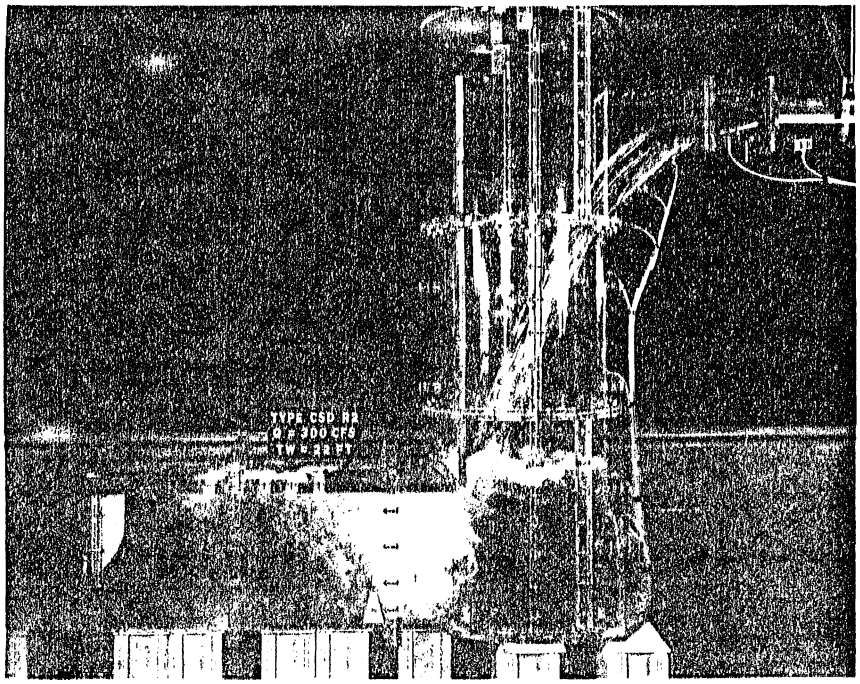


Photo 24 - Type CSD R2 dropshaft, Q = 300 cfs, T.W. = 22 ft.
The overall model.

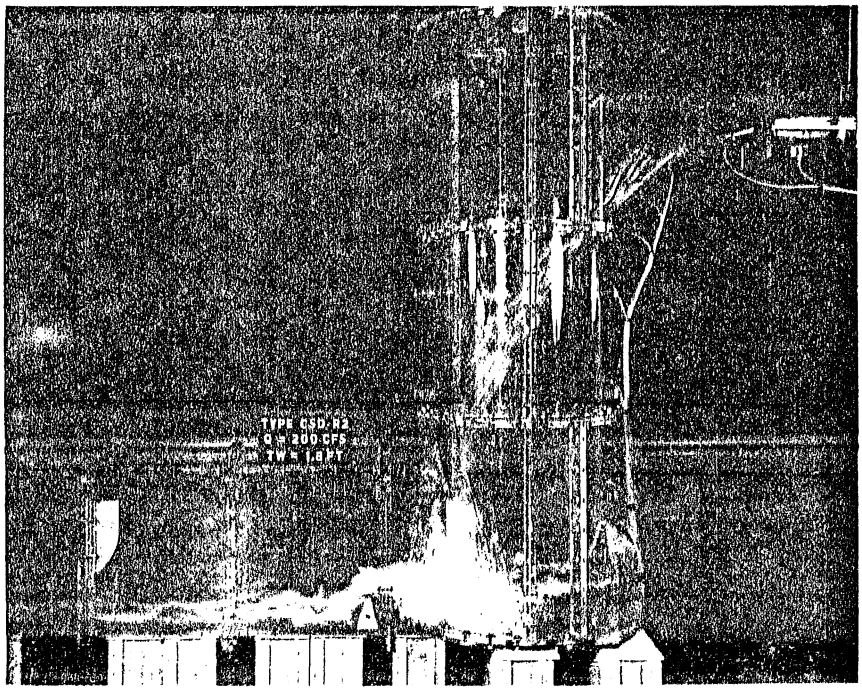


Photo 25 - Type CSD R2 dropshaft, Q = 200 cfs, T.W. = 1.8 ft.
The overall model

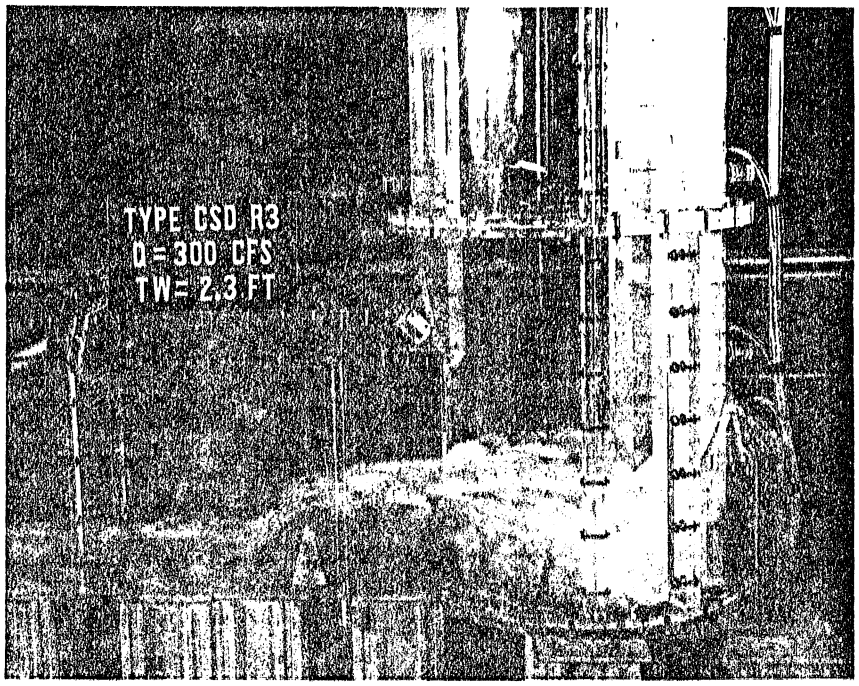


Photo 26 - Type CSD R3 dropshaft, Q = 300 cfs, T.W. = 2.3 ft. The surge shaft and deaeration chamber.

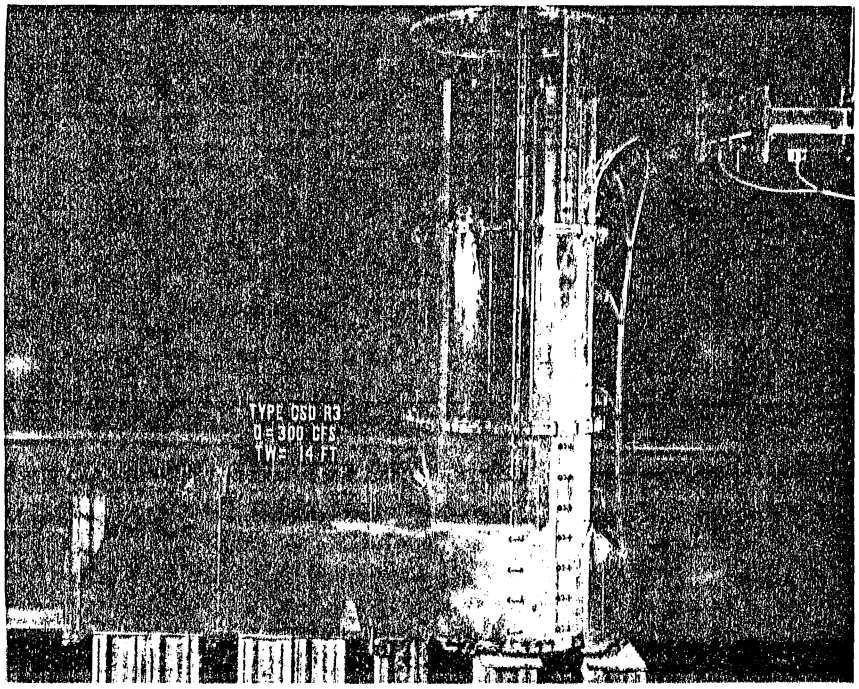


Photo 27 - Type CSD R3 dropshaft, Q = 300 cfs, T.W. = 14 ft. The overall model.

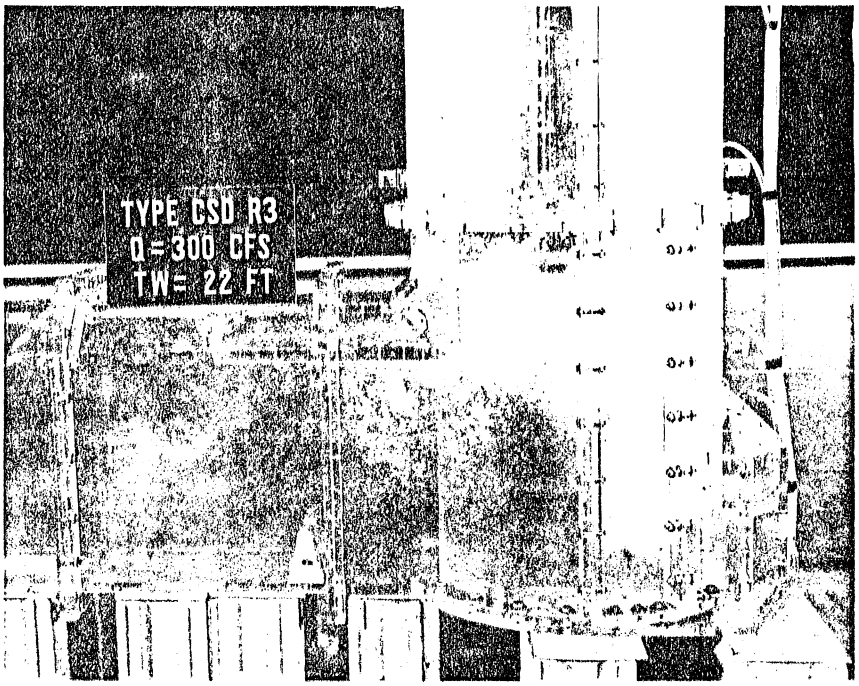


Photo 28 - Type CSD R3 dropshaft, Q = 300 cfs, T.W. = 22 ft. The surge shaft and deaeration chamber.

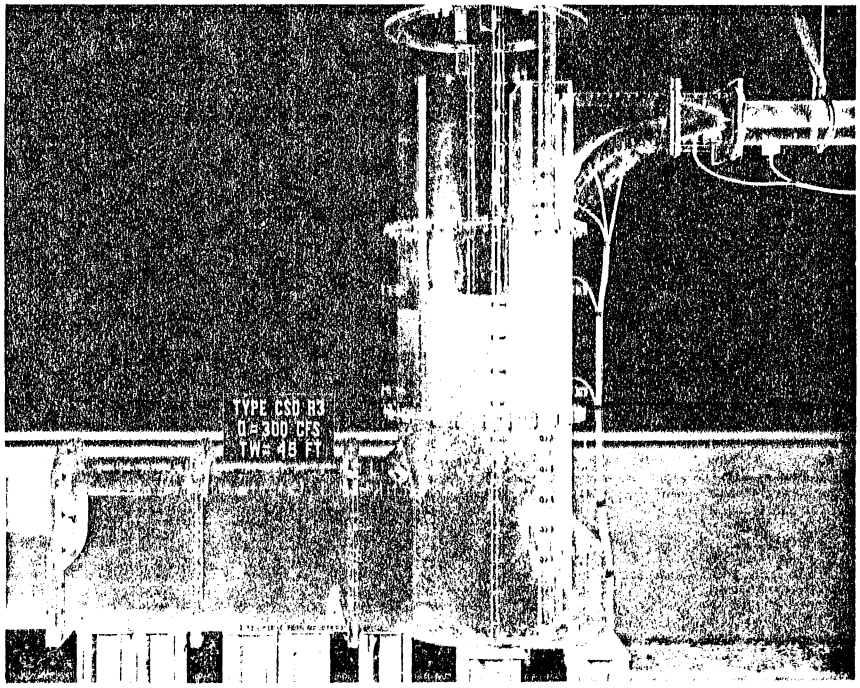


Photo 29 - Type CSD R3 dropshaft, Q = 300 cfs, T.W. = 45 ft. The overall model.

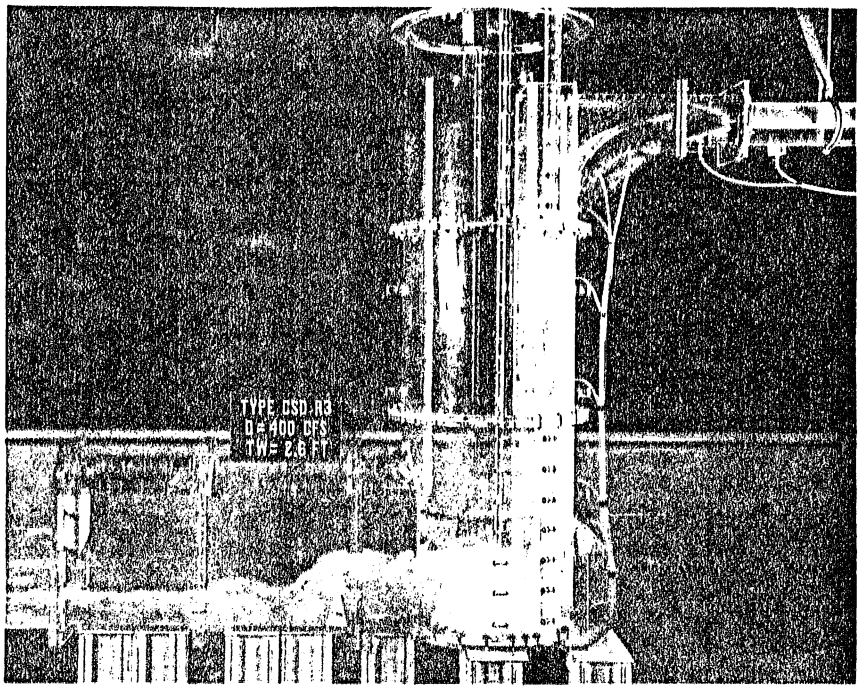


Photo 30 - Type CSD R3 dropshaft, Q = 400 cfs, T.W. = 2.6 ft. The overall model.

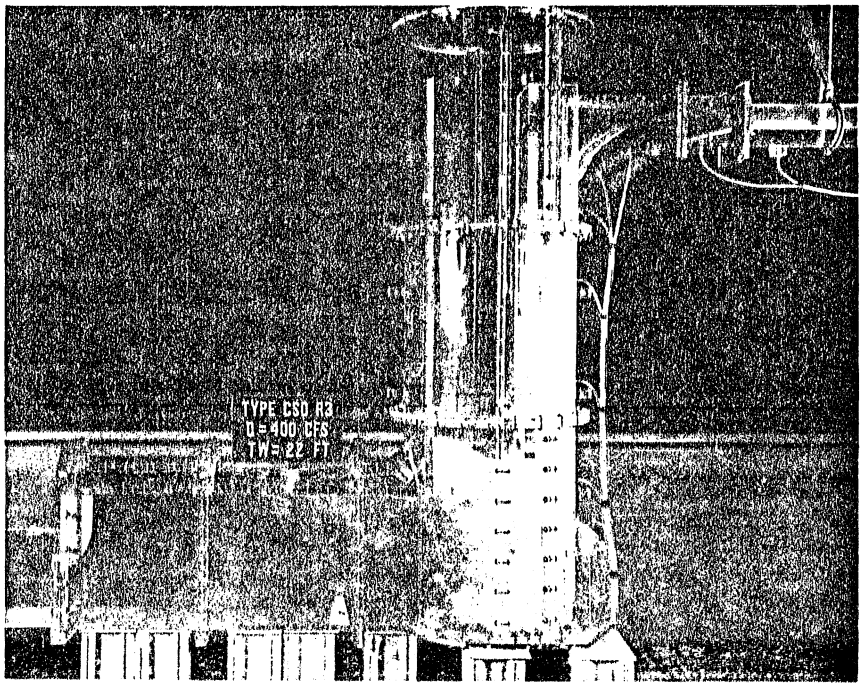


Photo 31 - Type CSD R3 dropshaft, Q = 400 cfs, T.W. = 22 ft. The overall model.

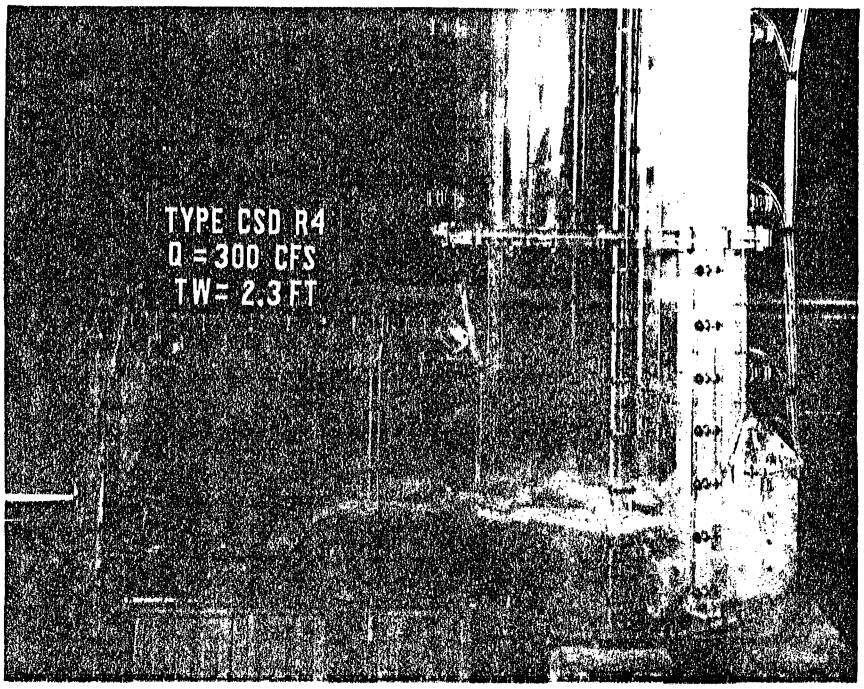


Photo 32 - Type CSD R4 dropshaft, Q = 300 cfs, T.W. = 2.3 ft. The surge shaft and deaeration chamber.

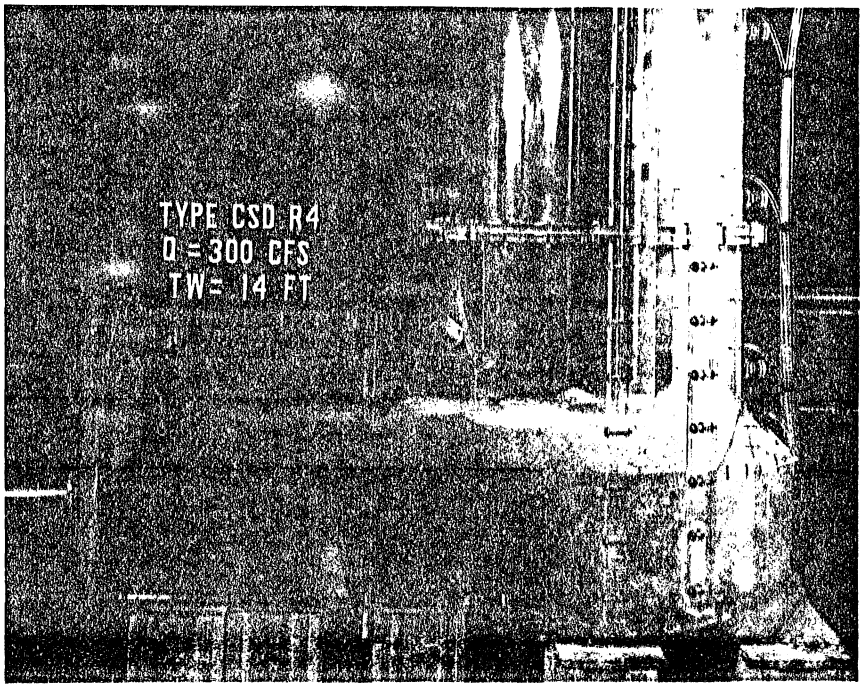


Photo 33 - Type CSD R4 dropshaft, Q = 300 cfs, T.W. = 14 ft. The surge shaft and deaeration chamber.

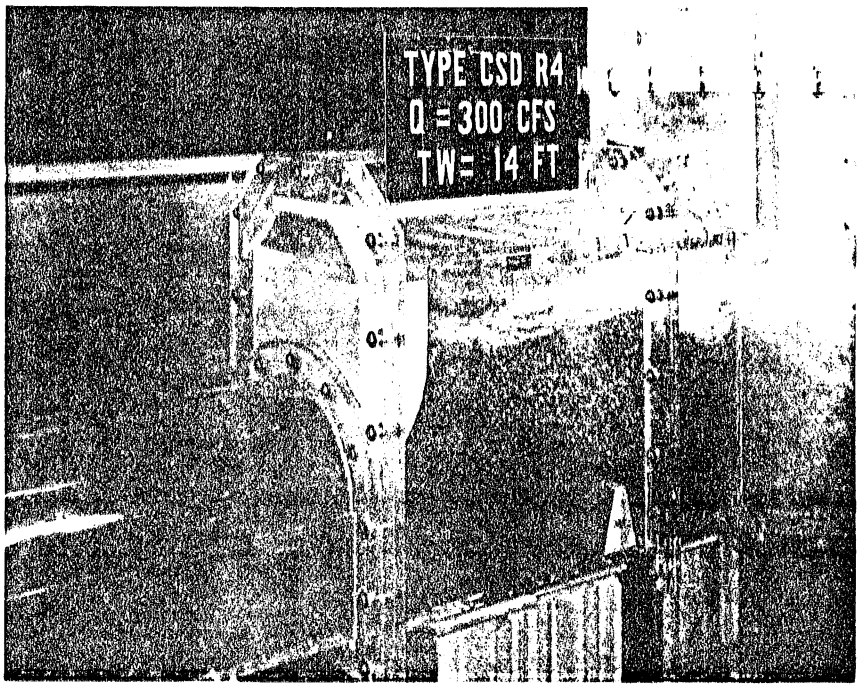


Photo 34 - Type CSD R4 dropshaft, Q = 300 cfs, T.W. = 14 ft.
The deaeration chamber and exit conduit.

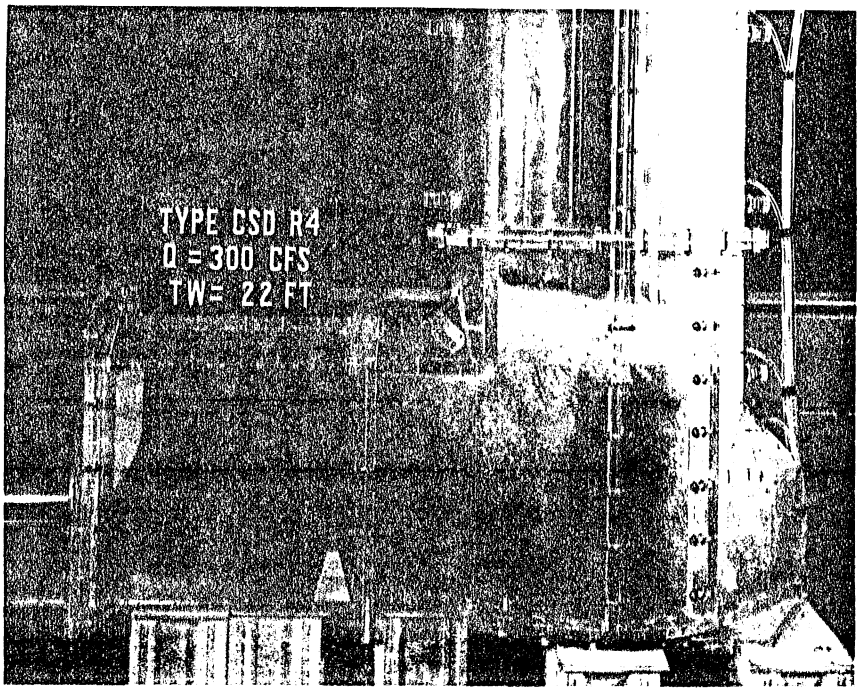


Photo 35 - Type CSD R4 dropshaft, Q = 300 cfs, T.W. = 22 ft.
The surge shaft and deaeration chamber.

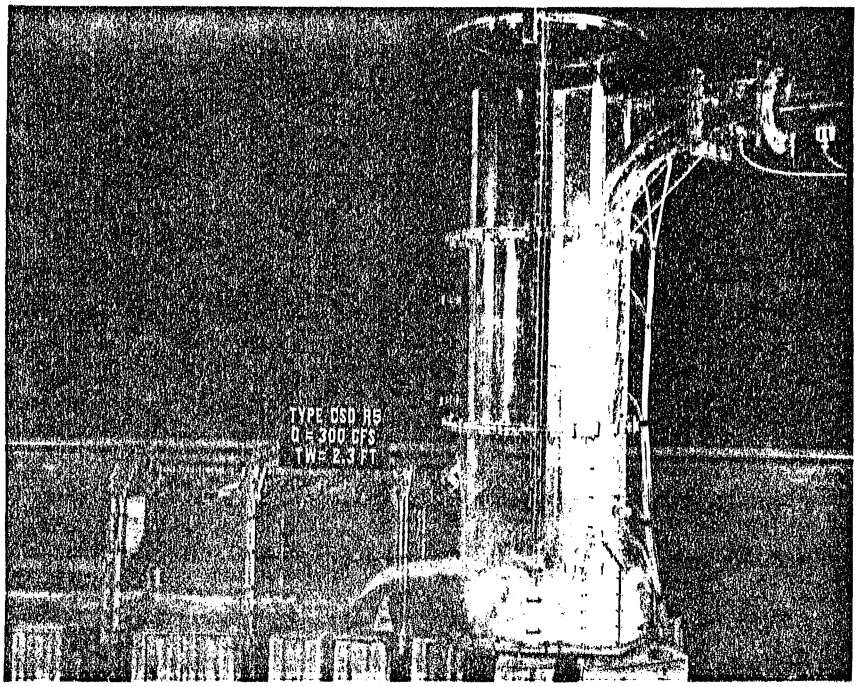


Photo 36 - Type CSD R5 dropshaft, Q = 300 cfs, T.W. = 2.3 ft. The overall model.

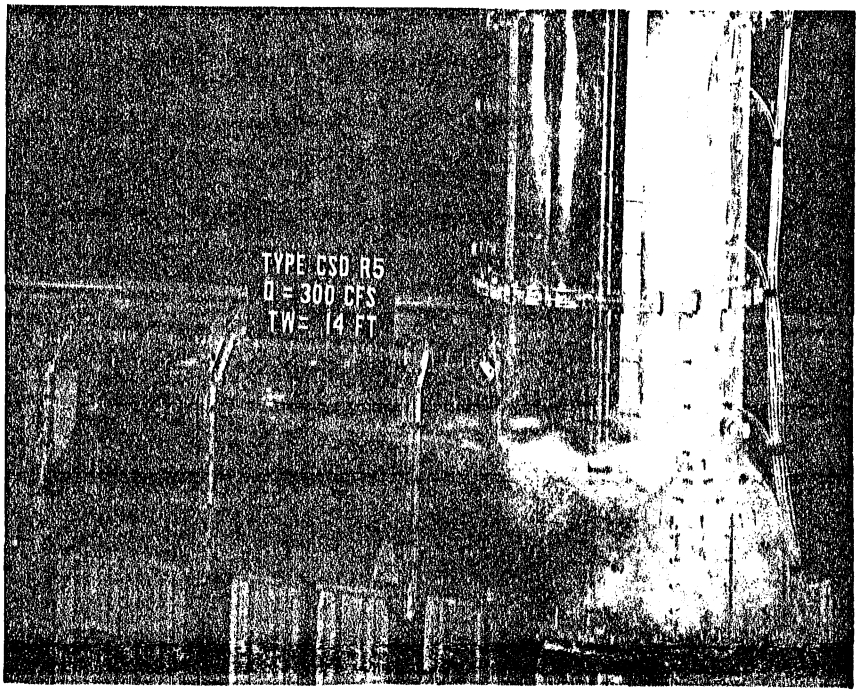


Photo 37 - Type CSD R5 dropshaft, Q = 300 cfs, T.W. = 14 ft. The surge shaft and deaeration chamber.

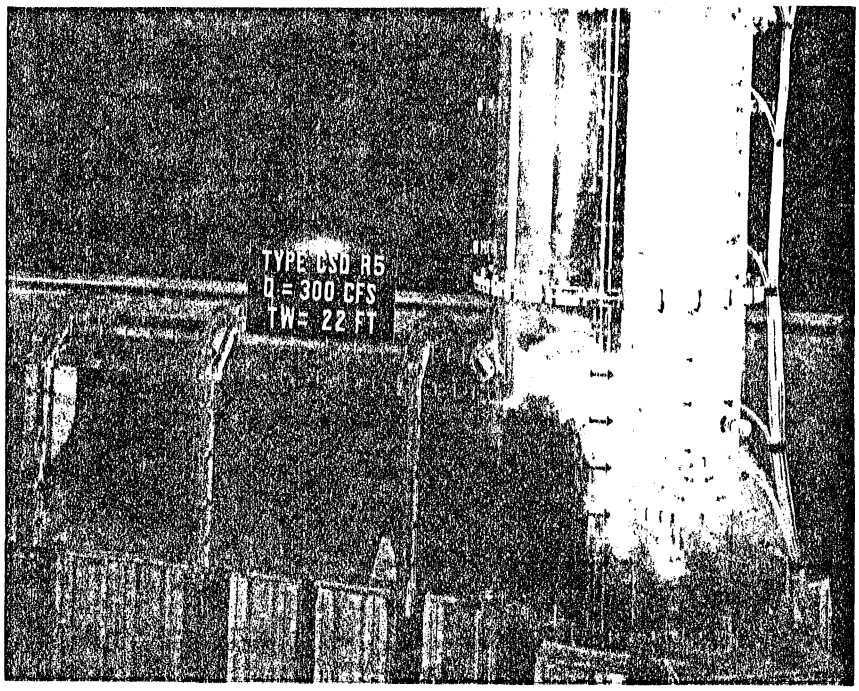


Photo 38 - Type CSD R5 dropshaft, Q = 300 cfs, T.W. = 22 ft. The surge shaft and deaeration chamber.

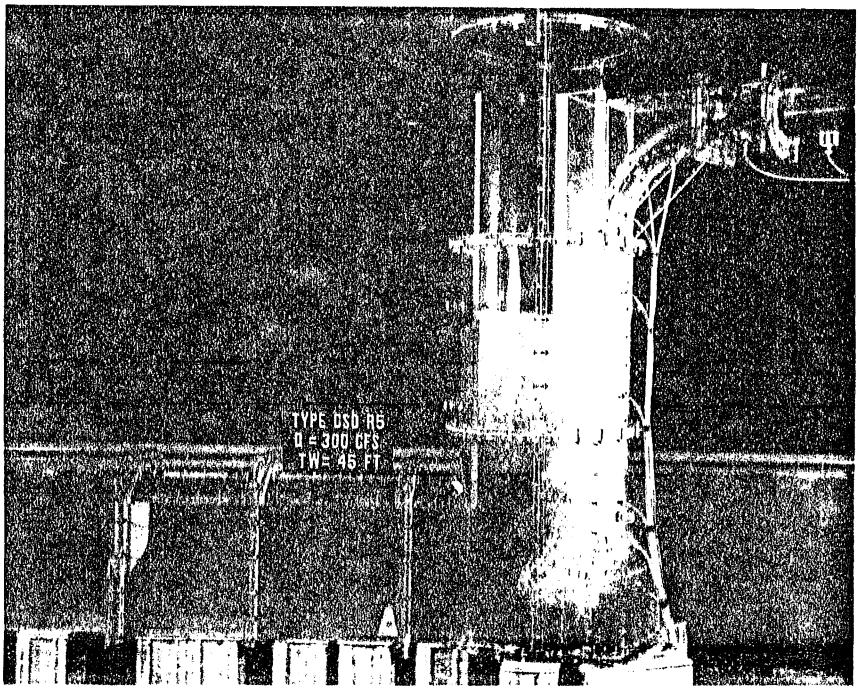


Photo 39 - Type CSD R5 dropshaft, Q = 300 cfs, T.W. = 45 ft. The overall model.

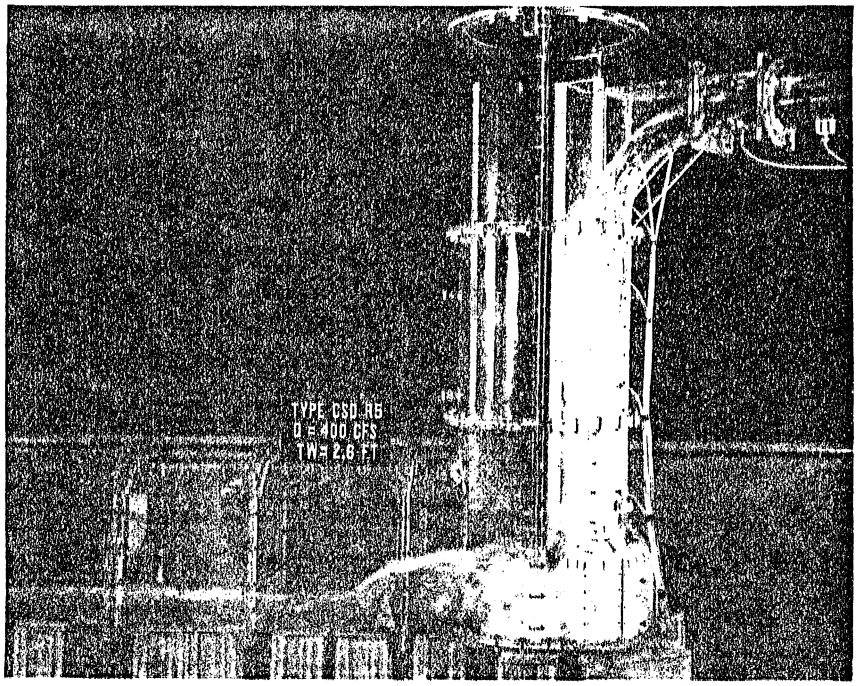


Photo 40 - Type CSD R5 dropshaft, Q = 400 cfs, T.W. = 2.6 ft. The overall model.

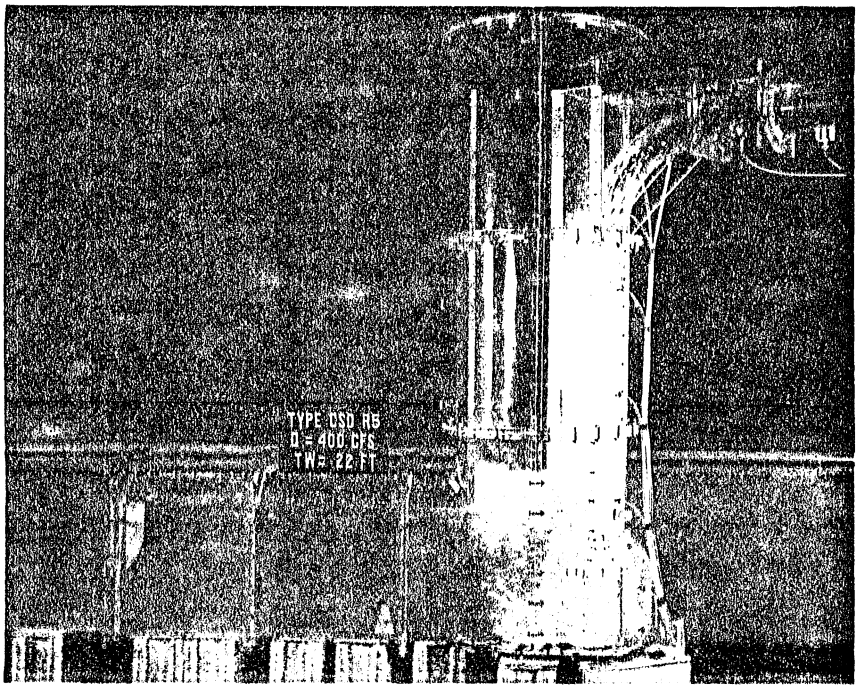


Photo 41 - Type CSD R5 dropshaft, Q = 400 cfs, T.W. = 22 ft. The overall model.

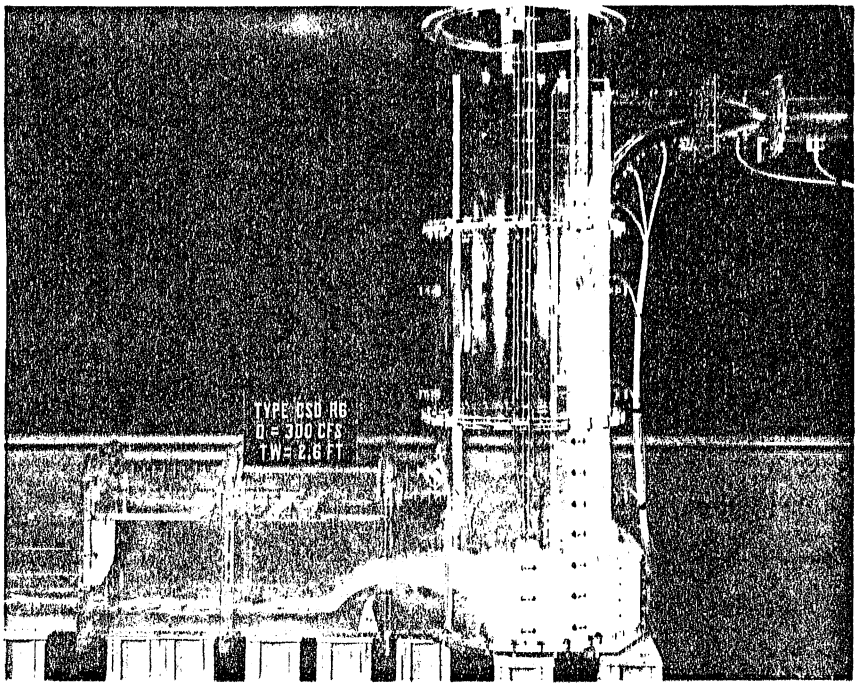


Photo 42 - Type CSD R6 dropshaft, Q = 300 cfs, T.W. = 2.6 ft. The overall model.

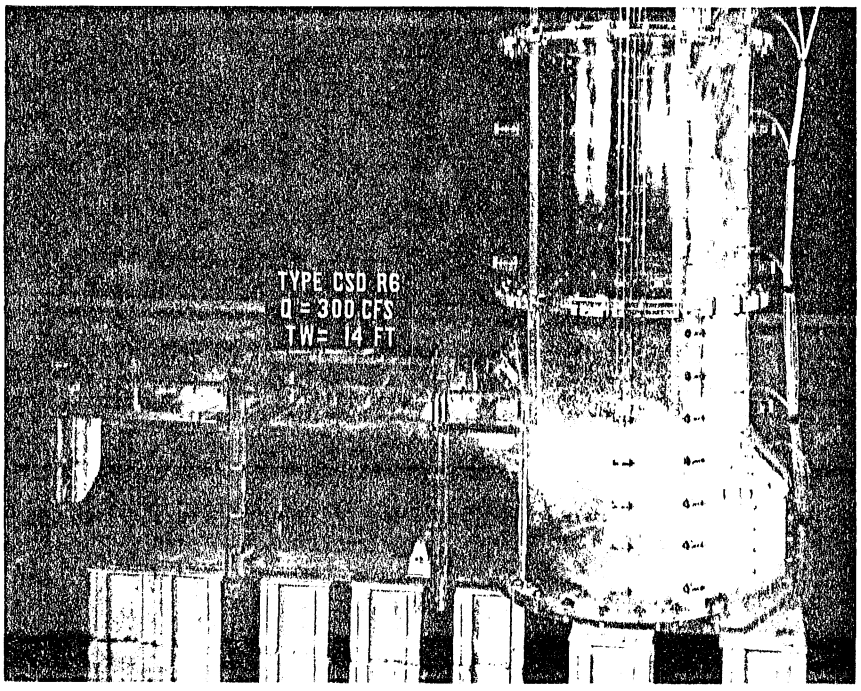


Photo 43 - Type CSD R6 dropshaft, Q = 300 cfs, T.W. = 14 ft. The surge shaft and deaeration chamber.

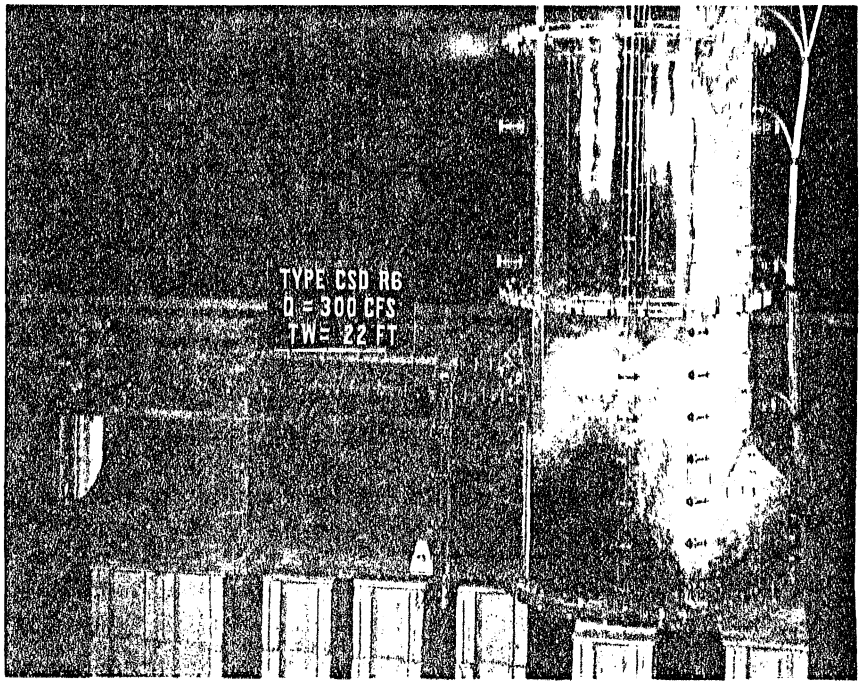


Photo 44 - Type CSD R6 dropshaft, Q = 300 cfs, T.W. = 22 ft. The surge shaft and deaeration chamber.

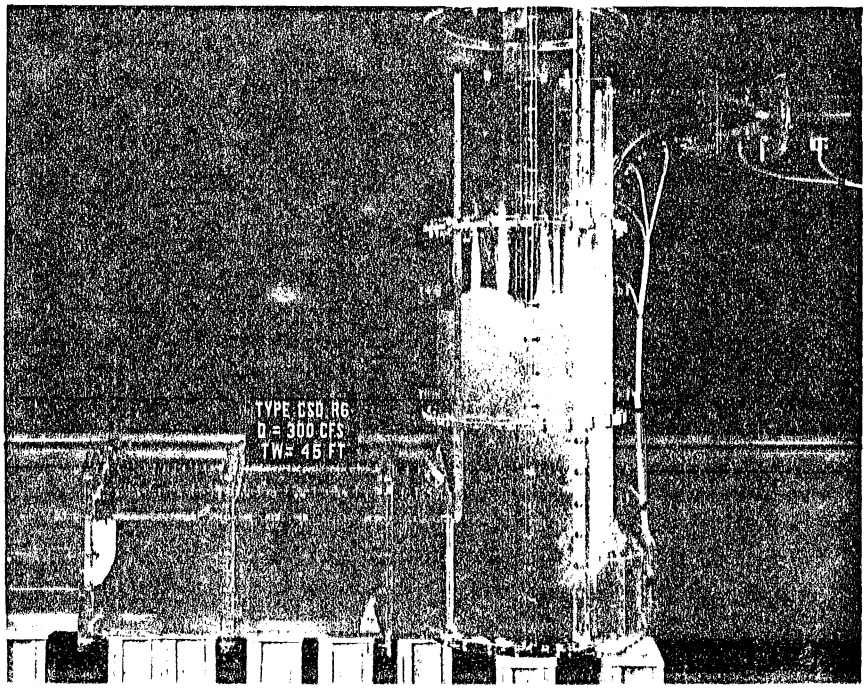


Photo 45 - Type CSD R6 dropshaft, Q = 300 cfs, T.W. = 45 ft. The overall model.

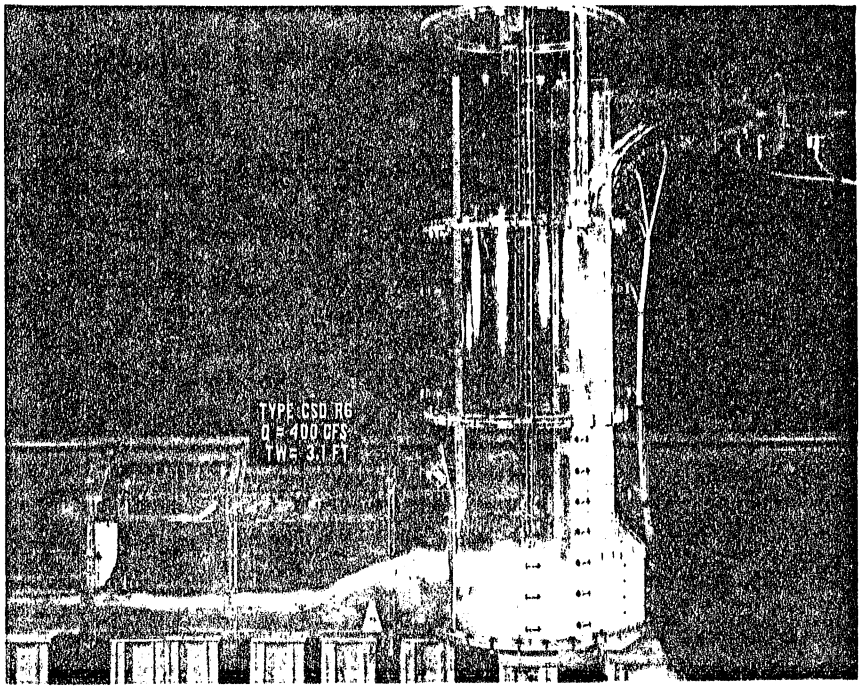


Photo 46 - Type CSD R6 dropshaft, Q = 400 cfs, T.W. = 3.1 ft. The overall model.

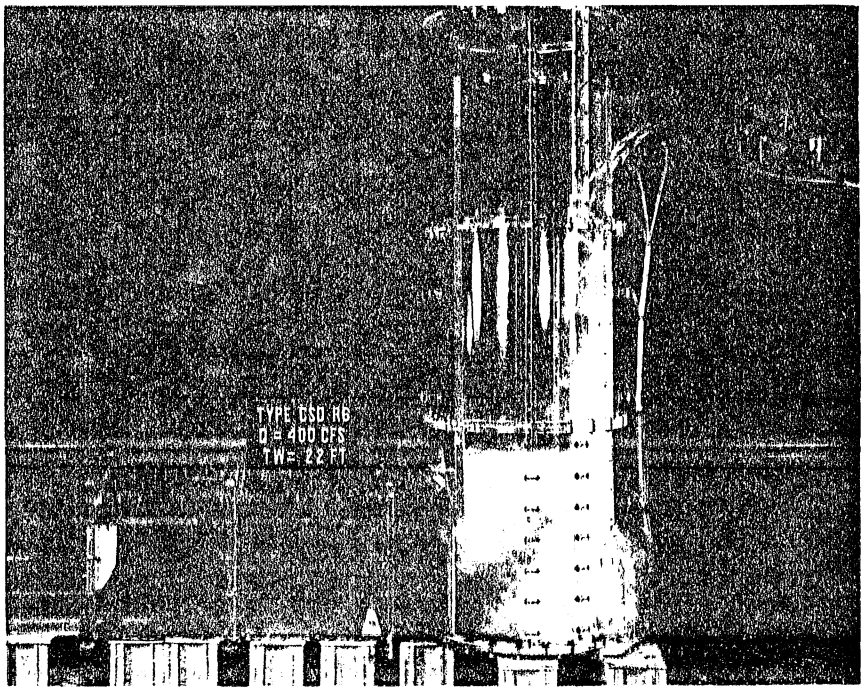


Photo 47 - Type CSD R6 dropshaft, Q = 400 cfs, T.W. = 22 ft. The overall model.

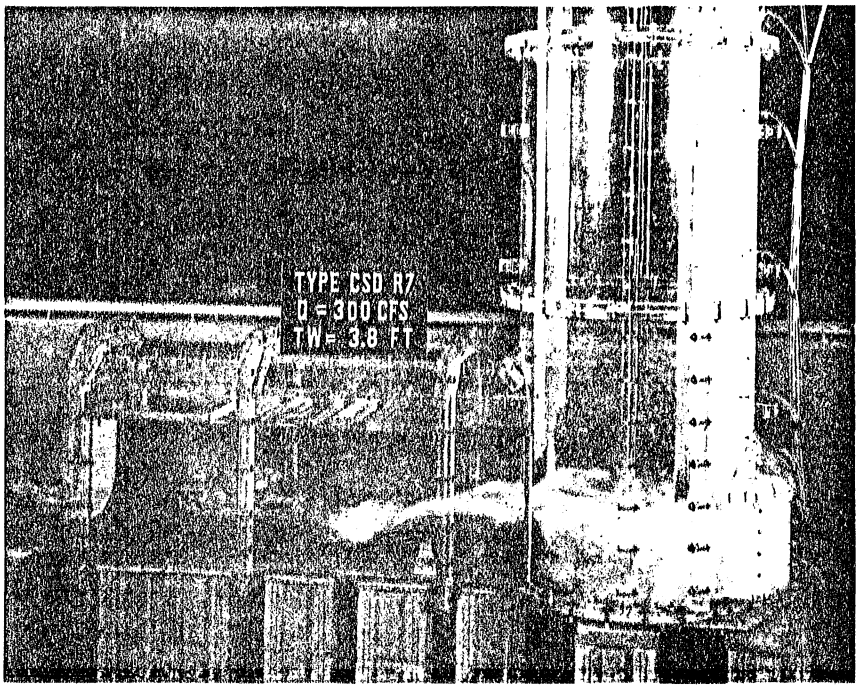


Photo 48 - Type CSD R7 dropshaft, Q = 300 cfs, T.W. = 3.8 ft. The surge shaft and deaeration chamber.

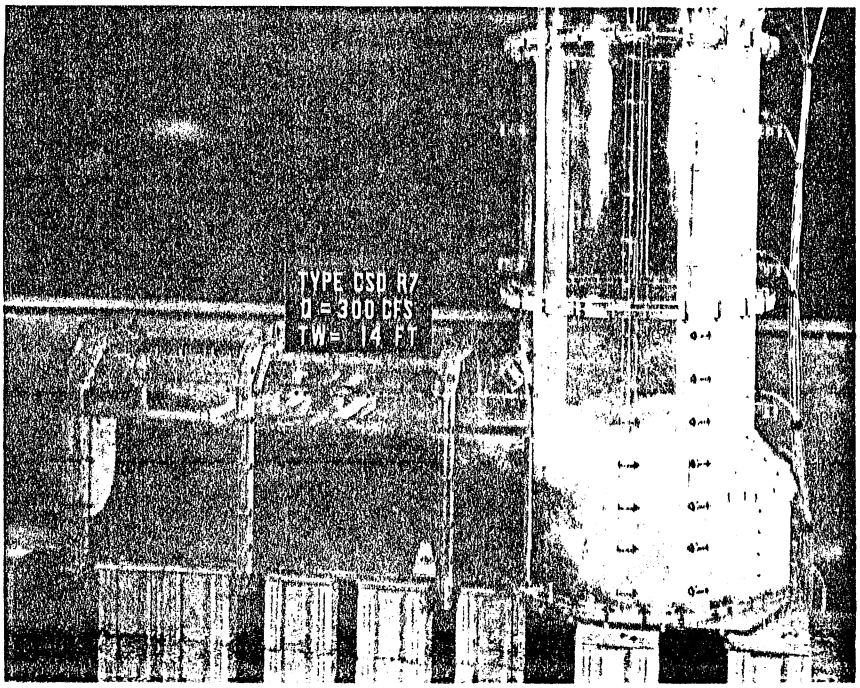


Photo 49 - Type CSD R7 dropshaft, Q = 300 cfs, T.W. = 14 ft. The surge shaft and deaeration chamber.

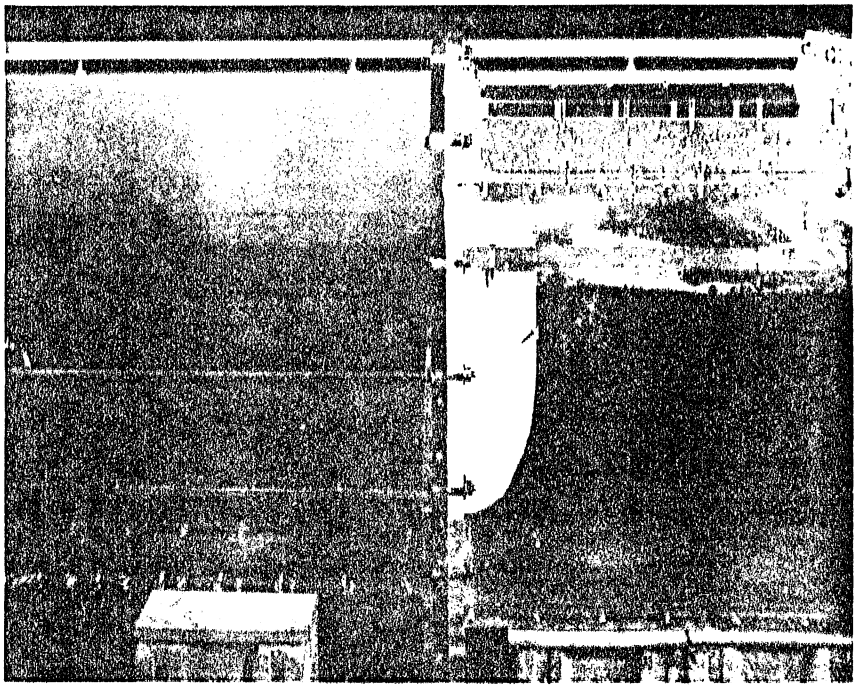


Photo 50 - Type CSD R7 dropshaft, Q = 300 cfs, T.W. = 14 ft.
The entrance to the exit conduit.

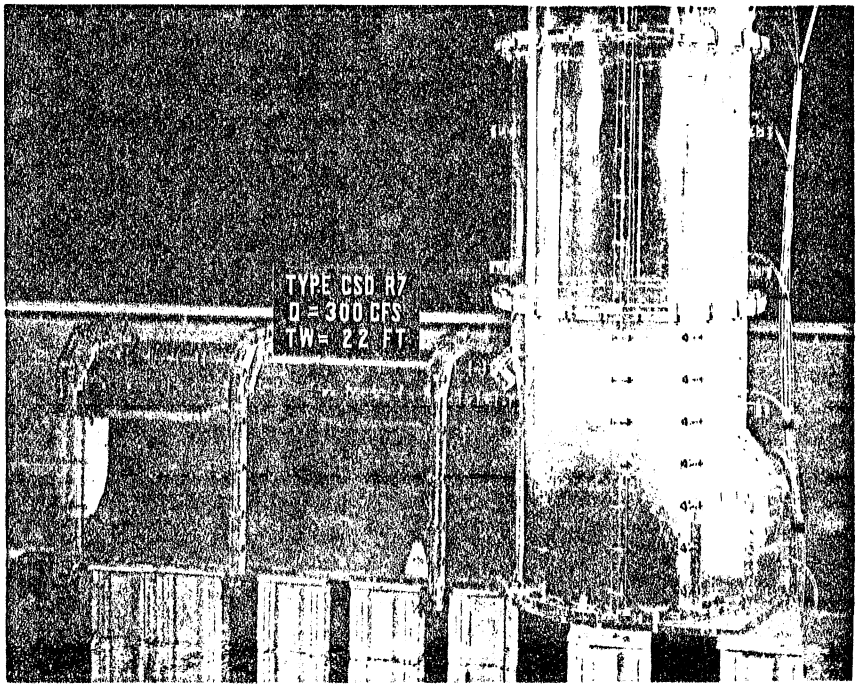


Photo 51 - Type CSD R7 dropshaft, Q = 300 cfs, T.W. = 22 ft.
The surge shaft and deaeration chamber.

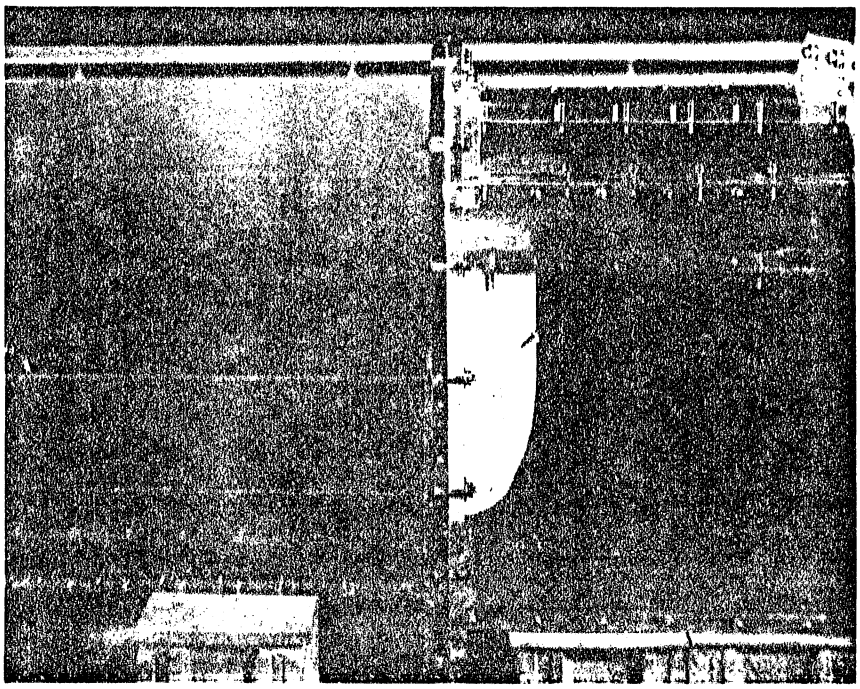


Photo 52 - Type CSD R7 dropshaft, Q = 300 cfs, T.W. = 22 ft.
The entrance to the exit conduit.

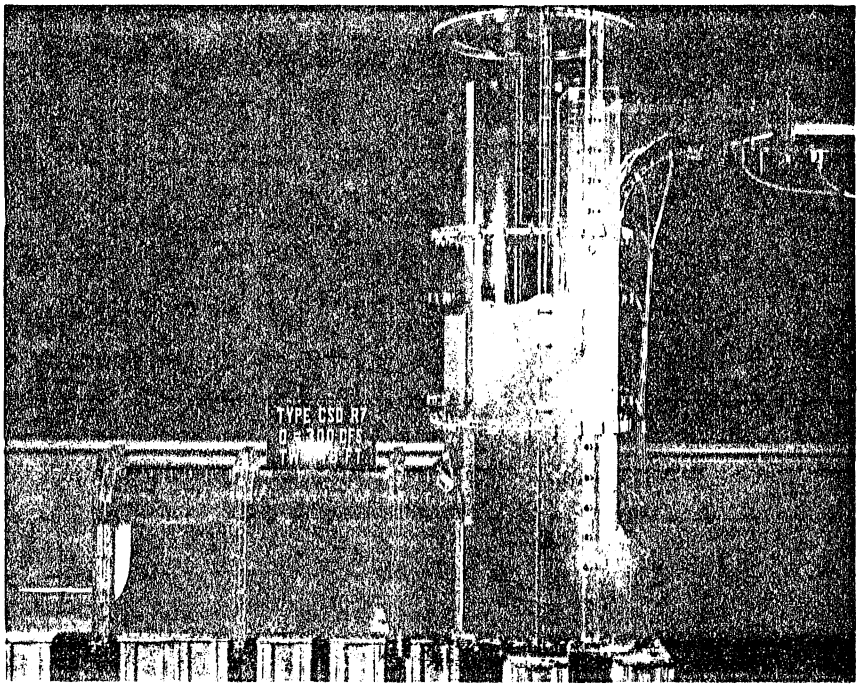


Photo 53 - Type CSD R7 dropshaft, Q = 300 cfs, T.W. = 45 ft.
The overall model.

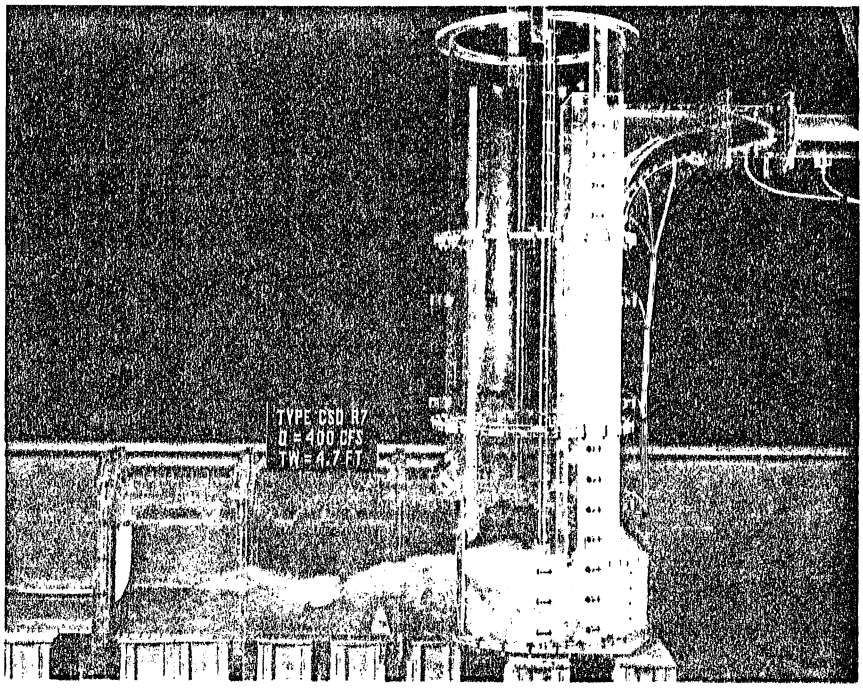


Photo 54 - Type CSD R7 dropshaft, Q = 400 cfs, T.W. = 4.7 ft. The overall model.

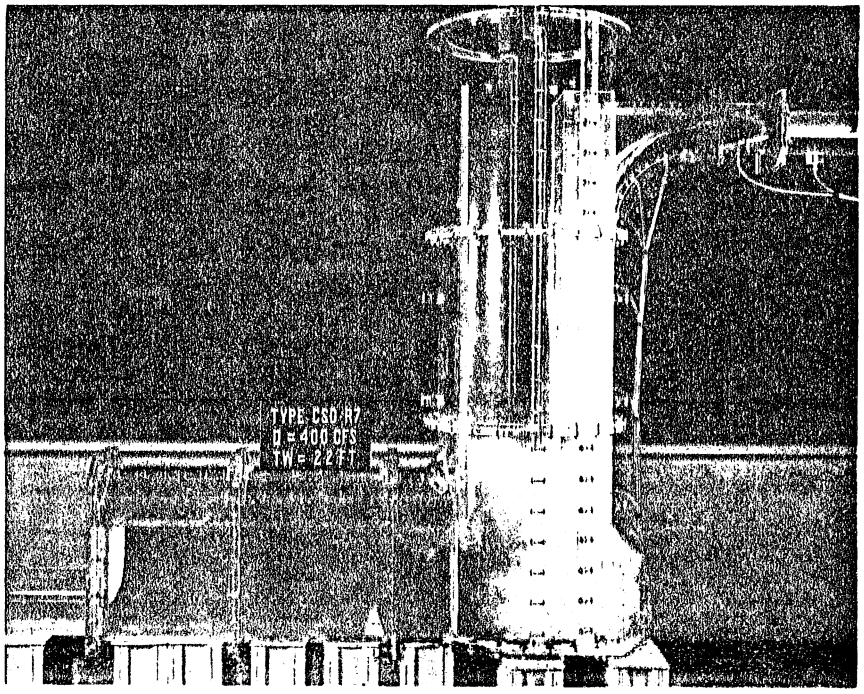


Photo 55 - Type CSD R7 dropshaft, Q = 400 cfs, T.W. = 22 ft. The overall model.

LIST OF CHARTS

CHART 20 (313A2322-74) Type CSD R1 dropshaft, Q = 200 cfs, tailwater varied. Piezometric pressures.

CHART 21 (313A2322-75) Type CSD R1 dropshaft, Q = 300 cfs, tailwater varied. Piezometric pressures.

CHART 22 (313A2322-76) Type CSD R1 dropshaft, Q = 400 cfs, tailwater varied. Piezometric pressures.

CHART 23 (313A2322-27) Type CSD R1 dropshaft, Q = 100 cfs, tailwater varied. Typical pressure fluctuations at Tap 17.

CHART 24 (313A2322-28) Type CSD R1 dropshaft, Q = 200 cfs, tailwater varied. Typical pressure fluctuations at Tap 17.

CHART 25 (313A2322-29) Type CSD R1 dropshaft, Q = 300 cfs, tailwater varied. Typical pressure fluctuations at Tap 17.

CHART 26 (313A2322-30) Type CSD R1 dropshaft, Q = 400 cfs, tailwater varied. Typical pressure fluctuations at Tap 17.

CHART 27 (313A2322-89) Type CSD R1 dropshaft, flow conditions varied. Typical pressure fluctuations at Tap 17.

CHART 28 (313A2322-90) Type CSD R1 dropshaft, flow conditions varied. Typical pressure fluctuations at Tap 17.

CHART 29 (313A2322-22) Type CSD R1 dropshaft, Q = 100 cfs, tailwater varied. Typical pressure fluctuations at Tap 18.

CHART 30 (313A2322-23) Type CSD R1 dropshaft, Q = 200 cfs, tailwater varied. Typical pressure fluctuations at Tap 18.

CHART 31 (313A2322-25) Type CSD R1 dropshaft, Q = 300 cfs, tailwater varied. Typical pressure fluctuations at Tap 18.

CHART 32 (313A2322-24) Type CSD R1 dropshaft, Q = 300 cfs, tailwater varied. Typical pressure fluctuations at Tap 18.

CHART 33 (313A2322-26) Type CSD R1 dropshaft, Q = 400 cfs, tailwater varied. Typical pressure fluctuations at Tap 18.

CHART 34 (313A2322-91) Type CSD R1 dropshaft, flow conditions varied. Typical pressure fluctuations at Tap 18.

CHART 35 (313A2322-92) Type CSD R1 dropshaft, flow conditions varied. Typical pressure fluctuations at Tap 18.

CHART 36 (313A2322-31) Type CSD R1 dropshaft, Q = 100 cfs, tailwater varied. Typical pressure fluctuations at Tap 19.

CHART 37 (313A2322-32) Type CSD R1 dropshaft, Q = 200 cfs, tailwater varied. Typical pressure fluctuations at Tap 19.

CHART 38 (313A2322-33) Type CSD R1 dropshaft, Q = 300 cfs, tailwater varied. Typical pressure fluctuations at Tap 19.

CHART 39 (313A2322-34) Type CSD R1 dropshaft, Q = 400 cfs, tailwater varied. Typical pressure fluctuations at Tap 19.

CHART 40 (313A2322-93) Type CSD R1 dropshaft, flow conditions varied. Typical pressure fluctuations at Tap 19.

CHART 41 (313A2322-94) Type CSD R1 dropshaft, flow conditions varied. Typical pressure fluctuations at Tap 19.

CHART 42 (313A2322-69) Type CSD R1 dropshaft, flow conditions varied. Summary of typical pressure fluctuations at Taps 17, 18, and 19.

CHART 43 (313A2322-35) Type CSD R1 dropshaft, Q = 300 cfs, tailwater varied. Typical pressure fluctuations at Taps 7 and 8.

CHART 44 (313A2322-39) Type CSD R1 dropshaft, Q = 300 cfs, tailwater varied. Typical pressure fluctuations at Taps 9 and 11.

CHART 45 (313A2322-43) Type CSD R1 dropshaft, Q = 300 cfs, tailwater varied. Typical pressure fluctuations at Taps 13 and 14.

CHART 46 (313A2322-51) Type CSD R1 dropshaft, Q = 100 cfs, tailwater varied. Typical pressure fluctuations at Taps 15 and 21.

CHART 47 (313A2322-53) Type CSD R1 dropshaft, Q = 200 cfs, tailwater varied. Typical pressure fluctuations at Taps 15 and 21.

CHART 48 (313A2322-47) Type CSD R1 dropshaft, Q = 300 cfs, tailwater varied. Typical pressure fluctuations at Taps 15 and 21.

CHART 49 (313A2322-55) Type CSD R1 dropshaft, Q = 400 cfs, tailwater varied. Typical pressure fluctuations at Taps 15 and 21.

CHART 50 (313A2322-52) Type CSD R1 dropshaft, Q = 100 cfs, tailwater varied. Typical pressure fluctuations at Taps 16 and 20.

CHART 51 (313A2322-54) Type CSD R1 dropshaft, Q = 200 cfs, tailwater varied. Typical pressure fluctuations at Taps 16 and 20.

CHART 52 (313A2322-48) Type CSD R1 dropshaft, Q = 300 cfs, tailwater varied. Typical pressure fluctuations at Taps 16 and 20.

CHART 53 (313A2322-56) Type CSD R1 dropshaft, Q = 400 cfs, tailwater varied. Typical pressure fluctuations at Taps 16 and 20.

CHART 54 (313A2322-49) Type CSD R1 dropshaft, Q = 300 cfs, tailwater varied. Typical pressure fluctuations at Taps 22 and 23.

CHART 55 (313A2322-50) Type CSD R1 dropshaft, Q = 300 cfs, tailwater varied. Typical pressure fluctuations at Taps 25 and 28.

CHART 56 (313A2322-108) Type CSD R1 dropshaft, flow conditions varied. Summary of typical pressure fluctuations at Taps 7 through 16.

CHART 57 (313A2322-109) Type CSD R1 dropshaft, flow conditions varied. Summary of typical pressure fluctuations at Taps 20 through 28.

CHART 58 (313A2322-77) Type CSD R5 dropshaft, Q = 100 cfs, tailwater varied. Piezometric pressures.

CHART 59 (313A2322-78) Type CSD R5 dropshaft, Q = 200 cfs, tailwater varied. Piezometric pressures.

CHART 60 (313A2322-79) Type CSD R5 dropshaft, Q = 300 cfs, tailwater varied. Piezometric pressures.

CHART 61 (313A2322-80) Type CSD R5 dropshaft, Q = 400 cfs, tailwater varied. Piezometric pressures.

CHART 62 (313A2322-1) Type CSD R5 dropshaft, Q = 100 cfs, tailwater varied. Typical pressure fluctuations at Tap 18.

CHART 63 (313A2322-2) Type CSD R5 dropshaft, Q = 200 cfs, tailwater varied. Typical pressure fluctuations at Tap 18.

CHART 64 (313A2322-4) Type CSD R5 dropshaft, Q = 300 cfs, tailwater varied. Typical pressure fluctuations at Tap 18.

CHART 65 (313A2322-3) Type CSD R5 dropshaft, Q = 300 cfs, tailwater varied. Typical pressure fluctuations at Tap 18.

CHART 66 (313A2322-5) Type CSD R5 dropshaft, Q = 400 cfs, tailwater varied. Typical pressure fluctuations at Tap 18.

CHART 67 (313A2322-96) Type CSD R5 dropshaft, flow conditions varied. Typical pressure fluctuations at Tap 18.

CHART 68 (313A2322-97) Type CSD R5 dropshaft, flow conditions varied. Typical pressure fluctuations at Tap 18.

CHART 69 (313A2322-6) Type CSD R5 dropshaft, Q = 300 cfs, tailwater varied. Typical pressure fluctuations at Tap 17.

CHART 70 (313A2322-7) Type CSD R5 dropshaft, Q = 300 cfs, tailwater varied. Typical pressure fluctuations at Tap 19.

CHART 71 (313A2322-95) Type CSD R5 dropshaft, Q = 300 cfs, T.W. = 2.3 ft. Typical pressure fluctuations at Taps 17 and 19.

CHART 72 (313A2322-70) Type CSD R5 dropshaft, flow conditions varied. Summary of typical pressure fluctuations at Taps 17, 18, and 19.

CHART 73 (313A2322-36) Type CSD R5 dropshaft, Q = 300 cfs, tailwater varied. Typical pressure fluctuations at Taps 7 and 8.

CHART 74 (313A2322-40) Type CSD R5 dropshaft, Q = 300 cfs, tailwater varied. Typical pressure fluctuations at Taps 9 and 11.

CHART 75 (313A2322-44) Type CSD R5 dropshaft, Q = 300 cfs, tailwater varied. Typical pressure fluctuations at Taps 13 and 14.

CHART 76 (313A2322-57) Type CSD R5 dropshaft, Q = 300 cfs, tailwater varied. Typical pressure fluctuations at Taps 15 and 21.

CHART 77 (313A2322-58) Type CSD R5 dropshaft, Q = 300 cfs, tailwater varied. Typical pressure fluctuations at Taps 16 and 20.

CHART 78 (313A2322-59) Type CSD R5 dropshaft, Q = 300 cfs, tailwater varied. Typical pressure fluctuations at Taps 22 and 23.

CHART 79 (313A2322-60) Type CSD R5 dropshaft, Q = 300 cfs, tailwater varied. Typical pressure fluctuations at Taps 25 and 28.

CHART 80 (313A2322-110) Type CSD R5 dropshaft, flow conditions varied. Summary of typical pressure fluctuations at Taps 7 through 28.

CHART 81 (313A2322-81) Type CSD R6 dropshaft, Q = 100 cfs, tailwater varied. Piezometric pressures.

CHART 82 (313A2322-82) Type CSD R6 dropshaft, Q = 200 cfs, tailwater varied. Piezometric pressures.

CHART 83 (313A2322-83) Type CSD R6 dropshaft, Q = 300 cfs, tailwater varied. Piezometric pressures.

CHART 84 (313A2322-84) Type CSD R6 dropshaft, Q = 400 cfs, tailwater varied. Piezometric pressures.

CHART 85 (313A2322-8) Type CSD R6 dropshaft, Q = 100 cfs, tailwater varied. Typical pressure fluctuations at Tap 18.

CHART 86 (313A2322-9) Type CSD R6 dropshaft, Q = 200 cfs, tailwater varied. Typical pressure fluctuations at Tap 18.

CHART 87 (313A2322-11) Type CSD R6 dropshaft, Q = 300 cfs, tailwater varied. Typical pressure fluctuations at Tap 18.

CHART 88 (313A2322-10) Type CSD R6 dropshaft, Q = 300 cfs, tailwater varied. Typical pressure fluctuations at Tap 18.

CHART 89 (313A2322-12) Type CSD R6 dropshaft, Q = 400 cfs, tailwater varied. Typical pressure fluctuations at Tap 18.

CHART 90 (313A2322-99) Type CSD R6 dropshaft, flow conditions varied. Typical pressure fluctuations at Tap 18.

CHART 91 (313A2322-100) Type CSD R6 dropshaft, flow conditions varied. typical pressure fluctuations at Tap 18.

CHART 92 (313A2322-13) Type CSD R6 dropshaft, Q = 300 cfs, tailwater varied. Typical pressure fluctuations at Tap 17.

CHART 93 (313A2322-14) Type CSD R6 dropshaft, Q = 300 cfs, tailwater varied. Typical pressure fluctuations at Tap 19.

CHART 94 (313A2322-98) Type CSD R6 dropshaft, Q = 300 cfs, T.W. = 2.6 ft. Typical pressure fluctuations at Taps 17 and 19.

CHART 95 (313A2322-71) Type CSD R6 dropshaft, flow conditions varied. Summary of typical pressure fluctuations at Taps 17, 18, and 19.

CHART 96 (313A2322-37) Type CSD R6 dropshaft, Q = 300 cfs, tailwater varied. Typical pressure fluctuations at Taps 7 and 8.

CHART 97 (313A2322-41) Type CSD R6 dropshaft, Q = 300 cfs, tailwater varied. Typical pressure fluctuations at Taps 9 and 11.

CHART 98 (313A2322-45) Type CSD R6 dropshaft, Q = 300 cfs, tailwater varied. Typical pressure fluctuations at Taps 13 and 14.

CHART 99 (313A2322-61) Type CSD R6 dropshaft, Q = 300 cfs, tailwater varied. Typical pressure fluctuations at Taps 15 and 21.

CHART 100 (313A2322-62) Type CSD R6 dropshaft, Q = 300 cfs, tailwater varied. Typical pressure fluctuations at Taps 16 and 20.

CHART 101 (313A2322-63) Type CSD R6 dropshaft, Q = 300 cfs, tailwater varied. Typical pressure fluctuations at Taps 22 and 23.

CHART 102 (313A2322-64) Type CSD R6 dropshaft, Q = 300 cfs, tailwater varied. Typical pressure fluctuations at Taps 25 and 28.

CHART 103 (313A2322-111) Type CSD R6 dropshaft, flow conditions varied. Summary of typical pressure fluctuations at Taps 7 through 28.

CHART 104 (313A2322-85) Type CSD R7 dropshaft, Q = 100 cfs, tailwater varied. Piezometric pressures.

CHART 105 (313A2322-86) Type CSD R7 dropshaft, Q = 200 cfs, tailwater varied. Piezometric pressures.

CHART 106 (313A2322-87) Type CSD R7 dropshaft, Q = 300 cfs, tailwater varied. Piezometric pressures.

CHART 107 (313A2322-88) Type CSD R7 dropshaft, Q = 400 cfs, tailwater varied. Piezometric pressures.

CHART 108 (313A2322-15) Type CSD R7 dropshaft, Q = 100 cfs, tailwater varied. Typical pressure fluctuations at Tap 18.

CHART 109 (313A2322-16) Type CSD R7 dropshaft, Q = 200 cfs, tailwater varied. Typical pressure fluctuations at Tap 18.

CHART 110 (313A2322-18) Type CSD R7 dropshaft, Q = 300 cfs, tailwater varied. Typical pressure fluctuations at Tap 18.

CHART 111 (313A2322-17) Type CSD R7 dropshaft, Q = 300 cfs, tailwater varied. Typical pressure fluctuations at Tap 18.

CHART 112 (313A2322-19) Type CSD R7 dropshaft, Q = 400 cfs, tailwater varied. Typical pressure fluctuations at Tap 18.

CHART 113 (313A2322-102) Type CSD R7 dropshaft, flow conditions varied. Typical pressure fluctuations at Tap 18.

CHART 114 (313A2322-103) Type CSD R7 dropshaft, flow conditions varied. Typical pressure fluctuations at Tap 18.

CHART 115 (313A2322-20) Type CSD R7 dropshaft, Q = 300 cfs, tailwater varied. Typical pressure fluctuations at Tap 17.

CHART 116 (313A2322-21) Type CSD R7 dropshaft, Q = 300 cfs, tailwater varied. Typical pressure fluctuations at Tap 19.

CHART 117 (313A2322-101) Type CSD R7 dropshaft, Q = 300 cfs, T.W. = 3.8 ft. Typical pressure fluctuations at Taps 17 and 19.

CHART 118 (313A2322-72) Type CSD R7 dropshaft, flow conditions varied. Summary of typical pressure fluctuations at Taps 17, 18, and 19.

CHART 119 (313A2322-38) Type CSD R7 dropshaft, Q = 300 cfs, tailwater varied. Typical pressure fluctuations at Taps 7 and 8.

CHART 120 (313A2322-42) Type CSD R7 dropshaft, Q = 300 cfs, tailwater varied. Typical pressure fluctuations at Taps 9 and 11.

CHART 121 (313A2322-46) Type CSD R7 dropshaft, Q = 300 cfs, tailwater varied. Typical pressure fluctuations at Taps 13 and 14.

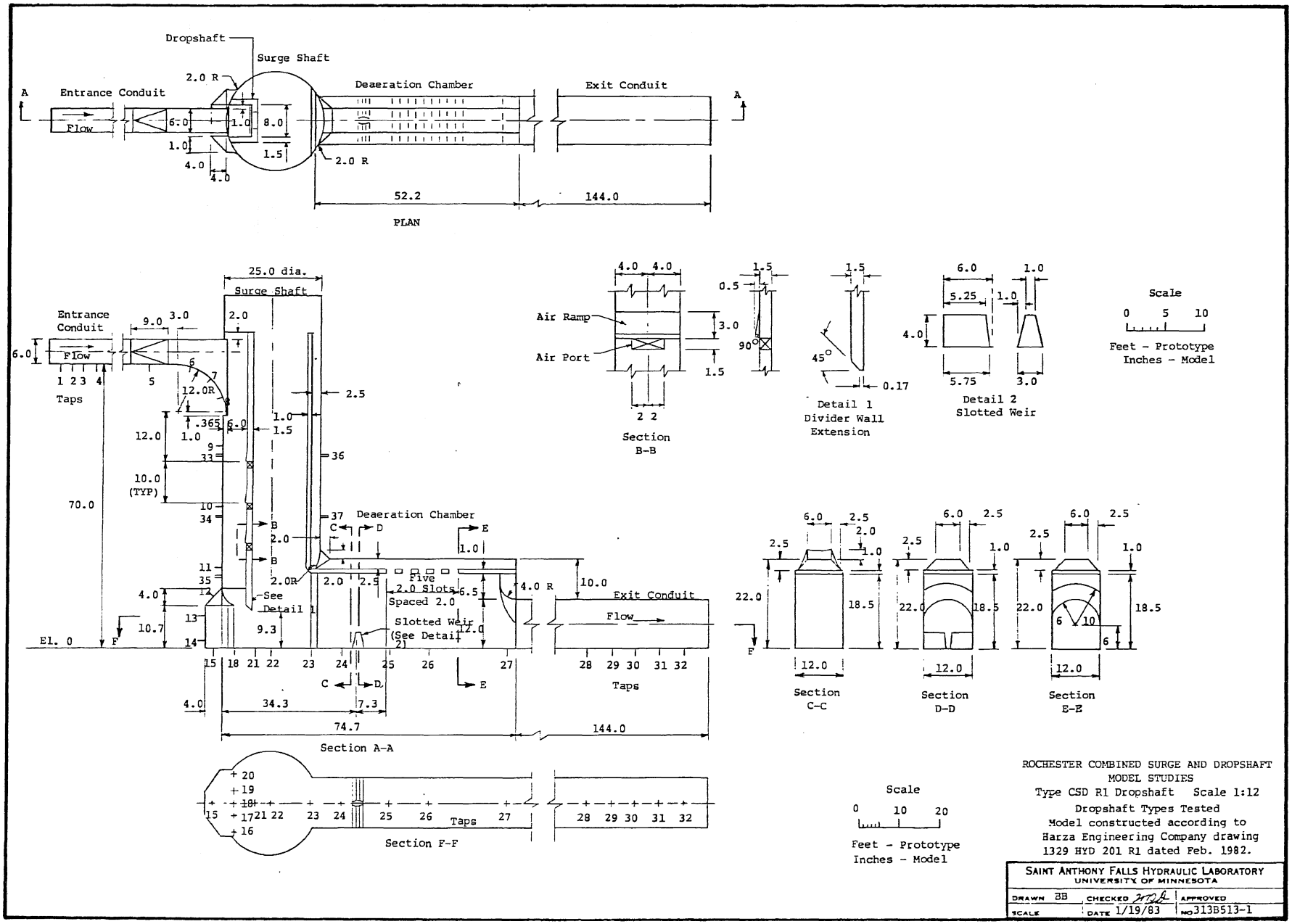
CHART 122 (313A2322-65) Type CSD R7 dropshaft, Q = 300 cfs, tailwater varied. Typical pressure fluctuations at Taps 15 and 21.

CHART 123 (313A2322-66) Type CSD R7 dropshaft, Q = 300 cfs, tailwater varied. Typical pressure fluctuations at Taps 16 and 20.

CHART 124 (313A2322-67) Type CSD R7 dropshaft, Q = 300 cfs, tailwater varied. Typical pressure fluctuations at Taps 22 and 23.

CHART 125 (313A2322-68) Type CSD R7 dropshaft, Q = 300 cfs, tailwater varied. Typical pressure fluctuations at Taps 25 and 28.

CHART 126 (313A2322-112) Type CSD R7 dropshaft, flow conditions varied. Summary of typical pressure fluctuations at Taps 7 through 28.



ROCHESTER COMBINED SURGE AND DROPSHAFT MODEL STUDIES

Type CSD R1 Dropshaft Scale 1:12

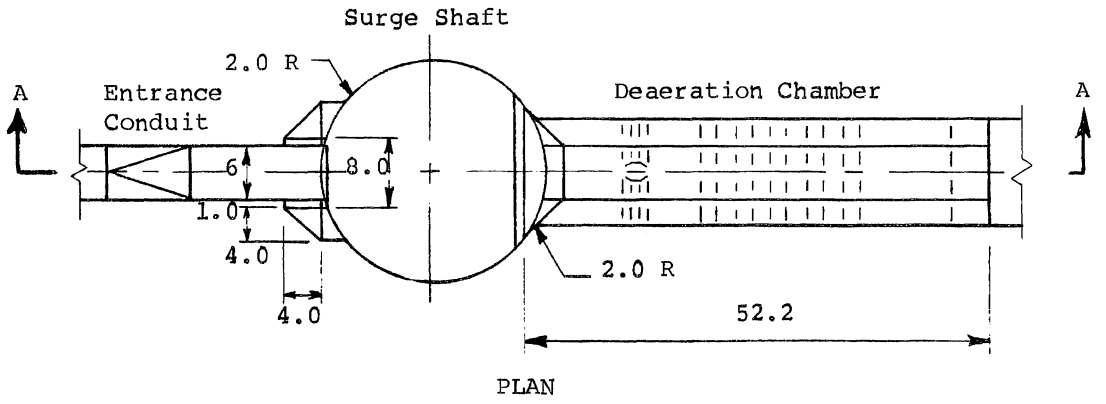
Dropshaft Types Tested

Model constructed according to Harza Engineering Company drawing 1329 HYD 201 R1 dated Feb. 1982.

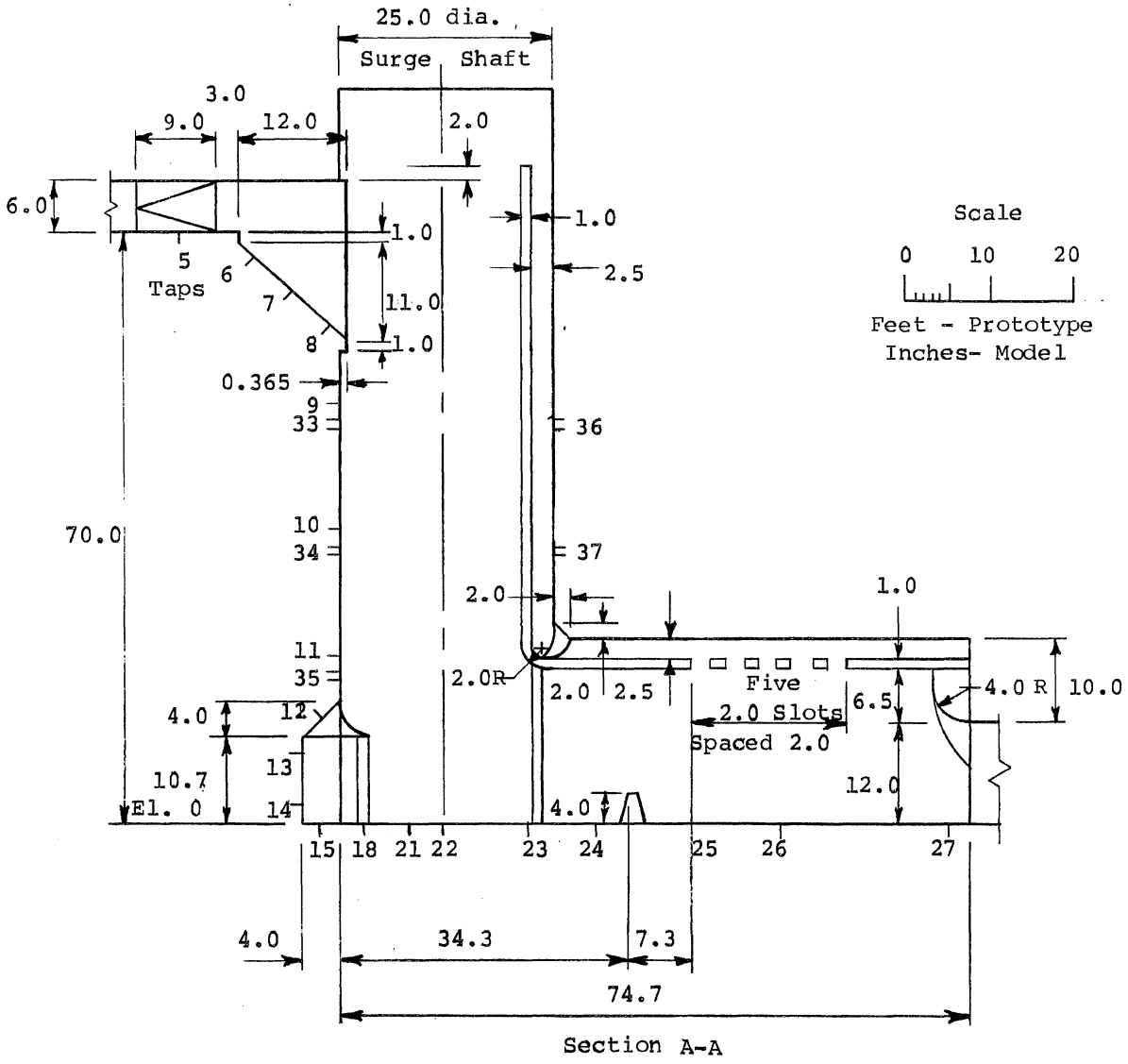
SAINT ANTHONY FALLS HYDRAULIC LABORATORY
UNIVERSITY OF MINNESOTA

DRAWN BB	CHECKED	APPROVED
SCALE	DATE 1/19/83	NO 313B513-1

CHART 1



PLAN

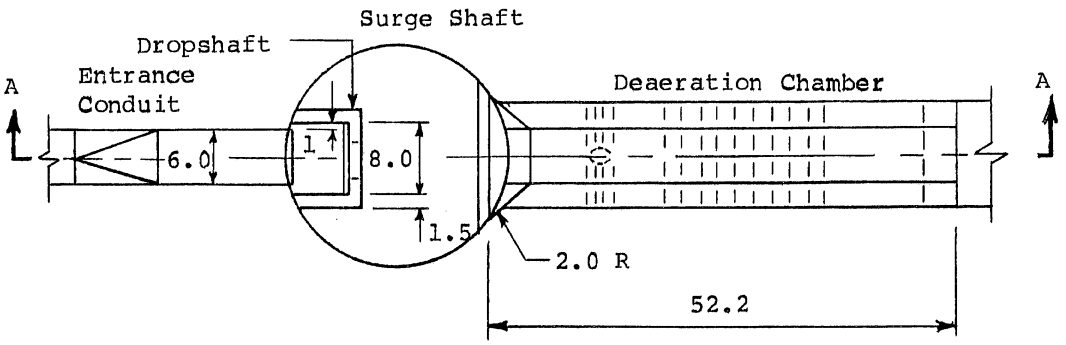


Scale
0 10 20
Feet - Prototype
Inches- Model

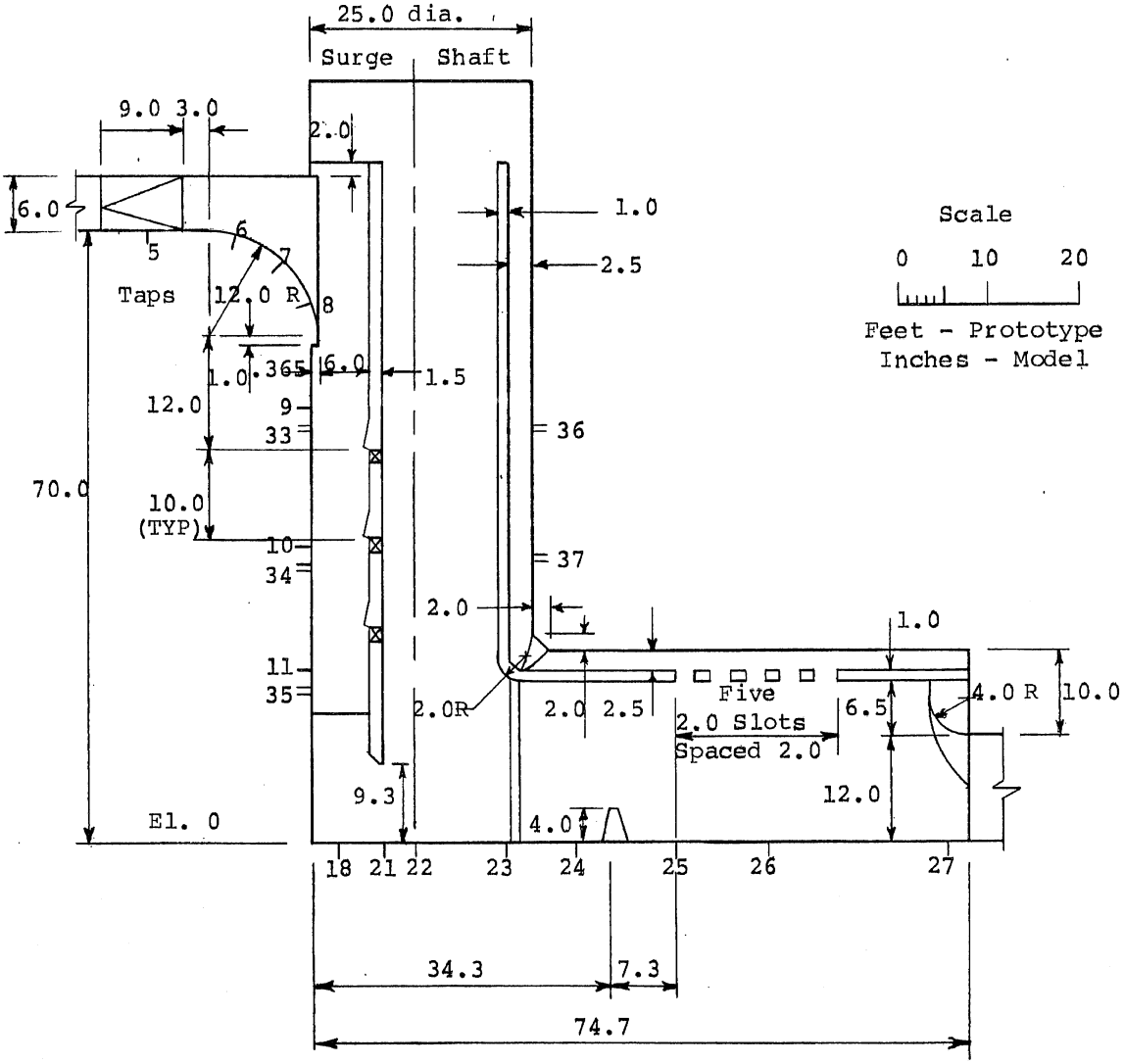
Section A-A

ROCHESTER COMBINED SURGE AND DROPSHAFT
MODEL STUDIES
Type CSD R2 Dropshaft Scale 1:12
Dropshaft Types Tested

SAINT ANTHONY FALLS HYDRAULIC LABORATORY UNIVERSITY OF MINNESOTA		
DRAWN BB	CHECKED	APPROVED
SCALE	DATE 1/19/83	NO. 313A2322-104



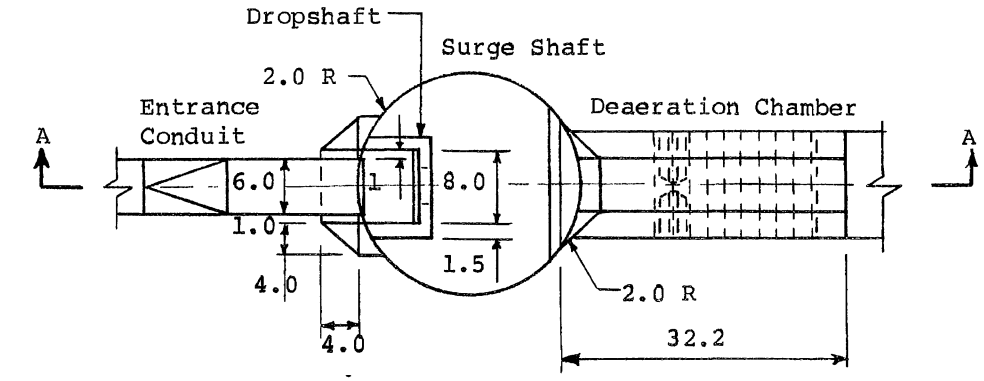
PLAN

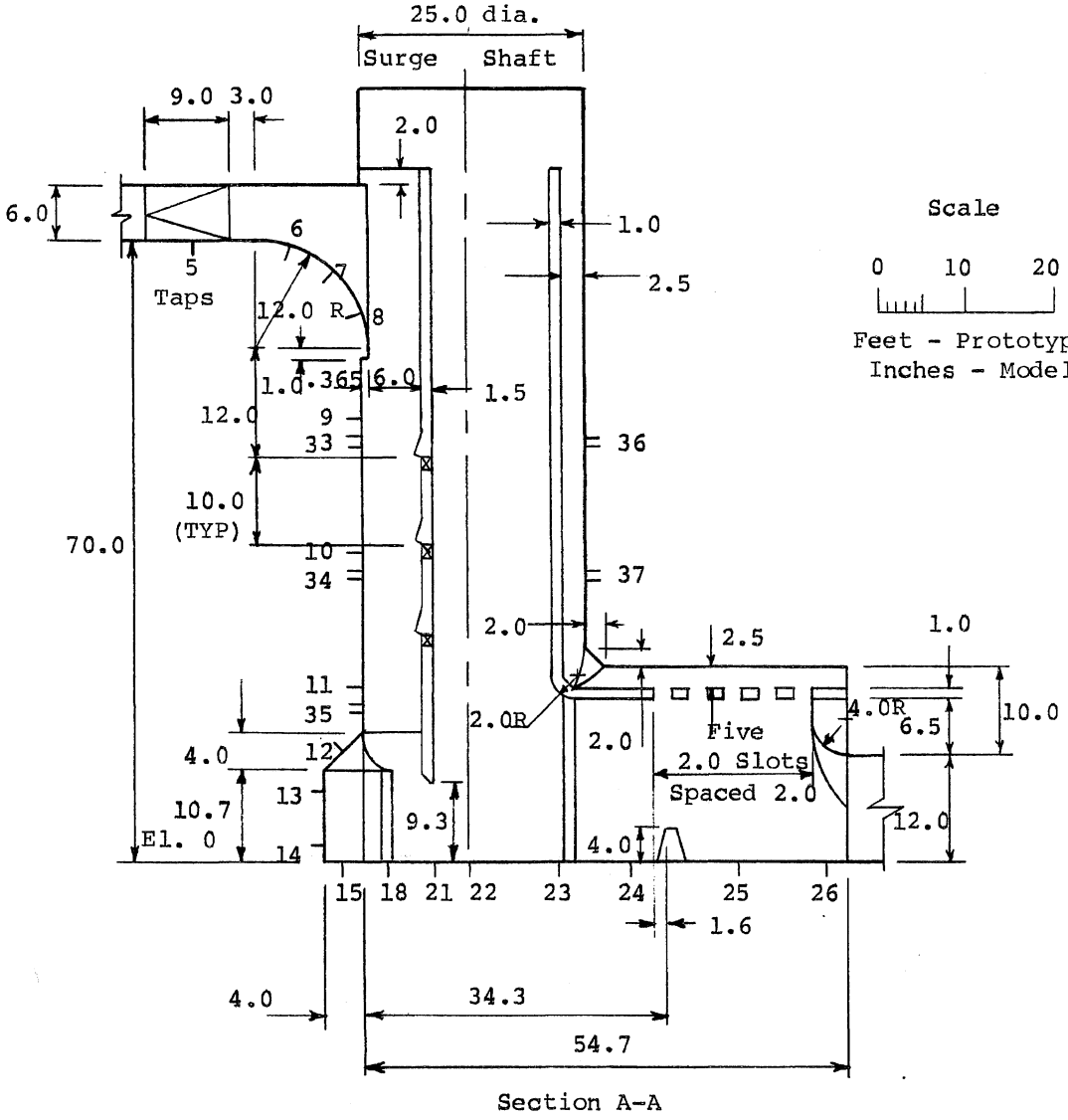


Section A-A

ROCHESTER COMBINED SURGE AND DROPSHAFT
MODEL STUDIES
Type CSD R3 Dropshaft Scale 1:12
Dropshaft Types Tested

SAINT ANTHONY FALLS HYDRAULIC LABORATORY UNIVERSITY OF MINNESOTA		
DRAWN BB	CHECKED	APPROVED
SCALE	DATE 1/19/83	NO. 313A2322-105

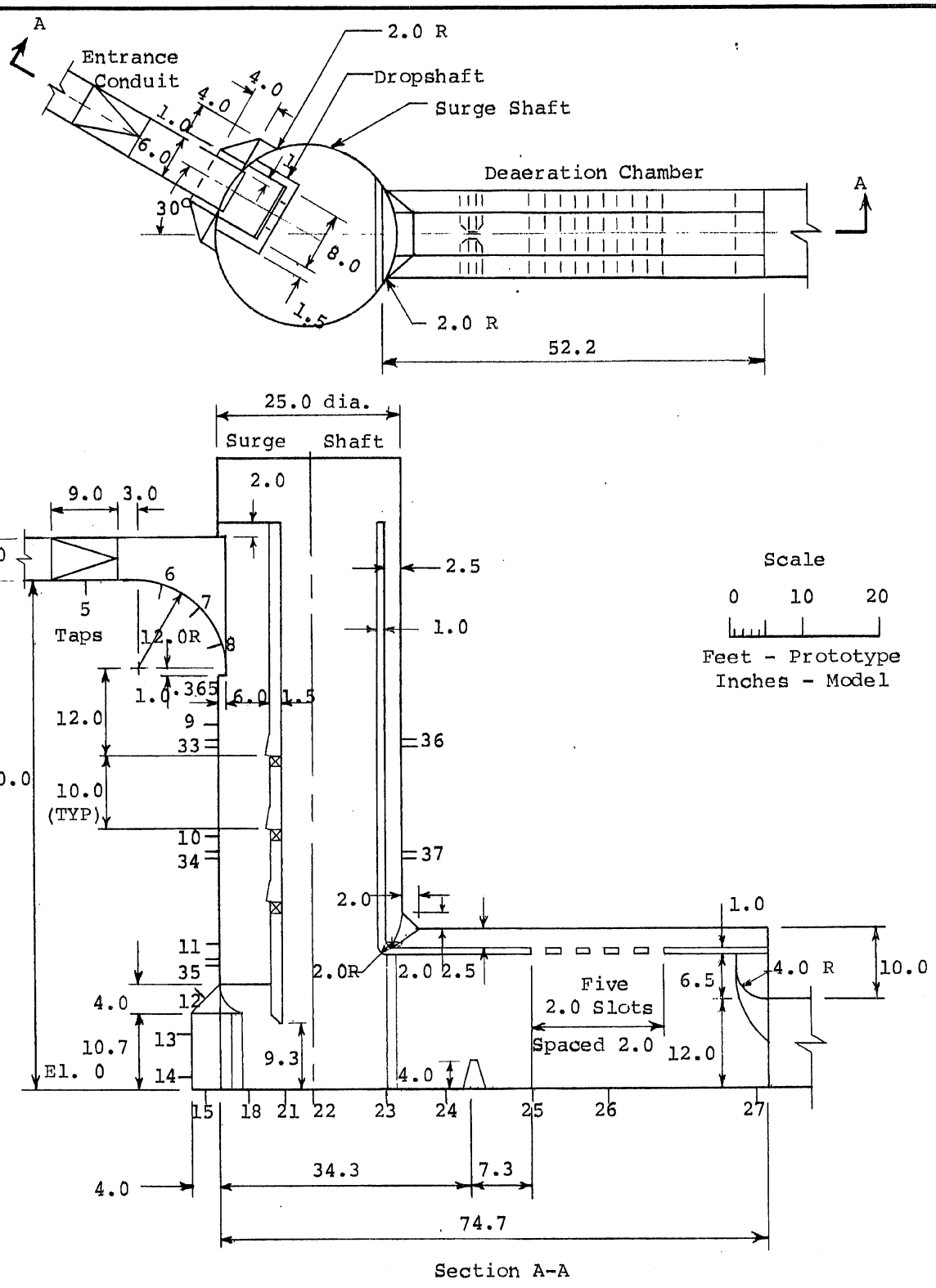




Section A-A

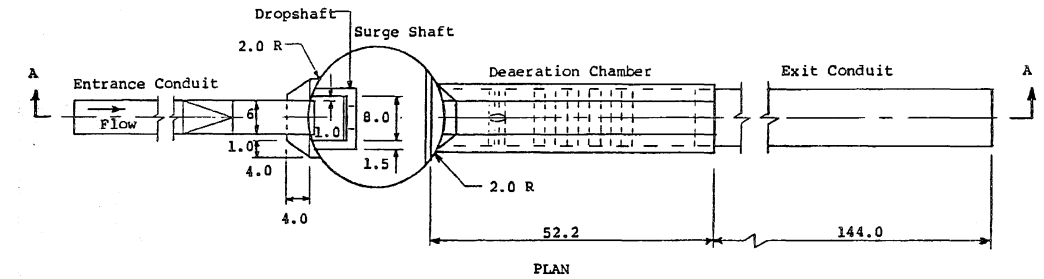
ROCHESTER COMBINED SURGE AND DROPSHAFT
MODEL STUDIES
Type CSD R4 Dropshaft Scale 1:12
Dropshaft Types Tested

SAINT ANTHONY FALLS HYDRAULIC LABORATORY UNIVERSITY OF MINNESOTA		
DRAWN BB	CHECKED	APPROVED
SCALE	DATE 1/19/83	NO 313A2322-106

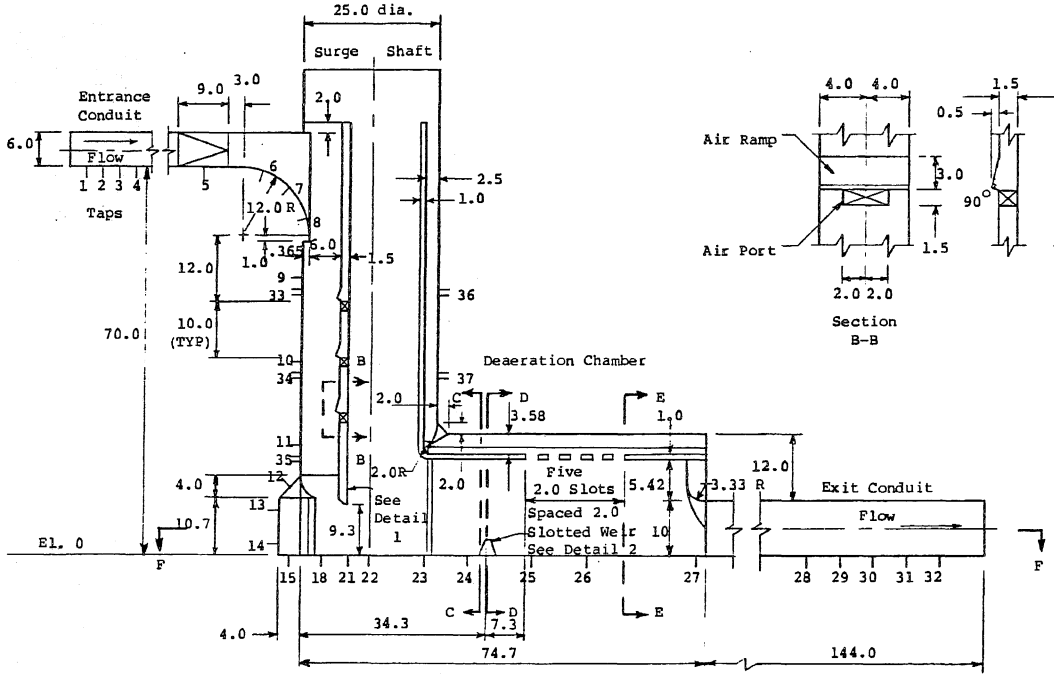


ROCHESTER COMBINED SURGE AND DROPSHAFT
MODEL STUDIES
Type CSD R5 Dropshaft Scale 1:12
Dropshaft Types Tested

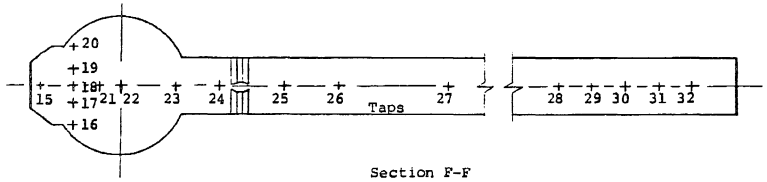
SAINT ANTHONY FALLS HYDRAULIC LABORATORY UNIVERSITY OF MINNESOTA		
DRAWN BB	CHECKED	APPROVED
SCALE	DATE 1/19/83	NO 313A2322-107



PLAN



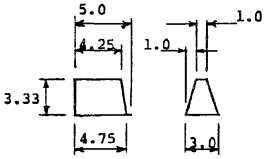
Section A-A



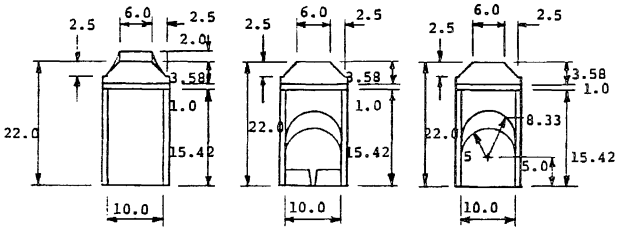
Section F-F

Section B-B

Detail 1
Divider Wall
Extension



Detail 2
Slotted Weir



Section C-C

Section D-D

Section E-E

Scale
0 5 10
Feet - Prototype
Inches - Model

Scale
0 10 20
Feet - Prototype
Inches - Model

ROCHESTER COMBINED SURGE AND DROPSHAFT
MODEL STUDIES
Type CSD R6 Dropshaft Scale 1:12
Dropshaft Types Tested

SAINT ANTHONY FALLS HYDRAULIC LABORATORY
UNIVERSITY OF MINNESOTA

DRAWN BB	CHECKED	APPROVED
SCALE	DATE 1/19/83	NO 313B513-2

CHART 6

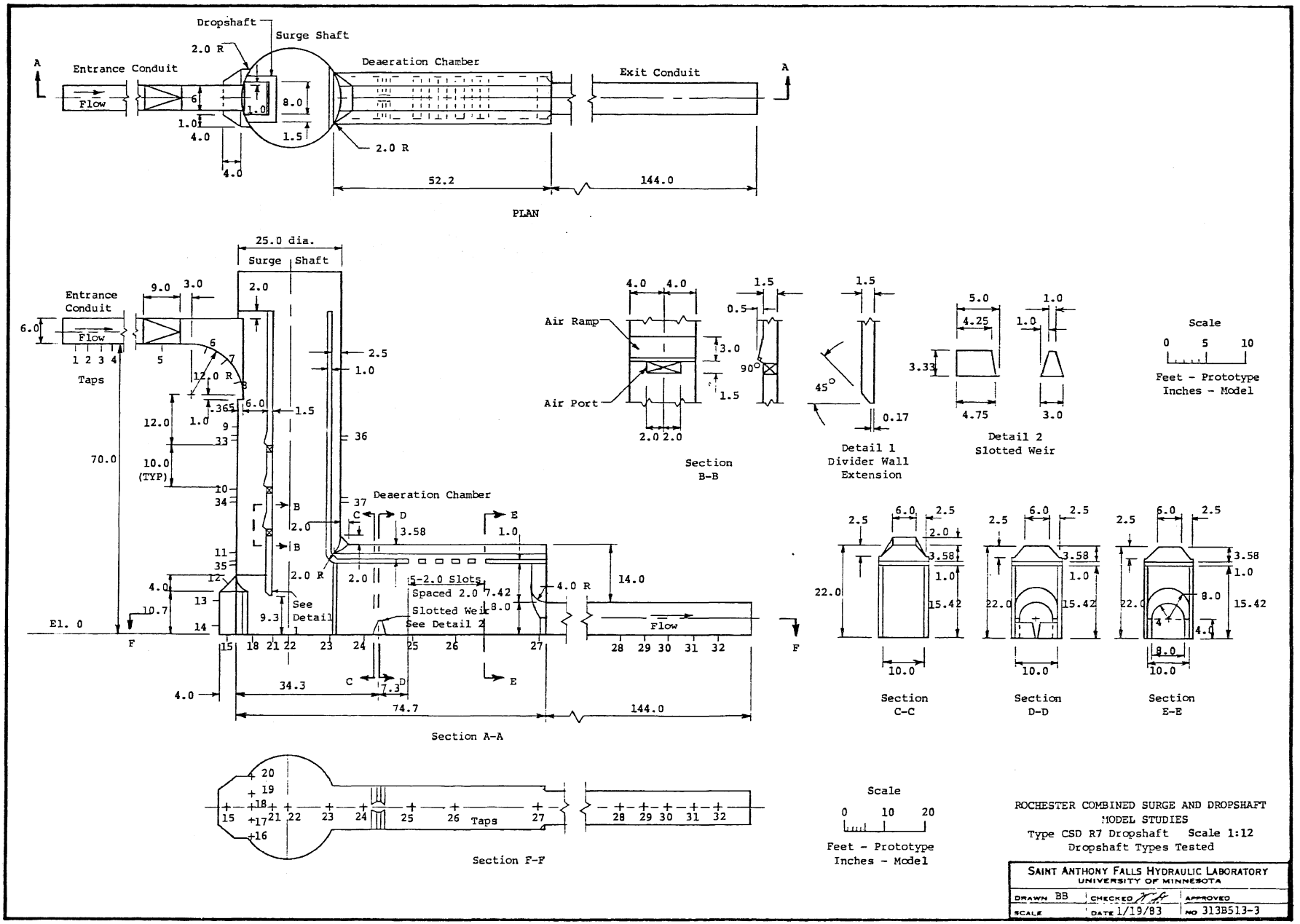

Dropshaft
Surge Shaft
2.0 R
Entrance Conduit
Deaeration Chamber
Exit Conduit
A
Flow
6
1.0
8.0
1.0
4.0
1.5
2.0 R
4.0
52.2
144.0
PLAN
25.0 dia.
Surge Shaft
Entrance Conduit
9.0
3.0
2.0
6.0
Flow
1 2 3 4
Taps
5
6
7
8
12.0 R
.365
2.5
1.0
1.5
12.0
1.0
9
33
36
70.0
10.0
(TYP)
10
34
37
Deaeration Chamber
B
C
D
E
2.0
3.58
1.0
11
35
12
2.0 R
2.0
5-2.0 Slots
Spaced 2.0
7.42
8.0
4.0 R
14.0
4.0
13
See
Detail
Slotted Weir
See Detail 2
10.7
El. 0
14
9.3
Flow
F
15 18 21 22 23 24 25 26 27 28 29 30 31 32
4.0
34.3
7.3
74.7
144.0
Section A-A
Air Ramp
Air Port
4.0 4.0
1.5
0.5
3.0
90°
1.5
2.0 2.0
Section
B-B
1.5
45°
0.17
Detail 1
Divider Wall
Extension
5.0
4.25
1.0
1.0
3.33
4.75
3.0
Detail 2
Slotted Weir
Scale
0 5 10
Feet - Prototype
Inches - Model
2.5
6.0
2.5
2.0
3.58
1.0
22.0
15.42
10.0
Section
C-C
Section
D-D
8.0
4.0
Section
E-E
20
19
18
15 17 21 22 23 24 25 26 Taps 27 28 29 30 31 32
16
Section F-F
Scale
0 10 20
Feet - Prototype
Inches - Model
ROCHESTER COMBINED SURGE AND DROPSHAFT
MODEL STUDIES
Type CSD R7 Dropshaft Scale 1:12
Dropshaft Types Tested
SAINT ANTHONY FALLS HYDRAULIC LABORATORY
UNIVERSITY OF MINNESOTA
DRAWN BB
CHECKED
APPROVED
SCALE
DATE 1/19/83
NO 313B513-3

CHART 7

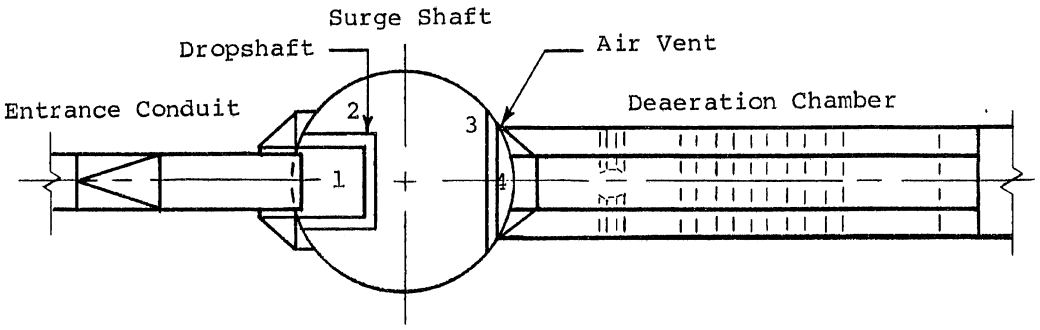
Type	Inlet Angle	Elbow	Dropshaft in Place	Boot in Place	Deaeration Chamber length-ft	Deaeration Chamber width-ft	Exit Conduit ft
CSD R1	0°	¼ Cylinder	Yes	Yes	52.2	12	12
CSD R2	0°	Free Trajectory	No	Yes	52.2	12	12
CSD R3	0°	¼ Cylinder	Yes	No	52.2	12	12
CSD R4	0°	¼ Cylinder	Yes	Yes	32.2	12	12
CSD R5	30°	¼ Cylinder	Yes	Yes	52.2	12	12
CSD R6	0°	¼ Cylinder	Yes	Yes	52.2	10	10
CSD R7	0°	¼ Cylinder	Yes	Yes	52.2	10	8

ROCHESTER COMBINED SURGE AND DROPSHAFT
MODEL STUDIES
Model Scale 1:12
Dropshaft Types Tested

SAINT ANTHONY FALLS HYDRAULIC LABORATORY
UNIVERSITY OF MINNESOTA

DRAWN WQD	CHECKED	APPROVED
SCALE	DATE 1/24/83	NO. 313A2322-123

CHART 8



Locations of Water Surface Fluctuations

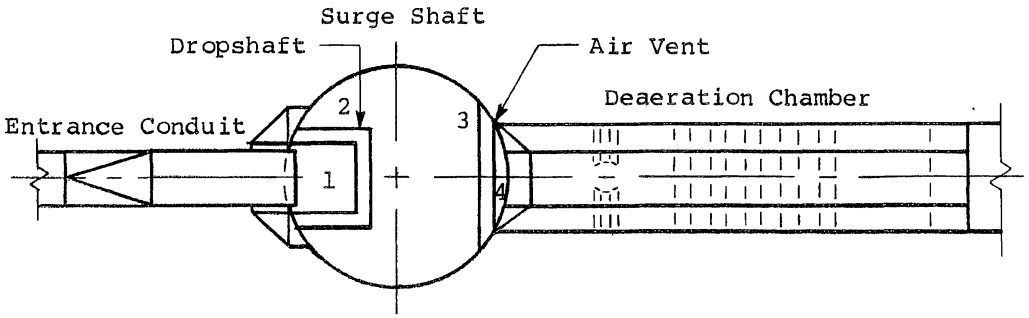
Q cfs	T.W. El. ft	Location 1 Dropshaft Max.-ft	Location 1 Dropshaft Min.-ft	Location 2 Surge Shaft Max.-ft	Location 2 Surge Shaft Min.-ft
100	1.6			6.2	5.0
100	10			13.0	10.5
100	22	27.5	26.0	26.0	23.0
100	30	37.0	35.0	31.0	29.6
100	45	49.5	48.0	46.0	44.6
100	70	69.7	69.3	70.1	70.1
200	2.2			7.5	6.0
200	10			13.5	11.0
200	22	25.0	22.5	26.0	23.5
200	30	36.5	33.5	36.0	32.0
200	45	50.0	48.0	46.6	44.6
200	70	69.4	68.8	70.1	70.1
300	2.3			11.5	8.5
300	10			14.5	11.5
300	22	21.0	18.0	26.0	23.5
300	30	32.5	29.0	36.5	32.0
300	45	50.5	48.0	50.5	46.0
300	70	70.0	69.2	70.4	70.2
400	2.6			14.0	9.5
400	10			14.5	11.0
400	22	18.5	16.0	26.0	23.5
400	30	27.0	24.5	34.5	31.5
400	45	47.0	45.0	50.5	46.5
400	70	71.5	70.0	70.7	70.4

Observations were made for a model time of 2 minutes at each location.

ROCHESTER COMBINED SURGE AND DROPSHAFT
MODEL STUDIES
Type CSD R1 Dropshaft Scale 1:12
Summary of Typical
Water Surface Fluctuations

SAINT ANTHONY FALLS HYDRAULIC LABORATORY
UNIVERSITY OF MINNESOTA

DRAWN WQD	CHECKED	APPROVED
SCALE	DATE 2/15/83	NO. 313A2322-113



Locations of Water Surface Fluctuations

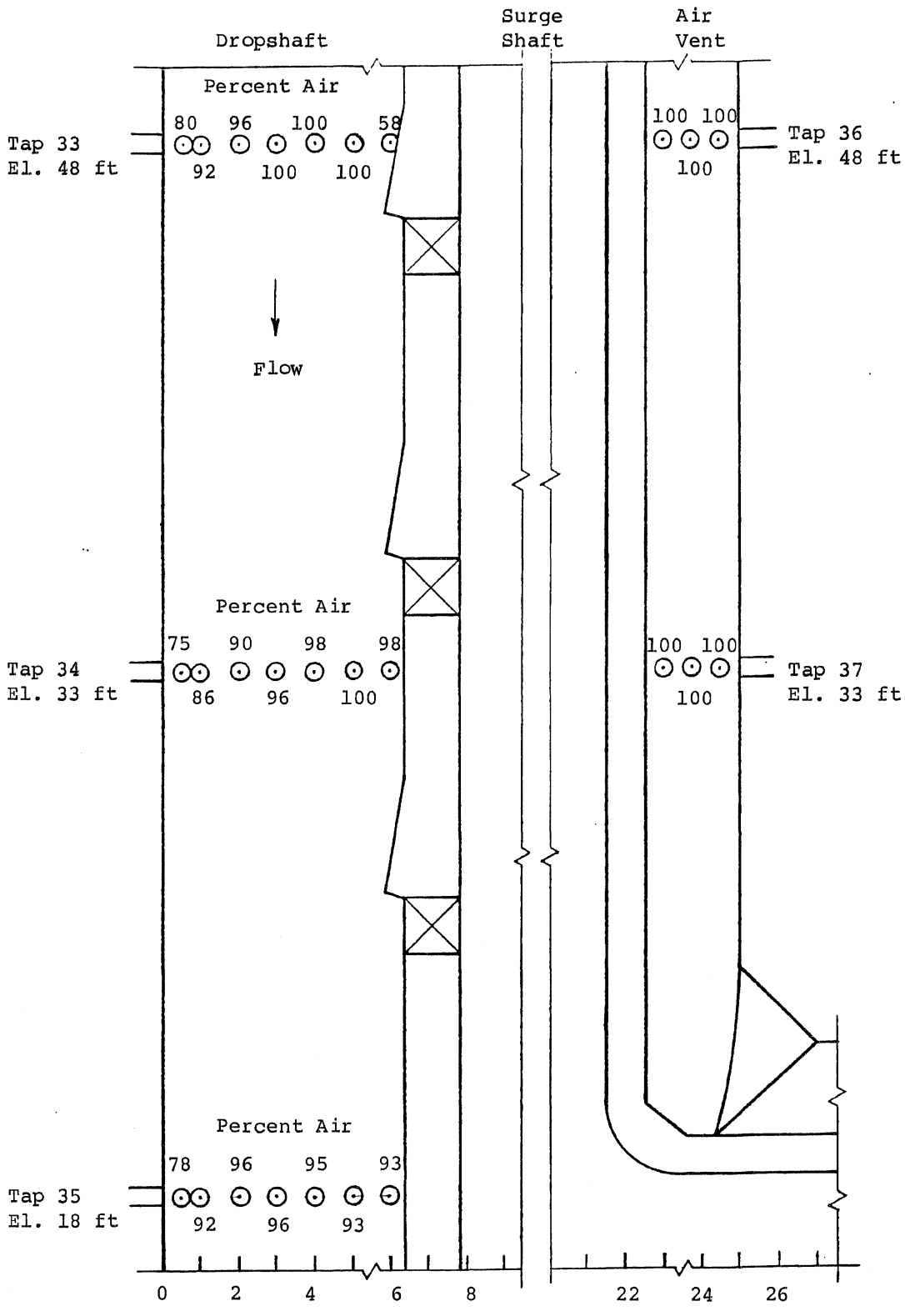
Q cfs	T.W. El. ft	Location 3 Surge Shaft Max.-ft	Location 3 Surge Shaft Min.-ft	Location 4 Air Vent Max.-ft	Location 4 Air Vent Min.-ft
100	1.6	6.6	5.2		
100	10	11.0	10.0		
100	22	23.6	22.2	22.5	22.2
100	30	31.0	29.5	30.2	30.0
100	45	45.8	44.8	45.1	45.0
100	70	70.1	70.1	70.1	70.1
200	2.2	7.2	5.8		
200	10	11.5	10.0		
200	22	24.0	22.0	22.4	21.6
200	30	32.5	30.5	30.4	30.0
200	45	46.5	45.0	45.1	45.0
200	70	70.2	70.1	70.2	70.1
300	2.3	9.0	7.0		
300	10	11.0	9.5		
300	22	25.0	22.5	23.5	21.5
300	30	34.5	30.5	31.0	30.0
300	45	48.0	45.5	45.2	45.0
300	70	70.4	70.2	70.3	70.2
400	2.6	10.0	8.5		
400	10	13.0	11.0		
400	22	25.0	22.0	23.5	21.5
400	30	34.0	31.5	32.0	30.0
400	45	48.5	46.5	45.4	45.0
400	70	70.7	70.4	70.4	70.2

Observations were made for a model time of 2 minutes at each location.

ROCHESTER COMBINED SURGE AND DROPSHAFT
MODEL STUDIES
Type CSD R1 Dropshaft Scale 1:12
Summary of Typical
Water Surface Fluctuations

SAINT ANTHONY FALLS HYDRAULIC LABORATORY
UNIVERSITY OF MINNESOTA

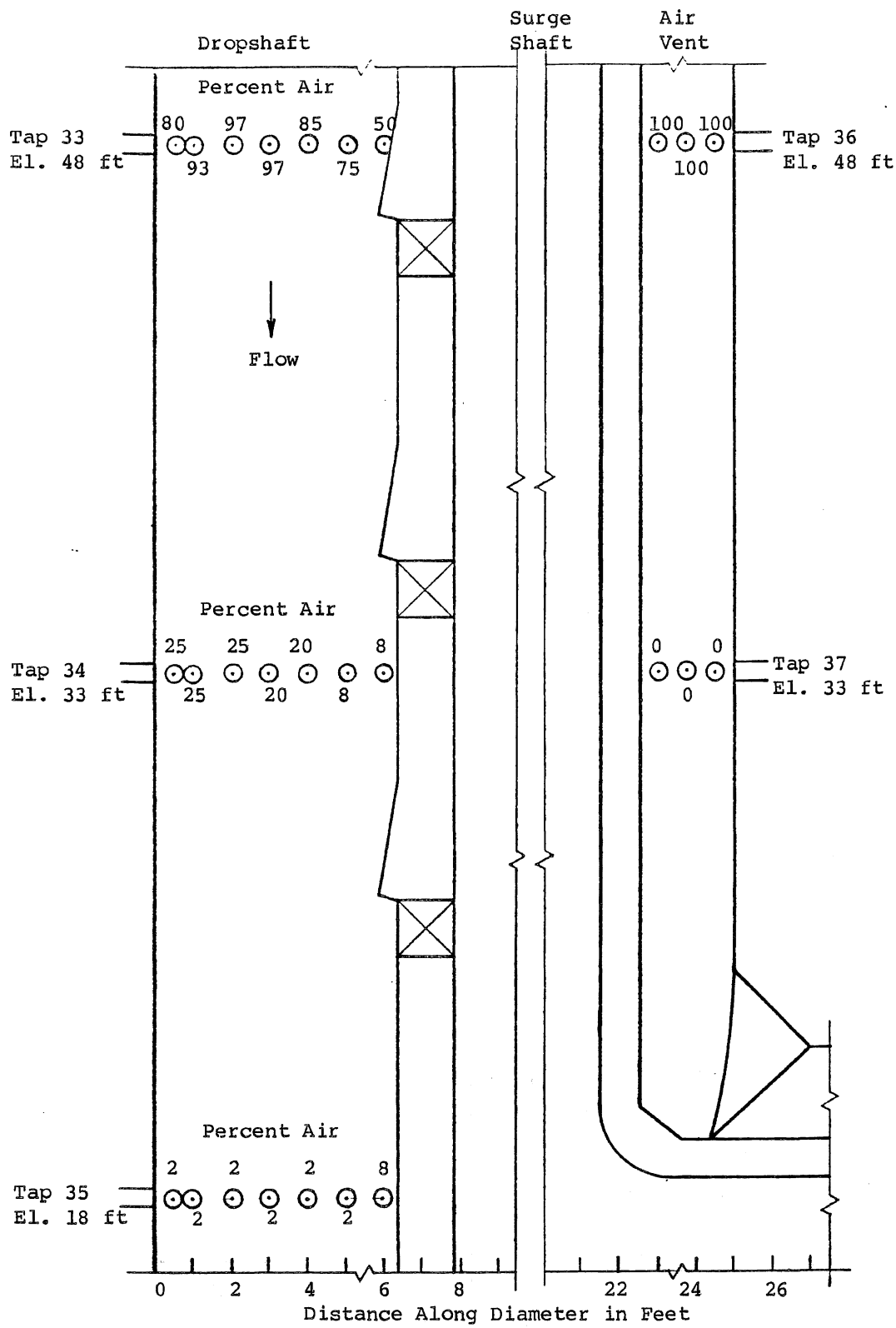
DRAWN WQD	CHECKED MRB	APPROVED
SCALE	DATE 2/15/83	NO. 313A2322-114



ROCHESTER COMBINED SURGE AND DROPSHAFT
MODEL STUDIES
Type CSD R1 Dropshaft Scale 1:12
Air Concentrations
Q = 100 cfs, T.W. Elev. = 1.6 ft

SAINT ANTHONY FALLS HYDRAULIC LABORATORY
UNIVERSITY OF MINNESOTA

DRAWN	BB	CHECKED		APPROVED	
SCALE		DATE	2/16/83	NO.	313A2322-115

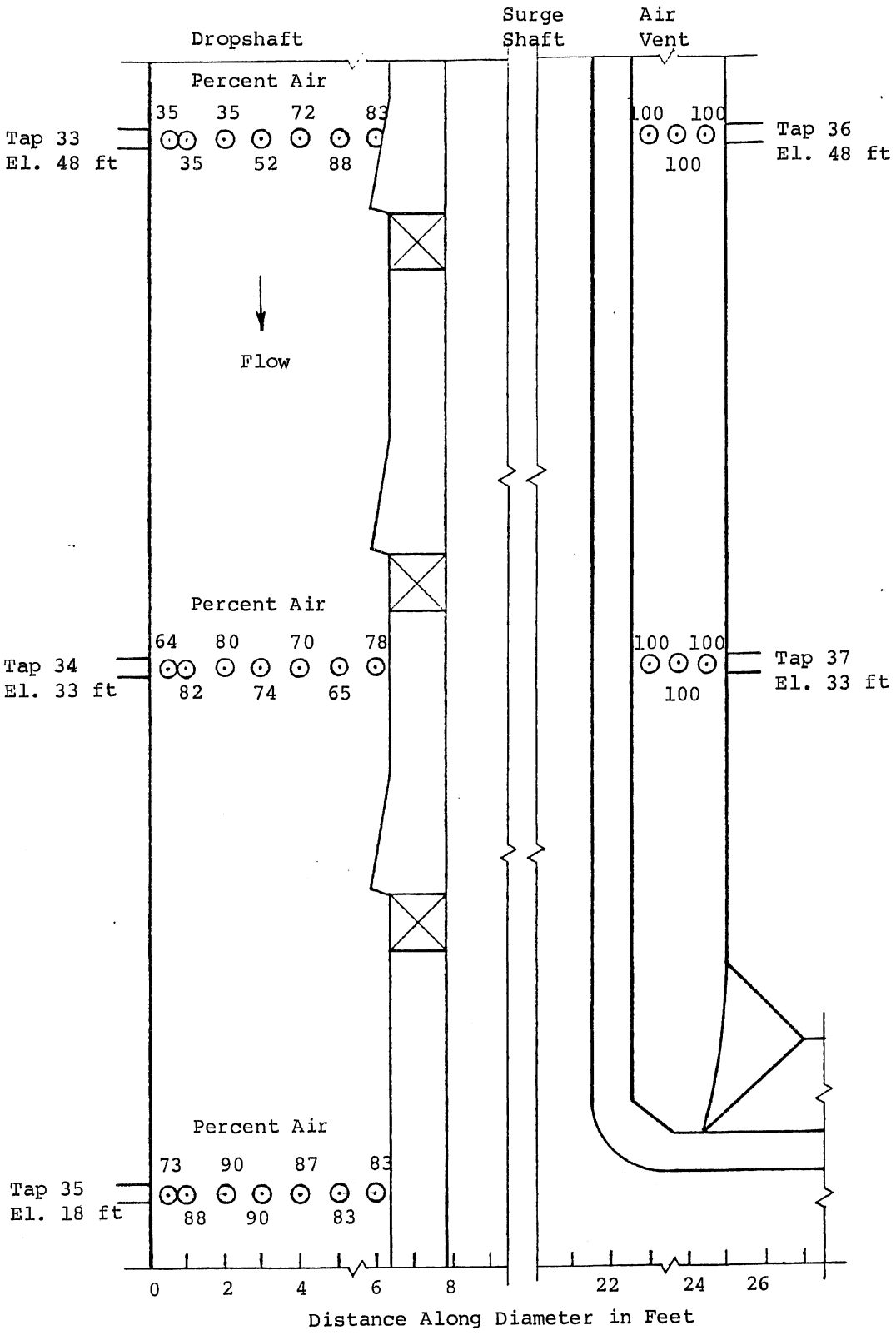


ROCHESTER COMBINED SURGE AND DROPSHAFT
MODEL STUDIES
Type CSD R1 Dropshaft Scale 1:12
Air Concentrations
Q = 100 cfs, T.W. Elev. = 45 ft

For a T.W. Elev. of 70 ft no air was present in air vent, ±1% in dropshaft.

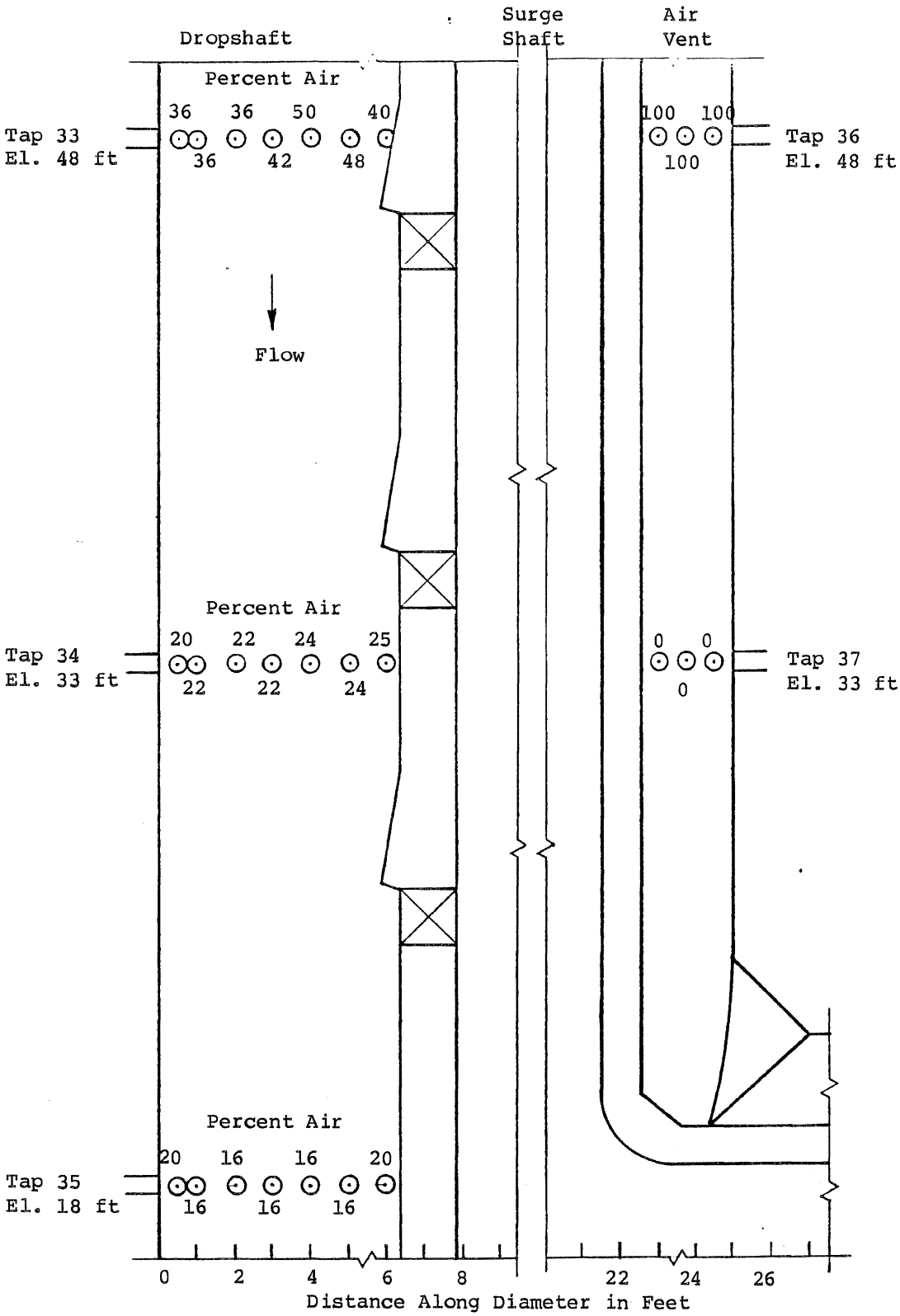
SAINT ANTHONY FALLS HYDRAULIC LABORATORY
UNIVERSITY OF MINNESOTA

DRAWN BB	CHECKED MDP	APPROVED
SCALE	DATE 2/16/83	NO. 313A2322-116



ROCHESTER COMBINED SURGE AND DROPSHAFT
MODEL STUDIES
Type CSD R1 Dropshaft Scale 1:12
Air Concentrations
Q = 200 cfs, T.W. Elev. = 2.2 ft

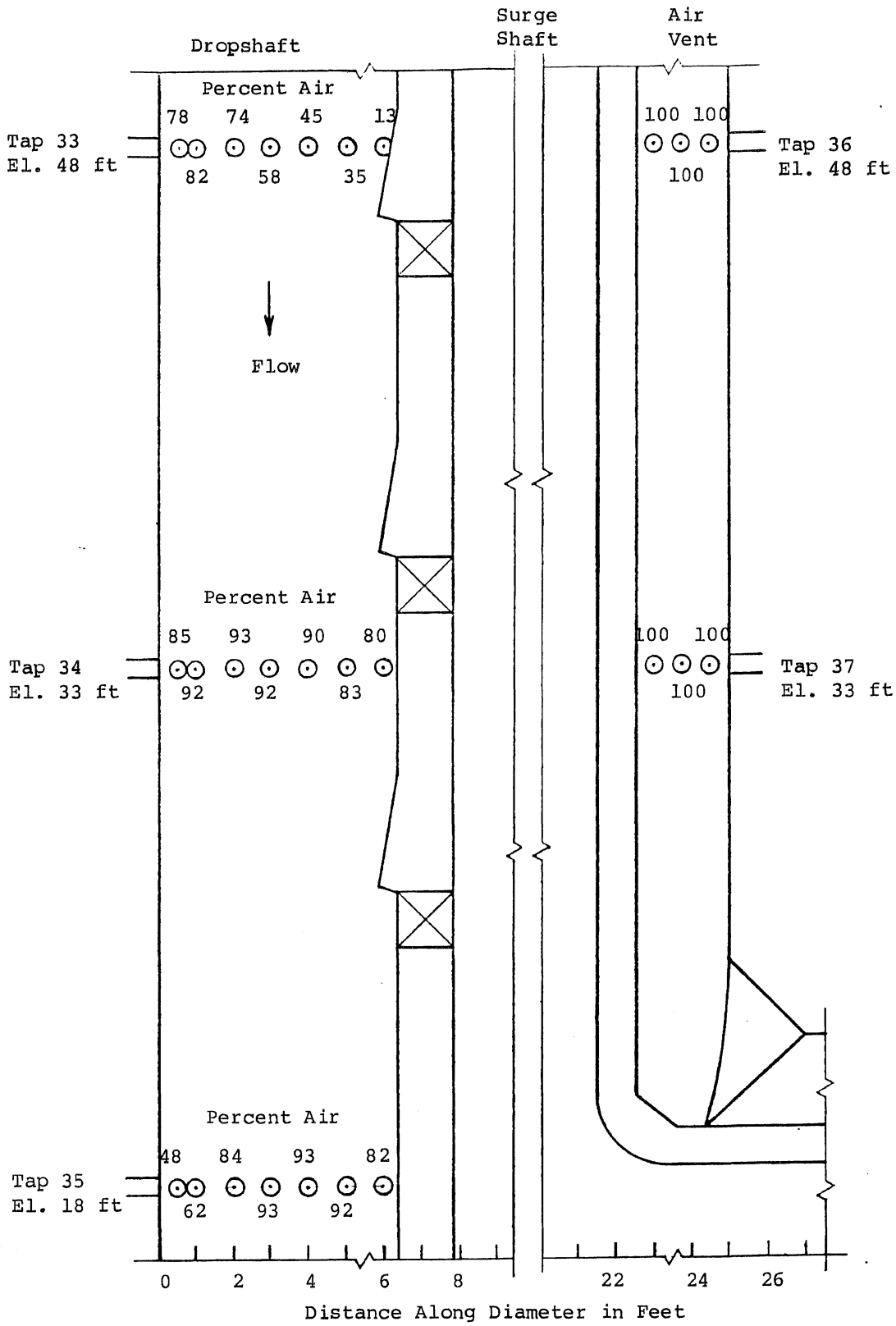
SAINT ANTHONY FALLS HYDRAULIC LABORATORY UNIVERSITY OF MINNESOTA		
DRAWN BB	CHECKED JDR	APPROVED
SCALE	DATE 2/16/83	NO. 313A2322-117



ROCHESTER COMBINED SURGE AND DROPSHAFT
MODEL STUDIES
Type CSD R1 Dropshaft Scale 1:12
Air Concentrations
Q = 200 cfs, T.W. Elev. = 45 ft

For a T.W. Elev. of 70 ft no air was present in air vent, ±1% in dropshaft.

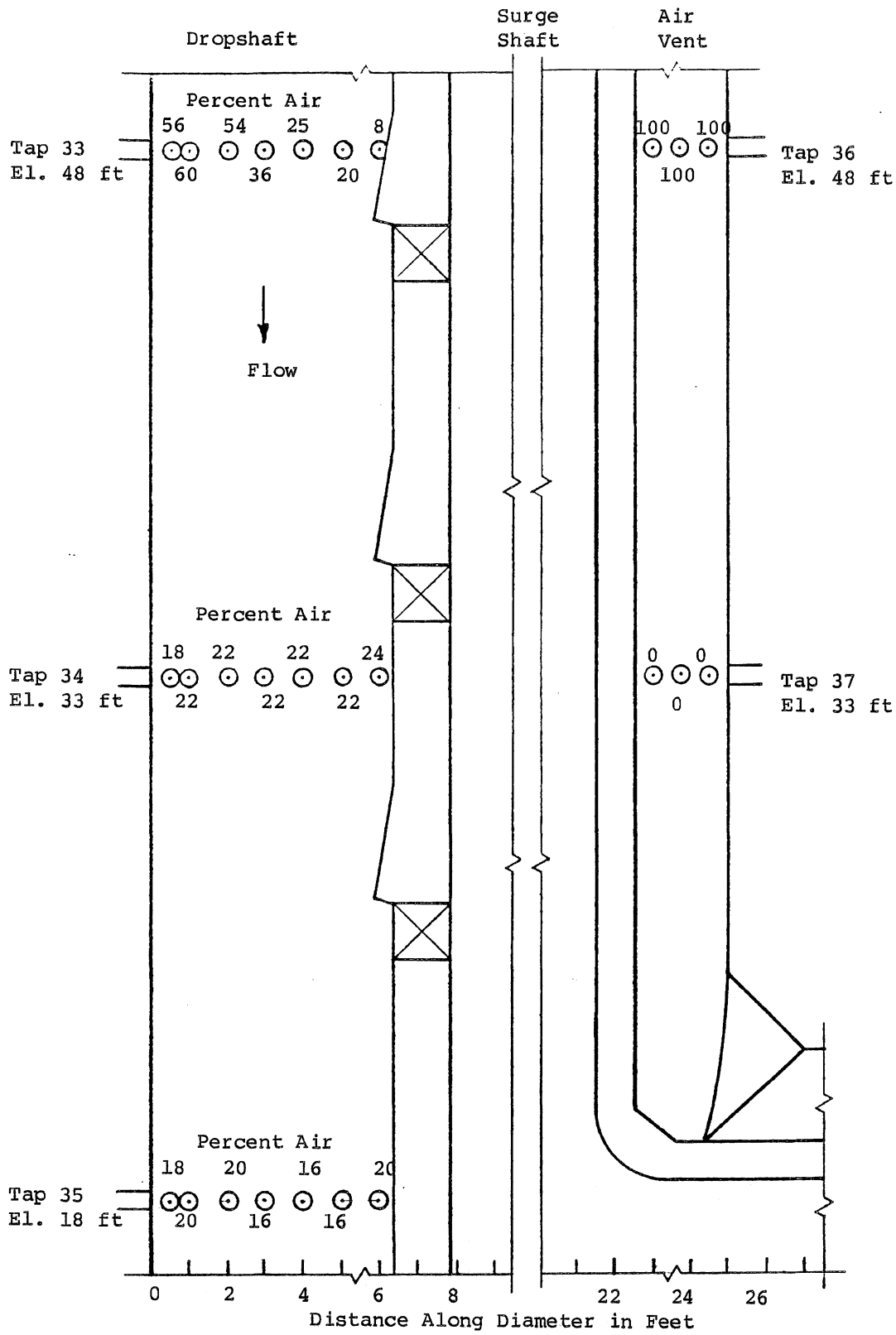
SAINT ANTHONY FALLS HYDRAULIC LABORATORY UNIVERSITY OF MINNESOTA		
DRAWN BB	CHECKED	APPROVED
SCALE	DATE 2/16/83	NO 313A2322-118



ROCHESTER COMBINED SURGE AND DROPSHAFT
MODEL STUDIES
Type CSD R1 Dropshaft Scale 1:12
Air Concentrations
Q = 300 cfs, T.W. Elev. = 2.3 ft

SAINT ANTHONY FALLS HYDRAULIC LABORATORY
UNIVERSITY OF MINNESOTA

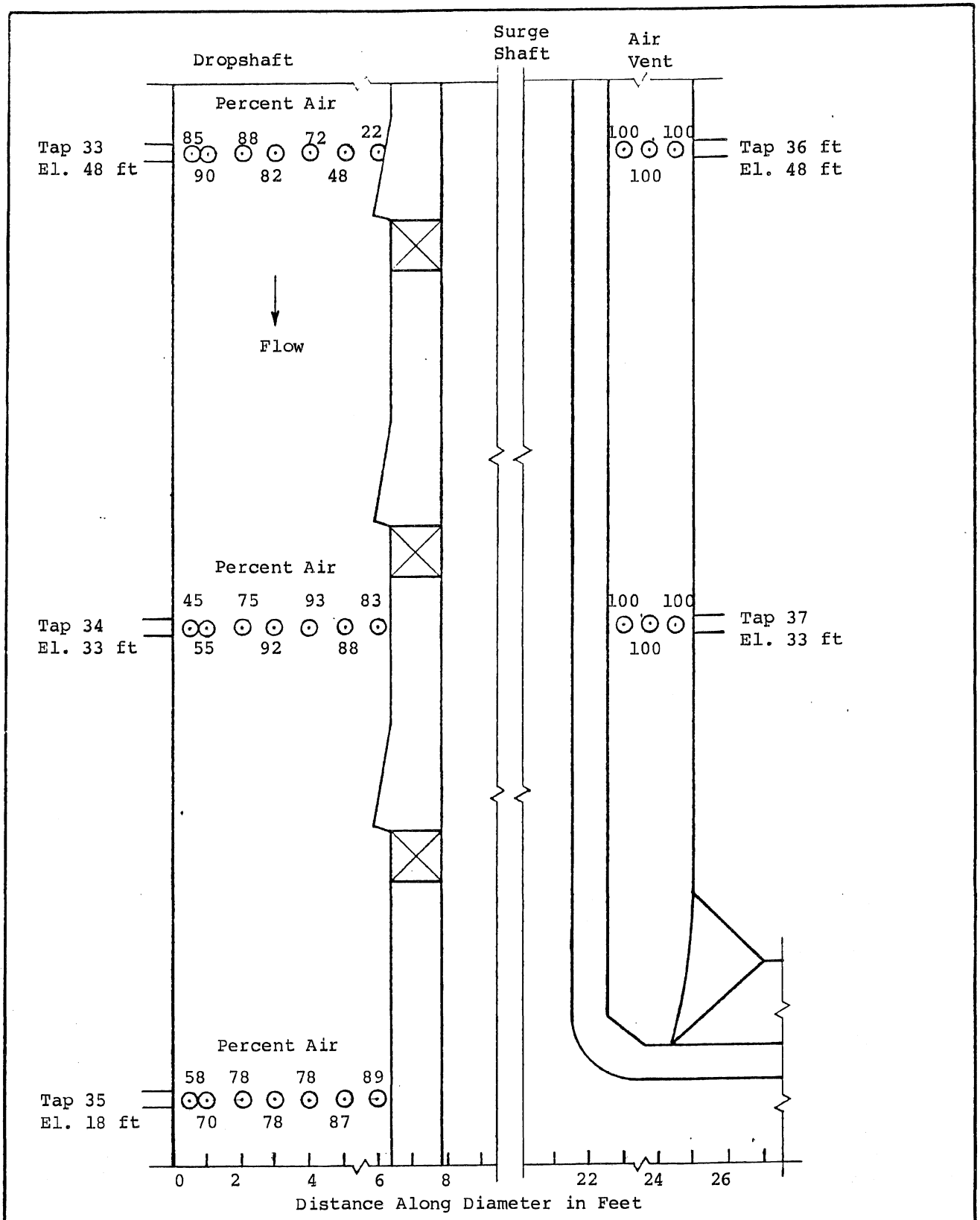
DRAWN BB	CHECKED	APPROVED
SCALE	DATE 2/16/83	NO. 313A2322-119



ROCHESTER COMBINED SURGE AND DROPSHAFT
MODEL STUDIES
Type CSD R1 Dropshaft Scale 1:12
Air Concentrations
Q = 300 cfs, T.W. Elev. = 45 ft

For a T.W. Elev. of 70 ft no air was present in air vent, 2 to 3% in dropshaft.

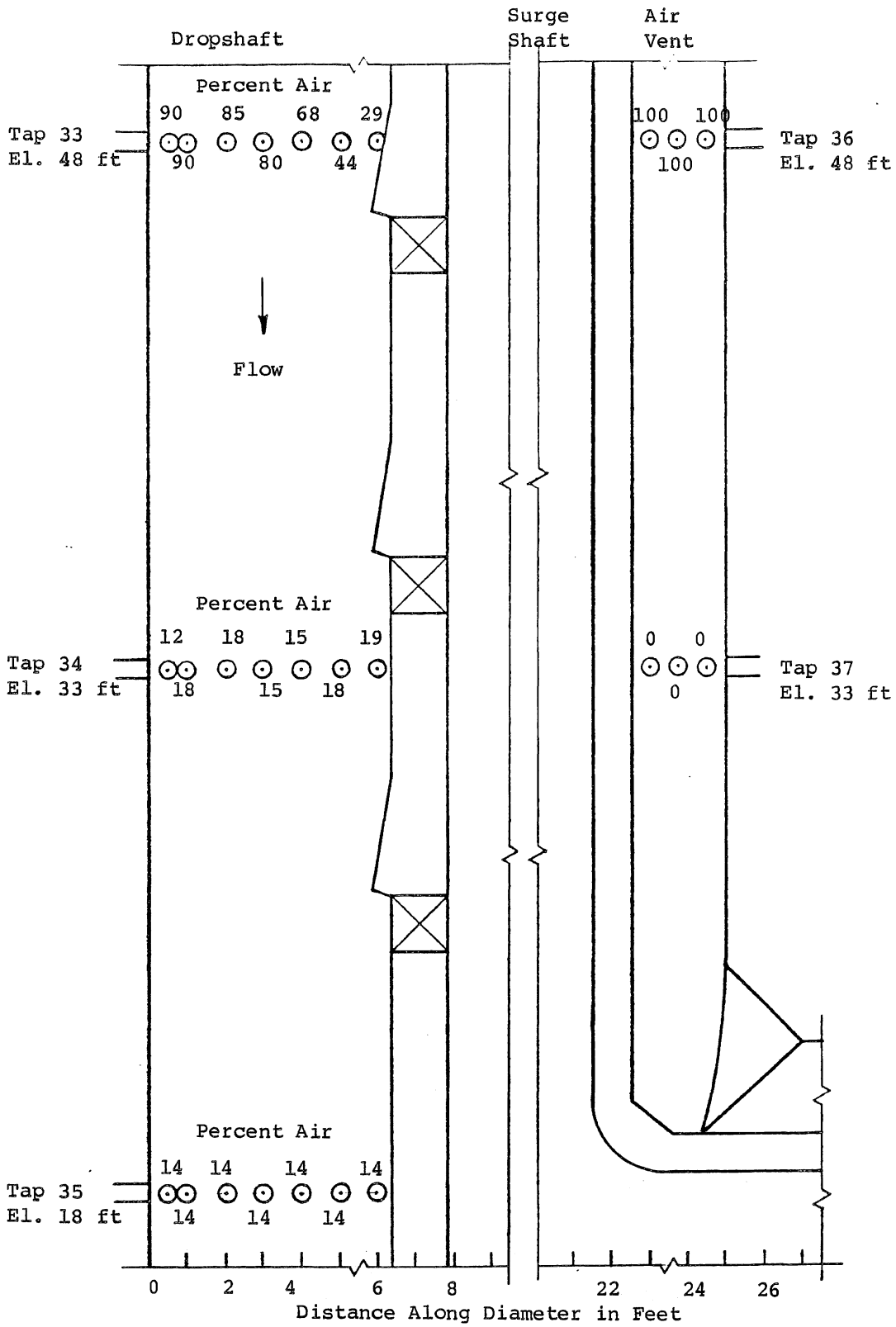
SAINT ANTHONY FALLS HYDRAULIC LABORATORY UNIVERSITY OF MINNESOTA		
DRAWN BB	CHECKED JWC	APPROVED
SCALE	DATE 2/16/83	NO. 313A2322-120



ROCHESTER COMBINED SURGE AND DROPSHAFT
MODEL STUDIES
Type CSD R1 Dropshaft Scale 1:12
Air Concentrations
Q = 400 cfs, T.W. Elev. = 2.6 ft

SAINT ANTHONY FALLS HYDRAULIC LABORATORY
UNIVERSITY OF MINNESOTA

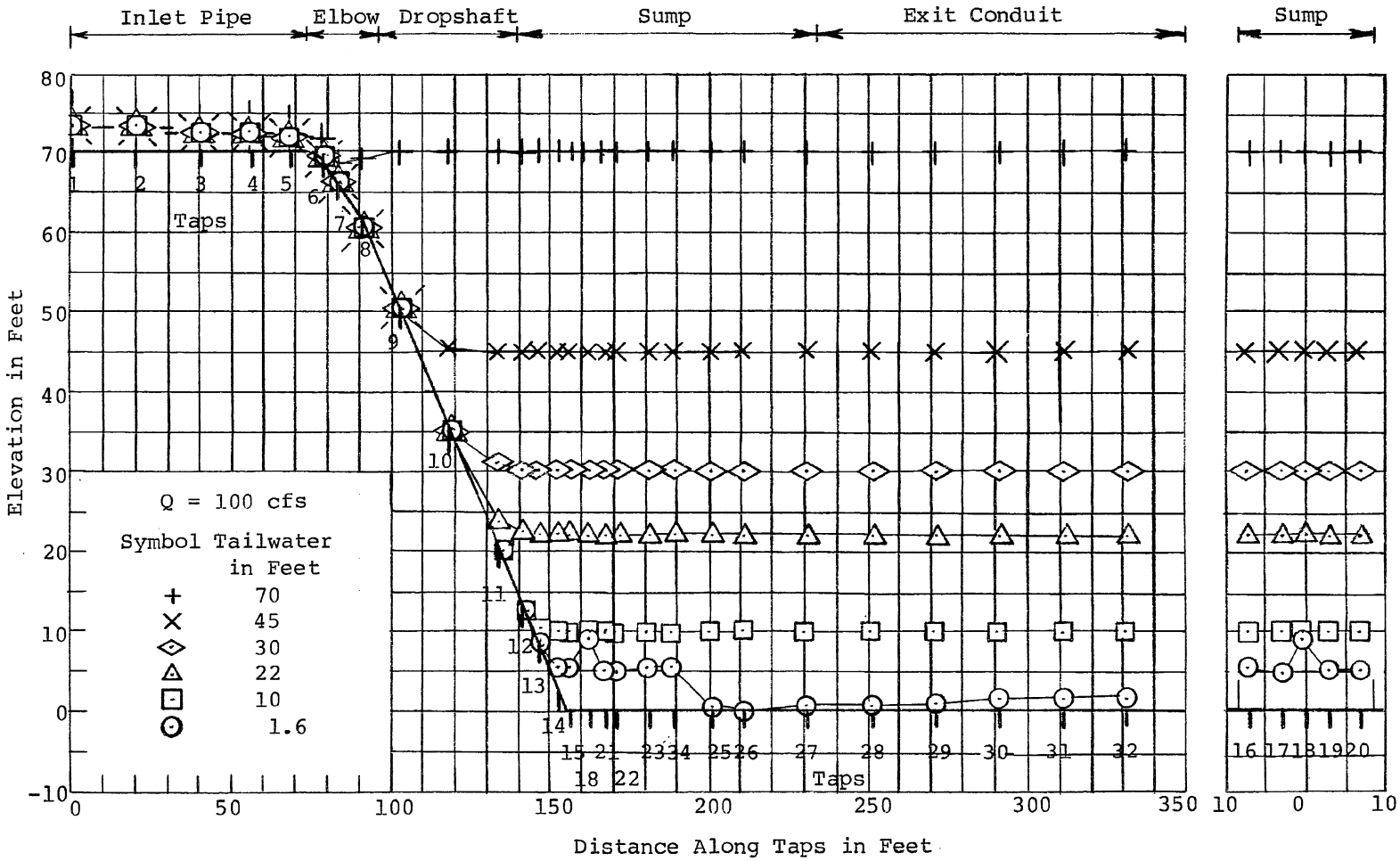
DRAWN BB	CHECKED	APPROVED
SCALE	DATE 2/16/83	NO. 313A2322-121



ROCHESTER COMBINED SURGE AND DROPSHAFT
MODEL STUDIES
Type CSD R1 Dropshaft Scale 1:12
Air Concentrations
Q = 400 cfs, T.W. Elev. = 45 ft

For a T.W. Elev. of 70 ft no air was present in air vent, 3 to 4% in dropshaft.

SAINT ANTHONY FALLS HYDRAULIC LABORATORY UNIVERSITY OF MINNESOTA		
DRAWN BB	CHECKED MSP	APPROVED
SCALE	DATE 2/16/83	NO 313A2322-122

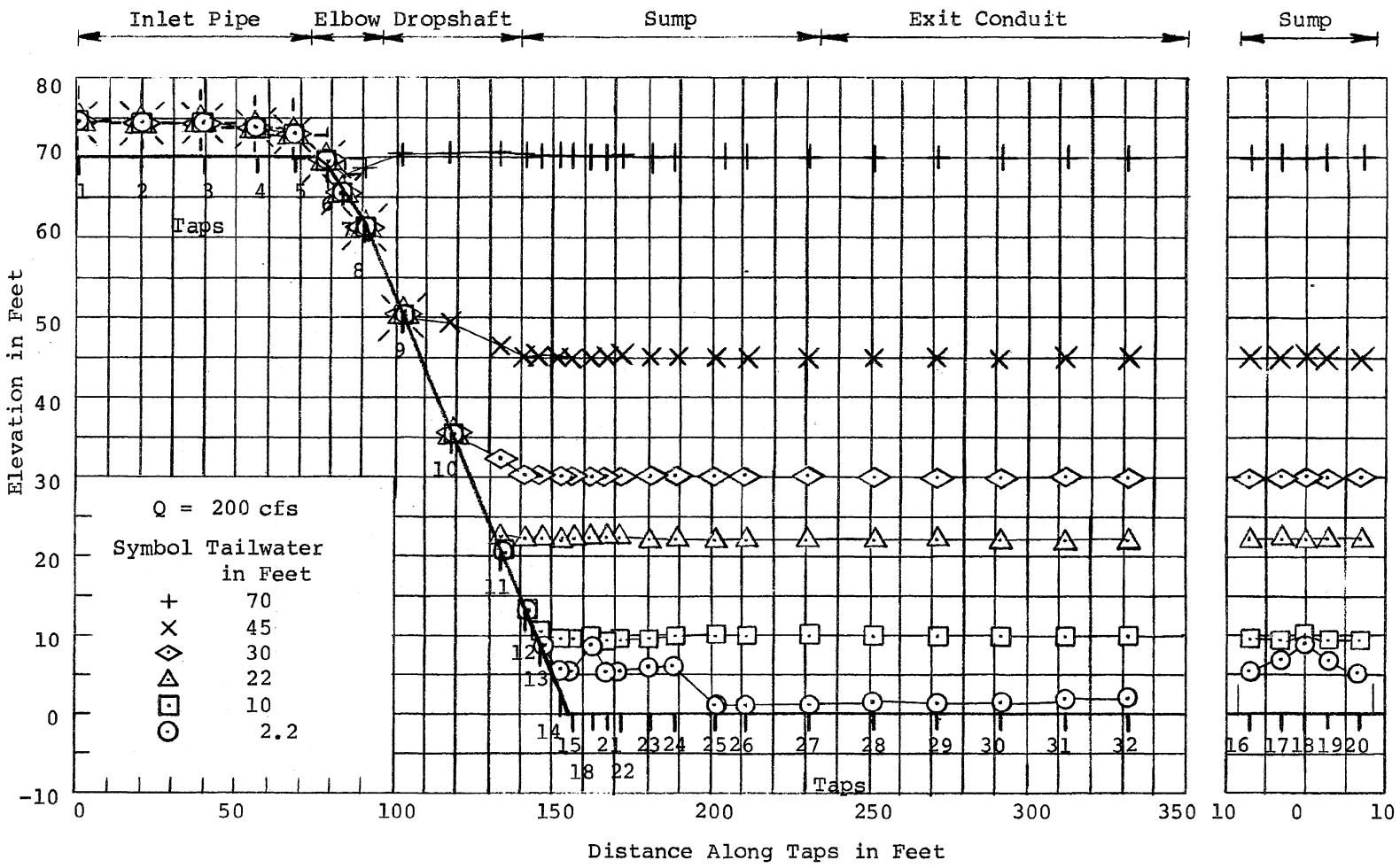


ROCHESTER COMBINED SURGE AND DROPSHAFT
MODEL STUDIES
Type CSD R1 Dropshaft Scale 1:12
Piezometric Pressures

SAINT ANTHONY FALLS HYDRAULIC LABORATORY
UNIVERSITY OF MINNESOTA

DRAWN BB	CHECKED	APPROVED
SCALE	DATE 1/11/83	NO. 313A2322-73

CHART 19

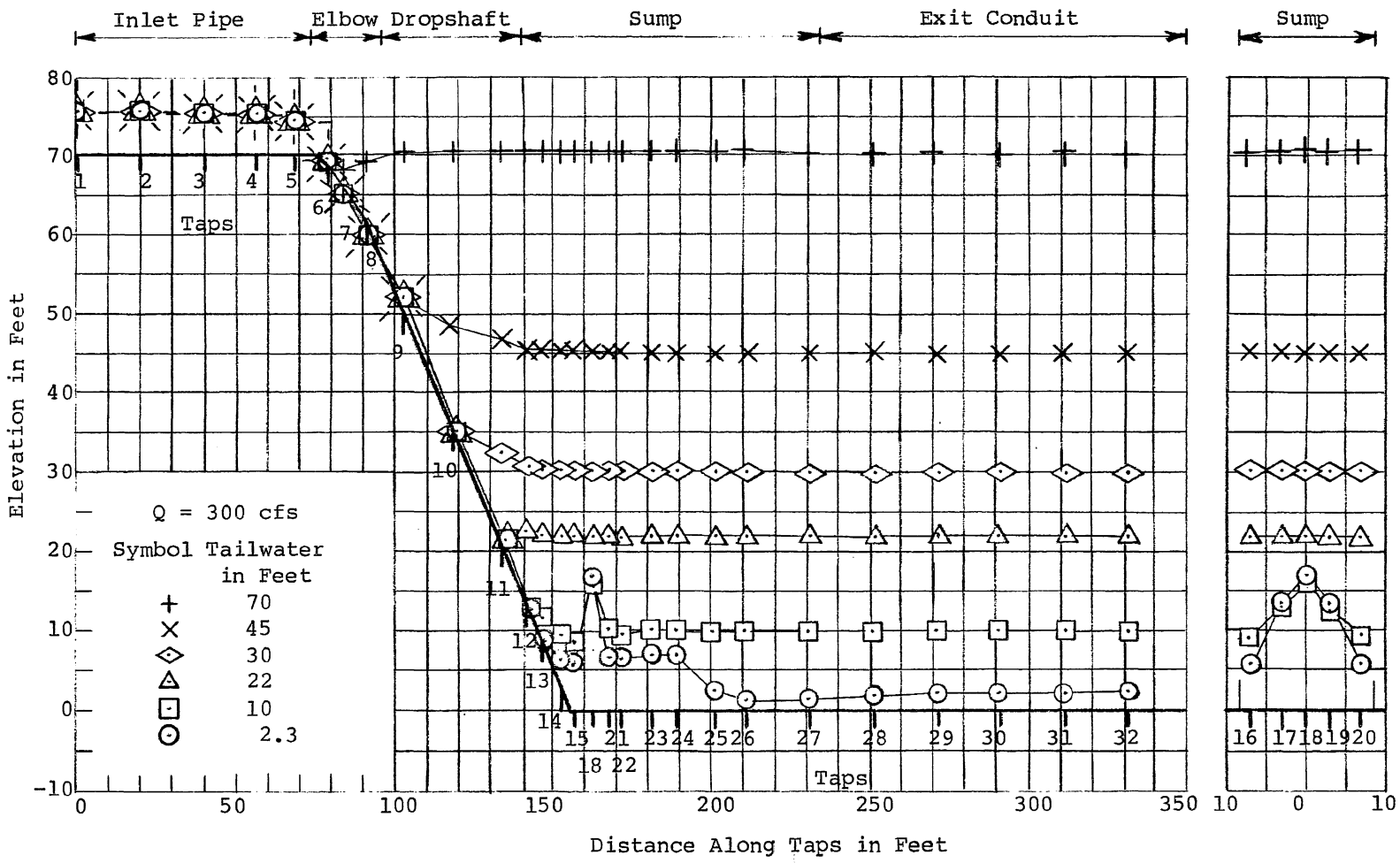


ROCHESTER COMBINED SURGE AND DROPSHAFT
MODEL STUDIES
Type CSD R1 Dropshaft Scale 1:12
Piezometric Pressures

SAINT ANTHONY FALLS HYDRAULIC LABORATORY
UNIVERSITY OF MINNESOTA

DRAWN BB	CHECKED	APPROVED
SCALE	DATE 1/11/83	NO. 313A2322-74

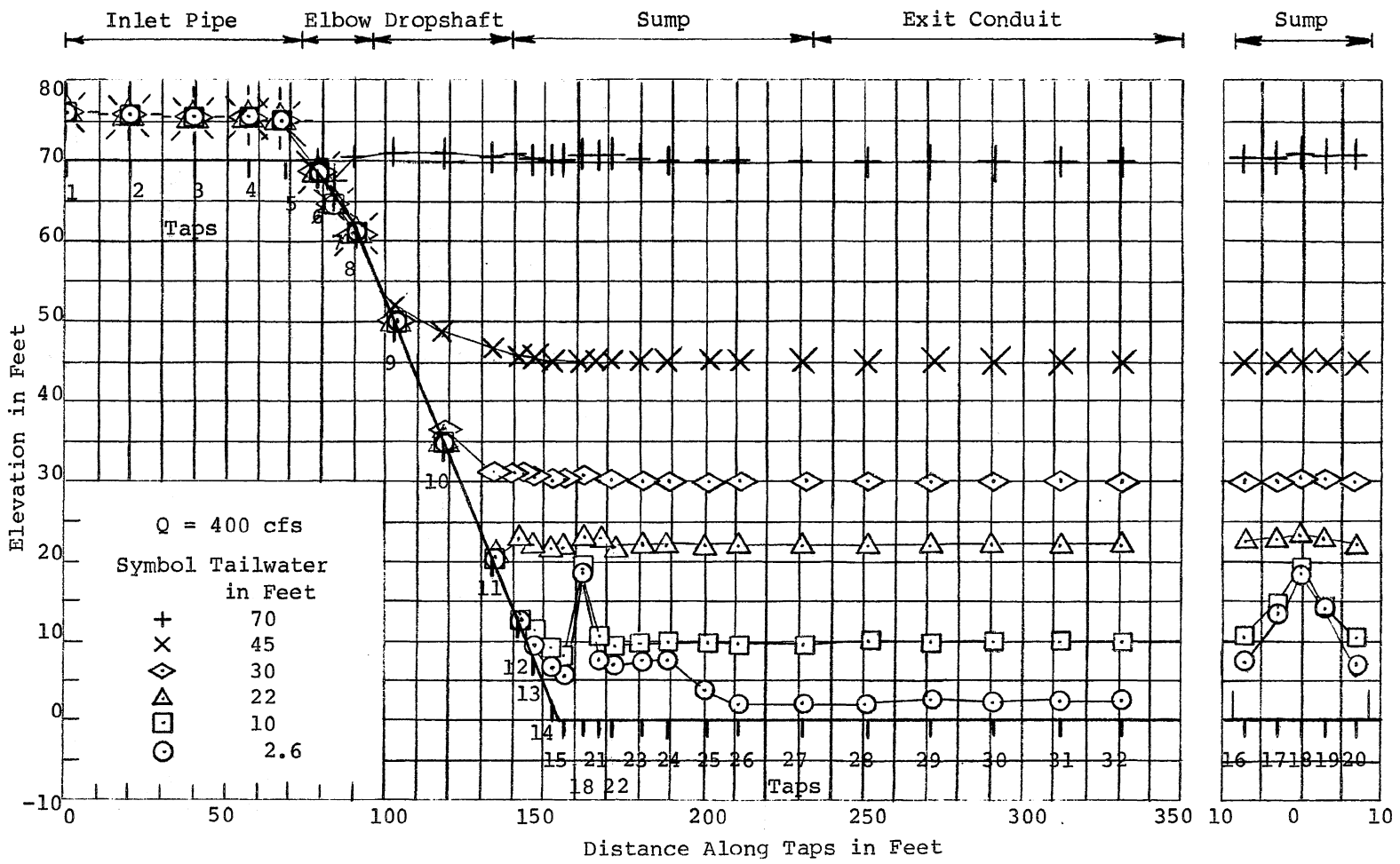
CHART 20



ROCHESTER COMBINED SURGE AND DROPSHAFT
MODEL STUDIES
Type CSD R1 Dropshaft Scale 1:12
Piezometric Pressures

SAINT ANTHONY FALLS HYDRAULIC LABORATORY UNIVERSITY OF MINNESOTA		
DRAWN BB	CHECKED	APPROVED
SCALE	DATE 1/11/83	NO. 313A2322-75

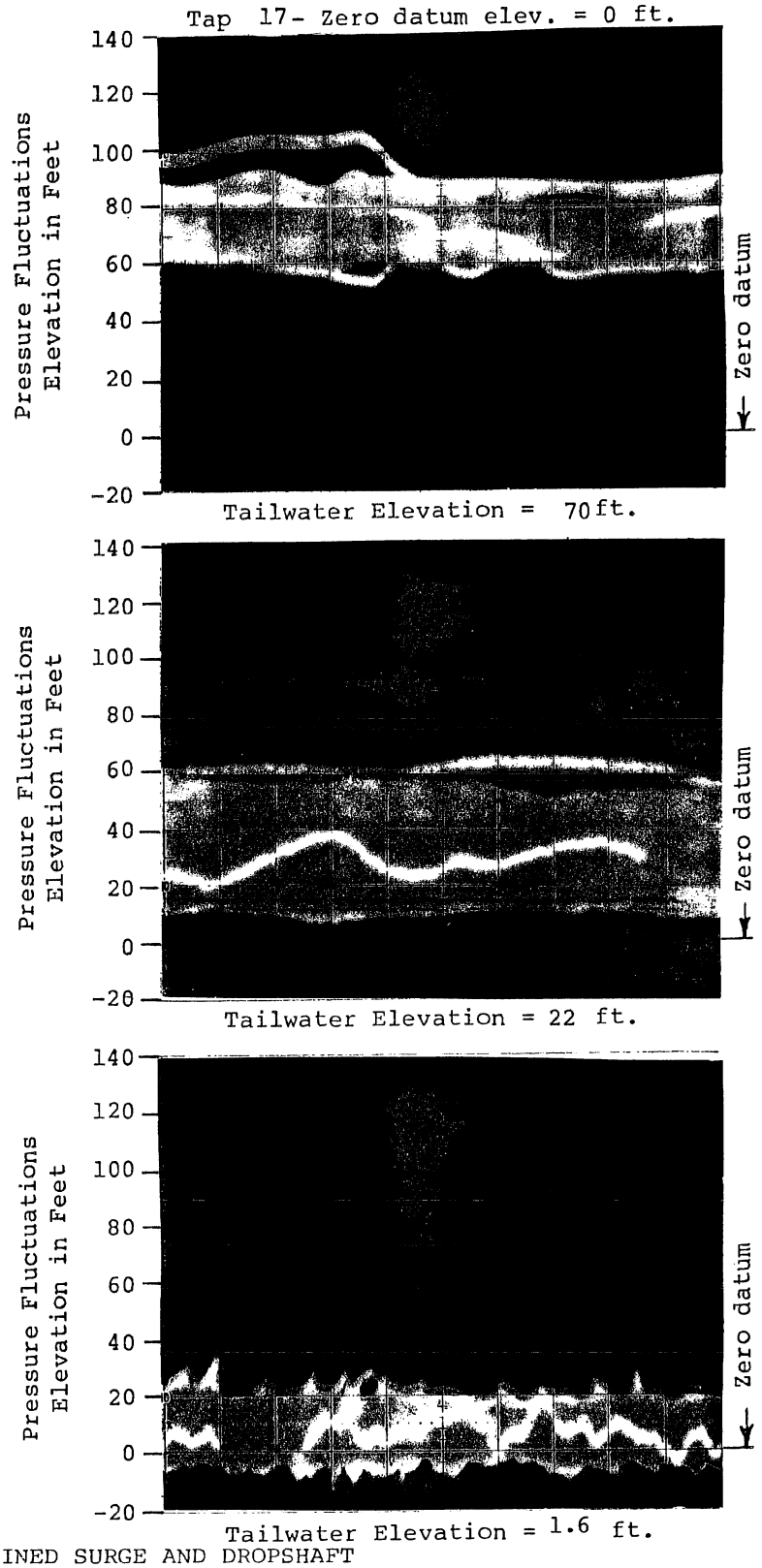
CHART 21



ROCHESTER COMBINED SURGE AND DROPSHAFT
MODEL STUDIES
Type CSD R1 Dropshaft Scale 1:12
Piezometric Pressures

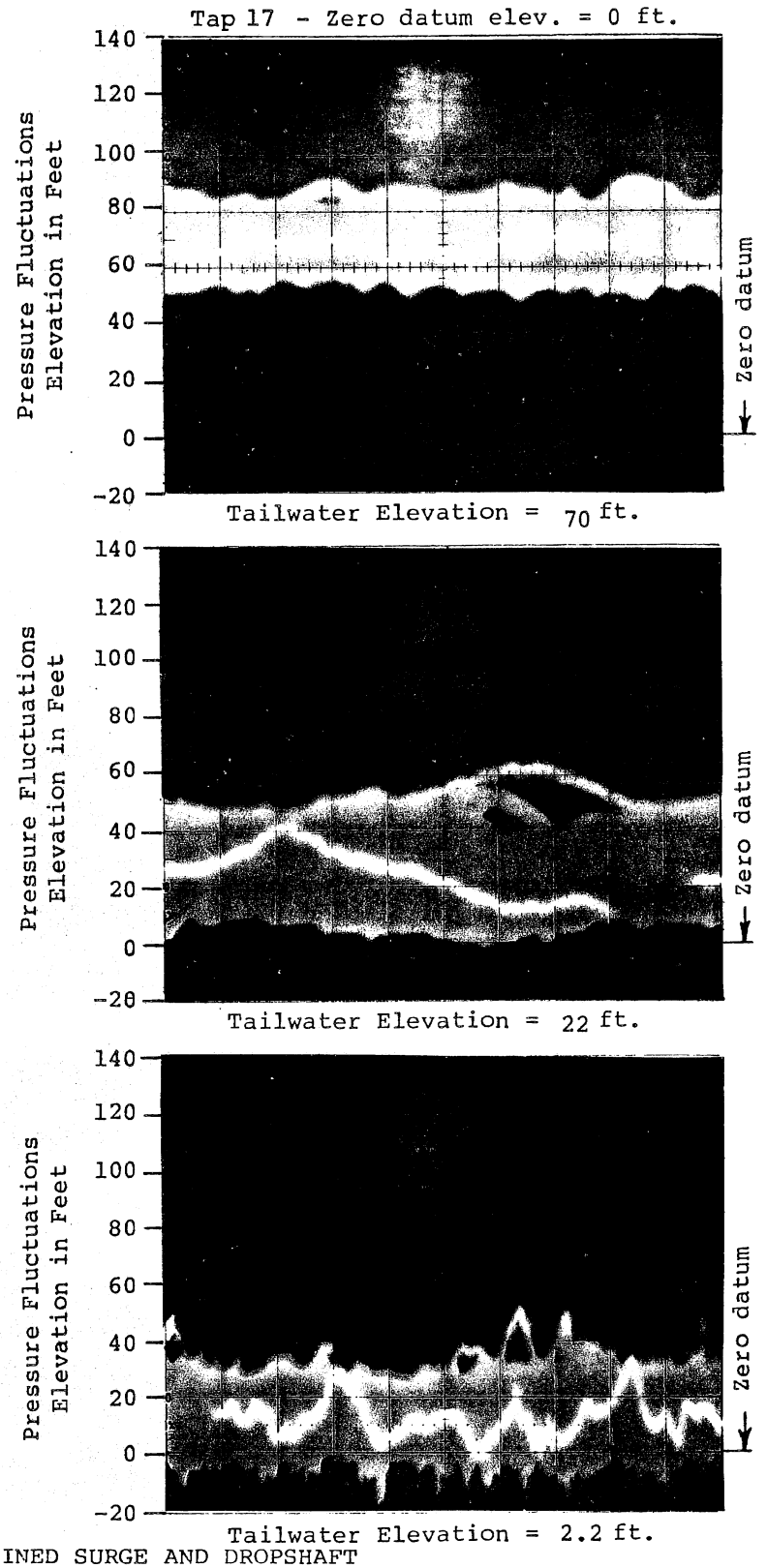
SAINT ANTHONY FALLS HYDRAULIC LABORATORY UNIVERSITY OF MINNESOTA		
DRAWN BB	CHECKED	APPROVED
SCALE	DATE 1/11/83	NO 313A2322-76

CHART 22



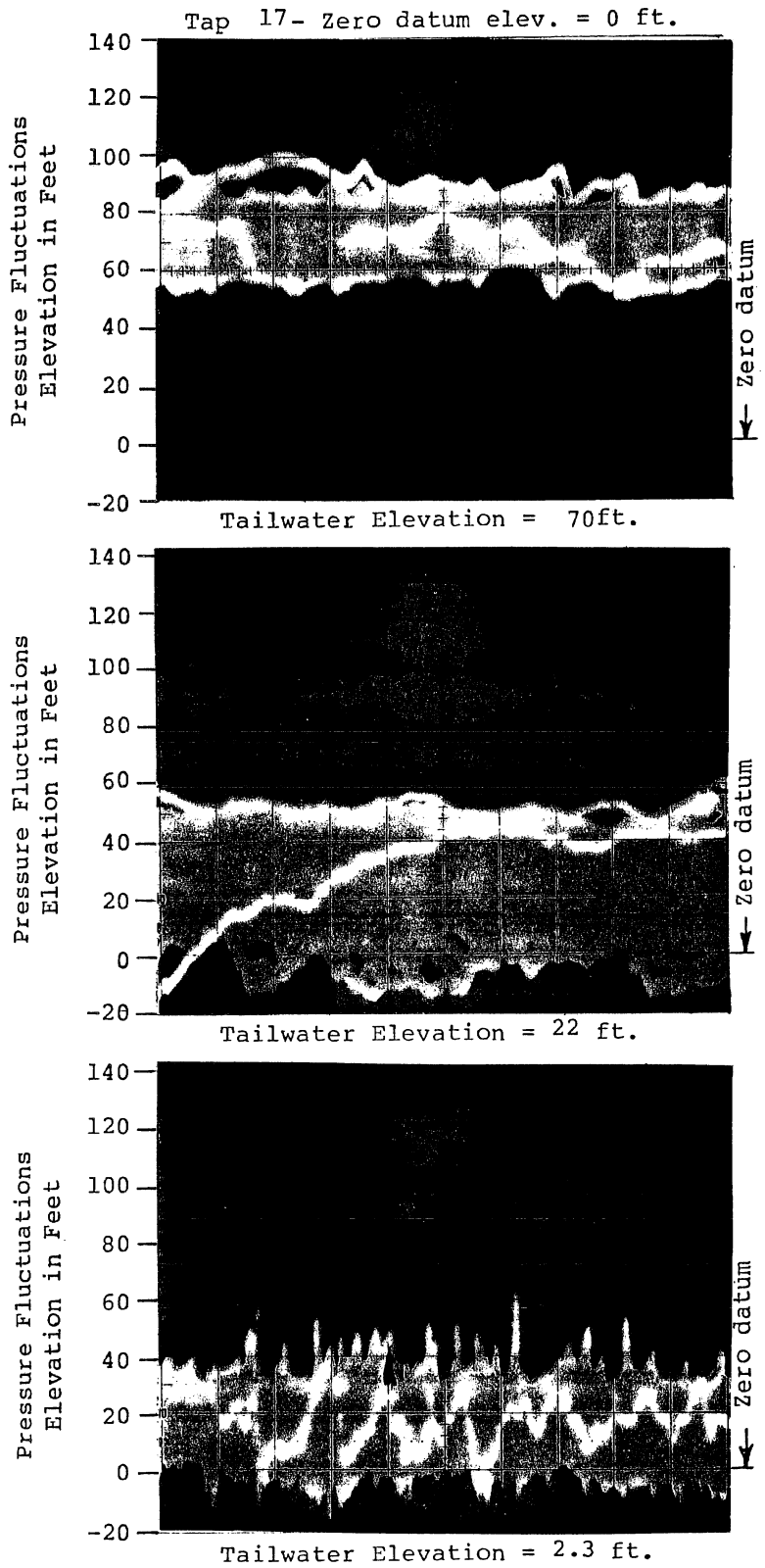
ROCHESTER COMBINED SURGE AND DROPSHAFT
MODEL STUDIES
Type CSD $_{R1}$ Dropshaft Scale 1:12
Typical Pressure Fluctuations
Q = 100 cfs
Model time of record = 1 minute

SAINT ANTHONY FALLS HYDRAULIC LABORATORY UNIVERSITY OF MINNESOTA		
DRAWN WQD	CHECKED BB	APPROVED
SCALE	DATE 12/9/82	NO 313A2322-27



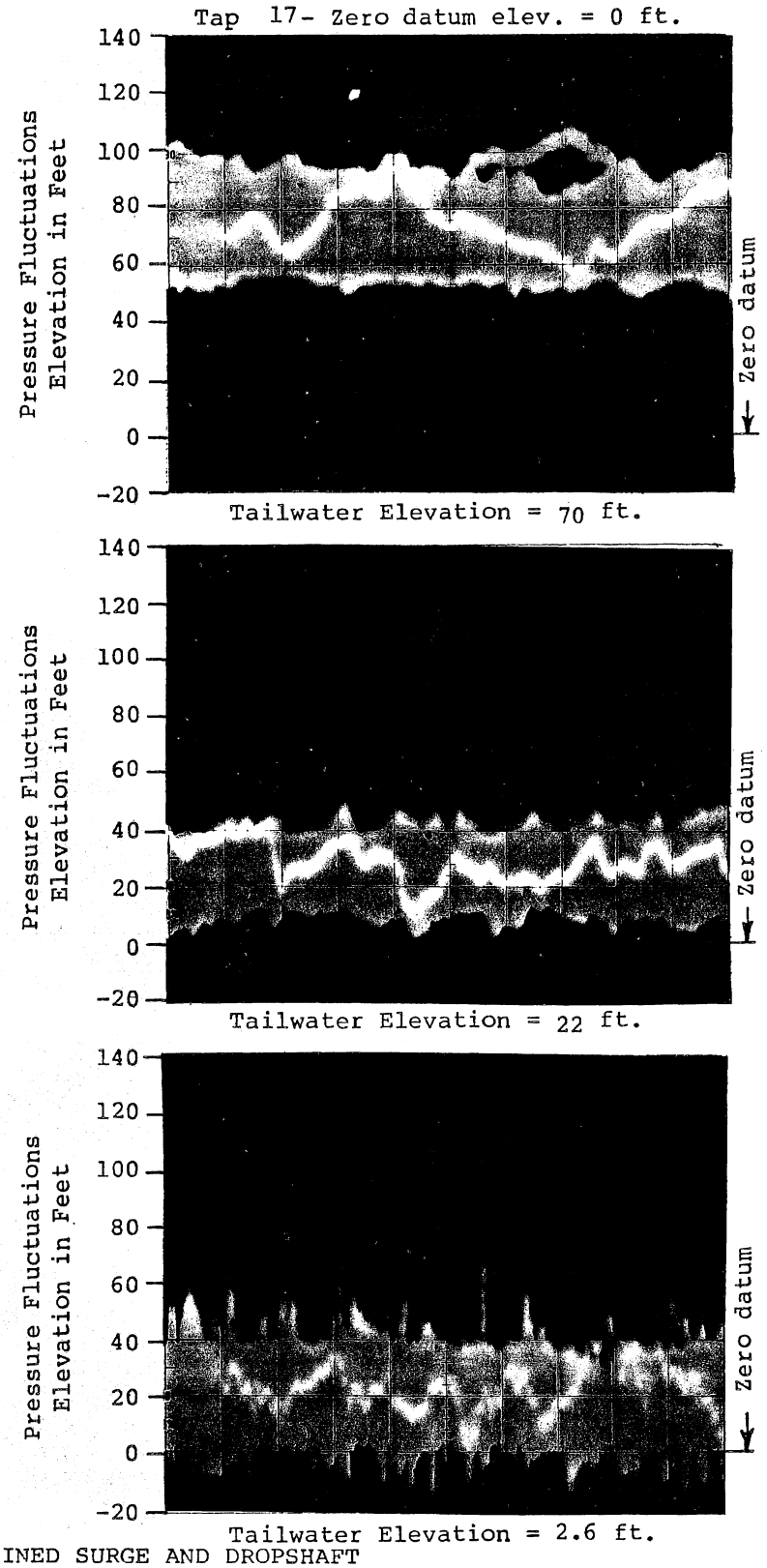
ROCHESTER COMBINED SURGE AND DROPSHAFT
MODEL STUDIES
Type CSD R1 Dropshaft Scale 1:12
Typical Pressure Fluctuations
Q = 200 cfs
Model time of record = 1 minute

SAINT ANTHONY FALLS HYDRAULIC LABORATORY UNIVERSITY OF MINNESOTA		
DRAWN WQD	CHECKED BB	APPROVED
SCALE	DATE 12/9/82	NO 313A2322-28



ROCHESTER COMBINED SURGE AND DROPSHAFT
MODEL STUDIES
Type CSDR1 Dropshaft Scale 1:12
Typical Pressure Fluctuations
Q = 300 cfs
Model time of record = 1 minute

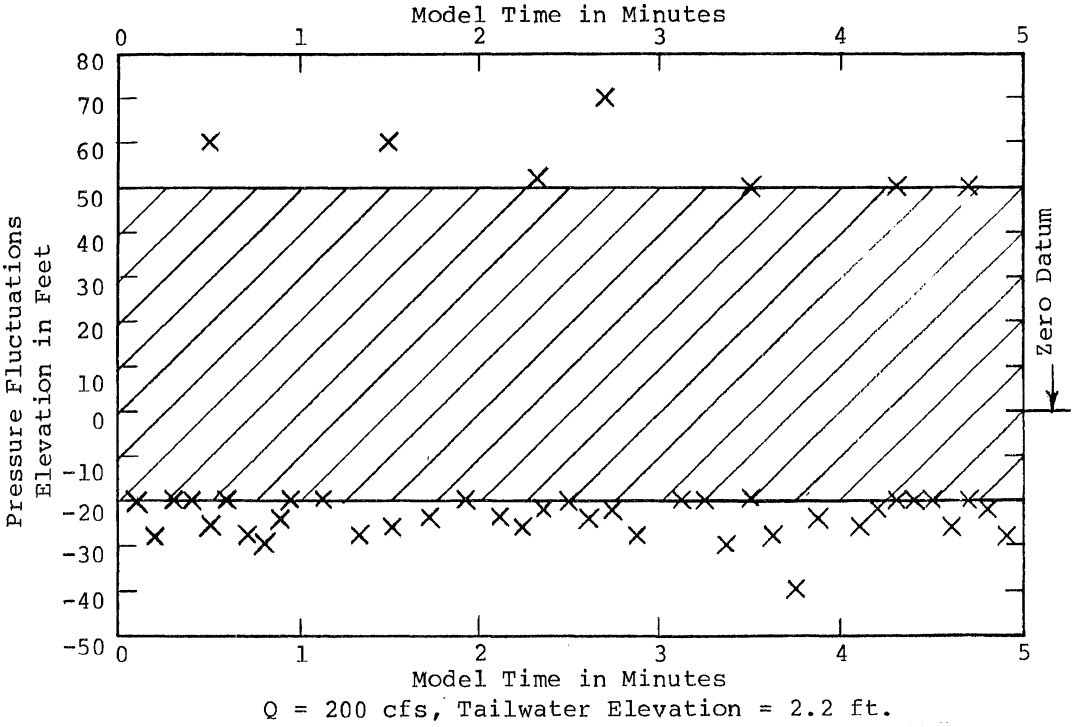
SAINT ANTHONY FALLS HYDRAULIC LABORATORY UNIVERSITY OF MINNESOTA		
DRAWN WQD	CHECKED BB	APPROVED
SCALE	DATE 12/9/82	NO 313A2322-29



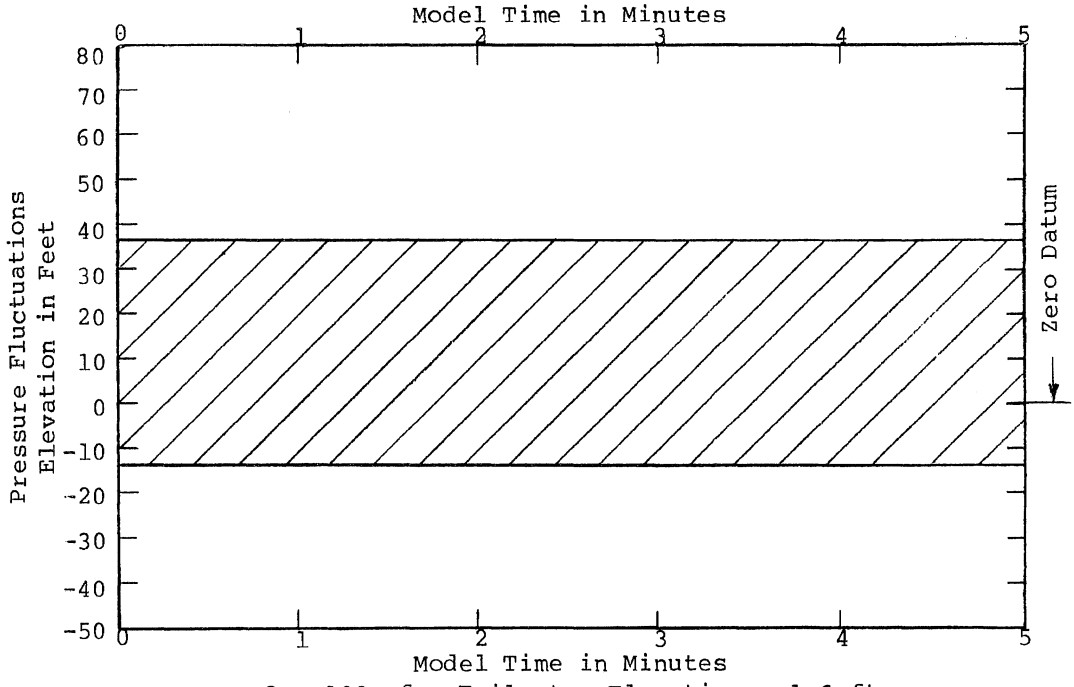
ROCHESTER COMBINED SURGE AND DROPSHAFT
MODEL STUDIES
Type CSDR1 Dropshaft Scale 1:12
Typical Pressure Fluctuations
Q = 400 cfs
Model time of record = 1 minute

SAINT ANTHONY FALLS HYDRAULIC LABORATORY UNIVERSITY OF MINNESOTA		
DRAWN WQD	CHECKED RB	APPROVED
SCALE	DATE 12/9/82	NO 313A2322-30

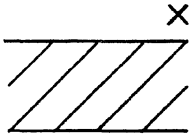
Tap 17 - Zero datum elev. = 0 ft.



Q = 200 cfs, Tailwater Elevation = 2.2 ft.



Q = 100 cfs, Tailwater Elevation = 1.6 ft.



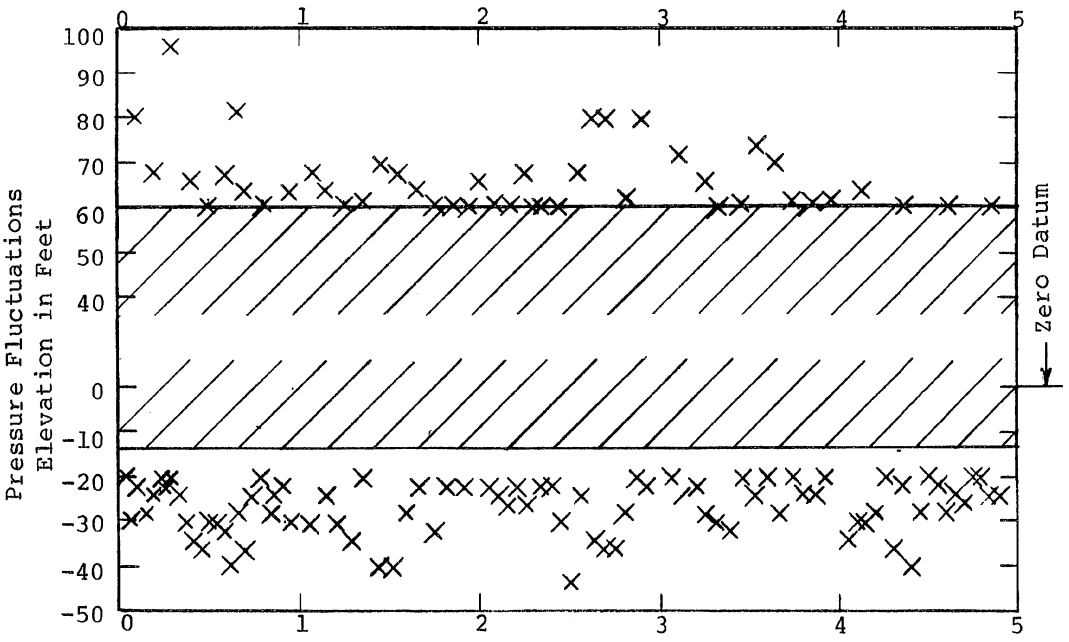
× Visually observed readings

Range from oscilloscope photos, Model time of record = 1 minute

ROCHESTER COMBINED SURGE AND DROPSHAFT
MODEL STUDIES
Type CSD R1 Dropshaft Scale 1:12
Typical Pressure Fluctuations

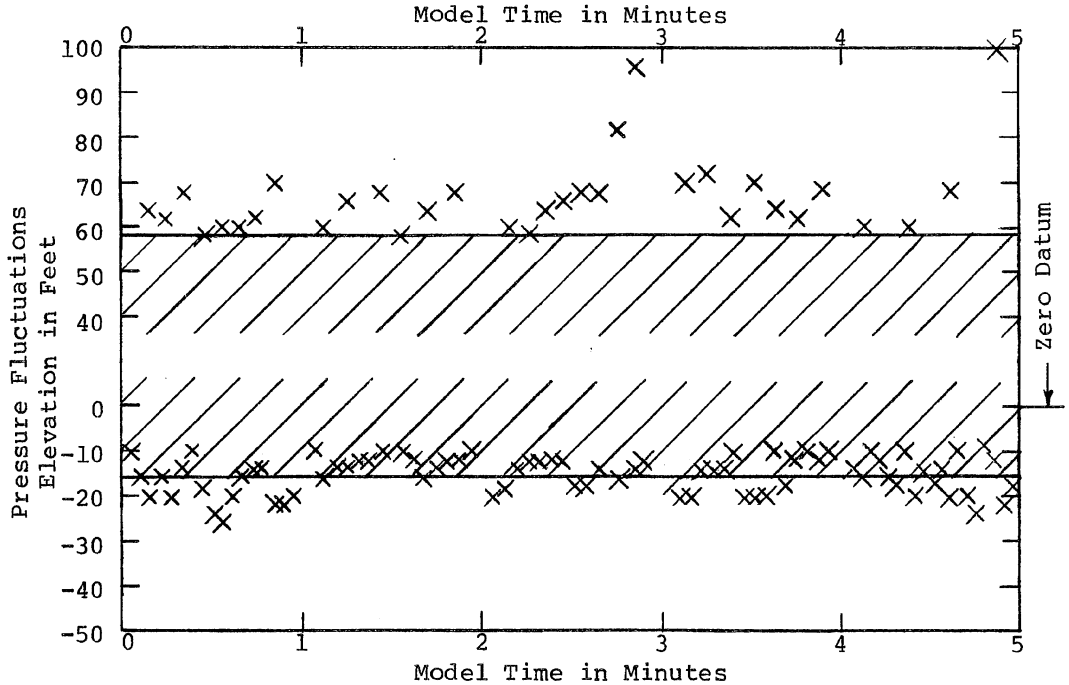
SAINT ANTHONY FALLS HYDRAULIC LABORATORY UNIVERSITY OF MINNESOTA		
DRAWN BB	CHECKED [illegible]	APPROVED
SCALE	DATE 1/17/83	NO. 313A2322-89

Tap 17 - Zero datum elev. = 0 ft.



Model Time in Minutes

Q = 400 cfs, Tailwater Elevation = 2.6 ft.



Model Time in Minutes

Q = 300 cfs, Tailwater Elevation = 2.3 ft.

× Visually observed readings

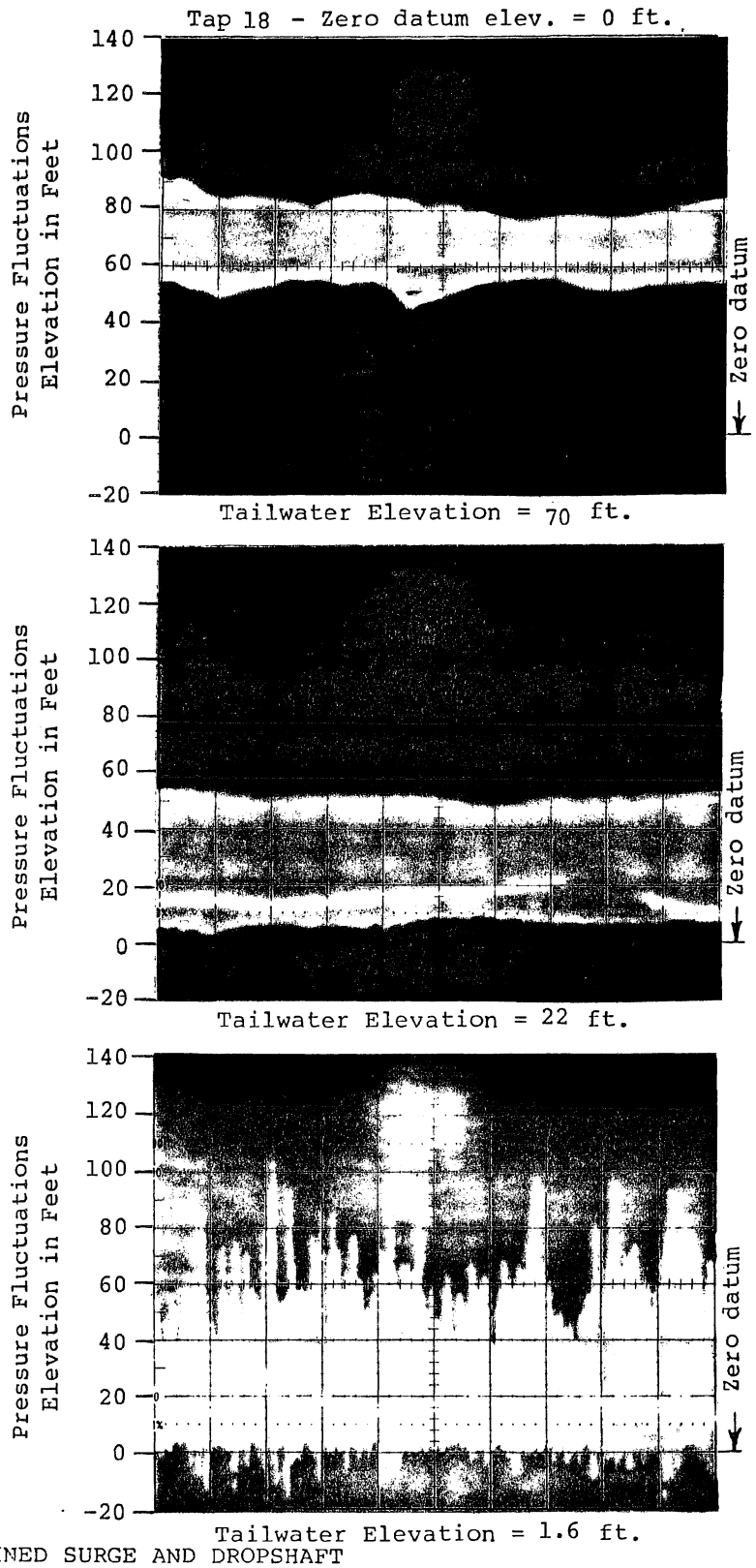
Range from oscilloscope photos, Model time of record = 1 minute

ROCHESTER COMBINED SURGE AND DROPSHAFT MODEL STUDIES

Type CSD R1 Dropshaft Scale 1:12

Typical Pressure Fluctuations

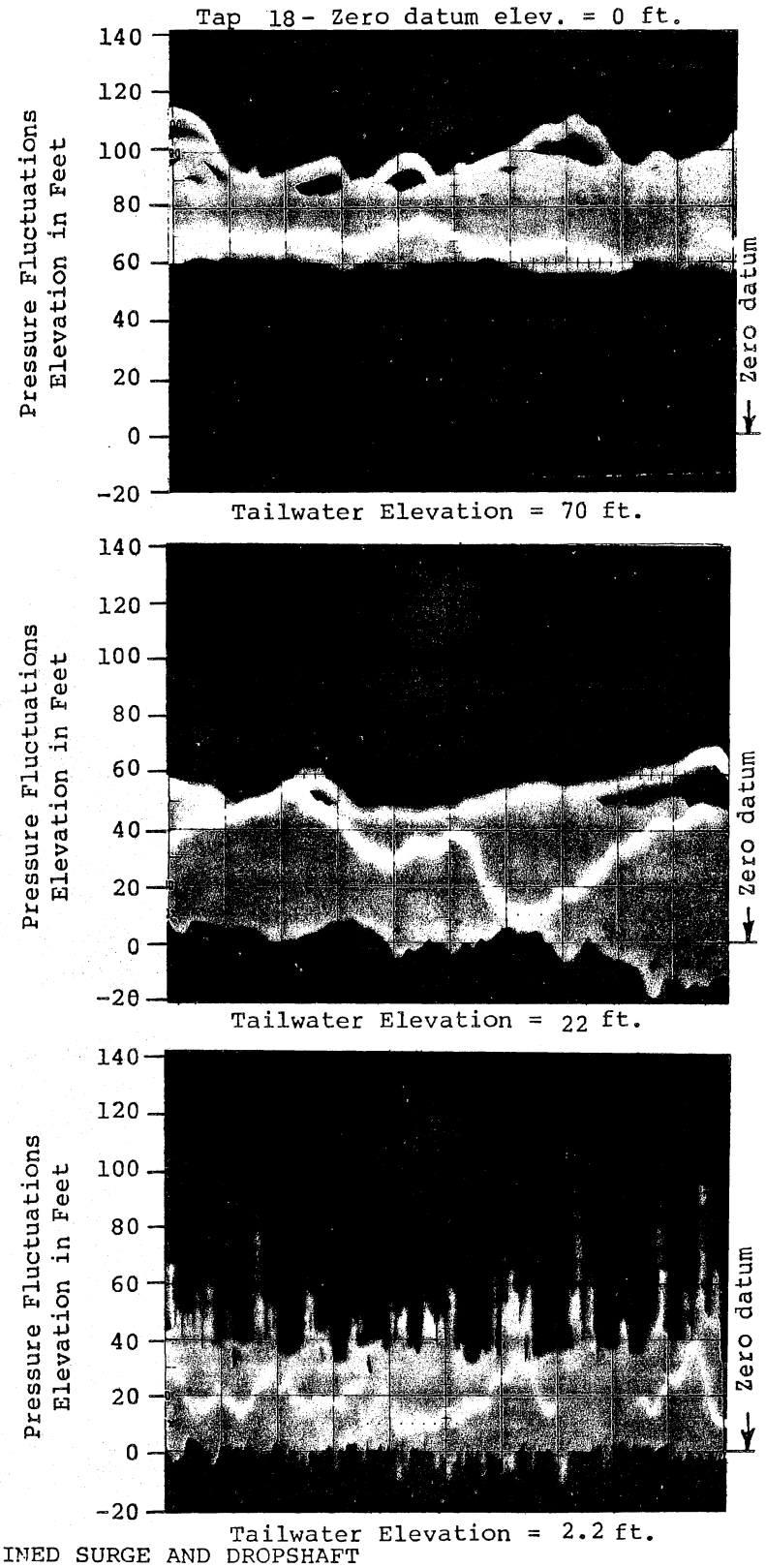
SAINT ANTHONY FALLS HYDRAULIC LABORATORY UNIVERSITY OF MINNESOTA		
DRAWN BB	CHECKED	APPROVED
SCALE	DATE 1/17/83	NO. 313A2322-90



ROCHESTER COMBINED SURGE AND DROPSHAFT
MODEL STUDIES
Type CSD R1 Dropshaft Scale 1:12
Typical Pressure Fluctuations
Q = 100 cfs
Model time of record = 1 minute

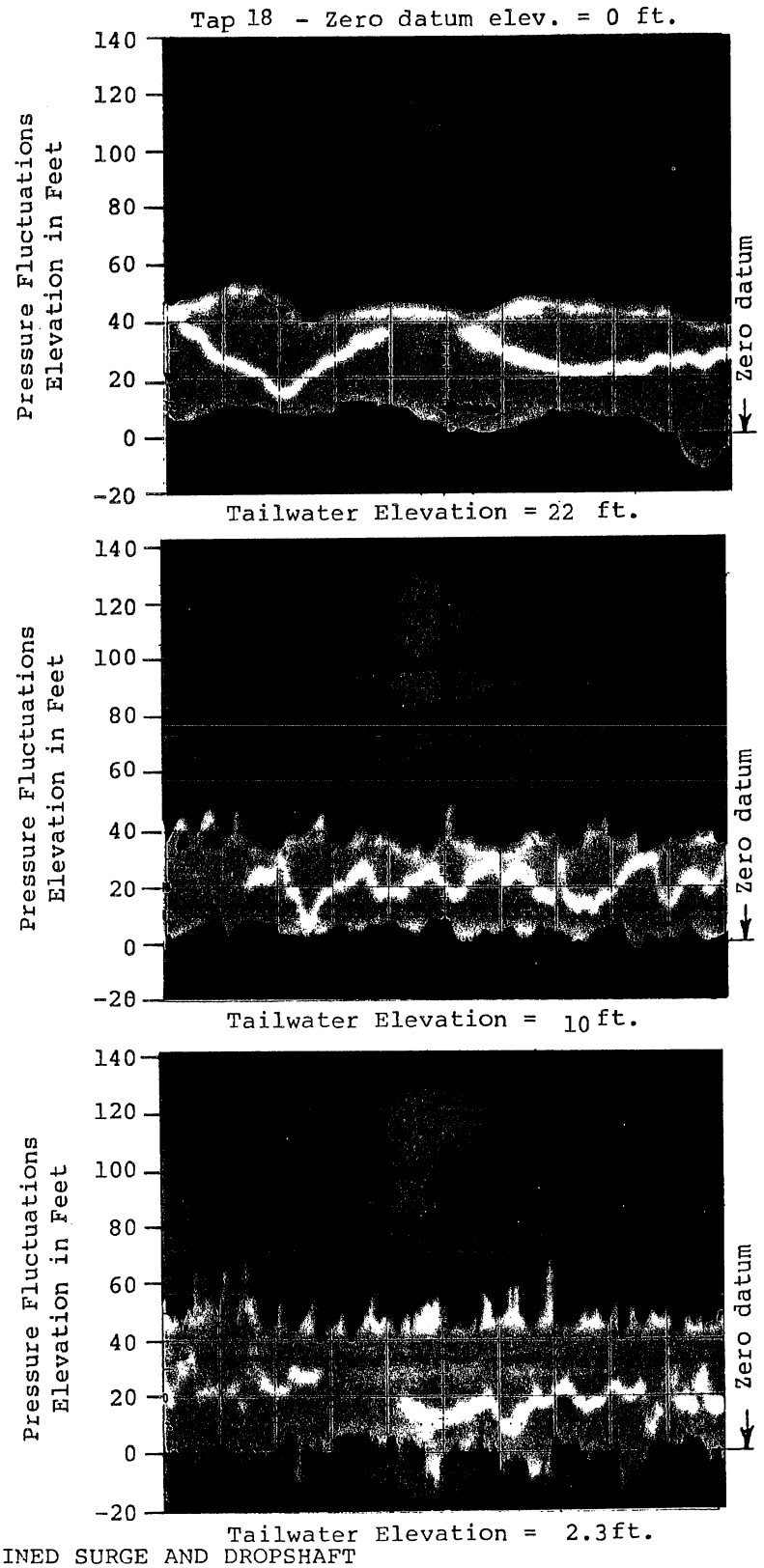
SAINT ANTHONY FALLS HYDRAULIC LABORATORY
UNIVERSITY OF MINNESOTA

DRAWN WQD	CHECKED BB	APPROVED
SCALE	DATE 12/9/82	NO 313A2322- 22



ROCHESTER COMBINED SURGE AND DROPSHAFT
MODEL STUDIES
Type CSD R1 Dropshaft Scale 1:12
Typical Pressure Fluctuations
Q = 200 cfs
Model time of record = 1 minute

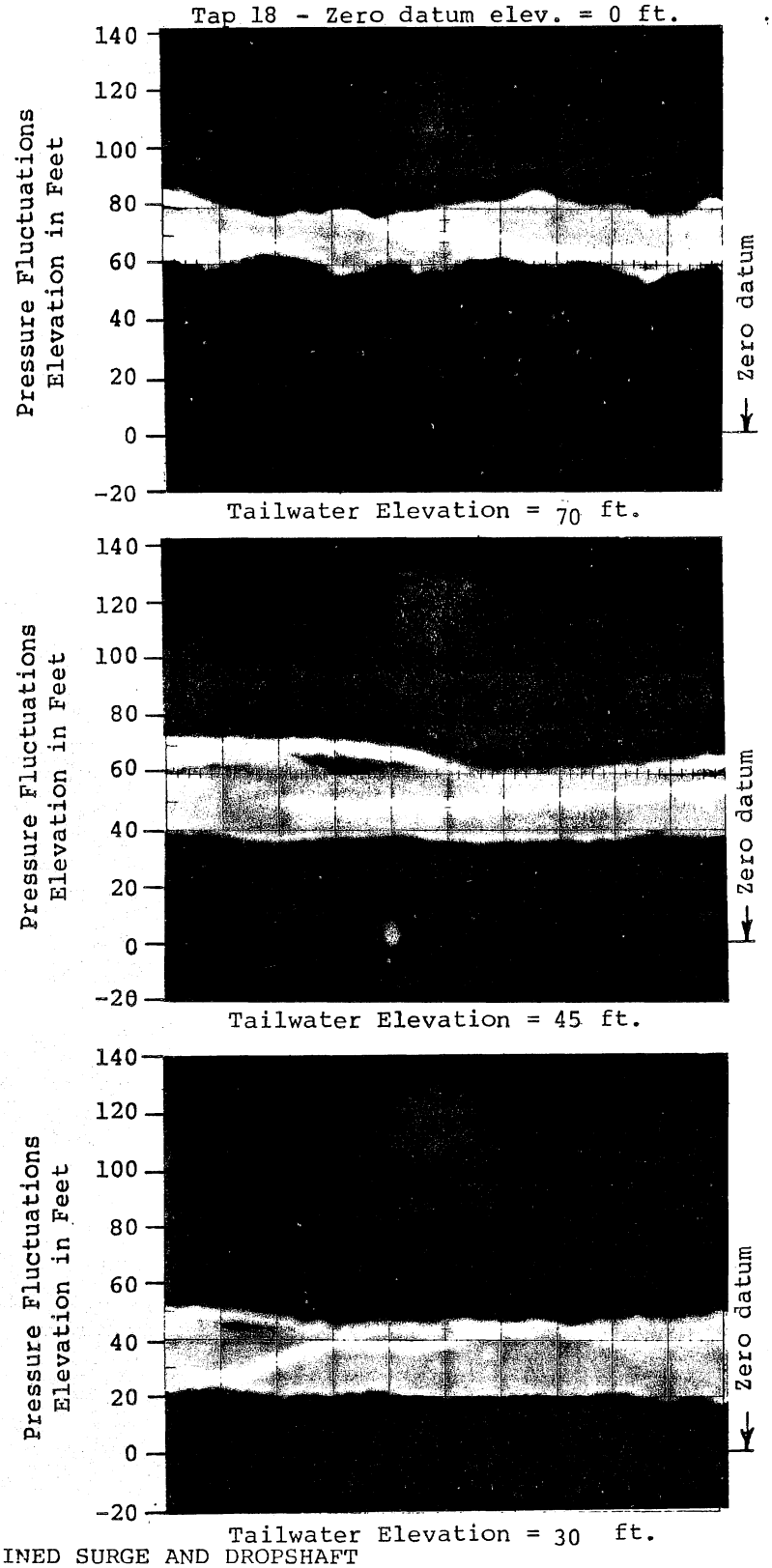
SAINT ANTHONY FALLS HYDRAULIC LABORATORY UNIVERSITY OF MINNESOTA		
DRAWN WQD	CHECKED BB	APPROVED
SCALE	DATE 12/9/82	NO 313A2322- 23



ROCHESTER COMBINED SURGE AND DROPSHAFT
MODEL STUDIES
Type CSDR1 Dropshaft Scale 1:12
Typical Pressure Fluctuations
Q = 300 cfs
Model time of record = 1 minute

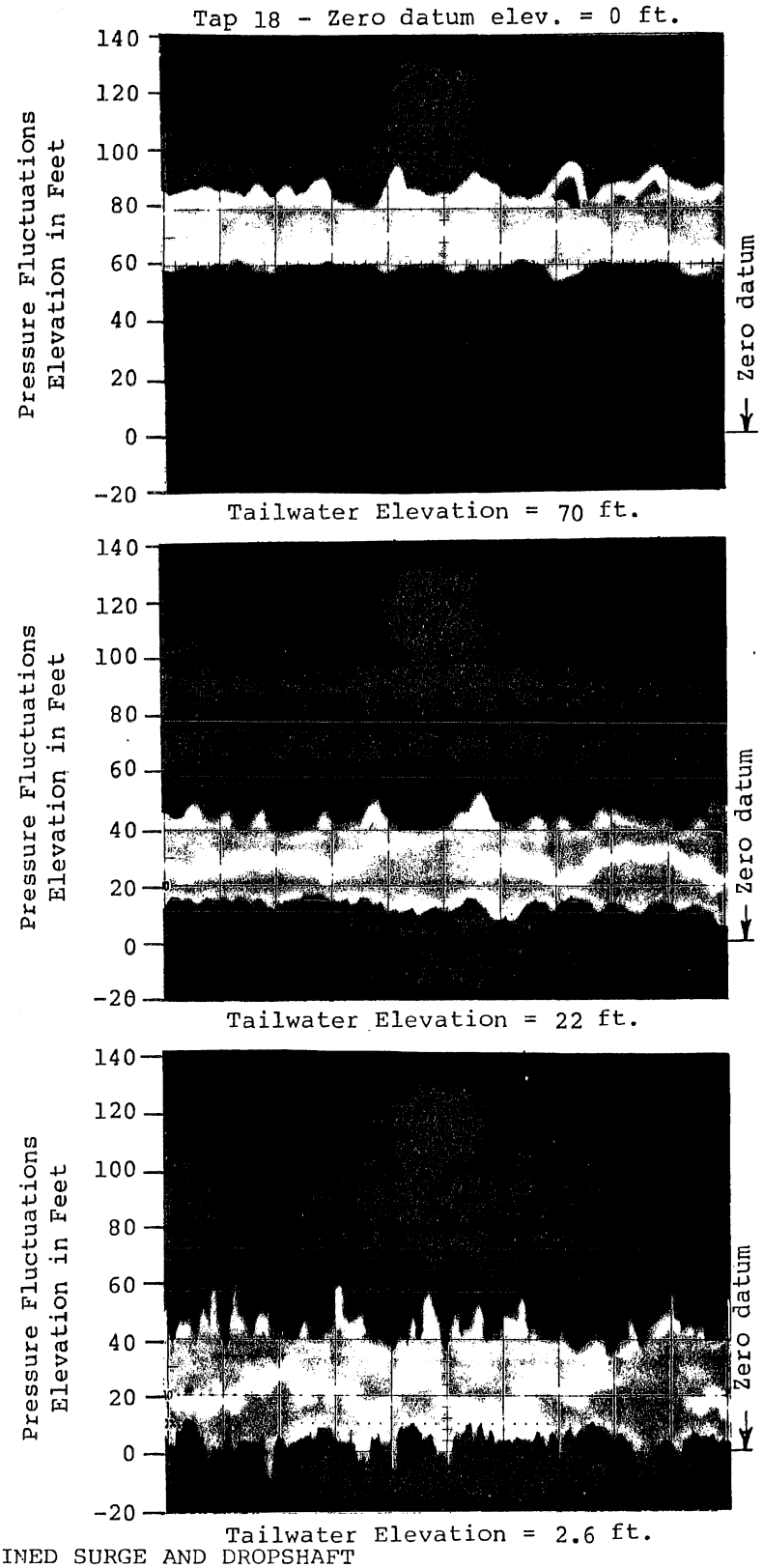
SAINT ANTHONY FALLS HYDRAULIC LABORATORY
UNIVERSITY OF MINNESOTA

DRAWN WQD	CHECKED BB	APPROVED
SCALE	DATE 12/9/82	NO 313A2322- 25



ROCHESTER COMBINED SURGE AND DROPSHAFT
MODEL STUDIES
Type CSD R1 Dropshaft Scale 1:12
Typical Pressure Fluctuations
Q = 300 cfs
Model time of record = 1 minute

SAINT ANTHONY FALLS HYDRAULIC LABORATORY UNIVERSITY OF MINNESOTA		
DRAWN WQD	CHECKED BB	APPROVED
SCALE	DATE 12/9/82	NO 313A2322- 24

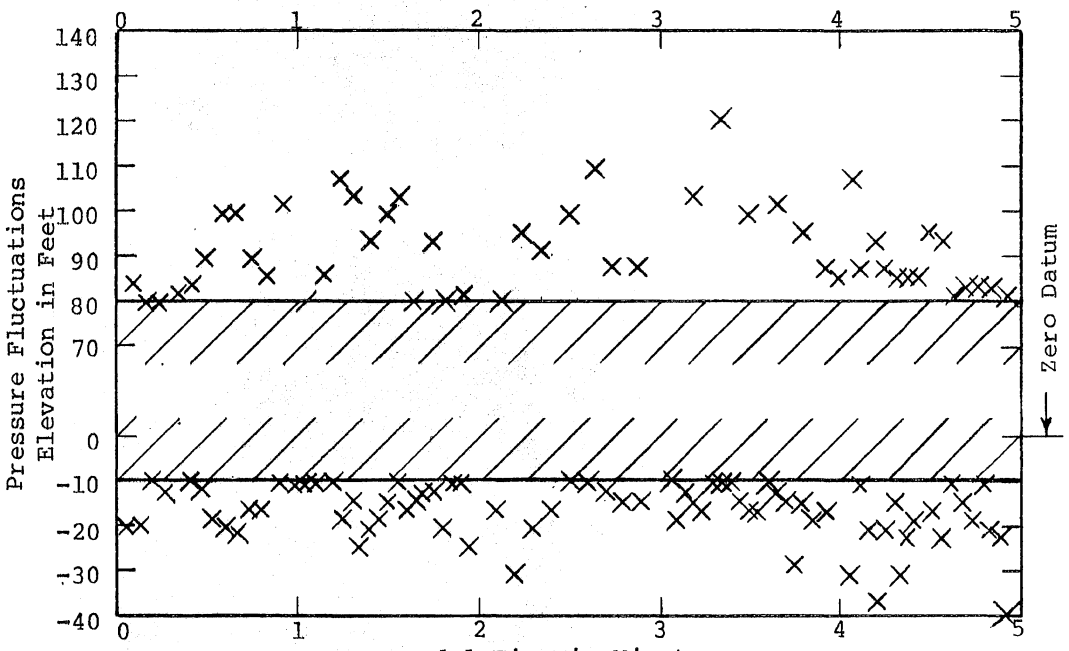


ROCHESTER COMBINED SURGE AND DROPSHAFT
MODEL STUDIES
Type CSD R1 Dropshaft Scale 1:12
Typical Pressure Fluctuations
Q = 400cfs
Model time of record = 1 minute

SAINT ANTHONY FALLS HYDRAULIC LABORATORY
UNIVERSITY OF MINNESOTA

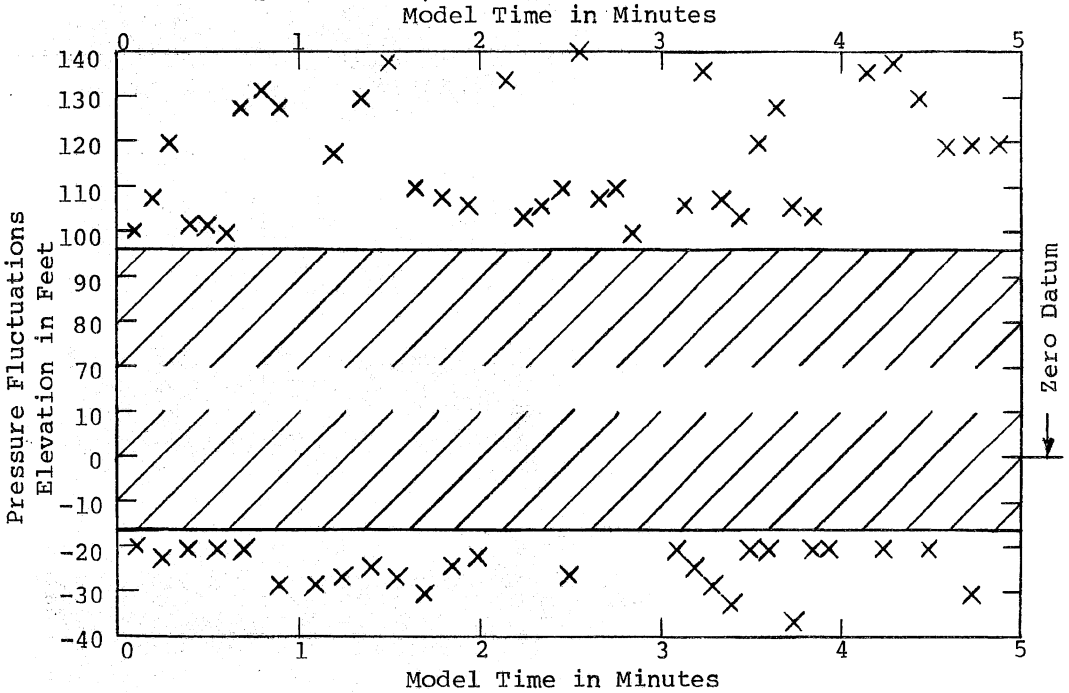
DRAWN WQD	CHECKED BB	APPROVED
SCALE	DATE 12/9/82	NO 313A2322- 26

Tap 18 - Zero datum elev. = 0 ft.



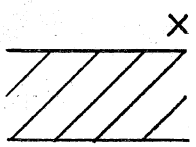
Model Time in Minutes

Q = 200 cfs, Tailwater Elevation = 2.2 ft.



Model Time in Minutes

Q = 100 cfs, Tailwater Elevation = 1.6 ft.



× Visually observed readings

Range from oscilloscope photos, Model time of record = 1 minute

ROCHESTER COMBINED SURGE AND DROPSHAFT MODEL STUDIES

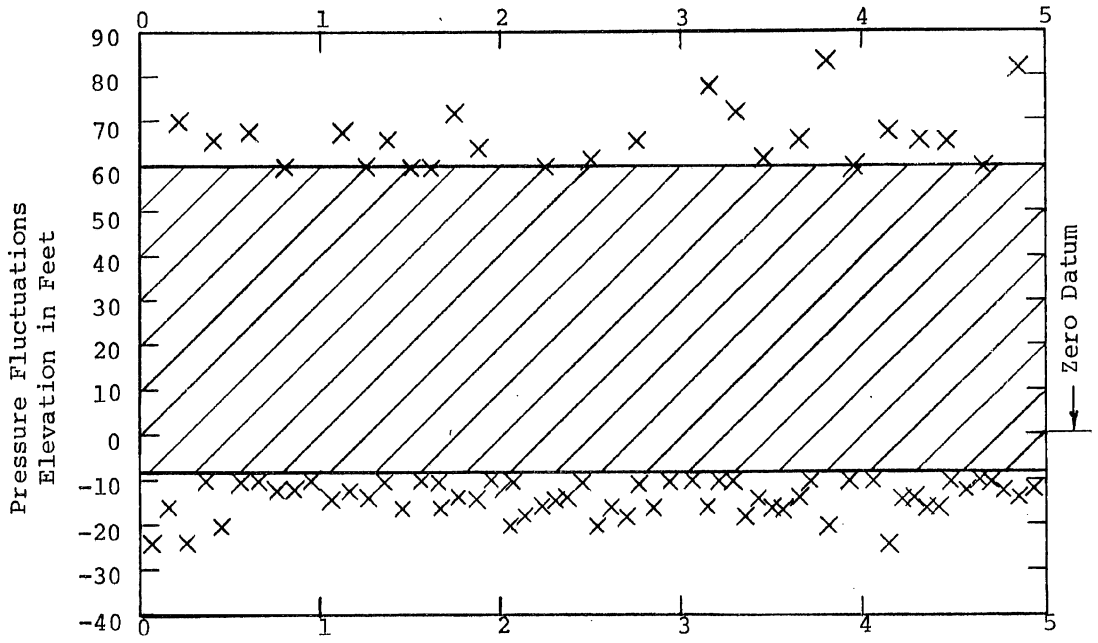
Type CSD R1 Dropshaft Scale 1:12

Typical Pressure Fluctuations

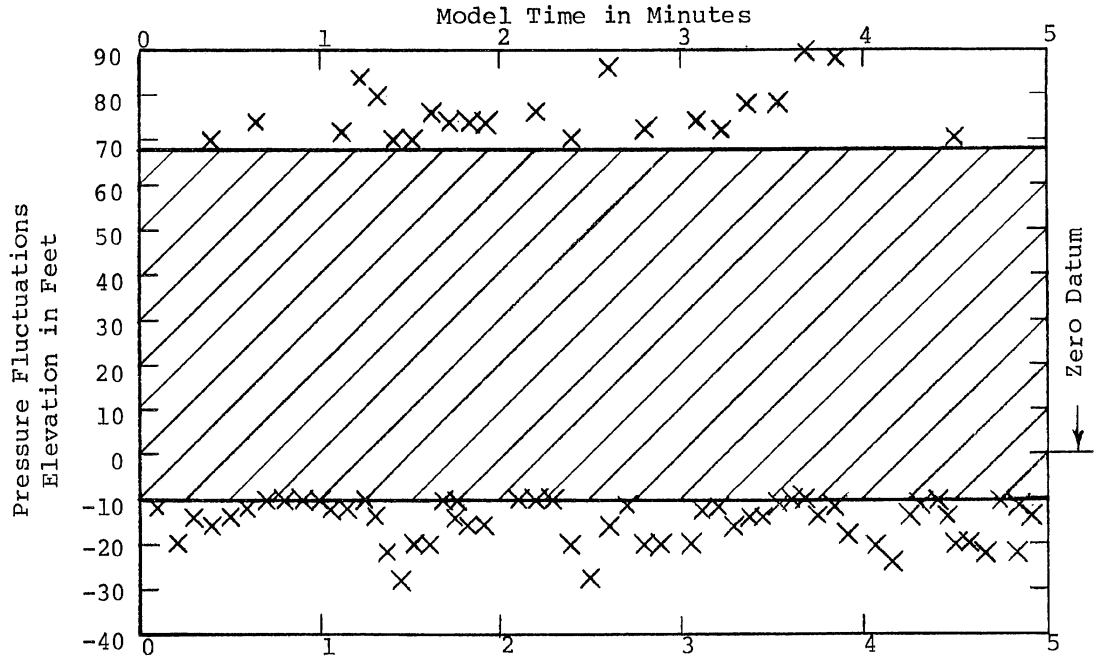
SAINT ANTHONY FALLS HYDRAULIC LABORATORY
UNIVERSITY OF MINNESOTA

DRAWN BB	CHECKED	APPROVED
SCALE	DATE 1/17/83	NO. 313A2322-91

Tap 18 - Zero datum Elev. = 0 ft.



Q = 400 cfs, Tailwater Elevation = 2.6 ft.



Q = 300 cfs, Tailwater Elevation = 2.3 ft.

× Visually observed readings

Range from oscilloscope photos, Model time of record = 1 minute

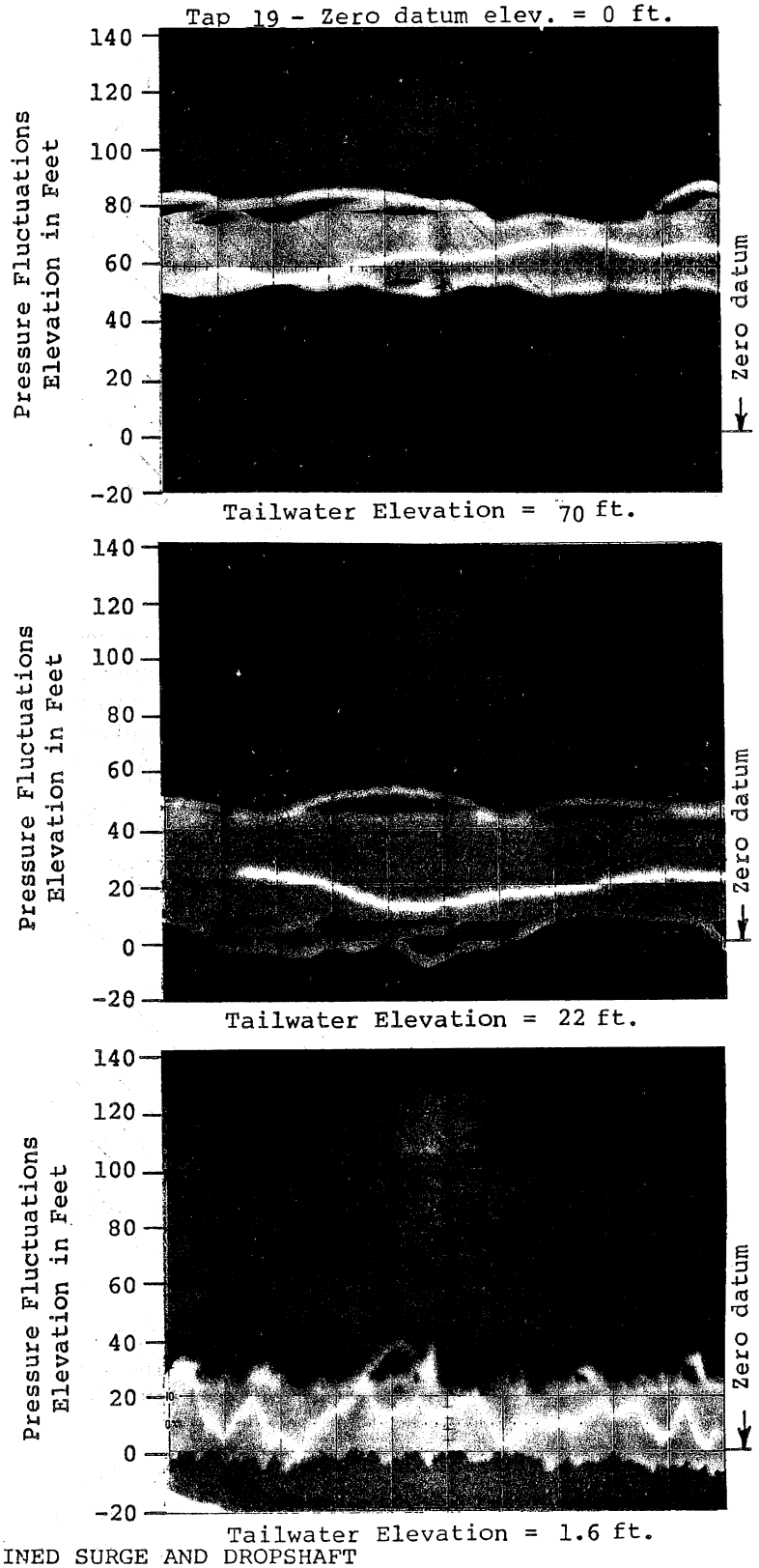
ROCHESTER COMBINED SURGE AND DROPSHAFT MODEL STUDIES

Type CSD R1 Dropshaft Scale 1:12

Typical Pressure Fluctuations

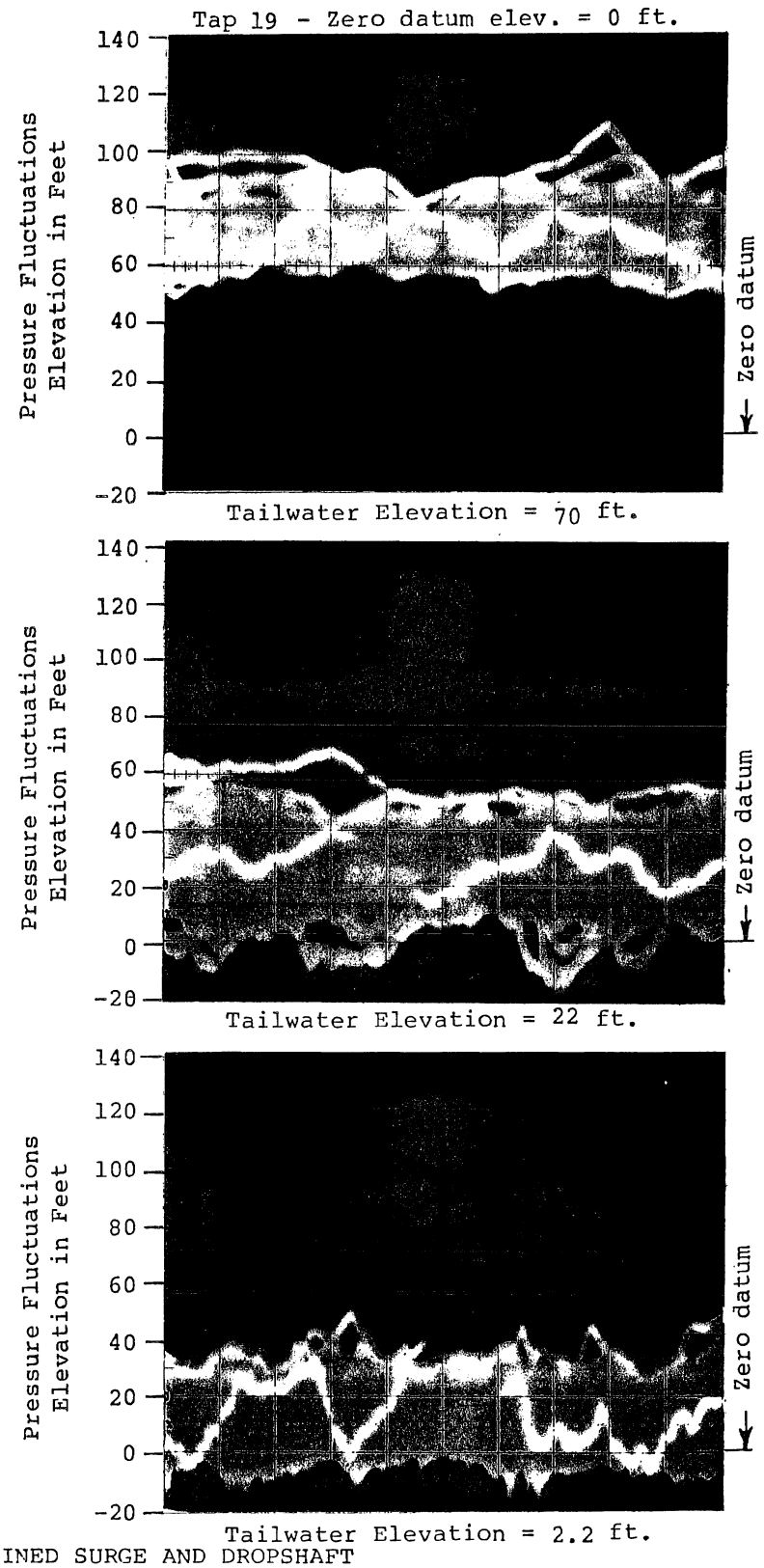
SAINT ANTHONY FALLS HYDRAULIC LABORATORY
UNIVERSITY OF MINNESOTA

DRAWN BB	CHECKED	APPROVED
SCALE	DATE 1/17/83	NO. 313A2322-92



ROCHESTER COMBINED SURGE AND DROPSHAFT
MODEL STUDIES
Type CSD R1 Dropshaft Scale 1:12
Typical Pressure Fluctuations
Q = 100cfs
Model time of record = 1 minute

SAINT ANTHONY FALLS HYDRAULIC LABORATORY UNIVERSITY OF MINNESOTA		
DRAWN WQD	CHECKED BB	APPROVED
SCALE	DATE 12/9/82	NO 313A2322-31

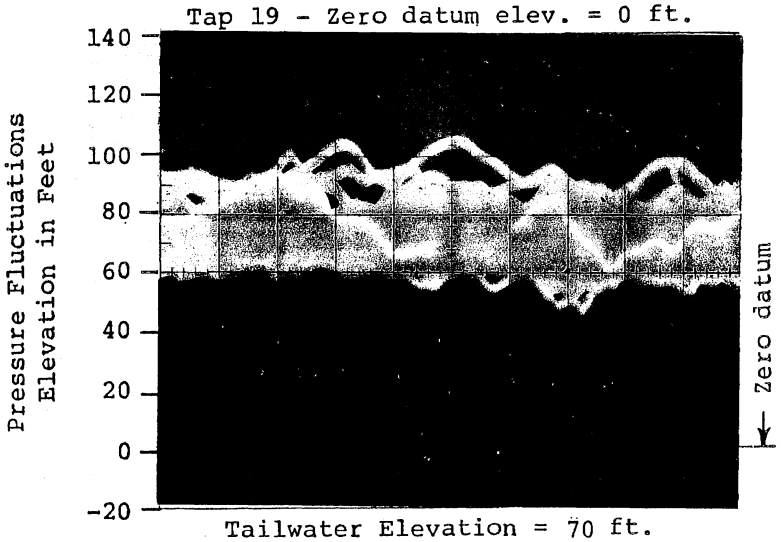


ROCHESTER COMBINED SURGE AND DROPSHAFT
MODEL STUDIES
Type CSDR1 Dropshaft Scale 1:12
Typical Pressure Fluctuations
Q = 200 cfs
Model time of record = 1 minute

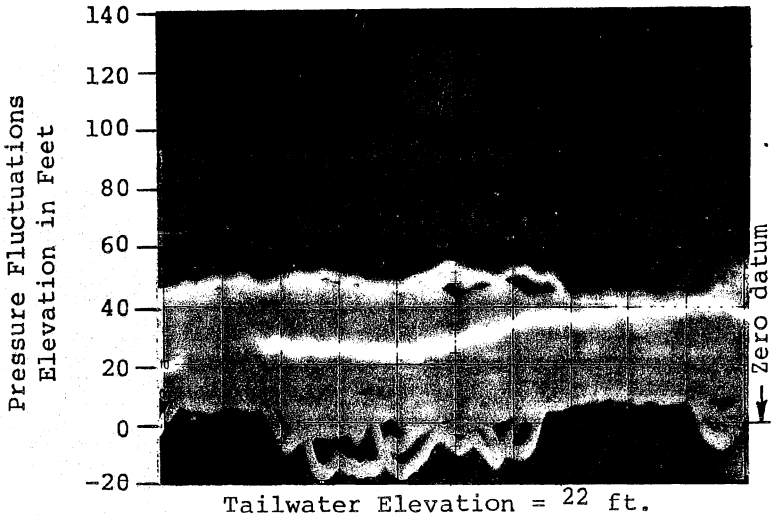
SAINT ANTHONY FALLS HYDRAULIC LABORATORY
UNIVERSITY OF MINNESOTA

DRAWN WQD	CHECKED BB	APPROVED
SCALE	DATE 12/9/82	NO 313A2322- 32

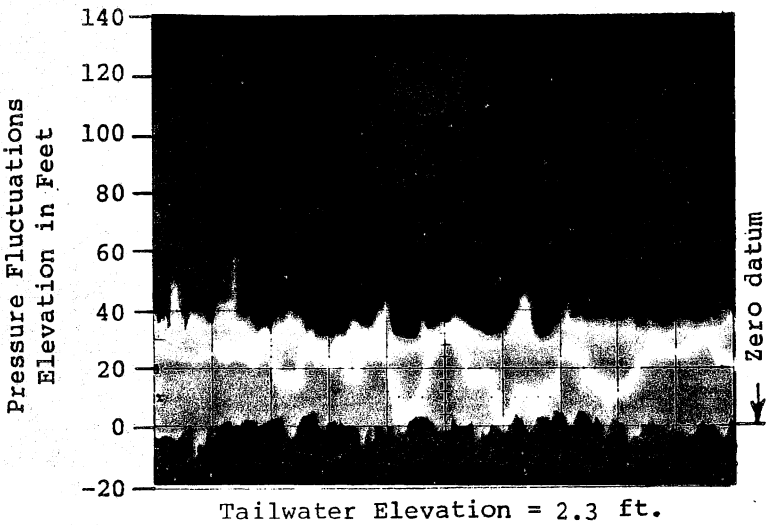
Tap 19 - Zero datum elev. = 0 ft.



Tailwater Elevation = 70 ft.



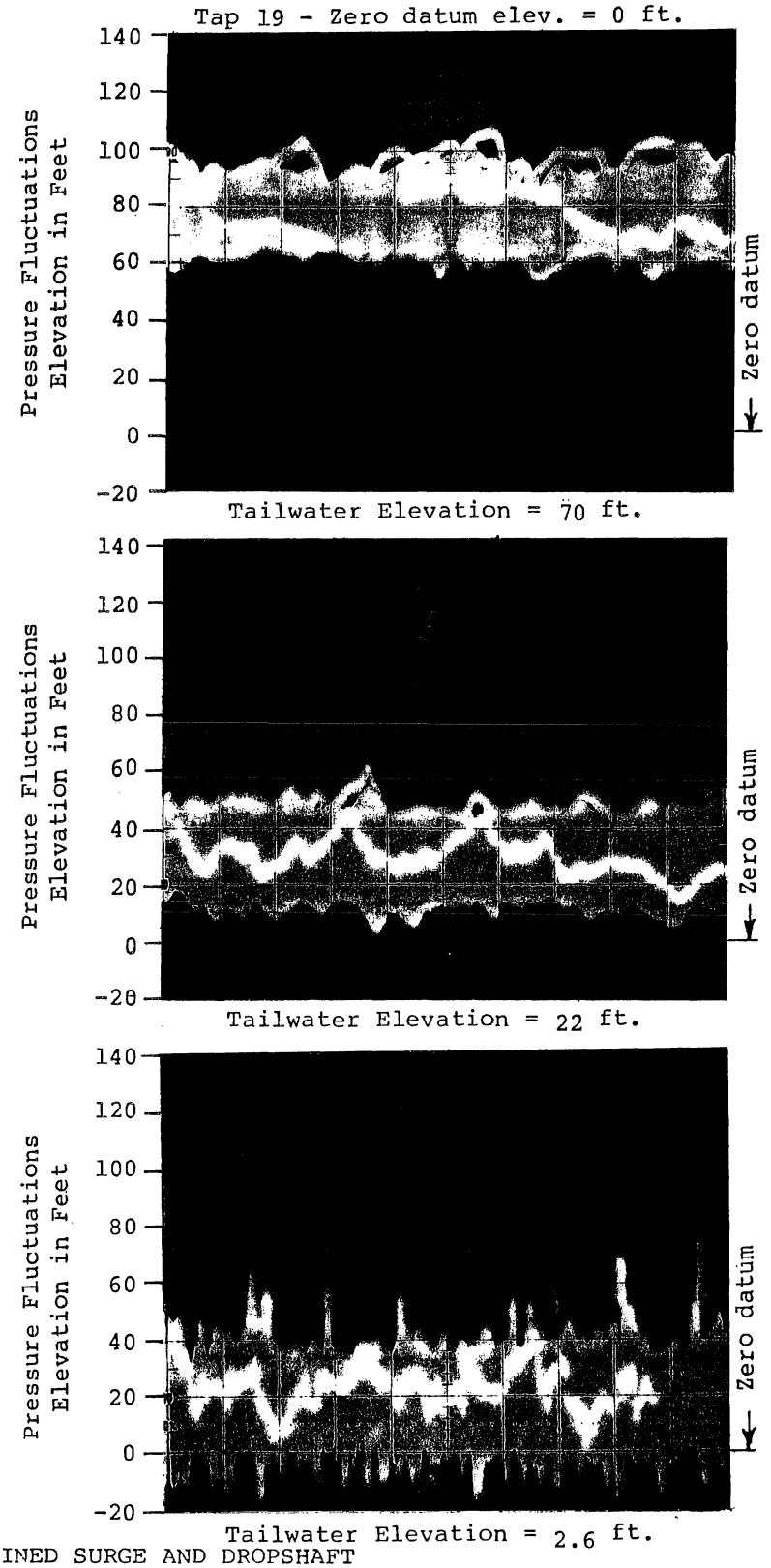
Tailwater Elevation = 22 ft.



Tailwater Elevation = 2.3 ft.

ROCHESTER COMBINED SURGE AND DROPSHAFT
MODEL STUDIES
Type CSD R1 Dropshaft Scale 1:12
Typical Pressure Fluctuations
Q = 300 cfs
Model time of record = 1 minute

SAINT ANTHONY FALLS HYDRAULIC LABORATORY UNIVERSITY OF MINNESOTA		
DRAWN WQD	CHECKED BB	APPROVED
SCALE	DATE 12/9/82	NO 313A2322- 33

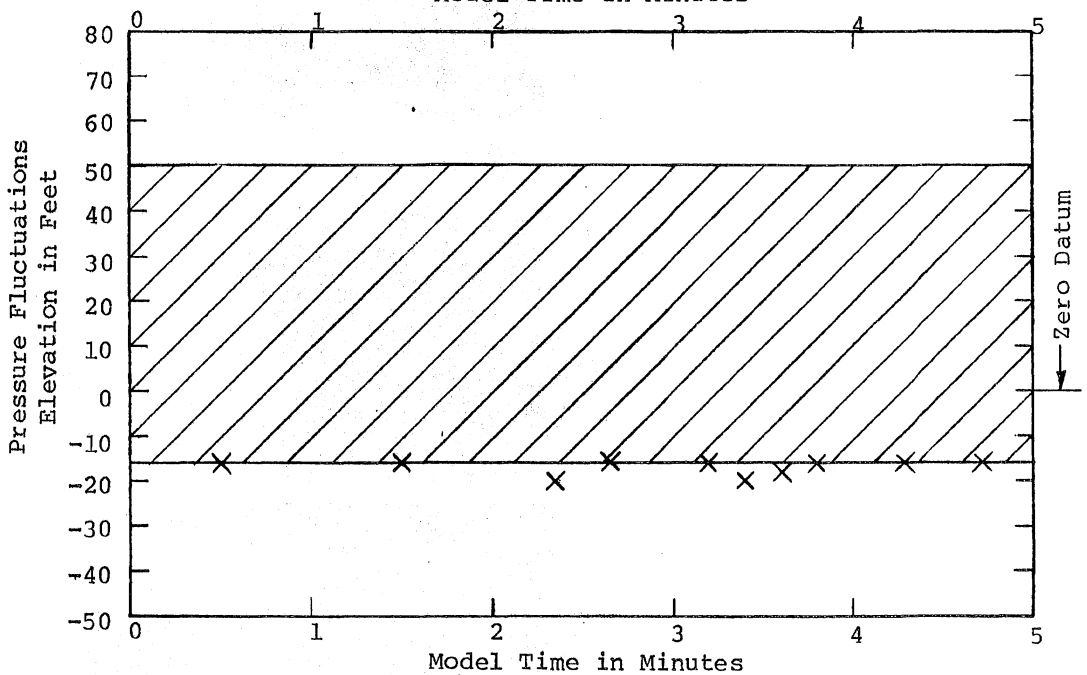


ROCHESTER COMBINED SURGE AND DROPSHAFT
MODEL STUDIES
Type CSDR1 Dropshaft Scale 1:12
Typical Pressure Fluctuations
Q = 400 cfs
Model time of record = 1 minute

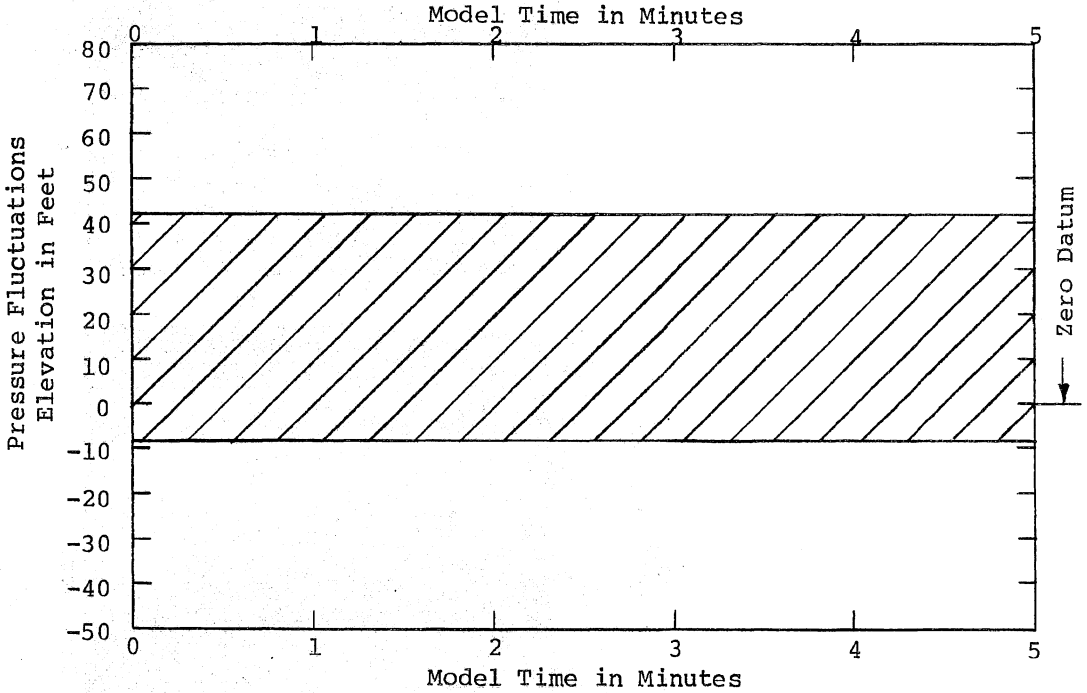
SAINT ANTHONY FALLS HYDRAULIC LABORATORY
UNIVERSITY OF MINNESOTA

DRAWN WQD	CHECKED BB	APPROVED
SCALE	DATE 12/9/82	NO 313A2322-34

Tap 19 - Zero datum elev. = 0 ft.



Q = 200 cfs, Tailwater Elevation = 2.2 ft.



Q = 100 cfs, Tailwater Elevation = 1.6 ft.

X Visually observed readings

Range from oscilloscope photos, Model time of record = 1 minute

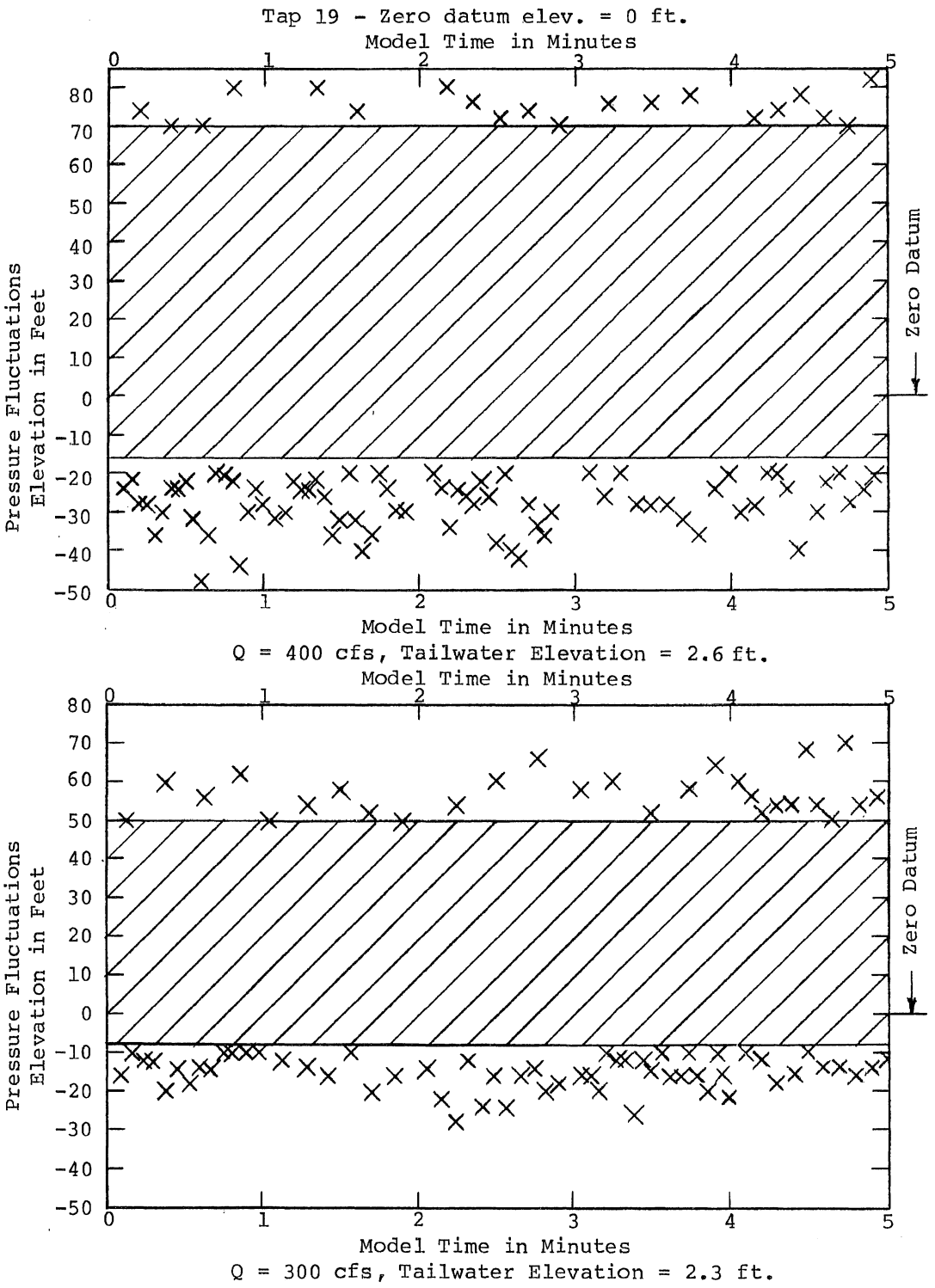
ROCHESTER COMBINED SURGE AND DROPSHAFT MODEL STUDIES

Type CSD R1 Dropshaft Scale 1:12

Typical Pressure Fluctuations

SAINT ANTHONY FALLS HYDRAULIC LABORATORY
UNIVERSITY OF MINNESOTA

DRAWN BB	CHECKED	APPROVED
SCALE	DATE 1/17/83	NO. 313A2322-93



ROCHESTER COMBINED SURGE AND DROPSHAFT MODEL STUDIES
Type CSD R1 Dropshaft Scale 1:12
Typical Pressure Fluctuations

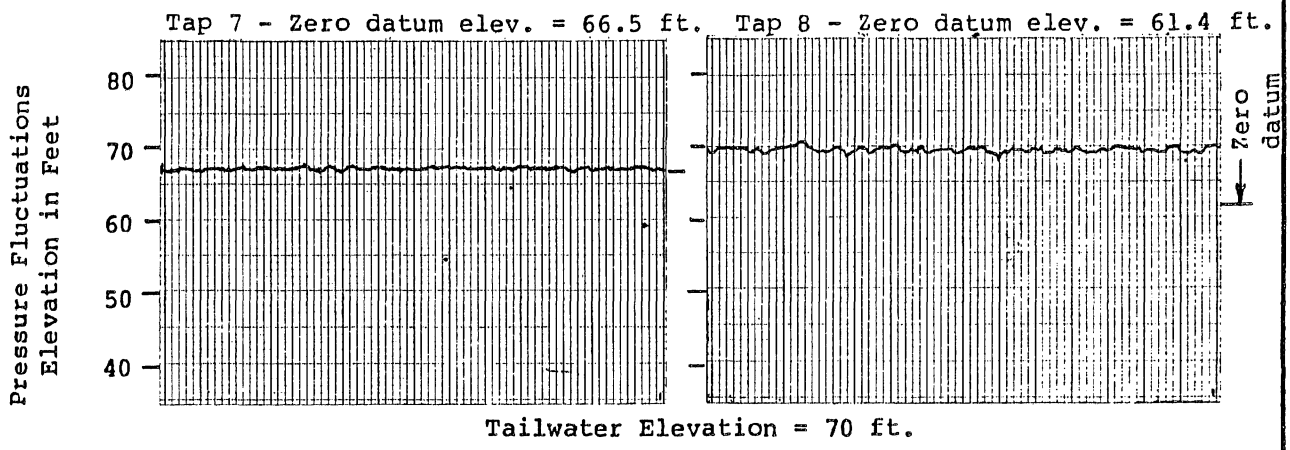
SAINT ANTHONY FALLS HYDRAULIC LABORATORY UNIVERSITY OF MINNESOTA		
DRAWN BB	CHECKED	APPROVED
SCALE	DATE 1/17/83	NO. 313A2322-94

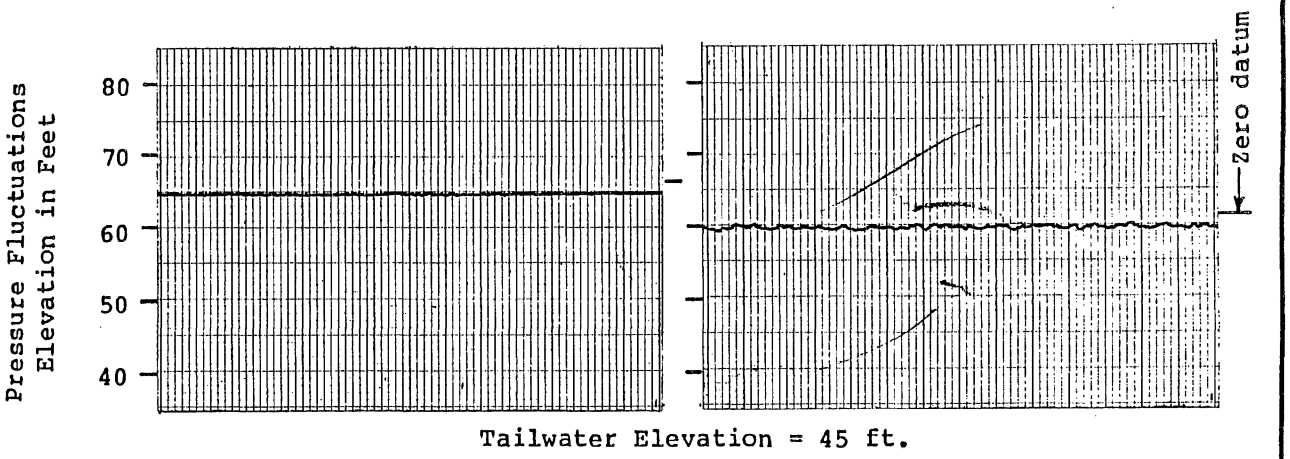
Q cfs	T.W. El. ft	Av. Piez. Press.-ft	Range from Photos Max.-ft	Range from Photos Min.-ft	Observed Readings Max.-ft	Observed Readings Min.-ft
		Tap 17 Elevation = 0 ft				
100	1.6	4.7	36	-14		
100	22	22.1	66	6		
100	70	70.1	108	52		
200	2.2	7.1	50	-20	68	-40
200	22	22.1	64	-2		
200	70	70.2	92	48		
300	2.3	13.1	58	-16	100	-26
300	22	22.1	62	-16		
300	70	70.5	102	50		
400	2.6	13.4	60	-14	96	-44
400	22	22.9	50	2		
400	70	70.6	108	48		
		Tap 18 Elevation = 0 ft				
100	1.6	9.1	96	-16	140	-36
100	22	22.1	54	2		
100	70	70.1	92	46		
200	2.2	9.1	80	-10	120	-40
200	22	22.1	70	-20		
200	70	70.2	116	56		
300	2.3	17.1	68	-10	90	-28
300	10	15.6	50	-2		
300	22	22.1	54	-12		
300	30	30.3	52	18		
300	45	45.3	74	36		
300	70	70.7	88	54		
400	2.6	18.6	60	-8	84	-24
400	22	23.3	54	6		
400	70	70.7	96	54		
		Tap 19 Elevation = 0 ft				
100	1.6	5.1	42	-8		
100	22	22.1	56	-10		
100	70	70.1	90	50		
200	2.2	6.9	50	-16	50	-20
200	22	22.1	50	-16		
200	70	70.2	112	48		
300	2.3	12.8	50	-8	70	-28
300	22	22.1	56	-20		
300	70	70.7	108	46		
400	2.6	14.1	70	-16	82	-48
400	22	22.9	54	2		
400	70	70.9	108	54		

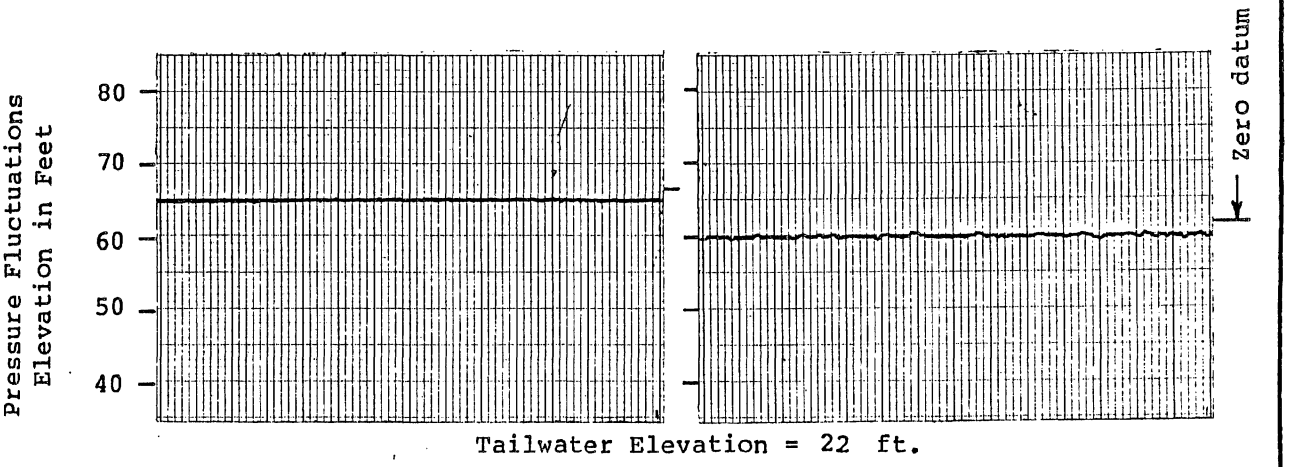
ROCHESTER COMBINED SURGE AND DROPSHAFT
MODEL STUDIES
Type CSD R1 Dropshaft Scale 1:12
Summary of Typical
Pressure Fluctuations

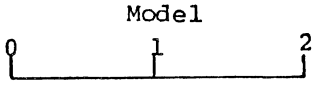
SAINT ANTHONY FALLS HYDRAULIC LABORATORY
UNIVERSITY OF MINNESOTA

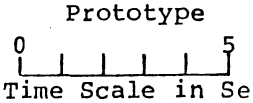
DRAWN WQD	CHECKED BB	APPROVED
SCALE	DATE 1-7-83	NO. 313A2322-69





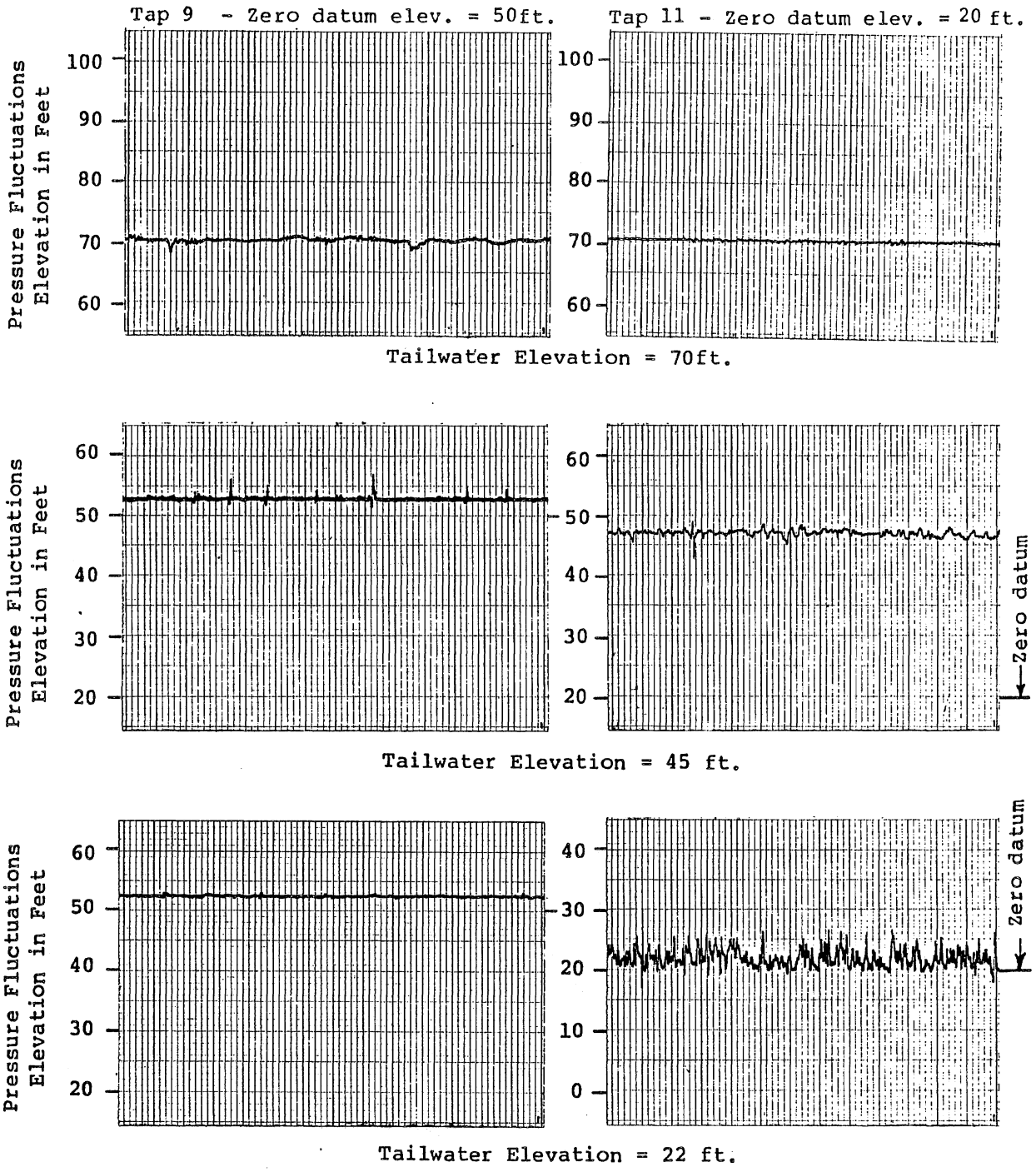






ROCHESTER COMBINED SURGE AND DROPSHAFT
MODEL STUDIES
Type CSD R1 Dropshaft Scale 1:12
Typical Pressure Fluctuations
Q = 300 cfs

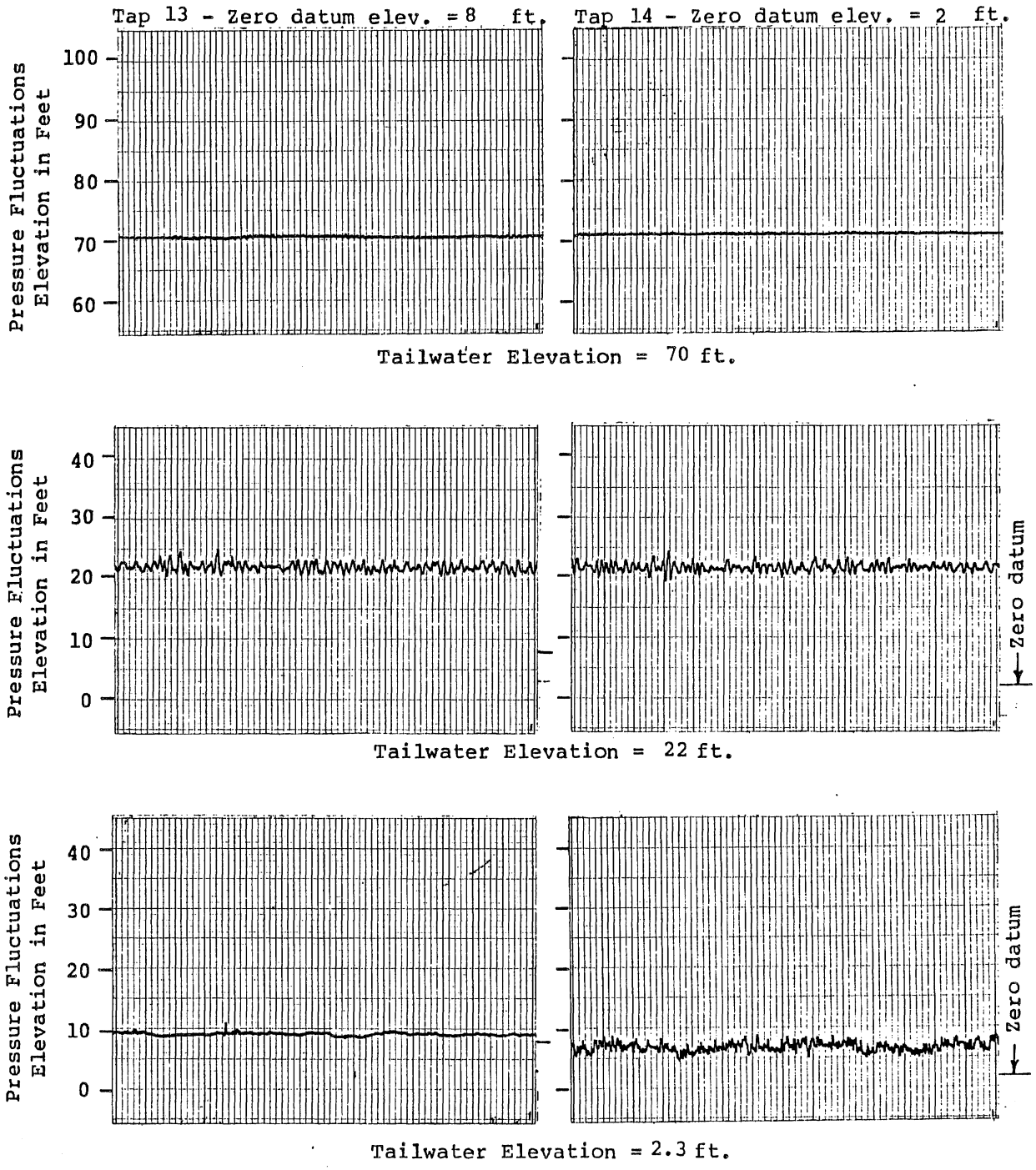
SAINT ANTHONY FALLS HYDRAULIC LABORATORY UNIVERSITY OF MINNESOTA		
DRAWN BB	CHECKED	APPROVED
SCALE	DATE 12/10/82	NO. 313 A2322-35



ROCHESTER COMBINED SURGE AND DROPSHAFT
MODEL STUDIES
Type CSD R1 Dropshaft Scale 1:12
Typical Pressure Fluctuations
Q = 300 cfs

SAINT ANTHONY FALLS HYDRAULIC LABORATORY
UNIVERSITY OF MINNESOTA

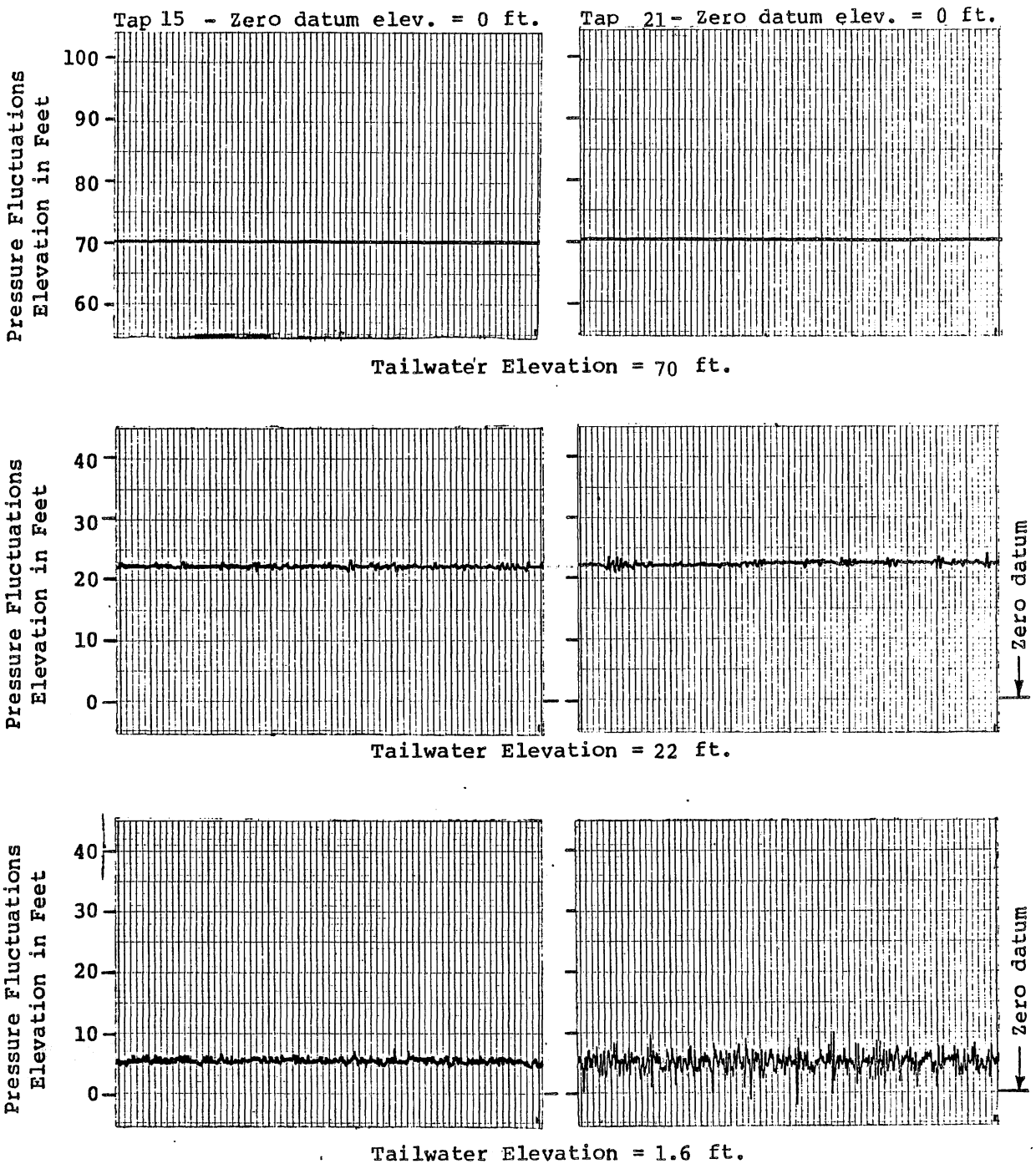
DRAWN	BB	CHECKED	APPROVED
SCALE		DATE 12/10/82	NO. 313A2322-39



ROCHESTER COMBINED SURGE AND DROPSHAFT
MODEL STUDIES
Type CSD R1 Dropshaft Scale 1:12
Typical Pressure Fluctuations
Q = 300 cfs

SAINT ANTHONY FALLS HYDRAULIC LABORATORY
UNIVERSITY OF MINNESOTA

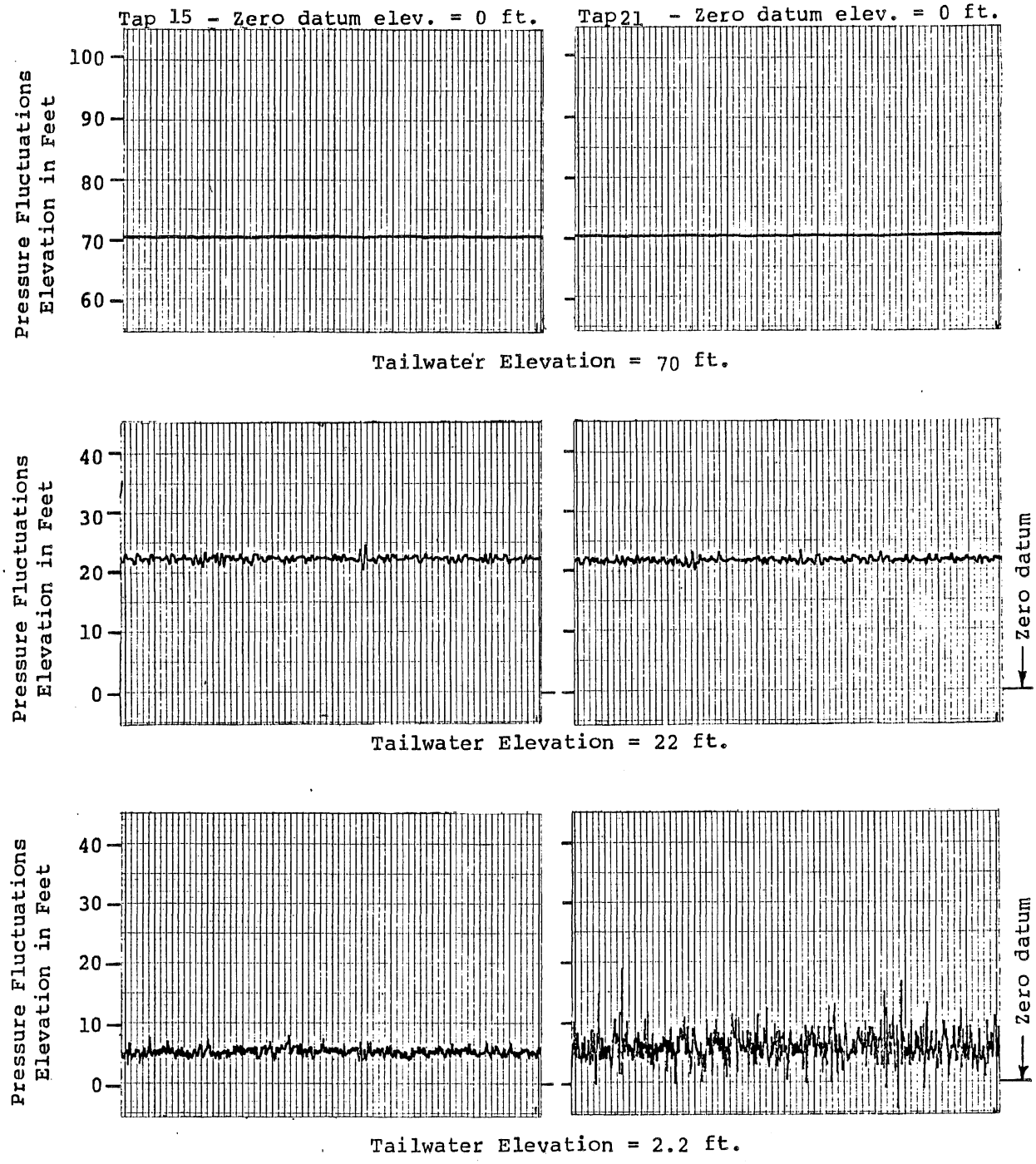
DRAWN BB	CHECKED	APPROVED
SCALE	DATE 12/10/82	NO. 313A2322-43



ROCHESTER COMBINED SURGE AND DROPSHAFT
MODEL STUDIES
Type CSD R1 Dropshaft Scale 1:12
Typical Pressure Fluctuations
Q = 100 cfs

SAINT ANTHONY FALLS HYDRAULIC LABORATORY
UNIVERSITY OF MINNESOTA

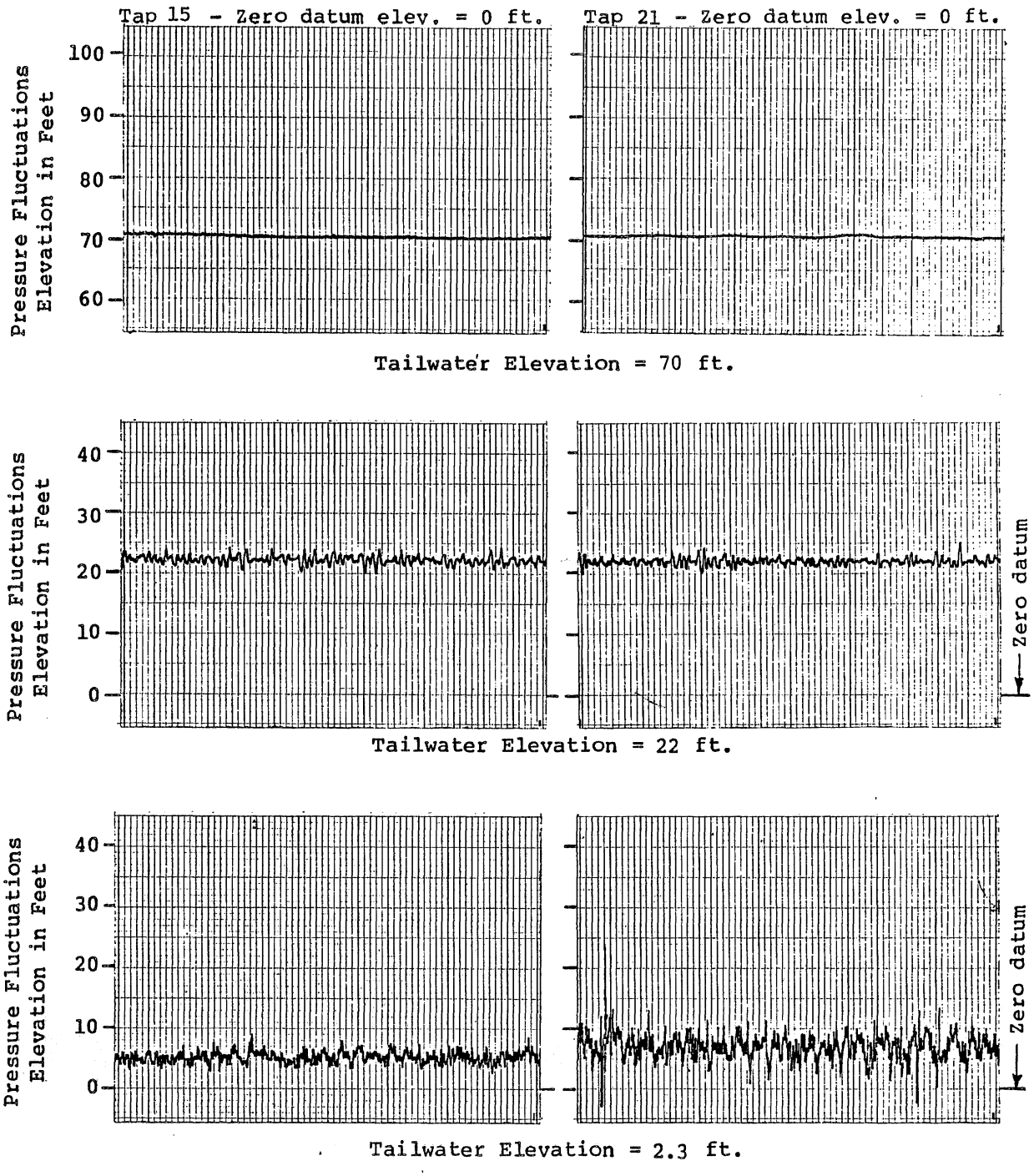
DRAWN BB	CHECKED WDA	APPROVED
SCALE	DATE 12/10/82	NO. 313A2322-51



ROCHESTER COMBINED SURGE AND DROPSHAFT
MODEL STUDIES
Type CSD R1 Dropshaft Scale 1:12
Typical Pressure Fluctuations
Q = 200 cfs

SAINT ANTHONY FALLS HYDRAULIC LABORATORY
UNIVERSITY OF MINNESOTA

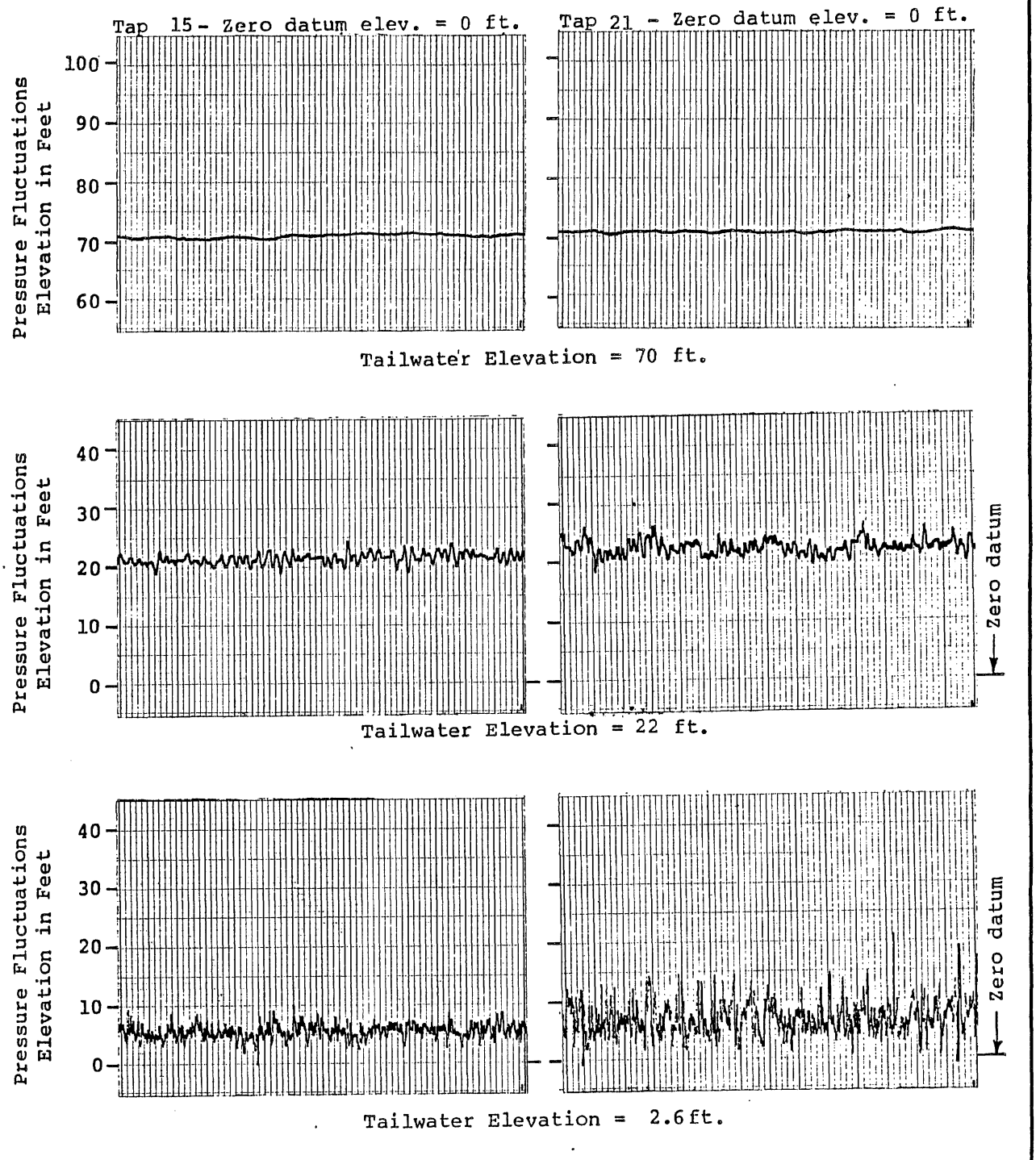
DRAWN BB	CHECKED MAD	APPROVED
SCALE	DATE 12/10/82	NO. 313A2322-53



ROCHESTER COMBINED SURGE AND DROPSHAFT
MODEL STUDIES
Type CSD R1 Dropshaft Scale 1:12
Typical Pressure Fluctuations
Q = 300 cfs

SAINT ANTHONY FALLS HYDRAULIC LABORATORY
UNIVERSITY OF MINNESOTA

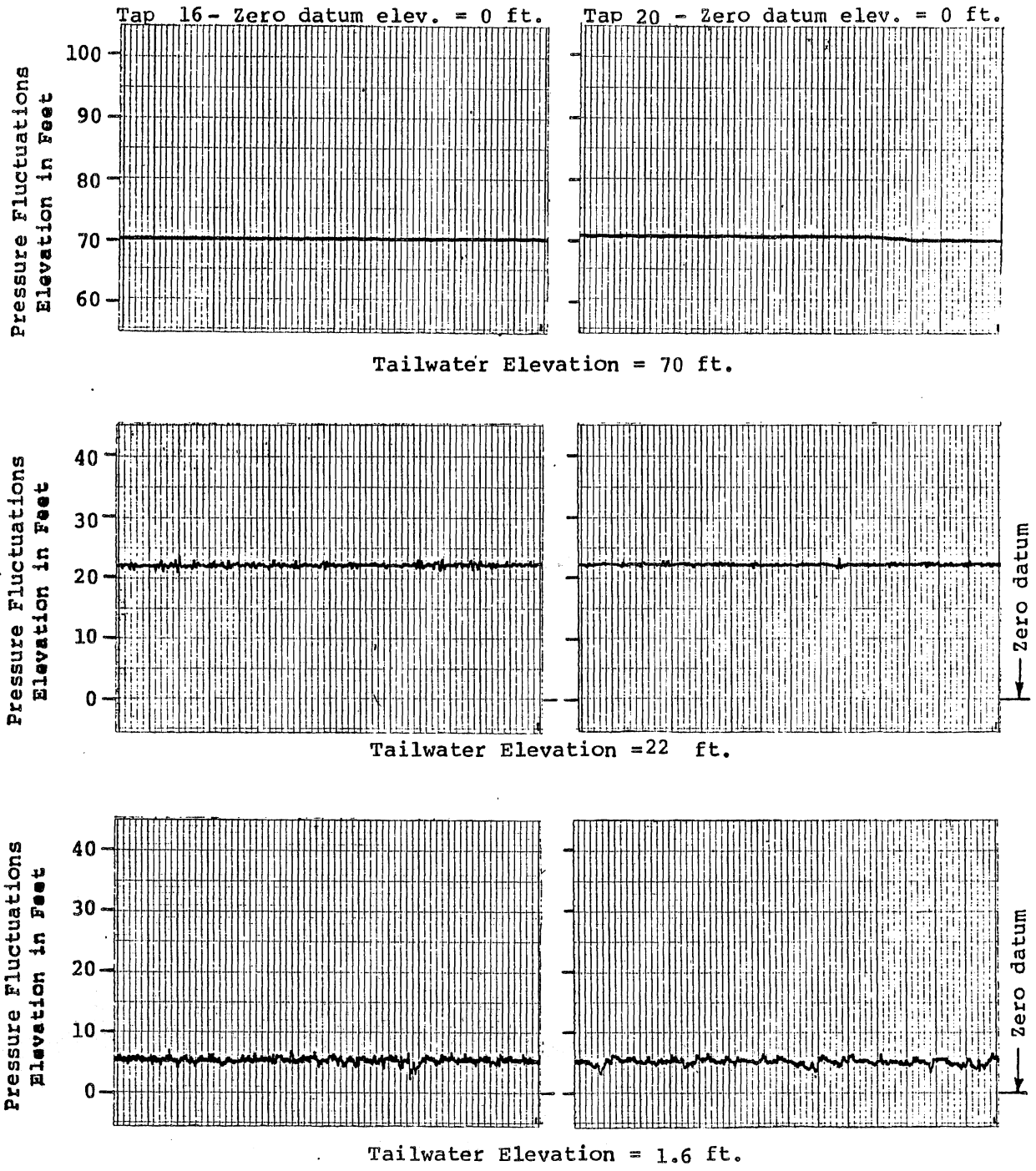
DRAWN BB	CHECKED	APPROVED
SCALE	DATE 12/10/82	NO. 313A2322- 47



ROCHESTER COMBINED SURGE AND DROPSHAFT
MODEL STUDIES
Type CSD R1 Dropshaft Scale 1:12
Typical Pressure Fluctuations
Q = 400 cfs

SAINT ANTHONY FALLS HYDRAULIC LABORATORY
UNIVERSITY OF MINNESOTA

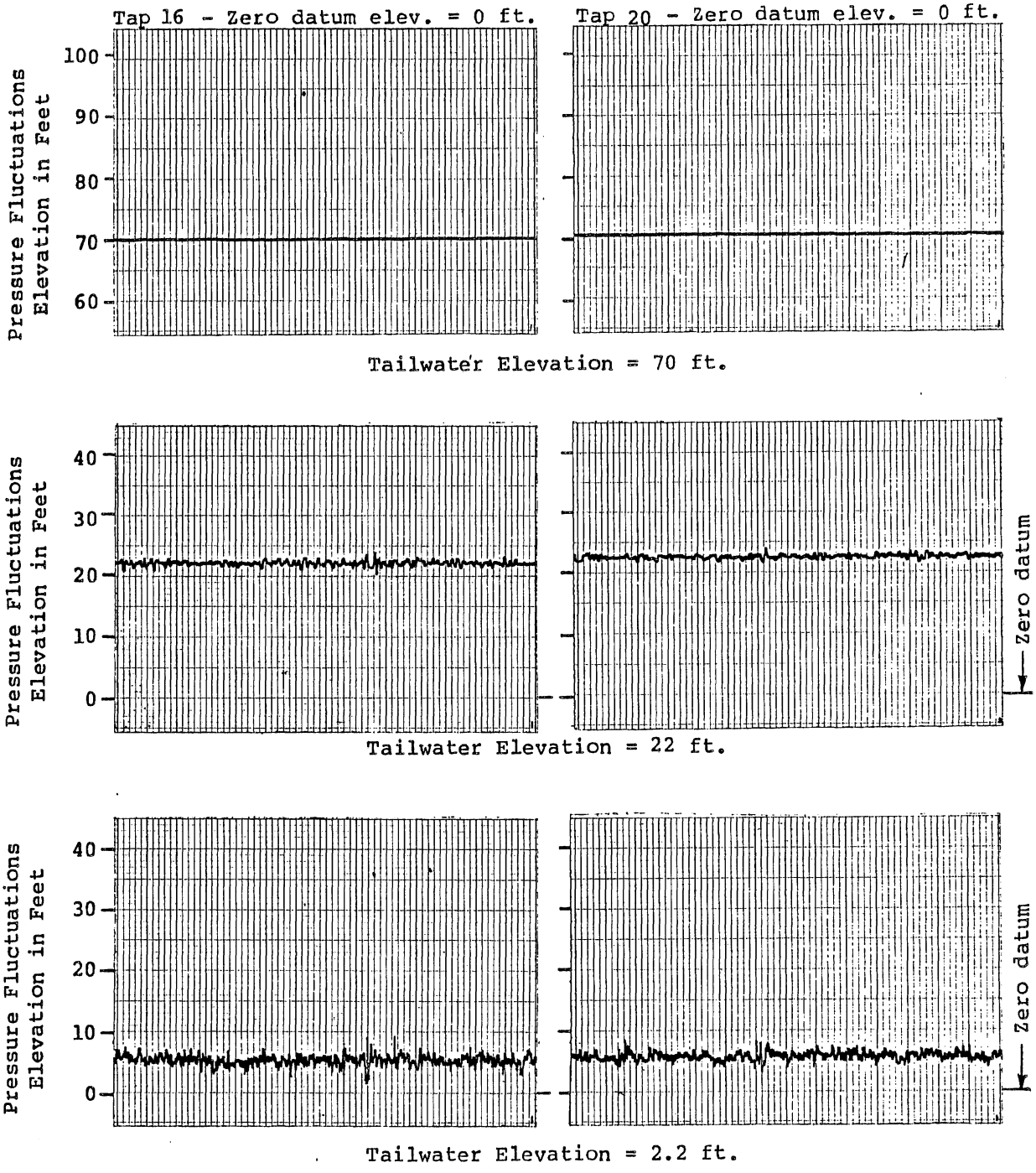
DRAWN BB	CHECKED	APPROVED
SCALE	DATE 12/10/82	NO. 313A2322-55



ROCHESTER COMBINED SURGE AND DROPSHAFT
MODEL STUDIES
Type CSD R1 Dropshaft Scale 1:12
Typical Pressure Fluctuations
Q = 100 cfs

SAINT ANTHONY FALLS HYDRAULIC LABORATORY
UNIVERSITY OF MINNESOTA

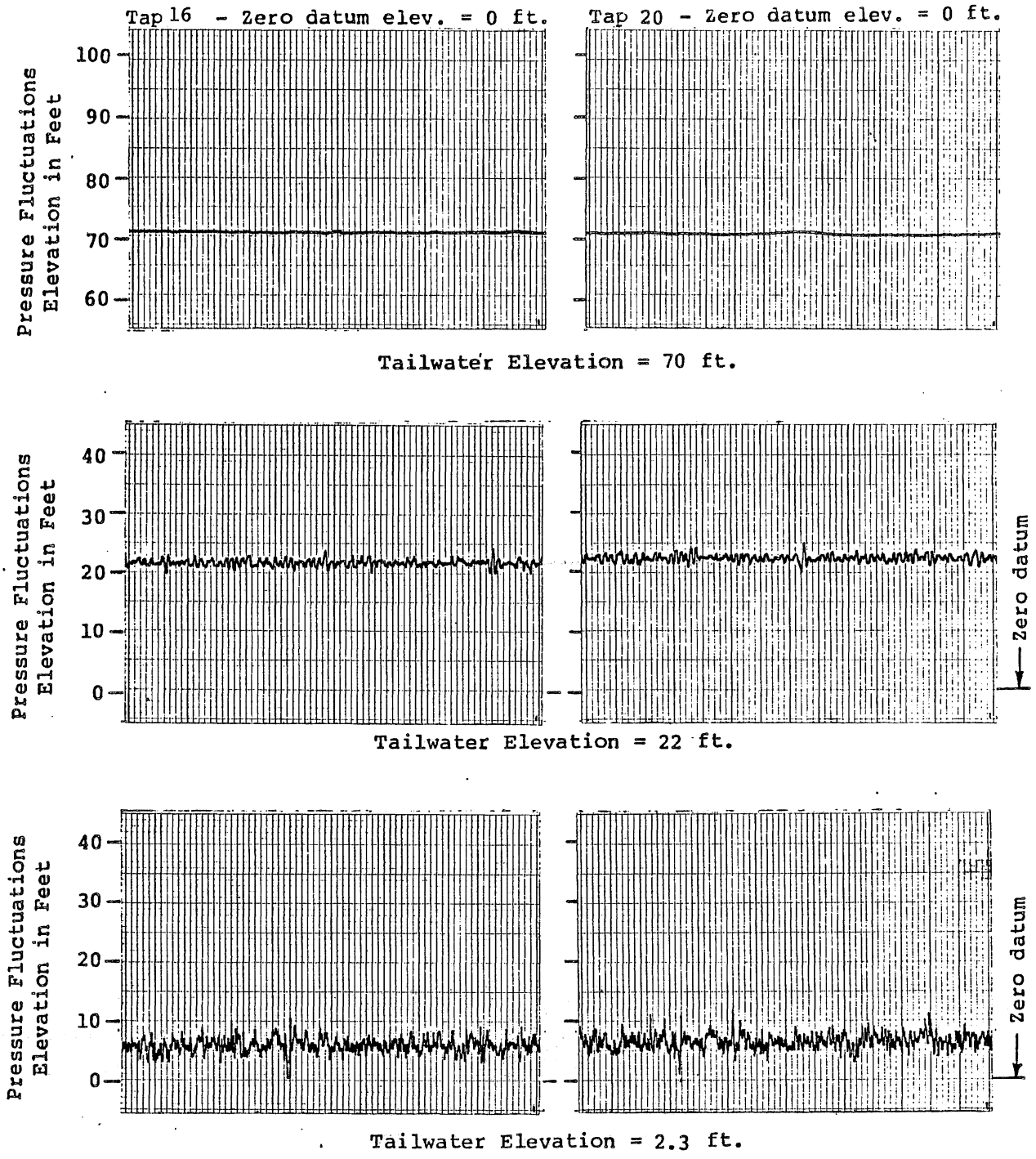
DRAWN BB	CHECKED JHA	APPROVED
SCALE	DATE 12/10/82	NO. 313A2322- 52



ROCHESTER COMBINED SURGE AND DROPSHAFT
MODEL STUDIES
Type CSD R1 Dropshaft Scale 1:12
Typical Pressure Fluctuations
Q = 200 cfs

SAINT ANTHONY FALLS HYDRAULIC LABORATORY
UNIVERSITY OF MINNESOTA

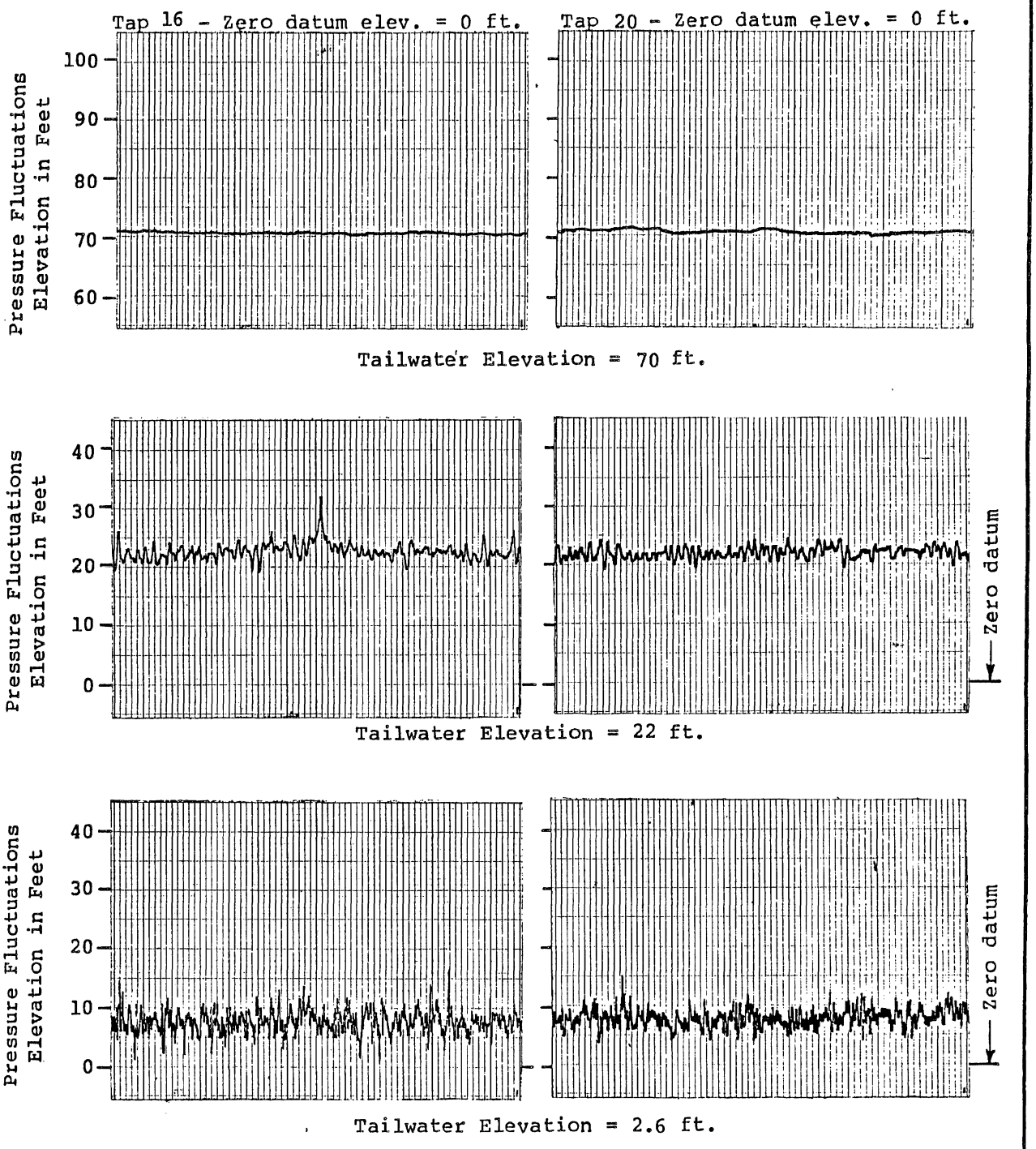
DRAWN BB	CHECKED	APPROVED
SCALE	DATE 12/10/82	NO. 313A2322-54



ROCHESTER COMBINED SURGE AND DROPSHAFT
MODEL STUDIES
Type CSD R1 Dropshaft Scale 1:12
Typical Pressure Fluctuations
Q = 300 cfs

SAINT ANTHONY FALLS HYDRAULIC LABORATORY
UNIVERSITY OF MINNESOTA

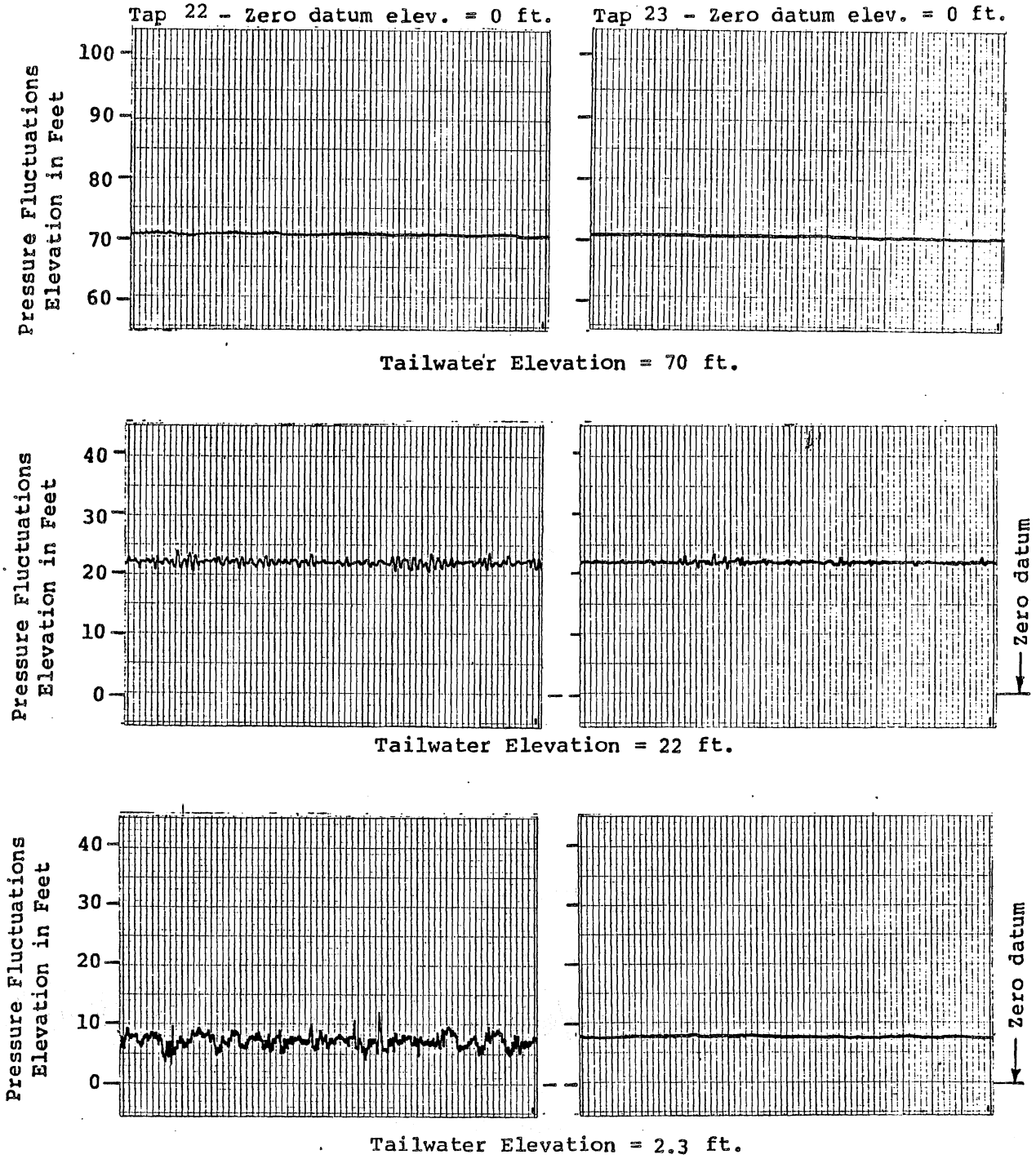
DRAWN BB	CHECKED MAB	APPROVED
SCALE	DATE 12/10/82	NO. 313A2322-48



ROCHESTER COMBINED SURGE AND DROPSHAFT
MODEL STUDIES
Type CSD R1 Dropshaft Scale 1:12
Typical Pressure Fluctuations
Q = 400 cfs

SAINT ANTHONY FALLS HYDRAULIC LABORATORY
UNIVERSITY OF MINNESOTA

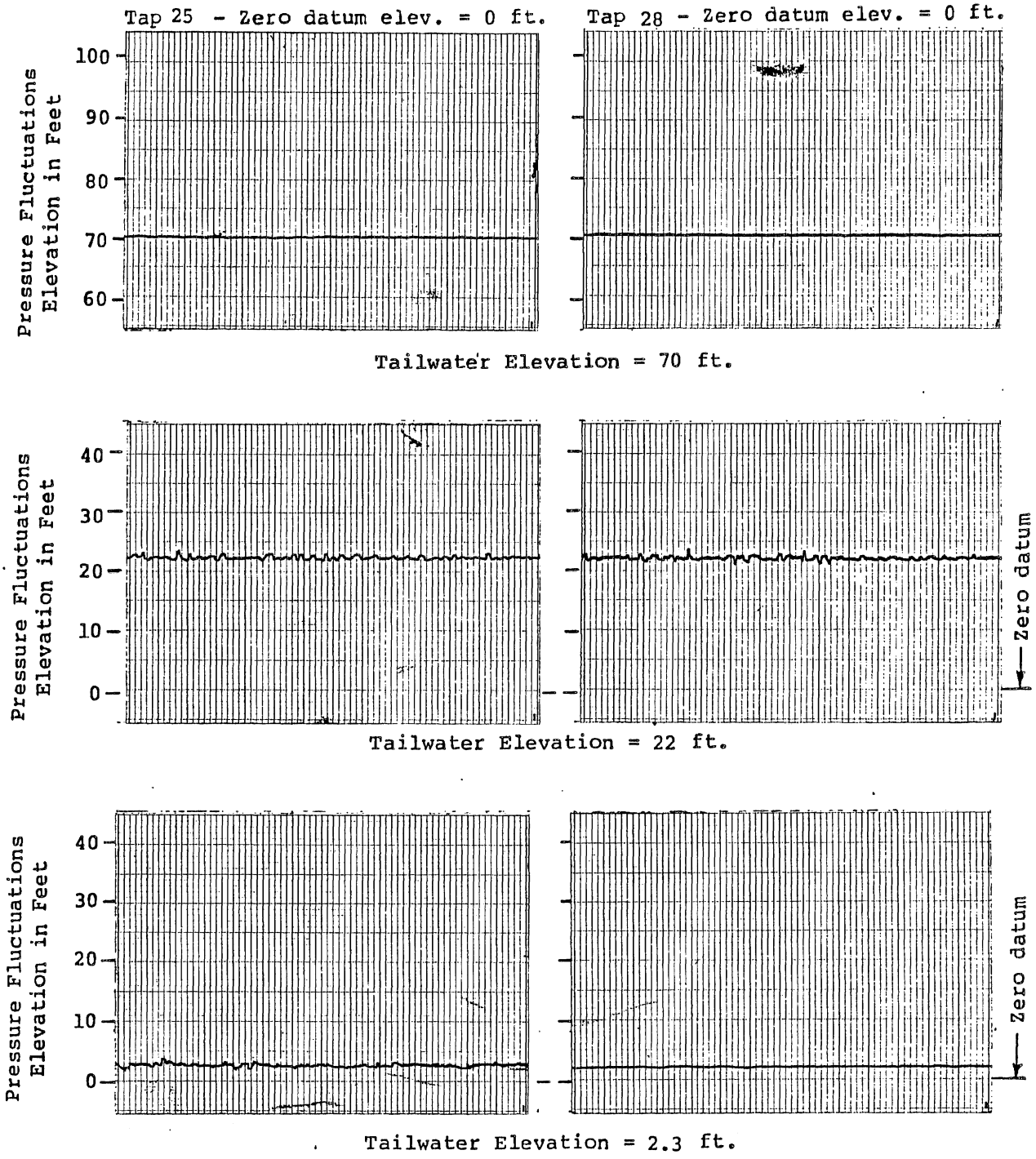
DRAWN BB	CHECKED	APPROVED
SCALE	DATE 12/10/82	NO. 313A2322-56



ROCHESTER COMBINED SURGE AND DROPSHAFT
MODEL STUDIES
Type CSD R1 Dropshaft Scale 1:12
Typical Pressure Fluctuations
Q = 300 cfs

SAINT ANTHONY FALLS HYDRAULIC LABORATORY
UNIVERSITY OF MINNESOTA

DRAWN BB	CHECKED	APPROVED
SCALE	DATE 12/10/82	NO. 313A2322-49



ROCHESTER COMBINED SURGE AND DROPSHAFT
MODEL STUDIES
Type CSD R1 Dropshaft Scale 1:12
Typical Pressure Fluctuations
Q = 300 cfs

SAINT ANTHONY FALLS HYDRAULIC LABORATORY
UNIVERSITY OF MINNESOTA

DRAWN BB	CHECKED MAD	APPROVED
SCALE	DATE 12/10/82	NO. 313A2322-50

Tap No.	Tap El. ft	Q cfs	T.W. El. ft	Av. Piez. Press.-ft	Pressure Fluctuations Max.-ft	Min.-ft
7	66.5	300	22	64.6	65.0	64.2
7	66.5	300	45	64.6	65.0	64.0
7	66.5	300	70	67.1	67.8	66.8
8	61.4	300	22	59.6	60.2	58.8
8	61.4	300	45	59.6	60.2	59.0
8	61.4	300	70	69.6	70.8	68.0
9	50	300	22	52.3	53.0	52.0
9	50	300	45	52.8	58.0	50.6
9	50	300	70	70.6	71.4	66.6
11	20	300	22	21.4	30.0	17.0
11	20	300	45	46.8	49.0	42.8
11	20	300	70	70.5	71.0	70.0
13	8	300	2.3	8.8	11.0	8.2
13	8	300	22	22.1	25.0	19.6
13	8	300	70	70.5	71.2	70.0
14	2	300	2.3	6.7	10.6	4.6
14	2	300	22	22.1	24.4	19.6
14	2	300	70	70.5	71.0	70.0
15	0	100	1.6	5.3	7.6	4.0
15	0	100	22	22.1	23.8	21.2
15	0	100	70	70.1	70.8	70.0
15	0	200	2.2	5.6	8.0	2.8
15	0	200	22	22.1	24.8	20.2
15	0	200	70	70.2	70.8	69.8
15	0	300	2.3	5.8	9.0	1.8
15	0	300	22	22.1	25.0	20.0
15	0	300	70	70.5	71.0	70.0
15	0	400	2.6	5.4	10.0	0.0
15	0	400	22	21.5	24.4	17.2
15	0	400	70	70.6	73.6	70.0
16	0	100	1.6	5.3	7.2	2.2
16	0	100	22	22.1	24.0	20.8
16	0	100	70	70.1	70.4	69.8
16	0	200	2.2	5.6	9.2	1.6
16	0	200	22	22.1	24.0	20.2
16	0	200	70	70.2	71.0	69.8
16	0	300	2.3	6.0	10.4	0.4
16	0	300	22	22.1	24.2	20.0
16	0	300	70	70.5	71.0	70.2
16	0	400	2.6	7.7	16.4	0.0
16	0	400	22	22.7	32.0	19.2
16	0	400	70	70.6	71.2	70.0

ROCHESTER COMBINED SURGE AND DROPSHAFT
MODEL STUDIES
Type CSD R1 Dropshaft Scale 1:12
Summary of Typical
Pressure Fluctuations

SAINT ANTHONY FALLS HYDRAULIC LABORATORY
UNIVERSITY OF MINNESOTA

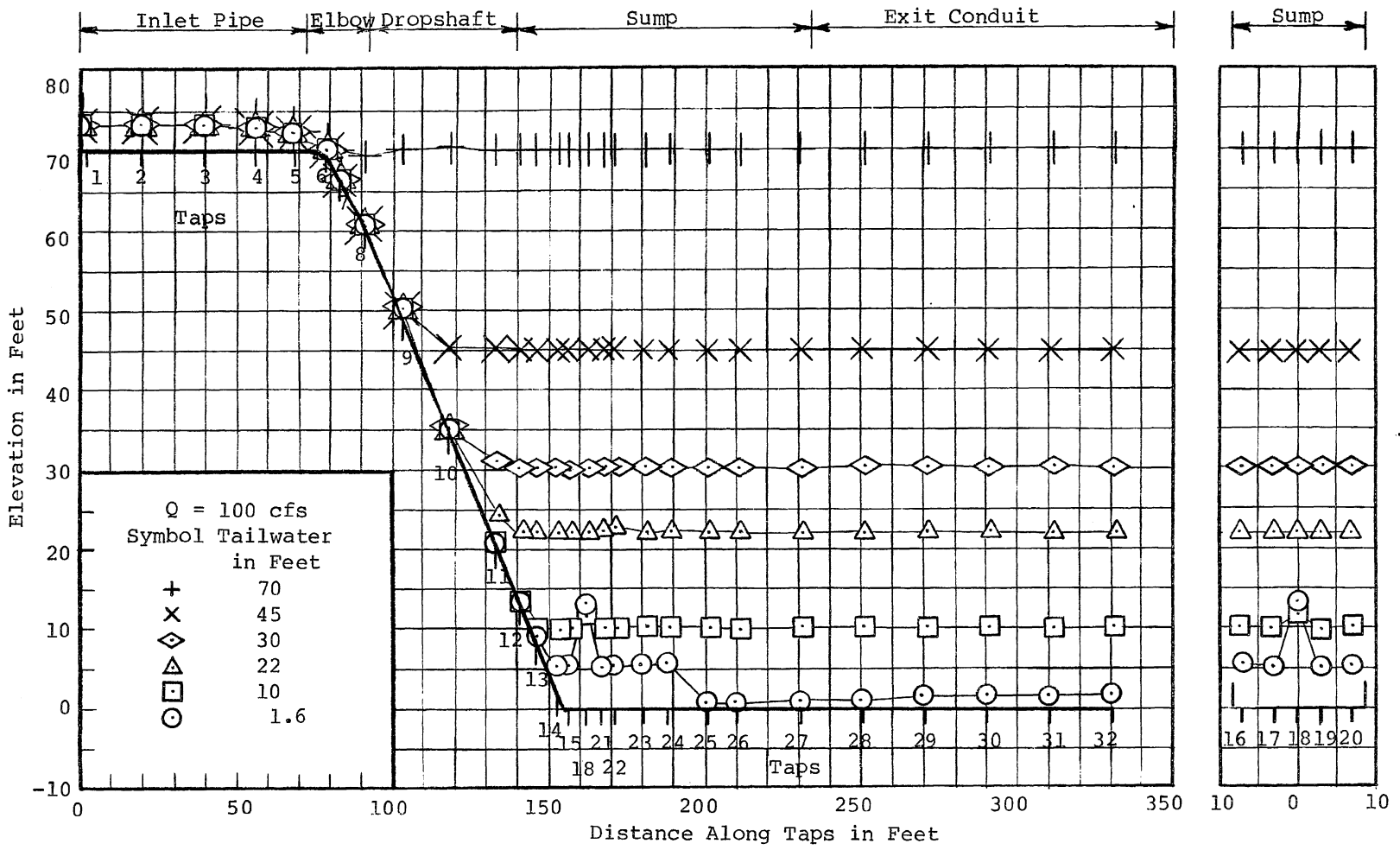
DRAWN WQD	CHECKED	APPROVED
SCALE	DATE 1/21/83	NO. 313A2322-108

Tap No.	Tap El. ft	Q cfs	T.W. El. ft	Av. Piez. Press.-ft	Pressure Fluctuations Max.-ft	Min.-ft
20	0	100	1.6	5.1	6.8	3.0
20	0	100	22	22.1	23.4	21.0
20	0	100	70	70.1	70.8	69.4
20	0	200	2.2	5.3	8.4	3.2
20	0	200	22	22.1	24.0	20.8
20	0	200	70	70.2	70.8	69.6
20	0	300	2.3	6.0	11.8	1.2
20	0	300	22	22.1	25.0	20.0
20	0	300	70	70.5	71.2	70.0
20	0	400	2.6	7.1	15.2	2.2
20	0	400	22	22.1	25.0	19.2
20	0	400	70	70.9	71.6	69.8
21	0	100	1.6	5.0	15.0	-3.2
21	0	100	22	22.0	24.0	20.8
21	0	100	70	70.1	70.4	69.8
21	0	200	2.2	5.6	18.8	-4.5
21	0	200	22	22.1	23.6	20.2
21	0	200	70	70.2	70.6	69.8
21	0	300	2.3	6.7	24.6	-4.0
21	0	300	22	22.1	25.0	20.0
21	0	300	70	70.5	71.0	70.0
21	0	400	2.6	7.4	21.2	-3.4
21	0	400	22	23.1	29.4	18.8
21	0	400	70	70.9	72.2	70.2
22	0	300	2.3	6.4	12.0	3.4
22	0	300	22	22.1	24.0	20.6
22	0	300	70	70.2	71.0	69.6
23	0	300	2.3	7.1	8.2	6.8
23	0	300	22	22.2	23.6	21.0
23	0	300	70	70.2	70.8	69.6
25	0	300	2.3	2.5	3.8	1.8
25	0	300	22	22.1	23.6	21.4
25	0	300	70	70.1	70.4	69.8
28	0	300	2.3	2.0	2.2	1.8
28	0	300	22	22.0	23.8	21.0
28	0	300	70	70.0	70.4	69.8

ROCHESTER COMBINED SURGE AND DROPSHAFT
MODEL STUDIES
Type CSD R1 Dropshaft Scale 1:12
Summary of Typical
Pressure Fluctuations

SAINT ANTHONY FALLS HYDRAULIC LABORATORY
UNIVERSITY OF MINNESOTA

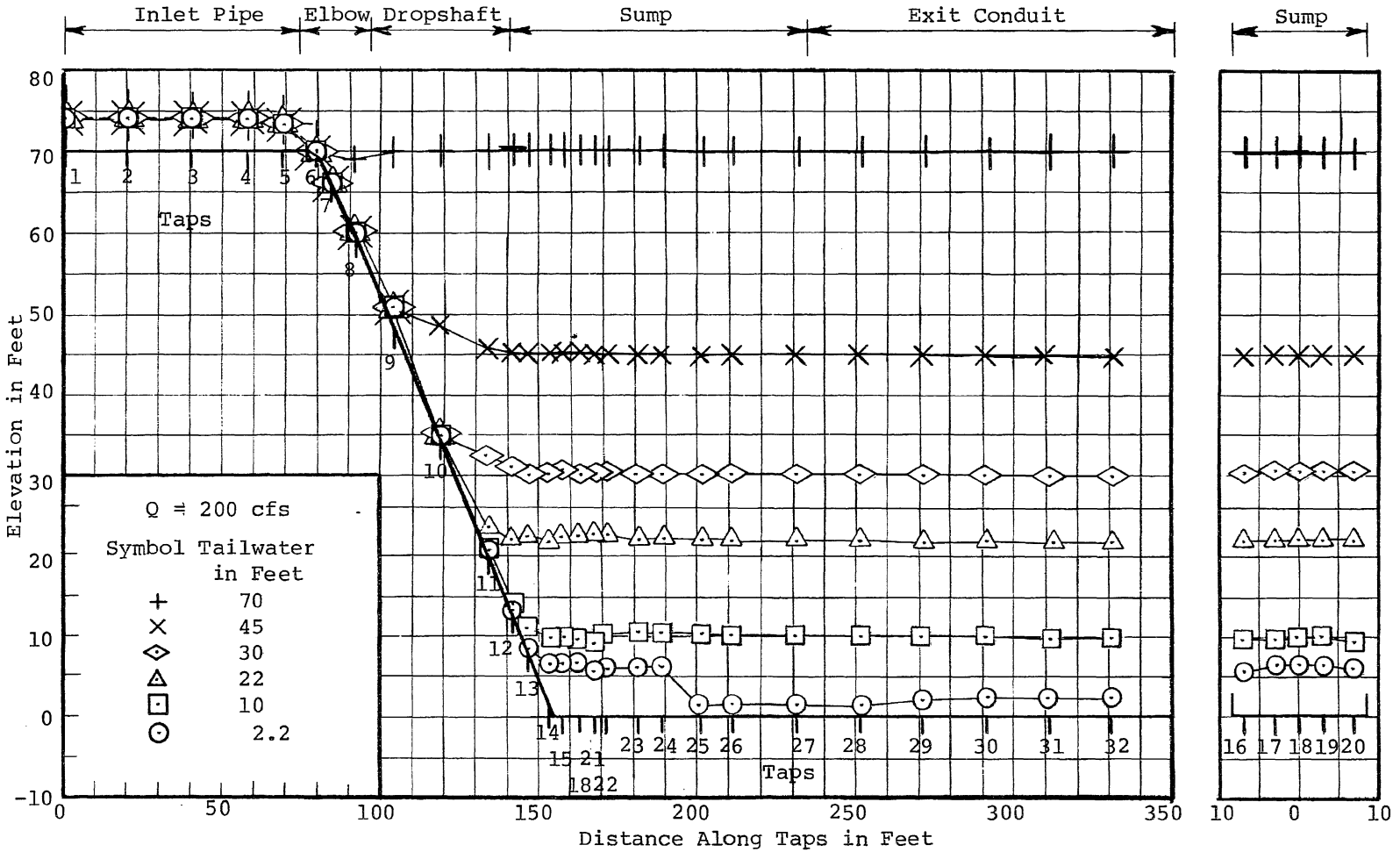
DRAWN WQD	CHECKED	APPROVED
SCALE	DATE 1/21/83	NO. 313A2322-109



ROCHESTER COMBINED SURGE AND DROPSHAFT
MODEL STUDIES
Type CSD R5 Dropshaft Scale 1:12
Piezometric Pressures

SAINT ANTHONY FALLS HYDRAULIC LABORATORY UNIVERSITY OF MINNESOTA		
DRAWN BB	CHECKED	APPROVED
SCALE	DATE 1/11/83	NO. 313A2322-77

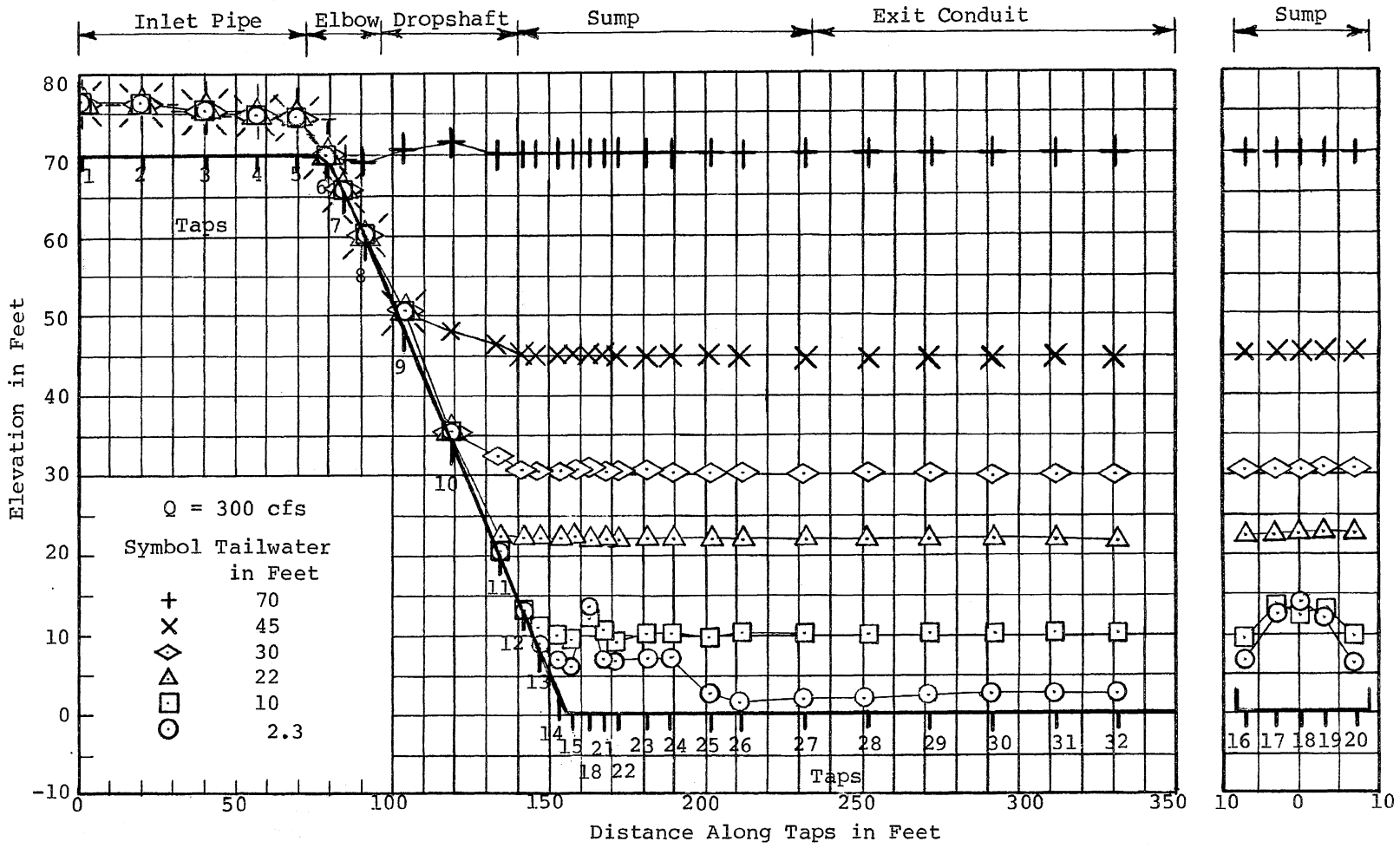
CHART 58



ROCHESTER COMBINED SURGE AND DROPSHAFT
MODEL STUDIES
Type CSD R5 Dropshaft Scale 1:12
Piezometric Pressures

SAINT ANTHONY FALLS HYDRAULIC LABORATORY UNIVERSITY OF MINNESOTA		
DRAWN BB	CHECKED	APPROVED
SCALE	DATE 1/11/83	NO. 313A2322-78

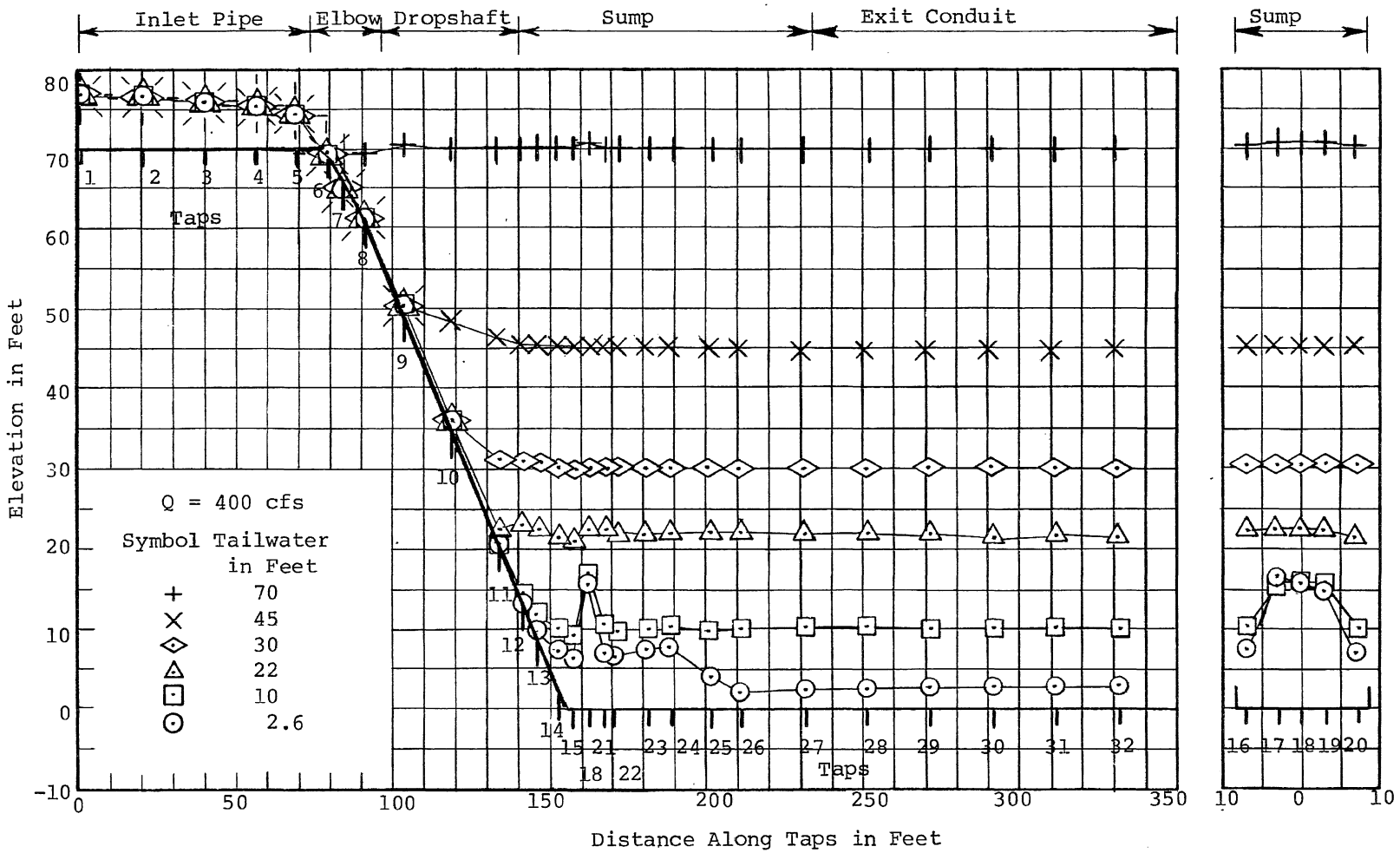
CHART 59



ROCHESTER COMBINED SURGE AND DROPSHAFT
MODEL STUDIES
Type CSD R5 Dropshaft Scale 1:12
Piezometric Pressures

SAINT ANTHONY FALLS HYDRAULIC LABORATORY UNIVERSITY OF MINNESOTA		
DRAWN BB	CHECKED	APPROVED
SCALE	DATE 1/11/83	NO. 313A2322-79

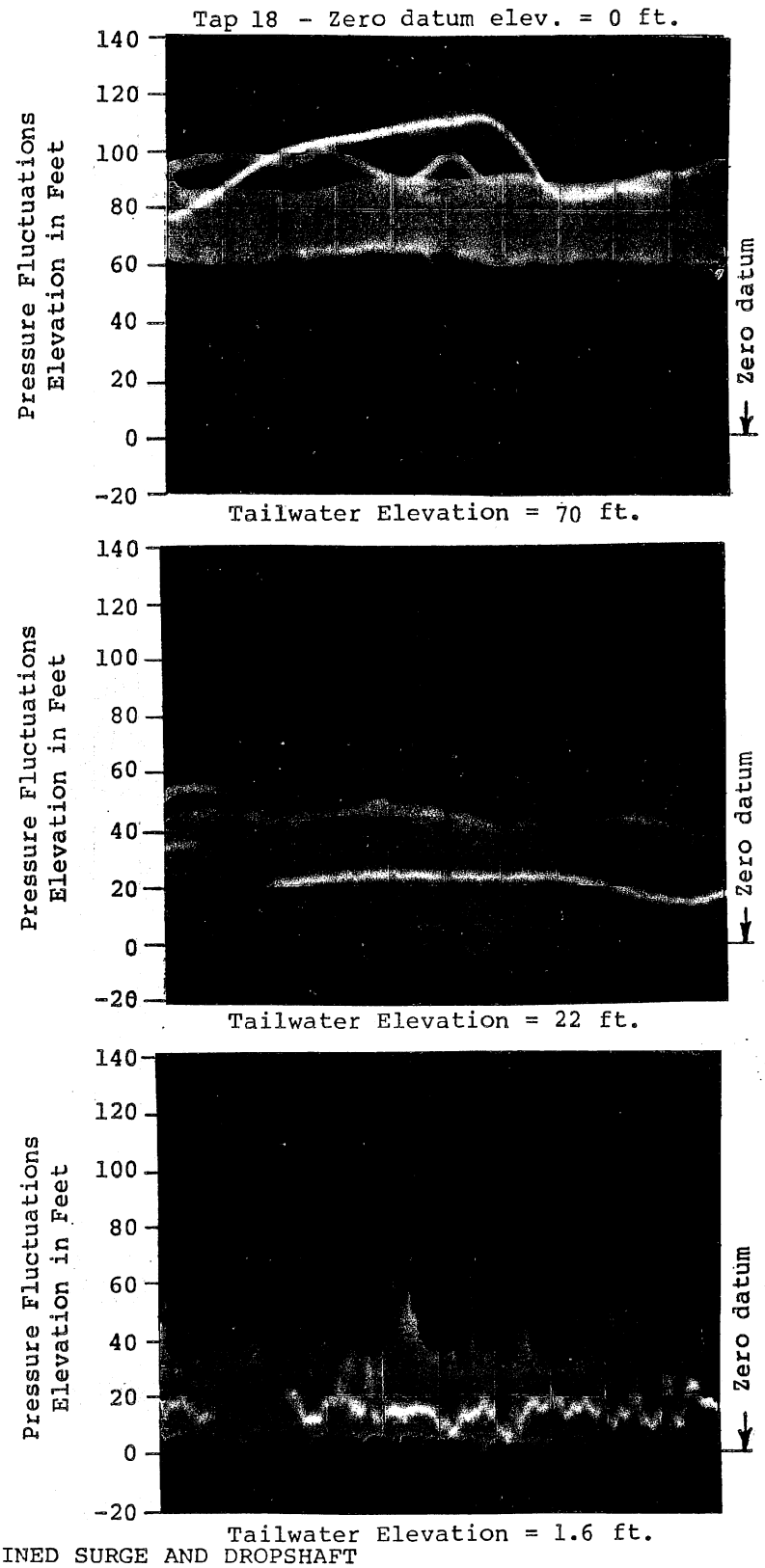
CHART 60



ROCHESTER COMBINED SURGE AND DROPSHAFT
MODEL STUDIES
Type CSD R5 Dropshaft Scale 1:12
Piezometric Pressures

SAINT ANTHONY FALLS HYDRAULIC LABORATORY UNIVERSITY OF MINNESOTA		
DRAWN BB	CHECKED	APPROVED
SCALE	DATE 1/11/83	NO. 313A2322-80

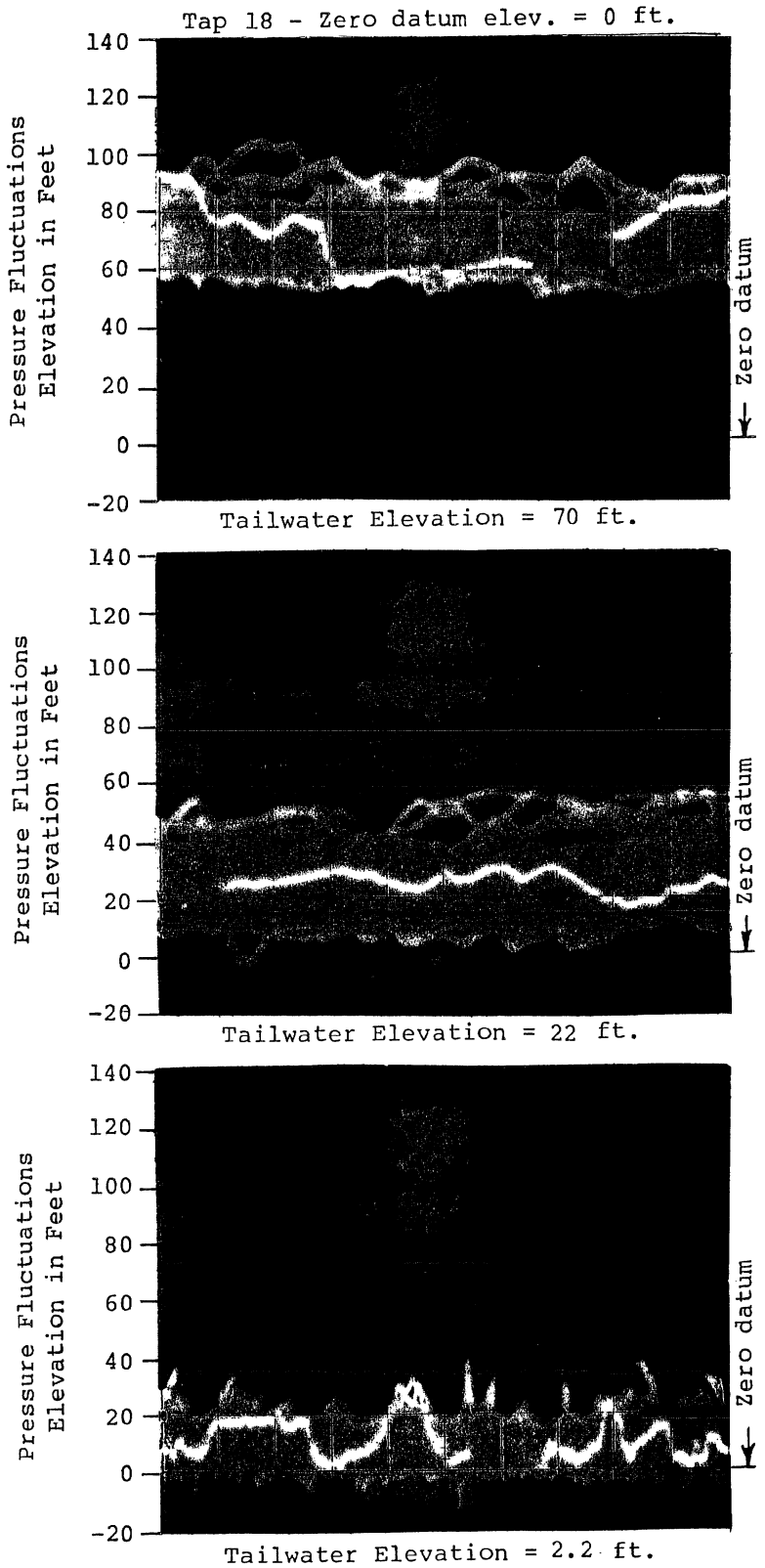
CHART 61



ROCHESTER COMBINED SURGE AND DROPSHAFT
MODEL STUDIES
Type CSDR5 Dropshaft Scale 1:12
Typical Pressure Fluctuations
Q = 100 cfs
Model time of record = 1 minute

SAINT ANTHONY FALLS HYDRAULIC LABORATORY
UNIVERSITY OF MINNESOTA

DRAWN WQD	CHECKED BB	APPROVED
SCALE	DATE 12/9/82	NO 313A2322-1

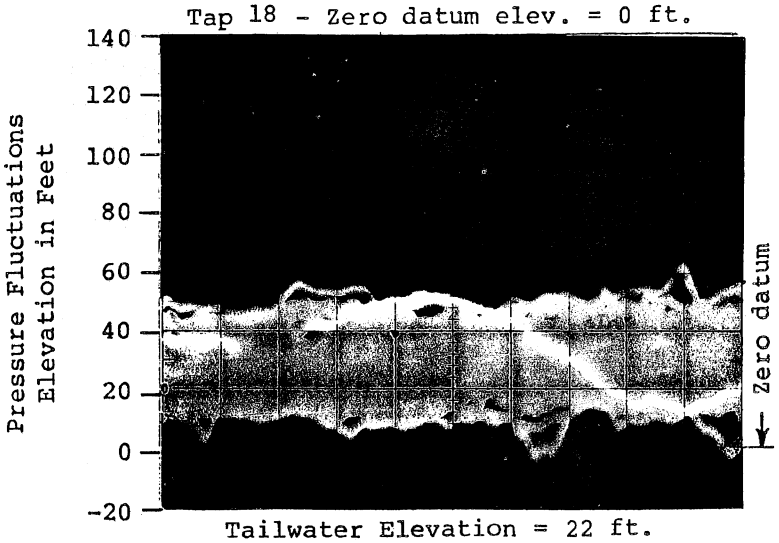


ROCHESTER COMBINED SURGE AND DROPSHAFT
MODEL STUDIES
Type CSD R5 Dropshaft Scale 1:12
Typical Pressure Fluctuations
Q = 200 cfs
Model time of record = 1 minute

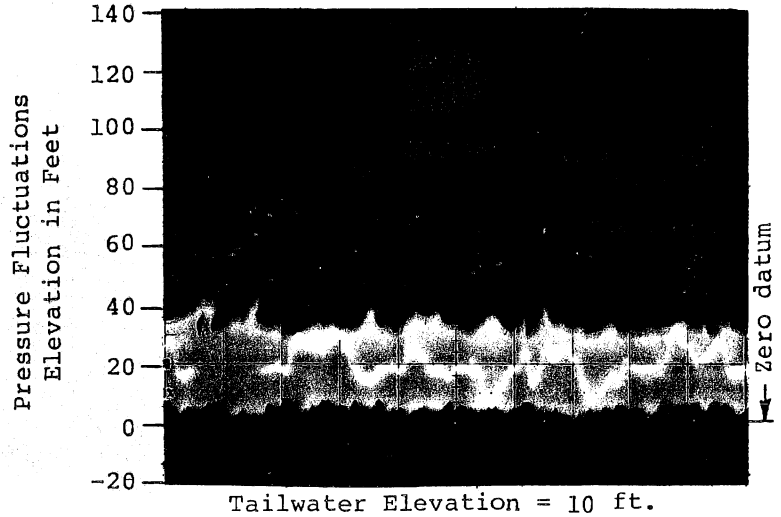
SAINT ANTHONY FALLS HYDRAULIC LABORATORY
UNIVERSITY OF MINNESOTA

DRAWN WQD	CHECKED BB	APPROVED
SCALE	DATE 12/9/82	NO 313A2322- 2

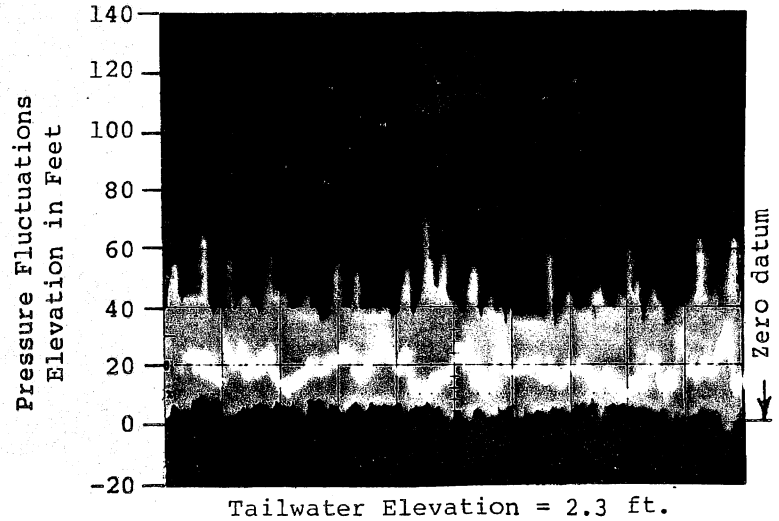
Tap 18 - Zero datum elev. = 0 ft.



Tailwater Elevation = 22 ft.



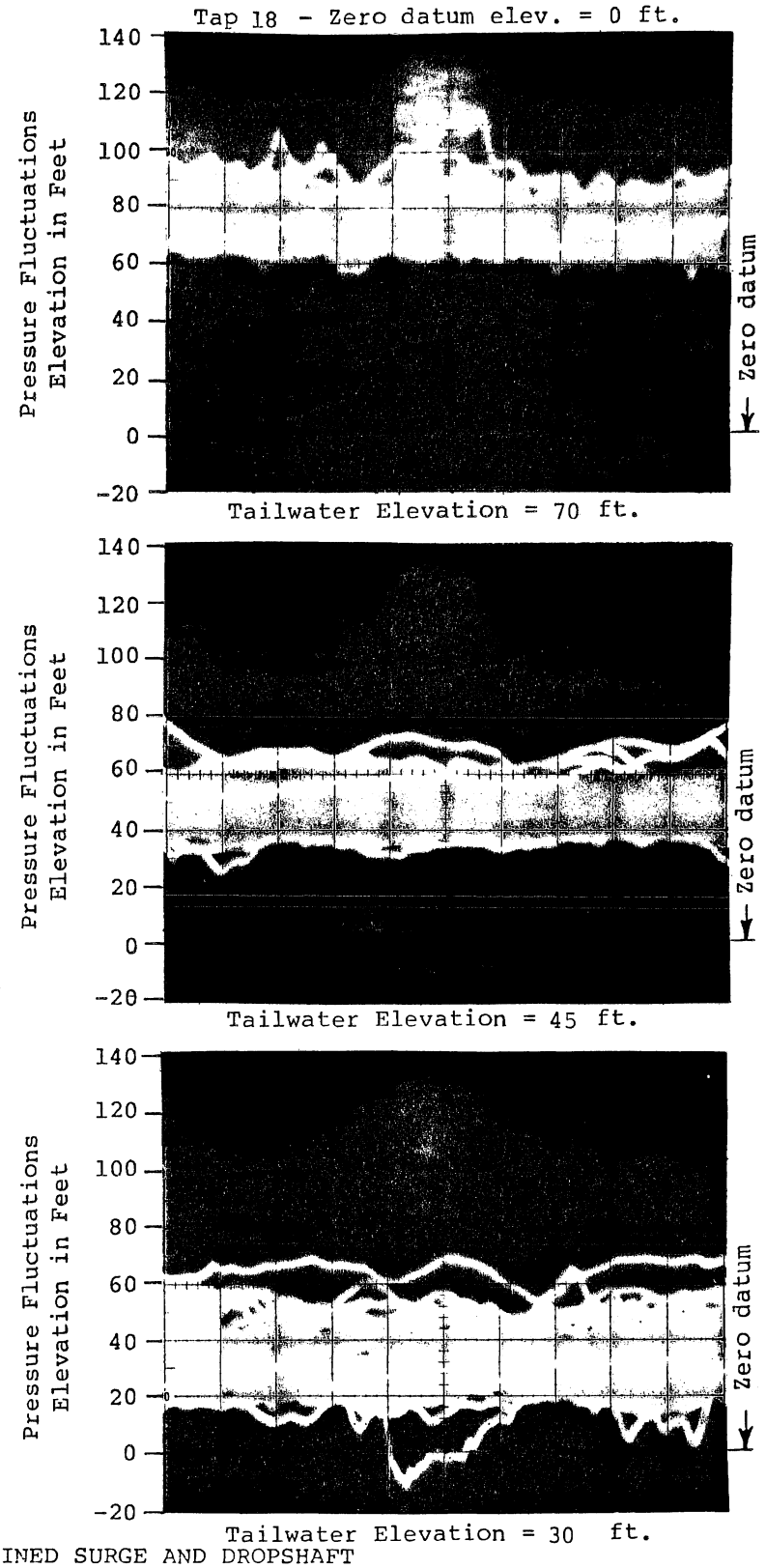
Tailwater Elevation = 10 ft.



Tailwater Elevation = 2.3 ft.

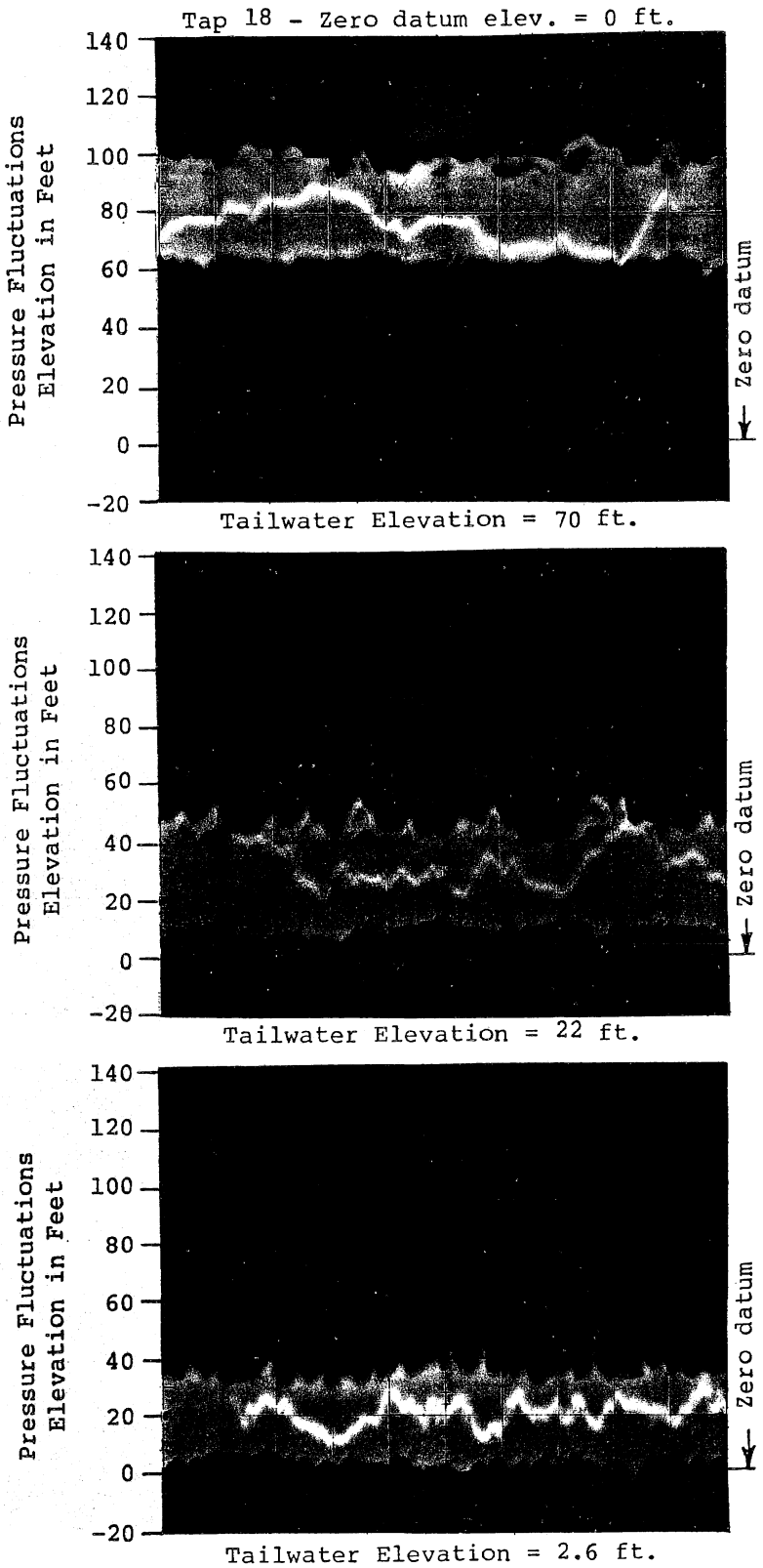
ROCHESTER COMBINED SURGE AND DROPSHAFT
MODEL STUDIES
Type CSD R5 Dropshaft Scale 1:12
Typical Pressure Fluctuations
Q = 300 cfs
Model time of record = 1 minute

SAINT ANTHONY FALLS HYDRAULIC LABORATORY UNIVERSITY OF MINNESOTA		
DRAWN WQD	CHECKED BB	APPROVED
SCALE	DATE 12/9/82	NO 313A2322-4



ROCHESTER COMBINED SURGE AND DROPSHAFT
MODEL STUDIES
Type CSD R5 Dropshaft Scale 1:12
Typical Pressure Fluctuations
Q = 300 cfs
Model time of record = 1 minute

SAINT ANTHONY FALLS HYDRAULIC LABORATORY UNIVERSITY OF MINNESOTA		
DRAWN WQD	CHECKED BR	APPROVED
SCALE	DATE 12/9/82	NO 313A2322-3

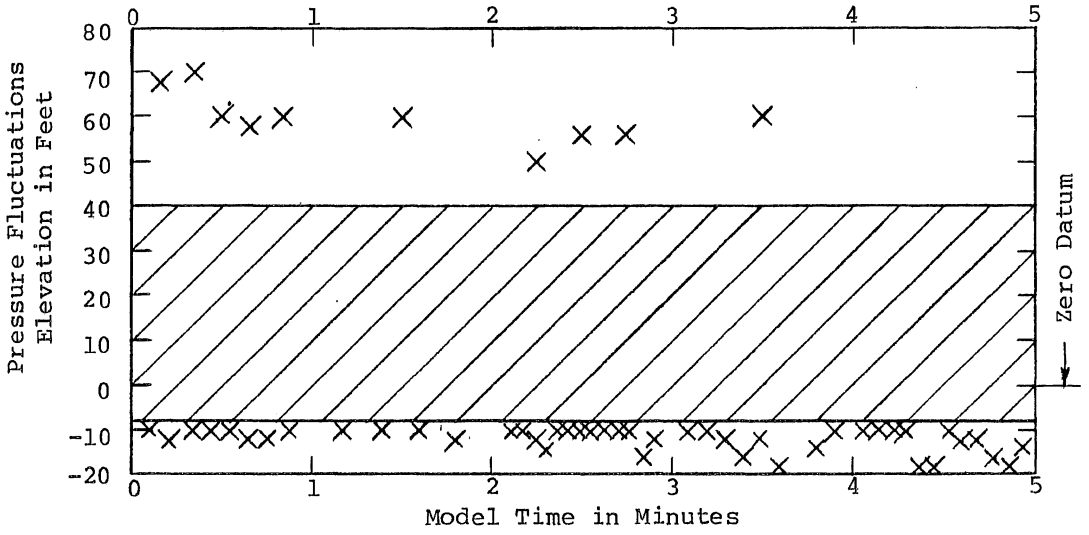


ROCHESTER COMBINED SURGE AND DROPSHAFT
MODEL STUDIES
Type CSDR5 Dropshaft Scale 1:12
Typical Pressure Fluctuations
Q = 400 cfs
Model time of record = 1 minute

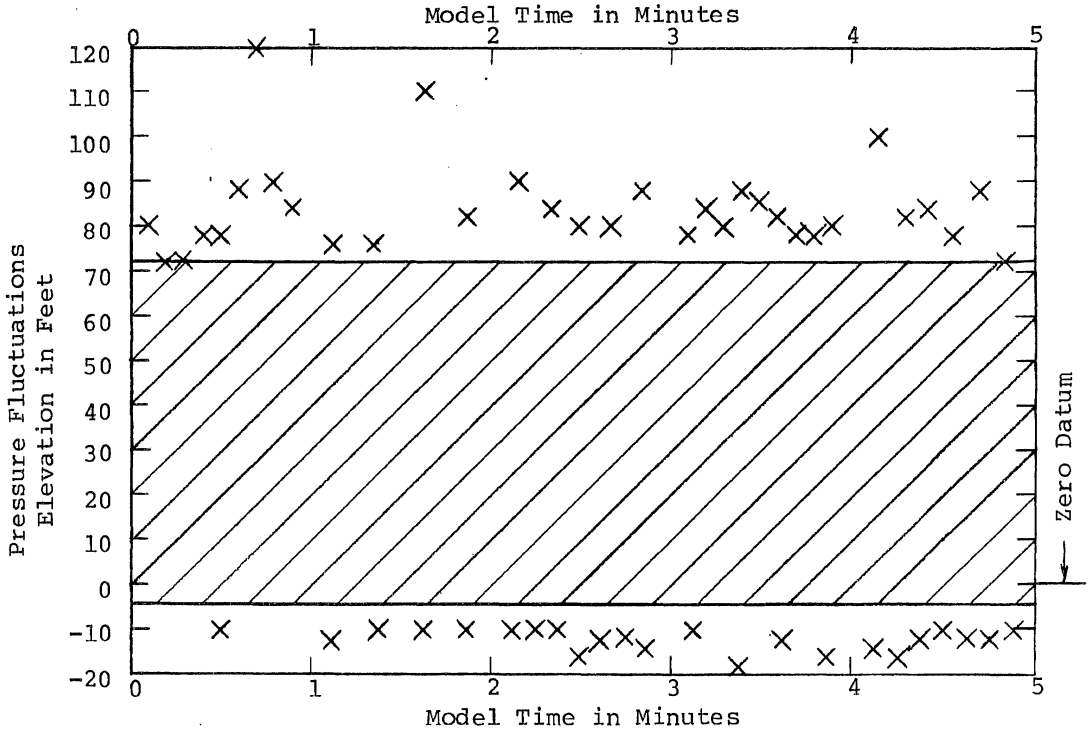
SAINT ANTHONY FALLS HYDRAULIC LABORATORY
UNIVERSITY OF MINNESOTA

DRAWN WQD	CHECKED BB	APPROVED
SCALE	DATE 12/9/82	NO 313A2322-5

Tap 18 - Zero datum elev. = 0 ft.



Q = 200 cfs, Tailwater Elevation = 2.2 ft.



Q = 100 cfs, Tailwater Elevation = 1.6 ft.

× Visually observed readings

Range from oscilloscope photos, Model time of record = 1 minute

ROCHESTER COMBINED SURGE AND DROPSHAFT MODEL STUDIES

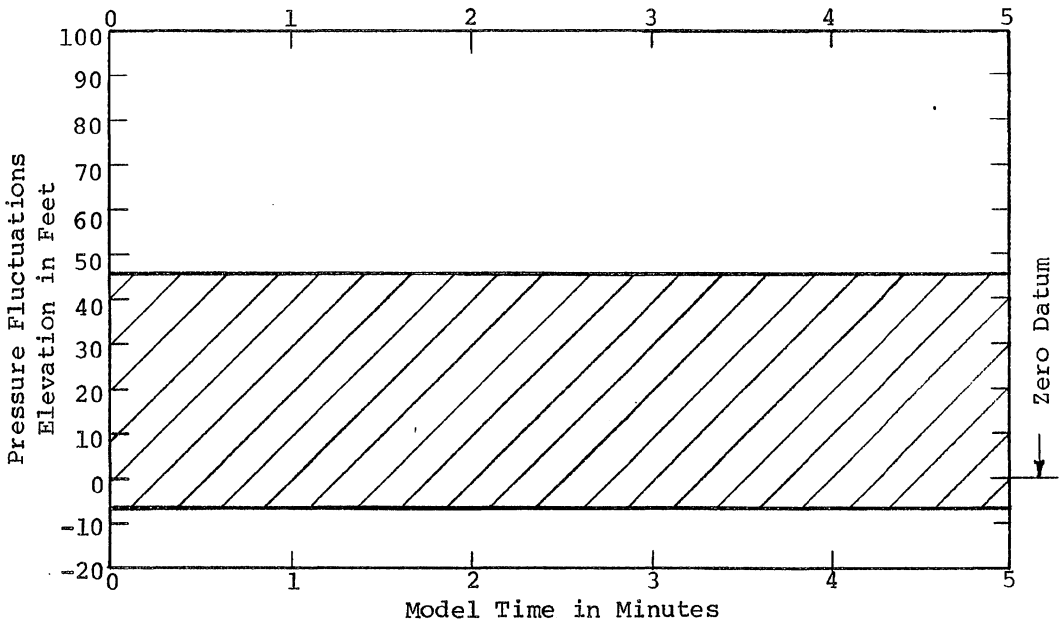
Type CSD R5 Dropshaft Scale 1:12

Typical Pressure Fluctuations

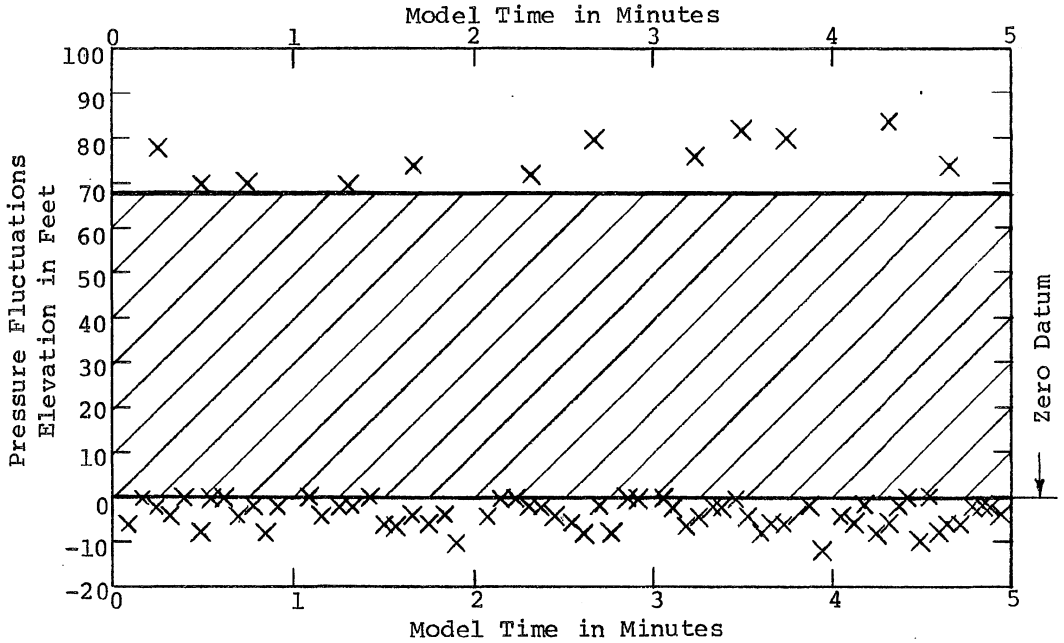
SAINT ANTHONY FALLS HYDRAULIC LABORATORY
UNIVERSITY OF MINNESOTA

DRAWN BB	CHECKED	APPROVED
SCALE	DATE 1/17/83	NO. 313A2322-96

Tap 18 - Zero datum elev. = 0 ft.



Q = 400 cfs, Tailwater Elevation = 2.6 ft.



Q = 300 cfs, Tailwater Elevation = 2.3 ft.

× Visually observed readings

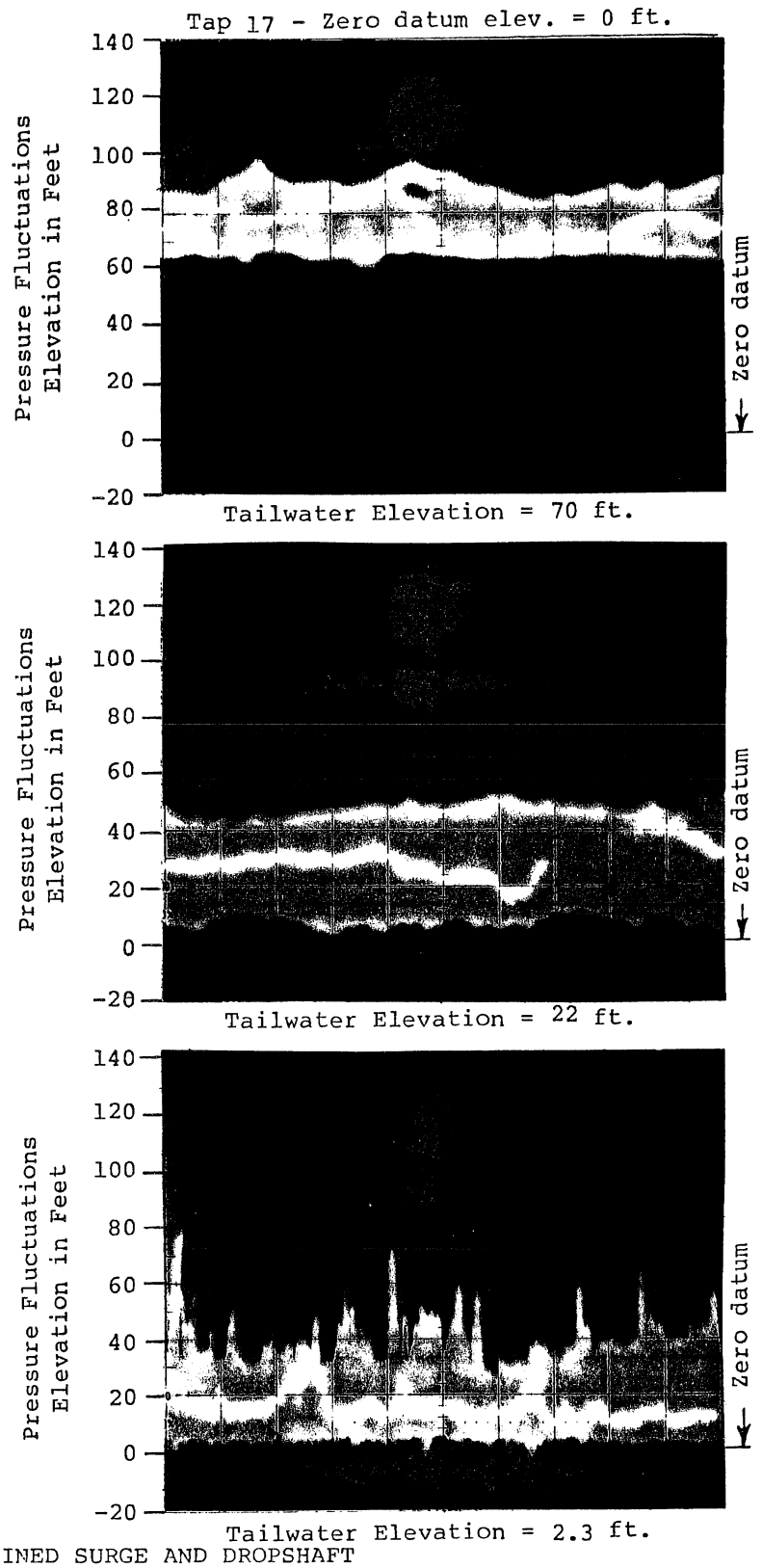
Range from oscilloscope photos, Model time of record = 1 minute

ROCHESTER COMBINED SURGE AND DROPSHAFT MODEL STUDIES

Type CSD R5 Dropshaft Scale 1:12

Typical Pressure Fluctuations

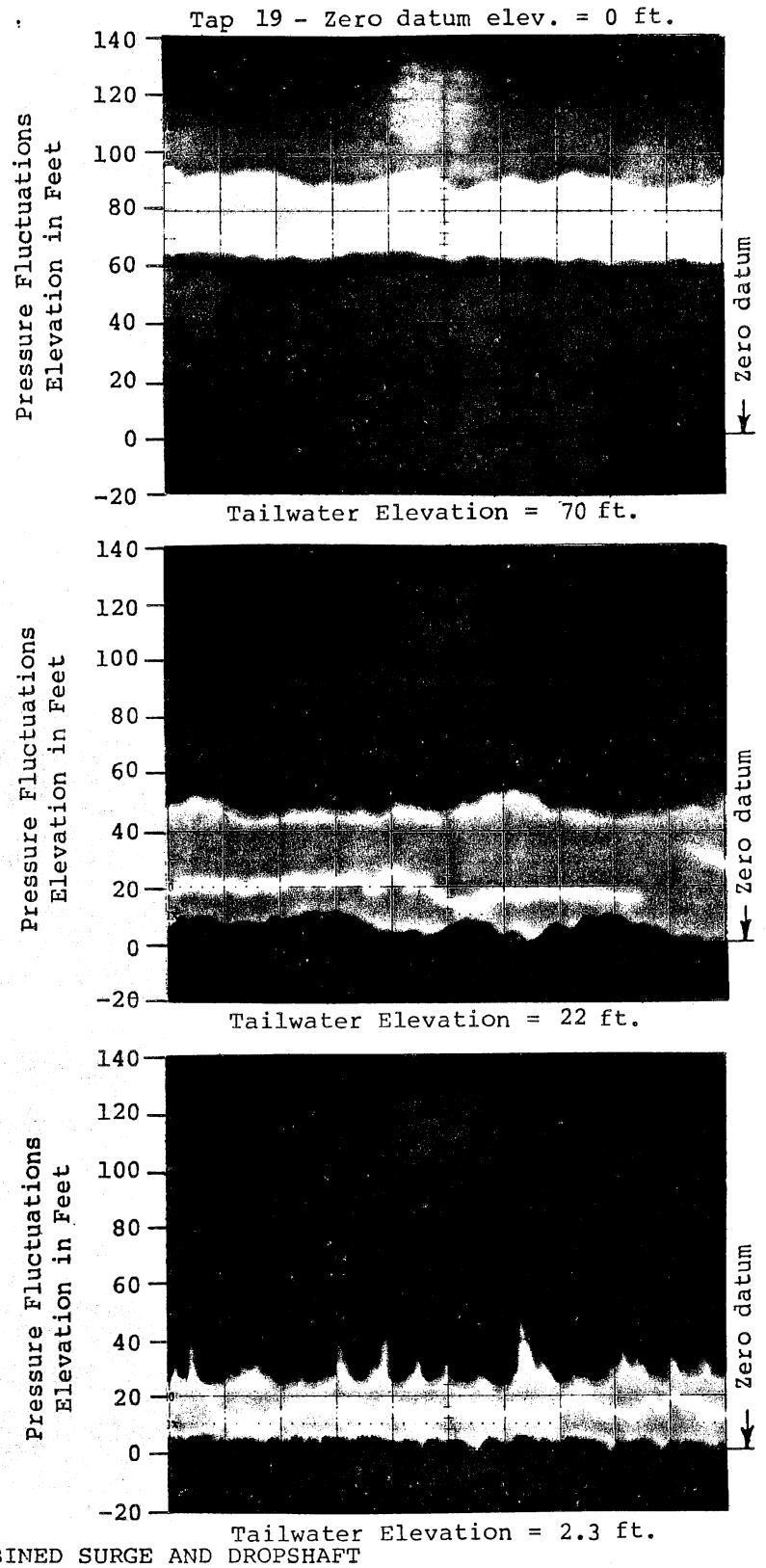
SAINT ANTHONY FALLS HYDRAULIC LABORATORY UNIVERSITY OF MINNESOTA		
DRAWN BB	CHECKED	APPROVED
SCALE	DATE 1/17/83	NO. 313A2322-97



ROCHESTER COMBINED SURGE AND DROPSHAFT
MODEL STUDIES
Type CSD R5 Dropshaft Scale 1:12
Typical Pressure Fluctuations
Q = 300 cfs
Model time of record = 1 minute

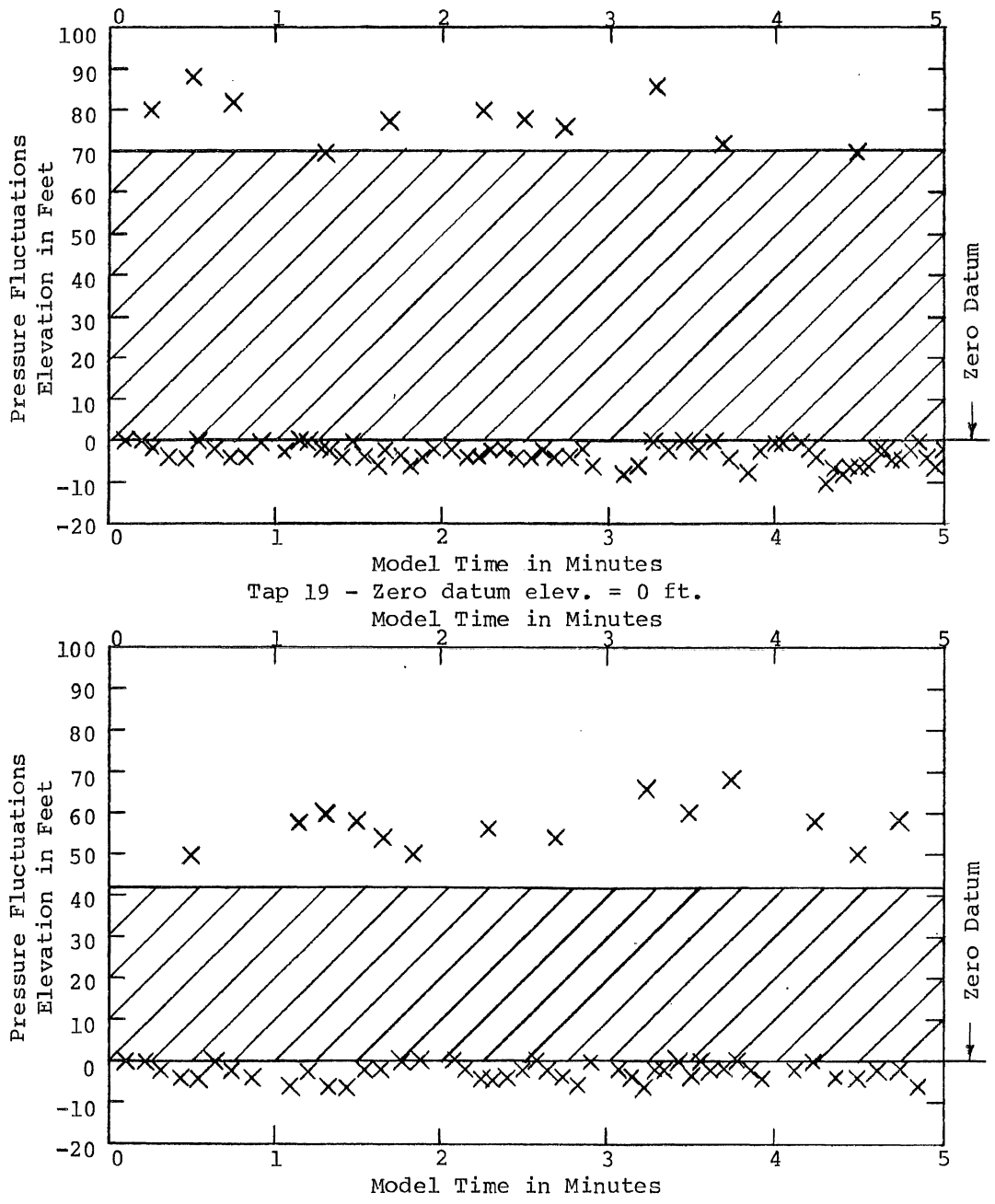
SAINT ANTHONY FALLS HYDRAULIC LABORATORY
UNIVERSITY OF MINNESOTA

DRAWN WQD	CHECKED BB	APPROVED
SCALE	DATE 12/9/82	NO 313A2322-6



ROCHESTER COMBINED SURGE AND DROPSHAFT
MODEL STUDIES
Type CSD R5 Dropshaft Scale 1:12
Typical Pressure Fluctuations
Q = 300 cfs
Model time of record = 1 minute

SAINT ANTHONY FALLS HYDRAULIC LABORATORY UNIVERSITY OF MINNESOTA		
DRAWN WQD	CHECKED BB	APPROVED
SCALE	DATE 12/9/82	NO 313A2322-7



× Visually observed readings

Range from oscilloscope photos, Model time of record = 1 minute

ROCHESTER COMBINED SURGE AND DROPSHAFT MODEL STUDIES
Type CSD R5 Dropshaft Scale 1:12
Typical Pressure Fluctuations
Q = 300 cfs, T.W. Elev. = 2.3 ft.

SAINT ANTHONY FALLS HYDRAULIC LABORATORY
UNIVERSITY OF MINNESOTA

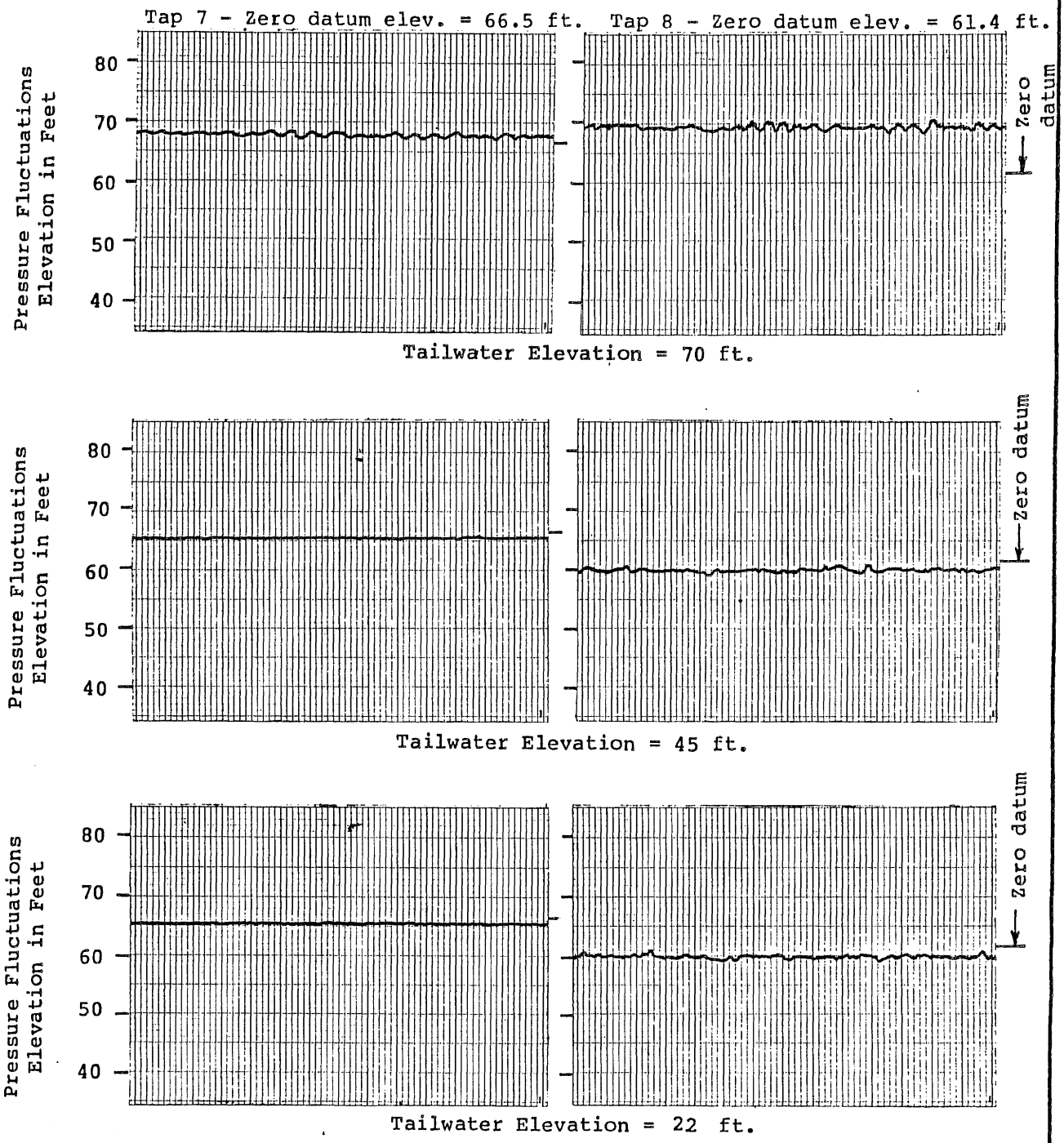
DRAWN BB	CHECKED JWJ	APPROVED
SCALE	DATE 1/17/83	NO. 313A2322-95

Q cfs	T.W. El. ft	Av. Piez. Press.-ft	Range from Photos Max.-ft	Range from Photos Min.-ft	Observed Readings Max.-ft	Observed Readings Min.-ft
		Tap 17 Elevation = 0 ft				
300	2.3	12.4	70	0	88	-10
300	22	22.2	54	4		
300	70	70.3	100	60		
		Tap 18 Elevation = 0 ft				
100	1.6	13.0	72	-4	120	-18
100	22	22.1	58	-10		
100	70	70.2	114	58		
200	2.2	6.6	40	-8	70	-18
200	22	22.2	50	-4		
200	70	70.2	106	50		
300	2.3	13.7	68	0	84	-12
300	10	12.7	44	-2		
300	22	22.2	64	-4		
300	30	30.4	70	-12		
300	45	45.2	80	24		
300	70	70.3	116	56		
400	2.6	15.2	46	-6		
400	22	22.7	58	4		
400	70	71.2	108	58		
		Tap 19 Elevation = 0 ft				
300	2.3	12.0	42	0	68	-6
300	22	22.2	54	0		
300	70	70.4	94	62		

ROCHESTER COMBINED SURGE AND DROPSHAFT
MODEL STUDIES
Type GSD R5 Dropshaft Scale 1:12
Summary of Typical
Pressure Fluctuations

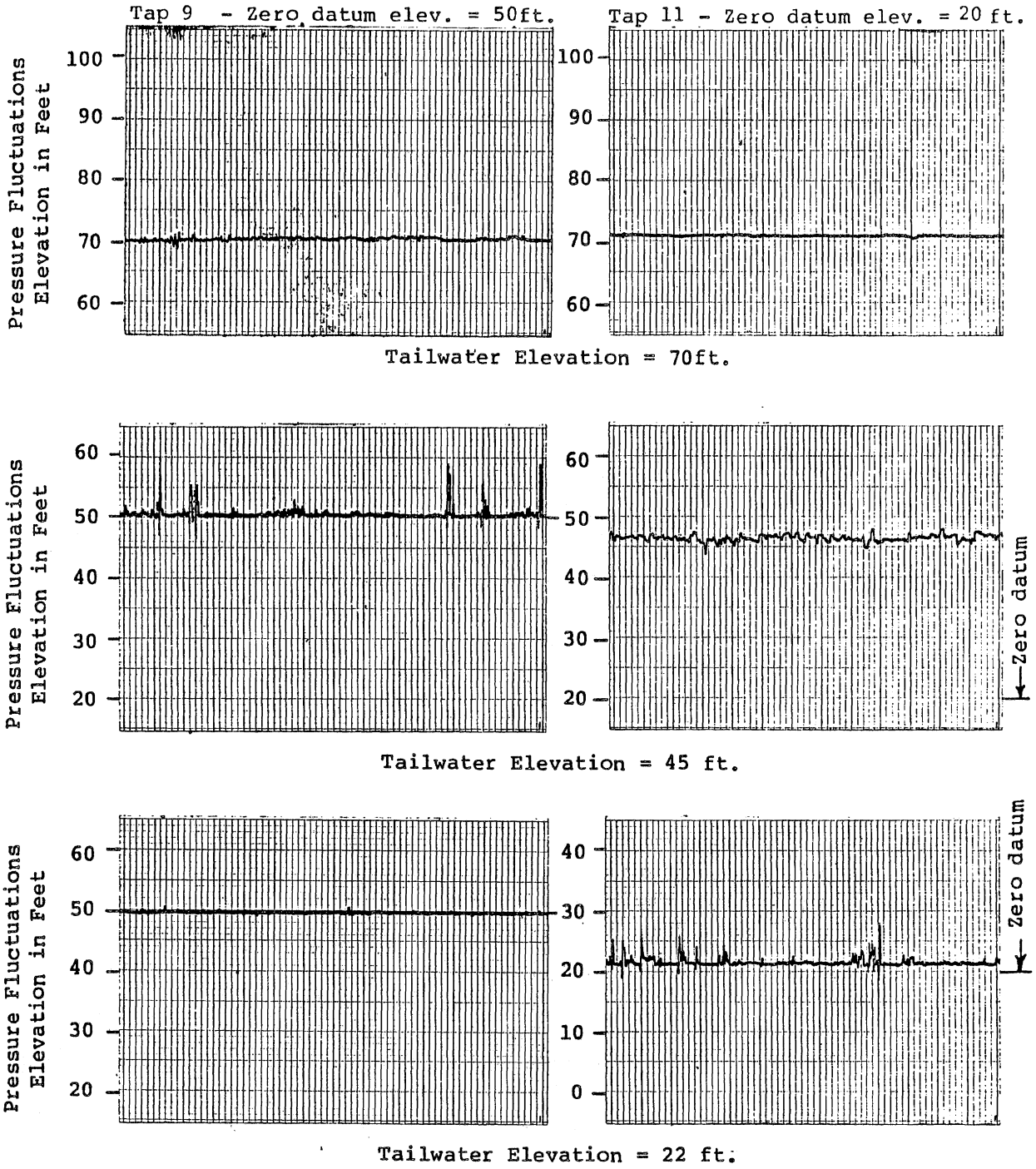
SAINT ANTHONY FALLS HYDRAULIC LABORATORY
UNIVERSITY OF MINNESOTA

DRAWN WQD	CHECKED BB	APPROVED
SCALE	DATE 1-7-83	NO. 313A2322-70



ROCHESTER COMBINED SURGE AND DROPSHAFT
MODEL STUDIES
Type CSD R5 Dropshaft Scale 1:12
Typical Pressure Fluctuations
Q = 300 cfs

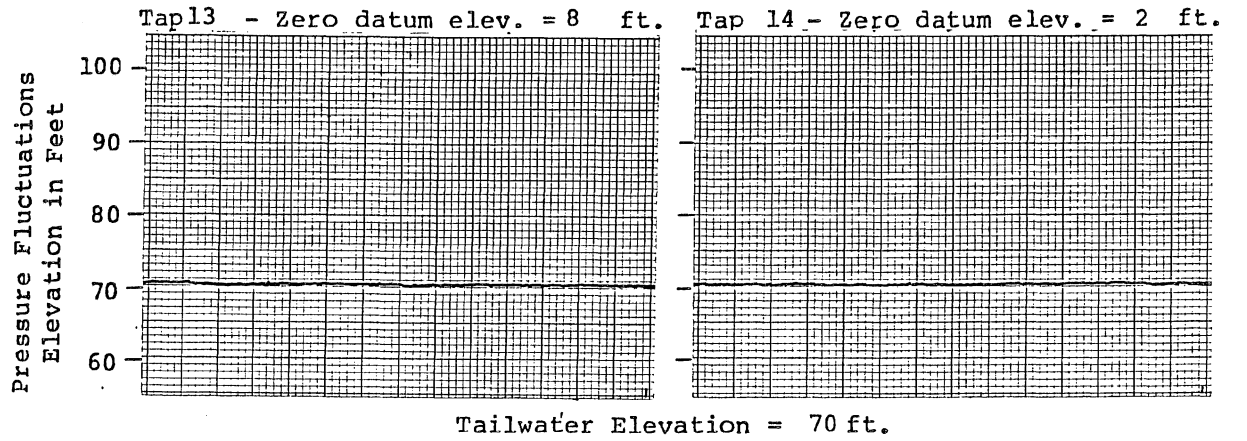
SAINT ANTHONY FALLS HYDRAULIC LABORATORY UNIVERSITY OF MINNESOTA		
DRAWN BB	CHECKED	APPROVED
SCALE	DATE 12/10/82	NO. 313 A2322-36



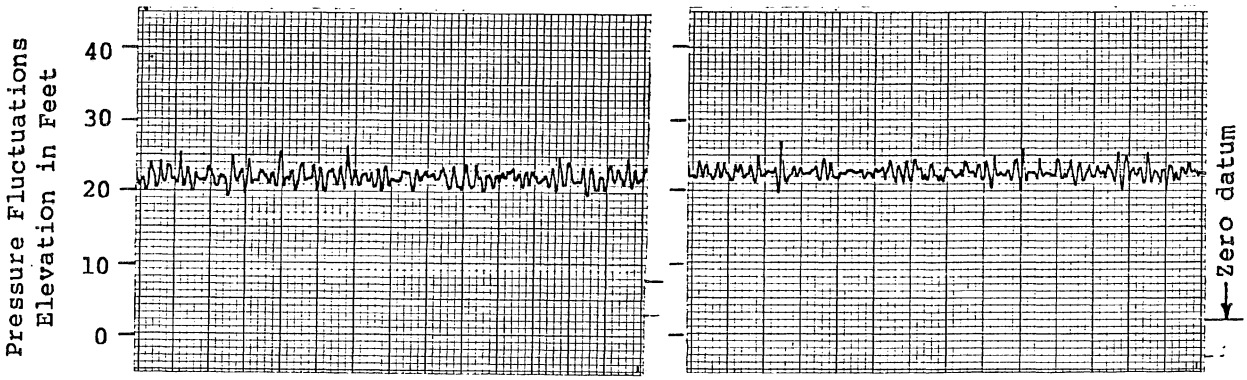
ROCHESTER COMBINED SURGE AND DROPSHAFT
MODEL STUDIES
Type CSD R5 Dropshaft Scale 1:12
Typical Pressure Fluctuations
Q = 300 cfs

SAINT ANTHONY FALLS HYDRAULIC LABORATORY
UNIVERSITY OF MINNESOTA

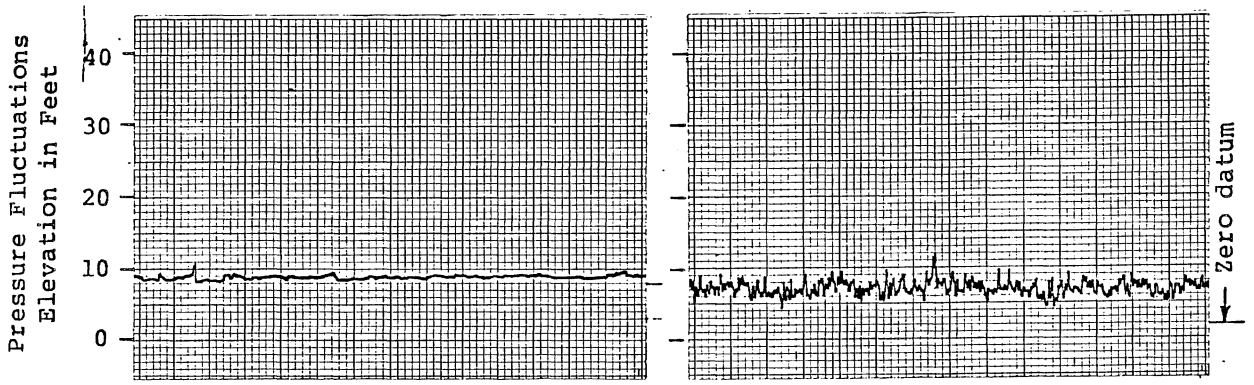
DRAWN BB	CHECKED MBS	APPROVED
SCALE	DATE 12/10/82	NO. 313A2322-40



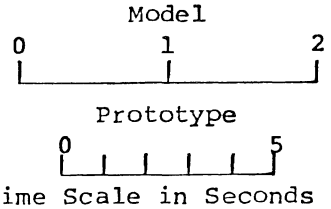
Tailwater Elevation = 70 ft.



Tailwater Elevation = 22 ft.

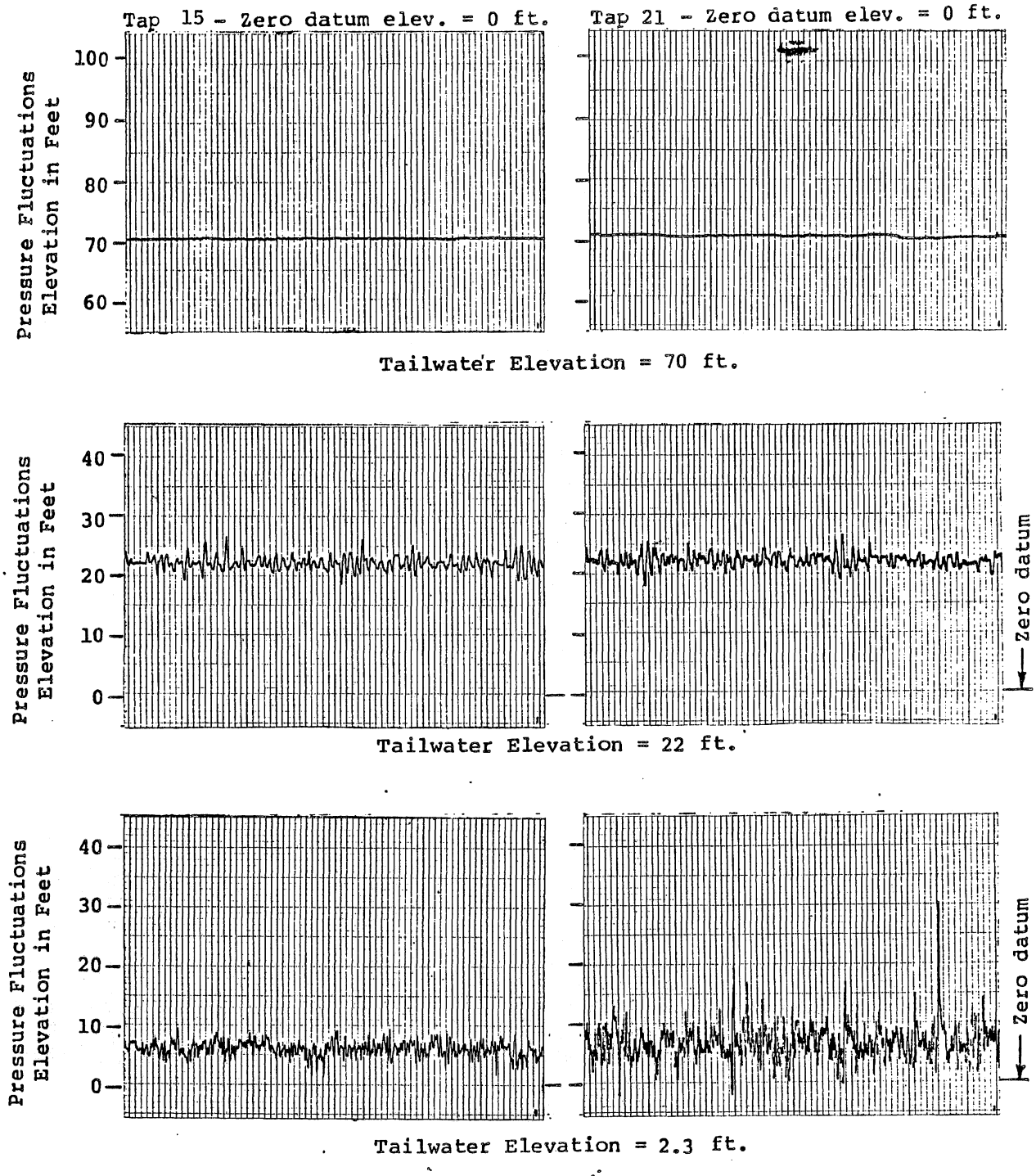


Tailwater Elevation = 2.3ft.



ROCHESTER COMBINED SURGE AND DROPSHAFT
MODEL STUDIES
Type CSD R5 Dropshaft Scale 1:12
Typical Pressure Fluctuations
Q = 300 cfs

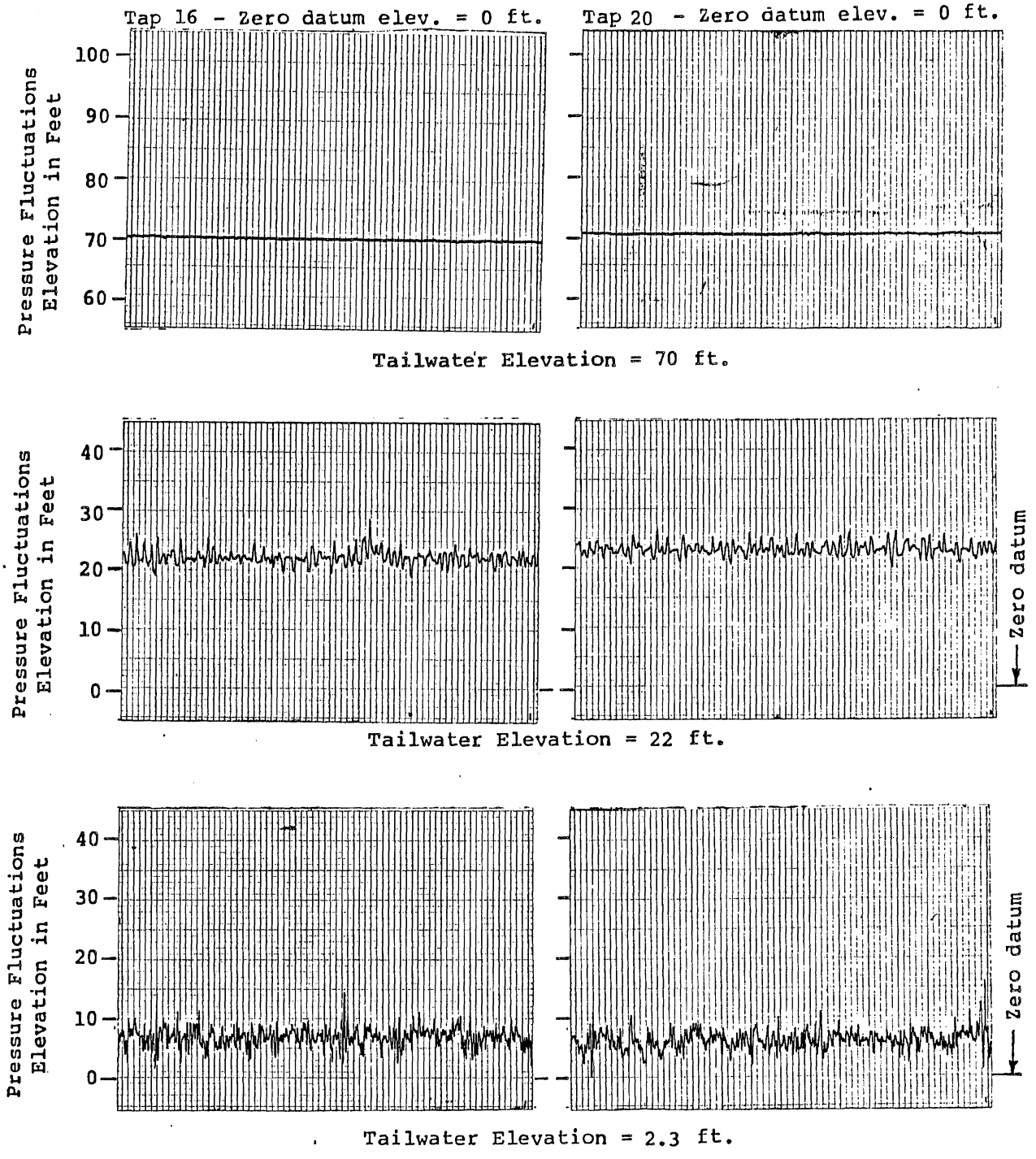
SAINT ANTHONY FALLS HYDRAULIC LABORATORY UNIVERSITY OF MINNESOTA		
DRAWN BB	CHECKED MDD	APPROVED
SCALE	DATE 12/10/82	NO. 313A2322- 44



ROCHESTER COMBINED SURGE AND DROPSHAFT
MODEL STUDIES
Type CSD R5 Dropshaft Scale 1:12
Typical Pressure Fluctuations
Q = 300 cfs

SAINT ANTHONY FALLS HYDRAULIC LABORATORY
UNIVERSITY OF MINNESOTA

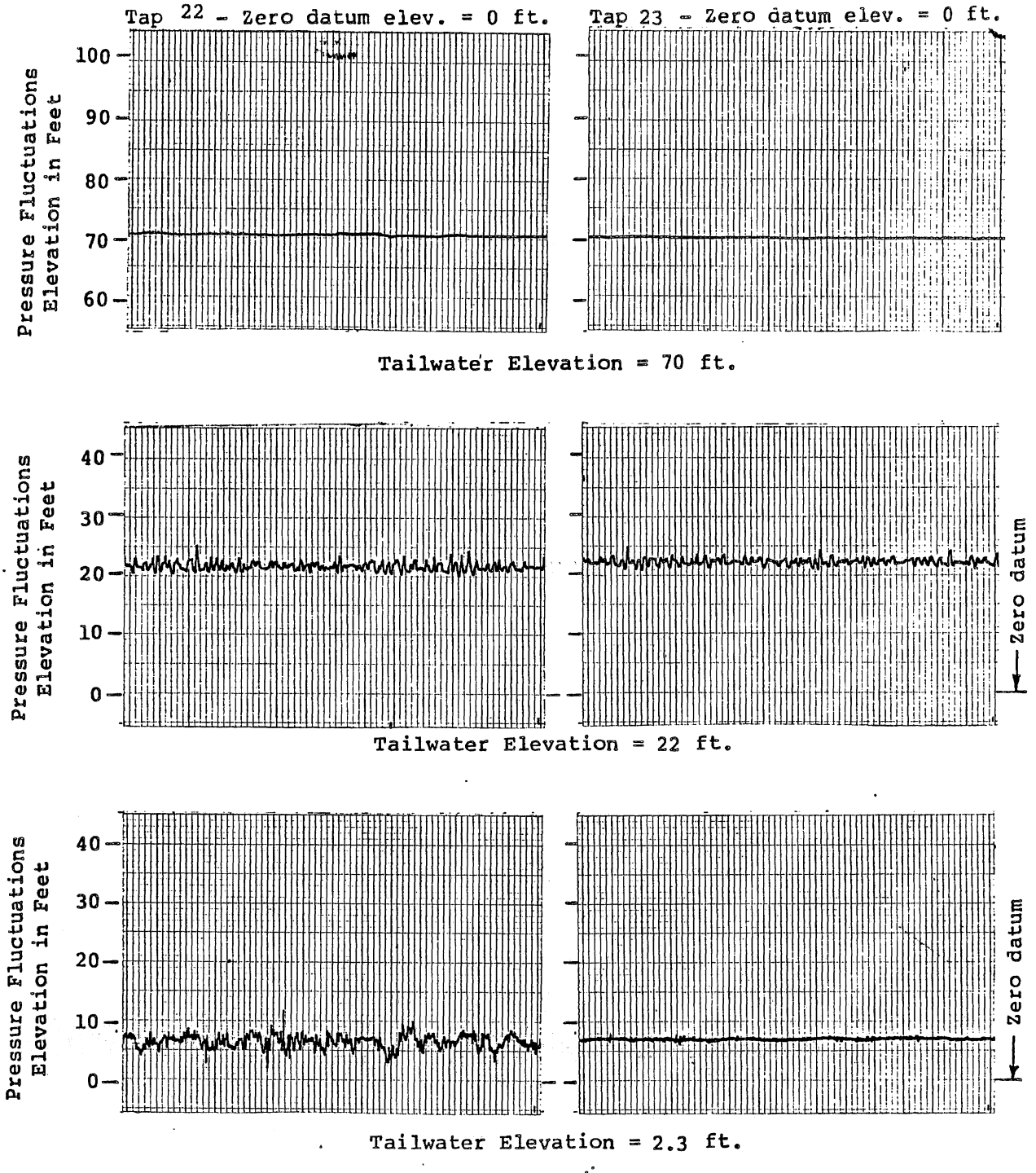
DRAWN BB	CHECKED	APPROVED
SCALE	DATE 12/10/82	NO. 313A2322- 57



ROCHESTER COMBINED SURGE AND DROPSHAFT
MODEL STUDIES
Type CSD R5 Dropshaft Scale 1:12
Typical Pressure Fluctuations
Q = 300 cfs

SAINT ANTHONY FALLS HYDRAULIC LABORATORY
UNIVERSITY OF MINNESOTA

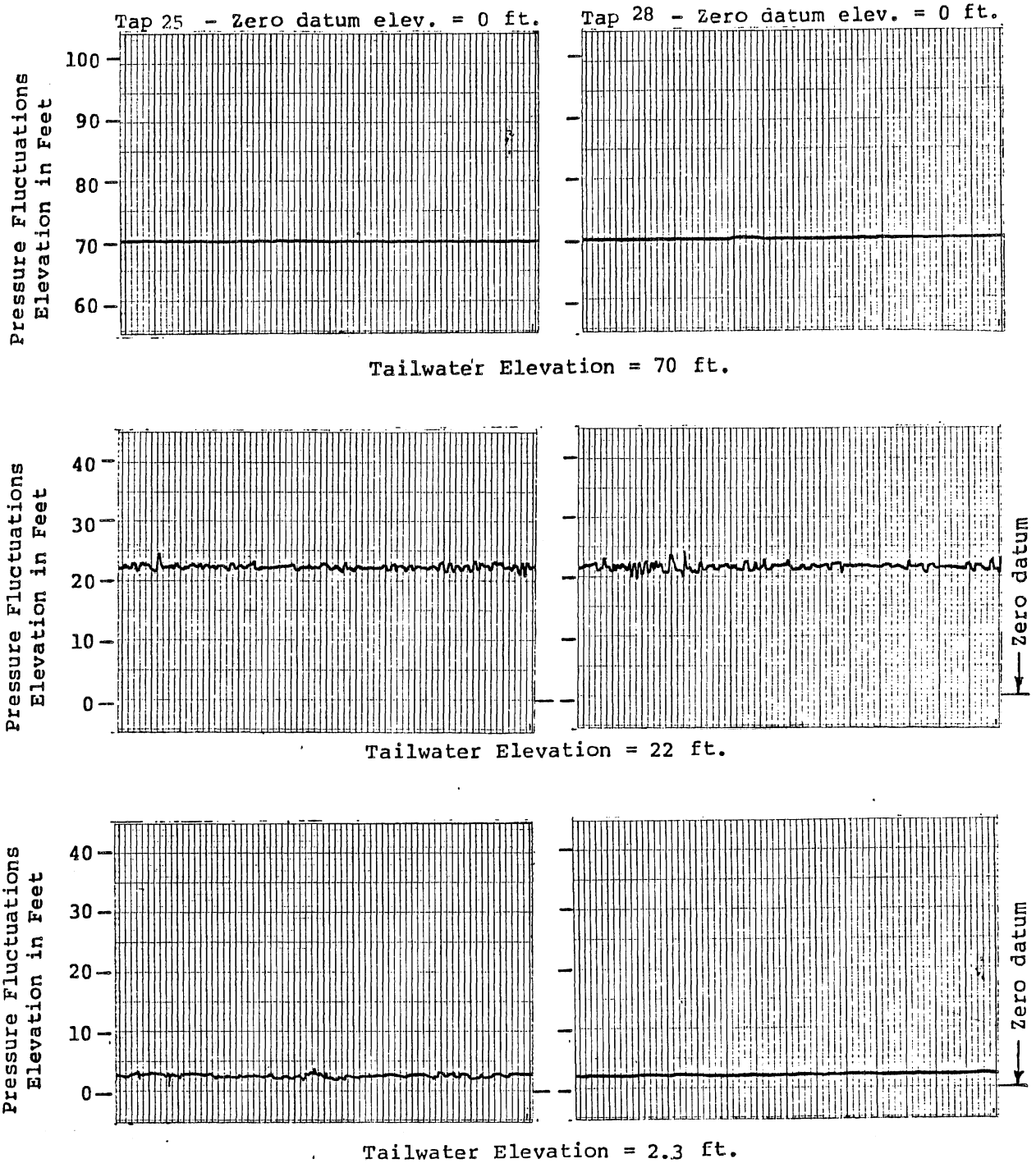
DRAWN BB	CHECKED JRD	APPROVED
SCALE	DATE 12/10/82	NO. 313A2322- 58



ROCHESTER COMBINED SURGE AND DROPSHAFT
MODEL STUDIES
Type CSD R5 Dropshaft Scale 1:12
Typical Pressure Fluctuations
Q = 300 cfs

SAINT ANTHONY FALLS HYDRAULIC LABORATORY
UNIVERSITY OF MINNESOTA

DRAWN BB	CHECKED MRO	APPROVED
SCALE	DATE 12/10/82	NO. 313A2322-59



ROCHESTER COMBINED SURGE AND DROPSHAFT
MODEL STUDIES
Type CSD R5 Dropshaft Scale 1:12
Typical Pressure Fluctuations
Q = 300 cfs

SAINT ANTHONY FALLS HYDRAULIC LABORATORY
UNIVERSITY OF MINNESOTA

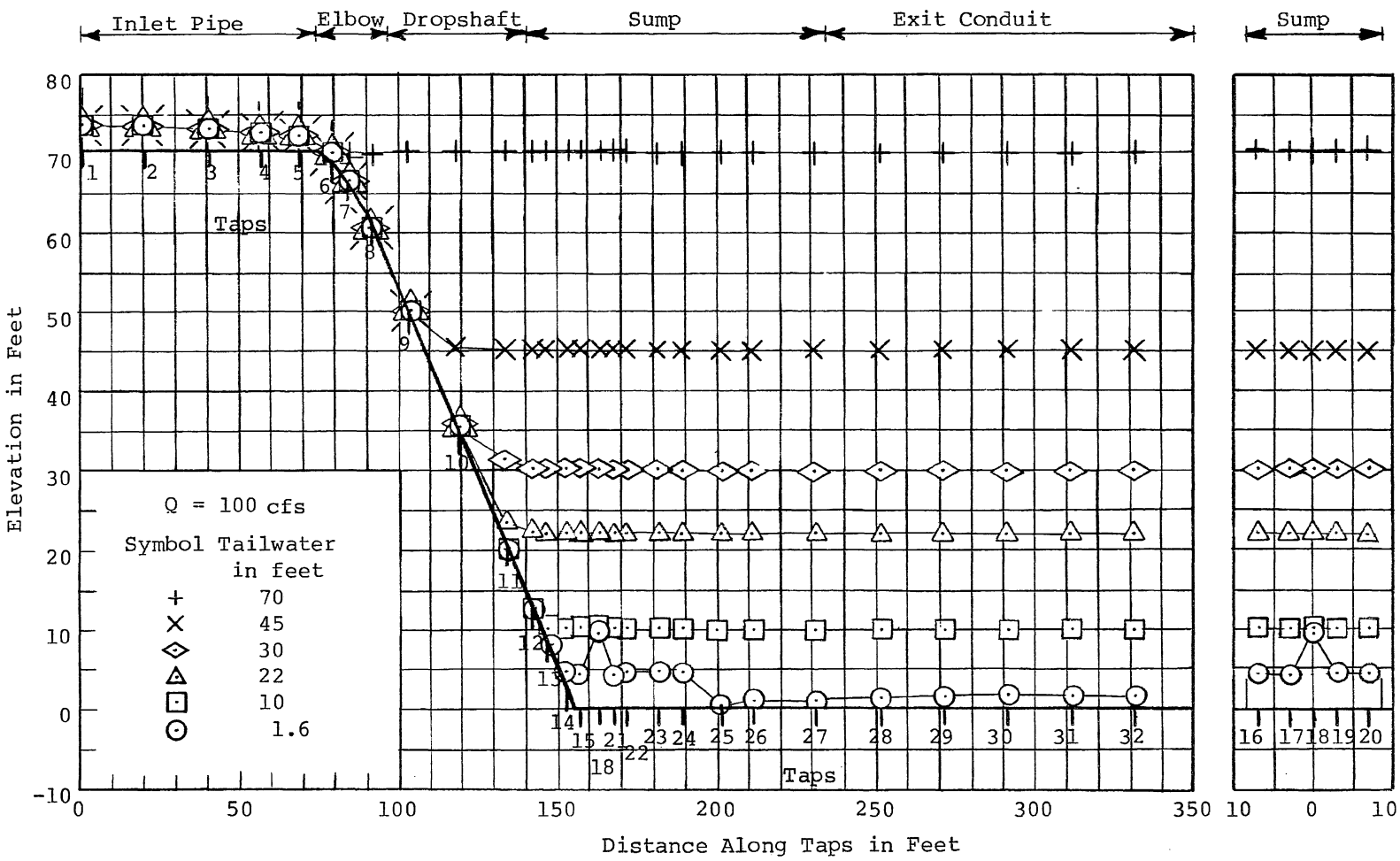
DRAWN BB	CHECKED MRD	APPROVED
SCALE	DATE 12/10/82	NO. 313A2322-60

Tap No.	Tap El. ft	Q cfs	T.W. El. ft	Av. Piez. Press.-ft	Pressure Fluctuations Max.-ft	Min.-ft
7	66.5	300	22	65.2	65.8	65.0
7	66.5	300	45	65.2	65.8	65.0
7	66.5	300	70	67.0	68.6	66.2
8	61.4	300	22	59.9	61.0	59.0
8	61.4	300	45	59.9	61.4	59.0
8	61.4	300	70	69.2	70.8	67.0
9	50	300	22	50.3	50.8	49.0
9	50	300	45	50.7	60.0	46.6
9	50	300	70	70.7	72.0	68.6
11	20	300	22	21.4	36.8	16.2
11	20	300	45	46.7	48.6	43.8
11	20	300	70	70.4	71.8	70.4
13	8	300	2.3	8.7	10.6	7.8
13	8	300	22	22.3	26.2	18.0
13	8	300	70	70.2	70.8	70.0
14	2	300	2.3	6.7	12.0	3.0
14	2	300	22	22.3	26.8	17.6
14	2	300	70	70.2	70.8	69.6
15	0	300	2.3	6.0	10.6	1.4
15	0	300	22	22.3	27.0	18.6
15	0	300	70	70.2	70.8	69.8
16	0	300	2.3	6.6	14.6	0.8
16	0	300	22	22.2	28.8	18.0
16	0	300	70	70.3	70.6	69.8
20	0	300	2.3	6.0	16.0	0.0
20	0	300	22	22.2	27.0	19.0
20	0	300	70	70.4	71.0	70.0
21	0	300	2.3	7.0	30.4	-3.6
21	0	300	22	22.2	26.6	18.0
21	0	300	70	70.3	71.0	69.8
22	0	300	2.3	6.6	13.0	2.0
22	0	300	22	22.2	25.2	19.0
22	0	300	70	70.2	71.0	70.0
23	0	300	2.3	7.0	8.0	6.0
23	0	300	22	22.2	25.0	20.8
23	0	300	70	70.2	70.4	69.8
25	0	300	2.3	2.4	3.8	0.8
25	0	300	22	22.2	24.6	20.8
25	0	300	70	70.1	70.8	69.8
28	0	300	2.3	2.0	2.8	1.8
28	0	300	22	22.1	24.8	19.8
28	0	300	70	70.0	70.6	69.8

ROCHESTER COMBINED SURGE AND DROPSHAFT
MODEL STUDIES
Type CSD R5 Dropshaft Scale 1:12
Summary of Typical
Pressure Fluctuations

SAINT ANTHONY FALLS HYDRAULIC LABORATORY
UNIVERSITY OF MINNESOTA

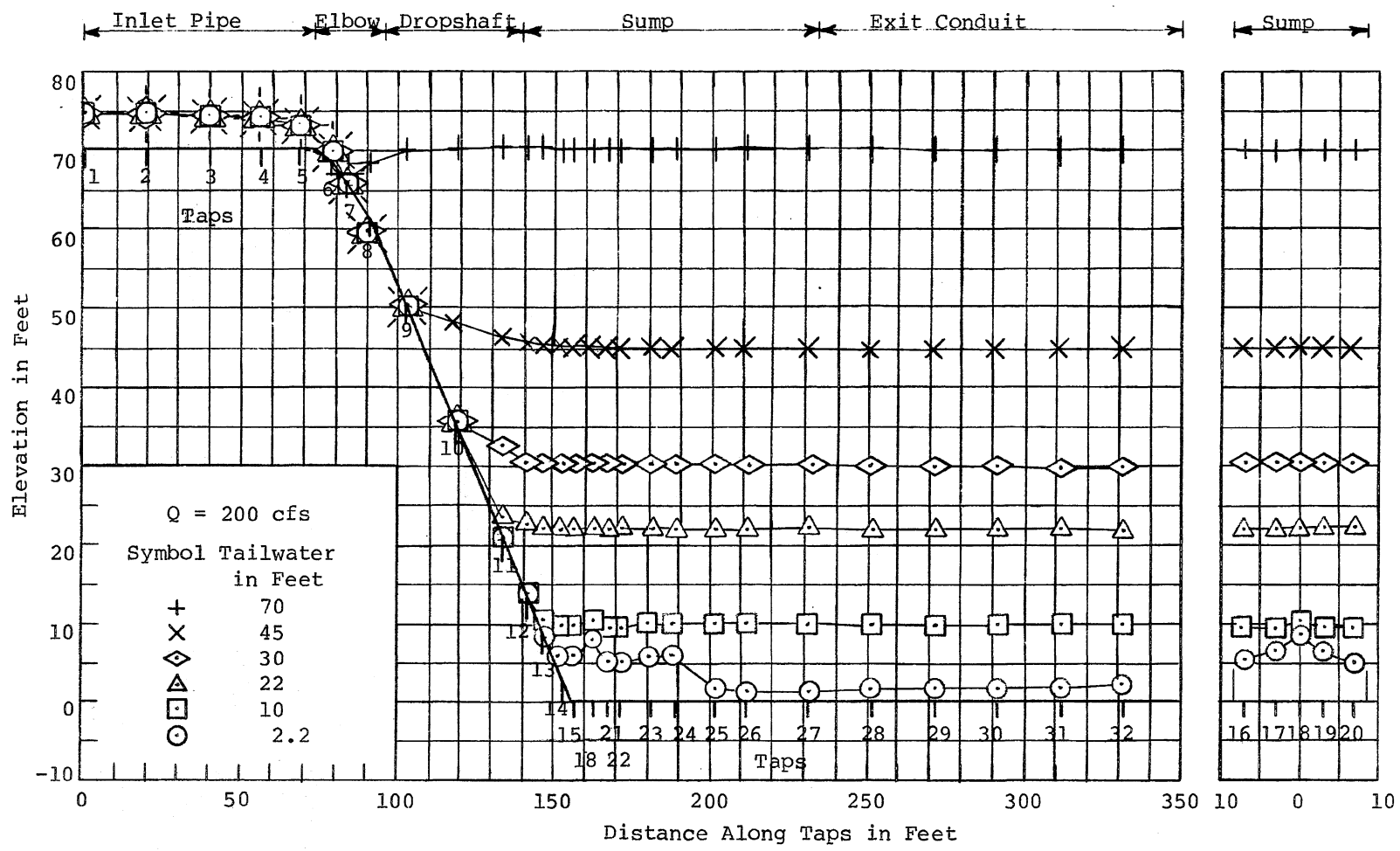
DRAWN WQD	CHECKED	APPROVED
SCALE	DATE 2/7/83	NO. 313A-2322-110



ROCHESTER COMBINED SURGE AND DROPSHAFT
MODEL STUDIES
Type CSD R6 Dropshaft Scale 1:12
Piezometric Pressures

SAINT ANTHONY FALLS HYDRAULIC LABORATORY UNIVERSITY OF MINNESOTA		
DRAWN BB	CHECKED	APPROVED
SCALE	DATE 1/11/83	NO. 313A2322-81

CHART 81

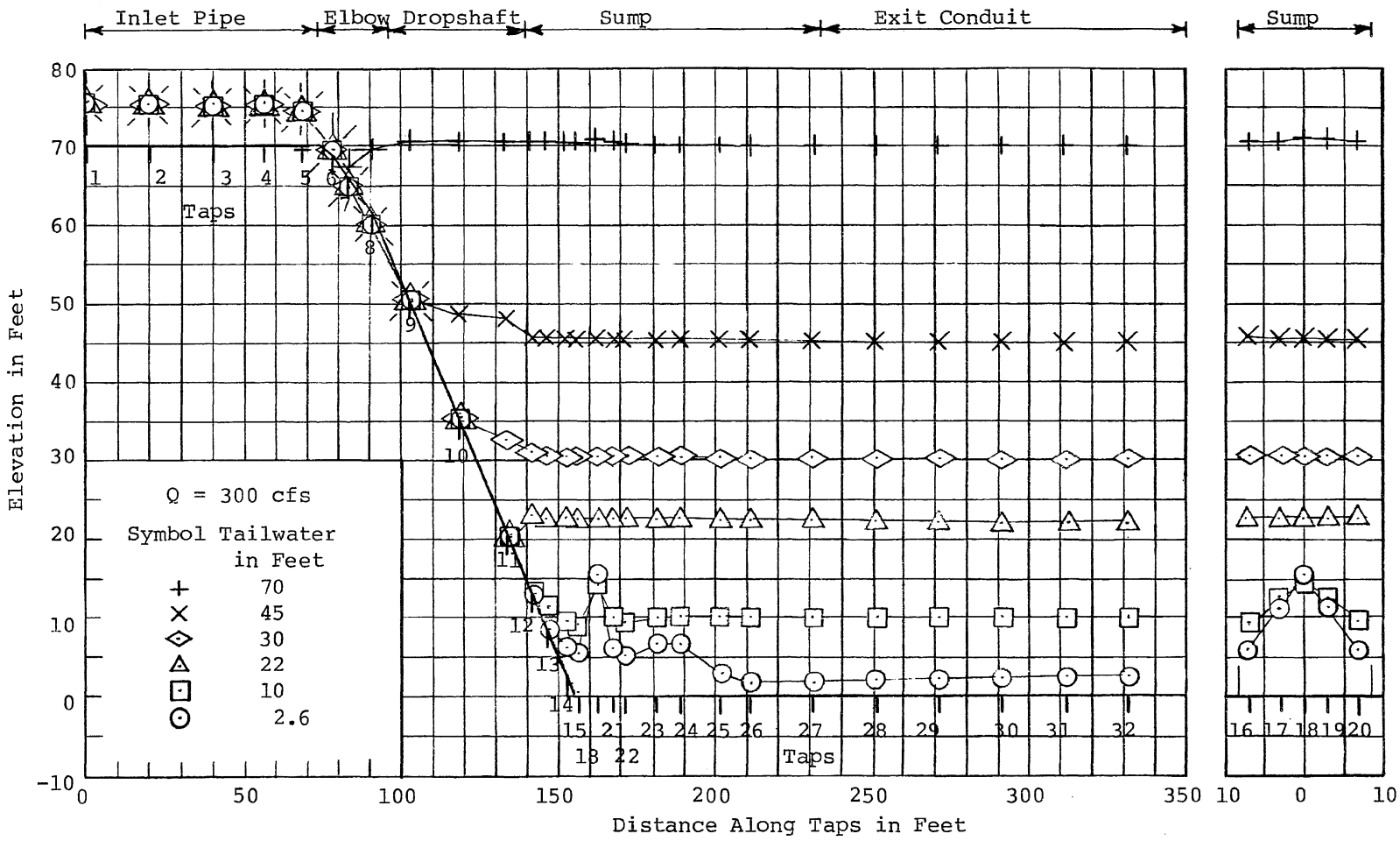


ROCHESTER COMBINED SURGE AND DROPSHAFT
MODEL STUDIES
Type CSD R6 Dropshaft Scale 1:12
Piezometric Pressures

SAINT ANTHONY FALLS HYDRAULIC LABORATORY
UNIVERSITY OF MINNESOTA

DRAWN BB	CHECKED	APPROVED
SCALE	DATE 1/11/82	NO. 313A2322-82

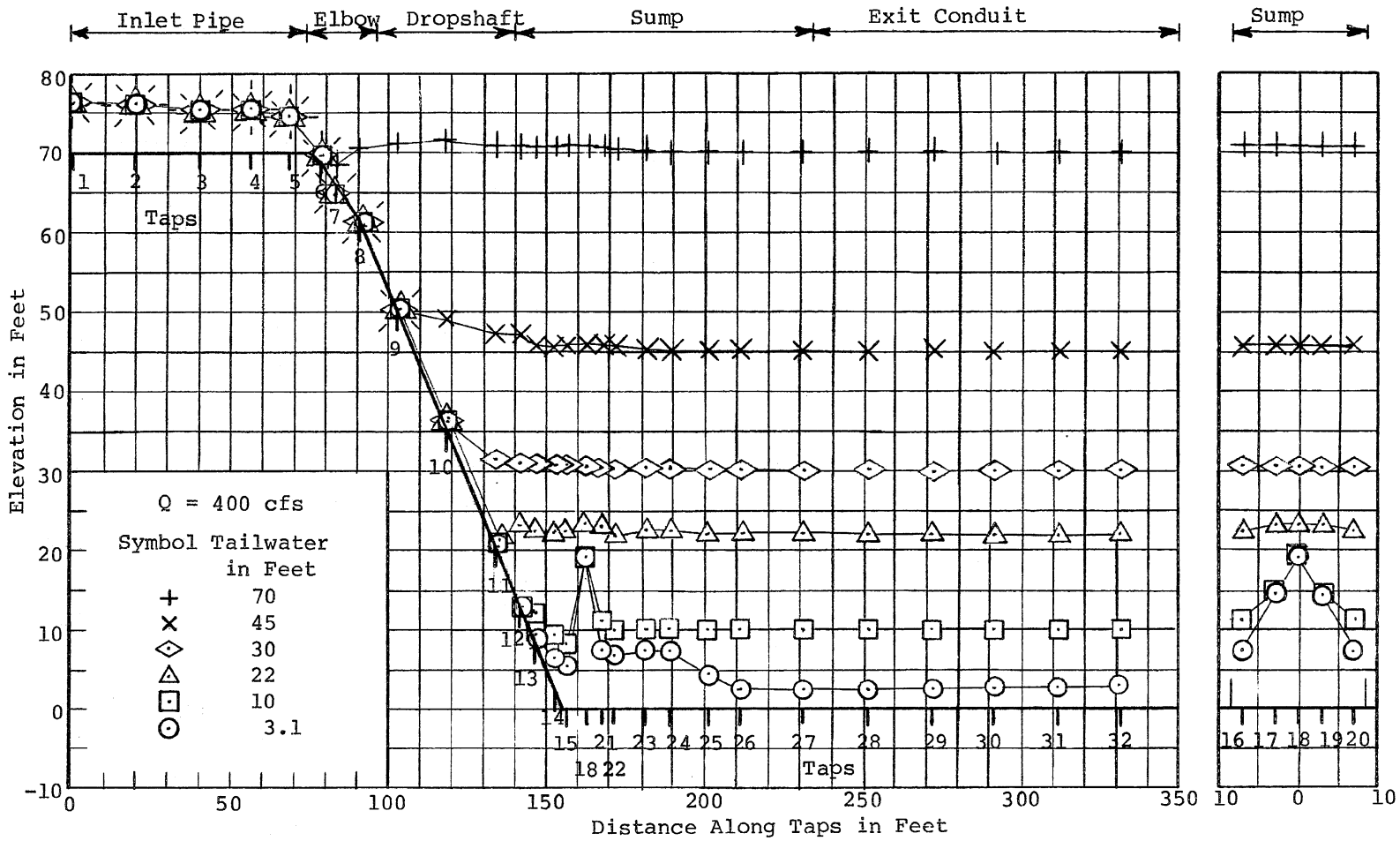
CHART 82



ROCHESTER COMBINED SURGE AND DROPSHAFT
MODEL STUDIES
Type CSD R6 Dropshaft Scale 1:12
Piezometric Pressures

SAINT ANTHONY FALLS HYDRAULIC LABORATORY UNIVERSITY OF MINNESOTA		
DRAWN BB	CHECKED	APPROVED
SCALE	DATE 1/11/83	NO. 313A2322-83

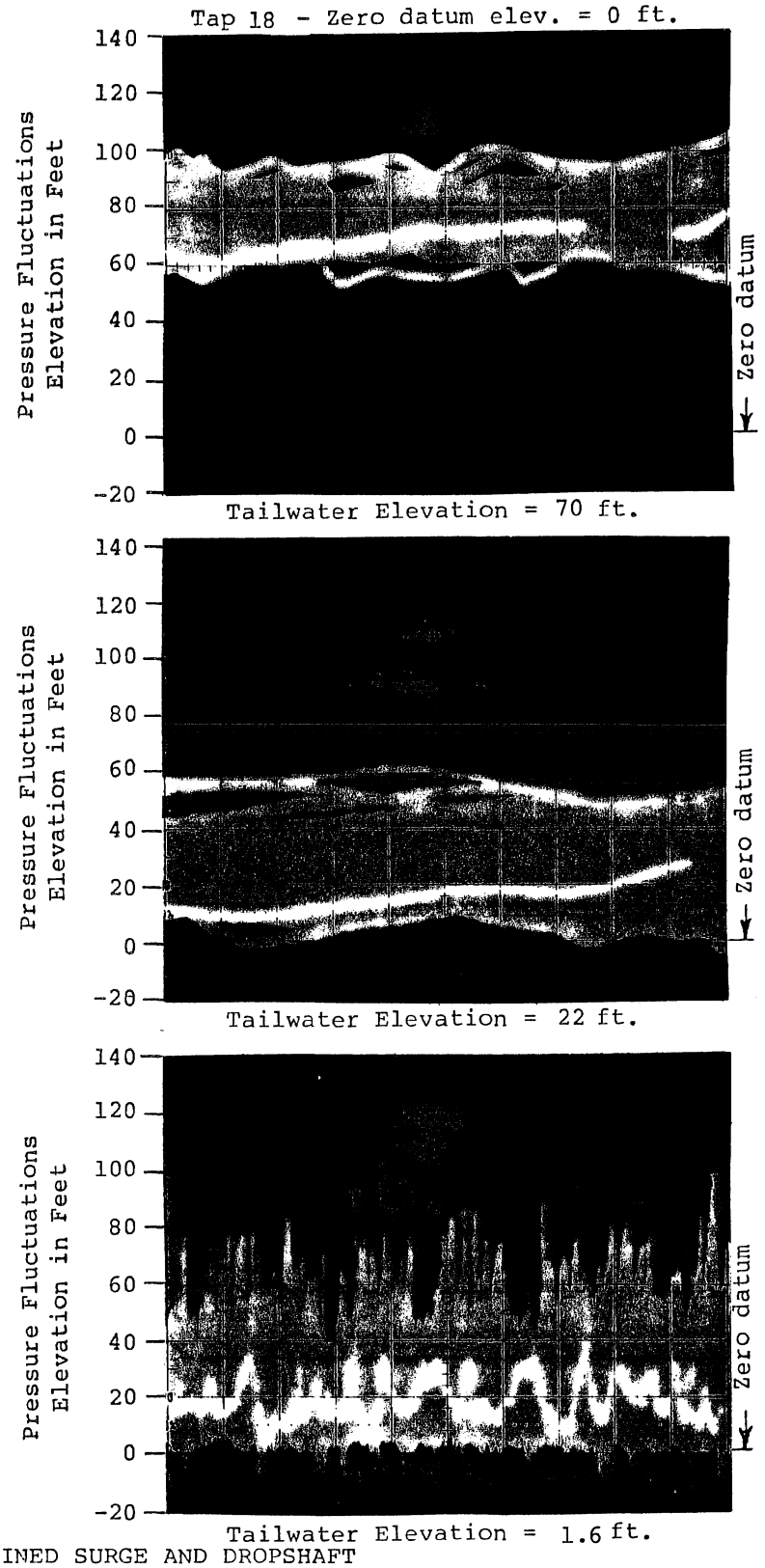
CHART 83



ROCHESTER COMBINED SURGE AND DROPSHAFT
MODEL STUDIES
Type CSD R6 Dropshaft Scale 1:12
Piezometric Pressures

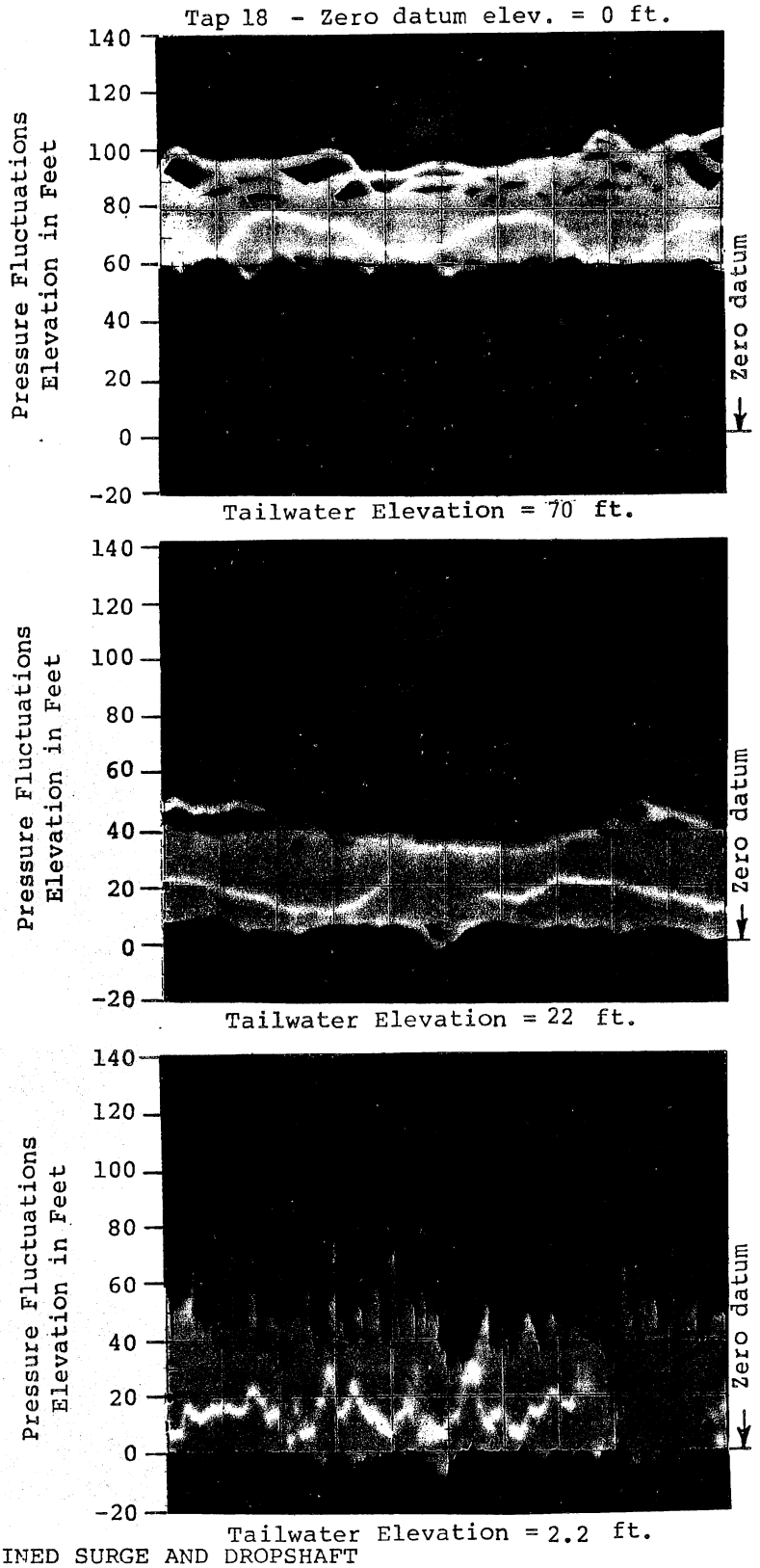
SAINT ANTHONY FALLS HYDRAULIC LABORATORY UNIVERSITY OF MINNESOTA		
DRAWN BB	CHECKED	APPROVED
SCALE	DATE 1/11/83	NO. 313A2322-84

CHART 84



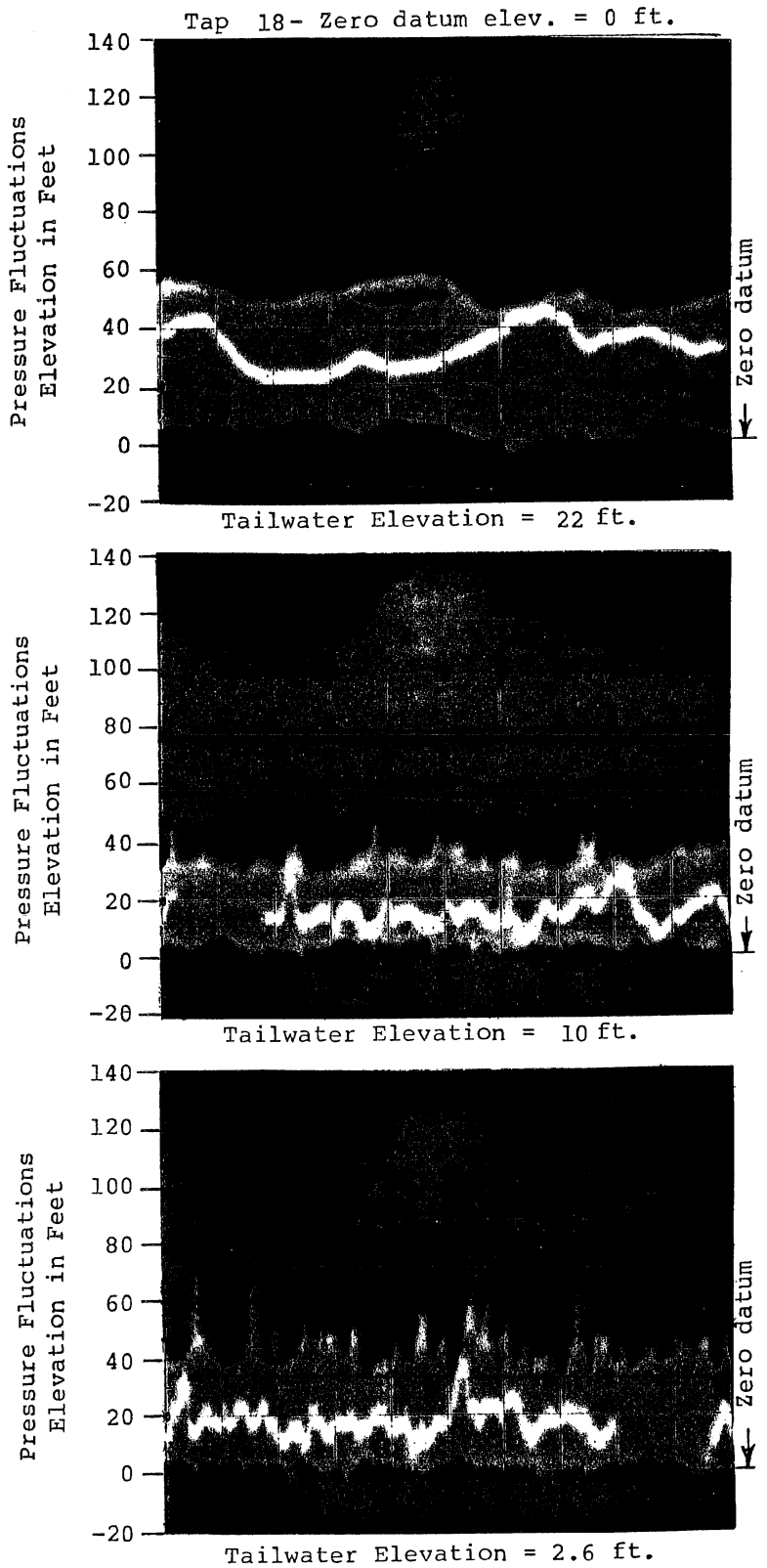
ROCHESTER COMBINED SURGE AND DROPSHAFT
MODEL STUDIES
Type CSD R6 Dropshaft Scale 1:12
Typical Pressure Fluctuations
Q = 100 cfs
Model time of record = 1 minute

SAINT ANTHONY FALLS HYDRAULIC LABORATORY UNIVERSITY OF MINNESOTA		
DRAWN WQD	CHECKED BB	APPROVED
SCALE	DATE 12/9/82	NO 313A2322- 8



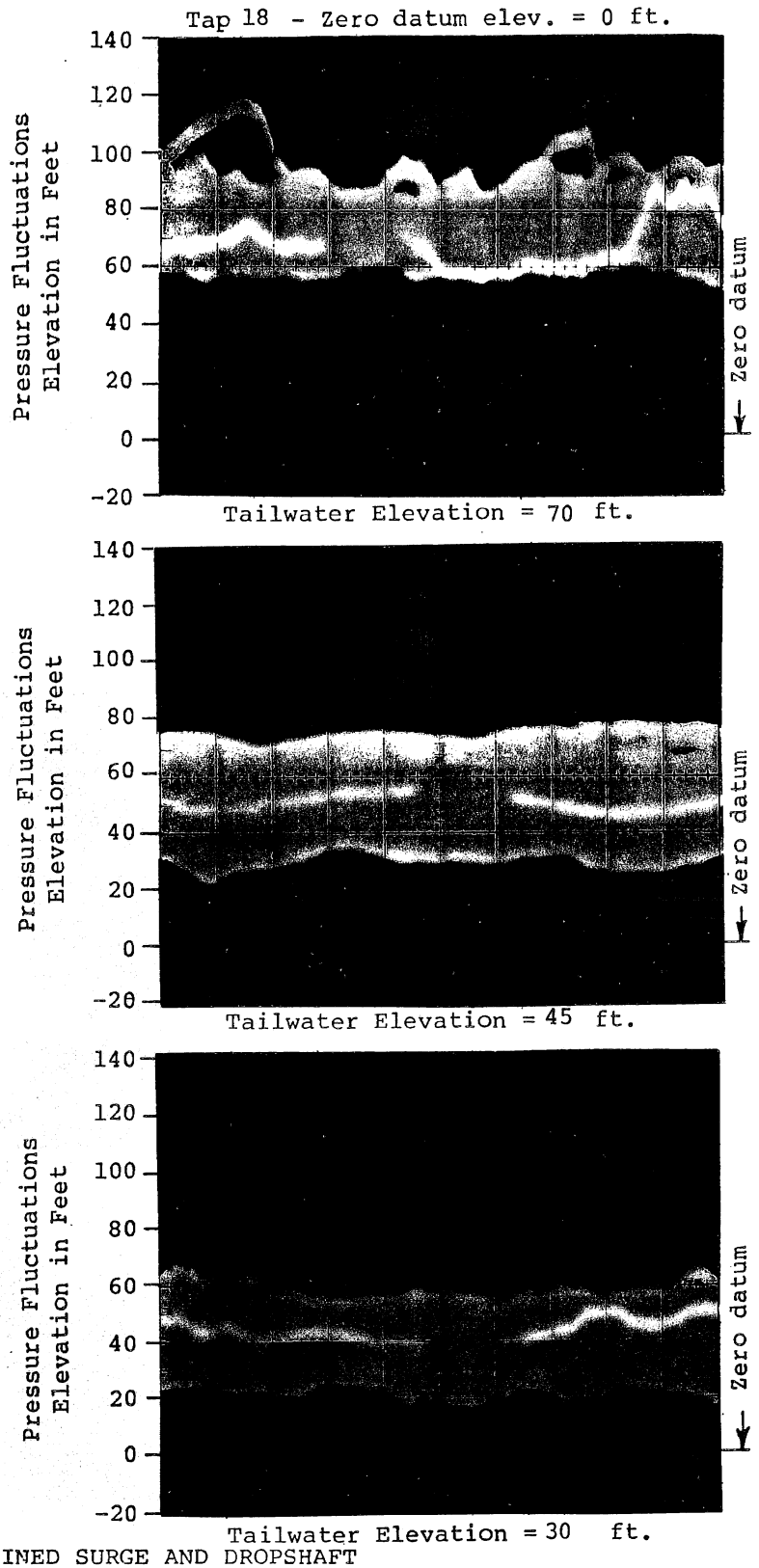
ROCHESTER COMBINED SURGE AND DROPSHAFT
MODEL STUDIES
Type CSD R6 Dropshaft Scale 1:12
Typical Pressure Fluctuations
Q = 200 cfs
Model time of record = 1 minute

SAINT ANTHONY FALLS HYDRAULIC LABORATORY UNIVERSITY OF MINNESOTA		
DRAWN WQD	CHECKED BB	APPROVED
SCALE	DATE 12/9/82	NO. 313A2322-9



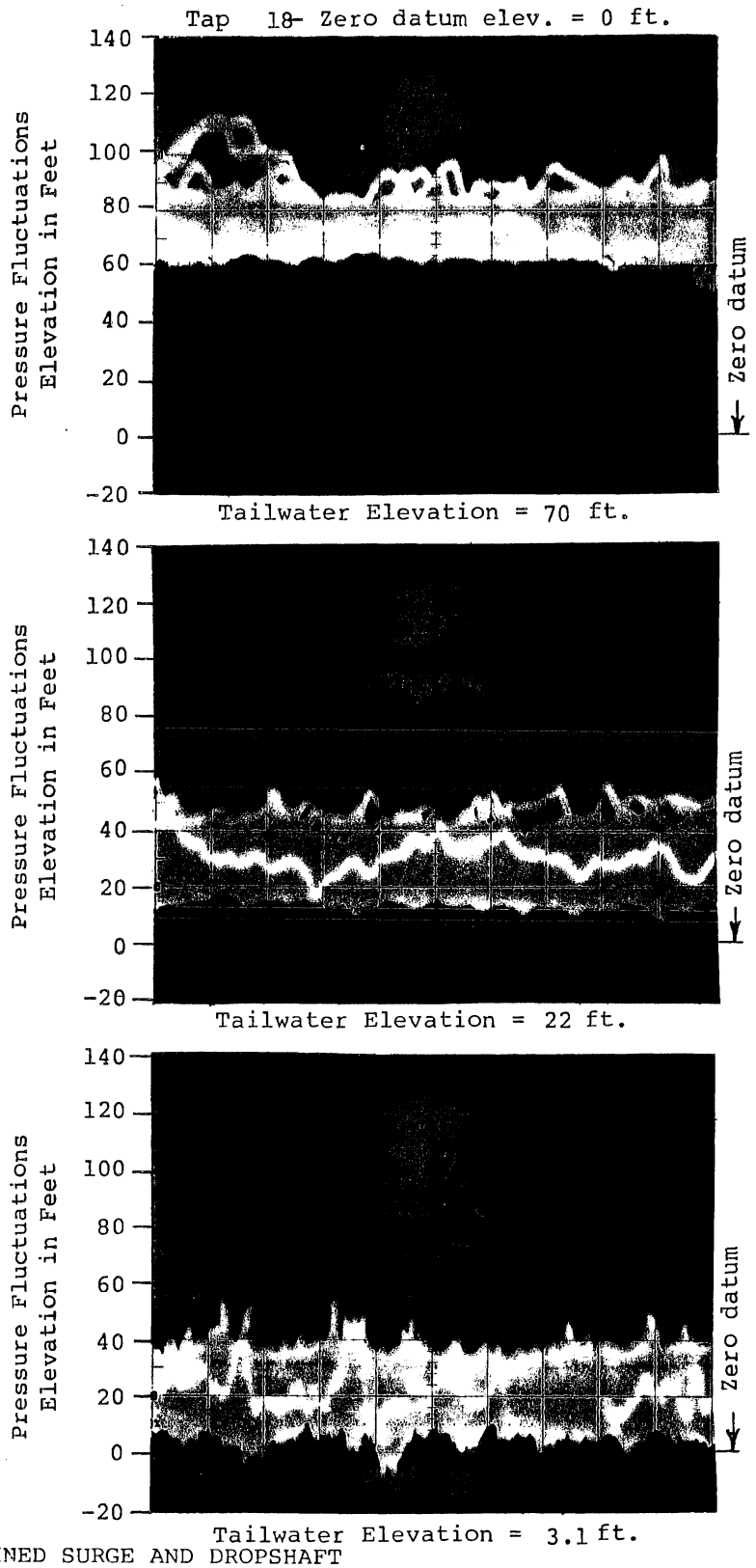
ROCHESTER COMBINED SURGE AND DROPSHAFT
MODEL STUDIES
Type CSD R6 Dropshaft Scale 1:12
Typical Pressure Fluctuations
Q = 300 cfs
Model time of record = 1 minute

SAINT ANTHONY FALLS HYDRAULIC LABORATORY UNIVERSITY OF MINNESOTA		
DRAWN WQD	CHECKED BB	APPROVED
SCALE	DATE 12/9/82	NO 313A2322-11



ROCHESTER COMBINED SURGE AND DROPSHAFT
MODEL STUDIES
Type CSD R6 Dropshaft Scale 1:12
Typical Pressure Fluctuations
Q = 300 cfs
Model time of record = 1 minute

SAINT ANTHONY FALLS HYDRAULIC LABORATORY UNIVERSITY OF MINNESOTA		
DRAWN WQD	CHECKED BB	APPROVED
SCALE	DATE 12/9/82	NO 313A2322-10

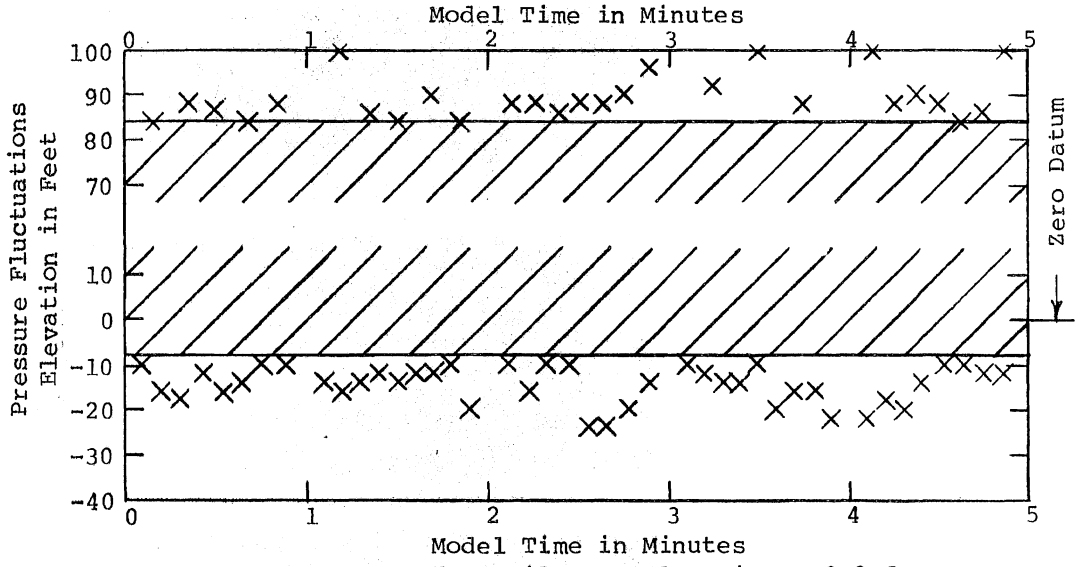


ROCHESTER COMBINED SURGE AND DROPSHAFT
MODEL STUDIES
Type CSD R6 Dropshaft Scale 1:12
Typical Pressure Fluctuations
Q = 400 cfs
Model time of record = 1 minute

SAINT ANTHONY FALLS HYDRAULIC LABORATORY
UNIVERSITY OF MINNESOTA

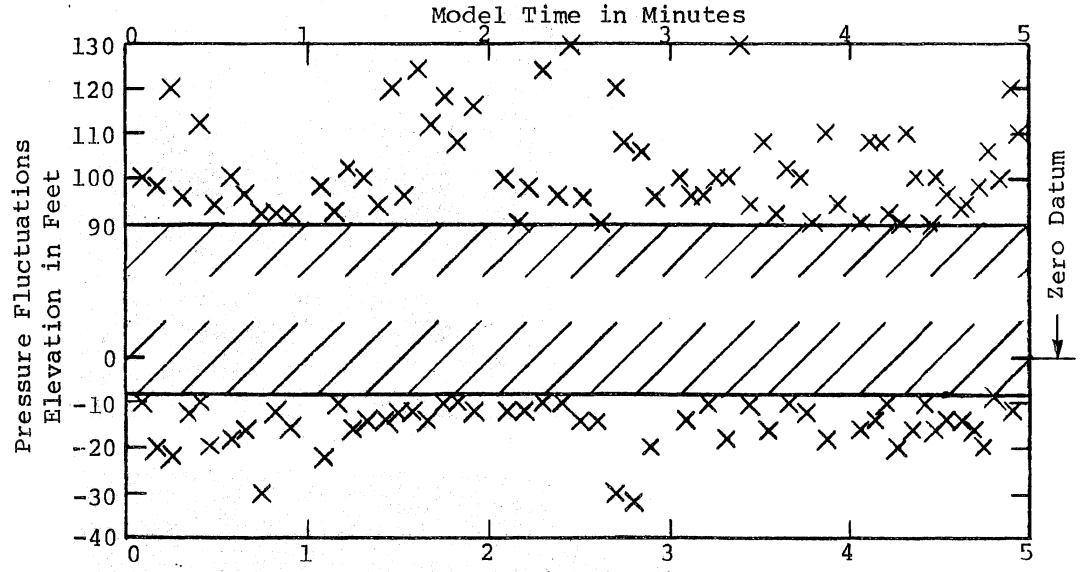
DRAWN WQD	CHECKED BB	APPROVED
SCALE	DATE 12/9/82	NO 313A2322-12

Tap 18 - Zero datum elev. = 0 ft.



Model Time in Minutes

Q = 200 cfs, Tailwater Elevation = 2.2 ft.



Model Time in Minutes

Q = 100 cfs, Tailwater Elevation = 1.6 ft.

× Visually observed readings

Range from oscilloscope photos, Model time of record = 1 minute

ROCHESTER COMBINED SURGE AND DROPSHAFT MODEL STUDIES

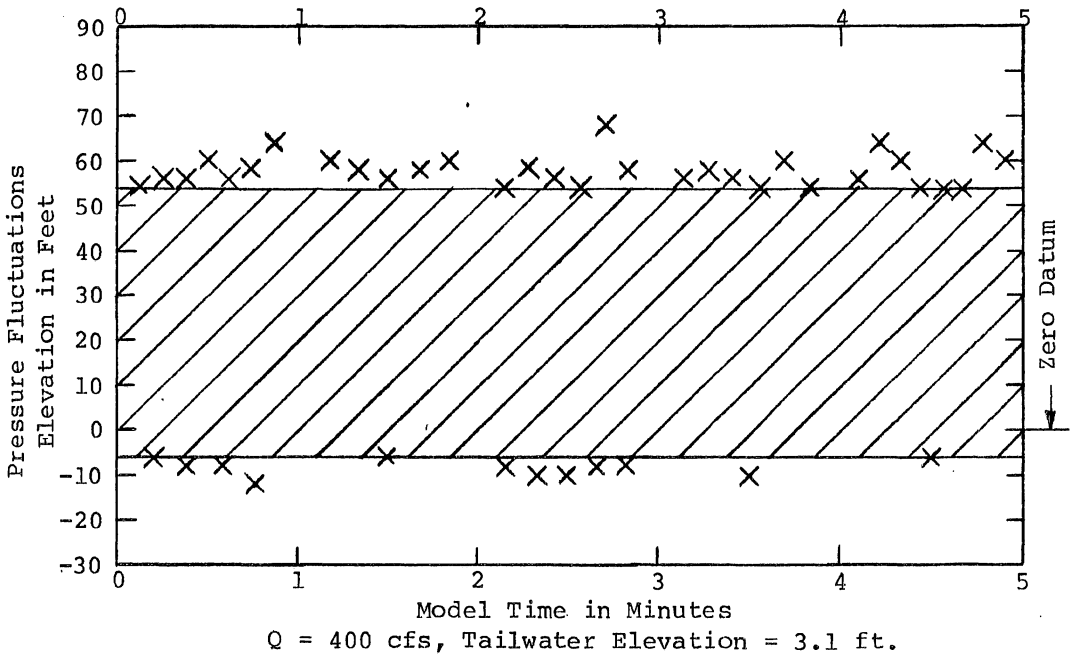
Type CSD R6 Dropshaft Scale 1:12

Typical Pressure Fluctuations

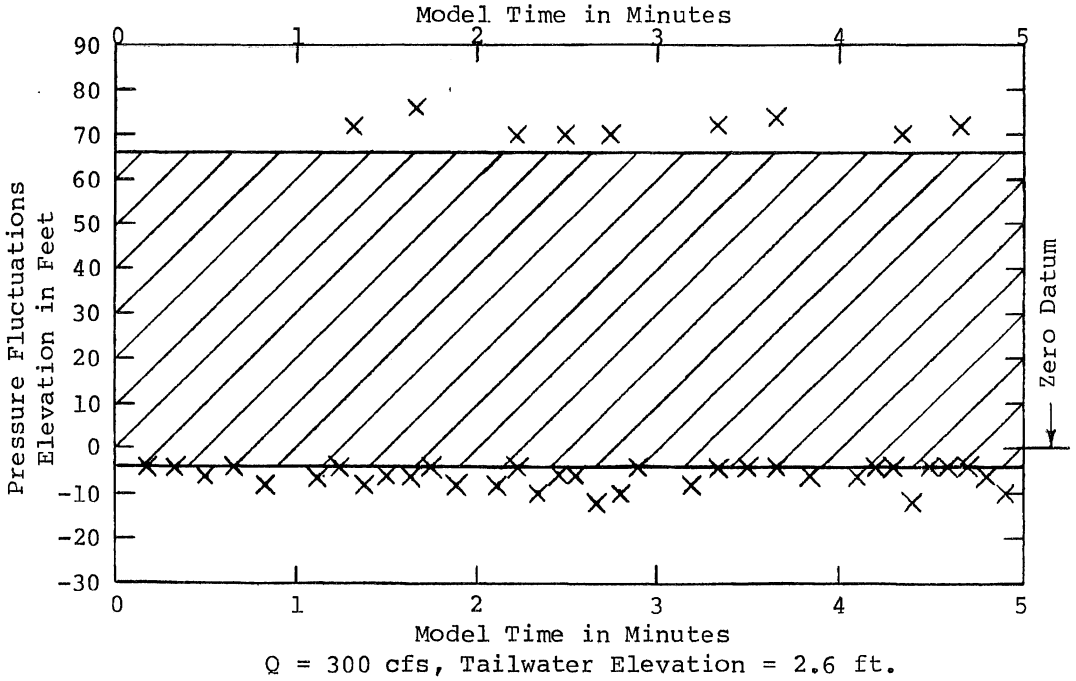
SAINT ANTHONY FALLS HYDRAULIC LABORATORY
UNIVERSITY OF MINNESOTA

DRAWN BB	CHECKED MAB	APPROVED
SCALE	DATE 1/17/83	NO. 313A2322-99

Tap 18 - Zero datum elev. = 0 ft.



Q = 400 cfs, Tailwater Elevation = 3.1 ft.



Q = 300 cfs, Tailwater Elevation = 2.6 ft.

× Visually observed readings

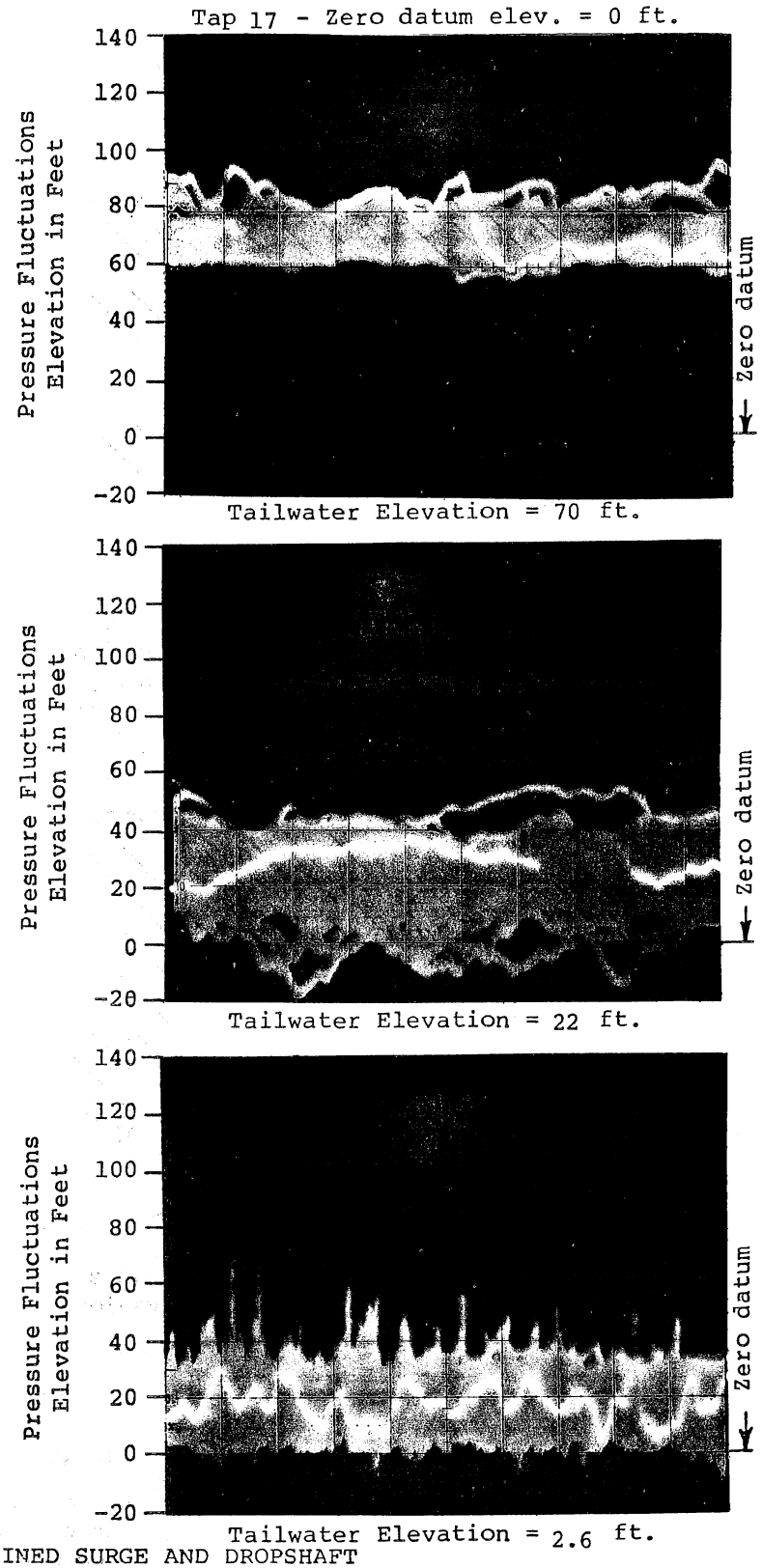
Range from oscilloscope photos, Model time of record = 1 minute

ROCHESTER COMBINED SURGE AND DROPSHAFT MODEL STUDIES

Type CSD R6 Dropshaft Scale 1:12

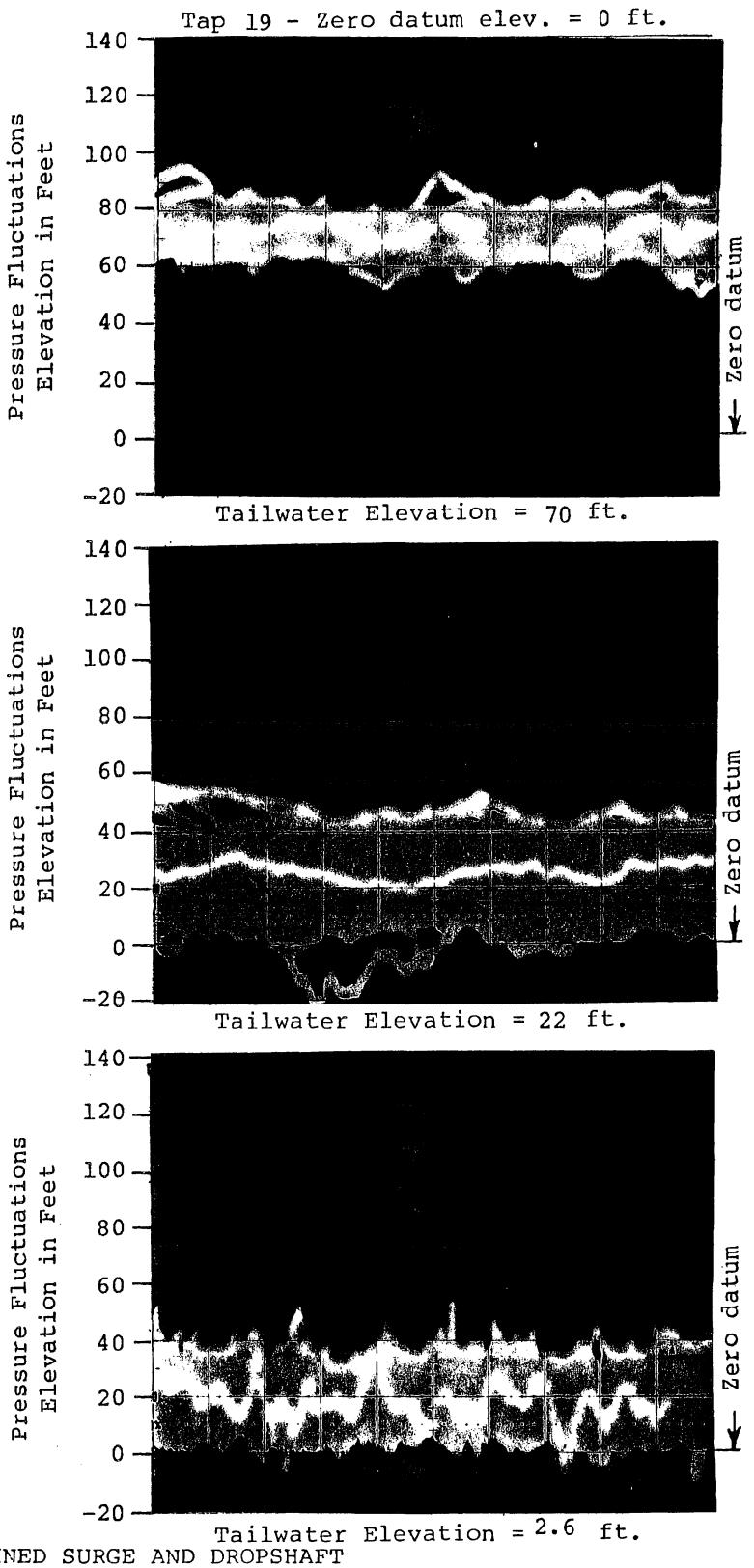
Typical Pressure Fluctuations

SAINT ANTHONY FALLS HYDRAULIC LABORATORY UNIVERSITY OF MINNESOTA		
DRAWN BB	CHECKED	APPROVED
SCALE	DATE 1/17/83	NO. 313A2322-100



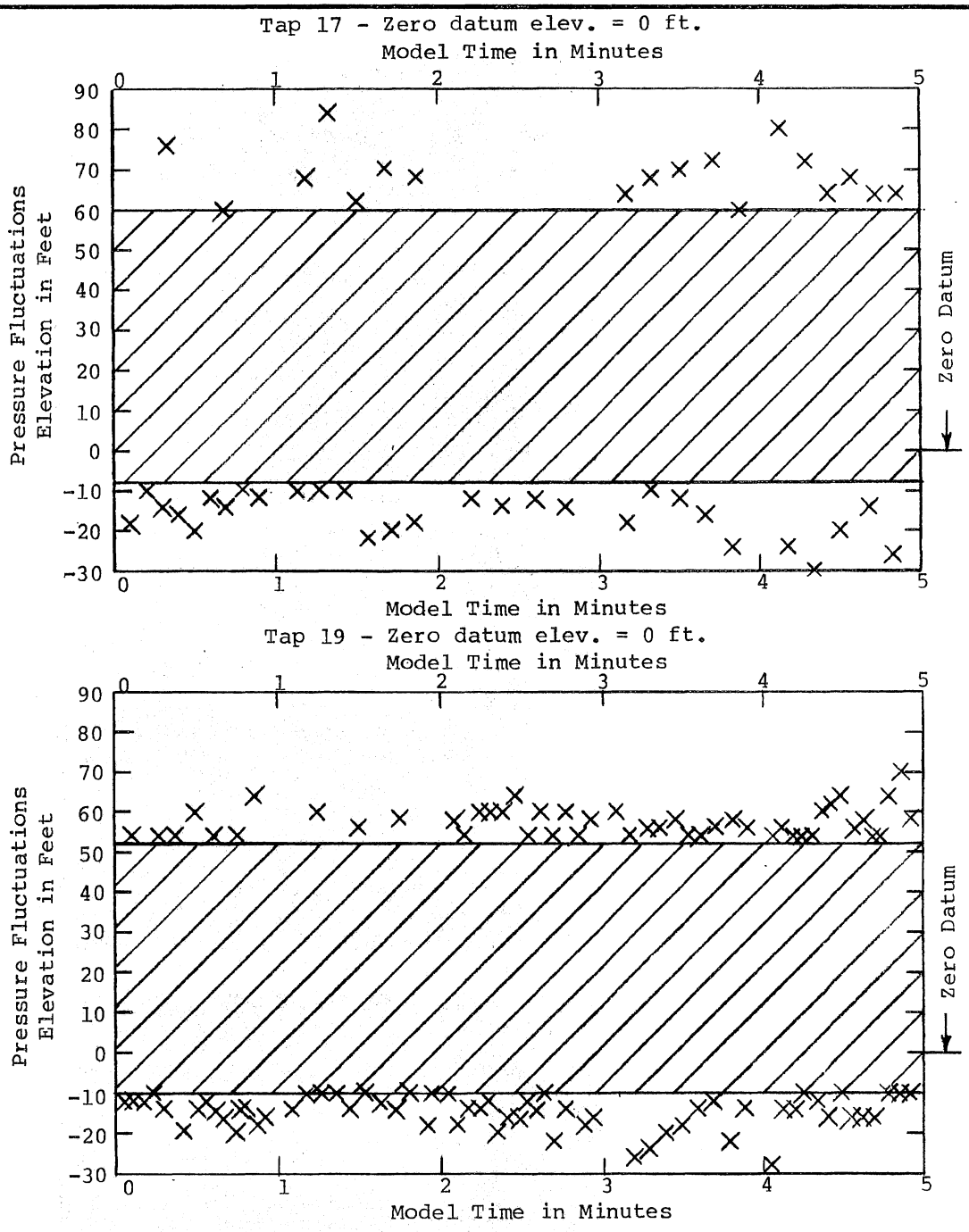
ROCHESTER COMBINED SURGE AND DROPSHAFT
MODEL STUDIES
Type CSD R6 Dropshaft Scale 1:12
Typical Pressure Fluctuations
Q = 300 cfs
Model time of record = 1 minute

SAINT ANTHONY FALLS HYDRAULIC LABORATORY UNIVERSITY OF MINNESOTA		
DRAWN WQD	CHECKED BB	APPROVED
SCALE	DATE 12/9/82	NO 313A2322- 13



ROCHESTER COMBINED SURGE AND DROPSHAFT
MODEL STUDIES
Type CSD R6 Dropshaft Scale 1:12
Typical Pressure Fluctuations
Q = 300 cfs
Model time of record = 1 minute

SAINT ANTHONY FALLS HYDRAULIC LABORATORY UNIVERSITY OF MINNESOTA		
DRAWN WQD	CHECKED BB	APPROVED
SCALE	DATE 12/9/82	NO 313A2322-14



× Visually observed readings

Range from oscilloscope photos, Model time of record = 1 minute

ROCHESTER COMBINED SURGE AND DROPSHAFT MODEL STUDIES
Type CSD R6 Dropshaft Scale 1:12
Typical Pressure Fluctuations
Q = 300 cfs, T.W. elev. = 2.6 ft.

SAINT ANTHONY FALLS HYDRAULIC LABORATORY
UNIVERSITY OF MINNESOTA

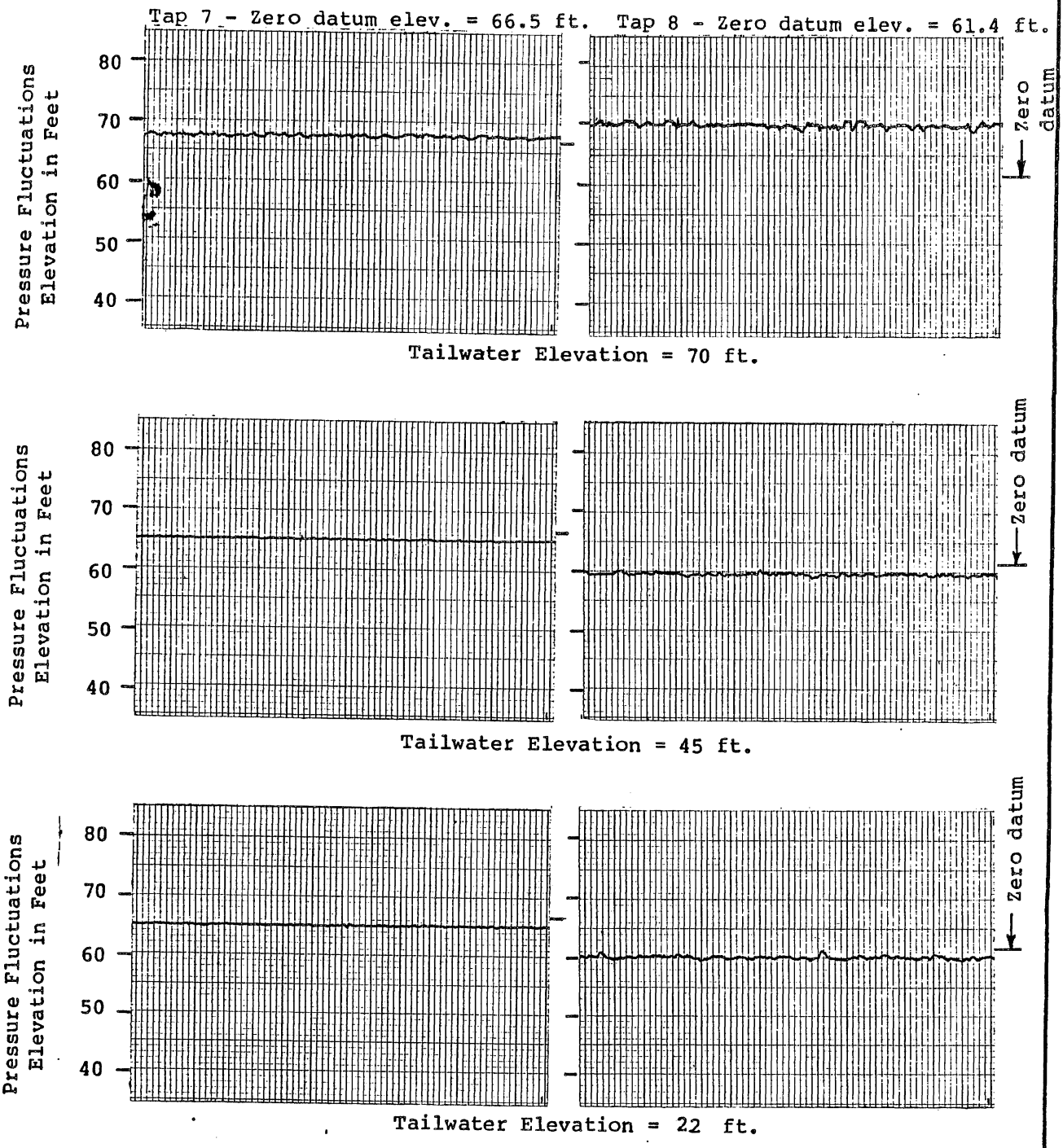
DRAWN BB	CHECKED WHS	APPROVED
SCALE	DATE 1/17/83	NO. 313A2322-98

Q cfs	T.W. El. ft	Av. Piez. Press.-ft	Range from Photos Max.-ft	Range from Photos Min.-ft	Observed Readings Max.-ft	Observed Readings Min.-ft
		Tap 17 Elevation = 0 ft				
300	2.6	11.4	60	-8	84	-30
300	22	22.4	56	-20		
300	70	70.6	98	54		
		Tap 18 Elevation = 0 ft				
100	1.6	9.5	90	-8	130	-32
100	22	22.1	62	-4		
100	70	70.1	106	52		
200	2.2	8.7	84	-8	100	-24
200	22	22.2	52	-2		
200	70	70.4	108	54		
300	2.6	15.4	66	-4	76	-12
300	10	14.1	48	0		
300	22	22.4	60	-4		
300	30	30.4	68	16		
300	45	45.5	80	22		
300	70	70.9	120	52		
400	3.1	19.1	54	-6	68	-12
400	22	23.1	60	8		
400	70	71.1	114	58		
		Tap 19 Elevation = 0 ft				
300	2.6	11.4	52	-10	70	-28
300	22	22.4	58	-24		
300	70	70.9	98	50		

ROCHESTER COMBINED SURGE AND DROPSHAFT
MODEL STUDIES
Type CSD R6 Dropshaft Scale 1:12
Summary of Typical
Pressure Fluctuations

SAINT ANTHONY FALLS HYDRAULIC LABORATORY
UNIVERSITY OF MINNESOTA

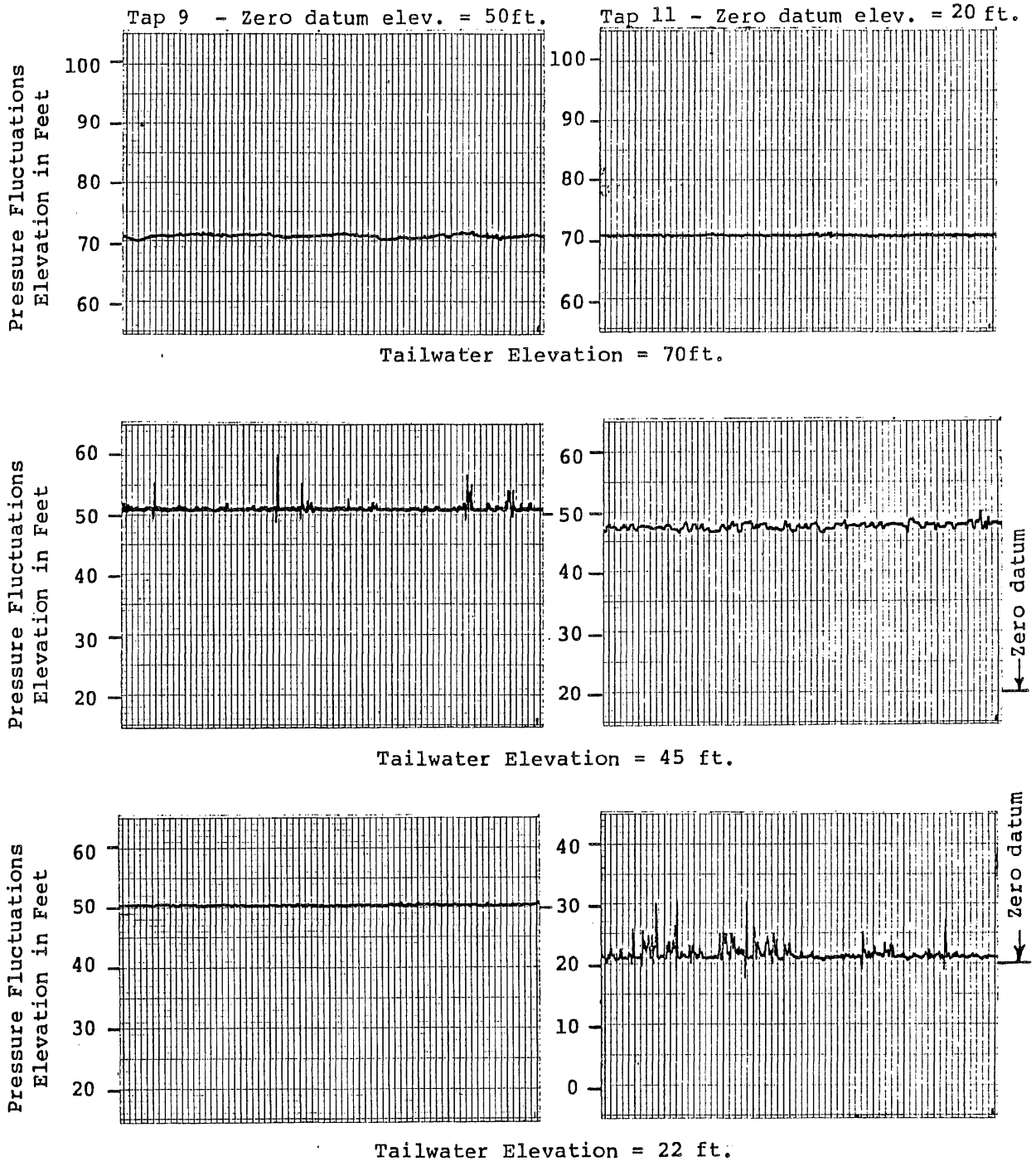
DRAWN WQD	CHECKED BB	APPROVED
SCALE	DATE 1-7-83	NO. 313A2322-71



ROCHESTER COMBINED SURGE AND DROPSHAFT
MODEL STUDIES
Type CSD R6 Dropshaft Scale 1:12
Typical Pressure Fluctuations
Q = 300 cfs

SAINT ANTHONY FALLS HYDRAULIC LABORATORY
UNIVERSITY OF MINNESOTA

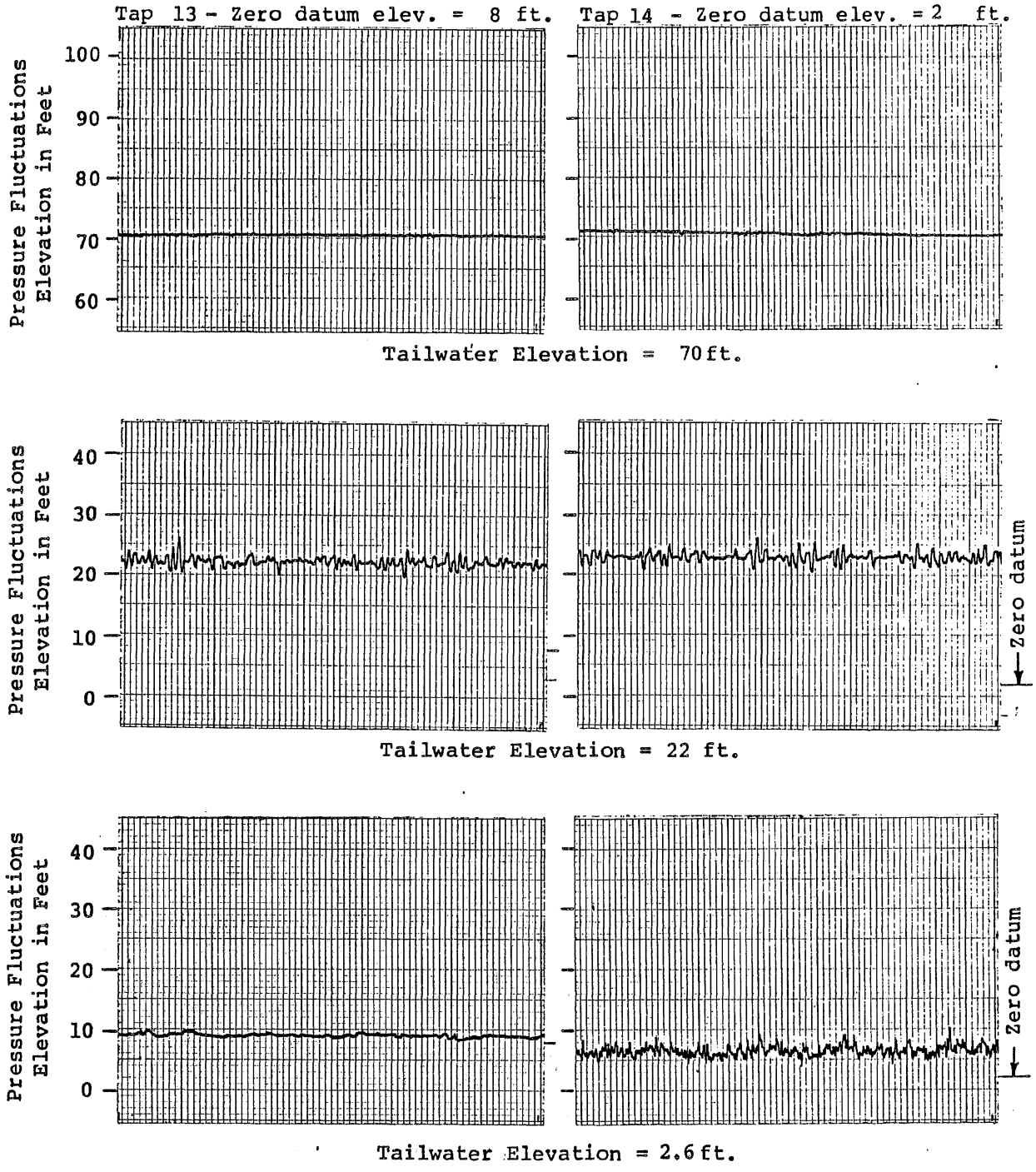
DRAWN BB	CHECKED	APPROVED
SCALE	DATE 12/10/82	NO. 313 A2322-37



ROCHESTER COMBINED SURGE AND DROPSHAFT
MODEL STUDIES
Type CSD R6 Dropshaft Scale 1:12
Typical Pressure Fluctuations
Q = 300 cfs

SAINT ANTHONY FALLS HYDRAULIC LABORATORY
UNIVERSITY OF MINNESOTA

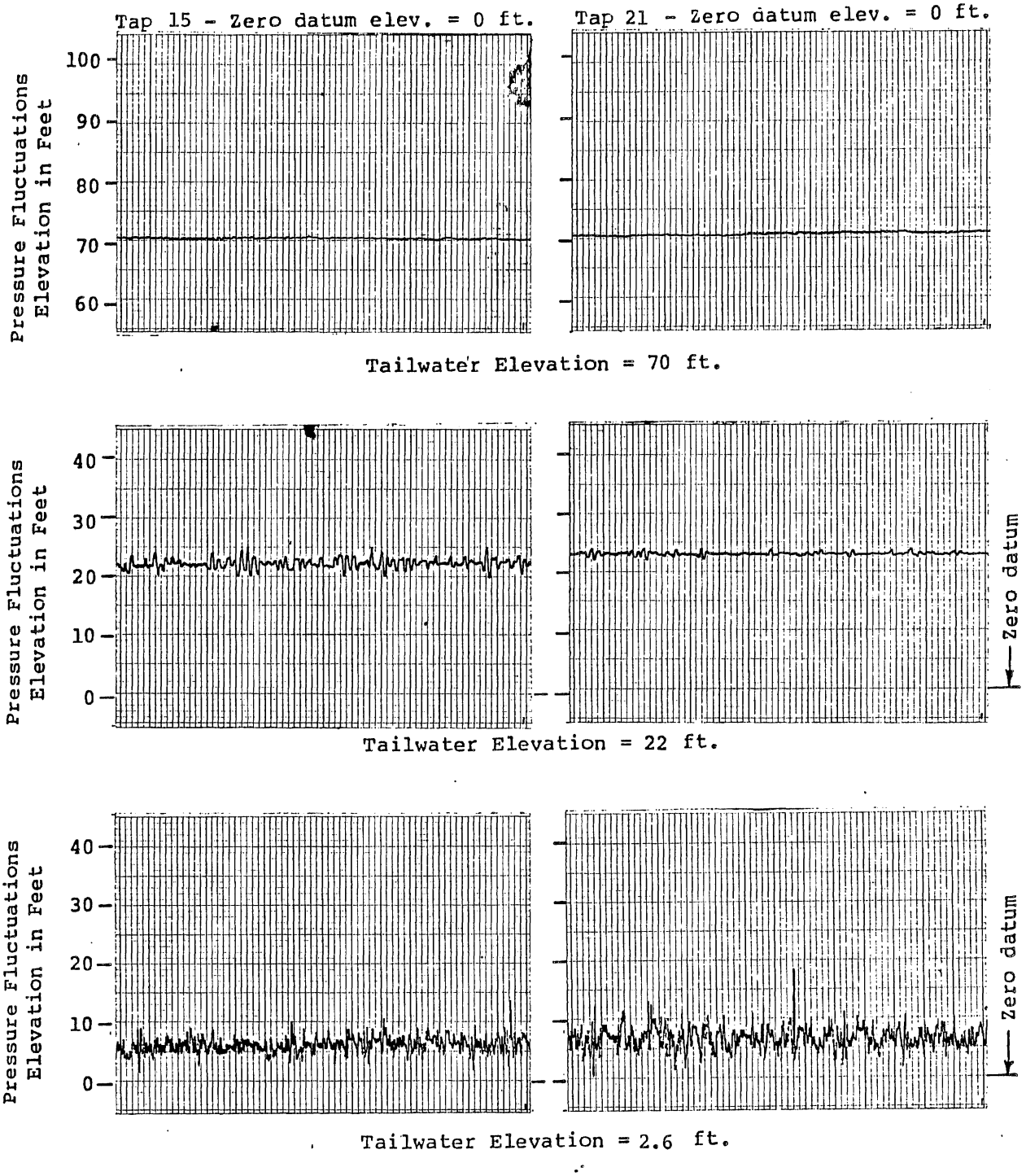
DRAWN BB	CHECKED	APPROVED
SCALE	DATE 12/10/82	NO. 313A2322-41



ROCHESTER COMBINED SURGE AND DROPSHAFT
MODEL STUDIES
TypeCSD R6 Dropshaft Scale 1:12
Typical Pressure Fluctuations
Q = 300cfs

SAINT ANTHONY FALLS HYDRAULIC LABORATORY
UNIVERSITY OF MINNESOTA

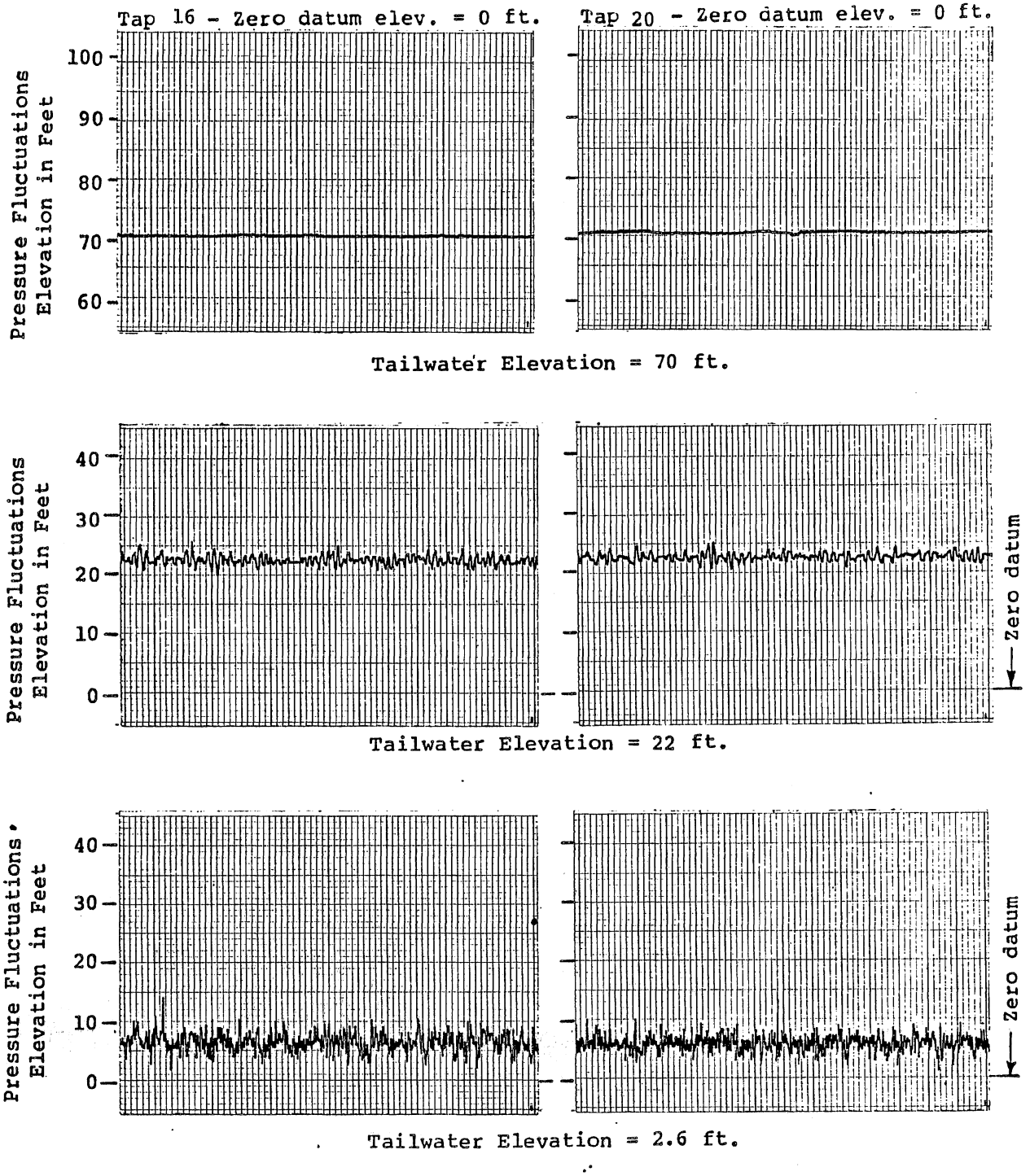
DRAWN BB	CHECKED	APPROVED
SCALE	DATE 12/10/82	NO. 313A2322- 45



ROCHESTER COMBINED SURGE AND DROPSHAFT
MODEL STUDIES
Type CSD R6 Dropshaft Scale 1:12
Typical Pressure Fluctuations
Q = 300 cfs

SAINT ANTHONY FALLS HYDRAULIC LABORATORY
UNIVERSITY OF MINNESOTA

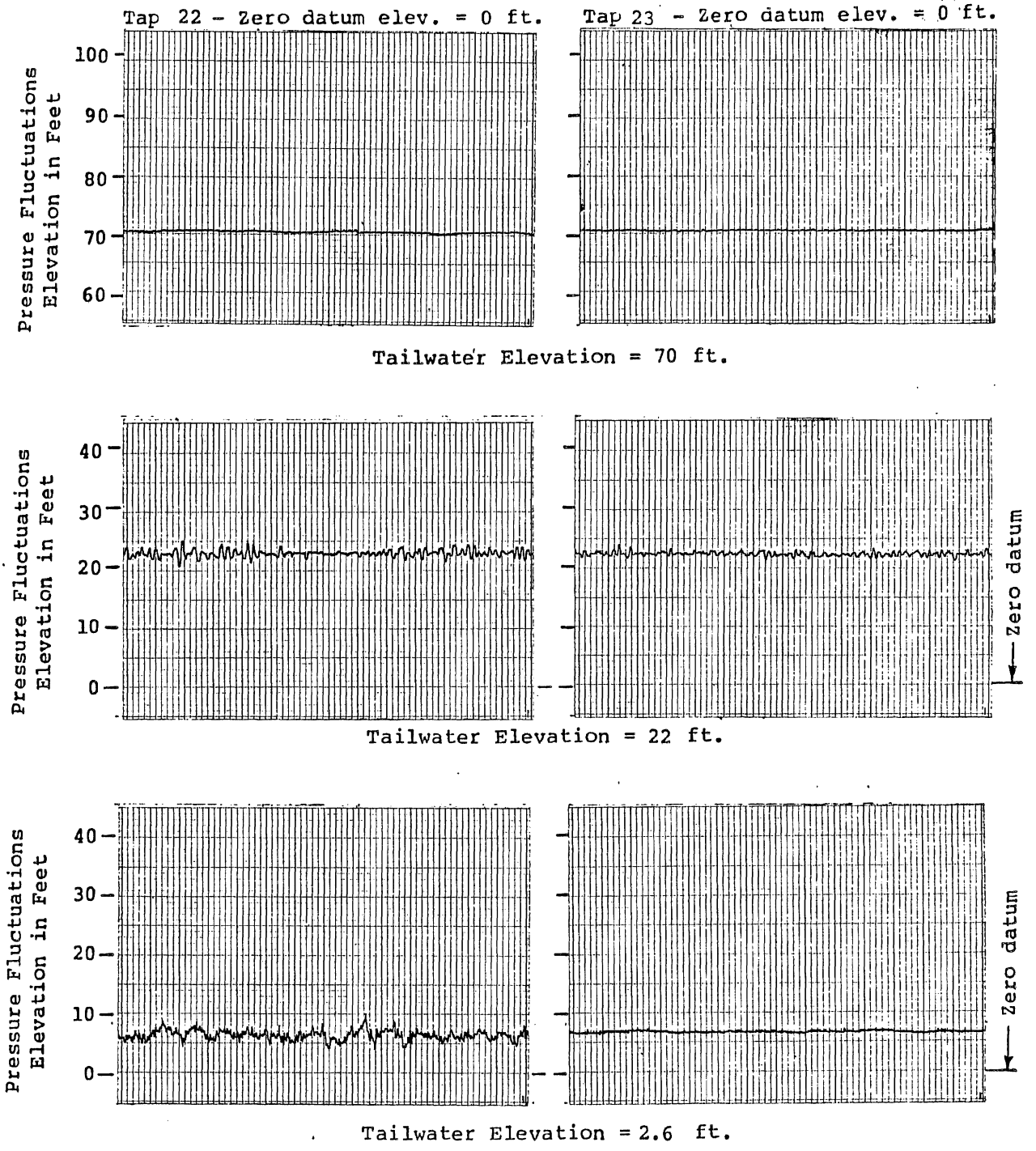
DRAWN BB	CHECKED	APPROVED
SCALE	DATE 12/10/82	NO. 313A2322-61



ROCHESTER COMBINED SURGE AND DROPSHAFT
MODEL STUDIES
Type CSD R6 Dropshaft Scale 1:12
Typical Pressure Fluctuations
Q = 300 cfs

SAINT ANTHONY FALLS HYDRAULIC LABORATORY
UNIVERSITY OF MINNESOTA

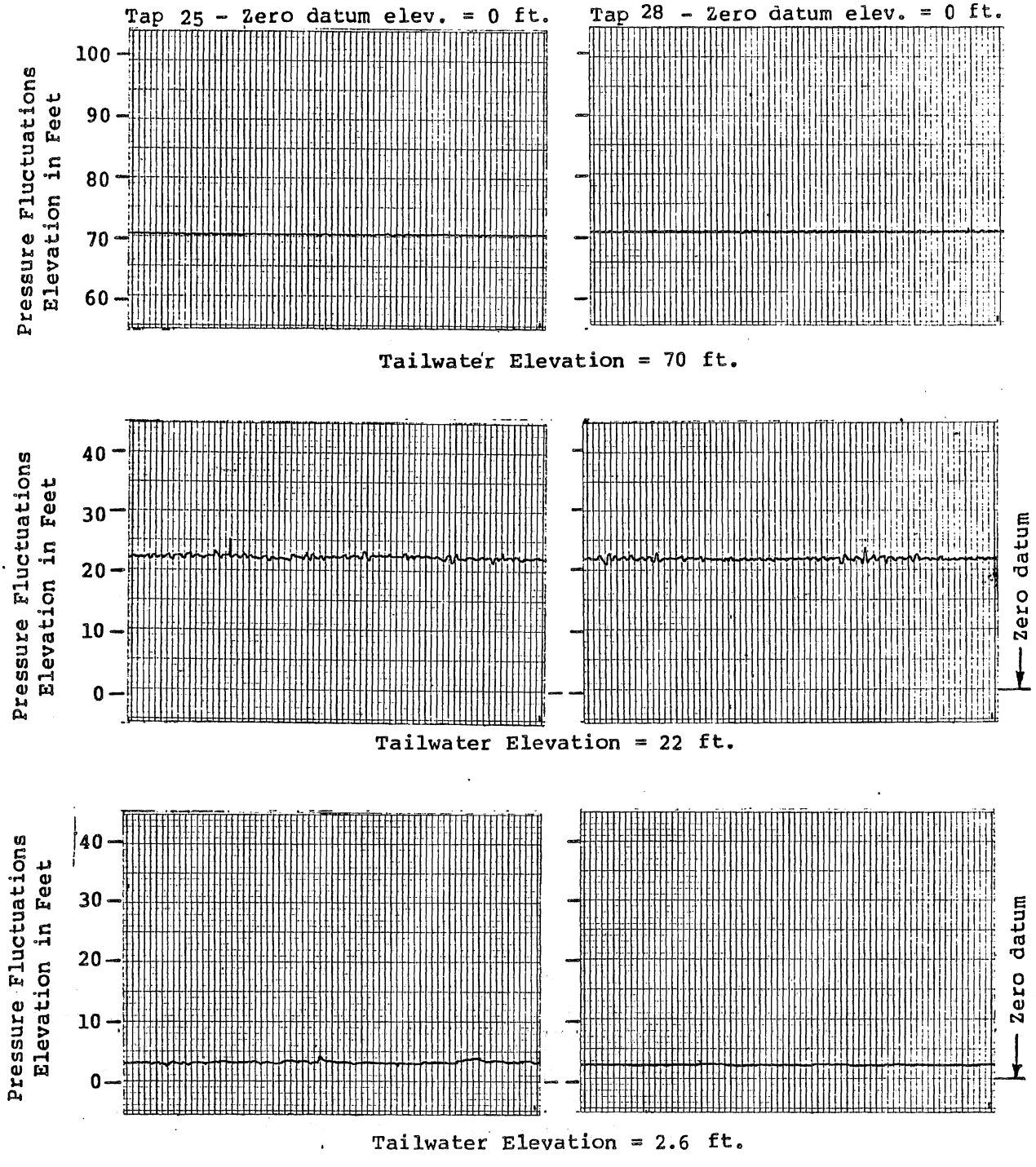
DRAWN BB	CHECKED MDS	APPROVED
SCALE	DATE 12/10/82	NO. 313A2322-62



ROCHESTER COMBINED SURGE AND DROPSHAFT
MODEL STUDIES
Type CSD R6 Dropshaft Scale 1:12
Typical Pressure Fluctuations
Q = 300 cfs

SAINT ANTHONY FALLS HYDRAULIC LABORATORY
UNIVERSITY OF MINNESOTA

DRAWN BB	CHECKED	APPROVED
SCALE	DATE 12/10/82	NO. 313A2322- 63



ROCHESTER COMBINED SURGE AND DROPSHAFT
MODEL STUDIES
Type CSD R6 Dropshaft Scale 1:12
Typical Pressure Fluctuations
Q = 300 cfs

SAINT ANTHONY FALLS HYDRAULIC LABORATORY
UNIVERSITY OF MINNESOTA

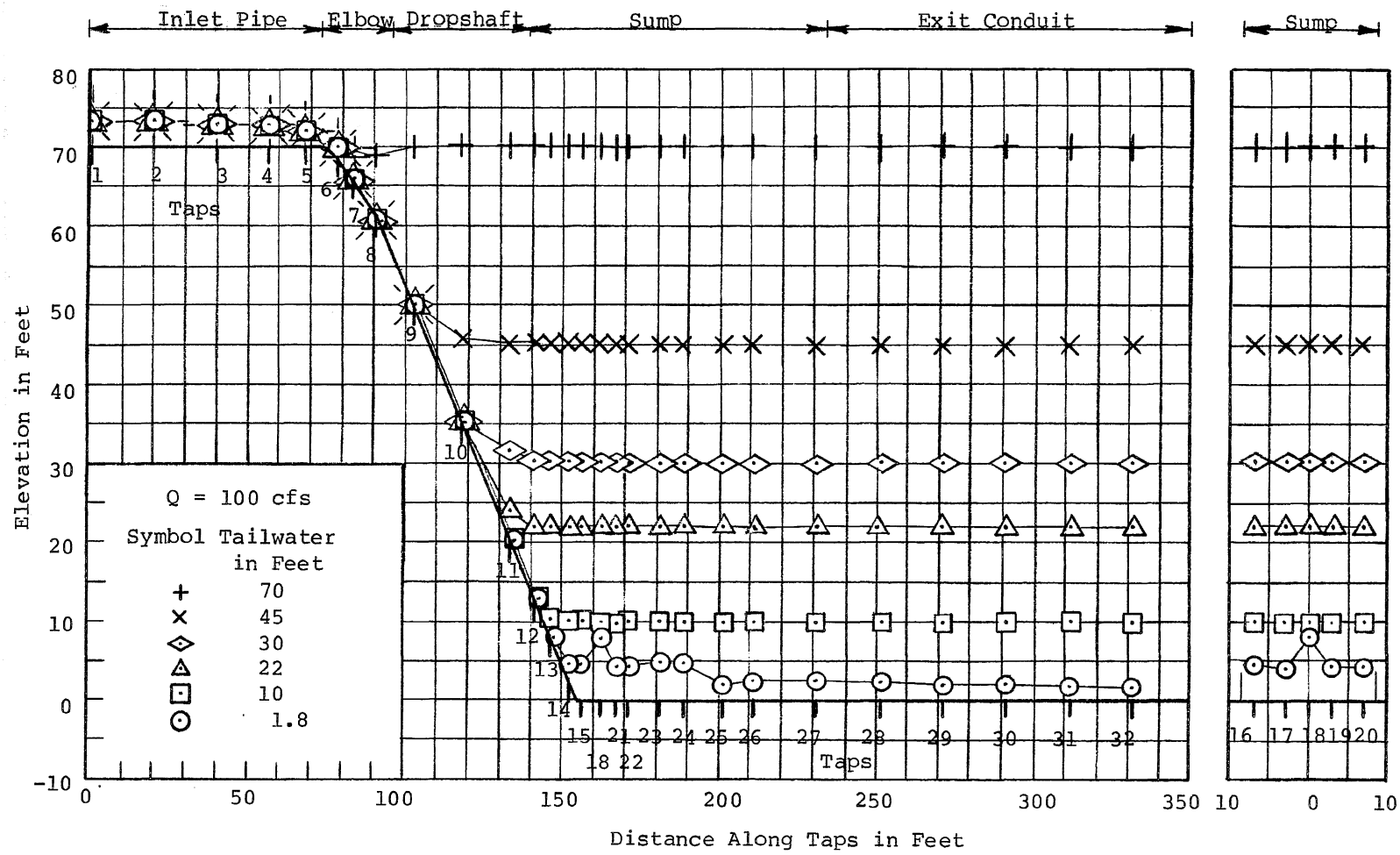
DRAWN BB	CHECKED [illegible]	APPROVED
SCALE	DATE 12/10/82	NO. 313A2322-64

Tap No.	Tap. El. ft	Q cfs	T.W. El. ft	Av. Piez. Press.-ft	Pressure Fluctuations Max.-ft	Min.-ft
7	66.5	300	22	64.9	65.4	64.6
7	66.5	300	45	64.9	65.6	64.8
7	66.5	300	70	67.2	68.8	66.8
8	61.4	300	22	59.8	61.2	59.4
8	61.4	300	45	59.7	60.4	59.0
8	61.4	300	70	69.6	71.0	68.0
9	50	300	22	50.1	51.2	49.8
9	50	300	45	50.5	59.8	48.8
9	50	300	70	70.7	71.8	69.0
11	20	300	22	21.5	30.4	17.8
11	20	300	45	47.0	50.0	45.0
11	20	300	70	70.6	71.6	69.8
13	8	300	2.6	8.7	10.4	8.0
13	8	300	22	22.4	26.2	19.8
13	8	300	70	70.6	71.2	70.0
14	2	300	2.6	6.3	10.2	4.0
14	2	300	22	22.4	26.0	20.4
14	2	300	70	70.6	71.6	69.0
15	0	300	2.6	5.4	13.6	1.6
15	0	300	22	22.4	25.4	19.8
15	0	300	70	70.6	71.0	70.0
16	0	300	2.6	6.1	14.0	-1.2
16	0	300	22	22.4	25.8	19.8
16	0	300	70	70.6	71.0	70.0
20	0	300	2.6	5.8	13.2	-0.8
20	0	300	22	22.4	25.2	20.6
20	0	300	70	70.7	71.8	69.8
21	0	300	2.6	6.2	18.4	-0.2
21	0	300	22	22.4	24.4	22.0
21	0	200	70	70.6	71.2	69.8
22	0	300	2.6	6.1	10.0	2.6
22	0	300	22	22.4	25.0	21.0
22	0	300	70	70.3	71.0	69.8
23	0	300	2.6	6.8	7.4	6.0
23	0	300	22	22.4	24.0	21.2
23	0	300	70	70.3	71.2	69.8
25	0	300	2.6	3.0	4.4	2.6
25	0	300	22	22.2	25.0	21.2
25	0	300	70	70.1	70.8	70.0
28	0	300	2.6	2.1	2.8	2.0
28	0	300	22	22.1	23.8	20.8
28	0	300	70	70.0	70.8	69.8

ROCHESTER COMBINED SURGE AND DROPSHAFT
MODEL STUDIES
Type CSD R6 Dropshaft Scale 1:12
Summary of Typical
Pressure Fluctuations

SAINT ANTHONY FALLS HYDRAULIC LABORATORY
UNIVERSITY OF MINNESOTA

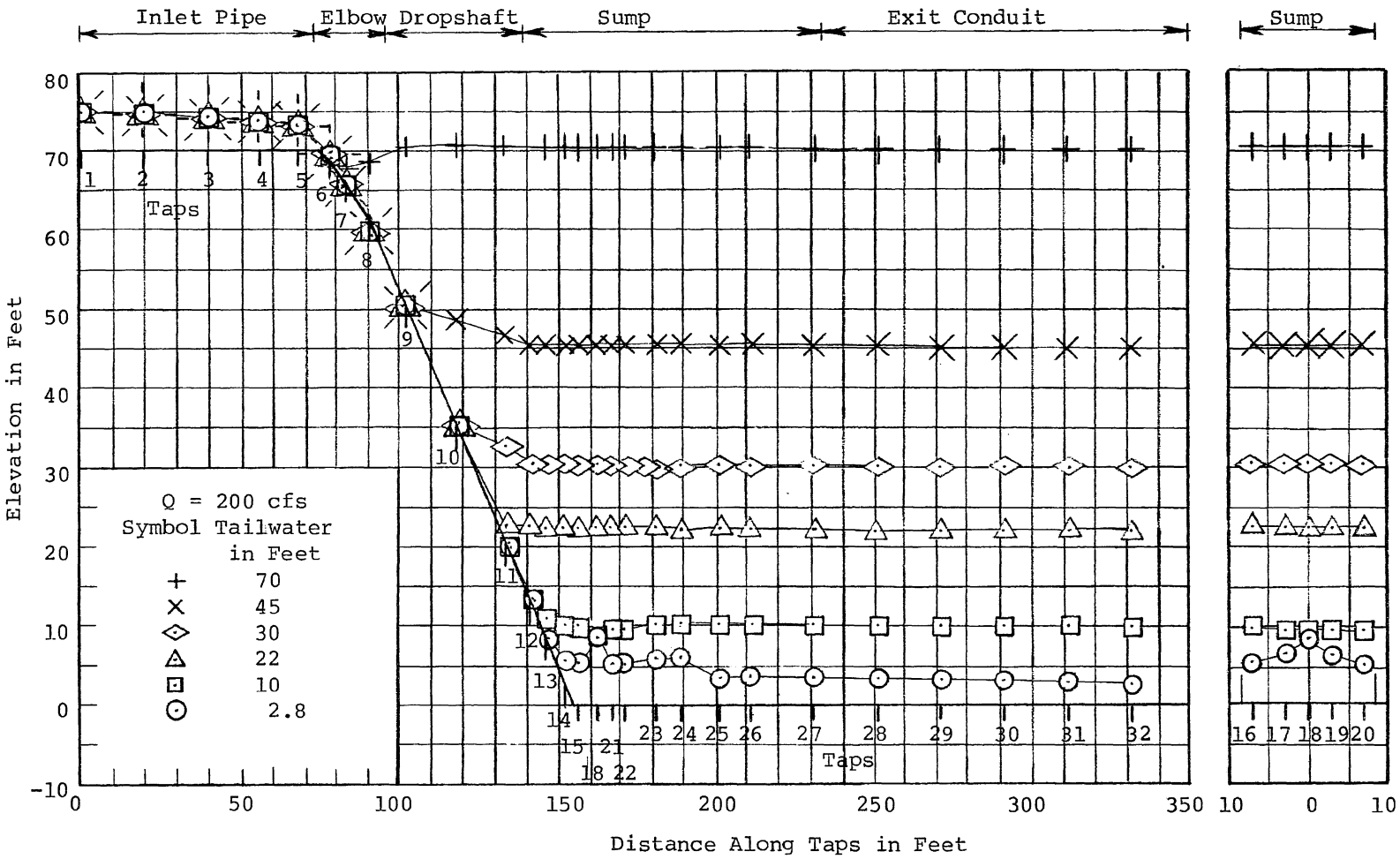
DRAWN WQD	CHECKED	APPROVED
SCALE	DATE 2/7/83	NO. 313A2322-111



ROCHESTER COMBINED SURGE AND DROPSHAFT
MODEL STUDIES
Type CSD R7 Dropshaft Scale 1:12
Piezometric Pressures

SAINT ANTHONY FALLS HYDRAULIC LABORATORY UNIVERSITY OF MINNESOTA		
DRAWN BB	CHECKED	APPROVED
SCALE	DATE 1/11/83	NO. 313A2322-85

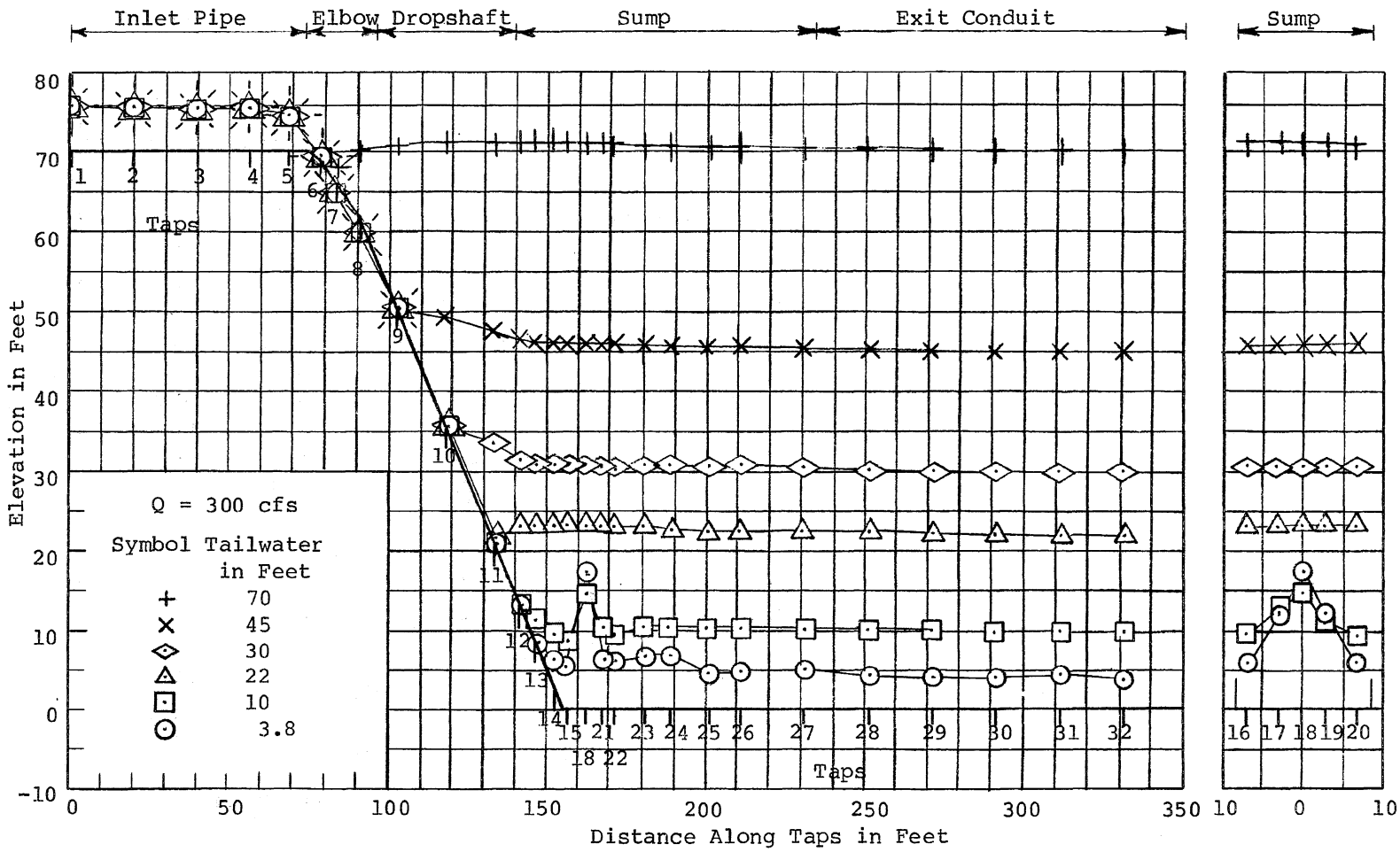
CHART 104



ROCHESTER COMBINED SURGE AND DROPSHAFT
MODEL STUDIES
Type CSD R7 Dropshaft Scale 1:12
Piezometric Pressures

SAINT ANTHONY FALLS HYDRAULIC LABORATORY UNIVERSITY OF MINNESOTA		
DRAWN BB	CHECKED	APPROVED
SCALE	DATE 1/11/83	NO. 313A2322-86

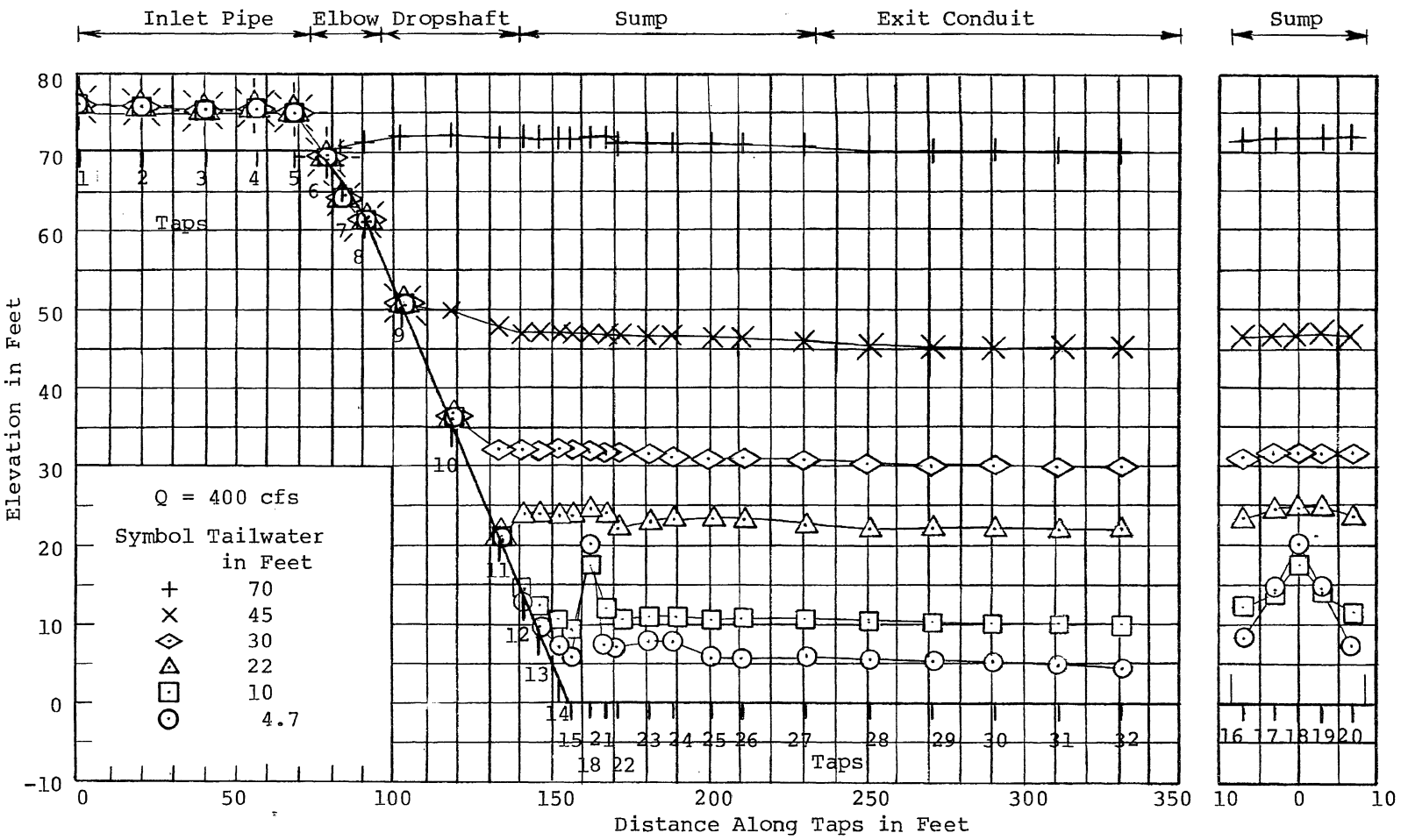
CHART 105



ROCHESTER COMBINED SURGE AND DROPSHAFT
MODEL STUDIES
Type CSD R7 Dropshaft Scale 1:12
Piezometric Pressures

SAINT ANTHONY FALLS HYDRAULIC LABORATORY UNIVERSITY OF MINNESOTA		
DRAWN BB	CHECKED	APPROVED
SCALE	DATE 1/11/83	NO. 313A2322-87

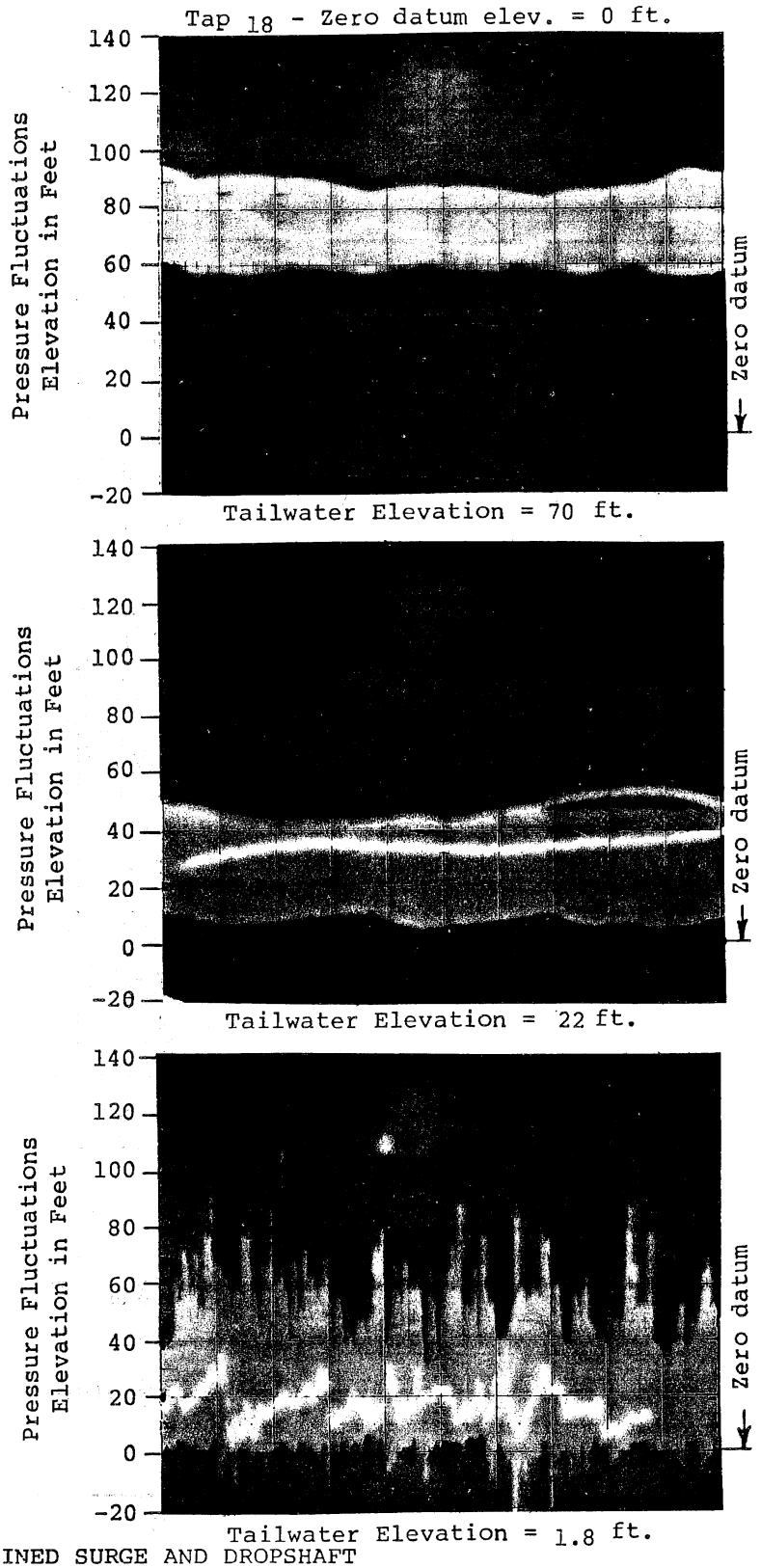
CHART 106



ROCHESTER COMBINED SURGE AND DROPSHAFT
MODEL STUDIES
Type CSD R7 Dropshaft Scale 1:12
Piezometric Pressures

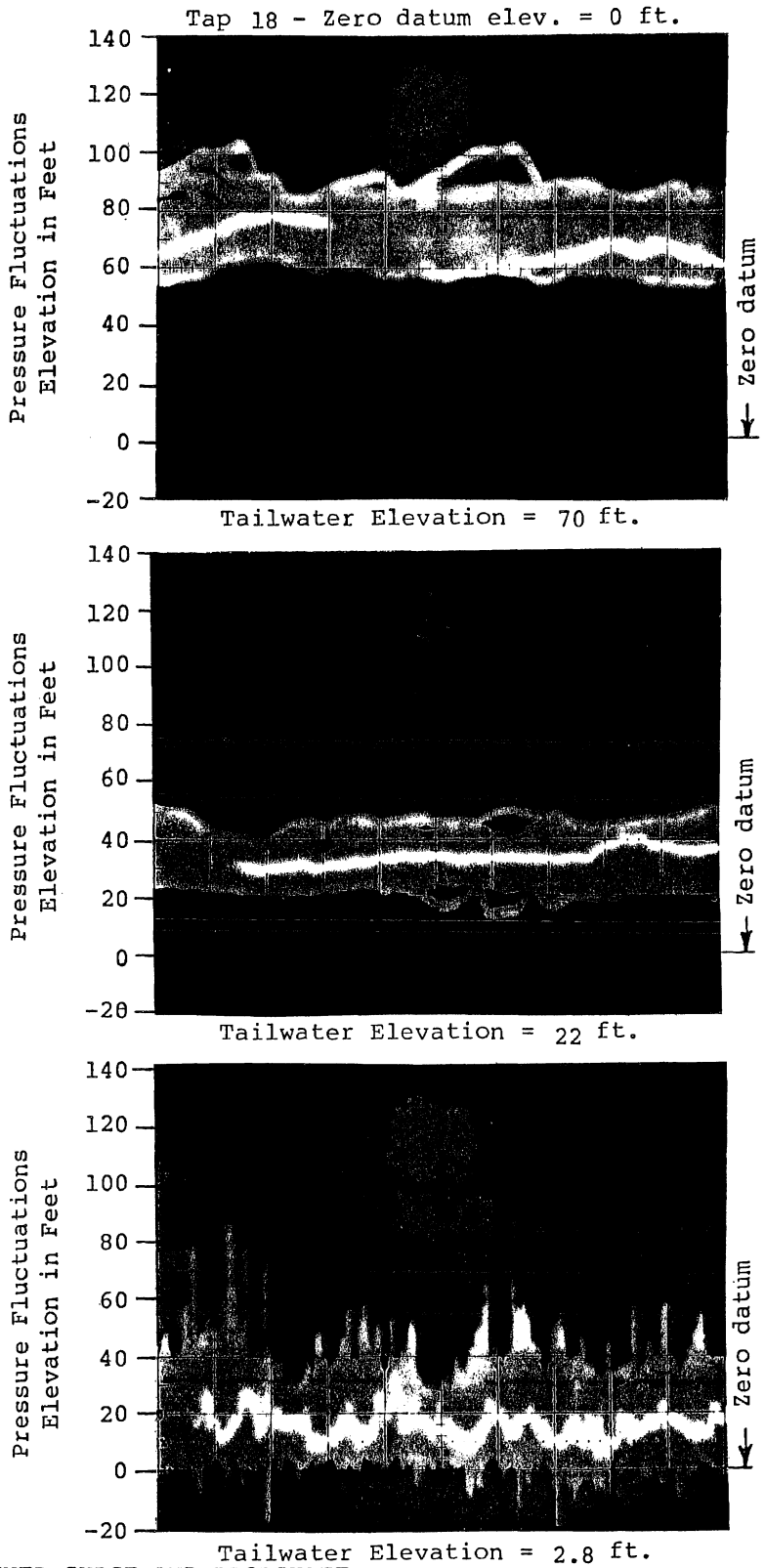
SAINT ANTHONY FALLS HYDRAULIC LABORATORY UNIVERSITY OF MINNESOTA		
DRAWN BB	CHECKED	APPROVED
SCALE	DATE 1/11/83	NO. 313A2322-88

CHART 107



ROCHESTER COMBINED SURGE AND DROPSHAFT
MODEL STUDIES
Type CSD R7 Dropshaft Scale 1:12
Typical Pressure Fluctuations
Q = 100 cfs
Model time of record = 1 minute

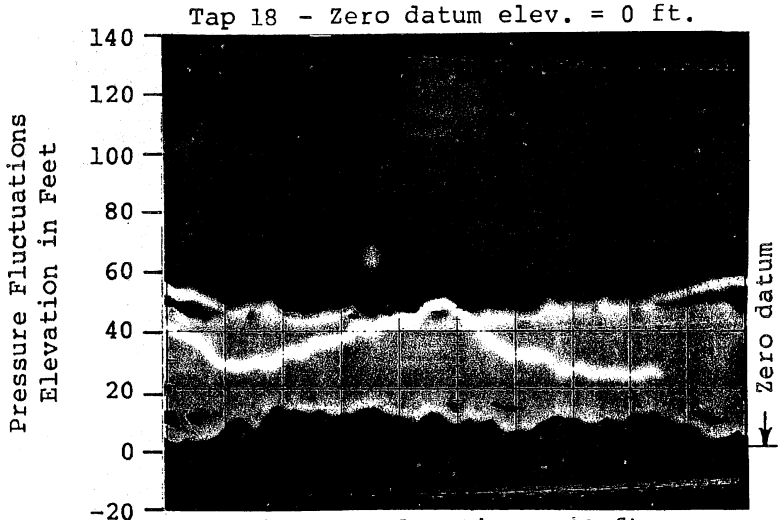
SAINT ANTHONY FALLS HYDRAULIC LABORATORY UNIVERSITY OF MINNESOTA		
DRAWN WQD	CHECKED BB	APPROVED
SCALE	DATE 12/9/82	NO. 313A2322-15



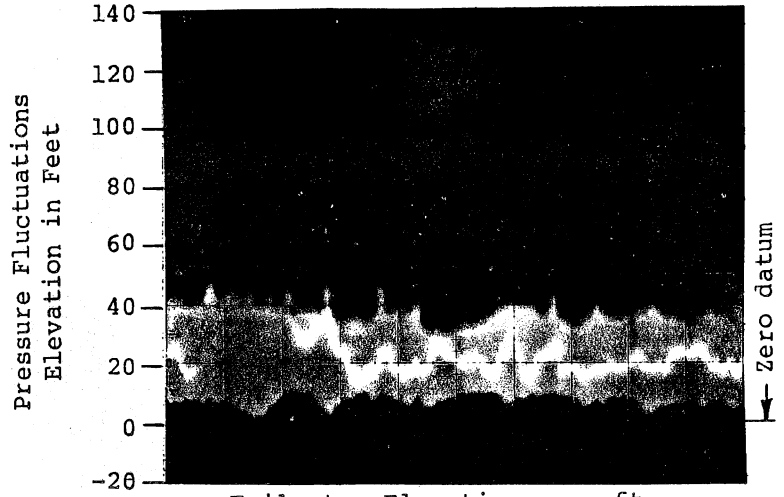
ROCHESTER COMBINED SURGE AND DROPSHAFT
MODEL STUDIES
Type CSD R7 Dropshaft Scale 1:12
Typical Pressure Fluctuations
Q = 200cfs
Model time of record = 1 minute

SAINT ANTHONY FALLS HYDRAULIC LABORATORY UNIVERSITY OF MINNESOTA		
DRAWN WQD	CHECKED BB	APPROVED
SCALE	DATE 12/9/82	NO 313A2322-16

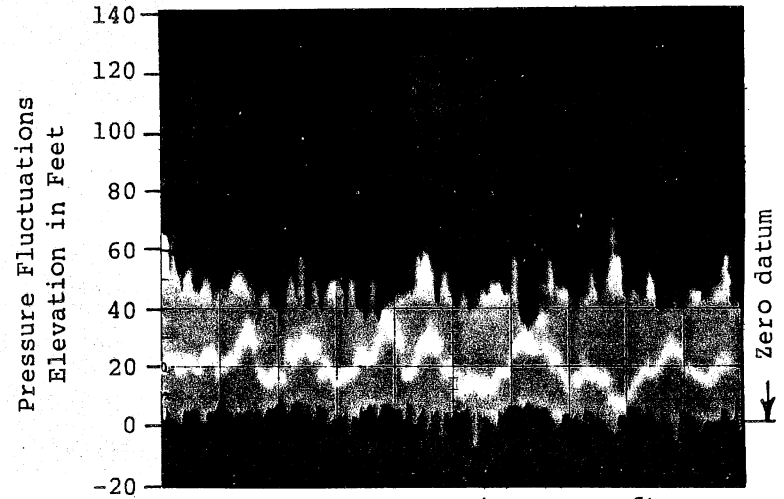
Tap 18 - Zero datum elev. = 0 ft.



Tailwater Elevation = 22 ft.



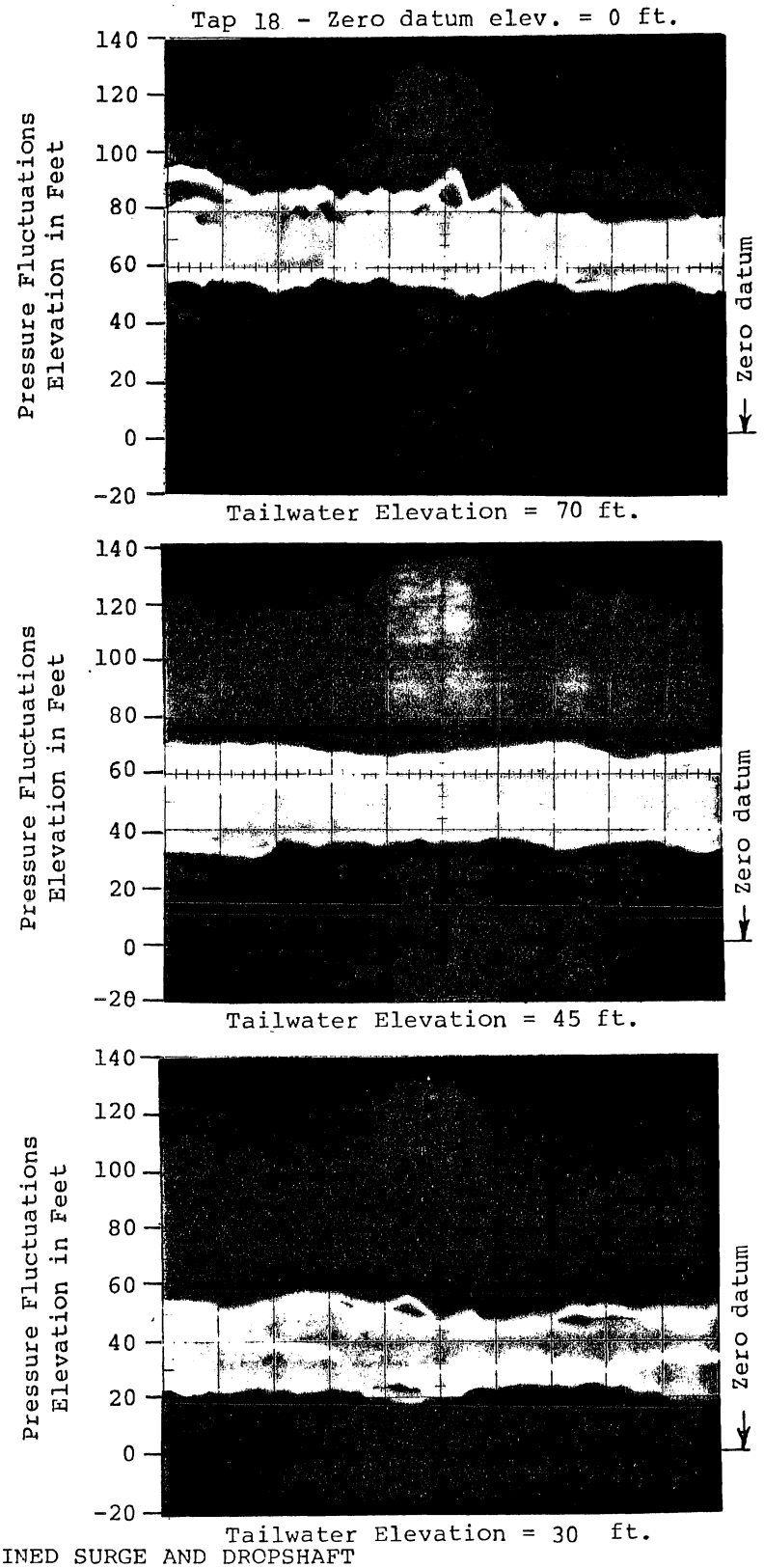
Tailwater Elevation = 10 ft.



Tailwater Elevation = 3.8 ft.

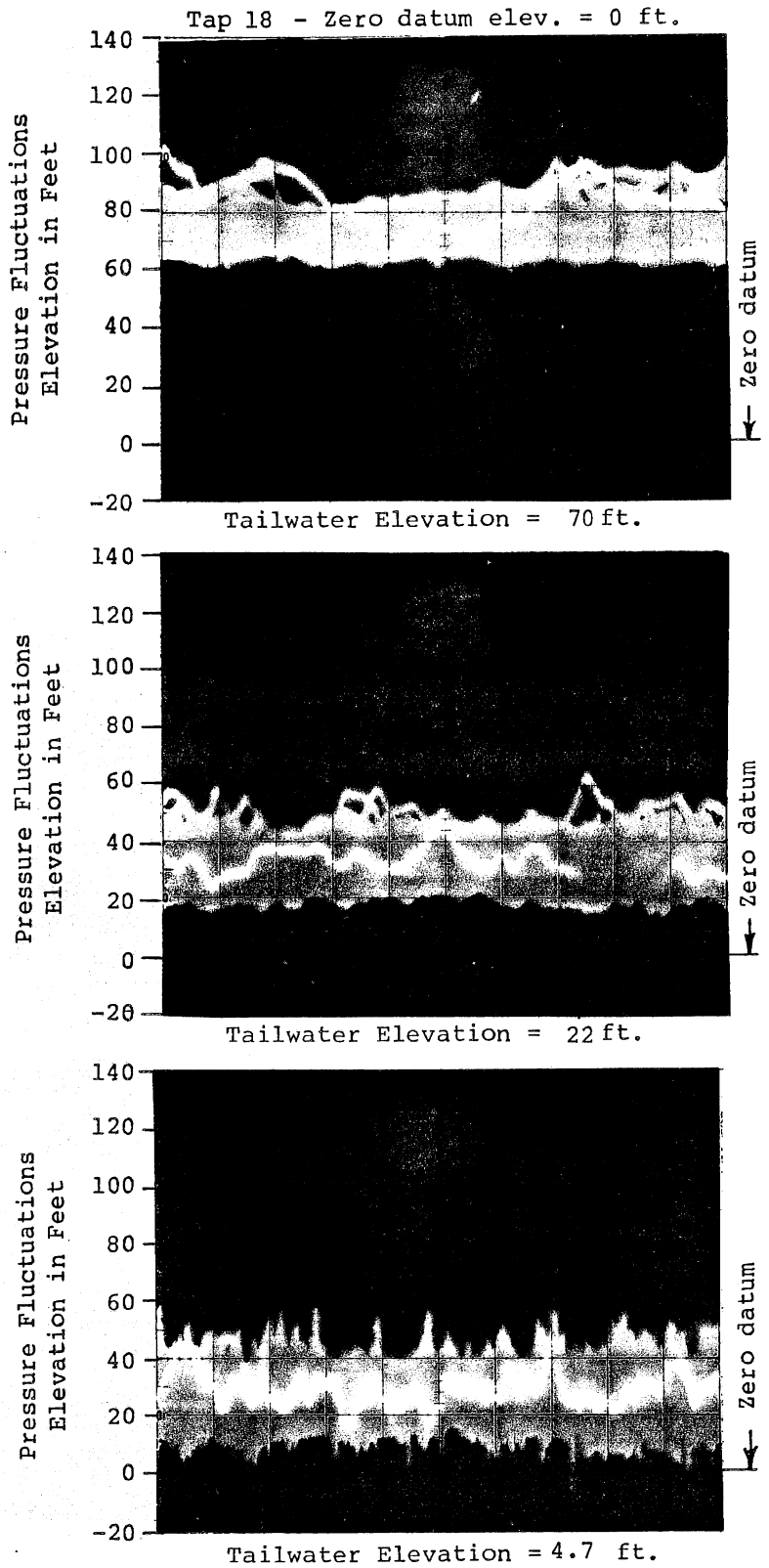
ROCHESTER COMBINED SURGE AND DROPSHAFT
MODEL STUDIES
Type CSD R7 Dropshaft Scale 1:12
Typical Pressure Fluctuations
Q = 300 cfs
Model time of record = 1 minute

SAINT ANTHONY FALLS HYDRAULIC LABORATORY UNIVERSITY OF MINNESOTA		
DRAWN WQD	CHECKED BB	APPROVED
SCALE	DATE 12/9/82	NO 313A2322- 18



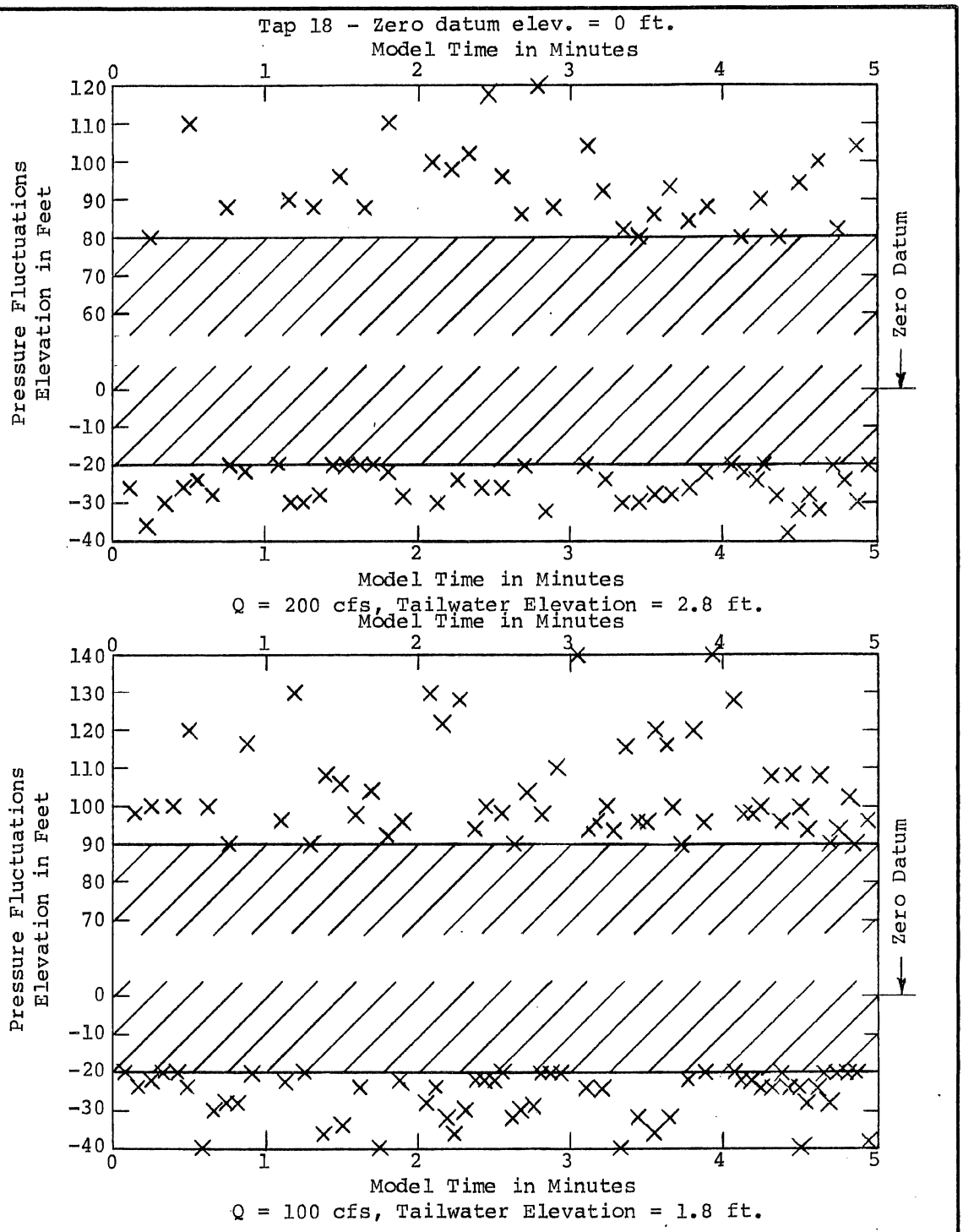
ROCHESTER COMBINED SURGE AND DROPSHAFT
MODEL STUDIES
Type CSD R7 Dropshaft Scale 1:12
Typical Pressure Fluctuations
Q = 300 cfs
Model time of record = 1 minute

SAINT ANTHONY FALLS HYDRAULIC LABORATORY UNIVERSITY OF MINNESOTA		
DRAWN WQD	CHECKED BB	APPROVED
SCALE	DATE 12/9/82	NO 313A2322- 17



ROCHESTER COMBINED SURGE AND DROPSHAFT
MODEL STUDIES
Type CSD R7 Dropshaft Scale 1:12
Typical Pressure Fluctuations
Q = 400 cfs
Model time of record = 1 minute

SAINT ANTHONY FALLS HYDRAULIC LABORATORY UNIVERSITY OF MINNESOTA		
DRAWN WQD	CHECKED BB	APPROVED
SCALE	DATE 12/9/82	NO 313A2322-19

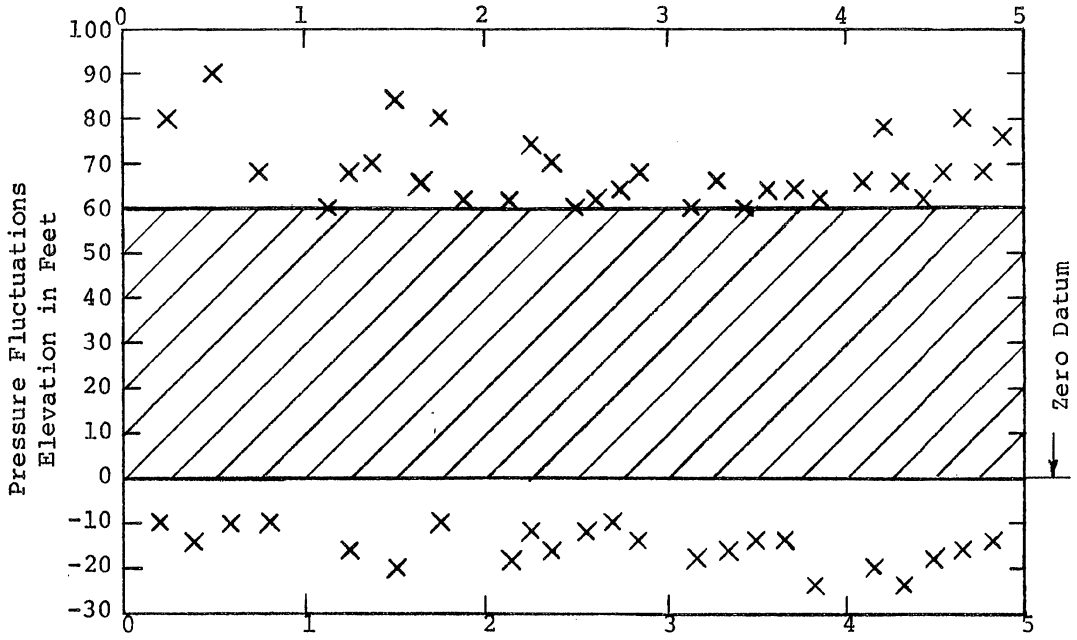


ROCHESTER COMBINED SURGE AND DROPSHAFT MODEL STUDIES
Type CSD R7 Dropshaft Scale 1:12
Typical Pressure Fluctuations

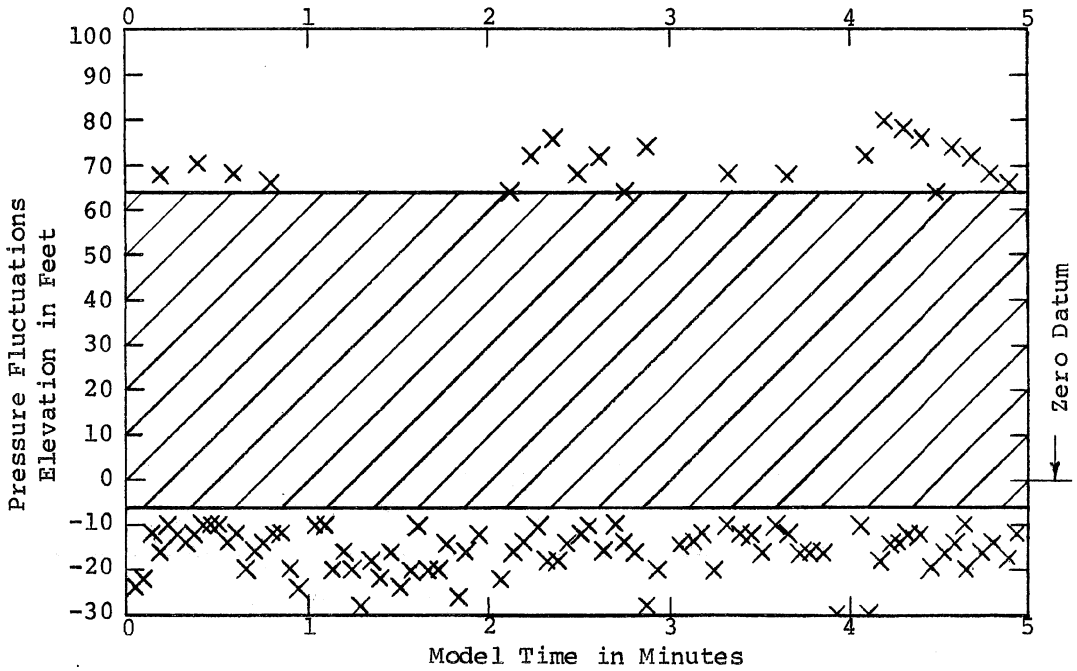
SAINT ANTHONY FALLS HYDRAULIC LABORATORY
UNIVERSITY OF MINNESOTA

DRAWN BB	CHECKED	APPROVED
SCALE	DATE 1/17/83	NO. 313A2322-102

Tap 18 - Zero datum elev. = 0 ft.



Q = 400 cfs, Tailwater Elevation = 4.7 ft.



Q = 300 cfs, Tailwater Elevation = 3.8 ft.

× Visually observed readings

Range from oscilloscope photos, Model time of record = 1 minute

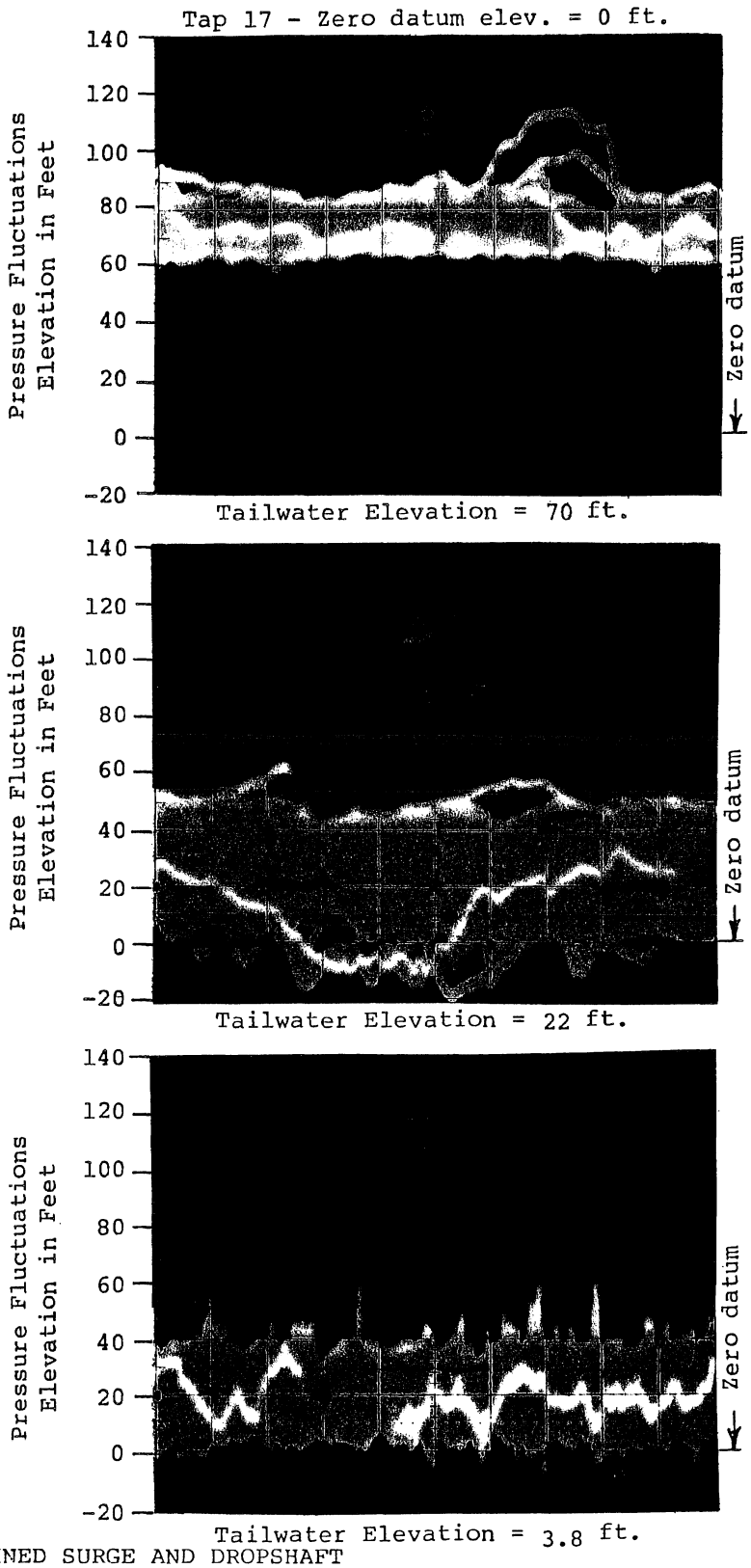
ROCHESTER COMBINED SURGE AND DROPSHAFT MODEL STUDIES

Type CSD R7 Dropshaft Scale 1:12

Typical Pressure Fluctuations

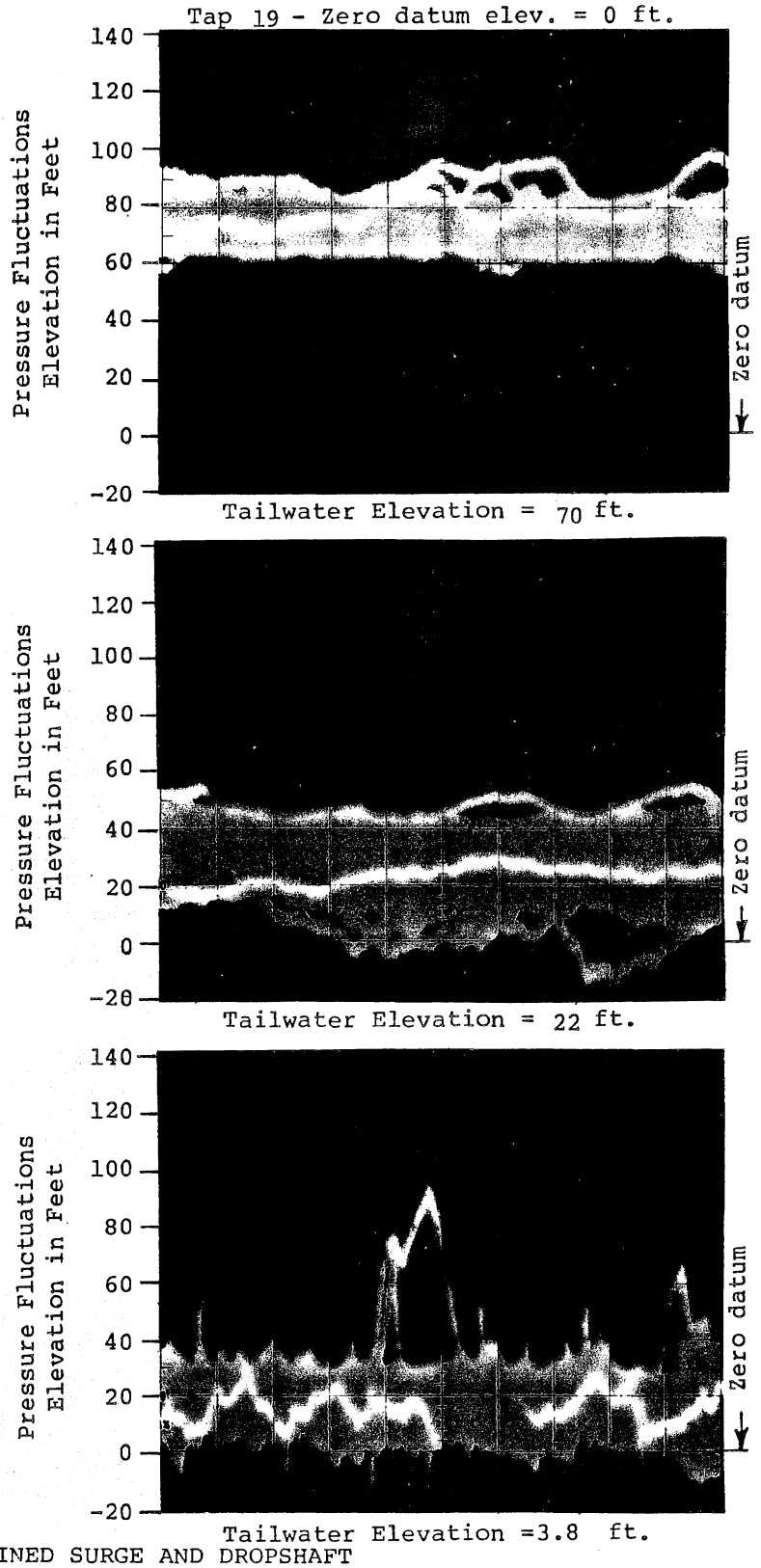
SAINT ANTHONY FALLS HYDRAULIC LABORATORY
UNIVERSITY OF MINNESOTA

DRAWN BB	CHECKED	APPROVED
SCALE	DATE 1/17/83	NO. 313A2322-103



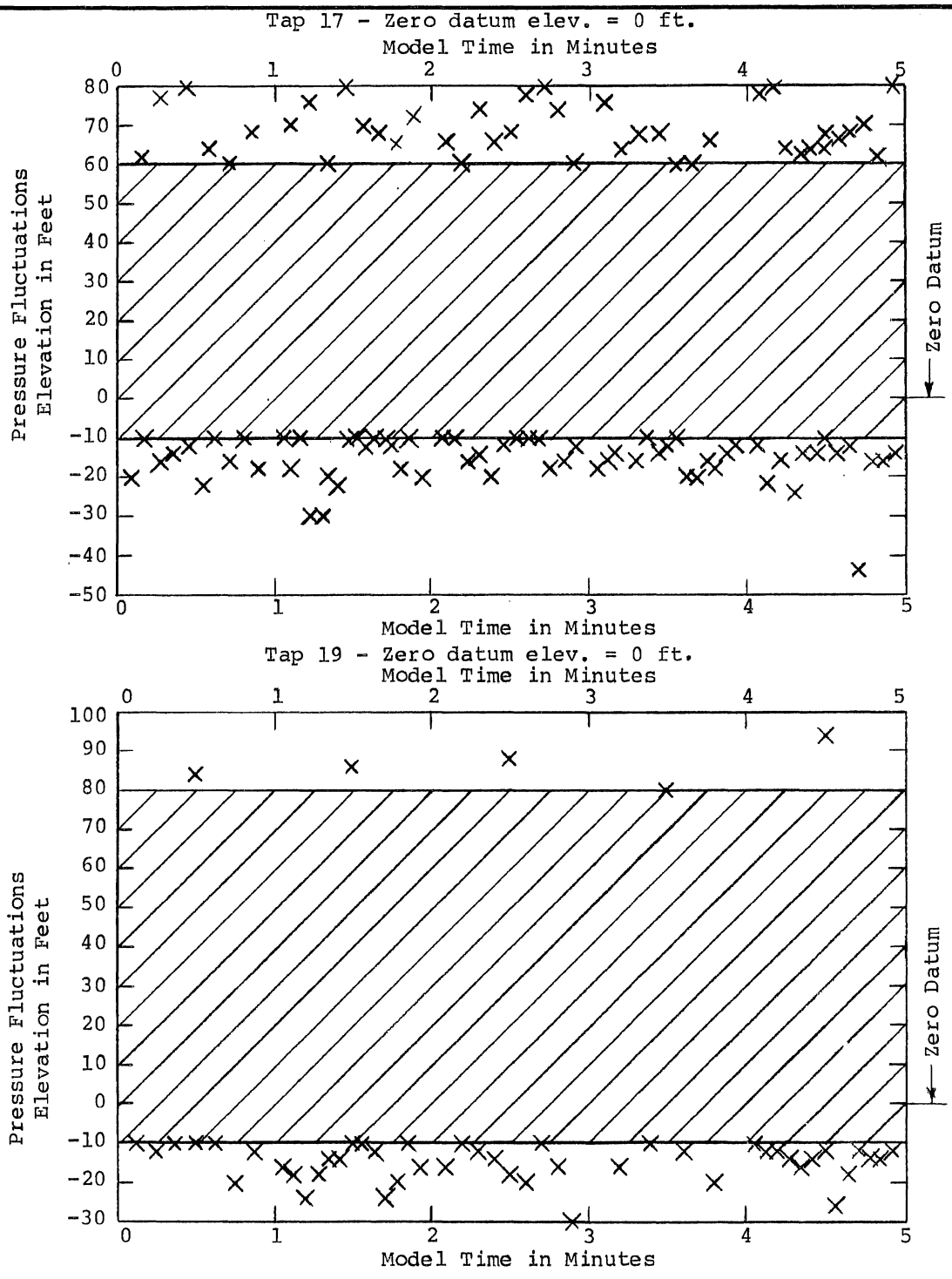
ROCHESTER COMBINED SURGE AND DROPSHAFT
MODEL STUDIES
Type CSD R7 Dropshaft Scale 1:12
Typical Pressure Fluctuations
Q = 300 cfs
Model time of record = 1 minute

SAINT ANTHONY FALLS HYDRAULIC LABORATORY UNIVERSITY OF MINNESOTA		
DRAWN WQD	CHECKED BB	APPROVED
SCALE	DATE 12/9/82	NO 313A2322- 20



ROCHESTER COMBINED SURGE AND DROPSHAFT
MODEL STUDIES
Type CSDR7 Dropshaft Scale 1:12
Typical Pressure Fluctuations
Q = 300 cfs
Model time of record = 1 minute

SAINT ANTHONY FALLS HYDRAULIC LABORATORY UNIVERSITY OF MINNESOTA		
DRAWN WQD	CHECKED BB	APPROVED
SCALE	DATE 12/9/82	NO 313A2322- 21



× Visually observed readings

Range from oscilloscope photos, Model time of record = 1 minute

ROCHESTER COMBINED SURGE AND DROPSHAFT MODEL STUDIES

Type CSD R7 Dropshaft Scale 1:12

Typical Pressure Fluctuations

Q = 300 cfs, T.W. Elev. = 3.8 ft.

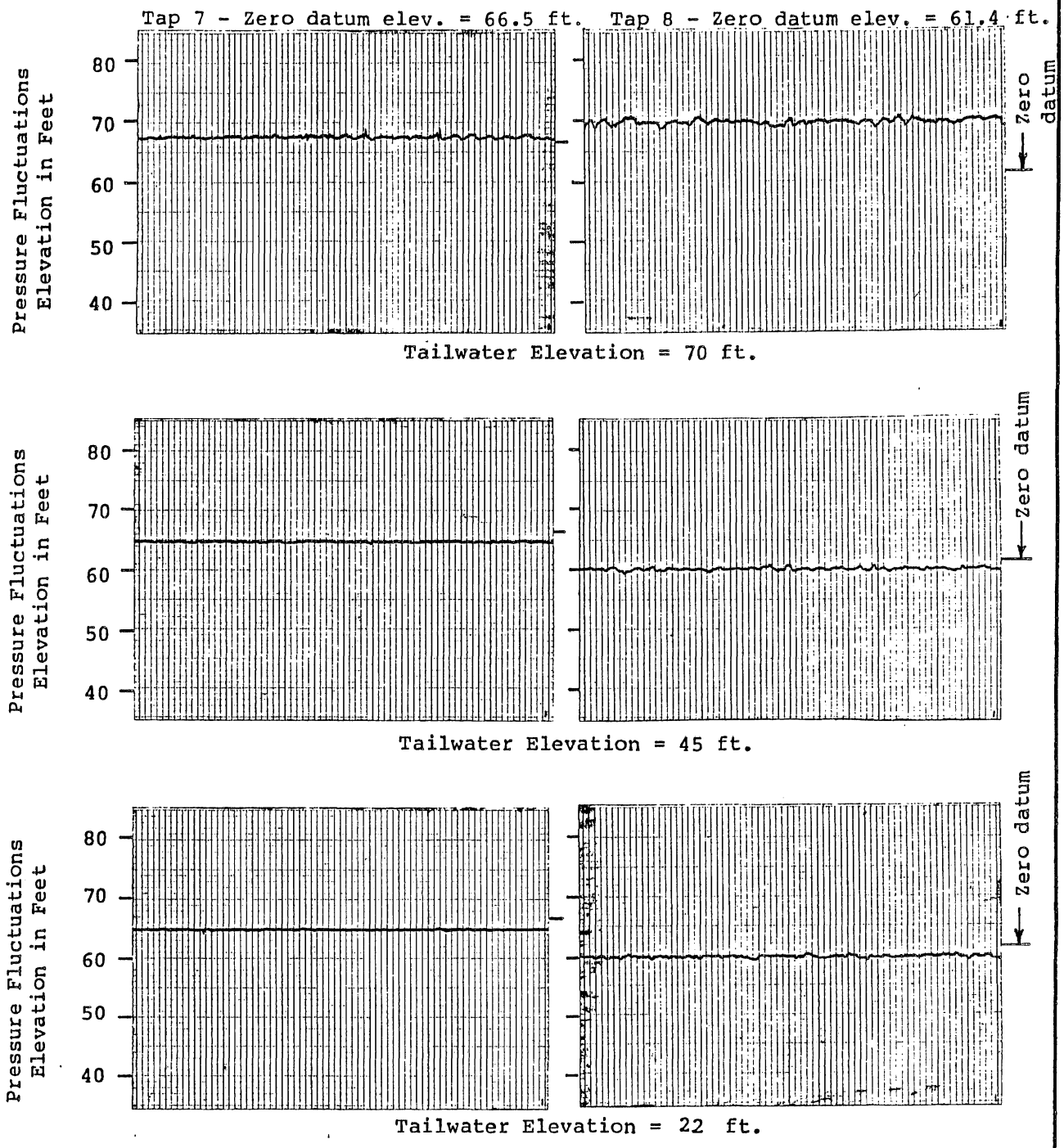
SAINT ANTHONY FALLS HYDRAULIC LABORATORY UNIVERSITY OF MINNESOTA		
DRAWN BB	CHECKED	APPROVED
SCALE	DATE 1/17/83	NO. 313A2322-101

Q cfs	T.W. El. ft	Av. Piez. Press.-ft	Range from Photos Max.-ft	Range from Photos Min.-ft	Observed Readings Max.-ft	Observed Readings Min.-ft
		Tap 17 Elevation = 0 ft				
300	3.8	12.1	60	-10	80	-44
300	22	23.1	64	-22		
300	70	71.2	118	58		
		Tap 18 Elevation = 0 ft				
100	1.8	8.1	90	-20	140	-40
100	22	22.1	56	4		
100	70	70.3	96	56		
200	2.8	8.4	80	-20	120	-38
200	22	22.4	54	12		
200	70	70.5	106	54		
300	3.8	17.6	64	-6	80	-30
300	10	14.9	48	0		
300	22	23.1	60	2		
300	30	30.9	58	18		
300	45	46.0	72	30		
300	70	71.1	96	50		
400	4.7	20.1	60	0	90	-24
400	22	24.6	64	14		
400	70	72.1	104	60		
		Tap 19 Elevation = 0 ft				
300	3.8	12.1	80	-10	94	-30
300	22	23.1	56	-16		
300	70	70.9	100	56		

ROCHESTER COMBINED SURGE AND DROPSHAFT
MODEL STUDIES
Type CSD R7 Dropshaft Scale 1:12
Summary of Typical
Pressure Fluctuations

SAINT ANTHONY FALLS HYDRAULIC LABORATORY
UNIVERSITY OF MINNESOTA

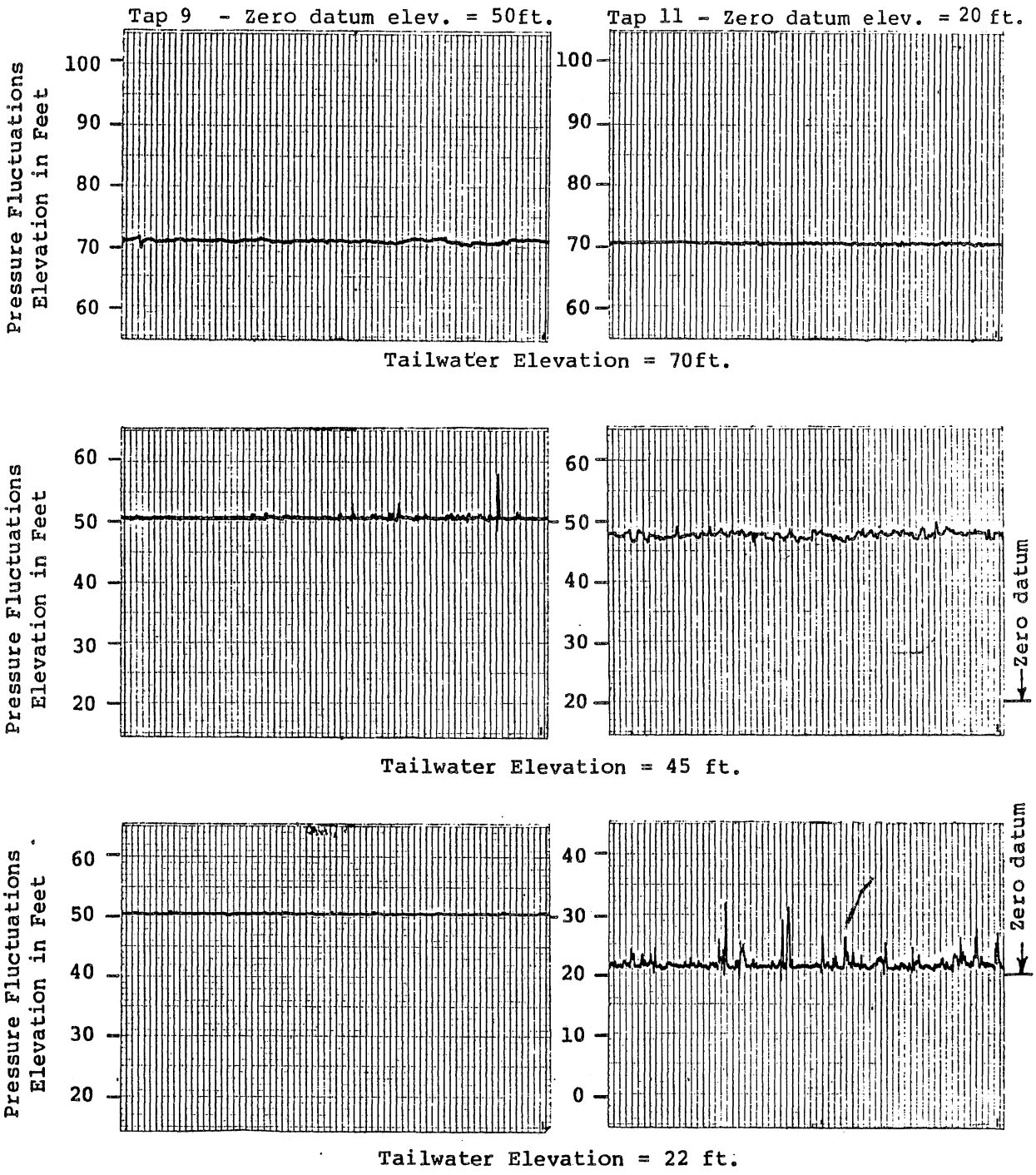
DRAWN WQD	CHECKED BB	APPROVED
SCALE	DATE 1-7-83	NO. 313A2322-72



ROCHESTER COMBINED SURGE AND DROPSHAFT
MODEL STUDIES
Type CSD R7 Dropshaft Scale 1:12
Typical Pressure Fluctuations
Q = 300 cfs

SAINT ANTHONY FALLS HYDRAULIC LABORATORY
UNIVERSITY OF MINNESOTA

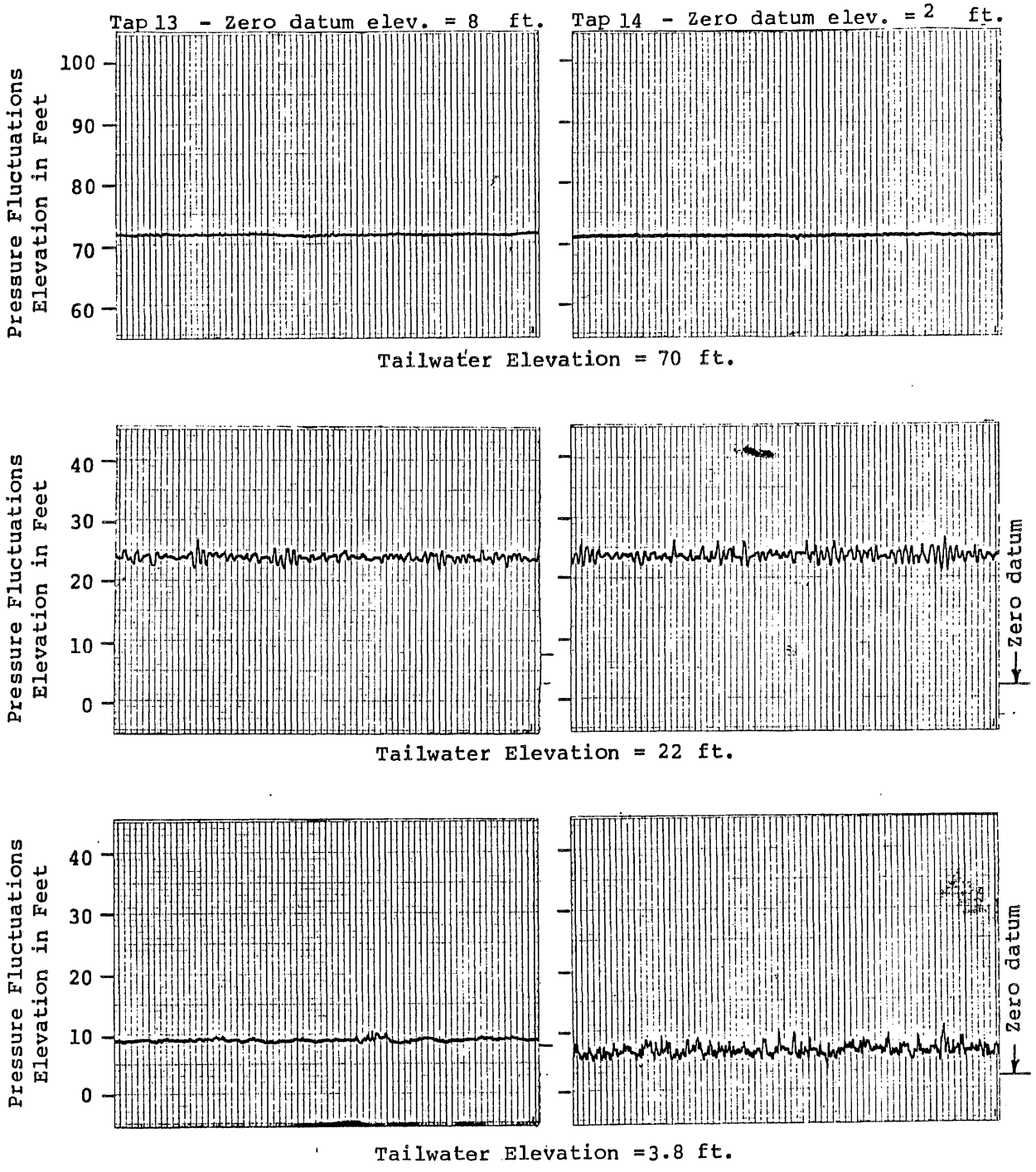
DRAWN BB	CHECKED	APPROVED
SCALE	DATE 12/10/82	NO. 313 A2322-38



ROCHESTER COMBINED SURGE AND DROPSHAFT
MODEL STUDIES
Type CSD R7 Dropshaft Scale 1:12
Typical Pressure Fluctuations
Q = 300 cfs

SAINT ANTHONY FALLS HYDRAULIC LABORATORY
UNIVERSITY OF MINNESOTA

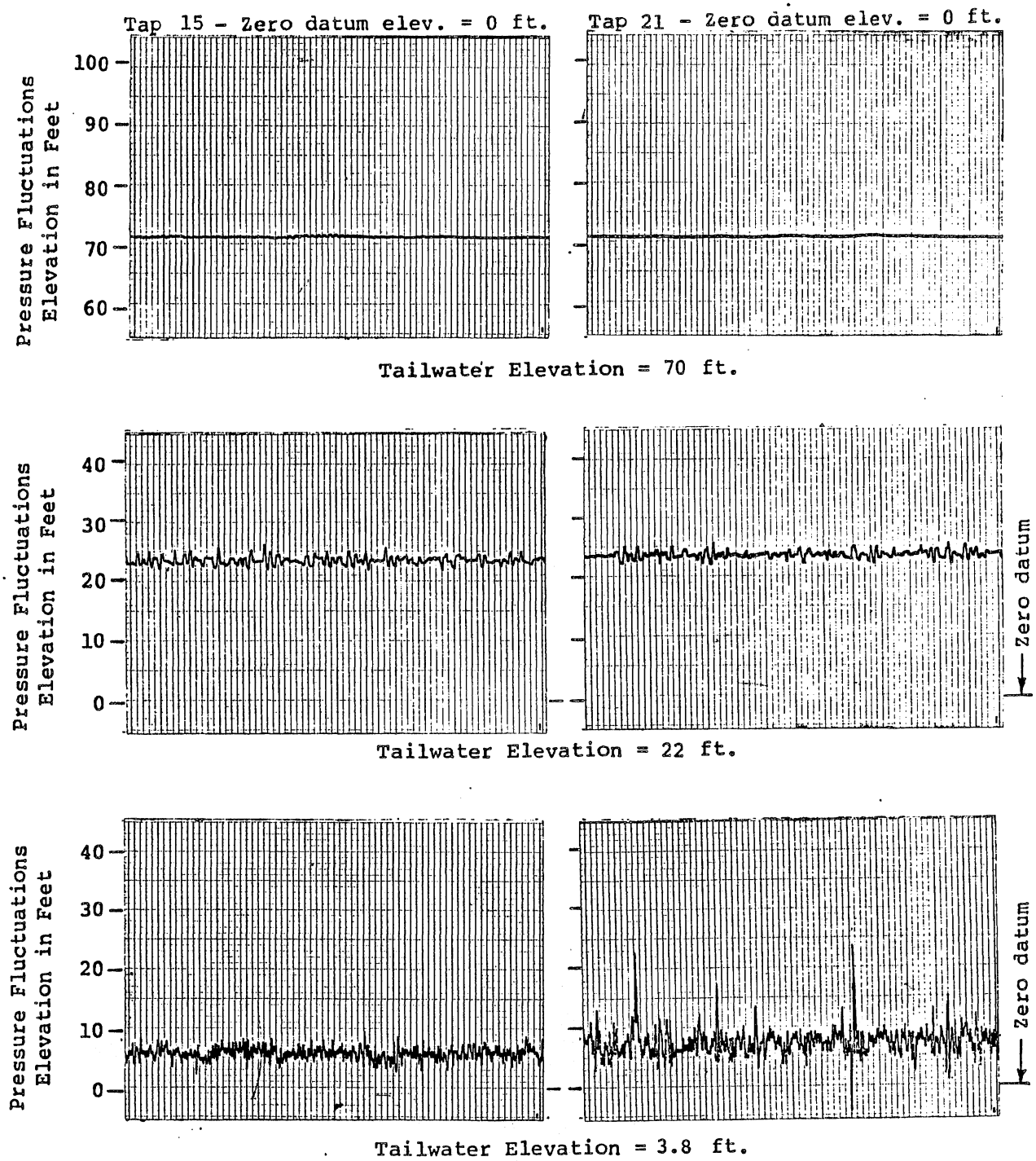
DRAWN	BB	CHECKED	APPROVED
SCALE		DATE 12/10/82	NO. 313A2322-42



ROCHESTER COMBINED SURGE AND DROPSHAFT
MODEL STUDIES
Type CSD R7 Dropshaft Scale 1:12
Typical Pressure Fluctuations
Q = 300 cfs

SAINT ANTHONY FALLS HYDRAULIC LABORATORY
UNIVERSITY OF MINNESOTA

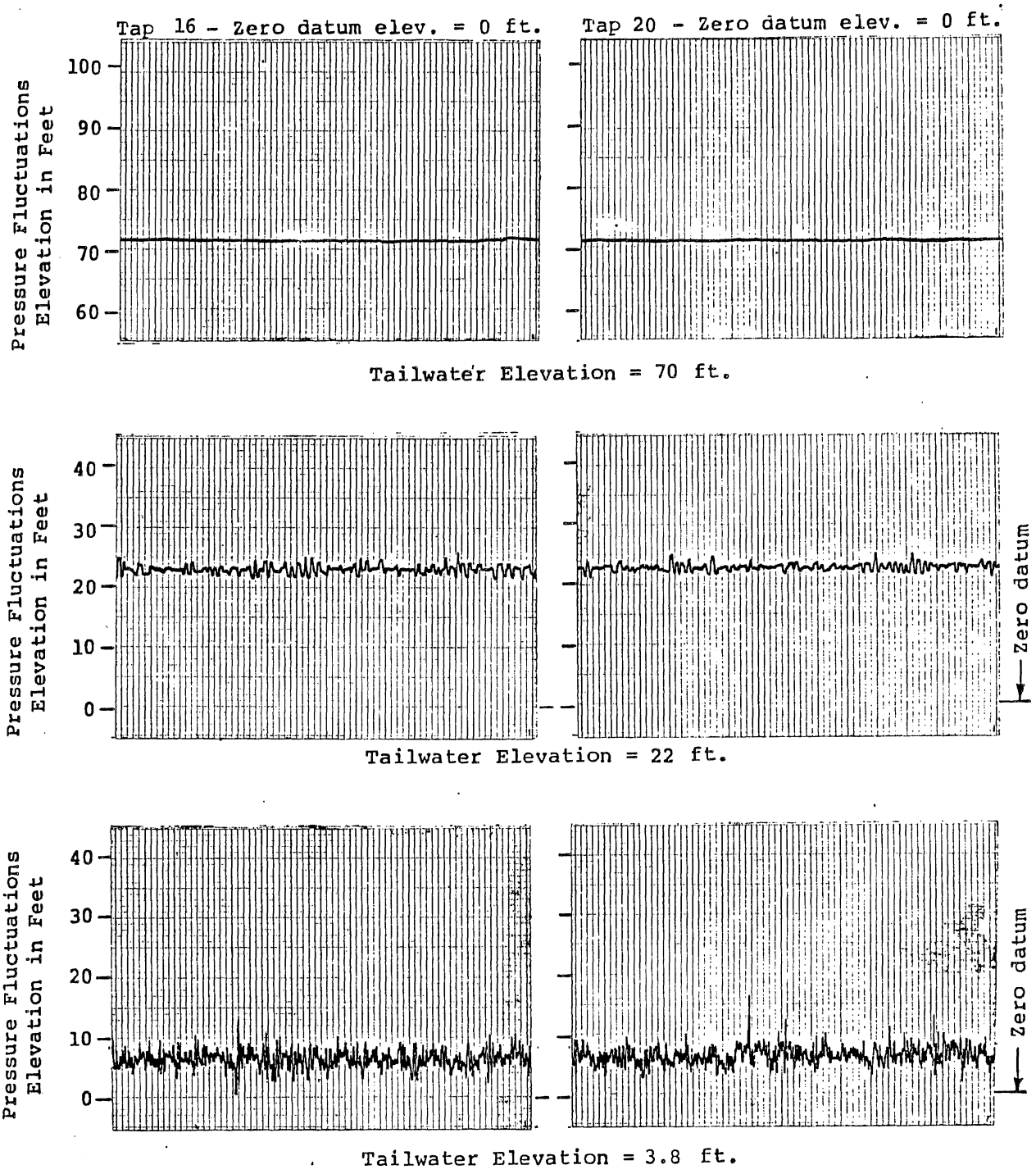
DRAWN BB	CHECKED JDD	APPROVED
SCALE	DATE 12/10/82	NO. 313A2322- 46



ROCHESTER COMBINED SURGE AND DROPSHAFT
MODEL STUDIES
Type CSD R7 Dropshaft Scale 1:12
Typical Pressure Fluctuations
Q = 300 cfs

SAINT ANTHONY FALLS HYDRAULIC LABORATORY
UNIVERSITY OF MINNESOTA

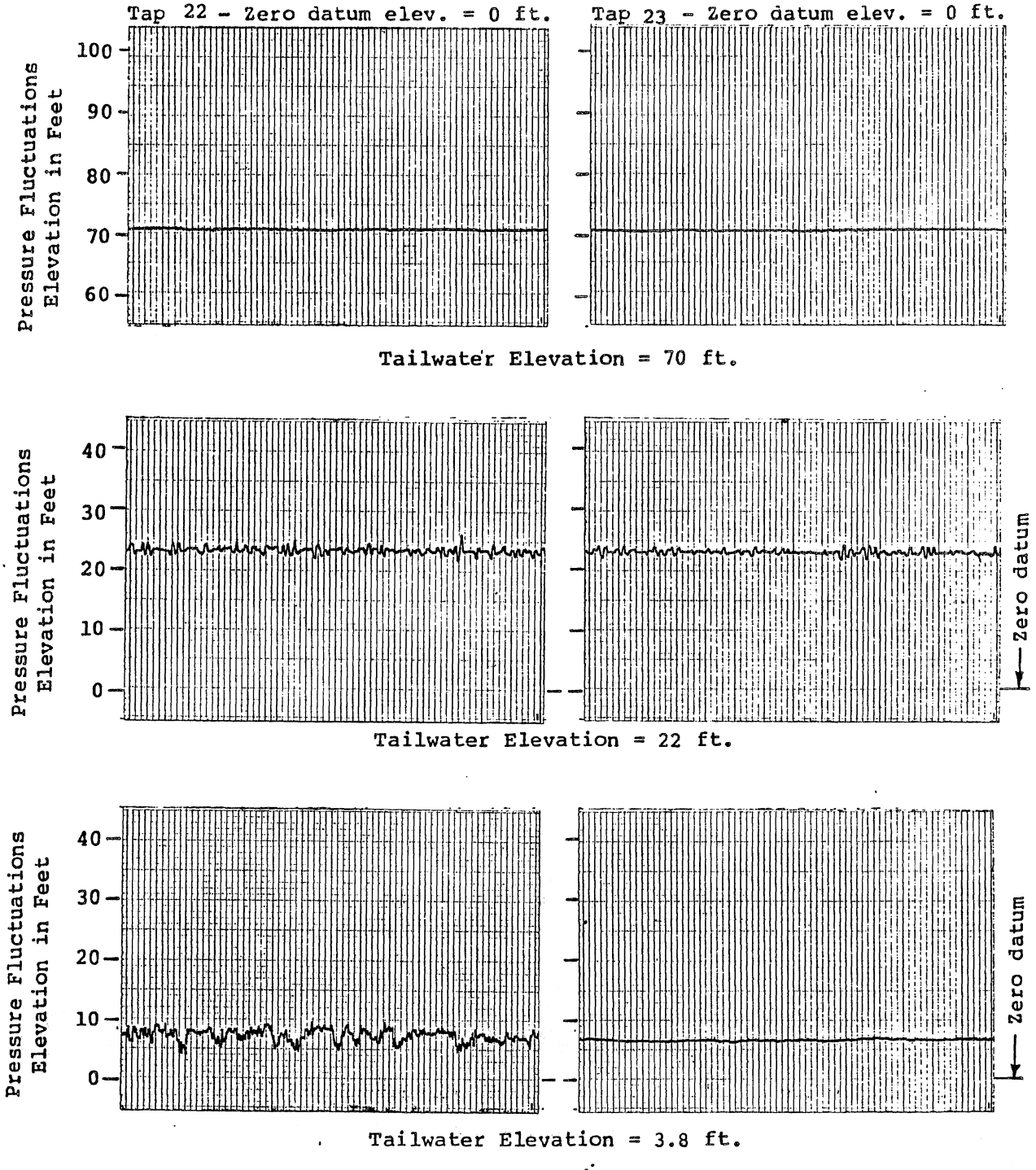
DRAWN BB	CHECKED	APPROVED
SCALE	DATE 12/10/82	NO. 313A2322-65



ROCHESTER COMBINED SURGE AND DROPSHAFT
MODEL STUDIES
Type CSD ^{R7} Dropshaft Scale 1:12
Typical Pressure Fluctuations
Q = 300 cfs

SAINT ANTHONY FALLS HYDRAULIC LABORATORY
UNIVERSITY OF MINNESOTA

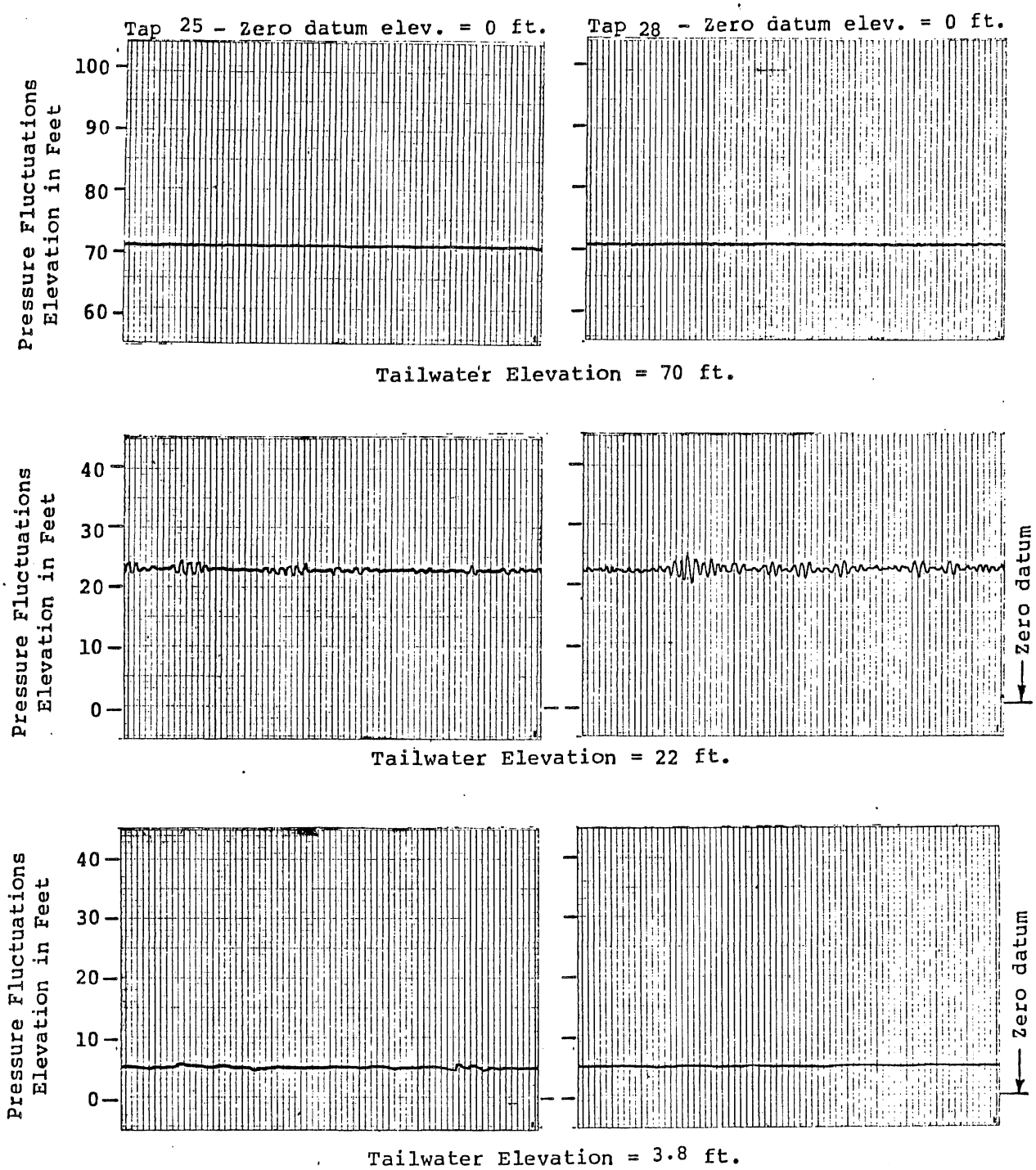
DRAWN BB	CHECKED	APPROVED
SCALE	DATE 12/10/82	NO. 313A2322-66



ROCHESTER COMBINED SURGE AND DROPSHAFT
MODEL STUDIES
Type CSD R7 Dropshaft Scale 1:12
Typical Pressure Fluctuations
Q = 300 cfs

SAINT ANTHONY FALLS HYDRAULIC LABORATORY
UNIVERSITY OF MINNESOTA

DRAWN BB	CHECKED MAB	APPROVED
SCALE	DATE 12/10/82	NO. 313A2322-67



ROCHESTER COMBINED SURGE AND DROPSHAFT
MODEL STUDIES
Type CSD R7 Dropshaft Scale 1:12
Typical Pressure Fluctuations
Q = 300 cfs

SAINT ANTHONY FALLS HYDRAULIC LABORATORY
UNIVERSITY OF MINNESOTA

DRAWN BB	CHECKED MAD	APPROVED
SCALE	DATE 12/10/82	NO. 313A2322-68

Tap No.	Tap El. ft	Q cfs	T.W. El. ft	Av. Piez. Press.-ft	Pressure Fluctuations Max.-ft	Min.-ft
7	66.5	300	22	64.9	65.2	64.2
7	66.5	300	45	64.9	65.2	64.2
7	66.5	300	70	67.6	69.0	67.0
8	61.4	300	22	59.9	60.8	59.0
8	61.4	300	45	59.9	61.0	59.4
8	61.4	300	70	69.9	71.2	68.4
9	50	300	22	50.6	51.0	50.2
9	50	300	45	50.7	58.0	48.6
9	50	300	70	70.9	72.2	69.6
11	20	300	22	21.8	31.8	17.8
11	20	300	45	47.6	49.8	45.4
11	20	300	70	70.9	71.2	70.0
13	8	300	3.8	8.7	10.4	8.0
13	8	300	22	23.1	26.8	21.2
13	8	300	70	71.2	72.0	70.8
14	2	300	3.8	6.6	10.6	3.4
14	2	300	22	23.1	26.6	21.0
14	2	300	70	71.2	71.8	70.2
15	0	300	3.8	5.5	9.8	2.2
15	0	300	22	23.1	26.2	21.2
15	0	300	70	71.2	71.8	70.8
16	0	300	3.8	6.1	12.8	0.6
16	0	300	22	23.1	25.8	20.2
16	0	300	70	71.2	72.0	70.4
20	0	300	3.8	6.1	16.2	1.0
20	0	300	22	23.1	25.0	20.8
20	0	300	70	70.9	71.4	70.4
21	0	300	3.8	6.6	26.2	-8.0
21	0	300	22	23.1	25.6	21.4
21	0	300	70	70.9	71.4	70.0
22	0	300	3.8	6.3	10.2	4.0
22	0	300	22	23.1	26.2	21.6
22	0	300	70	70.7	71.6	70.4
23	0	300	3.8	6.9	7.6	6.0
23	0	300	22	23.1	24.8	21.8
23	0	300	70	70.7	71.2	70.0
25	0	300	3.8	4.7	6.0	3.2
25	0	300	22	22.6	25.0	20.6
25	0	300	70	70.6	71.2	70.0
28	0	300	3.8	4.4	4.8	4.2
28	0	300	22	22.1	25.2	19.8
28	0	300	70	70.2	71.0	70.0

ROCHESTER COMBINED SURGE AND DROPSHAFT
MODEL STUDIES
Type CSD R7 Dropshaft Scale 1:12
Summary of Typical
Pressure Fluctuations

SAINT ANTHONY FALLS HYDRAULIC LABORATORY
UNIVERSITY OF MINNESOTA

DRAWN WQD	CHECKED	APPROVED
SCALE	DATE 2/7/83	NO. 313A2322-112