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MODEL STUDIES - FOOTHILL FEEDER PROJECT METROPOLITAN WATER DISTRICT OF SOUTHERN CALIFORNIA

PART II. BIG TUJUNGA GATE AND SPILLWAY STRUCTURE

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PREFACE

This report is the second in a series dealing with the gated control structures to be placed in the Foothill Feeder of the Metropolitan Water District of Southern California. The report describes the model experiments pertaining to the operation of the Big Tujunga Gate and Spillway Structure. The Big Tujunga Gate and Spillway Structure is designed to provide both flow control in the tunnel and spillway facilities for emergency flow rejection. The tests show that in general, the structure operated as designed with smooth, quiet flow for normal operating conditions. Information is also provided regarding the head differentials for various discharges. Pressures were measured in the structure and on the piers and floor downstream of the gates to delineate the cavitation potential. Observations were also made to determine the minimum head necessary to prevent sweepout from the gates. In these respects, the design was quite suitable.

Measurement of vibratory pressures on the gates in the model, combined with computations of the natural frequency of the prototype gates, indicated that special studies of gate vibrations should not be necessary because the natural frequency of the gates was appreciably higher than any of the frequencies measured in the model.

The studies also suggested some changes in the geometry upstream of the center gate, since an appreciable surface boil was generated when the center gate was closed.

The Big Tujunga Gate and Spillway Structure was similar in some respects to the Regular Gate Structure(1), previously tested, and many of the results obtained therein are applicable to this structure. This is particularly true for the air vent and air collector used in conjunction with the emergency weirs.

The model tests described in this report were sponsored by the Harza Engineering Company of Chicago, Illinois, which was represented by Dr. David Louie, Head of the Hydraulic Section of the Harza Engineering Company. The experiments were performed at the St. Anthony Falls Hydraulic Laboratory under the immediate direction of Alvin G. Anderson. The models were fabricated in the Laboratory shops with much of the experimentation carried on by David J. Anderson.

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(1) Model Studies - Foothill Feeder Project. Metropolitan Water District of Southern California - Part I. Regular Gate Structure. Project Report No. 91, St. Anthony Falls Hydraulic Laboratory, February 1967.

MODEL STUDIES - FOOTHILL FEEDER PROJECT
METROPOLITAN WATER DISTRICT OF SOUTHERN CALIFORNIA
PART II - BIG TUJUNGA GATE AND SPILLWAY STRUCTURE

I. INTRODUCTION

The Foothill Feeder Project of the Metropolitan Water District of Southern California incorporates a long tunnel that will be part of the system which will supply water to a large area in Southern California. In this system head control devices are needed to regulate the discharge through the tunnels and the appurtenant structures, and for this purpose gated structures open to the atmosphere were chosen. The gate structures, circular in plan with the necessary emergency overflow weirs, were made large enough so that machinery access into the tunnel for maintenance could be incorporated in the structure. The circular plan also provided certain structural advantages. The research described in this report was carried out to study in detail the hydraulic characteristics for a wide variety of flow conditions for one of these structures, the Big Tujunga Gate and Spillway Structure. More specifically, the items of special interest were:

1. The head differential through the structure for various discharges and gate openings.
2. The possibility of air entrainment at the structure for normal operation and the effect of air entrainment on the flow condition when the emergency weirs are operating.
3. Fluctuating pressures or water hammer that might result from the air entrainment process.
4. Pressure measurements downstream of the gates along the piers and adjacent floor to establish cavitation potential for extreme flow conditions.

The basic features of the Big Tujunga Gate and Spillway Structure are shown in Chart 1. They consist essentially of a vertical, circular shaft 56 ft in diameter fitted with gates and emergency weirs in a central dividing wall and a spillway on the downstream side connected with a spillway tunnel. The three gates in the dividing wall consist of two outside gates, 6 ft 3 in. wide, and a central gate which is 2 ft wide, each having a maximum gate opening of 18.5 ft. The crest of the emergency spillway is 58 ft above the invert of the main tunnel. The upstream and downstream segments of the tunnel leading to the gate structure are 18 ft 3 in. in diameter. On the downstream side, a segment of the tunnel is vertically enlarged in order to provide for the collection and release of any air entrained in the flow.

A. Description of Model and Appurtenances

The model was fabricated of a clear plastic (plexiglass) at a scale of 1:38.3. This scale ratio was chosen so that standard tubes could be used for the main tunnel and at the same time provide a model of reasonable size. Photo 1 is a general view of the model set up in the neighborhood of the gate structure. In addition to the structure itself, it shows the manometer boards attached by tubing to the piezometric pressure taps. Pressure transducers were also provided at various points to measure pressure fluctuations which were then recorded on charts of the recorder. Photo 2 was taken at the time of installation of the control structure and shows the gate openings for the two outside 6 ft 3 in. gates and the center 2 ft gate. Above the gate section the structure widens out to provide space for the spillway weir and tunnel and the emergency weirs over the gates. Photo 3, taken from overhead, clearly shows the arrangement of the gates, piers, and dividing walls, as well as the spillway weir and tunnel. The plastic construction of the model permits observation and photographs of the flow pattern developed by various types of operation.

The water supply was pumped from the Mississippi River through the Laboratory supply system. It was controlled by valves in the lines and measured by means of calibrated orifices for both large and small discharges. Before entering the tunnel sections, the flow was passed through wire meshes and a honeycomb section in order to remove large fluctuations and provide a reasonably uniform flow in a tunnel system. The model discharged into a tailwater reservoir, the level of which could be controlled to maintain the downstream tunnel pressure at prescribed values. From the tailwater reservoir the discharge was returned to the river through the Laboratory drainage system.

B. Scale Relationships for Hydraulic Similarity

The gate structure, in which exists a free surface exposed to atmospheri pressure, represents a hydraulic system operating under the force of gravity and the velocities, pressures, and water surface elevations represent gravitational phenomena. For this kind of system, dynamic similarity is obtained when the model-prototype relationships are determined by the Froude law of similarity. The following relationships for velocity, discharge, pressure, etc., in terms of the length scale ratio $(L_r = 38.3)$ are then obtained.

$$V_r = L_r^{1/2}$$

$$Q_r = L_r^{5/2}$$

$$P_r = L_r$$

$$T_r = L_r^{1/2}$$

By utilizing the above equations, the model discharge can be determined and pressures and velocities, as measured in the model, can be readily translated to the prototype values.

Complete similarity for the air entrainment and air removal process cannot in general be obtained because of the difficulty in controlling the size of air bubbles in the model. However, the processes involved are qualitatively similar and it is believed that the observations made in the model regarding the air removal pattern are qualitatively correct.

II. EXPERIMENTAL RESULTS

The results of the studies of the gate structure are described below under several headings describing the particular type of experiment. Those experiments dealing with the operation of the Big Tujunga structure at or near normal operating conditions will be described first. The tests for emergency conditions and non-normal operating patterns, which should be made in order to determine the range of operating characteristics or the safety of the structure in the event that such flow patterns occur, are described in the later portions of this report.

A. Head Differential Through the Structure

For normal operating conditions, the gate position and the headwater and tailwater elevation are predetermined for given discharges. These head differentials have been measured in the model and are shown in Chart 2, where the head differential, ΔH, has been plotted in terms of the discharge for fixed gate openings ranging from 5.5 per cent to 100 per cent. It is apparent from the chart that for small gate openings and discharges the head differential becomes very large, and when the gate opening is increased to full open, the maximum discharge can be obtained for very low head differentials. Based on the prescribed operating conditions, a normal operating curve (Big Tujunga Gate Tower Head Loss Curves - Heco Drawing No. 380SKC176) had been established and is superimposed on the experimentally determined head differential curves in the chart. This curve combined with the head differential curves then provides information as to the proper gate openings for particular discharges. It will be noted that as the discharge is increased, the prescribed gate opening is such that the head differential, or the head loss through the system, becomes less, so that for a discharge of 2250 cfs the head loss through the structure is of the order of 0.5 ft. In order to measure this small difference in the model, special precautions had to be taken in the establishment of the discharge and in the measurement of the head differential. A micromanometer was used. Photo 4 shows a discharge of 2250 cfs flowing through the structure with very little turbulence and small head differential. The sign showing the headwater and tailwater elevations only provides the order of magnitude of these levels. In this instance, the actual head difference as given in Chart 2 is only 0.5 ft.

In addition to Photo 4, Photos 5 and 6 illustrate normal operation for several discharges and gate openings. Photo 5 is a smaller discharge with the gate partially closed in order to reach the required head differential. Here the discharge is 1575 cfs with a gate opening of 4.1 ft. The head differential is approximately 16 ft; the flow pattern in the structure is smooth and water surfaces are without apparent disturbance. In Photo 6, for a discharge of 900 cfs, the tailwater is 30 ft above the invert and the gate opening is 1.9 ft. An air cavity is noticeable at the crown near the upstream end of the air collector. The effect of this air cavity on the flow and pressure is described below. Further closure of the gates for any of the discharges pictured will, of course, increase the head difference so that when the gates are closed sufficiently some of the flow will be forced over the emergency weirs. Such flow patterns will be described in later sections. The photographs show that there is relatively smooth operation of the structure for normal operating conditions.

For very small discharges, the 2 ft center gate only will be operated with the two outside gates closed. For this flow, the velocity in the tunnel is very small (for a discharge of 50 cfs, the tunnel velocity is less than 0.2 fps). The water surface is quite undisturbed. Special effort was made to photograph this condition and to delineate the flow pattern. Photo 7 shows a general view of the structure when passing 50 cfs with a normal tailwater elevation. Photo 8 is an attempt to show the flow pattern by the injection of a small quantity of dye. Dye streaks against the white background show the stream lines approaching the 0.75 ft gate opening. The velocity under the gate is greatly increased so that the dye streaks lose their identity. The largest discharge for which only the center gate will be in operation is 225 cfs. Photo 9 is a view of the structure which is taken from a relatively high position and shows the smooth water surfaces both upstream and downstream of the gates. Photo 10 shows dye being injected upstream from the center gate and indicates the flow patterns as the flow approaches and then passes under the gate. As is indicated by the photos, operation with the center gate only with normal tailwater elevations is quite smooth and satisfactory.

B. Calibration of Individual Gates

For the calibration of the individual gates, the discharge was measured by means of the previously calibrated orifice. The water surface elevations upstream and downstream of the gate section were measured by two methods. In the first, a point gage was mounted over the structure and the water surface was measured directly. In the second, piezometric pressure measurements were made in the tunnel and the hydraulic gradeline was projected upstream and downstream along the tunnel to the gate section. The difference in hydraulic gradeline at the gate structure then represented the head differential. Because of the disturbances generated by the flow through small gate openings, it was sometimes difficult to determine the downstream water surface elevation by a point gage. In addition, the water surface immediately downstream of the gate was lowered somewhat because of the momentum of the high velocity jet under the gate. Thus, the head differential measured by the point gage was larger than that determined from the hydraulic gradeline.

The results of the measurements for the 2 ft center gate and the 6 ft 3 in. side gate are shown individually in Chart 3, where the measured head differential, as determined from the hydraulic gradeline, has been plotted against discharge for various gate openings. Straight lines are drawn through the log-log plot of the experimental points and represent the calibration curves for these gates. The discharge coefficients for the 6 ft 3 in. outside gate for various gate openings have been plotted in Chart 4 and those for the 2 ft center gate in Chart 5. The discharge coefficient is defined by:

$$C_d = \frac{Q}{bd_o \; (2g\Delta H + V_1{}^2)^{1/2}}$$

where Q is the measured discharge, b is the gate width, d_o is the gate opening, g is the acceleration due to gravity, ΔH is the head differential, and V_1 is the approach velocity in the upstream channel. The approach velocity was included, since although the upstream head was rather large, the velocity approaching the gate was that of the water in the tunnel. In this case, the water in the gate tower above the tunnel crown elevation served only to increase the ambient pressure and did not affect the velocity. The discharge coefficient was a constant for each gate opening within the accuracy of the measurement but a systematic variation appeared with respect to the degree of gate opening. This variation occurred for both the center and the side gate. The coefficient tended to decrease slightly with increasing gate openings from a maximum at the small gate openings and then increased to a second peak at about 80 per cent gate opening. The range, however, was small and no attempt was made to determine the cause of this variation in the coefficient. The average value of the coefficient for the 2 ft center gate was found to be 0.790 and for the 6 ft 3 in. outside gate, 0.795.

At the same time that the calibration of the individual gates was being made, the discharge coefficient was computed for the gate structure when all three gates were opened as for normal operating conditions (Chart 2). The discharge coefficient was computed for the same discharges, gate openings, and head differentials used to establish the chart. The discharge coefficients have been plotted for various gate openings in Chart 6. They suggest the same trend as the coefficients for the individual gates, but the average coefficient was 0.830, which is somewhat higher than those obtained for the individual gates. This may be due to the difference in contraction at the entrance to the gates. For the 2 ft gate, the flow is highly contracted although the gate is symmetrically disposed. For the side gate, the contraction may be equally severe because of its position. When all three gates are in use the contraction is minimized and the flow pattern is very symmetrical.

C. Pressures on Piers and Floor Downstream of Gates

This section of the report deals with the pressure on the piers and floor downstream of the gates where the cavitation potential would be the greatest and describes the results of tests in which these pressures were measured. The results indicate that for the entire range of design tailwater elevations, as prescribed for normal operation, the minimum pressure measured anywhere on the floor and on the piers was of the same order as the tailwater pressure and hence well above the minimum pressure that would be necessary to initiate cavitation. It may be concluded, then, that cavitation will not be a problem and that although smoother flow between the piers would result, it is not necessary that the piers be further downstream.

Piezometric pressures were observed at various points along the floor near the piers and along the piers close to the floor in order to find the location of the minimum pressure for various gate openings. The piezometer taps were connected by means of plastic tubing to a manometer board on which the pressures could be observed. Because of the restricted area in which the pressures were taken, it was not possible to use a pressure transducer to measure fluctuating pressures. The values recorded and plotted on the charts (Charts 7 through 12) represent the minimum as observed on the manometers. The previous studies of the Regular Gate Structure indicated that the range of pressure fluctuations due to turbulence and inherent flow instabilities was less than ±10 ft of water from the mean. This would suggest that momentary pressures somewhat less than 10 ft below the plotted points may occur from time to time.

Charts 7 and 8 show the pressures observed downstream of one of the side gates on the floor and along the piers for the minimum design tailwater elevation and for various gate openings. Charts 9 and 10 show similar results on the floor and pier wall for the side gate when the tailwater elevation is maintained at its maximum design value. Charts 11 and 12, on the other hand, show pressure measurements downstream of the center gate for the minimum design tailwater elevation. Superimposed on the curves of minimum pressures is a dashed line designated as "normal operating line." This line shows the pressures at the designated points for gate opening corresponding to the given discharge as prescribed by the normal operating line. In all cases the minimum pressure on both pier and floor was found just downstream of the break in the pier wall geometry. At this point, because of the sharp change in direction, the streamlines separate from the pier and create the resulting low pressure. Therefore, the points as plotted on the charts are in actuality the pressures as measured at this point.

As might be expected, the minimum pressures occurred when the tailwater was at its minimum value, as shown in Charts 7 and 8. In Chart 7, the minimum pressure was 15.8 ft above the invert when the gate opening was 5 ft and the tailwater elevation was 29.7 ft above the invert, while in Chart 8, the minimum pressure of 14.0 ft was observed on the pier wall at the corresponding point. These pressures are over 45 ft above the vapor pressure of the water, which must be reached if cavitation is to occur.

Charts 9 and 10, which give the results for the same point and discharges when the tailwater is raised to the maximum values, show that pressures are correspondingly increased and hence, are even further above the vapor pressure of water.

Charts 11 and 12 show the results of pressure measurements downstream of the center gate which would be operating along for discharges above 50 cfs but less than 225 cfs. These results are very similar in character to those obtained at the side gates and show that the pressures are again well above that required for cavitation and are of the same order as the tailwater itself.

The results of these measurements indicate the following pressure characteristics when the structure is operating under normal flow conditions.

1. As might have been expected from the results of previous studies, the minimum pressure on both the floor and the pier walls occurred in the region just downstream of the break in the pier geometry where flow separation occurs.
2. In all cases, for both the low and high tailwaters, the minimum pressure in this area was very appreciably above the vapor pressure at which cavitation could occur. In fact, the pressures in all cases are positive, that is, considerably higher than the atmospheric pressure.
3. Although the flow pattern downstream of the gates would be considerably improved by streamlining the downstream portion of the piers, such streamlining is not necessary for the prevention of cavitation.

D. Pressure Fluctuations and Gate Vibrations

The gates controlling the flow through the Big Tujunga Gate and Spillway Structure are suspended from the operating platform at the top of the gate shaft by means of semi-rigid gate stems. The gates themselves are fabricated of steel shapes and move up and down in vertical gate slots. The gate system is a relatively flexible system that could vibrate or undergo an oscillating motion if acted upon by sufficiently large fluctuating forces. These fluctuating forces are inherent in the flow in the tunnel or can be generated by periodic vortices shed from the gate lip or other irregularities in the geometry.

The gate system itself has a certain natural frequency determined by its mass and rigidity. If the natural frequency approaches the forcing frequency, resonance will exist and rather large vertical oscillations may occur.

The magnitude of the oscillation is governed to a large extent by any damping forces such as gate friction that are inherent in the system and which may be enhanced by the large lateral force due to the head differential across the gate system.

This section deals with the studies undertaken to estimate the natural and forcing frequencies and hence, the liklihood that the vertical oscillations of the gate will be deleterious to the system. Since the model gates are not dynamically similar to the prototype gates, direct measurements of the oscillations were not feasible with the present apparatus. The model gates would have to be precisely fabricated so as to be geometrically and dynamically similar, and adjusted so that the gate friction would approximate the expected prototype friction reduced to model scale. In order to circumvent this situation, the estimate was based upon a comparison of computed values of the natural frequency and the forcing frequencies measured in the model.

To measure the fluctuating pressures on the gates in the model, a pressure transducer was flush mounted on the downstream side and the upstream side of opposite outside gates. In order to enclose the transducer and its electronic leads, a housing was added to the gate on the side opposite the sensing element. This limited the measurements to only one side of the particular gate. The gates were wedged rigidly in a closed position so that the transducer would measure only the pressures generated by the flow. Since the gates were closed, the maximum discharge was directed over the emergency weirs. It was felt that maximum pressure variation would occur for this flow condition. The frequency spectra of the pressure fluctuations are given for the upstream and downstream sides, respectively, in Chart 13. The plots show the root mean square (RMS) of the pressure fluctuation amplitudes in terms of the frequency with which they occur. Of significance is the frequency with which the various pressure pulses occur in relation to the natural frequency of the gates. For both the upstream and downstream side of the gate, only a very small portion of the total power occurs at frequencies of 10 cycles per second (cps) or more.

The natural frequencies of the gate system for both gates in various positions are also indicated in Chart 13. These are considerably larger than any of the frequencies measured for the pressure fluctuations. The measurements show that the maximum pressure fluctuations occur at very low frequencies and the amplitude more or less continually decreases as the frequency increases. The secondary peak of the spectrum for the upstream side of the gate is thought to be due to pressure pulses transmitted through the piping system by the pump which is used to supply the model. These were greatly reduced by by-passing a large part of the total pump discharge and thus diverting a relatively small portion through the model structure. If these pulses are neglected, the power inherent in frequencies greater than 1 cps is very small. Because the height of the tower for the Big Tujunga Gate and Spillway Structure is considerably less than that of the Regular Gate Structure, the gate hoist stems are proportionately shorter. The shorter gate stems give rise to higher natural frequencies and so the natural frequency of the Big Tujunga gate systems has been recomputed and the values are plotted in Chart 13.

These pressure fluctuation measurements are qualitatively very similar to those obtained in the Regular Gate Structure and the discussion of those results, as well as the comparison with equivalent prototype data given in Part I - Regular Gate Structure, also apply to these results.

The experiments indicate that in the model the pressure fluctuations generated by the water falling over the weir are relatively small and occur at a frequency which is considerably lower than the natural frequency of the gate system. It is expected, therefore, that gate vibrations will not be a problem of significant proportion in this structure even when operating at high discharges.

E. Minimum Tailwater Elevation to Prevent Formation of a Free Surface Near the Crown of the Air Collector

If the tailwater is lowered to the minimum normal value and the gate opening is small so that the head differential is large, the momentum of the high velocity jet under the gates tends to lower the tailwater immediately downstream of the gates. The water surface is drawn below the crown of the air collector and permits a large air cavity to form. This is shown in Photos 6 and 11 for successively lower tailwaters. In Photo 6, for a discharge of 900 cfs, the tailwater is 30 ft above the invert and the gate opening is only

1.9 ft. A slight air cavity is noticeable. When the tailwater is reduced further to 28.5 ft above the invert, the volume of air in the air collector is considerably greater, as shown in Photo 11.

In order to determine what effect free surface has on pressure fluctuations within the air collector, a transducer was mounted at the downstream end of the air collector as shown in Chart 14. Pressure fluctuations transmitted to this point were then recorded on charts so that the nature of the fluctuation could be observed. The transducer was mounted at the downstream end of the air collector because the magnitude of the pressure impacts would be greater here, particularly for those cases where a free surface existed in the air collector.

In Chart 14 are shown the pressure measurements for a discharge of 2250 cfs with three gates open 18.5 ft. The tailwater was set successively at 21.4 ft, 25.0 ft, 29.75 ft (the minimum design tailwater), and 44.2 ft (the maximum design tailwater). The chart shows that for all tailwater elevations there were no pressure fluctuations transmitted to the transducer at the downstream end of the air collector. For this discharge, the three gates were completely open so that the flow cross-section is not appreciably reduced. The velocities through the gate section were not increased to the point where the added momentum would cause significant changes in the flow pattern. Chart 15, which gives the results for a discharge of 1575 cfs, shows that if the tailwater is reduced below a certain elevation, pressure fluctuations are transmitted in the air collector. For this test with the gates opened to 4.1 ft, as for normal operating conditions, the chart shows that with the tailwater at 29.0 ft, which represents the minimum design tailwater, these pressure fluctuations will occur. However, when the tailwater is at 31.0 ft, the air pocket in the collector is eliminated and the pressure fluctuations are reduced to zero. At the maximum tailwater elevation of 36.1 ft the air collector remains full and the pressure fluctuations are eliminated. Similar results, although considerably less in magnitude, were observed for a discharge of 900 cfs as shown in Chart 16. When the tailwater elevation was lowered to the minimum design tailwater of 28.5 ft, the crown of the air collector was exposed slightly and occasionally a wave would be transmitted to the downstream end of the air collector. However, when the tailwater elevation was raised to 30.0 ft, any such fluctuations were effectively eliminated.

The photos and charts cited in this section have indicated that the minimum design tailwater for some discharges is such that the crown of the air collector is exposed, permitting waves and surges to develop on the free surface. This gives rise to pressure fluctuations of considerable magnitude. The tests show that these pressure pulses can be eliminated by increasing the minimum design tailwater approximately 1.5 ft so that the air collector is submerged. At such tailwater elevations the increase in momentum under the gate is not great enough to lower the tailwater immediately downstream of the gate sufficiently to expose the crown of the air collector. If the tailwater in this intermediate discharge range is increased, the tests demonstrate that a good, relatively undisturbed flow pattern will be obtained through the gate structure for normal operating conditions. However, if it is impracticable to increase the minimum tailwater at this structure to keep the air collector full, similar reduction in pressure pulses can be obtained by lowering the crown of the air collector a corresponding amount.

F. Minimum Tailwater Elevation to Prevent Formation of Hydraulic Jump in Tunnel

When the tailwater is drawn down to a minimum elevation, the water surface downstream of the gate may be below the crown of the air collector as was indicated in the previous section. If this condition is exaggerated by lowering the tailwater still more, the flow may separate from the gates and permit the formation of a hydraulic jump in the air collector or the tunnel. Along with the intense pressure fluctuations caused by the turbulence of the hydraulic jump, large amounts of air are entrained by the jump and released at a point some distance downstream. This air may enter the tunnel with consequently large pressure fluctuations. Tests have been made to determine the minimum tailwater elevation that would be required to keep the gates submerged for different discharges and gate openings. The character of the flow when a hydraulic jump does form is shown in Photos 12 and 13, which show an overall view of the complete jump and a close-up view of the jet leaving the gate. In Photo 12, the tailwater has been drawn down to 18.5 ft so that the hydraulic jump formed some distance downstream of the gates. The high degree of turbulence in the jump is shown by the entrained air. In Photo 13, which is a close-up of the jet in Photo 12, the high velocity jet along the piers has caused the flow to separate at the end of the pier permitting air to be drawn down into the cavity. This photo delineates clearly the region in which pressure on the pier will be a minimum. The results of the test, shown in Chart 17, indicate how headwater is drawn down from its initial elevation as the tailwater is reduced. In addition, the chart shows the minimum pressure on the pier wall to be less than zero when conditions for the hydraulic jump are created for each discharge. As suggested by Photo 12, the minimum pressure occurred downstream of the break in a pier wall at piezometer 5. A minimum pressure of -3.2 ft of water occurred when the discharge was 2250 cfs and the gate opening was 5.8 ft, and the tailwater elevation was lowered 16.5 ft above the invert.

This chart shows the consequence of lowering the tailwater too far. It also shows that the minimum design tailwater of 28.3 ft above the invert is sufficiently high to prevent separation at the gates and to maintain a relatively quiet flow. It should be noted that although the pressures found on the pier are negative, they still do not approach the pressure necessary to initiate cavitation.

G. Pressure Fluctuations due to Emergency Overflow when Operating at Normal Tailwater Elevations

In the previous report (Part I - Regular Gate Structure) it was suggested that the vent pipe in the air collector be moved to the upstream end of the collector and be throttled in order to reduce the pressure fluctuations in the air collector. The model test conducted on the Big Tujunga Gate and Spillway Structure was made with the vent pipe at the upstream end of the collector and with the pipe throttled to an area of 0.5 sq. ft.

If for any reason the gates are closed and the entire discharge flowing in the tunnel flows over the emergency weir to impinge on the flow downstream of the gates, large quantities of air will be entrained by the falling jet. This entrainment process and the disturbance created by the jet gives rise to large pressure fluctuations which may be transmitted through the tunnel. An attempt has been made to measure these pressure fluctuations and to develop a means of eliminating them if they are deleterious to the operation of the system. The high intensity pressure pulses are due to the explosive discharge of air through the water trapped in the vent pipe by the tailwater, whose elevation is always above the crown of the collector. As air is released from the flow it collects along the crown of the air collector. As more air is collected and the pressure increases, it collects in the vent pipe under the water. As it rises up through the vent pipe, it is suddenly released through the water to the atmosphere. This sudden release and the momentary reduction of collector pressure to the atmospheric pressure causes the water level in the collector to rise rapidly to the crown resulting in an appreciable impact. This impact may be transmitted down in the tunnel.

The results of these experiments are shown in Charts 18 through 21. The charts were prepared in order to compare normal operating conditions with emergency conditions when the entire discharge goes over the weirs. Chart 18 shows some of the typical pressure records with a maximum discharge of 2250 cfs using all three gates. The records include pressure measurements for the minimum design tailwater of 29.75 ft and for the maximum design tailwater of 44.2 ft. The results show that when the gates are fully open to 18.5 ft, there are no pressure fluctuations for either the minimum or maximum tailwaters. The air collector is completely full and the gates themselves provide no restriction to the flow. When the gates are closed, however, the water discharging over the emergency weirs impinges on the downstream pool, causing highly turbulent flow with very considerable air entrainment. The appearance of the flow over the weir and the turbulence generated in the downstream pool are shown in Photo 14. The pressure variations generated by the jet are transmitted to the downstream end of the air collector and are recorded on Chart 18. The maximum pressure pulse was about the same for both tailwater elevations and the principal bursts of the pressure pulses appear to have a fairly long period. When the water goes over the weirs, these pressure fluctuations are very similar to those observed previously in the Regular Gate Structure, which has a basic geometry very similar to the Big Tujunga Gate and Spillway Structure. In Chart 19 the results for a discharge of 1575 cfs are shown again for both the maximum and minimum tailwater, and with gates opened and closed. The same type of data as on the previous chart was collected and is presented here. When a tailwater is maintained at its maximum value of 36.1 ft, a discharge of

1575 cfs through the structures with the gates opened the prescribed amount flows smoothly without any disturbances. The reason for the periodic pressure fluctuations which appear when the tailwater is set at the minimum design value with the gates open 4.1 ft was discussed above.

When the gates are closed, the flow over the weirs generates turbulence and causes air entrainment in the same manner as that described with a higher discharge. The pressure fluctuations caused by this flow over the weirs are shown in Chart 19. The patterns are quite similar to those generated by the higher discharge and are only slightly less in magnitude. When the discharge has been reduced to 900 cfs, the whole system is much quieter for all conditions of flow. This is shown in Chart 20. It can be seen from Chart 21 that when discharges of 50 cfs and 225 cfs are discharged through the center gate, the flow is very quiet and smooth and there are no pressure fluctuations at the downstream end of the air collector for either discharge. Photo 15 shows a discharge of 225 cfs being passed through the center gate. The water surface both upstream and downstream of the gate has been covered with confetti. The smooth surface is plainly evident from the fact that the confetti remains relatively stationary on the surface. Even when the gate is closed the discharge over the weir is so small that no pressure fluctuations are transmitted downstream.

The tests have indicated that for low discharges, that is, 50 cfs and 225 cfs, the flow is quite undisturbed and even when the flow is discharging over the emergency weirs, pressure fluctuations are not apparent. However, when larger discharges are passed over the emergency weirs there are pressure pulses generated with magnitudes up to nearly 15 ft of water. Such pulses should be tolerable since the condition of weir overflow will happen very rarely if at all.

H. Effect of Center Gate Closure on Water Surface Elevations

This section deals with the rather turbulent and irregular water surface upstream of the gates when the center gate is closed and the other gates are open various amounts to pass the required discharges. It was observed that when the center gate was closed, a boil developed just upstream from the center gate. It was presumed that the boil was the consequence of the abrupt change in the momentum of the flow filaments directed towards the closed center gate, some of which could now flow upward along the gate between the adjacent piers. Attempts were made to eliminate this boil by the installation of a baffle-plate between the piers at the top of the gate in order that the water flowing vertically upward would be redirected horizontally upstream at the water surface.

Normally, for large discharges all the gates are opened equally and the water passes through the gate section with relatively little disturbance because the piers are reasonably streamlined and end in a point downstream of the gates. The gate section then acts as a sluice with essentially two-dimensional flow. When the center gate is closed, however, water in contact with the gate cannot flow laterally into the two outside openings because of the piers which project upstream on either side of the gate and prevent such lateral flow. Some of this water then tends to flow upward along the face of the gate and the momentum of the oncoming flow is sufficient to force it to rise above the surrounding water surface creating what appears to be a boil. As would be expected, as the discharge is decreased, the intensity of the boil is decreased. Likewise, when the water surface elevation upstream of the gates is increased, the intensity of the boil is decreased. In the first case, the strength of the boil is decreased by the decreasing momentum and in the second case, the intensity is reduced by the dissipation of the jet rising through a greater depth of water. The upward flow along the gate is shown in Photo 16, in which paths of dye streams immediately upstream of the center gate have been photographed. The photo shows the section of the gates and dye being ejected at various elevations through small holes in the dye injection tube which photographs as a vertical dark line upstream of the gate. It will be noted that the two upper jets are directed upward along the face of the gate, while the lower jets are directed more or less downward where considerable mixing occurs. The upward flow along the gate creates a boil. The appearance of the water surface immediately upstream of the gates is shown in Photo 17 for a high discharge and a closed center gate. In this photograph, the water surface was initially covered with aluminum powder and the upwelling in front of the center gate can be seen because of the displacement of the aluminum powder in this area. The extent of the upwelling can also be deduced from the photograph. The water surface profile immediately upstream of the center gate along a line normal to the gate section was measured for various discharges and for various headwater elevations on the upstream side of the gates. These data are shown in Charts 22 and 23. With the gate closed and without any modification of the gate structure, the rise in water surface can be seen for the larger discharges and the smaller heads.

Having observed the nature of the boil, it was felt that the upwelling could be eliminated and the upward flow redirected along the water surface if a horizontal plate were installed between the piers above the gate. This plate extended upstream to the pier noses and filled the space between them. The qualitative effect of the baffle-plate can be seen in Photos 18 and 19. In Photo 18, dye streams are ejected at various elevations from holes in the dye probe and flow toward the gate. In this case, however, the upward flow carrying the dye is drastically reduced, and after a first tendency to rise, the dye streams are directed downward along the gate. The relatively calm water surface after the baffle-plate had been fitted is shown in Photo 19, where the water surface has again been covered with aluminum powder. Small disturbances are seen on the water surface and in two small patches clear water can be seen. It appears from these photographs that the baffle-plate is rather effective in reducing the intensity of the boil. Measurements of the water surface profile upstream of the center gate, as plotted in Charts 22 and 23, show the water surface for comparison with the profile without the baffle-plate. It will be noted that with the baffle-plate the water surface is relatively smooth and horizontal for all discharges and headwater elevations, while the water surface without the baffle-plate shows the increase in water surface elevation caused by the upward flow along the gate in the longitudinal extent of the boil. Chart 22 shows the rather significant decrease in the size of the boil as the discharge decreases, so that for discharges of 1000 cfs, for minimum tailwater elevation, the water surface with and without the baffle-plate is nearly the same. There is appreciable difference for the two conditions when a discharge has been increased to 1500 cfs and more. In Chart 23, the discharge is constant at 2250 cfs while the headwater elevation has been increased successively from 31.0 ft to 51.3 ft by closing the outer gates in increasing increments. Here again, the water surface is essentially horizontal when a baffle-plate is used at the given headwater elevation. Without the baffle-plate the water surface near the gate is as much as half a foot higher than the surrounding surface. This baffle-plate may actually be any device structurally feasible that will prevent the upward flow at the top of the gate and redirect the jets in an upstream direction at the water surface. It appears that the presence of the boil has little influence on the operation of the gates or the character of the flow through the gates, and the use of the baffle-plate serves primarily to provide a smooth water surface in the upstream section of the gate tower.

I. Flow Through Emergency Spillway Tunnel

If for any reason the tunnel downstream of the Big Tujunga structure is fully or partially closed, the water flowing in the tunnel must be rejec~~ted~~. The spillway overflow weir and tunnel on the downstream side of the structure are designed to serve this purpose. Photo 20 shows the maximum design discharge passing over the weir and into the tunnel.

As designed, the facility is capable of passing the maximum discharge safely out of the structure. As can be seen in Photo 20, there is a tendency for the flow to spiral down the tunnel after leaving the structure. This is due to the unsymmetrical nature of the approach to the tunnel. The spiral flow, however, is not detrimental to the tunnel capacity, and, since the tunnel will rarely be used, studies leading to better flow patterns are not necessary.

Visual observations and photographs indicate that the spillway weir and tunnel can, if necessary, safely reject the maximum design discharge.

III. CONCLUSIONS

The experimental study of the Big Tujunga Gate and Spillway Structure was concerned with operating characteristics for both normal and non-normal conditions. The results of the study led to the following conclusions:

1. For normal operation, the flow in the structure was smooth and relatively undisturbed for all discharges.
2. The measurement of head differential compared well with preliminary computations.

3. Pressures on the piers and floor downstream of the gates in a region of high velocity are well above the cavitation pressure for both normal and non-normal operating conditions.

4. In order to prevent the formation of a free surface in the air collector for certain discharges and gate openings, it is recommended that either the tailwater elevation be increased by 1.5 ft or the crown of the air collector be lowered a similar amount.

5. The minimum tailwater elevation at which the gates are not exposed by the hydraulic jump is estimated as 19 ft. The minimum design tailwater for all discharges is at least 28.3 ft.

6. The natural frequency of the gates in comparison with the frequencies of the forcing functions are sufficiently large so that oscillations of the gates will be minimized. These and other experiments indicate that additional experiments on gate vibrations would probably not be worth the cost.

7. The pressure fluctuations due to the emergency overflow of the weirs are of a relatively small magnitude and should not cause hydraulic or structural problems.

8. It is recommended that in order to remove the surface boil which is sometimes apparent upstream from the center gate, the geometry be revised to include a baffle-plate mounted between the piers and above the center gate.

9. The spillway tunnel which leaves from the Big Tujunga structure on the downstream side is of sufficient capacity to handle the maximum discharge to be expected at the site of the Big Tujunga structure.

LIST OF PHOTOS

PHOTO 1 (Serial No. 168A-98) The experimental apparatus is fabricated of a transparent plastic so that the flow patterns could be easily observed and photographed. Piezometer taps and pressure transducers were installed in the model to measure pressure conditions at various points. The manometer board and transducer recorder are shown in the photograph of the model.

PHOTO 2 (Serial No. 168A-85) This is a dry view of the Big Tujunga model prior to its installation in the model tunnel. It is a view looking into the downstream end of the gate structure, showing the gate section and the rectangular flow passages. Upstream and downstream of the gate structure transitional sections from a square to a circular tunnel will be installed. A spillway tunnel inlet is also shown.

PHOTO 3 (Serial No. 168A-86) This is a view from over-head showing the geometry of the structure in plan. The piers and the dividing walls for the emergency weirs and the spillway are shown in their relative position. The narrow center gate to be used for low discharges is shown in comparison with the wider, outside gates.

PHOTO 4 (Serial No. 168A-87) This photograph is a close-up of the structure installed in the tunnel system and ready for testing. The gates, weirs, spillway tunnel, and transition sections are clearly shown in this view. It also shows the undisturbed water surface for a discharge of 2250 cfs through the tunnel with the gates wide open. This is a normal operating condition.

PHOTO 5 (Serial No. 168A-100) This photograph shows the operation of the Big Tujunga Gate and Spillway Structure, for a smaller gate opening and larger head differential. When the discharge is 1575 cfs, the gates are closed to 4.1 ft. The head differential is approximately 16 ft. This photo illustrates the character of the flow for approximately normal operating conditions as defined by the operating line in Chart 2. It shows that the flow is quiet and the water surface is undisturbed.

PHOTO 6 (Serial No. 168A-125) For a discharge of 900 cfs normal operating conditions require that the gates be closed to approximately 1.9 ft, for which condition the head differential is approximately 24 ft. This photograph shows the flow pattern for conditions closely similar to those for normal operation. The water surface on the upstream side of the gate structure is smooth and quiet, but the momentum of the high velocity under the gate has lowered the water level just downstream of the gates to a value below the crown of the air collector and below the downstream tailwater.

PHOTO 7 (Serial No. 168A-110) This photo shows the structure with a discharge of only 50 cfs and with a tailwater and gate opening at design values. The water surface downstream of the gates is quite smooth, even though there is a considerable head difference and a small gate opening.

PHOTO 8 (Serial No. 168A-112) This close-up view of the gate section for a discharge of 50 cfs shows dye being injected a short distance upstream of the center gate. The velocity of flow in this region is very low so that the dye streaks are not well defined. When the dye reaches the pier nose, and flows under the gate, the flow lines are better defined and downstream of the gate the dye loses its identity.

PHOTO 9 (Serial No. 168A-115) This photograph is a view of the structure for normal operating conditions for a discharge of 225 cfs. The photo, which was taken from a relatively high position, shows the smooth water surface both upstream and downstream of the gates.

PHOTO 10 (Serial No. 168A-114) This is a close-up view of dye being injected into the flow upstream of the gates for a discharge of 225 cfs through the center gate. The dye clearly defines the jet as it approaches the gate and the extent to which it penetrates downstream of the gate before it is mixed with the flow in the downstream tunnel.

PHOTO 11 (Serial No. 168A-124) For a discharge of 900 cfs at the minimum design tailwater the momentum of the jet under the gate reduces the water level in the region downstream of the gate below the design tailwater. The free surface at the upstream end of the air collector can be seen. This photograph should be compared with Photo 6, which shows the same condition except that the tailwater has been raised to 30 ft.

PHOTO 12 (Serial No. 168A-104) When the tailwater is lowered sufficiently, the flow separates from the downstream side of the gates and forms a hydraulic jump further downstream in the air collector or tunnel proper. For normal operation, the tailwater is at least 10 ft higher than that shown in this photograph, so that the gates will be fully submerged.

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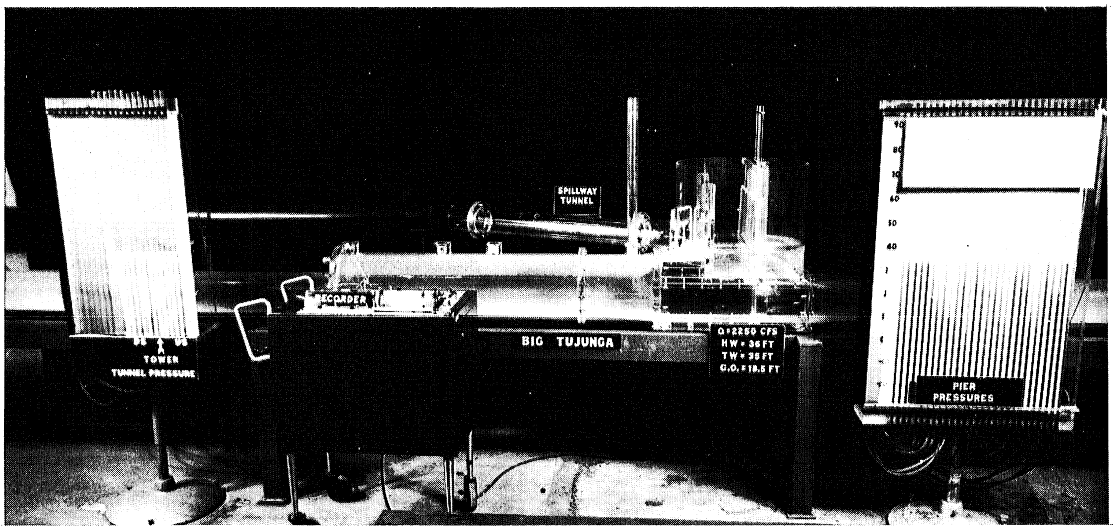
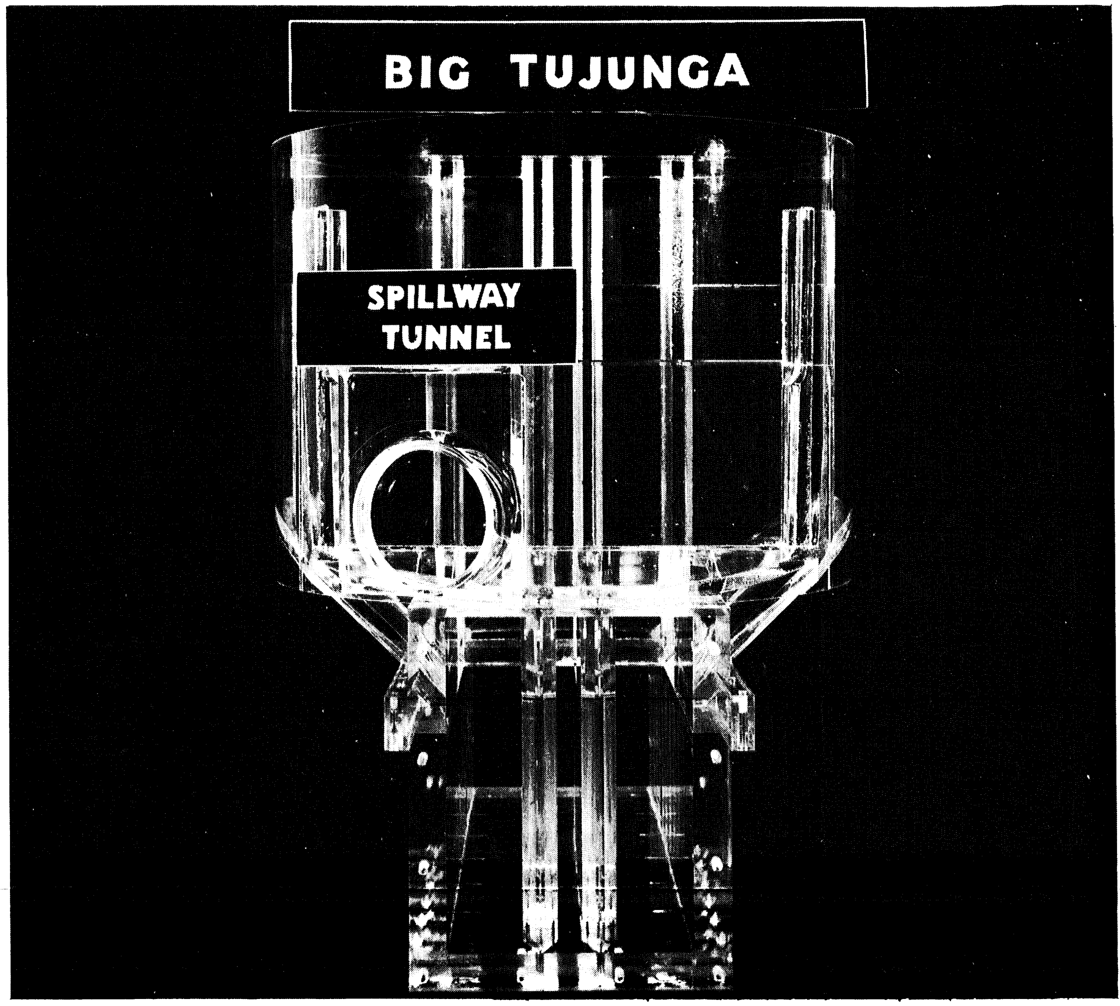


Photo 1



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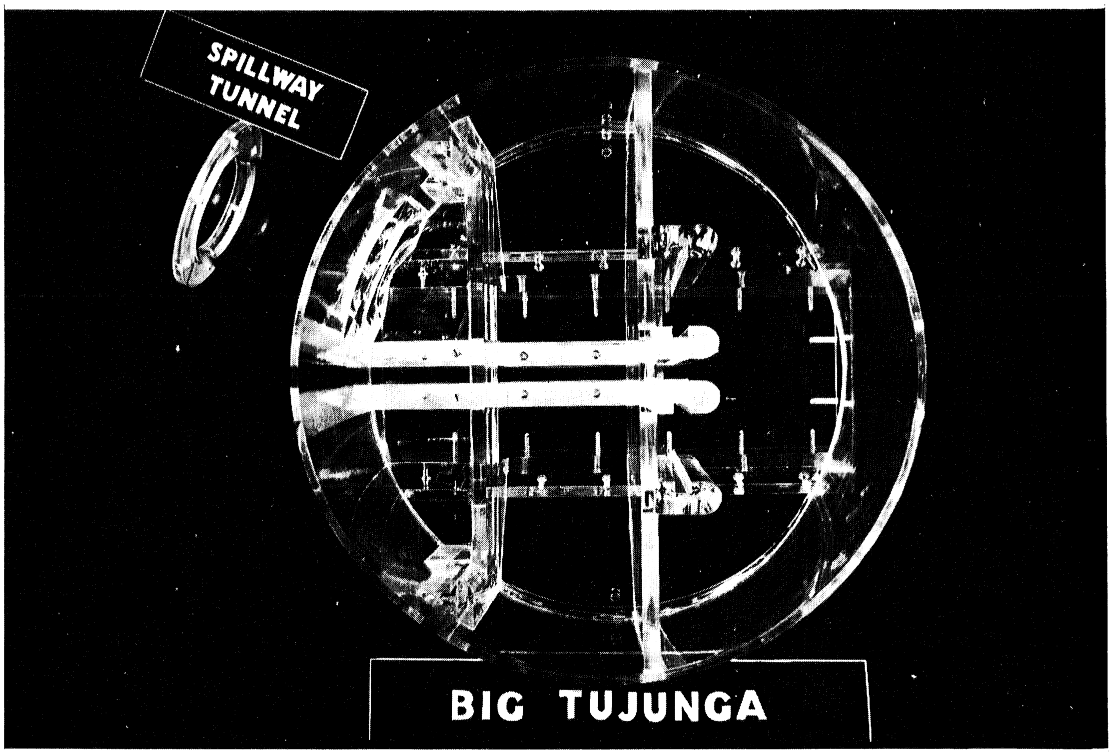

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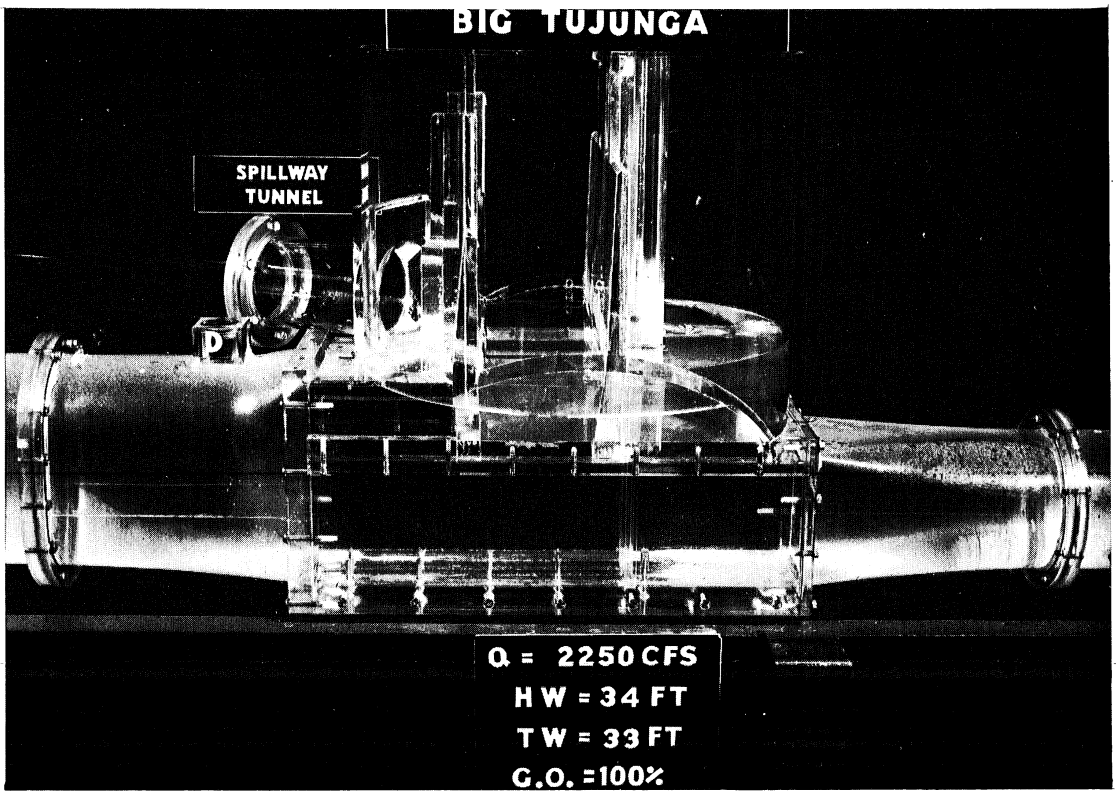

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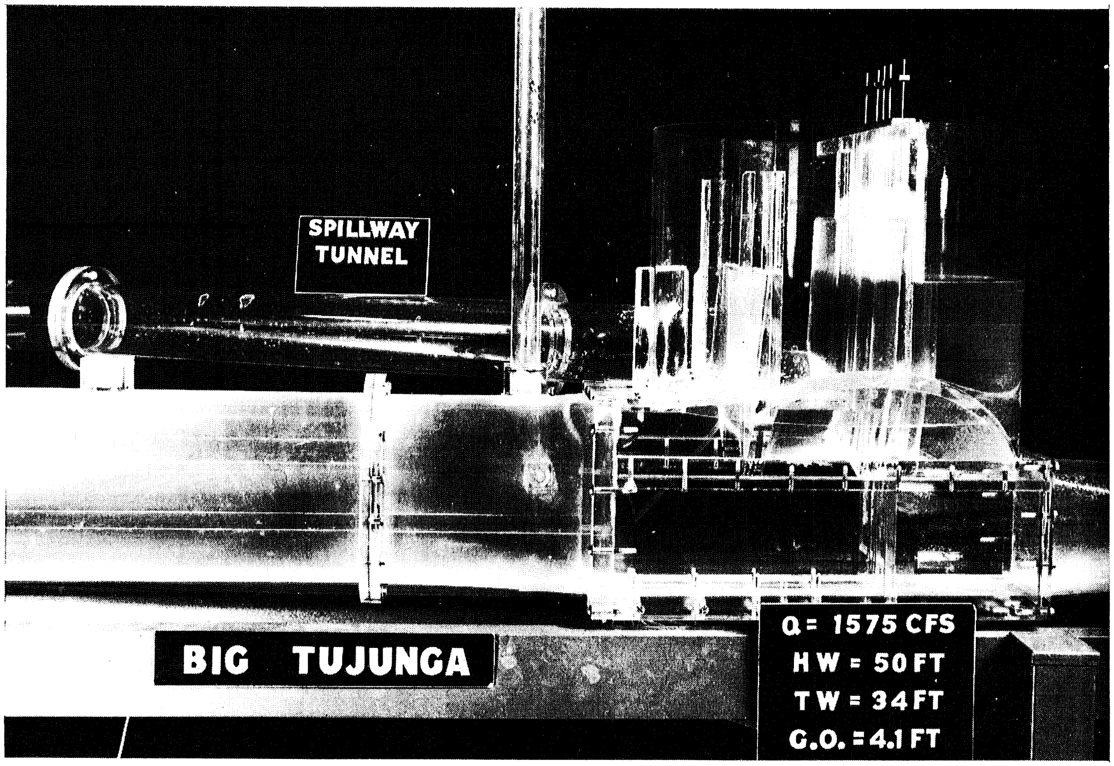

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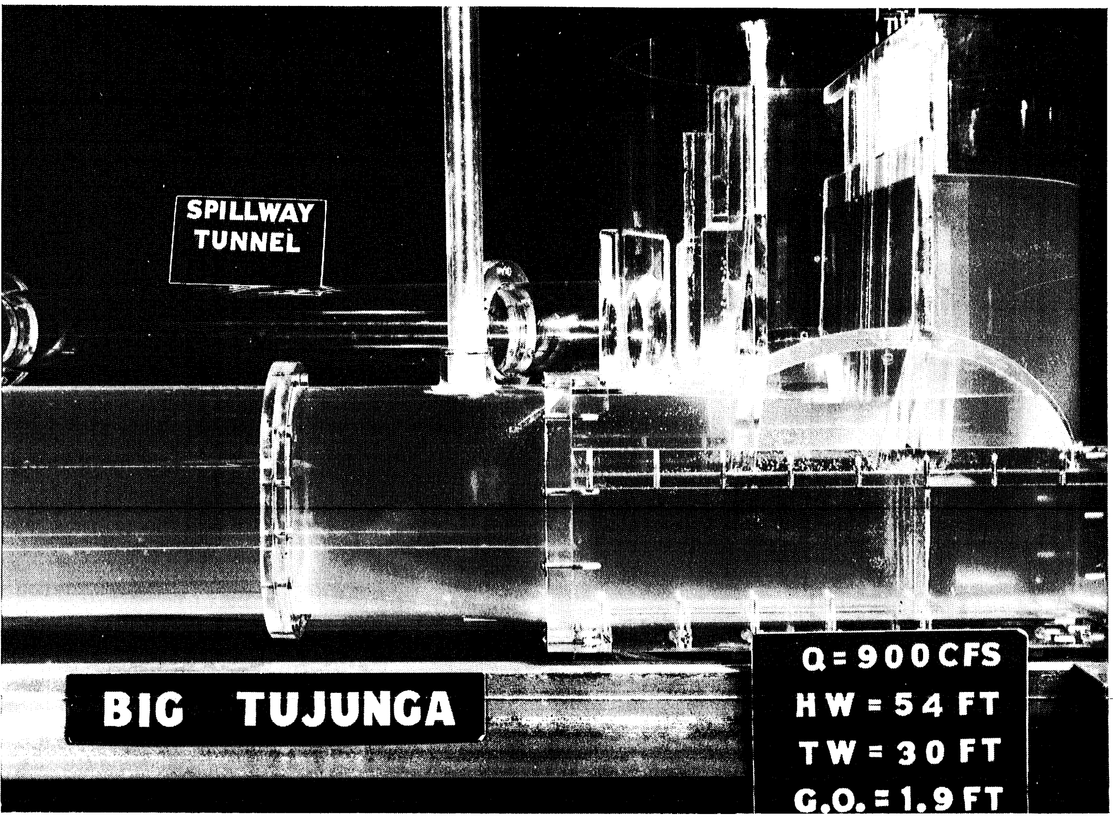

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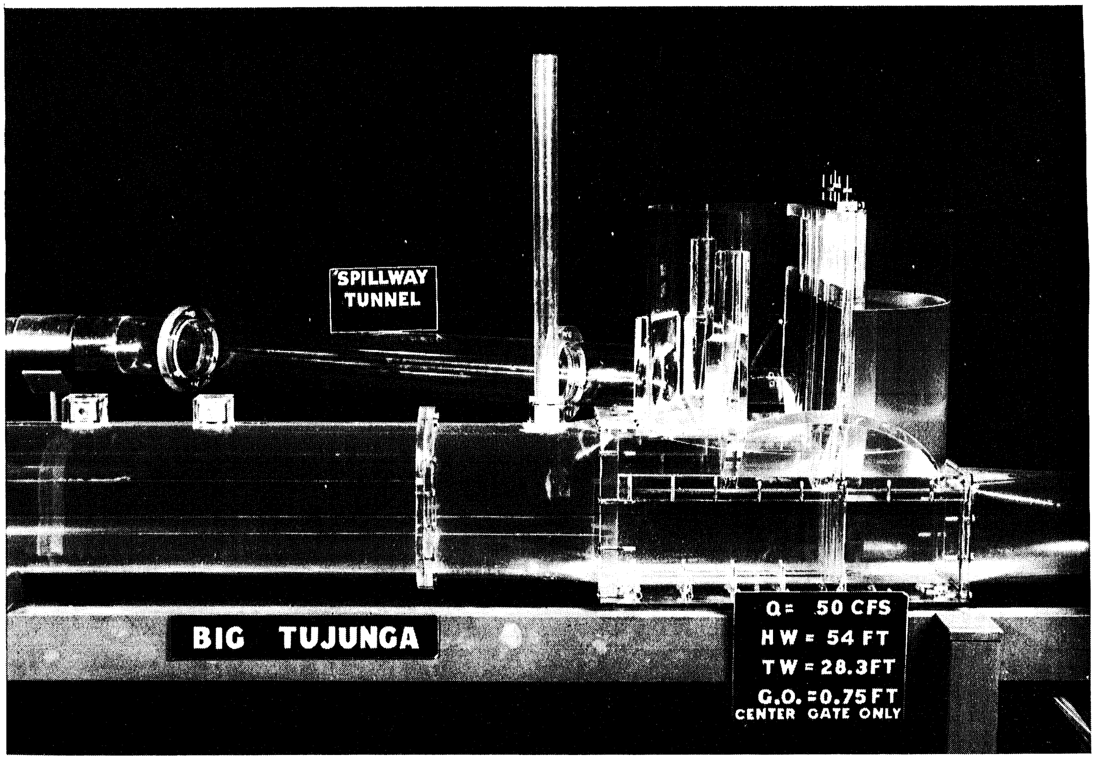

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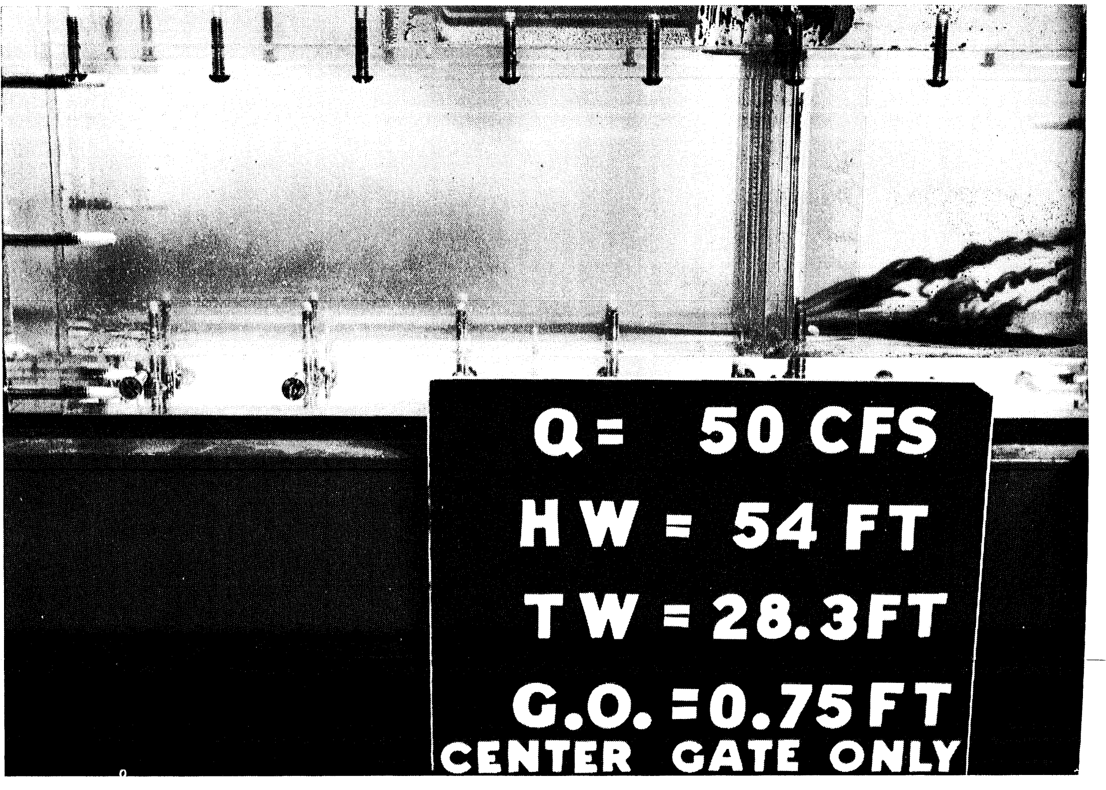

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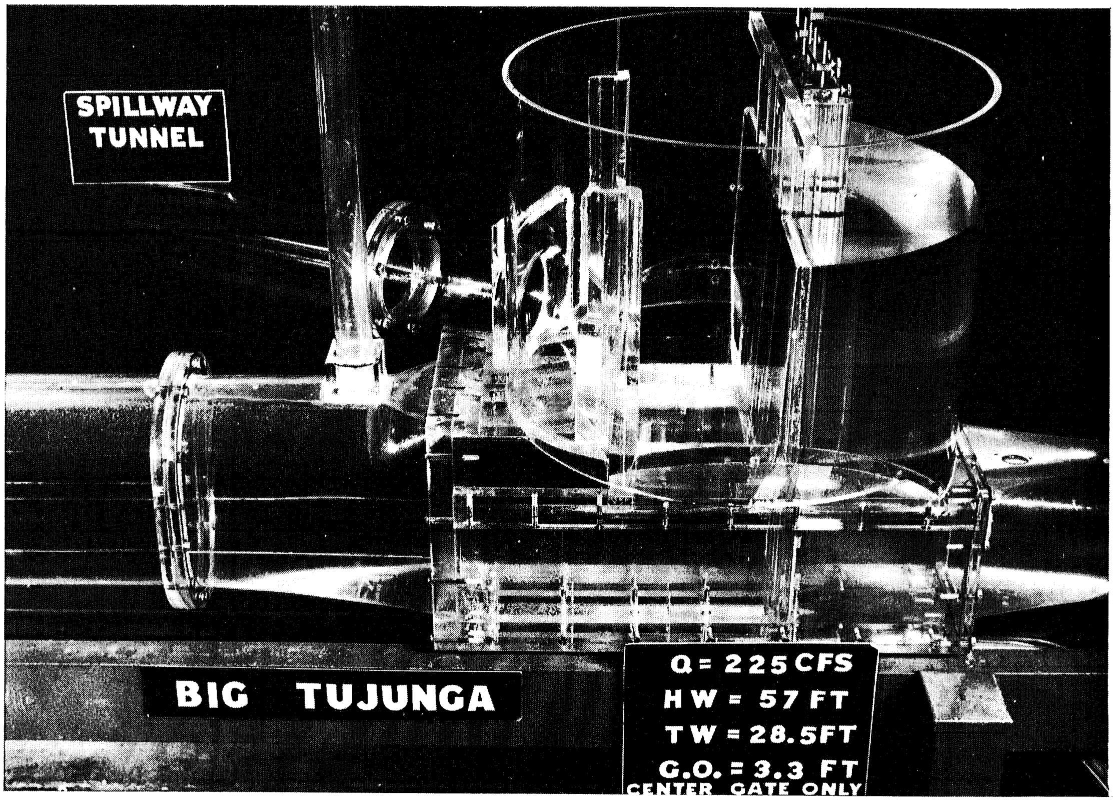

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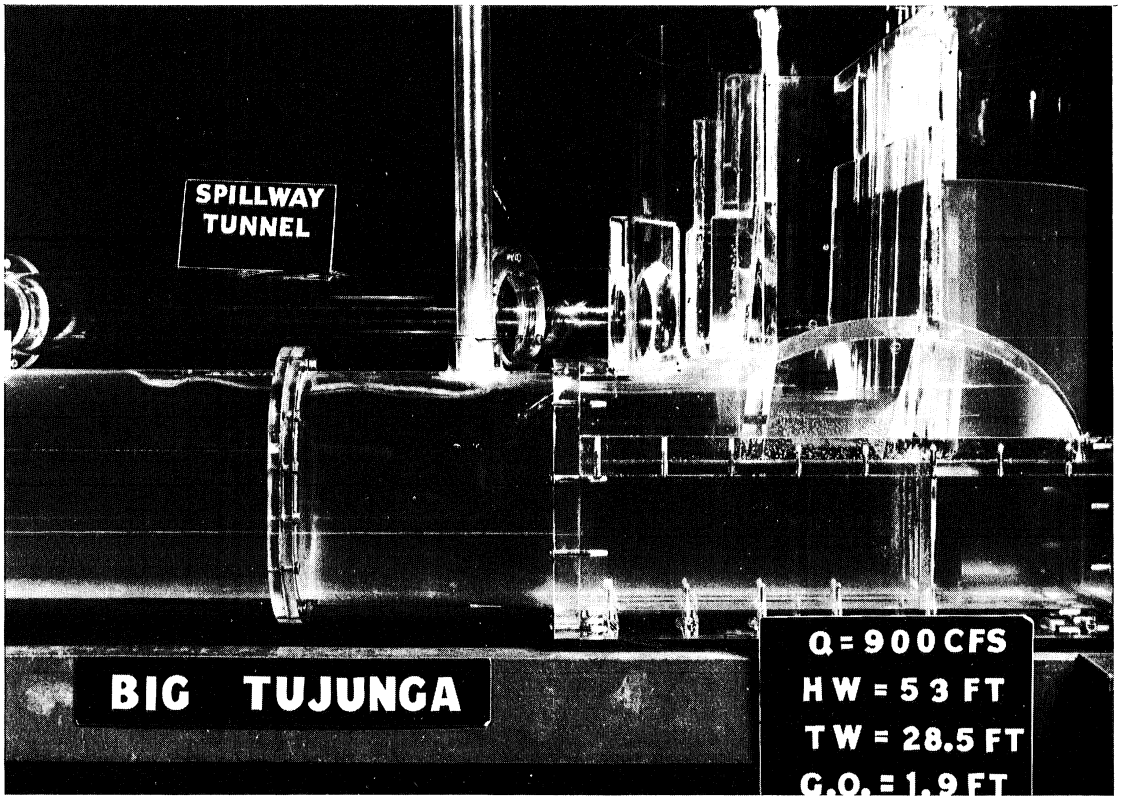

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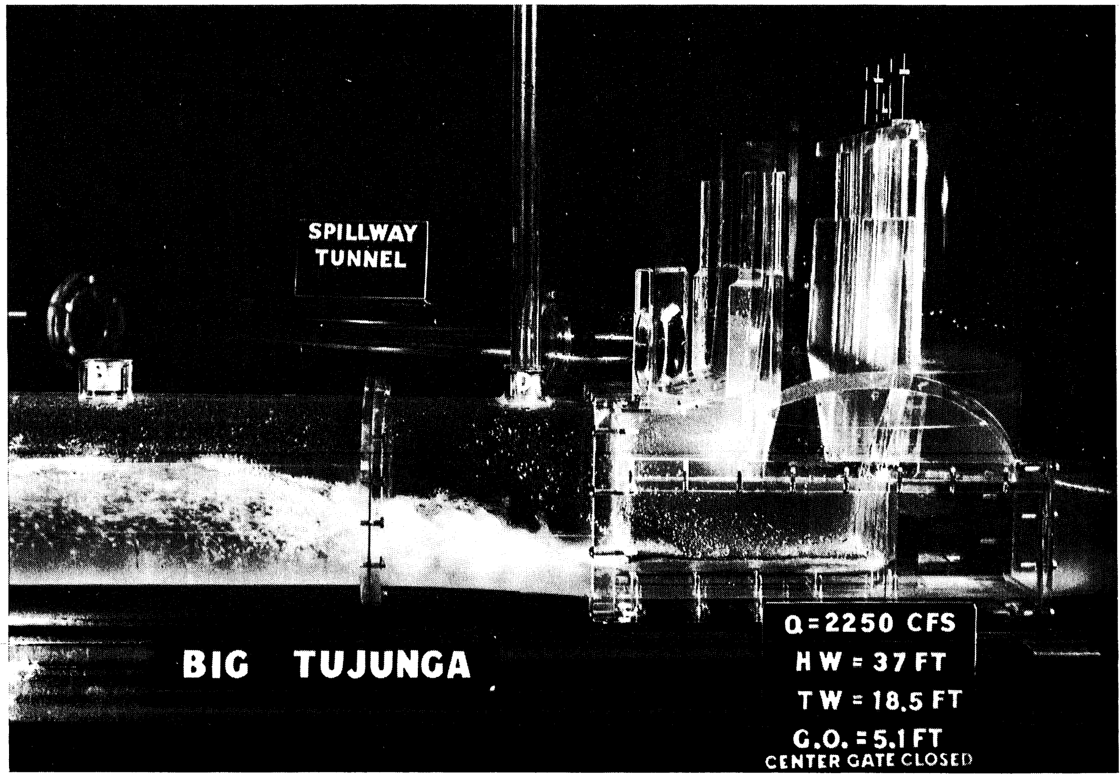

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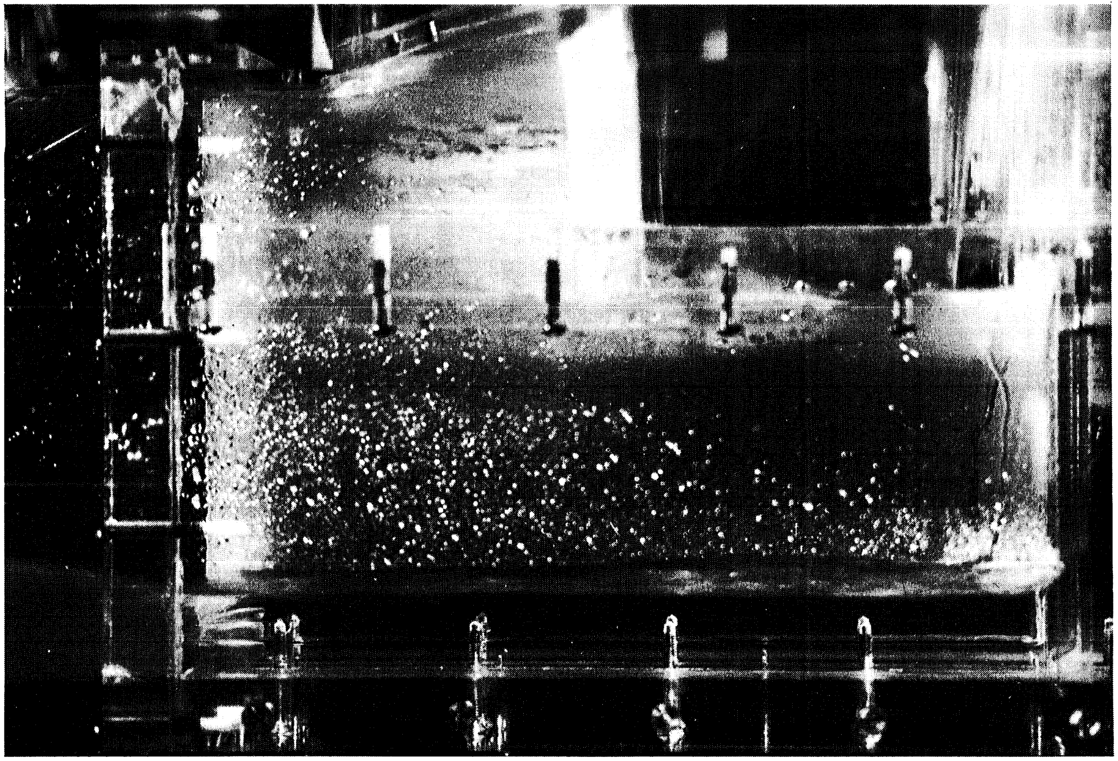

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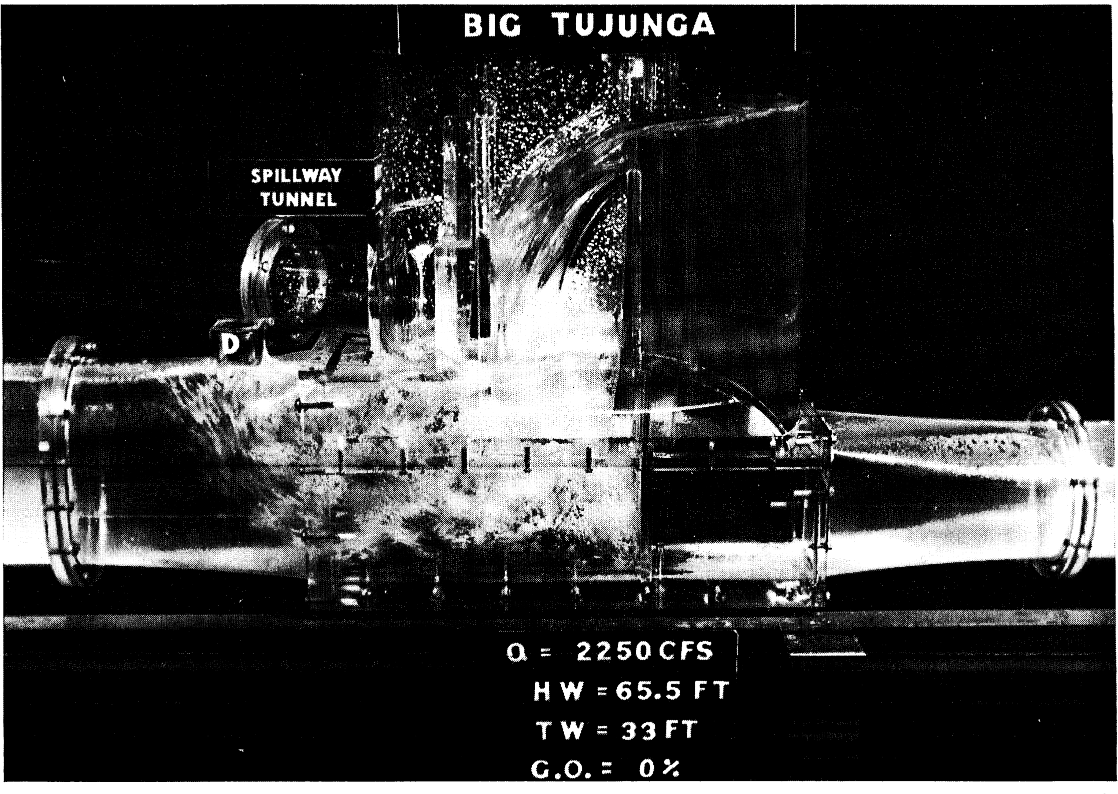

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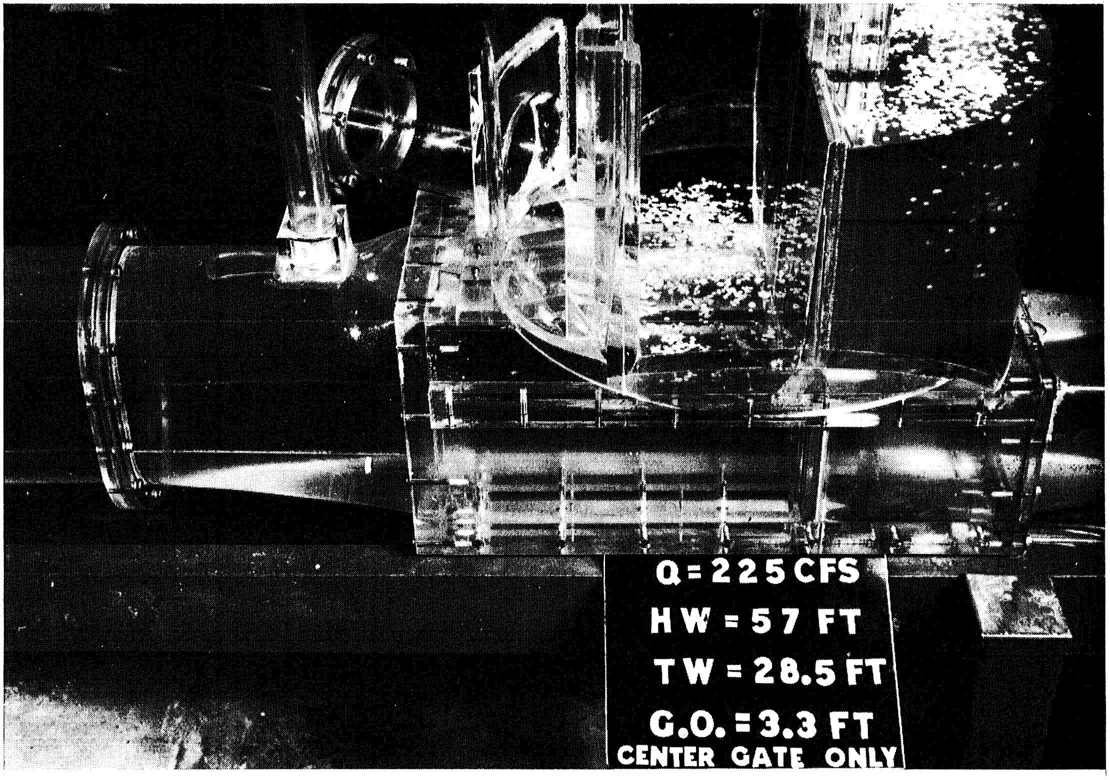

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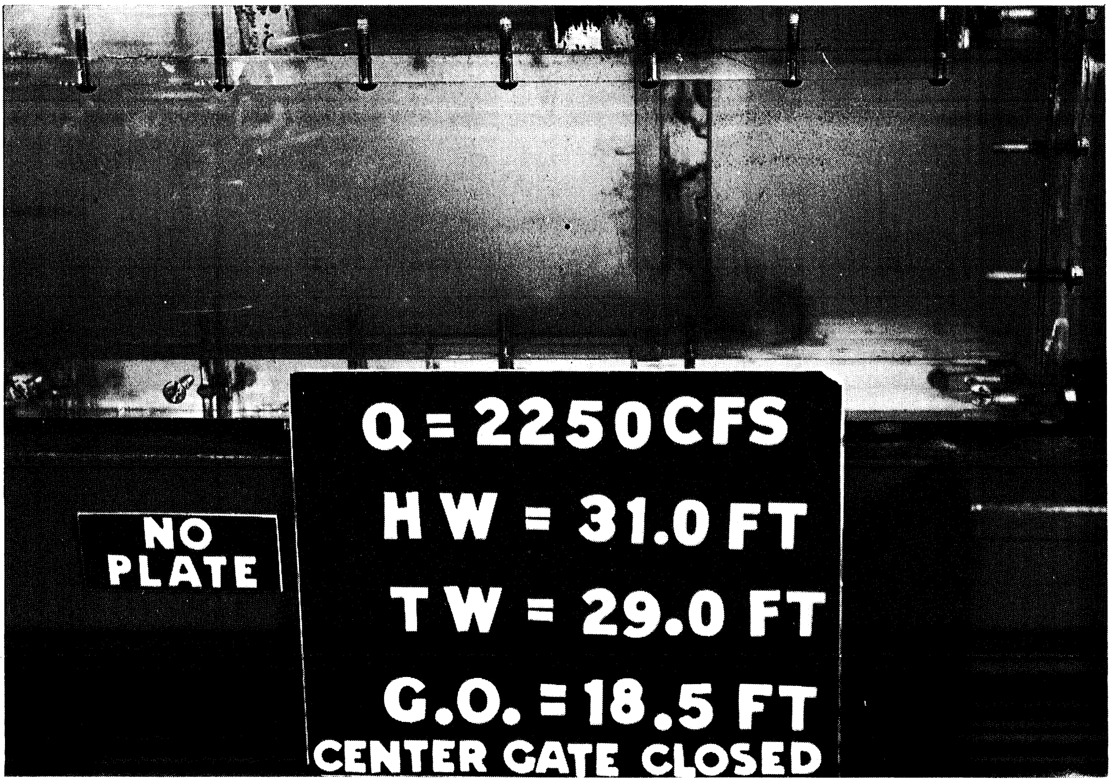

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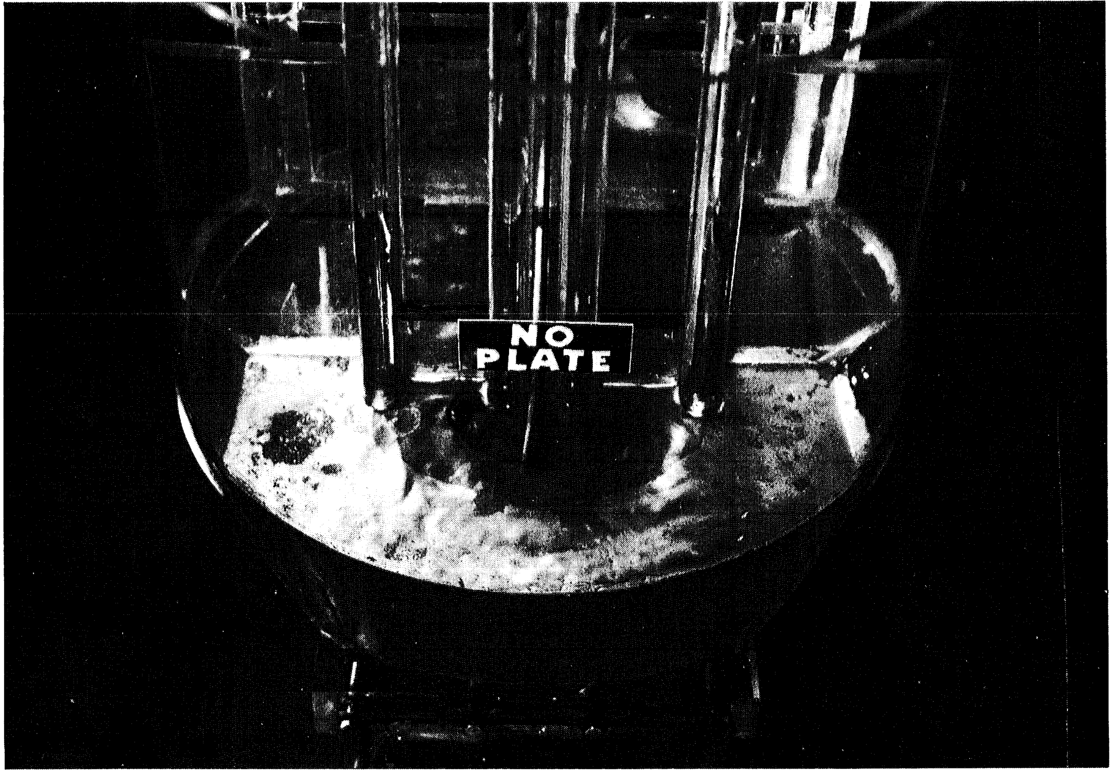

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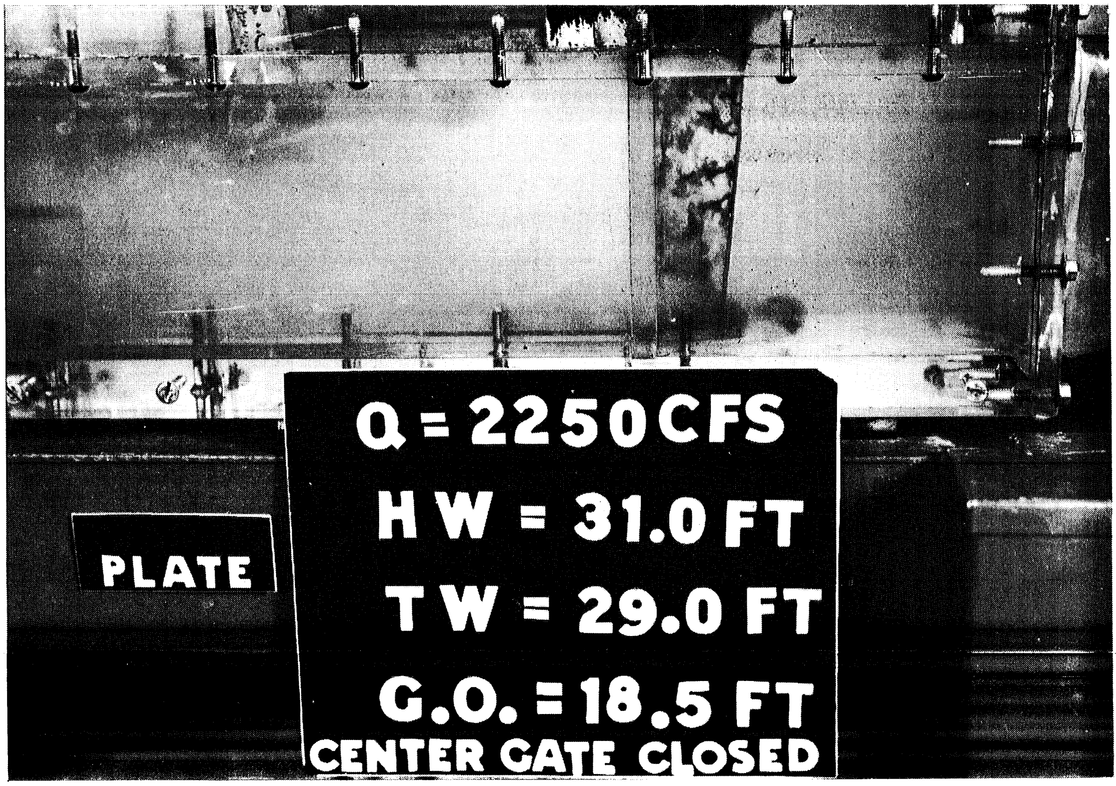

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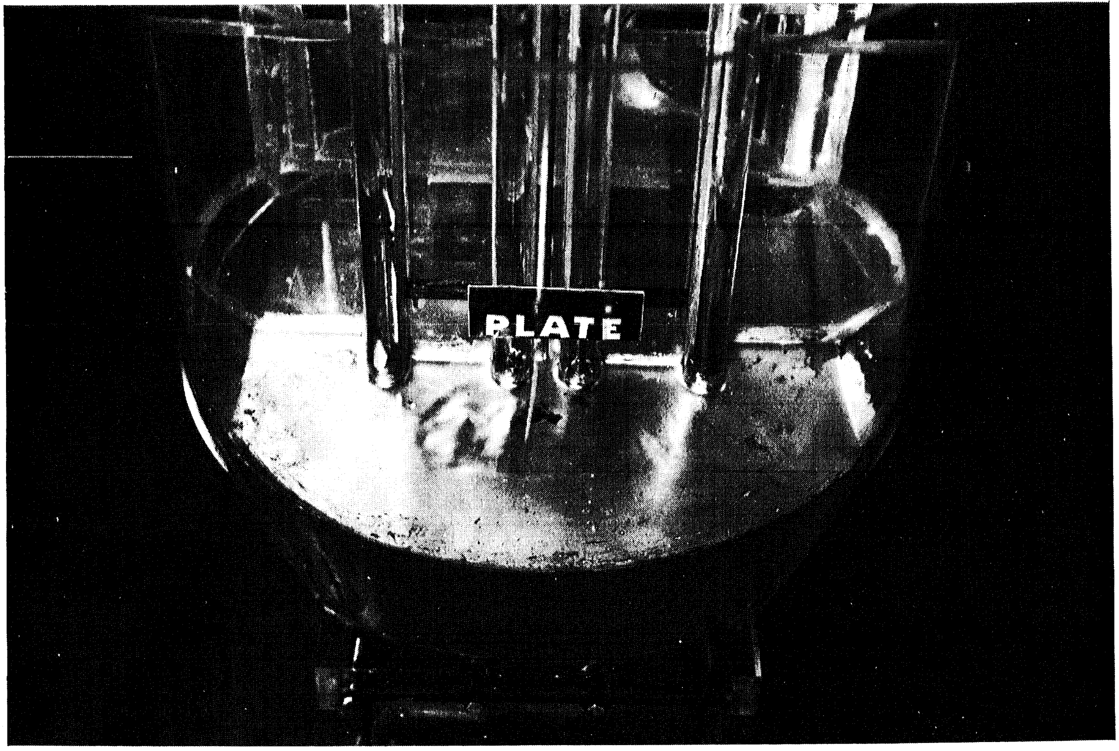

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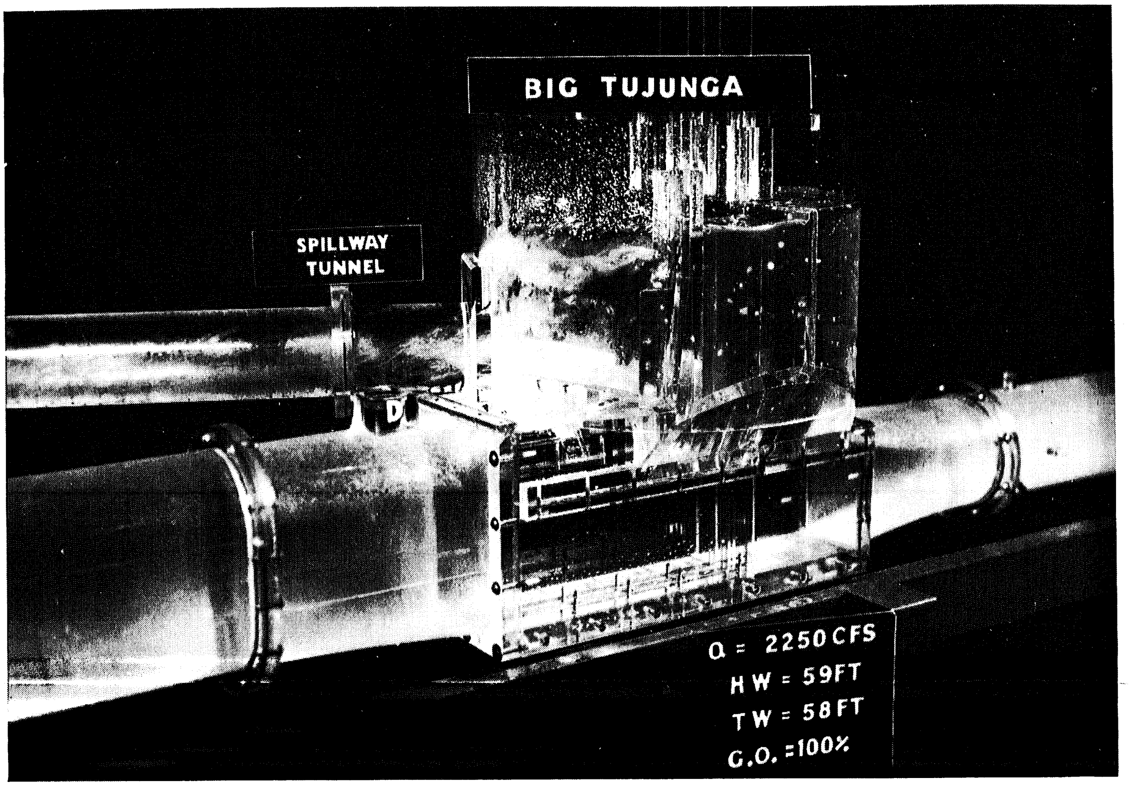

Photo 20

LIST OF CHARTS

CHART 15	(168B459-127) Comparison of fluctuating pressure in the air collector of the Big Tujunga gate structure due to variation of tailwater elevation. Q = 1575 cfs, three gates opened 4.1 ft.
CHART 16	(168B459-128) Comparison of fluctuating pressures in the air collector of the Big Tujunga gate structure due to variation of tailwater elevation. Q = 900 cfs, three gates opened at 1.9 ft.
CHART 17	(168B459-124) Minimum tailwater for inception of hydraulic jump in tunnel.
CHART 18	(168B459-114) Fluctuating pressures in the air collector of Big Tujunga gate tower due to change in tailwater elevation and gate opening. Q = 2250 cfs.
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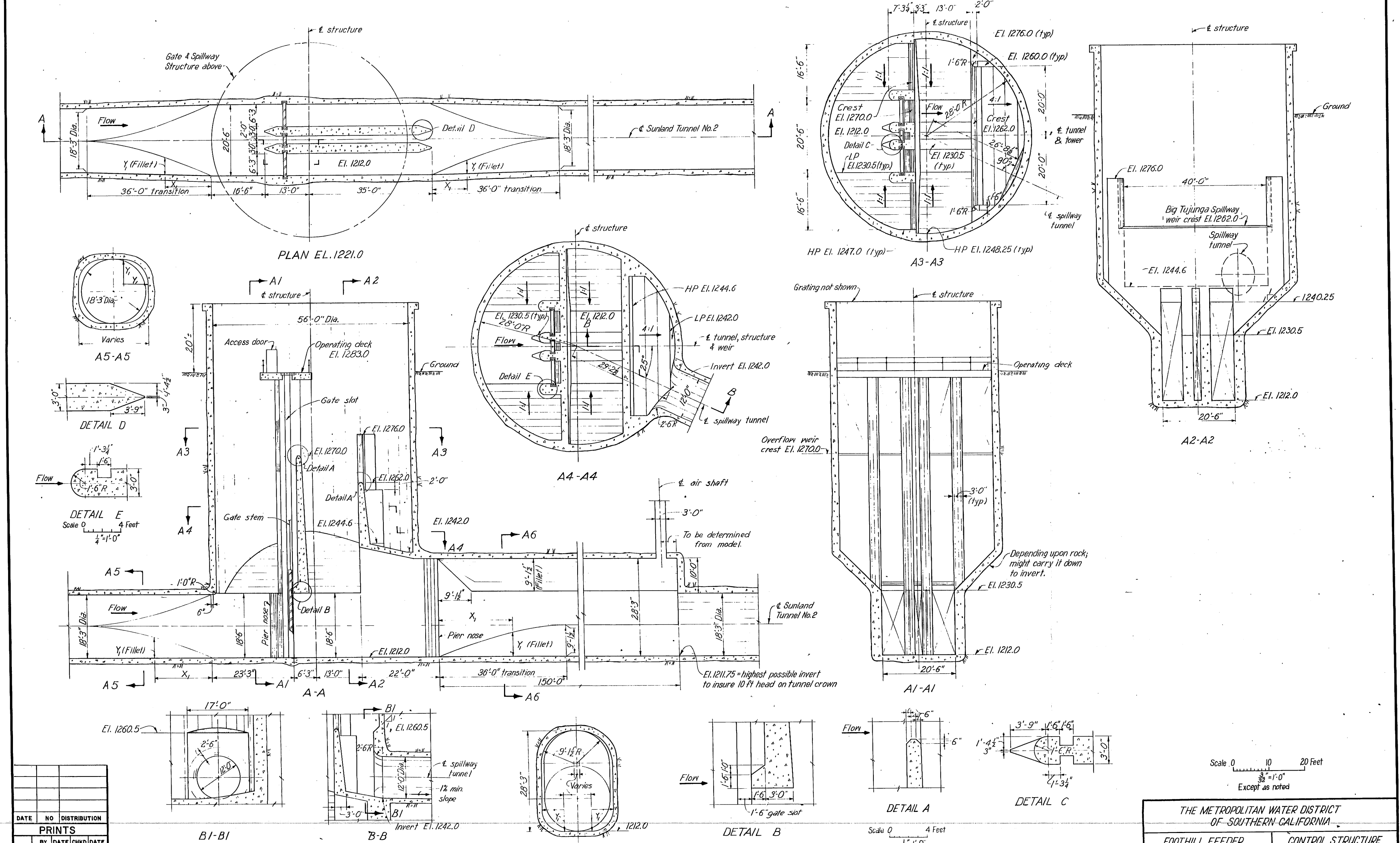
CHART 20	(168B459-116) Fluctuating pressures in the air collector of the Big Tujunga gate structure due to changes in tailwater elevation and gate opening. Q = 900 cfs.
CHART 21	(168B459-117) Fluctuating pressures in the air collector of the Big Tujunga gate structure due to change in discharge and gate opening. Q = 225 cfs and 50 cfs.
CHART 22	(168B459-132) Water surface profiles upstream from the center gate, with and without installation of baffle-plate for various discharges and minimum headwater elevation. Center gate closed.
CHART 23	(168B459-133) Water surface profiles upstream from the center gate, with and without baffle-plate for constant discharge of 2250 cfs and various headwater elevations. Center gate closed.



FILLET DATA

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6	2.75	16	5.90	26	8.18	36	9.125
8	3.45	18	6.46	28	8.48		

DATE	NO	DISTRIBUTION

PRINTS

	BY	DATE	CHKD.	DATE
DSGN.	UK	July '66	HWC	July '66
DWN.	UK	July '66	[illegible]	July '66

DEPT.	GROUP LEADER	SECT. HEAD	DEPT. HEAD
CIVIL			
MECH.			
ELECT.			
PLAN.			
STAFF			CH.ENGR

PRELIMINARY

REV. NO.	DATE	NATURE OF REVISION	BY	CHKD.	APPD.

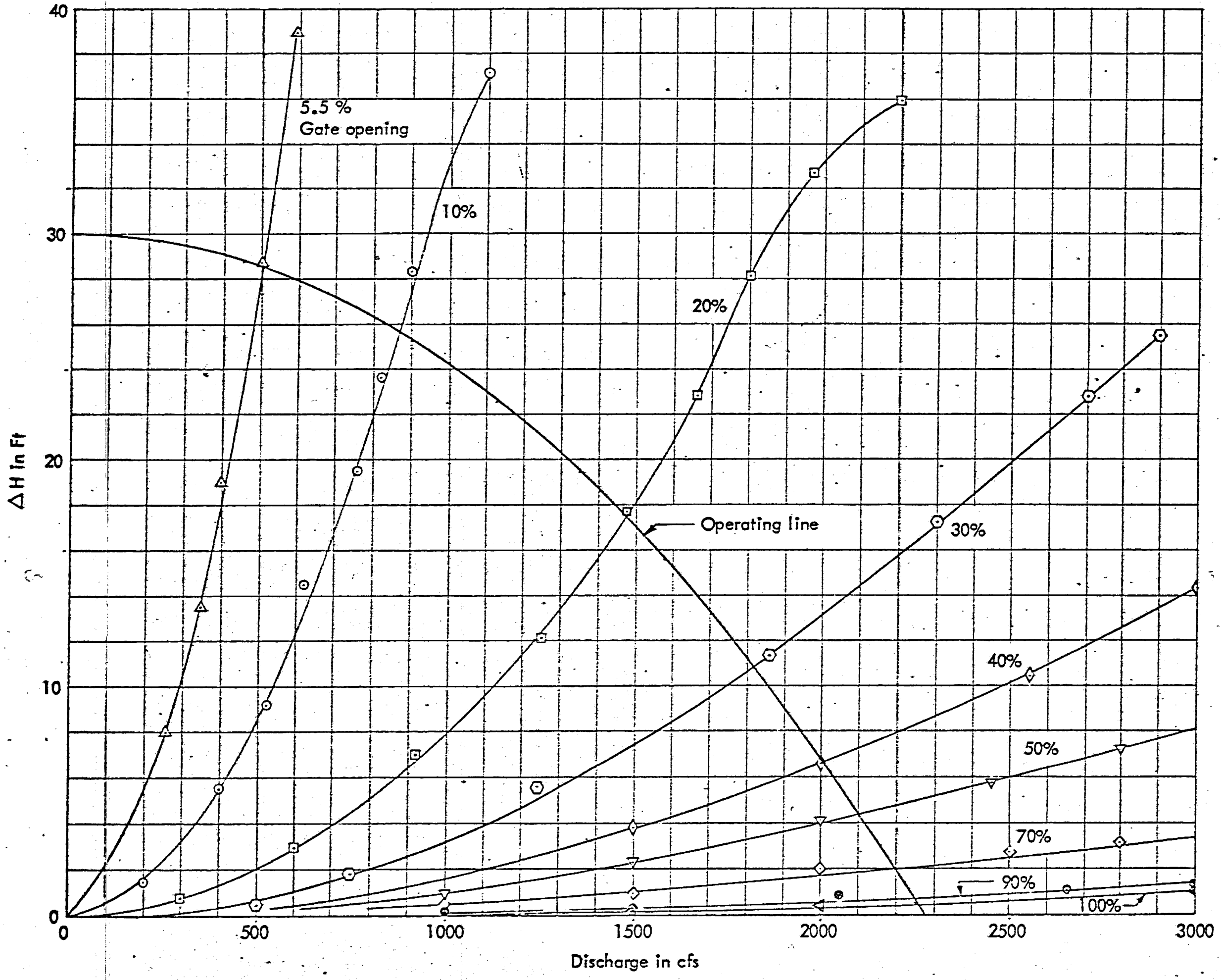
THE METROPOLITAN WATER DISTRICT
OF SOUTHERN CALIFORNIA

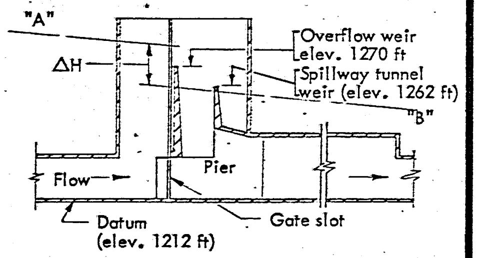
FOOTHILL FEEDER | CONTROL STRUCTURE

BIG TUJUNGA GATE
& SPILLWAY STRUCTURE

HARZA ENGINEERING COMPANY
APPROVED________________

CHICAGO, ILLINOIS | DATE July 25, 66 | DWG. NO. 380SKC143





Cross Section Along Centerline of Model

Notes:

1. ΔH = Head on gates.
2. Line "A" is an extension of the E.G.L. upstream of gate.
3. Line "B" is an extension of the E.G.L. downstream of gate.
4. All gates were open the same amount in the tests.
   Gates:
   2 outside gates, 6'-3" x 18'-6"
   1 center gate, 2'-0" x 18'-6"
5. Operating line obtained from Harza Eng. Co. Sketch No. 380-SKC-177.

HEAD LOSS CURVES

Model Scale 1:38.3

MODEL STUDIES-FOOTHILL FEEDER PROJECT
Metropolitan Water Dist. of Southern Californic
BIG TUJUNGA GATE & SPILLWAY STRUCTURE

Harza Engineering Co., Chicago, Ill.

SAINT ANTHONY FALLS HYDRAULIC LABORATORY
UNIVERSITY OF MINNESOTA

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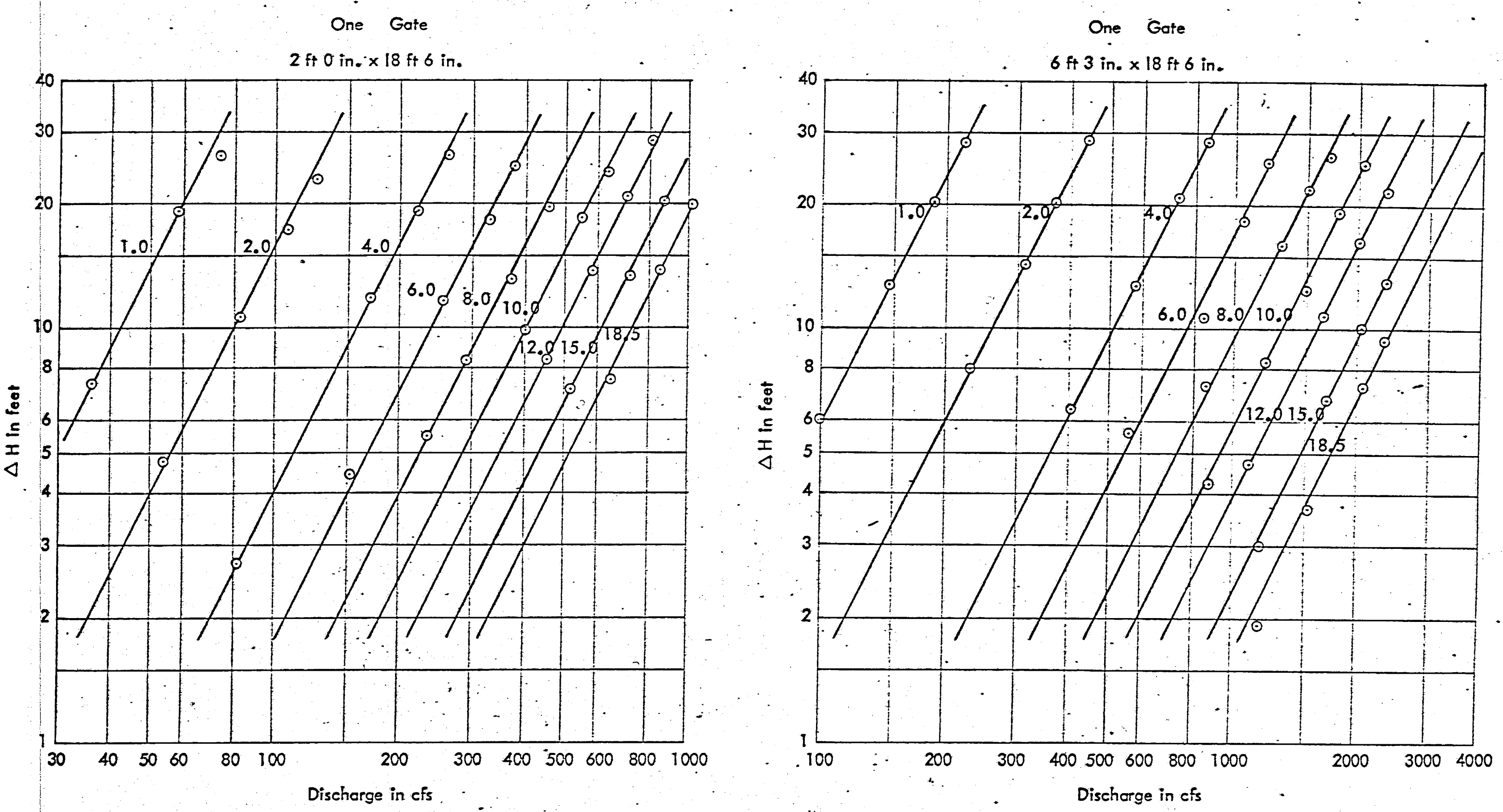
SCALE	DATE 12-23-66	NO. 1683-459-113

CHART 2



Notes:

1. Numbers on above curves indicate gate opening in feet.
2. The curves show the head differential developed when passing a given discharge through any one gate.
3. ΔH is the difference between the projected E.G.L. upstream of the structure and the projected E.G.L. downstream of the structure.
4. Discharge coefficient for one gate ($C_d = Q/bd_o\sqrt{2g\Delta H + V_1^2}$)

   V_1: approach velocity in tunnel

   C_d (Ave.) = 0.790 for 2'0" x 18'6" gate; C_d (Ave.) = 0.795 for 6'3" x 18'6" gate

RATING CURVES FOR INDIVIDUAL GATES
FOR VARIOUS GATE OPENINGS
Model Scale 1:38.3

MODEL STUDIES-FOOTHILL FEEDER PROJECT
Metropolitan Water Dist. of Southern California
BIG TUJUNGA GATE & SPILLWAY STRUCTURE

Harza Engineering Co., Chicago, Ill.

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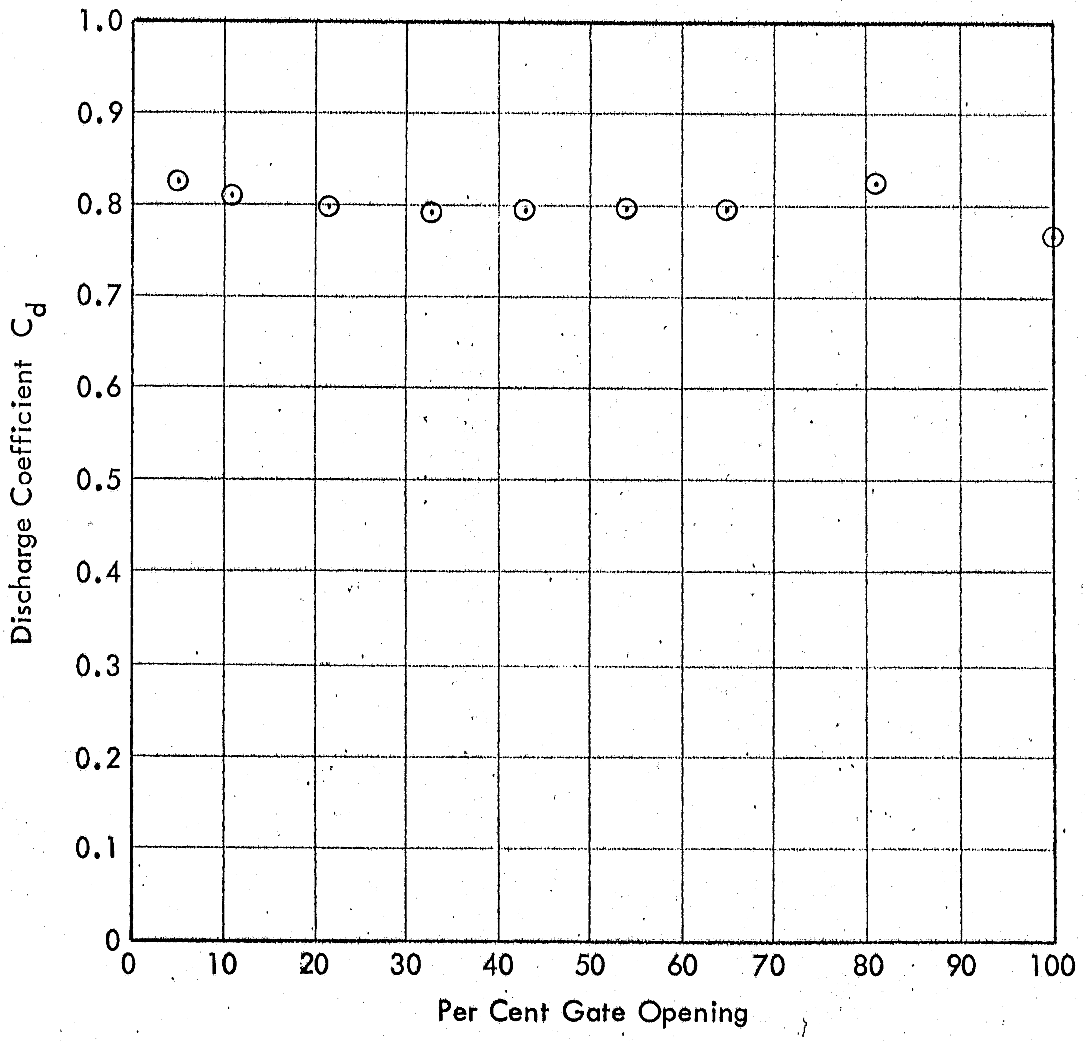
SCALE	DATE 4-20-67	NO. 168-3-459-12

CHART 3

CHART 4



Note:

1. Q and ΔH from rating curves. See drawing 168-B-459-129.
2. $Q = C_d \, b \, d_o \sqrt{2g\Delta H + V_1^2}$.

   Q: discharge in cfs for given ΔH

   b: gate width

   d_o: gate opening

   ΔH: differential head on gate in ft of water

   V_1: approach velocity in tunnel
3. Average C_d for all gate openings is 0.795

DISCHARGE COEFFICIENT WITH
ONE 6'3" x 18'6" GATE OPERATING

Model Scale 1:38.3

MODEL STUDIES-FOOTHILL FEEDER PROJECT
Metropolitan Water Dist. of Southern California
BIG TUJUNGA GATE & SPILLWAY STRUCTURE

Harza Engineering Co., Chicago, Ill.

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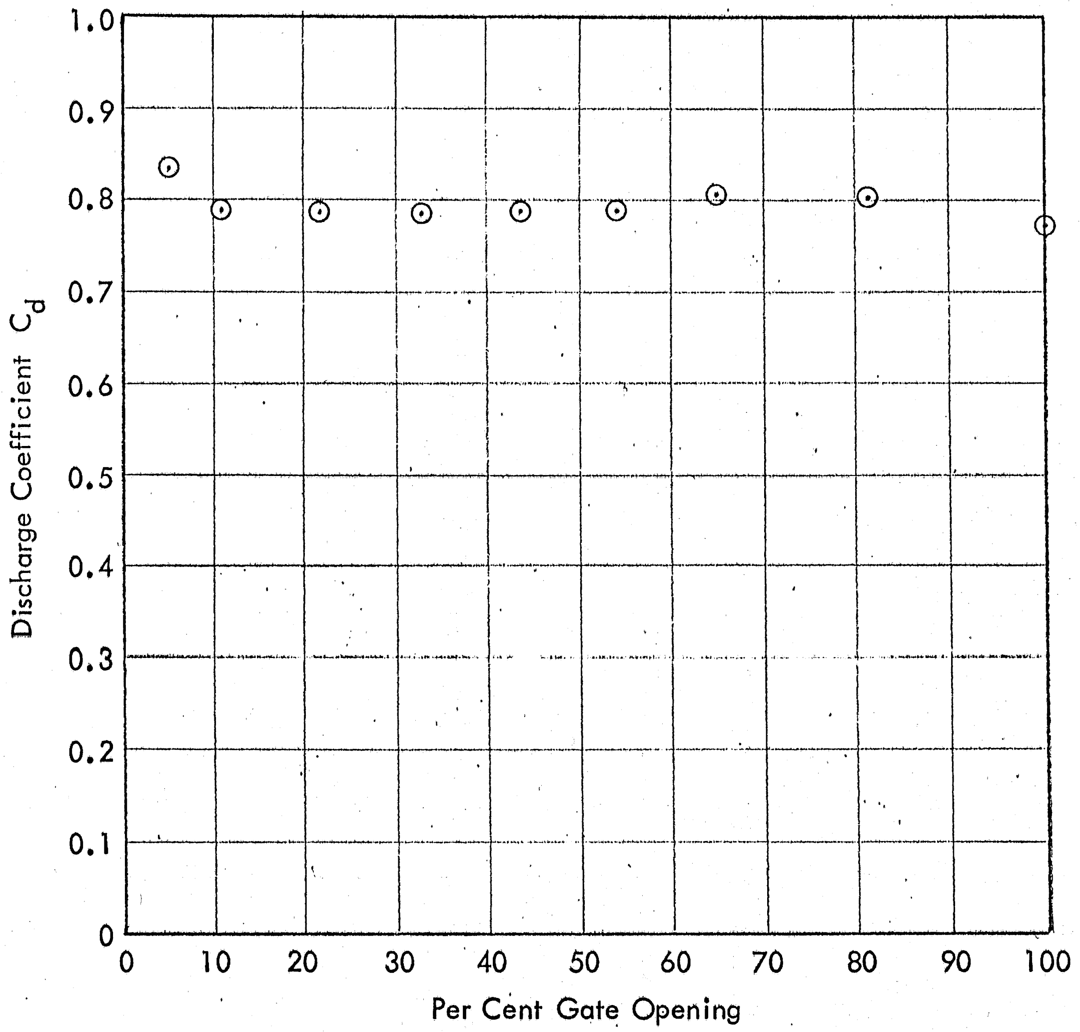
SCALE	DATE 5-18-67	NO. 168-A-2305-1



Note:

1. Q and $\triangle H$ from rating curves. See drawing 168-B-459-129

2. $Q = C_d \, b \, d_o \sqrt{2g\triangle H + V_1^2}$

   Q: discharge in cfs for given $\triangle H$

   b: gate width

   d_o: gate opening

   $\triangle H$: differential head on gate in ft of water

   V_1: approach velocity in tunnel

3: Average C_d for all gate openings is 0.790

DISCHARGE COEFFICIENT WITH
ONE 2'0" x 18'6" GATE OPERATING

Model Scale 1:38.3

MODEL STUDIES-FOOTHILL FEEDER PROJECT
Metropolitan Water Dist. of Southern California
BIG TUJUNGA GATE & SPILLWAY STRUCTURE

Harza Engineering Co., Chicago, Ill.

SAINT ANTHONY FALLS HYDRAULIC LABORATORY
UNIVERSITY OF MINNESOTA

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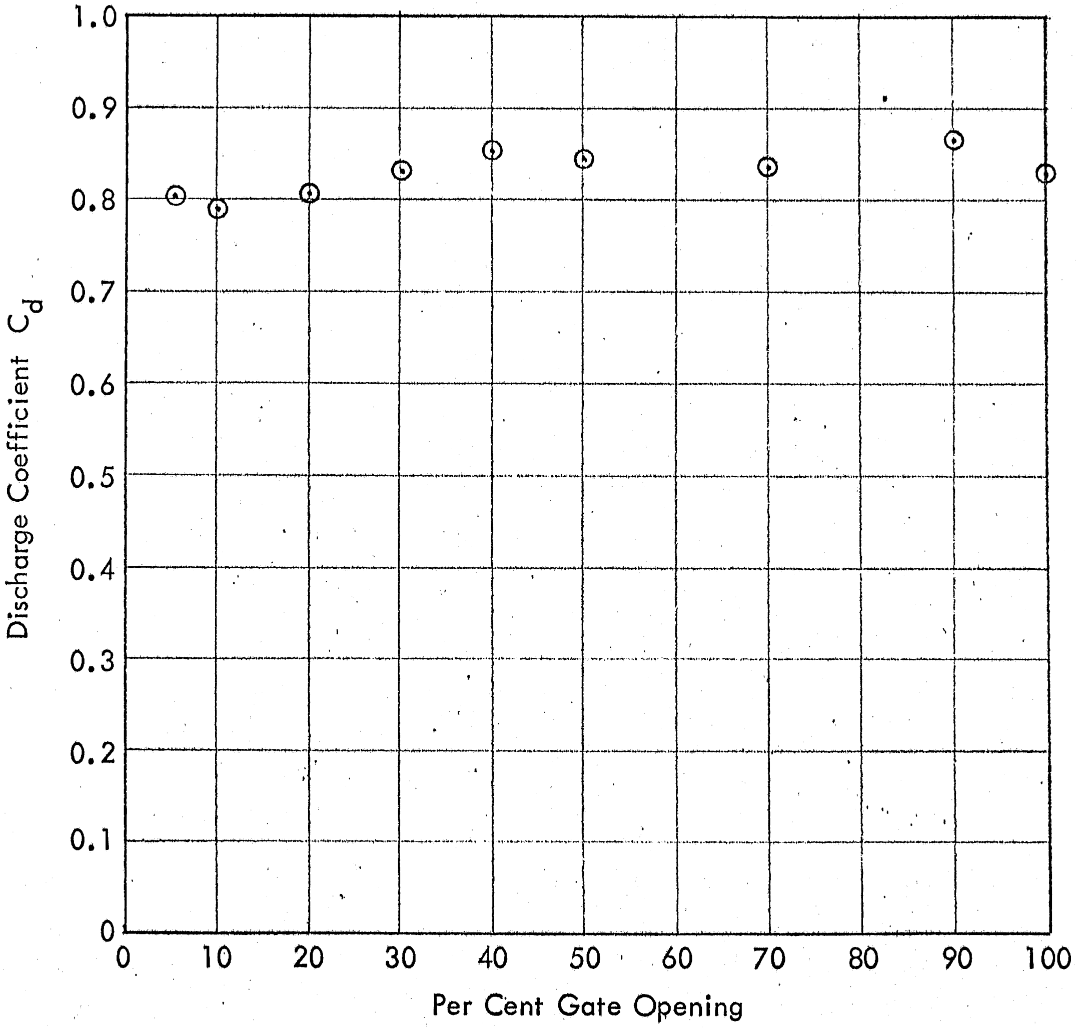
SCALE	DATE 5-18-67	NO. 168-A-2305-2

CHART 6



Note:

1. Q and ΔH from head loss curves. See drawing 168-B-459-113

2. $Q = C_d \, b \, d_o \sqrt{2g\Delta H + V_1^2}$

   Q: discharge in cfs for given gate opening.

   b: gate width

   d_o: gate opening

   ΔH: differential head on gate in ft of water for given gate opening

   V_1: approach velocity in tunnel

3. Average C_d for all gate openings is 0.830

DISCHARGE COEFFICIENT WITH
THREE GATES OPERATING

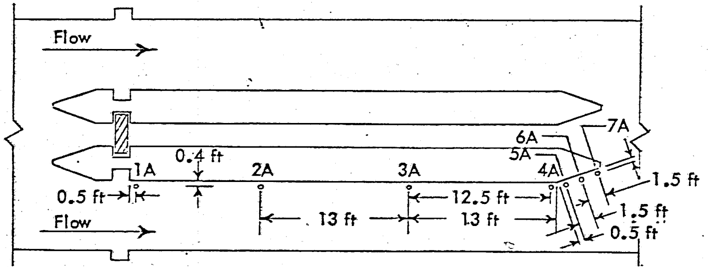
Model Scale 1:38.3

MODEL STUDIES-FOOTHILL FEEDER PROJECT
Metropolitan Water Dist. of Southern California
BIG TUJUNGA GATE & SPILLWAY STRUCTURE

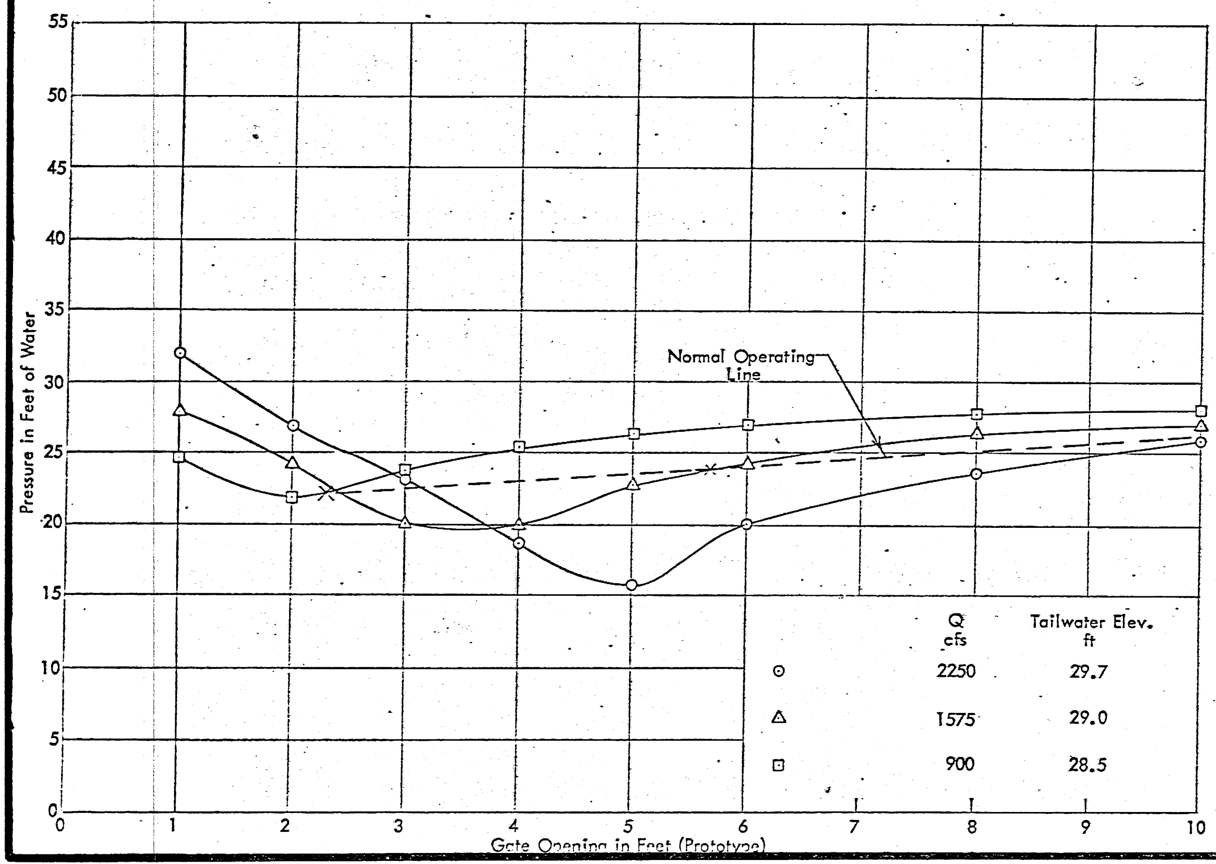
Harza Engineering Co., Chicago, Ill.

SAINT ANTHONY FALLS HYDRAULIC LABORATORY
UNIVERSITY OF MINNESOTA

DRAWN HYY	CHECKED	APPROVED
SCALE	DATE 5-18-67	NO. 168-A-2305-3



Plan view showing piezometer tap locations



Notes:

1. Side gates open equally, center gate closed.
2. Pressures were measured using piezometers located as shown in sketch, 0.4 ft from pier wall.
3. Tailwater elevation established using Harza sketch 380-SKC-177.
4. ΔH across the gates ranged up to 34.9 ft.
5. Minimum pressure occurred at location 5A for each condition tested.
6. Minimum pressure of +15.8 feet of water occurred when Q = 2250 cfs, ΔH = 28.2 ft, tailwater elev. = 29.7 ft, gate opening = 5 ft.

MINIMUM AVERAGE PRESSURE ON
FLOOR DOWNSTREAM OF SIDE GATE
NEAR PIER WALL

Q = 2250, 1575, and 900 cfs
Minimum Design Tailwater Elevation
Two 6 ft 3 in. (Outside) Gates Operating
Model Scale 1:38.3

MODEL STUDIES-FOOTHILL FEEDER PROJECT
Metropolitan Water Dist. of Southern Californi
BIG TUJUNGA GATE & SPILLWAY STRUCTURE

Harza Engineering Co., Chicago, Ill.

SAINT ANTHONY FALLS HYDRAULIC LABORATORY
UNIVERSITY OF MINNESOTA

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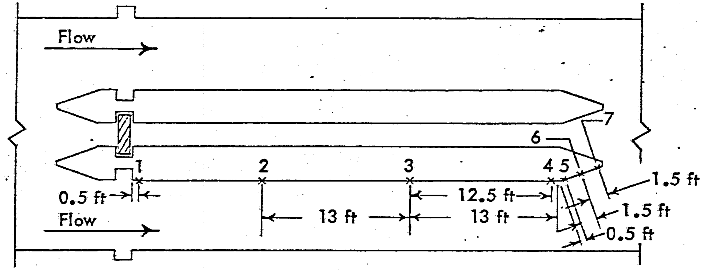
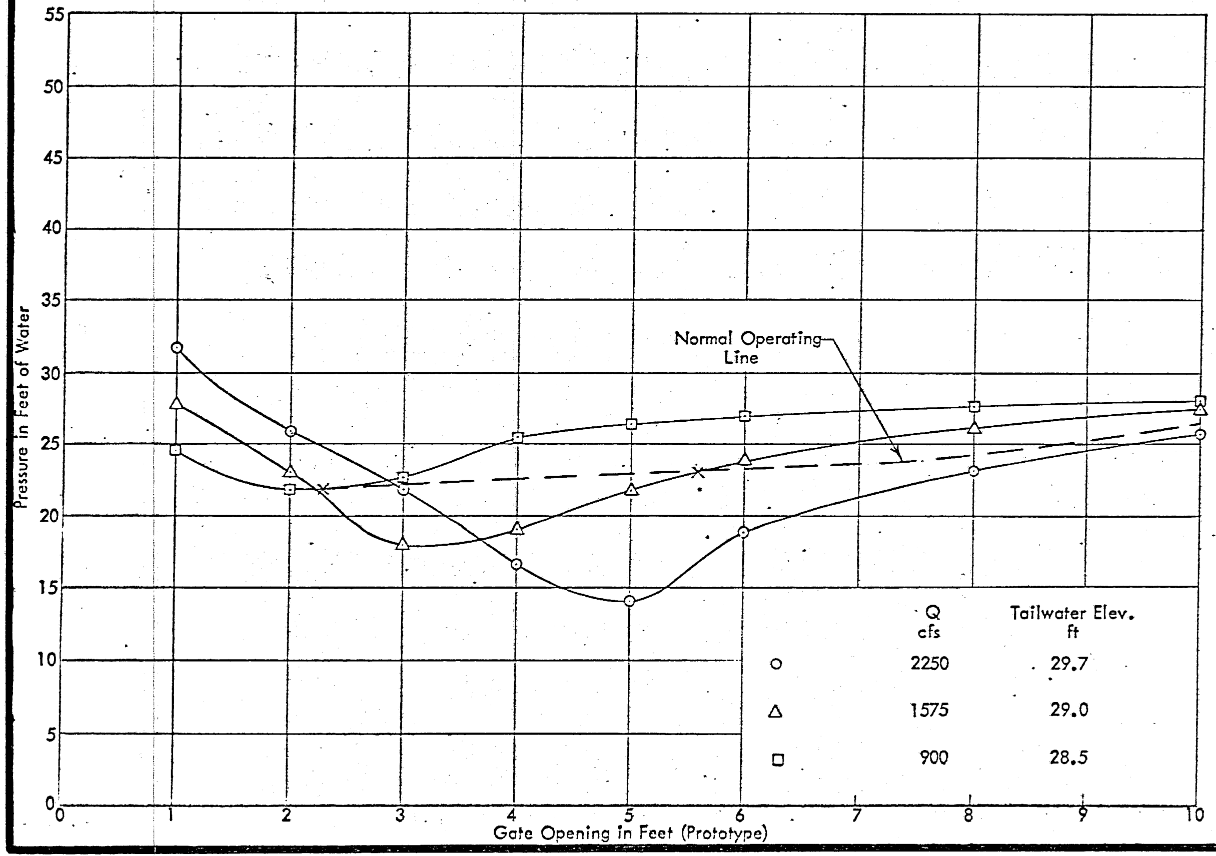
SCALE	DATE 2-13-67	NO. 162-B-459-11

CHART 7



Plan view showing piezometer tap locations



Notes:

1. Side gates open equally, center gate closed.
2. Pressures were measured using piezometer located as shown in sketch, 0.4 ft above the floor of the structure.
3. Tailwater elevation established using Harza sketch 380-SKC-177.
4. ΔH across the gates ranged up to 34.9 ft.
5. Minimum pressure of +14.0 ft of water occurred when Q = 2250 cfs, ΔH = 28.25 ft, tailwater elev. = 29.7 ft, gate opening = 5 ft.

MINIMUM AVERAGE PRESSURE ON
PIER WALL DOWNSTREAM OF SIDE GATE
Q = 2250, 1575, and 900 cfs
Minimum Design Tailwater Elevation
Two 6 ft 3 in. (Outside) Gates Operating
Model Scale 1:38.3

MODEL STUDIES-FOOTHILL FEEDER PROJECT
Metropolitan Water Dist. of Southern California
BIG TUJUNGA GATE & SPILLWAY STRUCTURE

Harza Engineering Co., Chicago, Ill.

SAINT ANTHONY FALLS HYDRAULIC LABORATORY
UNIVERSITY OF MINNESOTA

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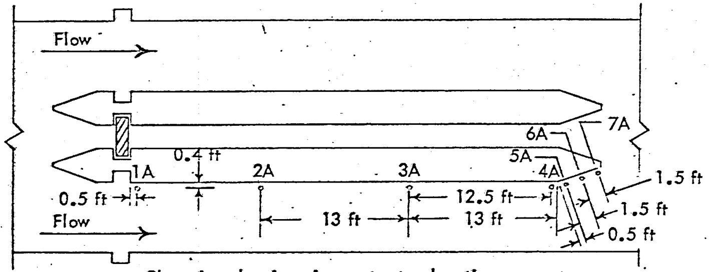
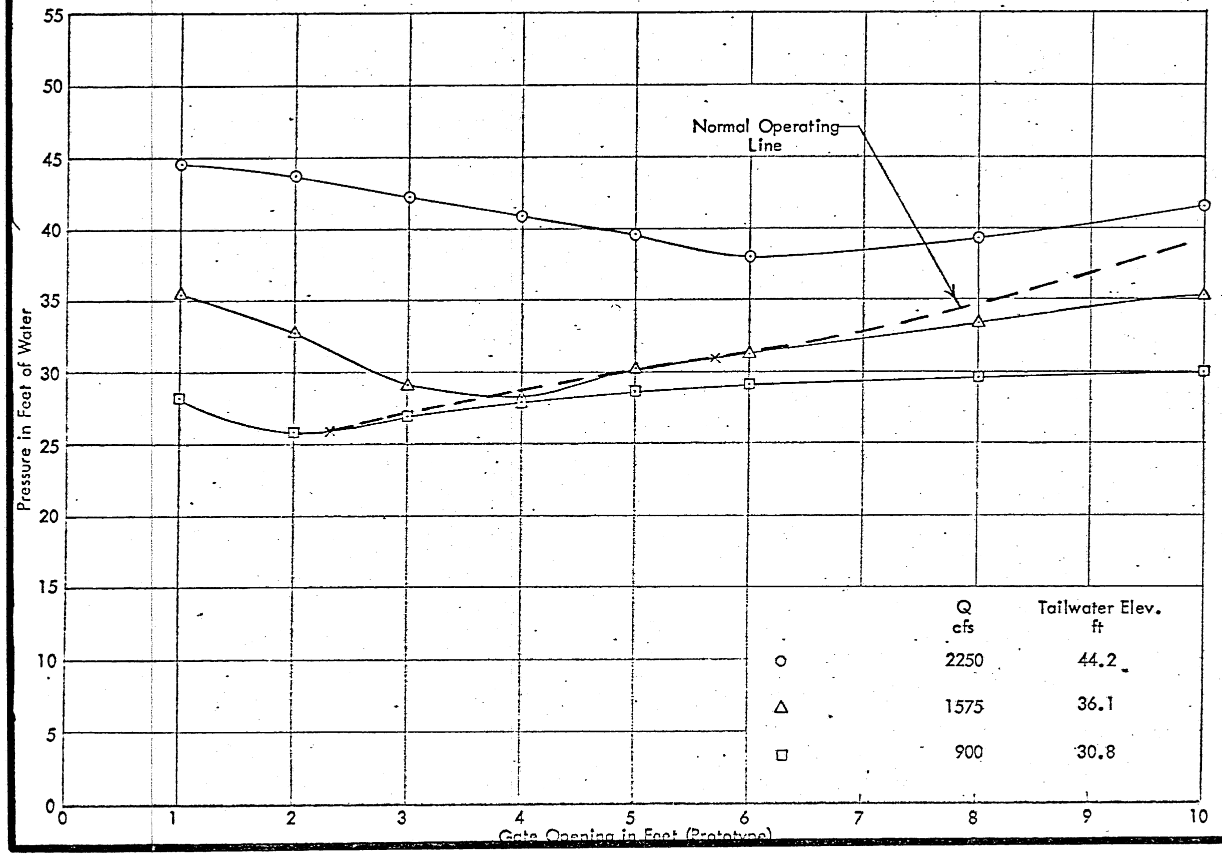
CHART 8



Plan view showing piezometer tap locations



Notes:

1. Side gates open equally, center gate closed.
2. Pressures were measured using piezometers located as shown in sketch, 0.4 ft from pier wall.
3. Tailwater elevation established using Harza sketch 380-SKC-177.
4. ΔH across the gates ranged up to 30.2 ft.
5. Minimum pressure occurred at location 5A for each condition tested.
6. Minimum pressure of +25.8 ft of water occurred when Q = 900 cfs, ΔH = 28.9 ft, tailwater elev. = 30.8 ft, gate opening = 2 ft. For this condition there is a small amount of flow over the weir.

MINIMUM AVERAGE PRESSURE ON FLOOR DOWNSTREAM OF SIDE GATE NEAR PIER WALL

Q = 2250, 1575, and 900 cfs
Maximum Design Tailwater Elevation
Two 6 ft 3 in. (Outside) Gates Operating
Model Scale 1:38.3

MODEL STUDIES–FOOTHILL FEEDER PROJECT
Metropolitan Water Dist. of Southern California
BIG TUJUNGA GATE & SPILLWAY STRUCTURE

Harza Engineering Co., Chicago, Ill.

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UNIVERSITY OF MINNESOTA

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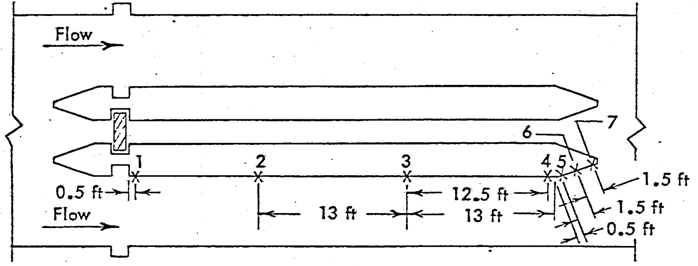
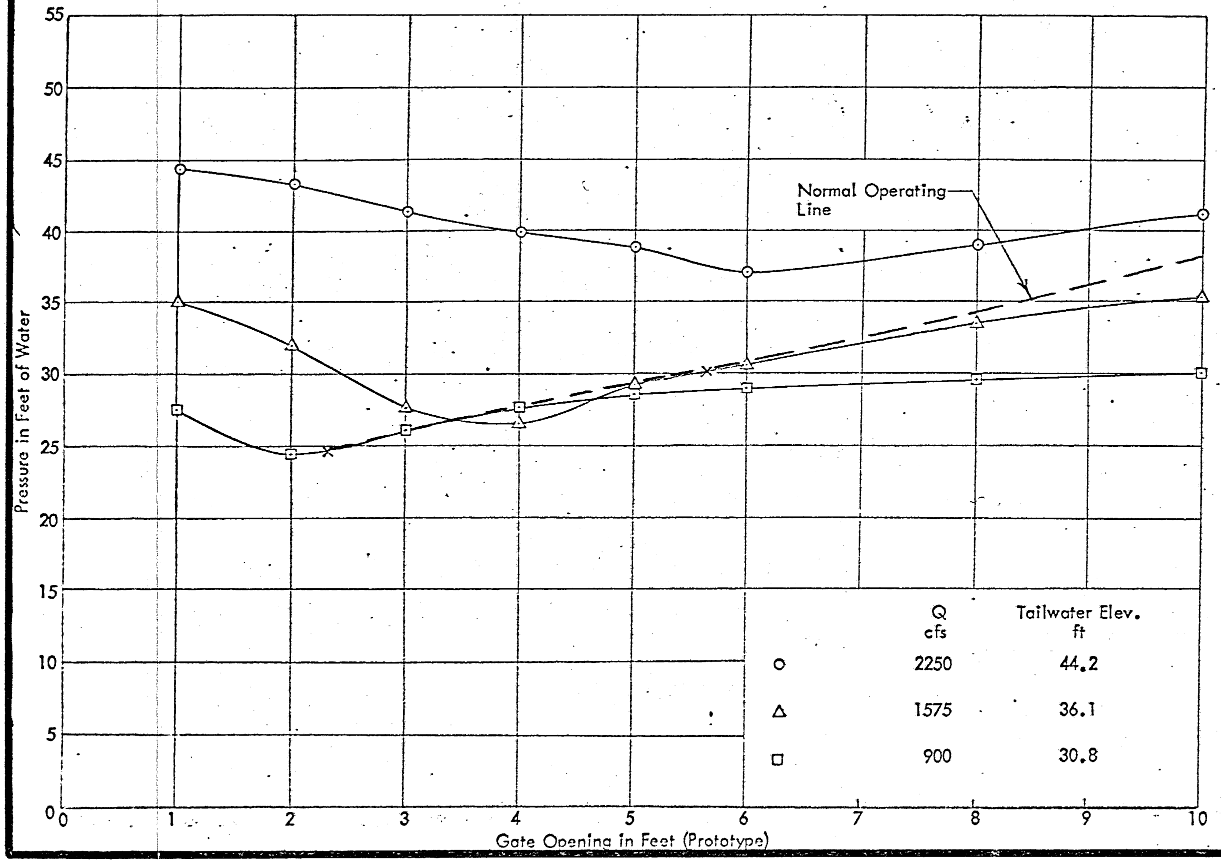
CHART 9



Plan view showing piezometer tap locations



Notes:

1. Side gates open equally, center gate closed.
2. Pressures were measured using piezometer located as shown in sketch, 0.4 ft above the floor of the structure.
3. Tailwater elevation established using Harza sketch 380-SKC-177.
4. ΔH across gates ranged up to 30.2 ft.
5. Minimum pressure occurred at location 5 for each condition tested.
6. Minimum pressure of +24.4 ft of water occurred when Q = 900 cfs, ΔH = 28.9 ft, tailwater elev. = 30.8 ft, gate opening = 2 ft. For this condition there is a small amount of flow over the weir.

MINIMUM AVERAGE PRESSURE ON
PIER WALL DOWNSTREAM OF SIDE GATE
Q = 2250, 1575, and 900 cfs
Maximum Design Tailwater Elevation
Two 6 ft 3 in. (Outside) Gates Operating
Model Scale 1:38.3

MODEL STUDIES-FOOTHILL FEEDER PROJECT
Metropolitan Water Dist. of Southern Californi
BIG TUJUNGA GATE & SPILLWAY STRUCTURE

Harza Engineering Co., Chicago, Ill.

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UNIVERSITY OF MINNESOTA

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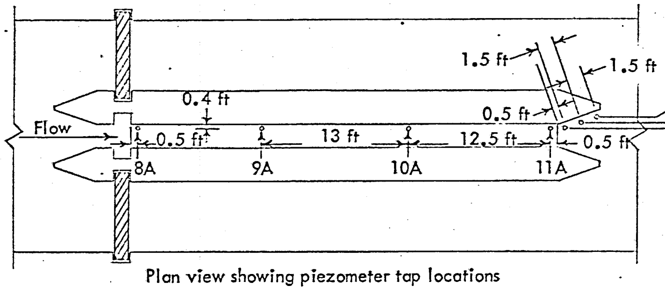
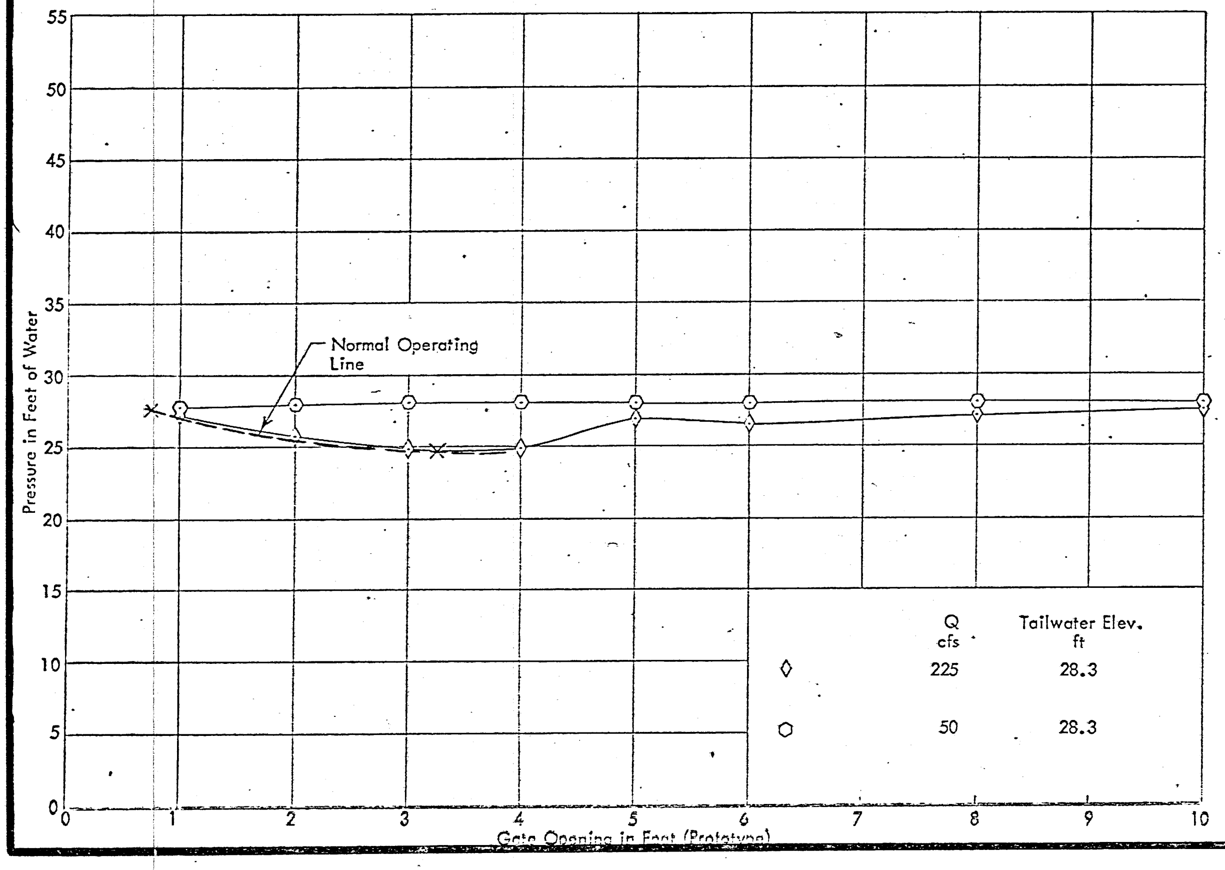
SCALE	DATE 2-14-67	NO. [illegible]

CHART 10



Plan view showing piezometer tap locations



Notes:

1. Side gates closed, center gate open.
2. Pressures were measured using piezometers located as shown in sketch, 0.4 ft from pier wall.
3. Tailwater elevation established using Harza sketch 380-SKC-177.
4. ΔH across the gate ranged up to 31.7 ft.
5. Minimum pressure occurred at location 12A for each condition tested.
6. Minimum pressure of +24.8 ft of water occurred when Q = 225 cfs, ΔH = 31.3 ft, tailwater elev. = 28.3 ft, gate opening = 3 ft. For this condition there is a small amount of flow over the weir.

MINIMUM AVERAGE PRESSURE ON
FLOOR DOWNSTREAM OF CENTER GATE
NEAR PIER WALL

Q = 225 and 50 cfs
Tailwater Elev. = 28.3 ft
One 2 ft (Center) Gate Operating
Model Scale 1:38.3

MODEL STUDIES–FOOTHILL FEEDER PROJECT
Metropolitan Water Dist. of Southern California
BIG TUJUNGA GATE & SPILLWAY STRUCTURE

Harza Engineering Co., Chicago, Ill.

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UNIVERSITY OF MINNESOTA

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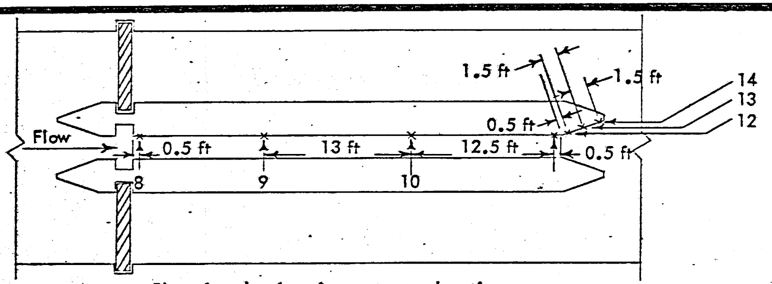
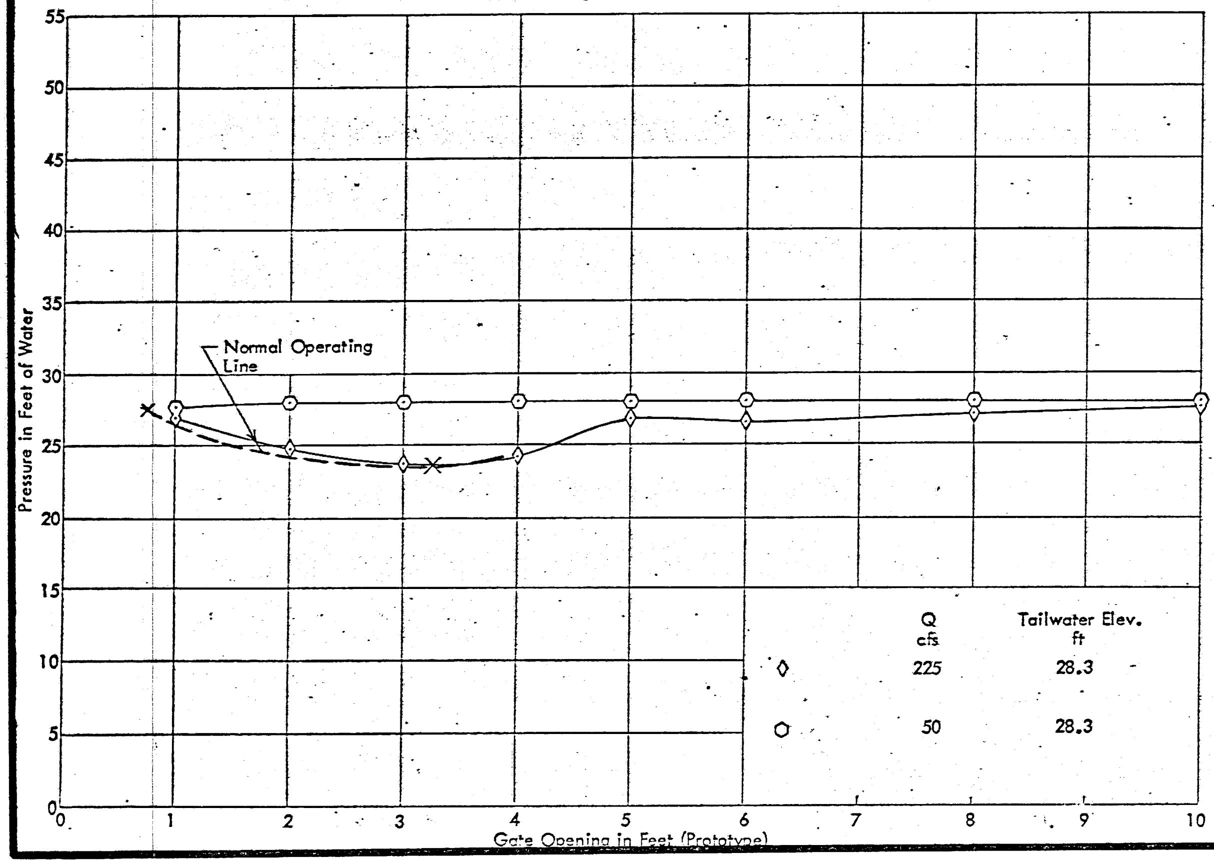
CHART 11



Plan view showing piezometer tap locations



Notes:

1. Side gates closed, center gate open.
2. Pressures were measured using piezometers located as shown in sketch, 0.4 ft above the floor of the structure.
3. Tailwater elevation established using Harza sketch 380-SKC-177.
4. ΔH across the gate ranged up to 31.7 ft.
5. Minimum pressure occurred at location 12 for each condition tested.
6. Minimum pressure of +23.8 ft of water occurred when Q = 225 cfs, ΔH = 31.3 ft, tailwater elev. = 28.3 ft, gate opening = 3 ft. For this condition there is a small amount of flow over the weir.

MINIMUM AVERAGE PRESSURE ON
PIER WALL DOWNSTREAM OF
CENTER GATE

Q = 225 and 50 cfs
Tailwater Elev. = 28.3 ft
One 2 ft (Center) Gate Operating
Model Scale 1:38.3

MODEL STUDIES–FOOTHILL FEEDER PROJECT
Metropolitan Water Dist. of Southern California
BIG TUJUNGA GATE & SPILLWAY STRUCTURE

Harza Engineering Co., Chicago, Ill.

SAINT ANTHONY FALLS HYDRAULIC LABORATORY
UNIVERSITY OF MINNESOTA

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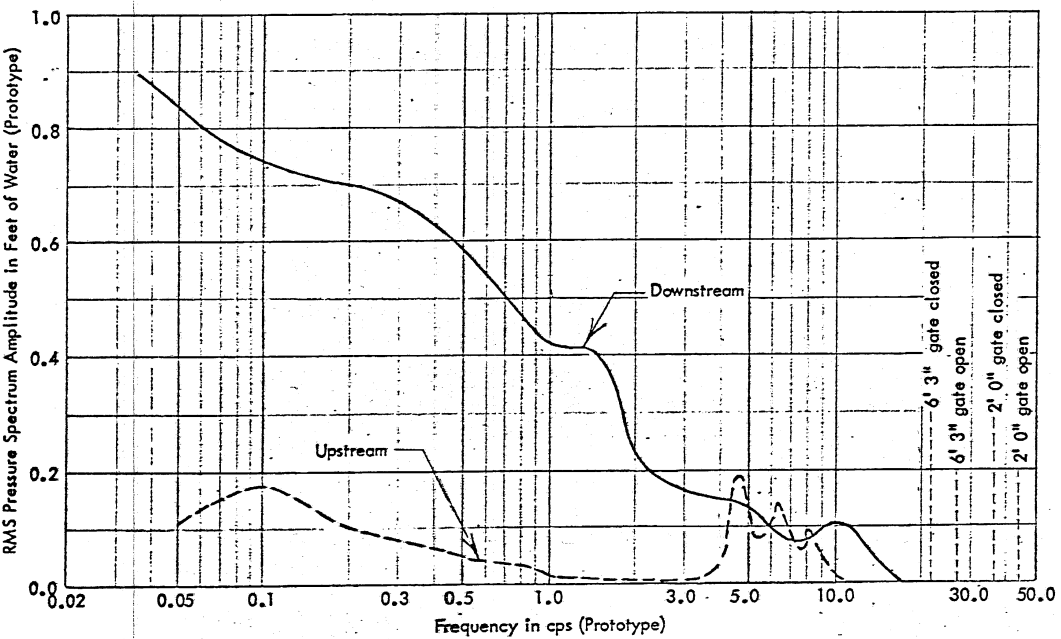
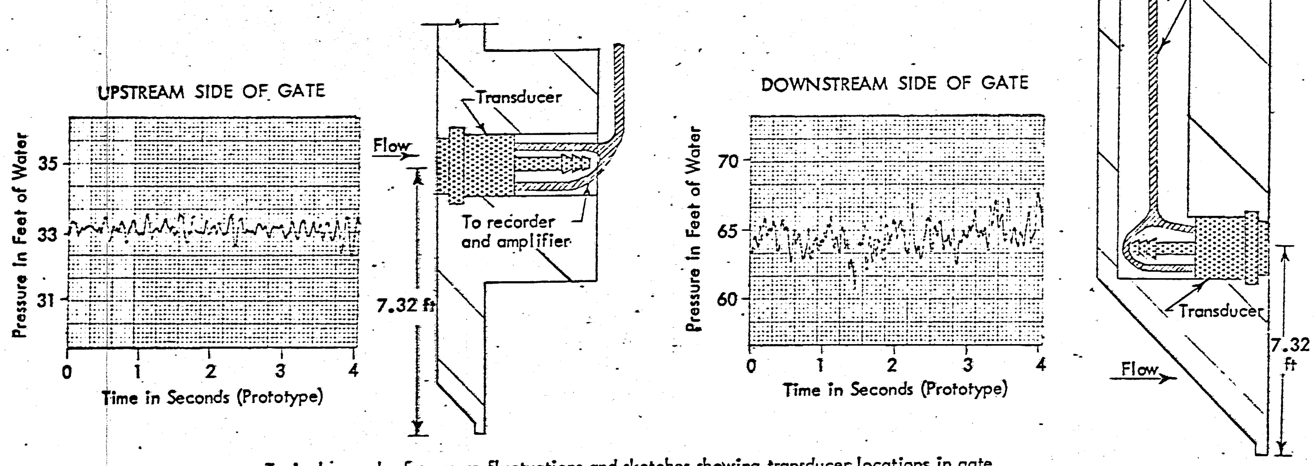
CHART 12



Notes:

1. Transducers were 2.5 psi C.E.C. chamber mounted type.
2. Gates closed, flow over the weir.
3. The transducers were mounted so as to record fluctuating pressures 7.32 ft above the bottom of the gate.
4. The spectrum was obtained by analysis of records similar to those shown below. The graph to the left is a plot of the Root Mean Square of the amplitude of the various pressure pulses which occur on the face of the gate in terms of the frequency with which these pulses occur.
5. Vertical dashed lines on graph indicate natural frequency of gates as designed by Harza Engineering Company and shown on Harza drawings 380-3KC-165 and 166.



Typical records of pressure fluctuations and sketches showing transducer locations in gate

HARMONIC WAVE ANALYSIS OF THE PRESSURE PULSES OCCURRING ON THE GATE

Q = 2250 cfs
T.W. Elev. = 33.0 ft
H.W. Elev. = 65.0 ft
Gate Opening = 0%

MODEL STUDIES–FOOTHILL FEEDER PROJECT
Metropolitan Water Dist. of Southern California
BIG TUJUNGA GATE & SPILLWAY STRUCTURE

Harza Engineering Co., Chicago, Ill.

SAINT ANTHONY FALLS HYDRAULIC LABORATORY
UNIVERSITY OF MINNESOTA

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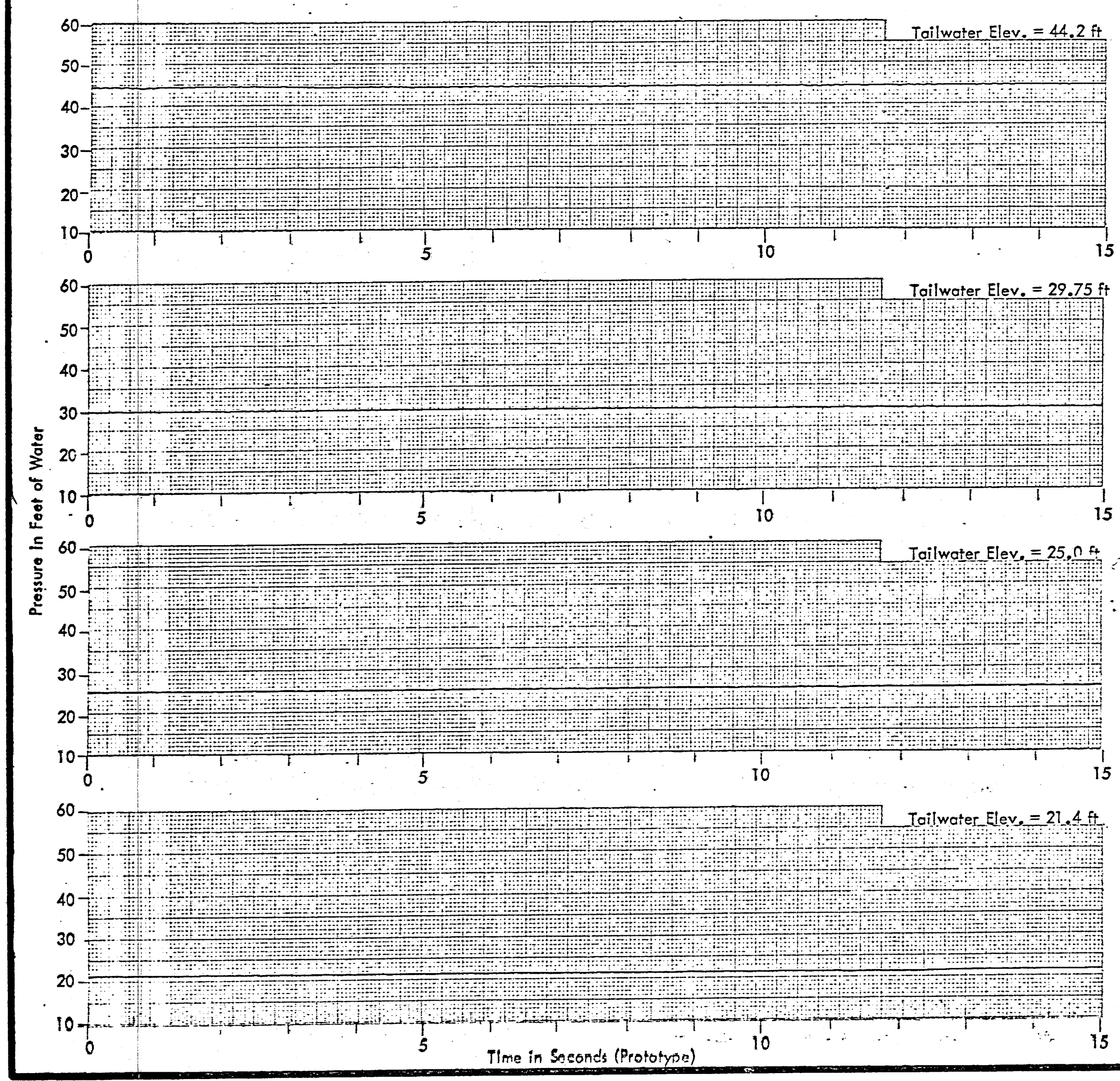
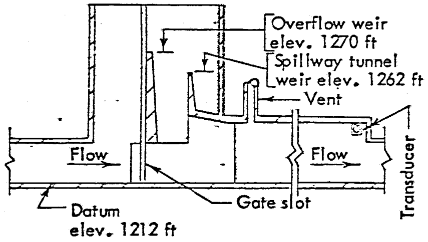
SCALE	DATE 8-30-67	NO. 168-3-459-134

CHART 13





Cross Section Along Model Centerline

Notes:

1. Transducer used was a 2.5 psi, C.E.C. chamber mounted type.
2. These tests were conducted in order to determine the range of tailwater elevations which is sufficient to eliminate any significant fluctuating pressures.
3. Maximum design tailwater elevation = 44.23 ft, minimum design tailwater elevation = 29.75 ft.

COMPARISON OF FLUCTUATING DYNAMIC PRESSURES IN AIR TRAP OF THE BIG TUJUNGA GATE AND SPILLWAY STRUCTURE DUE TO VARIATION OF THE TAILWATER ELEVATION

Q = 2250 cfs
Gate Opening = Three at 18.5 ft
Vent: 9 sq ft, 58 ft D.S. from gate slot
Model Scale 1:38.3

MODEL STUDIES-FOOTHILL FEEDER PROJECT
Metropolitan Water Dist. of Southern Californi
BIG TUJUNGA GATE & SPILLWAY STRUCTURE

Harza Engineering Co., Chicago, Ill.

SAINT ANTHONY FALLS HYDRAULIC LABORATORY
UNIVERSITY OF MINNESOTA

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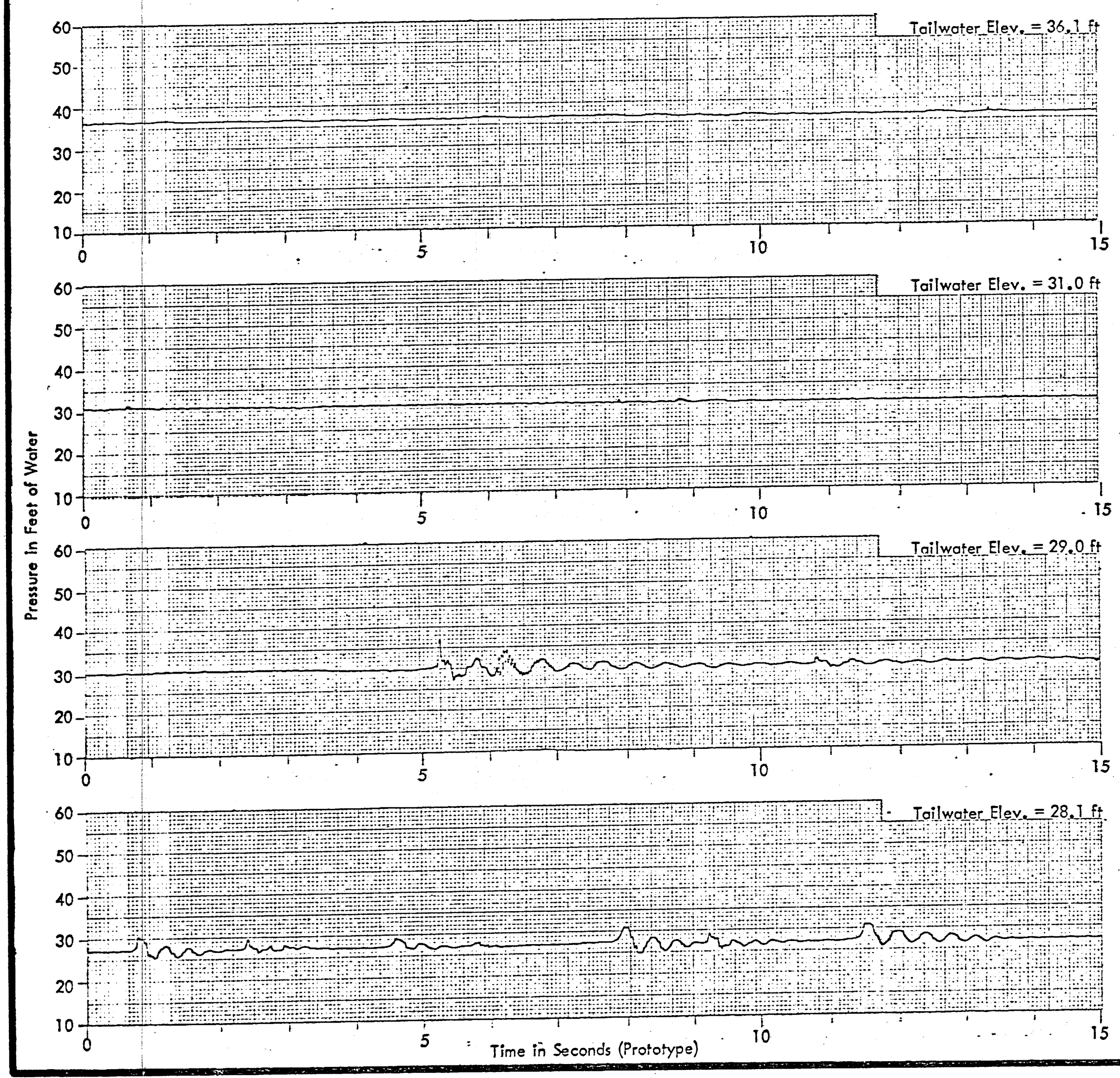
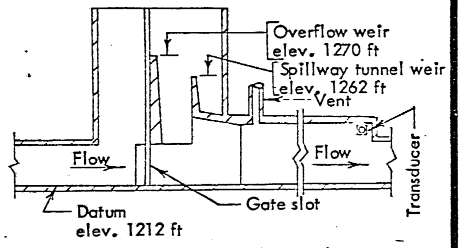
CHART 14





Cross Section Along Model Centerline

Notes:

1. Transducer used was a 2.5 psi, C.E.C. chamber mounted type.
2. These tests were conducted in order to determine the range of tailwater elevations which is sufficient to eliminate any significant fluctuating pressures.
3. Maximum design tailwater elevation = 36.07 ft, minimum design tailwater elevation = 28.98 ft.

COMPARISON OF FLUCTUATING DYNAMIC PRESSURES IN AIR TRAP OF THE BIG TUJUNGA GATE AND SPILLWAY STRUCTURE DUE TO VARIATION OF THE TAILWATER ELEVATION

Q = 1575 cfs
Gate Opening = Three at 4.1 ft
Vent: 9 sq ft, 58 ft D.S. from gate slot
Model Scale 1:38.3

MODEL STUDIES–FOOTHILL FEEDER PROJECT
Metropolitan Water Dist. of Southern California
BIG TUJUNGA GATE & SPILLWAY STRUCTURE

Harza Engineering Co., Chicago, Ill.

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UNIVERSITY OF MINNESOTA

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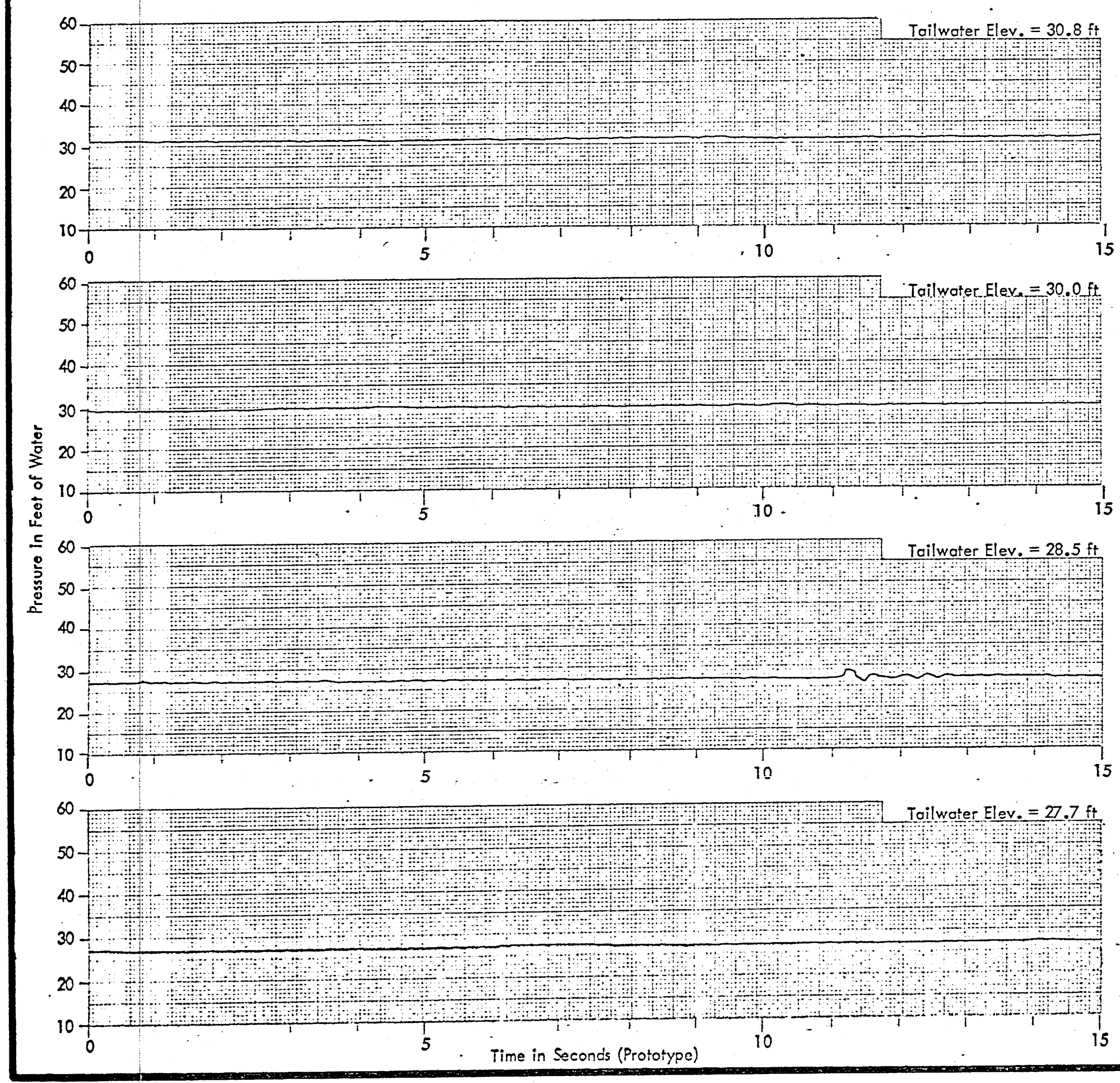
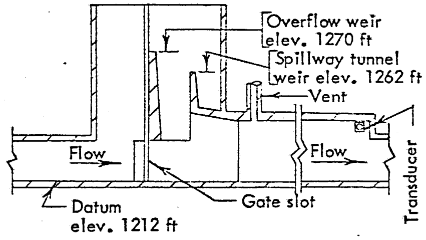
CHART 15





Cross Section Along Model Centerline

Notes:

1. Transducer used was a 2.5 psi, C.E.C. chamber mounted type.
2. These tests were conducted in order to determine the range of tailwater elevations which is sufficient to eliminate any significant fluctuating pressures.
3. Maximum design tailwater elevation = 30.80 ft, minimum design tailwater elevation = 28.49 ft.

COMPARISON OF FLUCTUATING DYNAMIC PRESSURES IN AIR TRAP OF THE BIG TUJUNGA GATE AND SPILLWAY STRUCTURE DUE TO VARIATION OF THE TAILWATER ELEVATION

Q = 900 cfs
Gate Opening = Three at 1.9 ft
Vent: 9 sq ft, 58 ft D.S. from gate slot
Model Scale 1:38.3

MODEL STUDIES–FOOTHILL FEEDER PROJECT
Metropolitan Water Dist. of Southern California
BIG TUJUNGA GATE & SPILLWAY STRUCTURE

Harza Engineering Co., Chicago, Ill.

SAINT ANTHONY FALLS HYDRAULIC LABORATORY
UNIVERSITY OF MINNESOTA

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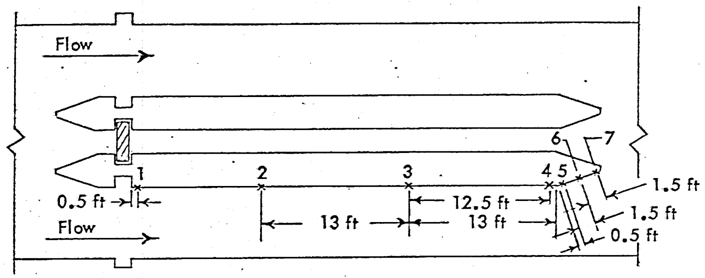
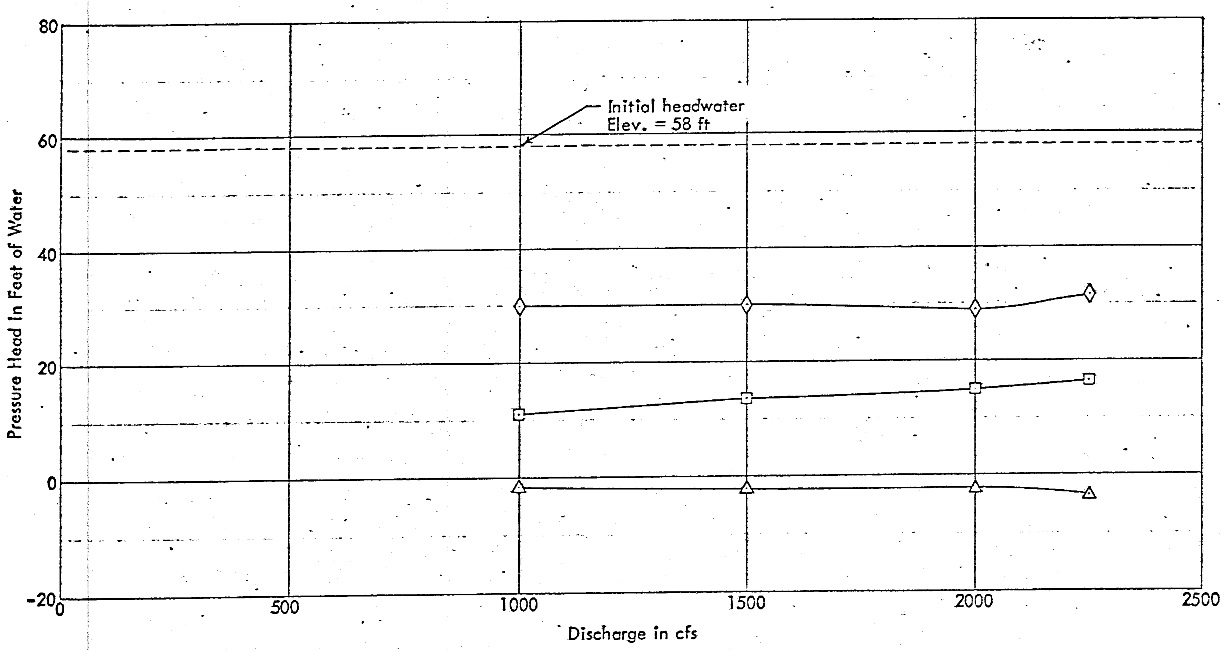
SCALE | DATE 4-3-67 | NO. 166-6-459-12

CHART 16



Plan view showing piezometer tap locations



Notes:

1. Side gates open equally, center gate closed.
2. Pressures were measured using piezometers located as shown in sketch, 0.4 ft above the floor of the structure.
3. Test procedure was as follows:
   a. A given discharge was established.
   b. The side gates were opened equally so that the headwater elev. = 58 ft.
   c. The tailwater elevation was decreased until the hydraulic jump was no longer submerged and had moved into the transition downstream of the gates.
   d. Data presented on this chart were then recorded.
4. Pressures on the floor of the structure were slightly higher (approximately 0.2 ft of water) than those on the pier wall.
5. Minimum pressure occurred at location 5 for all conditions tested.
6. Minimum pressure of -3.2 ft of water occurred when Q = 2250 cfs, tailwater elev. = 16.5 ft, gate opening = 5.8 ft.

△ Minimum pressure on pier wall

□ Tailwater elevation for inception of unsubmerged hydraulic jump

◇ Headwater elevation after hydraulic jump formed in tunnel

MINIMUM TAILWATER ELEVATION FOR INCEPTION OF HYDRAULIC JUMP IN TUNNEL

Headwater and Tailwater Elevations
Pier Pressures

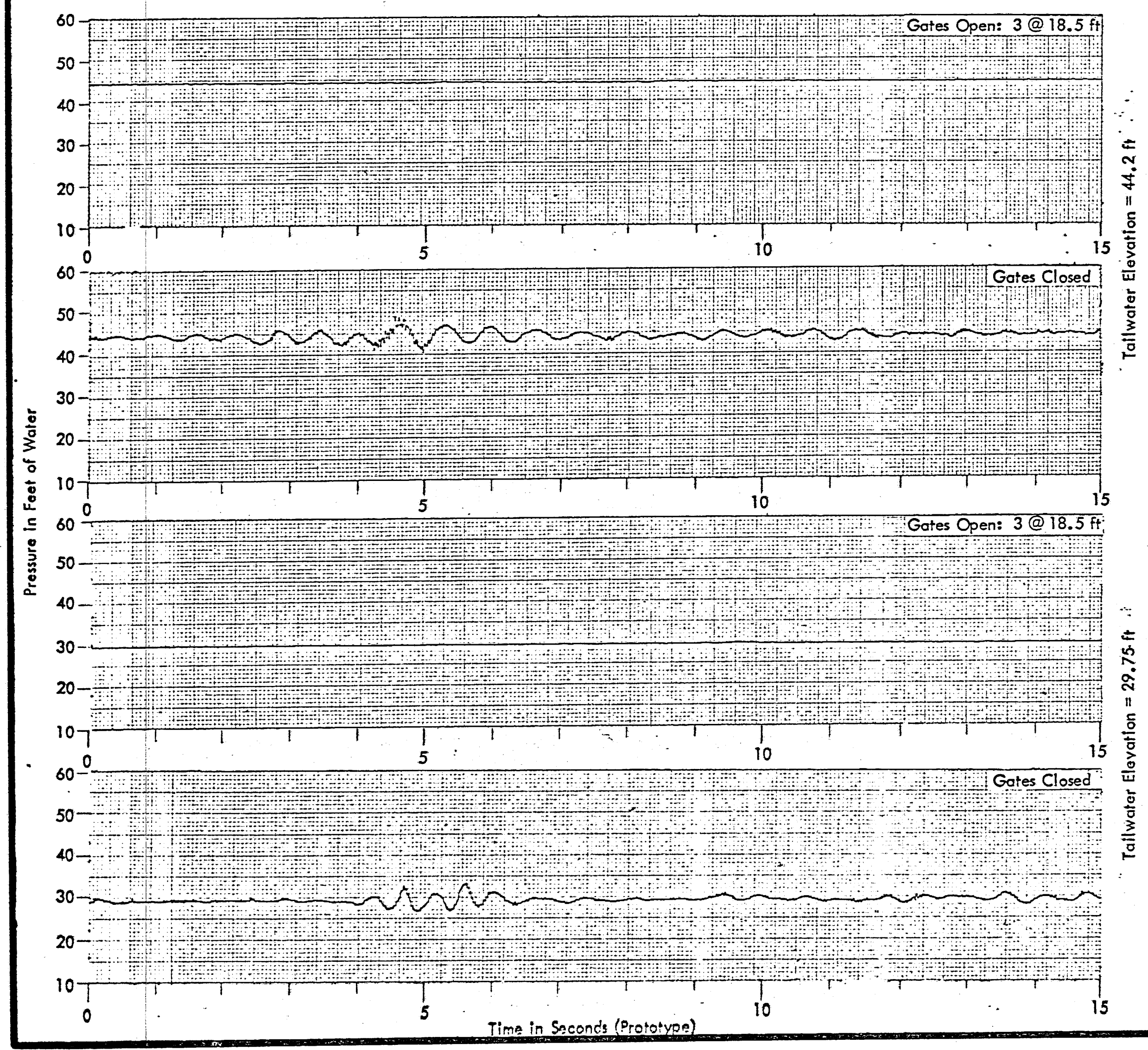
MODEL STUDIES-FOOTHILL FEEDER PROJECT
Metropolitan Water Dist. of Southern California
BIG TUJUNGA GATE & SPILLWAY STRUCTURE

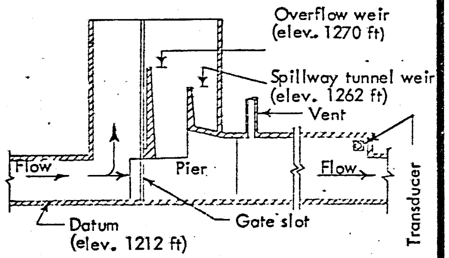
Harza Engineering Co., Chicago, Ill.

SAINT ANTHONY FALLS HYDRAULIC LABORATORY
UNIVERSITY OF MINNESOTA

DRAWN JRB	CHECKED	APPROVED
SCALE	DATE 2-21-67	NO [illegible]

CHART 17





Cross section along centerline of model

Notes:

1. Transducers used were 2.5 psi C.E.C., chamber mounted type.
2. With gates closed and flow over weir, air is entrained; air escaping through vent and overflow impacting on pool causes dynamic pressure oscillations.
3. In this test, the maximum and minimum design tailwaters were established, and the maximum design discharge was passed either through the gate openings or over the overflow weir.

	Gate Opening (ft)			
	3@18.5	0	3@18.5	0
T.W. Elevation	44.2	44.2	29.75	29.75
H.W. Elevation	45	65	30.5	65
Maximum Magnitude of Pulses (ft of water)	-	8.0	-	6.0

VARIATION OF FLUCTUATING PRESSURES IN AIR TRAP OF BIG TUJUNGA GATE TOWER DUE TO CHANGE IN T.W. ELEVATION AND GATE OPENING

Q = 2250 cfs
T. W. Elevation = 29.75 and 44.2
Gate Opening = 3 @ 18.5 ft and 0
Spillway Tunnel Q = 0
Vent: 9 sq ft,58 ft D.S. from gate slot
Model Scale 1:38.3

MODEL STUDIES-FOOTHILL FEEDER PROJECT
Metropolitan Water Dist. of Southern California
BIG TUJUNGA GATE & SPILLWAY STRUCTURE

Harza Engineering Co., Chicago, Ill.

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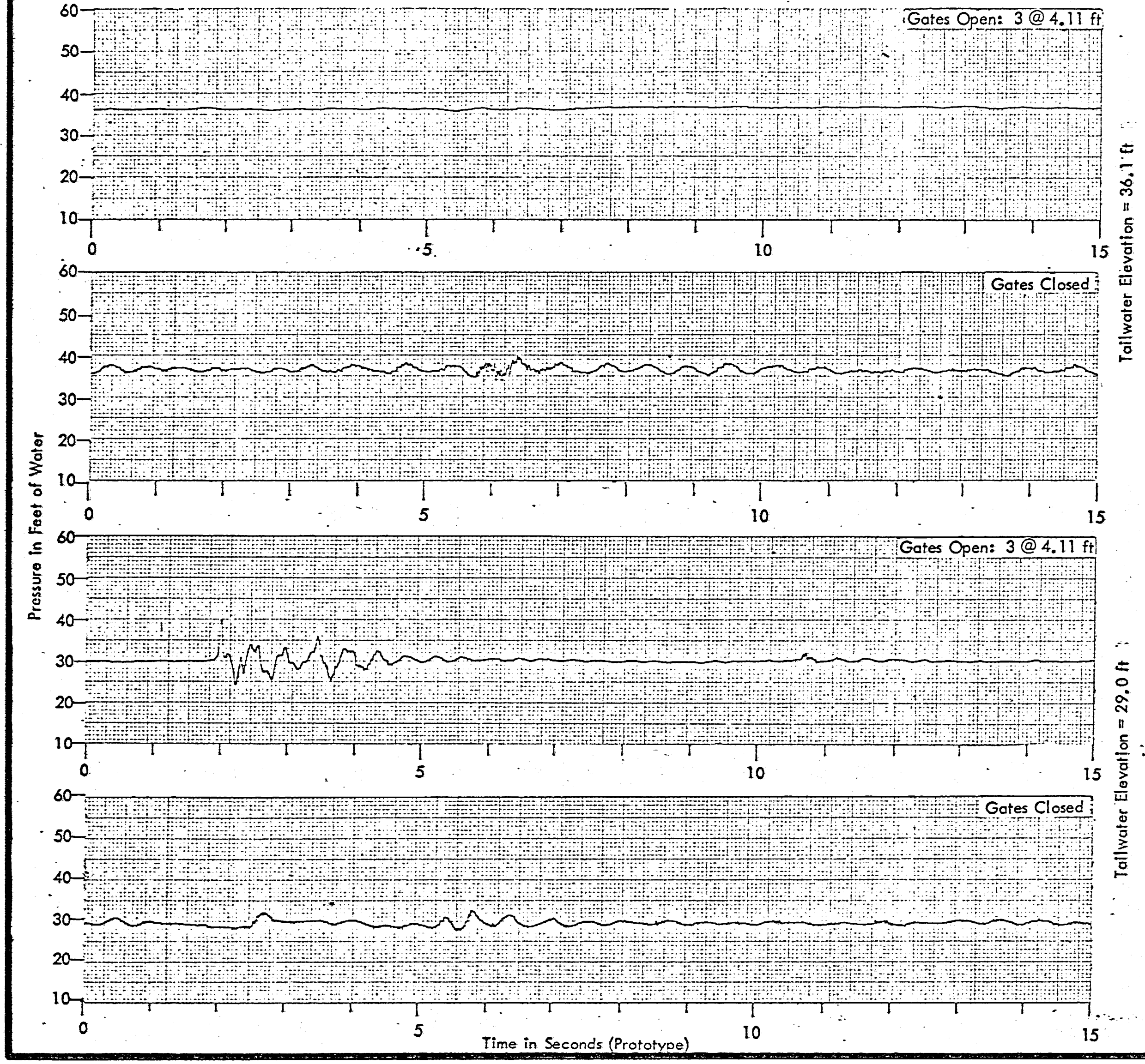
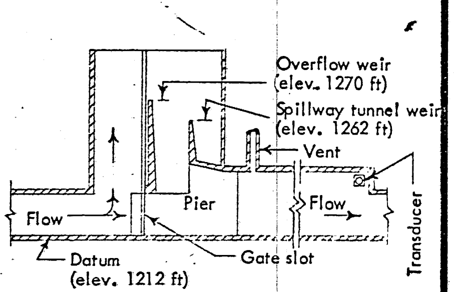
DRAWN JRB	CHECKED	APPROVED
SCALE	DATE 2-1-67	NO. 163-3-459-11

CHART 18





Cross section along centerline of model

Notes:

1. Transducers used were 2.5 psi C.E.C., chamber mounted type.
2. With gates closed and flow over the weir, air is entrained; air escaping through the vent and overflow impacting on pool causes dynamic pressure oscillations.
3. In this test, the maximum and minimum design tailwaters were established, and a flow of 1575 cfs was passed either through the gate openings or over the overflow weir.

	Gate Opening (ft)			
	3@4.11	0	3@4.11	0
T.W. Elevation	36.1	36.1	29.0	29.0
H.W. Elevation	52.5	64	46	63.5
Maximum Magnitude of Pulses (ft of water)	—	6.0	16.0	4.5

VARIATION OF FLUCTUATING PRESSURES IN AIR TRAP OF BIG TUJUNGA GATE TOWER DUE TO CHANGE IN T.W. ELEVATION AND GATE OPENING

Q = 1575 cfs
T. W. Elevation = 29.0 ft and 36.1 ft
Gate Opening = 3@4.11 ft and 0
Spillway Tunnel Q = 0
Vent: 9 sq ft, 58 ft D.S. from gate slot
Model Scale 1:38.3

MODEL STUDIES-FOOTHILL FEEDER PROJECT
Metropolitan Water Dist. of Southern California
BIG TUJUNGA GATE & SPILLWAY STRUCTURE

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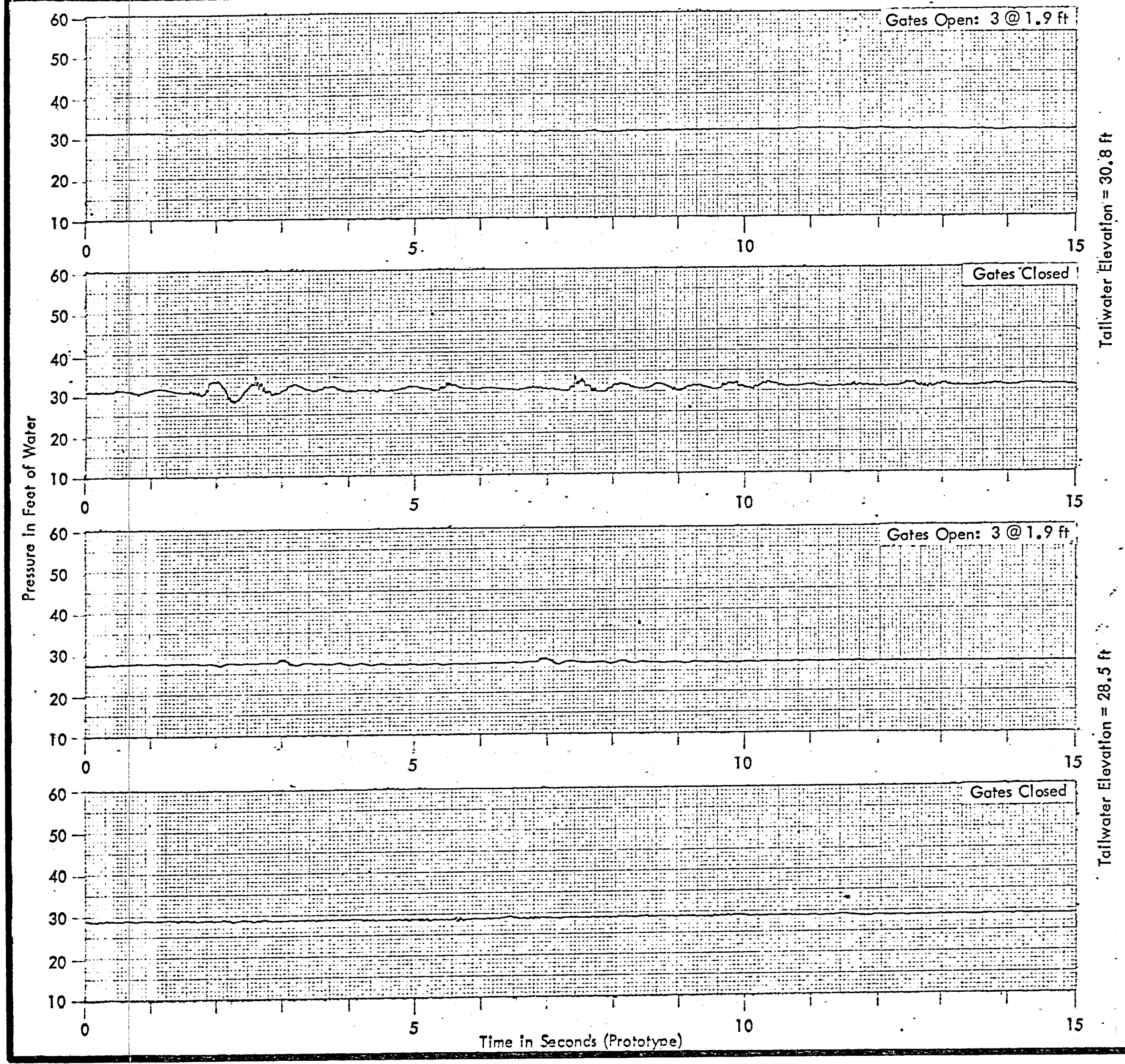
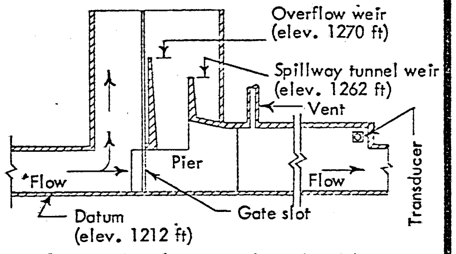
SCALE | DATE 2-6-67 | 168-3-459-115





Cross section along centerline of model

Notes:

1. Transducers used were 2.5 psi C.E.C., chamber mounted type.
2. With gates closed and flow over the weir, air is entrained; air escaping through the vent and overflow impacting on pool causes dynamic pressure oscillations.
3. In this test, the maximum and minimum design tailwaters were established, and a flow of 900 cfs was passed either through the gate openings or over the overflow weir.

	Gate Opening (ft)			
	3@1.9	0	3@1.9	0
T.W. Elevation	30.8	30.8	28.5	28.5
H.W. Elevation	59	62	57	62
Maximum Magnitude of Pulses (ft of water)	-	5.0	3.0	1.2

VARIATION OF FLUCTUATING PRESSURES IN AIR TRAP OF BIG TUJUNGA GATE TOWER DUE TO CHANGE IN T.W. ELEVATION AND GATE OPENING

Q = 900 cfs
T. W. Elevation = 28.5 and 30.8 ft.
Gate Opening = 3 @ 1.9 ft and 0
Spillway Tunnel Q = 0
Vent: 9 sq ft,58 ft D.S. from gate slot
Model Scale 1:38.3

MODEL STUDIES-FOOTHILL FEEDER PROJECT
Metropolitan Water Dist. of Southern California
BIG TUJUNGA GATE & SPILLWAY STRUCTURE

Harza Engineering Co., Chicago, Ill.

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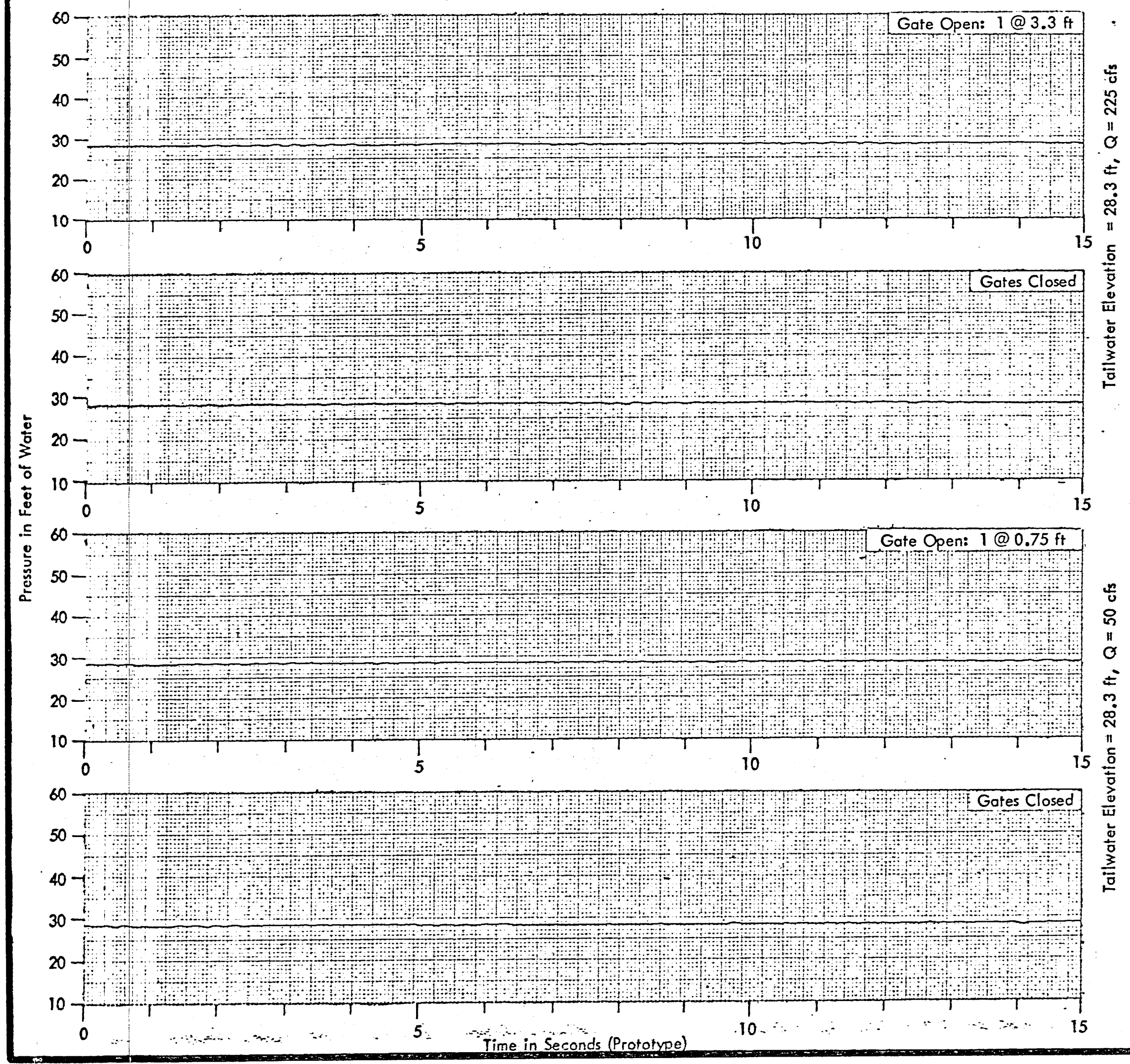
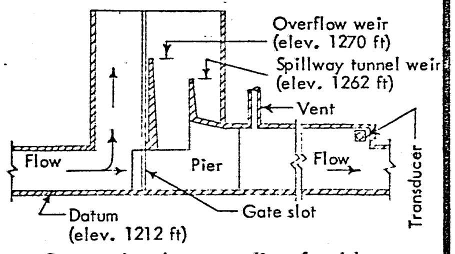
DRAWN JRB	CHECKED	APPROVED
SCALE	DATE 2-8-67	NO 163-3-459-116

CHART 20





Cross section along centerline of model

Notes:

1. Transducers used were 2.5 psi C.E.C., chamber mounted type.
2. With gates closed and flow over the weir, air is entrained; air escaping through the vent and overflow impacting on pool causes dynamic pressure oscillations.
3. In this test the design tailwater was established, and flows of 225 and 50 cfs were passed either through the gate openings or over the overflow weir.

	Gate Opening (ft)			
	1@3.3	0	1@0.75	0
T.W. Elevation	28.3	28.3	28.3	28.3
H.W. Elevation	57.5	60.0	58	59.0
Maximum Magnitude of Pulses (ft of water)	-	-	-	-

VARIATION OF FLUCTUATING PRESSURES IN AIR TRAP OF BIG TUJUNGA GATE TOWER DUE TO CHANGE IN DISCHARGE AND GATE OPENING

Q = 225 and 50 cfs
T. W. Elevation = 28.3 ft
Gate Opening = 1@3.3 and 0.75 ft
and 0 (center gate only)
Spillway Tunnel Q = 0
Vent: 9 sq ft, 58 ft D.S. from gate slot
Model Scale 1:38.3

MODEL STUDIES-FOOTHILL FEEDER PROJECT
Metropolitan Water Dist. of Southern California
BIG TUJUNGA GATE & SPILLWAY STRUCTURE

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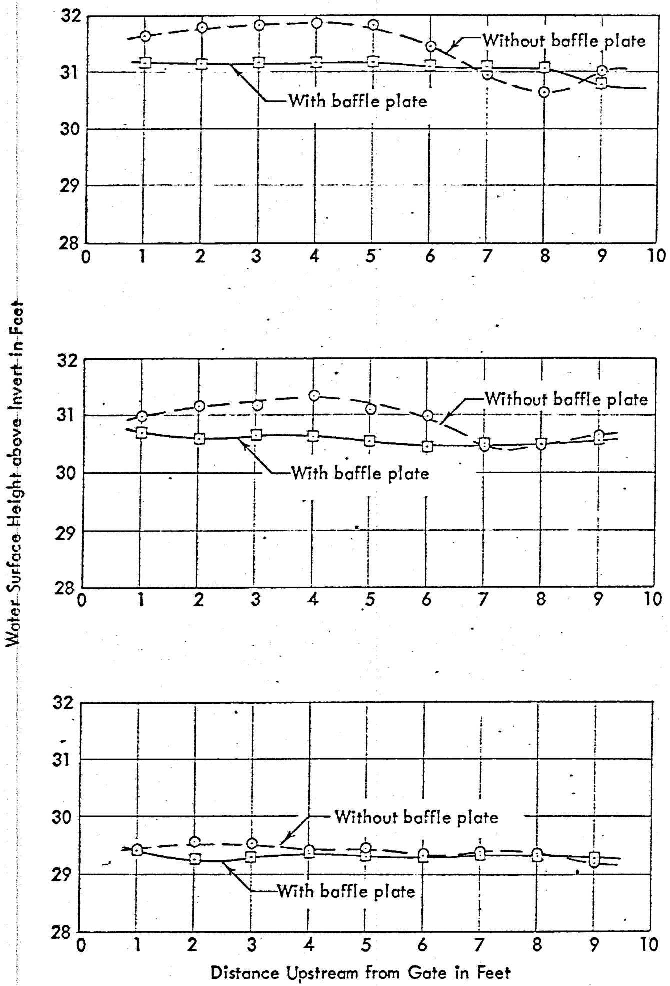
SCALE	DATE 2-7-	NO. -5-459-11

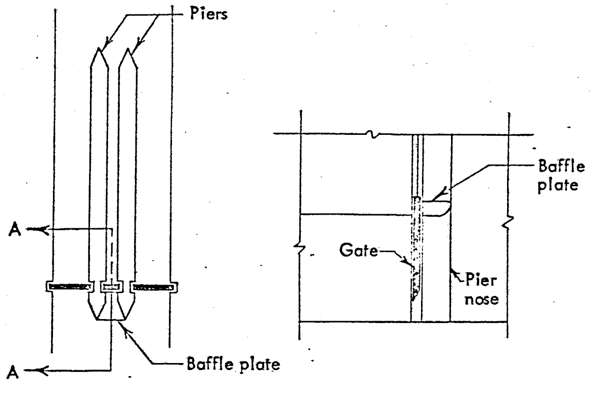
CHART 91



Q = 2250 cfs
H.W. Elev. = 30.8 ft
T.W. Elev. = 29.0 ft

Q = 1500 cfs
H.W. Elev. = 30.6 ft
T.W. Elev. = 29.0 ft

Q = 1000 cfs
H.W. Elev. = 29.4 ft
T.W. Elev. = 29.0 ft



Plan

Section A-A

Plan and section views showing the location of the baffle plate placed between the piers upstream from the center gate

Notes:

1. Center gate closed, outside gates fully open.
2. Tests conducted to determine effectiveness of baffle plate shown in above sketch in removing water surface fluctuations upstream from center gate.

WATER SURFACE PROFILES UPSTREAM FROM CENTER GATE WITH AND WITHOUT BAFFLE PLATE

Q = 2250, 1500, and 1000 cfs
T.W. Elev. = 29.0 ft
Model Scale 1:38.3

MODEL STUDIES–FOOTHILL FEEDER PROJECT
Metropolitan Water Dist. of Southern California
BIG TUJUNGA GATE & SPILLWAY STRUCTURE

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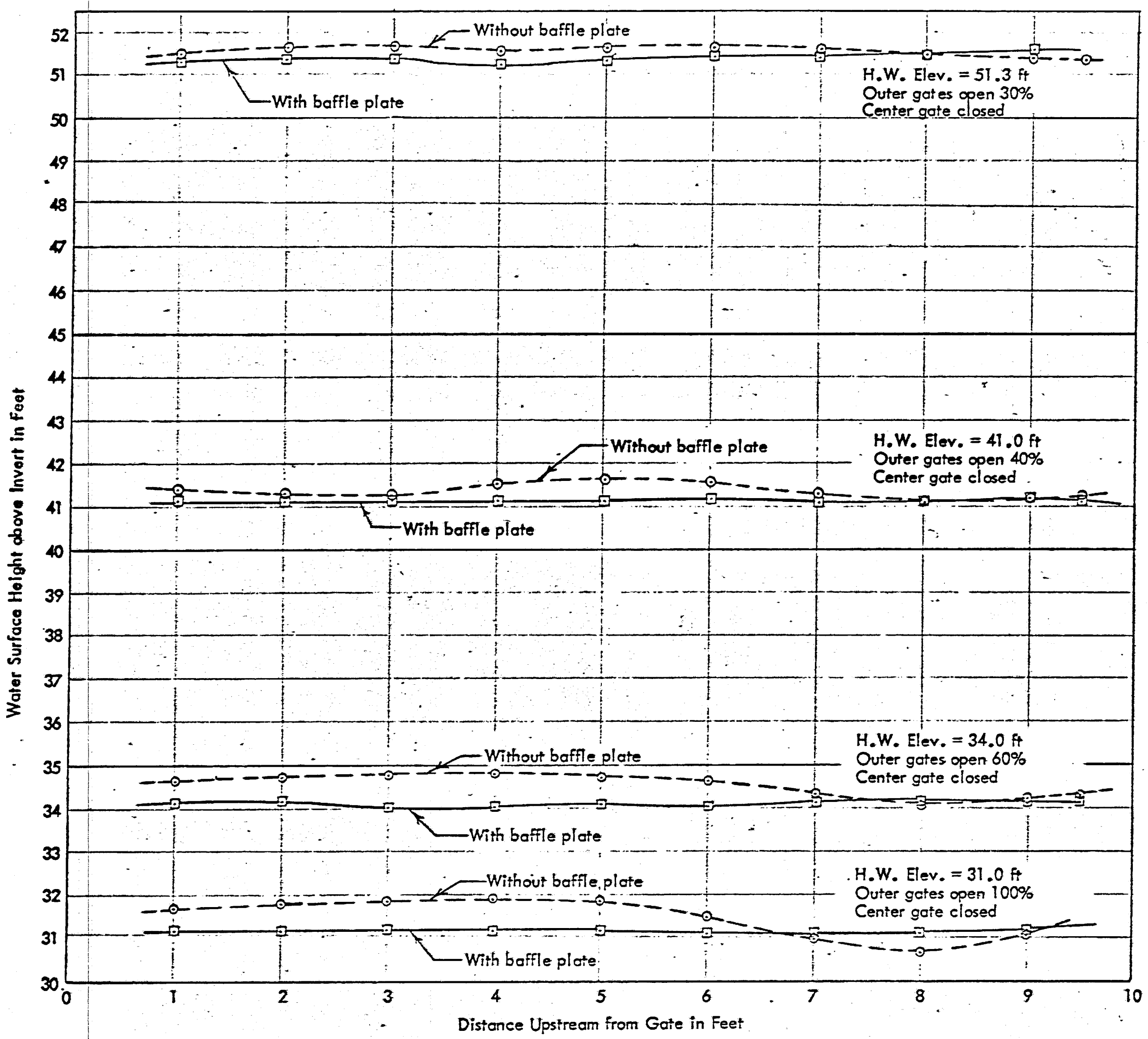
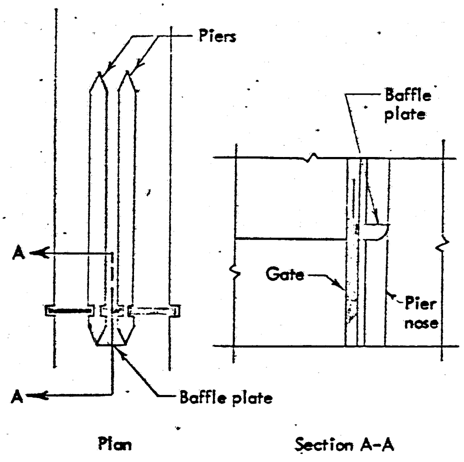
DATE 8-23-67

CHART 22





Plan

Section A-A

Plan and section views showing the location of the baffle plate placed between the piers upstream from the center gate

Notes:

1. Center gate closed, outside gate opening varied.
2. Tests conducted to determine the effectiveness of baffle plate shown in above sketch in removing water surface fluctuations upstream from the center gate.

WATER SURFACE PROFILES
UPSTREAM FROM CENTER GATE
WITH AND WITHOUT BAFFLE PLATE

Q = 2250 cfs
T.W. Elev. = 29.0 ft
Model Scale 1:38.3

MODEL STUDIES–FOOTHILL FEEDER PROJECT
Metropolitan Water Dist. of Southern California
BIG TUJUNGA GATE & SPILLWAY STRUCTURE

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