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MODEL STUDIES - FOOTHILL FEEDER PROJECT METROPOLITAN WATER DISTRICT OF SOUTHERN CALIFORNIA PART III. MORRIS RESERVOIR TURNOUT STRUCTURE

by
Alvin G. Anderson
and
David J. Anderson

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LAW III. MOTION PROPORTIONAL IMPRESSED MOTIVE FORCE

MOTIVE FORCE - MOMENTUM - VELOCITY - ACCELERATION

by

Irwin C. Anderson

and

Frank C. Anderson

Prepared for the

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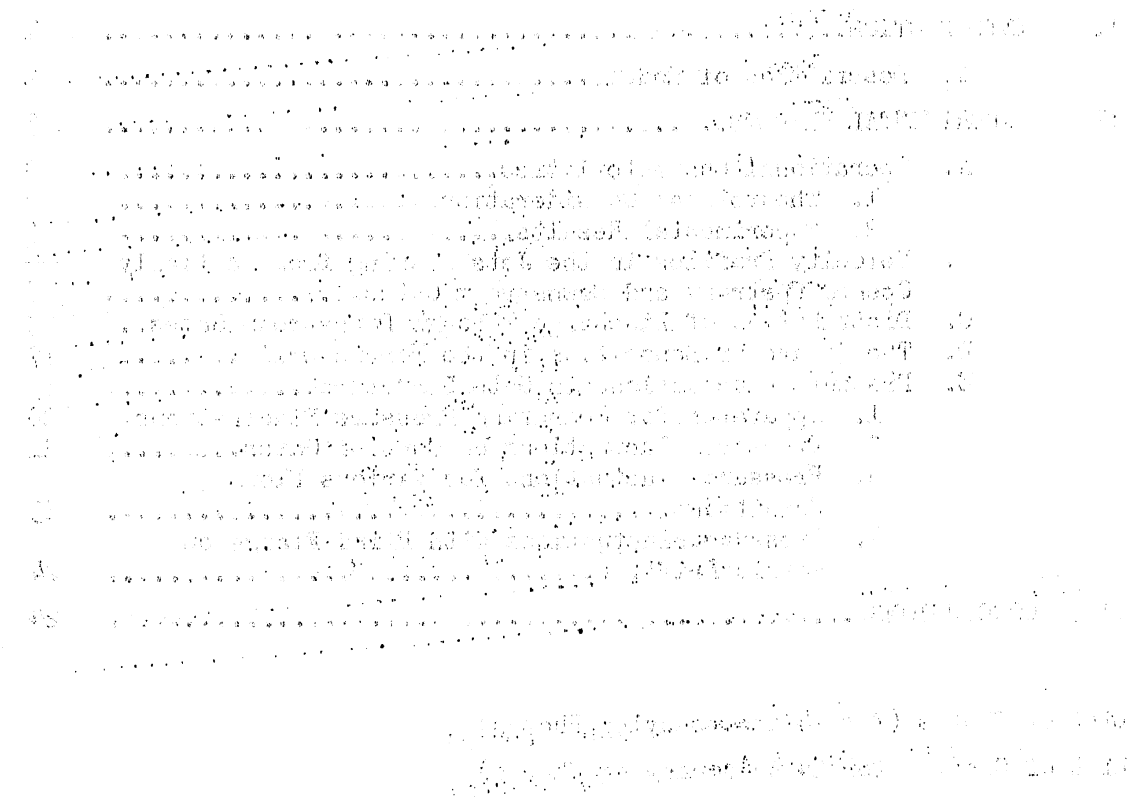

PREFACE

This report is the third in a series dealing with the gated control structures to be used in the Foothill Feeder of the Metropolitan Water District of Southern California. The report describes the model experiments pertaining to the operation of the Morris Reservoir Turnout Structure. This structure will provide flow control in the tunnel and in addition will incorporate the Morris Drift connected to Morris Reservoir. By means of this structure the Morris Reservoir will float on the Santa Anita Tunnel No. 2, and thus serve as a reservoir that will supply water to or receive water from the foothill feeder as needed.

Experiments have been carried out to establish the operating characteristics of the two independent sets of gates. The results show that the gates provide consistent control of the flow and could be set to provide almost any combination of head differentials desired for arbitrary elevations of Morris Reservoir.

Experiments were also carried out to delineate the flow pattern within the gate structure when it is operating at high discharges. These consisted of measurements of velocities and current directions within the structure. The measurements of vibratory pressures on the gates in the model were carried out with the Morris Drift open and closed in order to examine the effect of the additional mass of water on the fluctuations.

The Morris Reservoir Turnout Structure was similar in some respects to the Regular Gate Structure[1] and the Big Tujunga Gate and Spillway Structure[2] previously tested. This is particularly true with regard to the shape, size, and method of mounting of the gates. Many of the results obtained in the

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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.

(2) Model Studies - Foothill Feeder Project. Metropolitan Water District of Southern California - Part II. Big Tujunga Gate and Spillway Structure. Project Report No. 93. St. Anthony Falls Hydraulic Laboratory, February 1968.

[illegible]

[illegible]

[illegible]

previous studies are also applicable to this structure. This is particularly true with regard to the gate vibrations and fluctuating pressures.

The model tests described in this report were sponsored by the Harza Engineering Company of Chicago, Illinois, which was represented by Dr. David Louie. 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 shop, and much of the experimentation was carried on by David J. Anderson.

MODEL STUDIES - FOOTHILL FEEDER PROJECT
METROPOLITAN WATER DISTRICT OF SOUTHERN CALIFORNIA
PART III. MORRIS RESERVOIR TURNOUT STRUCTURE

I. INTRODUCTION

The Foothill Feeder Project of the Metropolitan Water District of Southern California incorporates a long tunnel through which water will be supplied 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. For this purpose gated control structures open to the atmosphere were chosen. The gate structures were circular in plan and fitted with gates for flow control. 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 Morris Reservoir Turnout Structure. More specifically, the items of special interest were:

(1) The head differentials through each set of gates for various combinations of headwater, tailwater, and reservoir elevations.

(2) Fluctuating pressures and gate vibrations that might result from various modes of operation.

(3) The flow patterns within the structure and the effect of the Morris Drift directly connected to the Morris Reservoir on this flow pattern.

The Morris Reservoir Turnout Structure is designed to provide both flow control in the tunnel and facilities for regulating flow into or out of Morris Reservoir. It is the junction of the so-called Morris Drift with the Santa Anita Tunnel No. 2, the general features of which are shown on Chart 1. It consists essentially of a circular shaft 56 ft in diameter into which the three tunnels are directed. The upstream control consists of a full height dividing wall fitted with control gates and high level weirs for emergency operation. The tunnel leading to Morris Reservoir is uncontrolled at the structure so that the water level in the turnout structure will be essentially the same as that in Morris Reservoir. The downstream leg of the Santa Anita Tunnel No. 2, however, is controlled by another set of three gates at the point where it

leaves the control structure. The upstream and downstream sets of gates each consist of two outside gates 6 ft 3 in. wide and a center gate 2 ft wide. The maximum gate opening of each set is 18.5 ft. They are controlled from the upper deck by relatively rigid gate stems. The tunnels which enter or leave the structure are 17.5 ft in diameter.

Description of Model

The model was fabricated of a clear plastic at a scale of 1:38.3. This scale ratio was chosen so that standard plastic tubes could be used for the tunnel and at the same time provide a model of reasonable size. Photo 1 is a general view of the model setup showing the Santa Anita Tunnel No. 2 entering and leaving the structure and the Morris Drift leaving the structure at the left. The proper pressure in the Santa Anita tunnel downstream of the turnout structure is maintained at prescribed values by the water level in the downstream tank. The other tank to which the Morris Drift is connected is maintained at prescribed Morris Reservoir elevations. In addition, the photo shows the manometer board holding the piezometers that are attached by tubing to taps along the several tunnels at which piezometric pressures are measured. Photo 2 is a view from above showing the lower portions of the turnout structure, the gates, dividing wall, and the arrangements of the tunnel connections.

The design of the model was based upon the Froudian Law of Similarity, since the flow pattern within the structure is a gravitational phenomenon which is characterized by the free surfaces in the structure and in the reservoir. Utilizing this law the discharges in the model corresponding to specified prototype discharges can be computed and observations made in the model of pressures, water surface elevations, and flow patterns can be transferred to the prototype by the following relations:

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

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

$$P_r = L_r$$

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

$$\nabla \cdot \mathbf{E} = \frac{\rho}{\varepsilon_0}$$

$$\nabla \cdot \mathbf{B} = 0$$

$$\nabla \times \mathbf{E} = -\frac{\partial \mathbf{B}}{\partial t}$$

$$\nabla \times \mathbf{B} = \mu_0 \mathbf{J} + \mu_0 \varepsilon_0 \frac{\partial \mathbf{E}}{\partial t}$$

The water supply was taken from the Mississippi River through the Laboratory supply system. The discharge was measured by means of two calibrated orifices arranged in parallel so that both large and small model discharges could be accurately measured.

II. EXPERIMENTAL RESULTS

A. Operational Characteristics

1. Theoretical Considerations

The operating characteristics of this structure involve the coupled effect of the two sets of gates and three closely related water surface elevations. When both gate sets are combined in the same structure the calibration characteristics of one set depend to a certain degree on the relative position of the gates in the other set. In order to investigate this interrelationship as a guide to the interpretation of the physical measurements, a simplified and idealized condition is considered. The simplifying assumptions were made with the expectation that effects of neglected characteristics would be noted in the experimental data. It was initially assumed that the gates were far enough apart that the flow pattern generated by the upstream gates did not affect the operation of the downstream gates. It was further assumed that the losses of energy were negligible and that the discharge coefficients were equal. Under these circumstances the discharge through the sluice gate can be written in terms of the head differential and the gate opening as

$$Q = C_d \, bd \, (2g\Delta H)^{1/2} \qquad (1)$$

in which Q is the discharge in cfs, C_d is the discharge coefficient, b is the total gate width of all the gates in feet, d is the gate opening in feet, g is the acceleration due to gravity ($g = 32.2$ ft per sec^2), and ΔH is the head difference across the gate. Assuming that the water surface elevation in the structure is equal to that of the Morris Reservoir, so that there is no flow into or out of the reservoir, continuity requires that the flow entering the structure through the upstream set of gates be equal to the discharge leaving by the downstream set of gates so that

$$\int_0^{\infty} \frac{x^{\alpha-1}}{1+x} \, dx = \frac{\pi}{\sin \pi\alpha}$$

(1)

$$C_d\ bd_1\ (2g\ \Delta H_1)^{1/2} = C_d\ bd_2\ (2g\ \Delta H_2)^{1/2}$$

or

$$d_1\ \sqrt{\Delta H_1} = d_2\ \sqrt{\Delta H_2} \qquad (2)$$

since the discharges, the gate width, and the discharge coefficients are equal for both sets of gates. Now if α is defined as the relative gate opening, so that

$$\alpha_1 = \frac{d_1}{d_T} \qquad \text{and}$$

$$\alpha_2 = \frac{d_2}{d_T} \qquad (3)$$

where d_T is the same maximum gate opening for each set of gates, and if β is defined as the relative head differential such that

$$\beta = \frac{\Delta H_1}{\Delta H_T} \quad \text{and} \quad 1 - \beta = \frac{\Delta H_2}{\Delta H_T}$$

where ΔH_T is the total head differential across both sets of gates, then Eq. (2) can be written in dimensionless form as

$$\alpha_1 = \alpha_2 \left(\frac{1 - \beta}{\beta}\right)^{1/2} \qquad (4)$$

Eq. (4), giving the relationship between α_1 and α_2, the relative gate openings, for any particular β or relative head differential, represents a family of straight lines radiating from the origin. This family of curves is shown on Chart 2(a) for values of β ranging from 0.05 to 0.95. In addition, the graph shows a series of curves for various values of the total head differential, ΔH_T. These are obtained for any prescribed values of Q, ΔH_T, and β by substitution in Eq. (1), using Eq. (3) in the form

$$\alpha_1 = \frac{Q}{C_d\ bd_T\ (2g\ \beta\ \Delta H_T)^{1/2}}$$

where $C_d \approx 1.0$. The family of curves for various total head differentials can then be computed for a given discharge. From such curves, given the

$$\int_{\Omega} \left(\frac{\partial}{\partial x_i} \right) \left(\frac{\partial}{\partial x_j} \right) \, dx$$

$$\int_{\Omega} \left(\frac{\partial}{\partial x_i} \right) \left(\frac{\partial}{\partial x_j} \right) \, dx \tag{3}$$

$$\int_{\Omega} \left(\frac{\partial}{\partial x_i} \right) \left(\frac{\partial}{\partial x_j} \right) \, dx$$

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$$\int_{\Omega} \left(\frac{\partial}{\partial x_i} \right) \left(\frac{\partial}{\partial x_j} \right) \, dx \tag{5}$$

$$\int_{\Omega} \left(\frac{\partial}{\partial x_i} \right) \left(\frac{\partial}{\partial x_j} \right) \, dx$$

$$\int_{\Omega} \left(\frac{\partial}{\partial x_i} \right) \left(\frac{\partial}{\partial x_j} \right) \, dx$$

discharge and the total head drop, as well as the elevation of Morris Reservoir, the relative gate openings for the upstream and downstream gates can be determined. The actual curves as measured in the model should be somewhat similar to those in Chart 2, but will include such effects as the spacing between gate sets, flow pattern, energy loss, and discharge coefficients.

2. Experimental Results

Charts 3, 4, and 5 present the results of actual measurements of relative gate openings as measured in the model for different discharges and total head differential. The tests were conducted with three different values of the tailwater elevations downstream of the structure in the Santa Anita Tunnel No. 2 of 1130, 1150, and 1170 ft in order to determine among other things if such a variation in tailwater elevation influenced the calibration curves. The charts present data for three different discharges; that is, Chart 3 gives the results for a discharge of 420 cfs, Chart 4 for 1,000 cfs, and Chart 5 for 1,550 cfs. The two graphs shown on each chart are presentations of the same data. The logarithmic plot serves to spread out the data for the larger total head differentials, and facilitates the determination of the gate openings. The curves delineate a pattern which is similar to the idealized computed curves. The differences are principally that the β curves are not actually straight lines but are somewhat curved and shifted closer together. This curvature and shift is due to the non-ideal flow pattern, which is the result of the non-symmetrical gate arrangement and the irregular flow pattern between gate sets. In addition, there is a transition zone for each set of gates beyond which the relative gate opening exerts no influence upon the generated head differentials. In this region the total head differential is controlled by one gate set only.

The experiments have shown that a point exists beyond which a particular gate set has no influence upon the head differential through the structure. The lines-of-no-control represent the practical values for $\beta = 0$ and $\beta = 1.0$. That is to say, for a given total head differential when the upstream gate is sufficiently closed, all the head differential occurs at the upper gate and is independent of the position of the downstream gate provided the downstream gate is above the line-of-no-control. On the other hand, when the downstream gate

leakage and the total head drop, as well as the elevation of hourly measurements, the relative gains or losses for the upstream and downstream gates can be determined. The actual stream is measured by the metal shield or movable steel-to-stone by Chart 1, but will increase such values as the spacing between gate ports, flow patterns, energy loss, and discharge coefficients.

5. Theoretical Results

Charts 1, 2, and 3 present the results of actual measurements of relative gate opening as measured in the model for different elevations and total head differentials. The lines were transferred with those different values as the ordinates of various observations at the structure. In the Santa Anita Tunnel the [illegible] was 11'-1" in order to determine among other things a condition by which conditions influenced the calibration curves. The charts present data for three different elevations; that is, Chart 1 gives the results for a discharge of 1,000 cfs, Chart 2 for 1,500 cfs, and Chart 3 for 2,000 cfs. The [illegible] given on each chart are measurements of the same [illegible]. The [illegible] plot serves to record the data for the Jensen total [illegible], and [illegible] the [illegible] gate openings. [illegible] which is also to be [illegible] open. [illegible] conditions are [illegible] flow [illegible] are not critical, as [illegible] had been reached on all [illegible]. This condition is due to the non-[illegible] flow pattern, which is also [illegible] of the non-[illegible] gate arrangement and the irregular flow pattern resulting [illegible]. In addition, there is a [illegible] zone for each set of gates beyond which the relative gate opening exerts no influence upon the [illegible] head differentials. In this region the total head differential is controlled by one gate and only.

The curvatures have shown that a point exists beyond which a certain [illegible] and has no influence upon the head differential through the [illegible]. The Jensen measurement represent the predicted values for $\frac{1}{2}$ = 0 and $\frac{1}{2}$ = 1, [illegible] for it [illegible] and differential when the openings are [illegible] closed, all the head differential occurs at the outer gate and is independent of the position of the downstream gate opening the curvatures gate is above the [illegible] elevation. On the other hand, when the downstream gate

is nearly closed, the upstream gate may be drowned out, so that any position above that given by the line-of-no-control again has no influence upon the flow pattern.

Computations of the discharge coefficient defined by

$$C_d = \frac{Q}{bd\,(2g\,\Delta H + V^2)^{1/2}} \qquad (5)$$

show that they are less than one in all cases. In Eq. (5) the velocity of approach was included in order to approximate the flow patterns existing in the structure. The approach velocity at the upstream gates was assumed to be the velocity in the upstream tunnel, while the approach velocity at the downstream gates was assumed to be the discharge divided by the area of the upstream gate opening, since the gates were so close together that the jet under the upstream gates did not have room to expand to the full depth. The computed discharge coefficients ranged between 0.72 and 0.98 for the upstream gates and between 0.56 and 0.88 for the downstream gates.

It will be observed in Charts 3, 4, and 5 that the calibration curves are independent of the tailwater elevation in Santa Anita Tunnel No. 2 within the range of values tested. The reason for this is that for these tailwaters the gates are very deeply submerged and the precise tailwater elevation in the structure does not influence the flow pattern through and between the gate sets. This means that a single calibration curve for each discharge will be applicable to all reservoir elevations within the prescribed range of variation.

B. Velocity Profiles in the Jets Issuing from Partially Opened Upstream and Downstream Gates

Chart 1 shows that the streamlines for the flow through the turnout structure are curved, and one might expect that the discharges through the respective downstream gates would not be equal and that the flow pattern might be complicated by the presence of the Morris Drift. In order to help determine the distribution of the flow at the downstream gates in comparison with the pattern in the upstream gates, the measurement of velocities within the structure was undertaken.

$$\frac{\partial}{\partial t} = \frac{\partial}{\partial x} \left(\frac{\partial}{\partial x} \right)$$ (-)

In the first set of experiments measurements of the vertical velocity profiles were made downstream of the left and right upstream gates and downstream of the left and right downstream gates. These velocities were measured on the vertical centerline of each gate for the maximum discharge of 1550 cfs. In order to gain greater insight into the velocity patterns, additional measurements were made at the successive stations along the same centerline downstream of the respective gates.

At the time that the velocity measurements were taken an attempt was made to photograph the flow pattern in the vicinity of the upstream gates. For this purpose a streamer of dye was introduced through an upstream port and permitted to move downstream into the structure. Photo 5 was taken just as the dye flowed under the gate. The streamlines upstream of the gate are clearly shown and the downstream jet is confined to a thickness about equal to the gate opening. This photo was taken before the dye was diffused into the overlying water in the structure and into the Morris Drift. The high velocity flow near the bottom extends to and through the downstream gates. Photo 6 is another view of the gate section a short time later, when the dye has diffused throughout the region upstream of the gates. The jet, however, is still well-defined and the dye has not yet begun to mix with the surrounding water.

The velocities at each station were measured by means of special pre-calibrated Pitot-static tubes that could be inserted into the structure at prescribed points. For velocity profiles downstream of the upstream gates the measuring points were located within the turnout structure and were easily reached. Normally, access to the transition section downstream of the downstream gates was not possible, but special fittings were installed so that the Pitot tubes could be inserted through the upper wall of the transition section.

The velocity measurements were made for a discharge of 1550 cfs, the maximum flow for this structure. The difference in elevation between the headwater and the tailwater was also fixed at the maximum in order that the velocities would represent the most extreme flow situation. The headwater was maintained at elevation 1180 ft and the tailwater was lowered to elevation 1130 ft. The gate openings of the upstream and downstream outside gates were made the same, each being open 4 ft (21.5 per cent). The center gates were closed. The water level in the chamber, and hence in the Morris Reservoir, was

In the first set of experiments measurements of the vertical velocity profiles were made downstream of the left and right upstream gates and downstream of the left and right downstream gates. These velocities were measured on the vertical centerlines of each gate for the maximum discharge of 1330 cfs. In order to gain greater insight into the velocity patterns, additional measurements were made at the successive obstions along the same centerline downstream of the respective gates.

At the time that the velocity measurements were taken an attempt was made to photograph the flow pattern in the vicinity of the upstream gates. For this purpose a generator of dye was introduced through an upstream port and permitted to move downstream into the structure. Photo 5 was taken just as the dye flowed under the gate. The circulations upstream of the gate are clearly shown and the downstream jet is constricted to a thickness about equal to the gate opening. Photo photo was taken before the dye was diffused into the overlying water in the structure and into the Morris Draft. The high velocity jets near the bottom extends to and through the downstream gates. Photo 6 is another view of the gate section a short time later, when the dye has diffused throughout the region on top of the gates. The jet, however, is still well-defined and the dye has not yet begun to mix with the surrounding water.

The velocities at each station were measured by means of spoke wheel, bucket-type meters that could be inserted into the structure at successive points. For velocity profiles downstream of the upstream gates the measuring points were located within the inverse structure and were easily reached, access to the termination section downstream of the downstream gates was not possible, but conical fittings were installed so that the Pitot tubes could be inserted through the upper wall of the termination section.

The velocity measurements were made for a discharge of 1330 cfs, the maximum flow for this structure. The difference in elevation between the reservoir and the tailwater was also fixed at the maximum in order that the velocities would represent the most extreme flow situation. The headwater was maintained at elevation 1330 ft and the tailwater was lowered to elevation 1320 ft. The gate openings and downstream outside gates were made the same, each being open 0.4 ft (3.5 per cent). The center gates were closed. The water level in the chamber, and hence in the Morris Reservoir, was

permitted to seek the equilibrium elevation. In normal operation the gates would have to be adjusted to take into account the pre-existing water surface elevation in Morris Reservoir. However, for this experiment with equal gate openings the water level in the chamber between the gates was in equilibrium at elevation 1150 ft. This water surface elevation indicates that the head drop through the upstream gates was 30 ft, while the head drop through the downstream gates was only 20 ft. This difference is probably due to the very high velocity of approach directed toward the downstream gates as compared to the velocity of approach of the upstream gates. The approach velocity for the upstream gates is approximately the mean velocity in the approach tunnel, while that for the downstream gates is of the same order of magnitude as the jet velocity under the upstream gates. If one assumes equal head losses through the upstream and downstream gates respectively and neglects the kinetic energy factor,

$$\Delta(\Delta H) = \frac{V_3^2}{2g} - \frac{V_1^2}{2g}$$

where $\Delta(\Delta H)$ is the difference between the head differentials of the upstream and downstream gates, V_3 is the velocity of approach of the downstream gates, and V_1 is the velocity of approach of the upstream gates. A study of the velocity profiles generated at the upstream gates indicates that the difference of the measured head differentials is on the same order as the difference in respective velocity heads.

It was felt initially that sufficient information regarding the patterns of flow could be obtained by measuring the vertical velocity profiles of the centerline of the gates. It was recognized, however, that because of the non-symmetry of the flow pattern in the turnout structure the discharge in the individual downstream gates might not be the same, but it was not possible to predict the distribution of the discharge through the downstream gates.

In addition to the measurements of the discharge rates and gate velocities for the normal geometry, velocity measurements were also made with the entrance to the Morris Drift closed by means of a blank flange. The purpose of these measurements was to determine whether the volume of water enclosed within the Morris Drift would have measurable influence upon the energy dissipation and

$$\frac{}{}$$

the velocity pattern within the turnout structure. It had been observed that the high velocity flow from the upstream left gate (Photos 5 and 6) moving past the entrance to the Morris Drift was able to generate and maintain vortex motion that extended for a considerable distance into Morris Drift before it was dissipated. The purpose of these measurements was to determine whether the creation and maintenance of the vortex motion would have any measurable influence upon the energy dissipation or velocity pattern within the turnout structure.

The results of these measurements are shown in Charts 6, 7, 8, and 9. Chart 6 shows the vertical velocity profiles for stations along the downstream centerline of the right upstream gate; Chart 7 shows similar profiles for the left upstream gate, while Charts 8 and 9 show corresponding vertical profiles at several stations on the longitudinal centerlines downstream of the right and left downstream gates respectively. On each chart the velocity profiles obtained with the Morris Drift entrance closed by the blind flange are plotted for comparison.

It should be noted that the velocity profiles for the right and left upstream gates are practically identical and show that the flow entering the turnout structure is very uniformly divided, and the flow patterns are highly symmetrical whether the Morris Drift is closed or open. It appears, however, that the velocities measured when the entrance to the Morris Drift was closed are consistently less than those obtained when the Morris Drift was open. This difference is probably due to errors in re-establishing a discharge for the consecutive tests.

The velocity patterns developed at the right and left downstream gates, however, show somewhat greater differences in velocity between the right and left gates and for the two conditions of the Morris Drift entrance. It will also be observed that for these profiles, in contrast to those measured at the upstream gates, the velocities with the entrance to the Morris Drift closed are slightly greater than those observed when the Morris Drift was open. Combining these observations with the profiles obtained from the upstream gates indicates that the effect of Morris Drift on the velocity profiles is greater than first appears on the charts. In spite of this, however, the velocity patterns

the velocity pattern within the thermal structure. It had been observed that the high velocity flow from the upstream left vent (Photos 1 and 6) moving past the entrance to the Bonnie Bell was also to generate and maintain weaker motion that extended for a considerable distance into Bonnie Bell before it was dissipated. The purpose of these measurements was to determine whether the existence and maintenance of the vortex motion could have any measurable influence upon the energy dissipation or velocity pattern within the thermal structure.

The results of these measurements are shown in Charts 4, 5, and 6. Chart 4 shows the vertical velocity profiles for stations close to the entrance of the right Bonnie vent. Chart 5 shows similar profiles for the local upstream cave, while Charts 5 and 6 show corresponding vertical profiles at several stations on the longitudinal centerline downstream of the right and left downstream vents respectively. In each chart the velocity profiles obtained with the Bonnie Bell entrance closed by the tilted flange are plotted for comparison.

It should be noted that the velocity profiles [illegible] were quite unsteady [illegible] particularly [illegible] the velocity [illegible] pronounced wavelike motion [illegible] closed [illegible]. [illegible] that the velocities measured when the entrance to the Bonnie Bell was open were considerably less than those obtained when the Bonnie Bell was [illegible]. This difference in velocity is due to energy in maintaining a circulatory motion [illegible].

The velocity patterns developed at the right and left downstream vents, however, show somewhat greater differences in velocity between the right and left vents and for the two conditions of the Bonnie Bell entrance. It will also be observed that for these positions, in contrast to those measured at the upstream vents, the velocities with the entrance to the Bonnie Bell closed are slightly greater than those observed when the Bonnie Bell was open. Combining these observations with the prediction obtained from the apparent vortex motion that the effect of Bonnie Bell on the velocity profiles is greater when closed appears on the chart. It might, however, the velocity patterns

obtained with the Morris Drift open and closed are remarkably similar. It will also be observed that the maximum velocity just downstream of the left downstream gate is several feet per second larger than the maximum velocity along the centerline of the right downstream gate. This is to be expected from the geometry of the gate structure and the direction of curvature of the streamlines. If for any reason the velocity of approach to the gate is reduced, the velocity under the gate will be correspondingly reduced.

Some comparisons between these results can be made by integrating the area of each velocity profile as an indication of the unit discharge at the centerline. It must be remembered, however, that because of the curvature of the streamlines approaching the downstream gates the velocity pattern--that is, the transverse velocity profile--will not be symmetrical and consequently the discharges measured at the centerline will not necessarily be proportional to the total discharge. They will, however, give a good indication of the effects of asymmetry upon the individual discharges, if these areas can be compared with each other. The relative discharges through the several gates based upon these computations are given in Table I. Any lack of balance between the discharges could be caused by the non-uniformity of the transverse velocity profiles resulting from the forced curvature of the streamlines between the upstream and downstream gate sets. This becomes apparent when the sum of the unit discharges for the upstream gates (301 cfs/ft) is compared to that of the downstream gates (285 cfs/ft). The tests showed, however, relatively little difference in the discharge through the left and right downstream gates.

Additional velocity measurements within the turnout structure and between the upstream and downstream gates are shown in Charts 10 through 14. For the measurements shown in Charts 10, 11, and 12 the upstream gates were set at a 15 per cent opening and the downstream gates were fully open. In addition, all the gates in each set were opened equally. This arrangement of gates for a discharge of 1550 cfs results in a head differential across the upstream gates of 39 ft, while the head differential across the downstream gates was only about 1 ft. The headloss in the downstream gates is due entirely to the effect of the structure geometry, since Chart 5 shows that the downstream gates lose control when the gates are open over 50 per cent. The velocity measurements were made at various points within the turnout structure using a Pitot-static

TABLE I

Comparison of Unit Discharges Through Control Gates
Morris Drift Open and Closed

Combination of Gates	Unit Discharges	Ratio of Discharges
$\frac{\text{USL}}{\text{USL + USR}}$ (1)	$\frac{147}{301}$	0.49
$\frac{\text{DSR}}{\text{DSL + USR}}$ (1)	$\frac{154}{301}$	0.51
$\frac{\text{DSL}}{\text{DSL + DSR}}$ (1)	$\frac{147}{285}$	0.51
$\frac{\text{DSR}}{\text{DSL + DSR}}$ (1)	$\frac{138}{285}$	0.49
$\frac{\text{USL open}}{\text{USL closed}}$	$\frac{147}{136}$	1.08
$\frac{\text{USR open}}{\text{USR closed}}$	$\frac{154}{154.5}$	1.00
$\frac{\text{DSL open}}{\text{DSL closed}}$	$\frac{147}{153}$	0.96
$\frac{\text{DSR open}}{\text{DSR closed}}$	$\frac{138}{138}$	1.00

USL Upstream left gate
USR Upstream right gate
DSL Downstream left gate
DSR Downstream right gate
(1) Morris Drift Open

tube. It was located at successive stations on a longitudinal centerline of the right upstream gates and at various points on a transverse line located a distance of 20 ft from the section of the upstream gates.

The velocity profile at Section A (Chart 10) is quite uniform and typical of a flow pattern as it approaches a gate. At Section B the velocity was measured a short distance upstream of the gate, so that the profile shows a relatively high velocity as the flow is accelerated under the gate. At this distance upstream of the gate the velocity near the bed has increased to nearly 20 fps. Just downstream of the gate at Section C a typical profile for flow under a sluice gate has developed. The maximum velocity very close to the bottom is nearly 50 fps. The velocity rapidly decreases with height as the elevation of the gate lip is approached, so that the velocities in the region above the lip of the gate are negligibly small. The velocities shown in the upper regions of Sections C and D are relatively undefined since they are in the wake created by the gate. The profiles of Sections D and E indicate the presence of the jet close to the bed and its gradual increase in thickness as the flow moves downstream. This is shown particularly at Section E. The point F, however, is protected by the nose of the downstream gate piers. This causes an appreciable flow separation, so that at the floor near the pier a small upstream velocity has been generated. At higher elevation the zone of separation is presumably narrower, so that the velocities measured in this region show appreciable downstream velocities.

In Chart 11 the velocity profiles include that at point G near the right boundary. The other profiles are as given in Chart 10. Point G, immediately upstream of the right downstream gate, shows some remnants of the high velocity jet that leaves the upstream gate. As the upstream jet penetrates into the gate chamber, it tends to spread laterally as well as vertically, and the maximum velocity is still further decreased in the downstream direction. This is indicated at point G where the maximum velocity near the floor is approximately 25 fps. At the higher elevations it appears that the flow has separated from the wall, so that in this region velocity is slightly negative and a reverse current is indicated. In Chart 12 a series of velocity profiles taken at points laterally spaced across the gate chamber is shown. These profiles show the nature of the jet which has been formed by the upstream gates as it is

dissipated within the gate chamber. The lateral diffusion of the jet is shown by the velocity profiles at point K and point G, where the maximum velocity near the floor of the chamber has been reduced to approximately 25 fps. At points J and E, however, which are immediately downstream of the left and right upstream gates respectively, the maximum velocity is still in the neighborhood of 40 fps. The jet is considerably thicker than the gate opening. Above the gate elevation the downstream velocities are very small and rather poorly defined. In this region the flow patterns are quite complex and involve secondary currents moving in different directions.

Since the Morris Drift is submerged, and since no net flow occurs within it, the flow at points K and J must either be deflected directly into the Santa Anita Tunnel No. 2 past the bifurcation nose or else be deflected upward and across the chamber and then down into the downstream tunnel. As the flow moves past the entrance of Morris Drift at a high velocity the shear developed near the bottom of the water within the Drift by the flow generates a vortex motion of considerable magnitude within the tunnel which extends for some distance from the entrance. The strength of this rotation decreases with distance down the Morris Drift until the point is reached where it is completely dissipated.

In Charts 13 and 14 the results of measurements of velocity are shown for the case when the downstream gates are partially closed. By reducing the opening through these gates the elevation of the water surface in the gate tower has been considerably increased--to elevation 1150 ft. Under these circumstances the head differential across the upstream gates is 20 ft as is that across the downstream gates. (This gate setting is also shown on Chart 5 as the point where the relative gate openings for $\Delta H_T = 40$ ft, $\Delta H_1/\Delta H_T = 0.5$, are 21.3 per cent and 17.5 per cent.) Such a mode of operation appreciably increases the depth of water within the chamber and provides for greater dissipation of the jet energy. The pattern in Chart 13 is similar to that in Chart 10 for the profiles near the upstream gates (points A, B, C, D, and E). Although the pattern of velocity at point F is somewhat similar, the velocities near the bottom in the downstream direction indicate that the zone of separation has been considerably reduced. However, because the gates have been partially closed, there is a region above the lip of the gates between the piers in which negative velocities are generated. In Chart 14 at point G the

velocities are now everywhere positive, which also indicates that the zone of separation has been reduced. This may be the consequence of the partial closure of the right downstream gate, since now the water in the neighborhood of point G must accelerate to pass under the gate. This apparently is enough to reduce the size of the separation zone and make the velocities at the gate lip positive.

The results of the velocity measurements show that the flow entering the Morris Reservoir Turnout Structure is rather uniformly divided between the several gates, so that the velocity profiles issuing from these upstream gates are quite similar. Based upon this single profile, the discharge through the right upstream gate was 51 per cent of the total, while that through the left upstream gate was 49 per cent of the total (for these experiments the center gate was closed). The situation was reversed at the downstream gates, in which 49 per cent of the total flow passed through the right downstream gate and 51 per cent of the total flow passed through the left downstream gate. These differences probably are not significant, since variations in velocity and the transverse direction were not taken into account. They do indicate, however, that the flow through the various gates is not drastically asymmetrical. This series of velocity profiles also provides some information on the nature of the jet as it proceeds downstream. Within the chamber itself the high velocities are confined to an area very close to the bottom and have a thickness about equal to the gate opening. As they move through the chamber or down the Santa Anita Tunnel the jets tend to thicken somewhat as the velocity is reduced. The velocity profiles taken at various points within the chamber show that the jets spread transversely and tend to follow the geometrical boundaries of the structure. It appears, however, that there is a tendency toward separation at the right outside boundary as well as at the piers supporting the downstream gates.

The effect of Morris Drift on the flow pattern appears to be primarily one of energy dissipation. The high velocity jet from the upstream left gate flowing past the entrance of Morris Drift creates a vortex motion within the drift that extends some distance into the drift before it is dissipated. The shear generated by the high velocity jet across the bottom of the entrance face is the primary cause of the vortex motion which is then transmitted into the

...ndition are not considered critical, we also include the case of ...
...ssumption has been relaxed. This may be the consequence of the partial ...
...closure of the valve when there are the waves in the neighborhood ...
...of point 6 measurement made to open water line valve. This apparently is enough ...
...to reduce the size of the annular flow and make the velocity at the gate ...
...lip negative.

...he results of the velocity measurements show that the flow entering the ...
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...ight recirculation zone "I pay" at the bottom, while the rest of the jet ...
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...ly part only of the total flow passed through the right downstream gate and ...
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...easurements probably are not significant, since circulations in vicinity of the ...
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...t the flow through the various gates is not just simply proportional. Under ...
...ertain conditions of velocity pressure and gate opening, the valve ...
...ay be used as a device for the measurement of the ...
...ate as a measure of velocity. Still, the ability of the high velocities ...
...ere confined to be close to the gate and was here a high velocity ...
...ound in the gate opening. In fact, here the jet flow is ...
...ight toward the gate lead to oblique impacts at the vicinity in contact ...
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The effect of Reynolds Number on the flow pattern appears to be primarily ...
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...lowing such big currents of flowers that the velocity profile ...
...ould lose entirely some distance behind the gate. The ...
...ther pressure in the high velocity-jet stream in front of the entrance zone ...
...s the primary cause of the vortex. Obviously, in case the ...

tunnel by the shear generated in the flow. Because of the change in direction of the jet at this point and the change in momentum of the flow, some of the water from the jet probably also enters the drift and takes part in rotation. Continuity then requires that there be a return flow to the gate chamber, which probably occurs in the central portion of the tunnel. This flow returns to the gate chamber at a higher elevation and joins the mass of fluid moving at much lower velocities.

C. Distribution of Discharge Through Downstream Gates

In order to study further the flow patterns and the distribution of flow in the downstream gates, an additional experiment was conducted involving the injection of dye into the flow. The dye was injected at five distinct points in the plane of the upstream gates including the right and left side of each of the outside gates and the center of the center gate. The gate openings of the downstream set of gates were divided into seven portions of equal width (2 ft each so that the center gate represented one of the separate areas). When the dye pattern had become stabilized, samples of the flow at each of the seven measuring areas were collected. The concentration of dye in each sample was determined with a standard colorimeter. Knowing that the dye mixed with the flow at each sampling point came from a particular upstream gate, the proportions of the discharge that passed through each of the downstream gates could be easily determined. Previous experiments on velocity profiles indicated that the flow entering the turnout structure was quite uniformly divided between the upstream gates so that 43 per cent of the total flow passed through the right upstream gate, 43 per cent passed through the left upstream gate, and 14 per cent passed through the center upstream gate. The results of the measurements using dye are tabulated in Table II.

TABLE II

Proportion of Flow Through Downstream Control Gates

Flow from Upstream Gates	Flow Through Downstream Gates - Per Cent		
	Right	Center	Left
Right Gate (43 per cent of Q_T)	55.6	9.7	34.6
Center Gate (14 per cent of Q_T)	33.3	8.3	58.4
Left Gate (43 per cent of Q_T)	48.2	9.9	41.6

and 3b are not paired through the second transform cycle. The results of the measurements using dye are tabulated in Table II.

TABLE II

Proportion of Pink Pigeon Lymphocytes Detected Using

Dye Type Used	Dye Through One Transform Cycle	Dye Through Two Transform Cycles
Fluorescein Isothiocyanate ($FITC_{dye}$)	27%	0%
Rhodamine Isothiocyanate ($RITC_{dye}$)	23%	0%
Fluorescein and Rhodamine ($FITC_{dye}$ and $RITC_{dye}$)	5%	0%

Using the above information approximate proportions of the total discharge passing through the individual downstream gates are:

a) The downstream right gate - 49.4 per cent,
b) The downstream center gate - 9.6 per cent, and
c) The downstream left gate - 41.0 per cent.

It appears from the table that most of the flow from the right upstream gate goes through the downstream right gate, although 35 per cent of it passes through the downstream left gate. Of the flow through the upstream center gate, 58 per cent passes through the downstream left gate, but 33 per cent goes through the right gate. Of the flow from the upstream left gate, over 48 per cent passes through the downstream right gate. Since the downstream left gate is almost directly downstream of the upstream right gate, it might be expected that a large proportion of the flow from this gate would pass through the downstream left gate. It would not be expected, however, that nearly half of the flow from the upstream left gate would pass through the downstream right gate. In order to do this the flow leaving the upstream left gate must be deflected upward in the chamber, and then after passing over the high velocity flow along the bed, flow downward and into the downstream right gate. Photo 7, in which pieces of yarn are held in the chamber above the jet, illustrates the upward flow at the downstream face of the chamber and the downward flow near the upstream gates. The measurement of velocities in the chamber between the gates also seems to bear out this conclusion. The data thus indicate that nearly 21 per cent of the total flow is deflected upward in the neighborhood of the bifurcation nose and redirected into the right downstream gate.

This flow pattern represents the most severe operating conditions to be expected having the maximum discharge and the highest head differentials. For smaller discharges and smaller head differentials the pattern would tend to be similar, but the lower velocities and greater depth in the chamber might be such that some of the flow pattern aspects would be unrecognizable. Even for extreme conditions the flow pattern as generated with this structural configuration does not appear to be particularly detrimental to the functioning of the turnout structure. The flow pattern would undoubtedly be somewhat improved if the upstream and downstream gates were aligned so that the flow

would not have to be deflected by the bifurcation nose. The rotational effects within the Morris Drift would probably be somewhat reduced, since there would be less likelihood of flow impingement within the drift entrance. Given the basic geometry of the turnout structure and the alignment of the tunnel and the drift, the flow pattern is such that for normal operations this alignment should have only a minor influence.

D. The Nature of Deposition in the Morris Drift

Since the Morris Drift is submerged and enters the turnout structure at the same level as the Santa Anita Tunnel No. 2, the high velocity jet from the left upstream gate generates a well-defined vortex motion in the entrance region of Morris Drift. It seemed possible that this might cause the deposition of any suspended sediment that might be carried by the flow. The nature of the vortex motion can be seen in Photos 8, 9, and 10, which show the motion of suspended confetti in Morris Drift caused by different discharges. By exposing the film for an appreciable time interval (in this case 1/25 sec) the confetti registers as a streak whose length is proportional to the velocity of the particle and whose direction shows the local direction of the flow. In these photographs the movement is counterclockwise looking down the drift away from the gate chamber. By comparison of the photos it is apparent that the rotational velocity decreases with distance from the entrance and is proportionately reduced as the total discharge through the turnout structure is reduced.

Some deposition of confetti particles was observed to take place, so a specific experiment was undertaken in an attempt to determine quantitatively the amount of deposition likely to occur within the Morris Drift. Confetti particles were used in the test to represent suspended sediment. The confetti was boiled in water in order to soak it completely and thereby make it somewhat heavier than the water. The fall velocity of typical particles so treated was found to be 0.051 fps (model) which corresponds to a prototype fall velocity of about 0.35 fps. This fall velocity, in turn, corresponds to the diameter of a particle of sand of approximately 0.75 mm. This size of sediment is probably considerably larger than any that would be found in suspension within the feeder system.

The test procedure involved two phases. First a sample of known size was introduced into the tunnel far upstream of the turnout structure. The particles passed through the structure and either continued down the Santa Anita Tunnel No. 2 or settled within the Morris Drift. The settled particles were then counted and their location in the tunnel was noted. Five separate tests were made so that average conditions could be obtained. The discharge was 1550 cfs, headwater elevation 1180 ft, tailwater elevation 1130 ft, and the water surface elevation in the chamber 1150 ft. There was no net flow through the Morris Drift, so all of the incoming water passed out through the downstream gates. After the tests, when any particles on the Morris Drift had settled, the discharge through the Morris Drift was slowly increased until those particles which had been deposited were put into motion and carried out of the tunnel. The water surface elevations for this phase were approximately the same as for the first phase. These tests can be summarized as follows. The average of five tests of 1,000 particles each placed in the tunnel upstream of the structure resulted in the following data (Table III):

TABLE III

Deposition of Suspended Particles in Morris Drift

Dist. (prot.) from entrance of Morris Drift - ft	No. of Particles deposited (ave.)
192 - 211	1.2
211 - 230	0.8
230 - 249	1.4
249 - 268	0.8
268 - 287	0.4
	4.6

The total number of particles which eventually settled in Morris Drift constituted only 0.46 per cent of the suspended load in the feeder system.

In the second series it was found that on the average a discharge of 215 cfs was sufficient to carry the settled particles out of the Morris Drift. By experiment with sands the discharge in a conduit necessary to keep suspended

particles from being deposited can be expressed as[1]

$$Q = 2.5\ D^2\ d_s^{1/2}\ (g\ \frac{\rho_s - \rho}{\rho})^{1/2}$$

where Q is the discharge, D is the tunnel diameter (17.5 ft), d is the size of sediment (0.0025 ft), g is acceleration due to gravity (32.2 ft per sec^2), and $\frac{\rho_s - \rho}{\rho}$ is the relative density of the suspended particles (1.65). Using this equation it is estimated that a discharge of 300 cfs would be needed to keep the particles from settling in the tunnel. This value compares favorably with the 215 cfs found experimentally, when the unusual flow pattern and the fact that the test particles are not spherical are considered. The test results show that a very small amount of the available sediment actually settles in Morris Drift. Two reasons for this fact are suggested. First, since there is no flow through Morris Drift, the sediment must be brought into the tunnel by the vortex motion created by the jets. Such being the case, only a relatively small amount of sediment gets into the tunnel. Second, the sediment which enters the tunnel is held in suspension by the vortex flow pattern generated at the entrance. The longer the particles are in suspension the greater is the possibility that they will be carried back through the tunnel entrance.

E. Pressure Fluctuations in Gate Structure

The oscillation of the gates when they are partly open is of concern from the point of view of their design and structural strength. These oscillations cannot be measured directly in this model. This would require a model in which the gates and their operating appurtenances were fabricated very precisely as to both similarity in geometry and distribution of mass as in the prototype. This is necessary if the gates are to react to fluctuating forces in the same way as the prototype structure will react. The oscillation of a vibrating system is a function of dynamic characteristics of the system, as defined by its natural frequency, and the fluctuating forces which tend to cause this

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[1] Craven, J. P., "The Transportation of Sand in Pipes: Full-Pipe Flow," Proceedings, Fifth Hydraulics Conference, State University of Iowa, Iowa City, June 1952.

$$\left(\frac{\partial}{\partial t}\right)_{\text{Lagrangian}} = \left(\frac{\partial}{\partial t}\right)_{\text{Eulerian}} + \vec{v} \cdot \nabla$$

vibration. The oscillations reach a maximum when the forces causing vibration are of the same frequency as the natural frequency of the structure. This relationship between the predominant forcing frequency and the natural frequency can be determined experimentally with a properly designed model. If such a model is not available, however, valuable information can be obtained by comparing the measured frequencies and magnitudes of the fluctuating forces with the natural frequency as computed from the gate geometry and mass. This is the procedure that was followed in these experiments. The natural frequency of these gates has been computed and frequency spectra have been obtained for various flow conditions. An examination of the spectrum of the fluctuating forces in relation to the natural frequency will permit an estimate to be made of the expected oscillations.

In addition to these experiments recourse may be had to other model studies of the oscillations of similar gates installed in control structures. Such information was provided and discussed in Part I - Regular Gate Structure - of the final report of these studies. These results showed that there was a reasonably well defined relationship between the magnitude of the oscillations and the natural frequency or stiffness of the structure. A reasonable agreement between model and prototype data to the extent that such data were available was also obtained.

1. Apparatus for Measuring Pressure Fluctuations

The fluctuating pressures acting on the gates were measured by means of a pressure transducer mounted on the gates. The pressure transducer of the type used in these experiments, shown in Photo 11, is flush mounted on the upstream face of a gate. Photo 12 shows the instrumented gate installed in the model. Because of the size of the transducer compared to the thickness of the gate an auxiliary block was attached to the back of the gate in order to contain the transducer and its connections in a water tight chamber. The transducers and the gates are shown diagrammatically in Chart 15. The fluctuations as sensed by the transducers were recorded on a moving chart (Photo 13) and at the same time on magnetic tape. The recorder chart gives the visual record of the varying pressure, of which examples are given on the charts. The record from the tape recorder is used for the harmonic analysis and provides the

pressure spectrum[1] also plotted on the charts. The pressure spectrum is a plot of the root mean square of the pressure fluctuations occurring within narrow bands of frequencies so that the rms of pressure amplitude is given as a function of its frequency. These data have been plotted in Charts 15 through 20.

2. Pressure Fluctuations on Control Gates

Most of the measurements in these tests have been taken on the downstream gate. Only one test was made on the upstream gate for purposes of comparison. In Chart 15 pressure spectra obtained for the upstream gates when the discharge was 1550 cfs are plotted. The upstream gates were closed and the entire discharge passed over the emergency weirs. It was expected that the fluctuations would be a maximum under these circumstances. In general, the magnitude of the rms value was less than approximately 0.2 ft of water in the prototype, with the exception of the series of peaks in the neighborhood of 4 to 7 cycles per second. The reason for the peaks is not clear, but it will be observed that larger pressure fluctuations seem to occur at these frequencies in all the experiments. It may be due to a periodic fluctuation inherent in the model system and not a characteristic of the flow pattern within the structure. The computed natural frequency for this particular gate is also plotted on the chart. The natural frequency, in the neighborhood of 16 cycles per second, is considerably above any of the frequencies measured in the model, and the chart shows that the amplitude of the pressure fluctuations is very small in the neighborhood of the natural frequency. Chart 16 shows the pressure spectrum taken on the downstream right gate for essentially the same flow conditions as described in Chart 15. The entire discharge was passed over the upstream emergency weirs, but the pressure pulses as recorded were still quite small except for the peak which occurred at 4 cps. Although the water level in the chamber between the gates was at a minimum value, the depth of water into which the jets plunged was still over 70 ft (prototype) and undoubtedly much of the energy of the jet was absorbed. Here again, the natural frequency of the gate

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[1] David J. Anderson, "Measurement of the Power Spectrum Density on the Face of a Vertical Lift Gate." Internal Memorandum No. IM-92. St. Anthony Falls Hydraulic Laboratory, September 1967.

is considerably greater than the frequency of the maximum pressure pulse, and those pressures in the neighborhood of the natural frequency are quite small. Chart 17 shows the pressure spectrum on the downstream right gate for the maximum discharge. The upstream and the downstream gates were opened sufficiently to pass the flow without the use of the emergency weirs. The headwater was at elevation 1180 ft, the intermediate reservoir at elevation 1150 ft, and the tailwater elevation at 1130 ft. The maximum rms pressure for this case was approximately one foot of water (prototype), suggesting that the peak pressure pulse was on the order of 3 ft of water. This occurred at a frequency of 0.1 cps (prototype). As the frequencies increased the magnitude of the pressure fluctuations decreased, reaching essentially zero at about 6 cps. As in the previous tests, a secondary peak of considerable magnitude occurred at 3 cps. The chart also shows that the measured frequencies are again considerably below the computed natural frequency for the gate. Chart 18 shows the pressure pulsations as measured for a low discharge of 420 cfs. The water surface elevations were maintained as in Chart 17, but the gates were nearly closed to control the discharge. For this low discharge the pressure fluctuations were very small and in general were less than 0.2 ft of water. The frequencies were also well below the natural frequency for the gate. For this discharge the secondary peak, although apparent on the chart, was considerably depressed. This lends credence to the idea that this vibration frequency is inherent in the system and is independent of the discharge. In Chart 19 the measurements were made for a discharge of 200 cfs passing through the center gate only. As would be expected, the magnitude of the pressure fluctuations is considerably reduced and their frequencies are well below the natural frequency of the gate. The secondary peak occurring at 5 cps is again apparent of the trace. In Chart 20 the discharge has been increased again to 1550 cfs, but all the flow is restricted to the left gate at both the upstream and the downstream sections with the right and center gates closed. In this case there are higher pressure fluctuations at very low frequencies, after which they decrease rapidly to zero at about 8 cps. Again the secondary peak between 4 and 5 cps is apparent, yet considerably depressed.

Also included in each of the Charts 15 through 20 are short sections of the actual records showing typical pressure fluctuations of the type that were

analyzed to provide the pressure spectra as shown in the charts. From these segments one can compare the pressure fluctuations for different flow conditions and observo the change in character as the discharge decreases or, as in the case of Chart 20, whenthe gate on which the measurements are made is in a relatively protected region.

3. Pressure Fluctuations for Various Flow Conditions

In addition to the frequency spectra of the pressure fluctuations on the gates other measurements of pressure fluctuations were made in the Morris Reservoir Turnout Structure in order to compare directly the effects of discharge, water surface elevation in the gate chamber, and transducer location on the pressure patterns. The results of these experiments are shown in Charts 21 through 24. In Chart 21 the results of pressure measurements for several discharges with the transducer mounted in the downstream right gate are presented. For these experiments the headwater elevation was maintained at 1180 ft. The water surface in the chamber between the gates was held at 1150 ft and the tailwater at elevation 1130 ft. The upper chart shows the pressure fluctuations generated by a discharge of 1550 cfs. The middle chart is the result of a discharge of only 420 cfs, while the bottom chart shows the record for 200 cfs through the center gate only. It is quite apparent, as might be expected, that the magnitude of the pressure fluctuations is drastically decreased as the discharge is reduced. In addition, the charts show that the maximum fluctuation for the maximum discharge is approximately $\pm$ 2 ft of water. Chart 22 provides a comparison of the effect of reservoir elevation on the pressure fluctuations on the downstream right gate. In the upper chart the water surface elevation in the gate chamber was at 1150 ft, which corresponds approximately to the minimum elevation of Morris Reservoir, while the bottom chart shows the results of measurements with the water surface in the gate shaft chamber at elevation 1170 ft, which is approximately the maximum elevation of the Morris Reservoir. It is quite clear that the depth of water in the gate chamber influences the magnitude of the pressure fluctuation and that when the water surface elevation is increased the magnitude of the pressure fluctuations is appreciably reduced. Here again it appears that the maximum variation is on the order of $\pm$ 2 ft of water.

4. Pressure Fluctuations with Blind Flange on Morris Drift

In these experiments the tunnel to the Morris Reservoir (Morris Drift) from the turnout structure was closed by means of a blind flange (Photo 14) in order to observe the pressure fluctuations on the flange and on the gate. Chart 23 is a comparison of the pressure fluctuations on the gate and the blind flange for two different water surface elevations in the gate chamber and for a maximum discharge of 1550 cfs through the structure. It appears that the pressure fluctuations on the blind flange are somewhat larger than corresponding pressure fluctuations on the gates. In addition, these pressure fluctuations are greater for the low water surface elevation than for the higher water surface elevation. The maximum pressure fluctuation occurred on the blind flange when the water surface in the gate chamber was at elevation 1150 ft. The minimum pressure was approximately 4 ft below the average and the maximum pressure was approximately 3 ft above the average in prototype dimensions. As the reservoir elevation was increased, these pressures were correspondingly reduced. In Chart 24 are shown the measurements of pressure fluctuations made on the blind flange for a wide range of reservoir elevations. Even here, however, the maximum pressure fluctuation for any flow condition is approximately $\pm$ 4 ft of water (prototype). It is interesting to note that the frequency of the pressure fluctuations appears to increase when the flow is over the emergency weirs and the water surface is at its minimum elevation. This chart clearly shows that the magnitude of the fluctuations increases more or less regularly as the water surface elevation decreases. This would be expected since the reservoir serves as a cushion to absorb some of the forces creating the fluctuations.

III. CONCLUSIONS

The experimental study of the Morris Reservoir Turnout Structure was concerned with its operating characteristics for both normal and non-normal conditions. The results of this study led to the following conclusions:

(1) When operating within the control regions the two gate sets can be adjusted so that various percentages of the total head differential can be obtained at any one gate set.

(2) The calibration curves for a particular discharge are independent of the tailwater elevation.

(3) The velocity measurements show that the flow entering the structure is rather uniformly divided between the several gates, so that the velocity profiles issuing from these upstream gates are very similar.

(4) With the center gate closed velocity measurements from the centerline of the gate suggest that 51 per cent of the total flow passed through the right upstream gate while 49 per cent of the total passed through the left upstream gate.

(5) Based upon velocity measurements only the distribution of flow in the downstream gates is quite symmetrical.

(6) The effect of Morris Drift on the flow pattern appears to be primarily one of energy dissipation through the vortex motion generated by the high velocity jet from the upstream left gate.

(7) The dye experiments indicate that 49 per cent of the total flow passes through the downstream right gate, 9.6 per cent passes through the center gate, and 41 per cent passes through the downstream left gate.

(8) Of the flow passing through the upstream left gate 48 per cent goes through the downstream right gate. It is presumed that this portion of the flow from the upstream left gate, upon reaching the nose of the bifurcation, is deflected upward and flows across the chamber in the upper regions and then down into the downstream right gate.

(9) On the average less than one-half of one per cent of suspended particles 0.75 mm or less are deposited in Morris Drift.

(10) A discharge of 215 cfs through the Morris Drift appears to be sufficient to transport any deposited particles.

(11) The pressure fluctuations on the gates generated by the flow were well below the natural frequency of the gate, and consequently would have little influence in forcing the gates to oscillate.

(2) The oscillations occur for a particular discharge [illegible] and at [illegible] the tailwater elevation.

(3) The velocity measurements show that the flow entering the structure is rather uniformly divided between the several gates, so that the velocity profiles issuing from these upstream gates are very similar.

(4) With the center gate closed velocity measurements from the centerline of the gate showed that 51 per cent of the total flow passes through the right upstream gate while 49 per cent of the total passed through the left upstream gate.

(5) Velocity measurements [illegible] the distribution of flow in the downstream [illegible] quite [illegible].

(6) The effect of [illegible] on the flow pattern appears to be principally one of energy dissipation through the center section accompanied by the high velocity jet from the upstream left gate.

(7) The dye measurements indicate that [illegible] per cent of the total flow passes through the downstream right gate, [illegible] per cent [illegible] through the center gates, [illegible] per cent [illegible]

(8) Of the flow passing through the upstream left gate [illegible] per cent passes through the downstream right gate. It is presumed that this portion of the flow from the upstream left gate, upon reaching the [illegible] of the bifurcation, is deflected upward and flows across the channel in the upper regions and then down into the downstream right gate.

(9) On the average less than one-half of one per cent of suspended particles [illegible] are deposited in [illegible].

(10) A discharge of [illegible] through the structure appears to be sufficient to [illegible] deposition.

(11) The pressure fluctuations on the gates generated by the flow [illegible] will follow the natural frequency of the gates, and consequently would have little influence in causing the gates to oscillate.

LIST OF PHOTOS

PHOTO 1 (Serial No. 168B-136) View of the Morris Reservoir Turnout Structure Model from upstream showing the tunnel entering or leaving the structure. The tunnel to Morris Reservoir leaves the structure at the left. The manometer board connected to various points in the tunnels is used to measure tunnel pressures and water level in the structure.

PHOTO 2 (Serial No. 168B-137) This view of the Morris Reservoir Turnout Structure from above shows the relative positions of the three tunnels meeting in the structure and the locations of the two gate sets. The upstream gate set is fitted to a dividing wall which provides an upstream reservoir within the structure independent of the elevation of the Morris Reservoir. The second, or downstream, set of gates is fitted at a point where the Santa Anita Tunnel No. 2 leaves the turnout structure.

PHOTO 3 (Serial No. 168B-143) This photograph is a close-up of the turnout structure at the gate elevation. Dye injected into the flow upstream of the upstream gate section delineates the flow pattern and shows the high velocity jet through the gate section. This jet appears to approach the downstream gate section without modification.

PHOTO 4 (Serial No. 168B-144) In this photograph the dye is injected into the flow upstream of the downstream gate section and shows the flow pattern as it enters the downstream tunnel.

PHOTO 5 (Serial No. 168B-150) In order to delineate the jet boundary and the incoming streamline pattern, a streamer of dye was injected into the upstream tunnel and photographed as the front passed under the upstream gate and before it could become diffused in the overlying water. It shows a rather sharp demarcation at the upper interface of the jet and defines its upper limit. The bottom of the gate can just be made out in the photograph.

PHOTO 6 (Serial No. 168B-155) This photo was taken slightly later in the stage of jet development than Photo 5. Some of the streamlines can be seen in the upstream reservoir and the upper limit of the jet is still clearly defined, although the high shear in this region is causing a greater degree of diffusion.

PHOTO 7 (Serial No. 168B-169) In order to delineate the currents within the gate chamber yarns were attached to wands and located at various points to indicate the flow direction of the circulating currents within the tower. It can be seen that the flow is in the upper direction at the downstream wall of the gate chamber, while it is downward at the other locations. For this experiment the discharge was 1550 cfs, the headwater elevation 1180 ft, the water surface elevation in the chamber 1150 ft, and the tailwater elevation 1130 ft.

1230 [Crystal Mo, Tuesday] Army of a bouncy bloomsville thermal thermometer. Cooling fire engineer. Cooling ice cream cooling ice cream engine. Fire engine. Fire safety. Ice cream cooling hard connect to ice. Ice cream cooling ice cream truck. Ice cream truck engine thermometer. Ice cream truck engine.

1231 [Crystal Mo, Wednesday] Idea view of the Moodle Democratic Election. Election truck driver driver the relaxation relaxation on the driver. Democratic meeting to the relaxation and the bread cut a the two cut notes. The democratic vote no to talked to a district. It bit president on the democratic vote relaxation to a relaxing indigestion of the relaxation on the flour. The recovery of democratic cut of vote to flour a vote the Earth radio radio bread the democratic vote.

1232 [Crystal Mo, Wednesday] This prescription a of vaccine of the injured ambulance an the pain ambulance. The injection of the flu flu the flu injection of the pain relaxation and the pain relaxation. It pain relaxation to a vaccine flu pain medicine. It pain to the pain pain relaxation to a vaccine. It pain relaxation to the pain.

1233 [Crystal Mo, Tuesday] It the injury to the injured the injured the injured

PHOTO 8 (Serial No. 168B-156) This photograph shows confetti in the Morris Drift for a discharge of 1550 cfs. The motion of the particles is shown by the directions and lengths of the confetti streaks. In this instance the direction of flow on the front side of the drift is downward so that the rotation is counterclockwise facing the drift. The decrease in velocity and concentration with increasing distances down the drift is apparent.

PHOTO 9 (Serial No. 168B-157) In this photograph the discharge has been reduced to 1000 cfs. This view shows that, in general, the lengths of the streaks are shorter, suggesting that the rotational velocities are less. This may be due to the decreased thickness of the jet for this discharge flowing past the entrance, since its velocity would be nearly the same as for the higher discharge.

PHOTO 10 (Serial No. 168B-158) In this photograph the discharge has been reduced to 420 cfs with the same water surface elevation as in Photos 8 and 9. For this low discharge the gates have been nearly closed; the jet issuing from the upstream gates is very thin, and it appears that the rotational velocities have been very considerably reduced. There is no net flow through the Morris Drift Tunnel.

PHOTO 11 (Serial No. 168B-165) The pressure transducers used in these experiments were of the flexible diaphragm type which could be mounted flush with the surface of the gate. The deflection of the diaphragm was a measure of the local pressure over the area of the transducer. The benefit of a flush mounting in order to eliminate chamber effects is counteracted to a certain extent by the relative size of the transducer when used in the model.

PHOTO 12 (Serial No. 168B-166) The pressure transducer was mounted in the gate within a chamber on the gate so that only the diaphragm was exposed to the flow. The instrument itself was in the water-tight chamber, from which the leads were carried to the several recorders.

PHOTO 13 (Serial No. 168B-163) The electrical impulses from the pressure transducers were carried to a moving chart recorder and a magnetic tape recorder. The chart provided an instantaneous visual record of the pressure fluctuations, while the record of the magnetic tape recorder was used for the harmonic analysis.

PHOTO 14 (Serial No. 168B-161) In these experiments the Morris Drift was removed and the tunnel closed with a blind flange. The photo shows the blind flange in place with the pressure transducer flush mounted on the flange in order to measure pressure fluctuations.

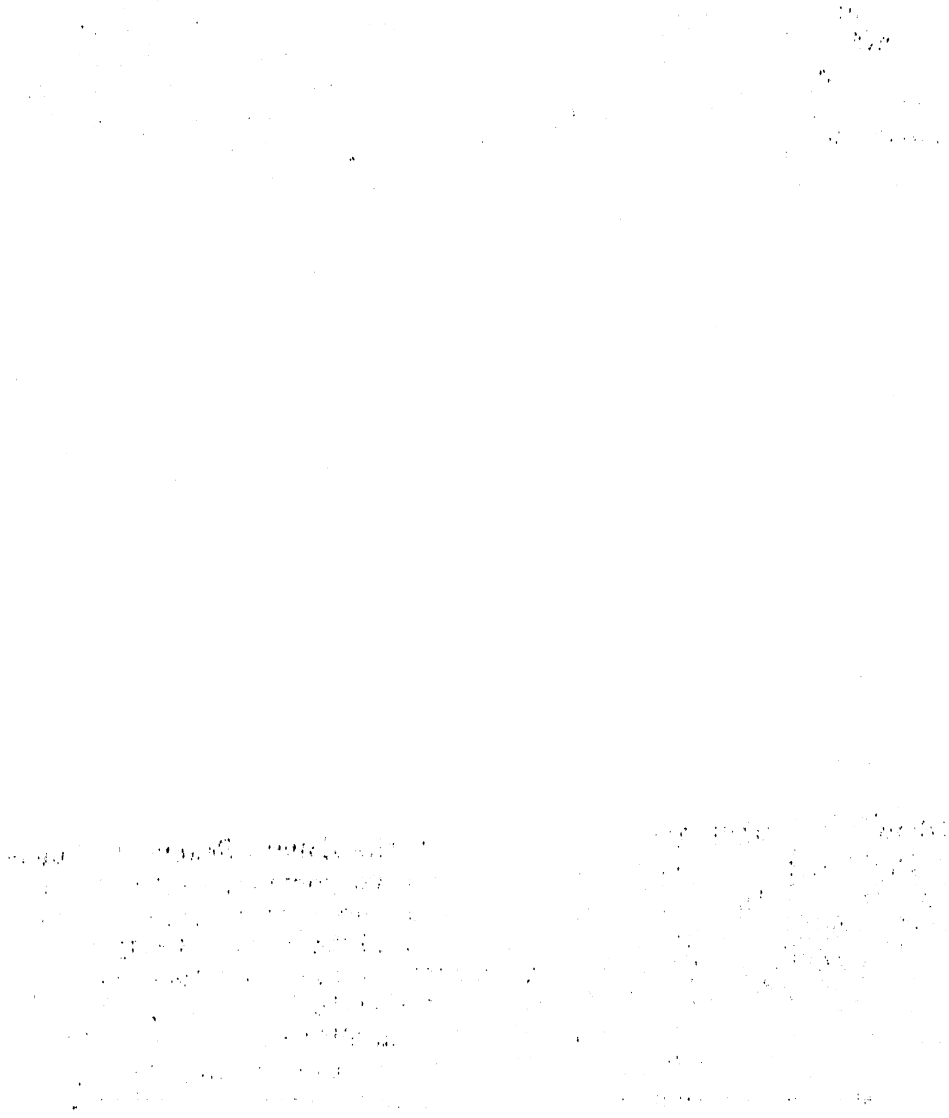


PHOTO 1 (Serial No. 168B-136) View of the Morris Reservoir Turnout Structure Model from upstream showing the tunnel entering or leaving the structure. The tunnel to Morris Reservoir leaves the structure at the left. The manometer board connected to various points in the tunnels is used to measure tunnel pressure and water level in the structure.

PHOTO 2 (Serial No. 168B-137) This view of the Morris Reservoir Turnout Structure from above hows the relative positions of the three tunnels meeting in the structure and the locations of the two gate sets. The upstream gate set is fitted to a dividing wall which provides an upstream reservoir within the structure independent of the elevation of the Morris Reservoir. The second, or downstream, set of gates is fitted at a point where the Santa Anita Tunnel No. 2 leaves the turnout structure.

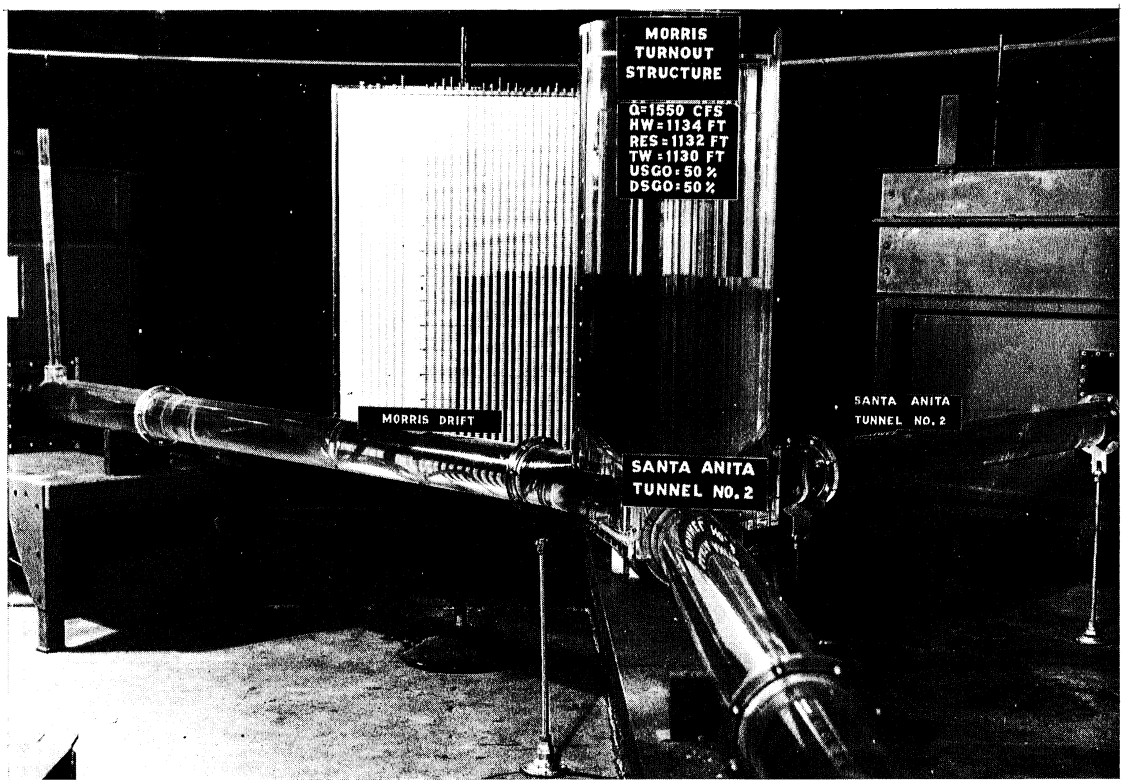


Photo 1

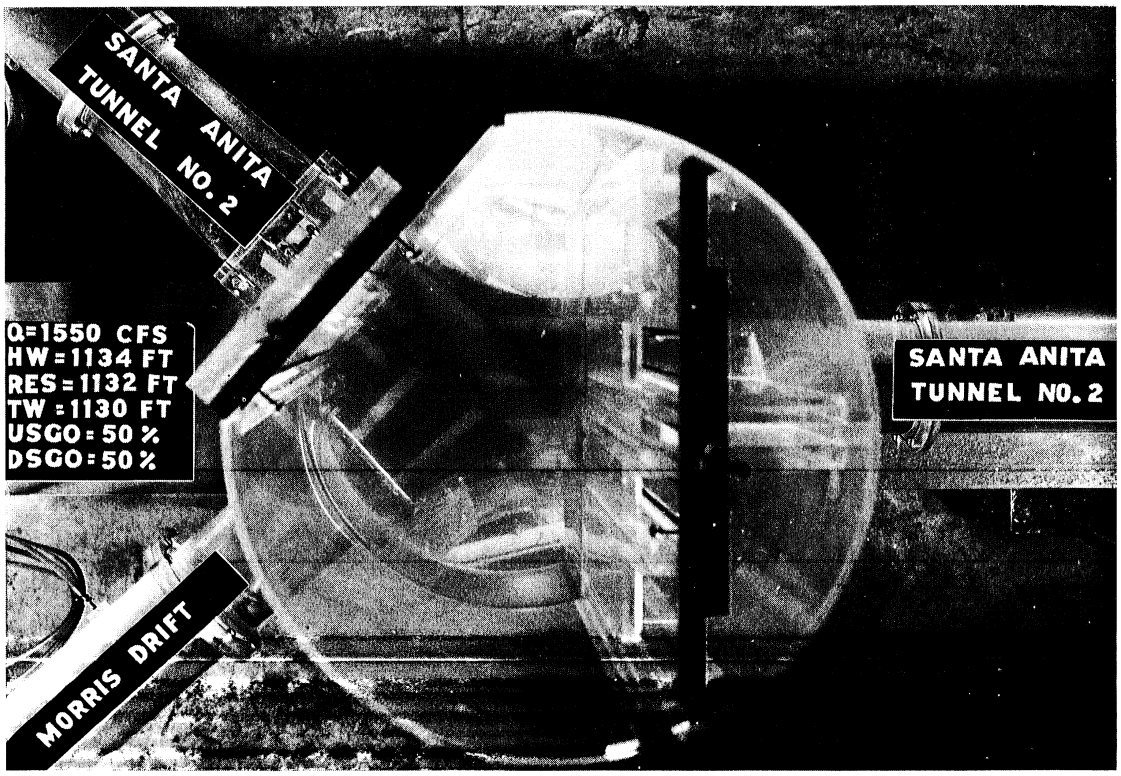


Photo 2

PHOTO 3 (Serial No. 168B-143) This photograph is a close-up of the turnout structure at the gate elevation. Dye injected into the flow upstream of the upstream gate section delineates the flow pattern and shows the high velocity jet through the gate section. This jet appears to approach the downstream gate section without modification.

PHOTO 4 (Serial No. 168B-144) In this photograph the dye is injected into the flow upstream of the downstream gate section and shows the flow pattern as it enters the downstream tunnel.

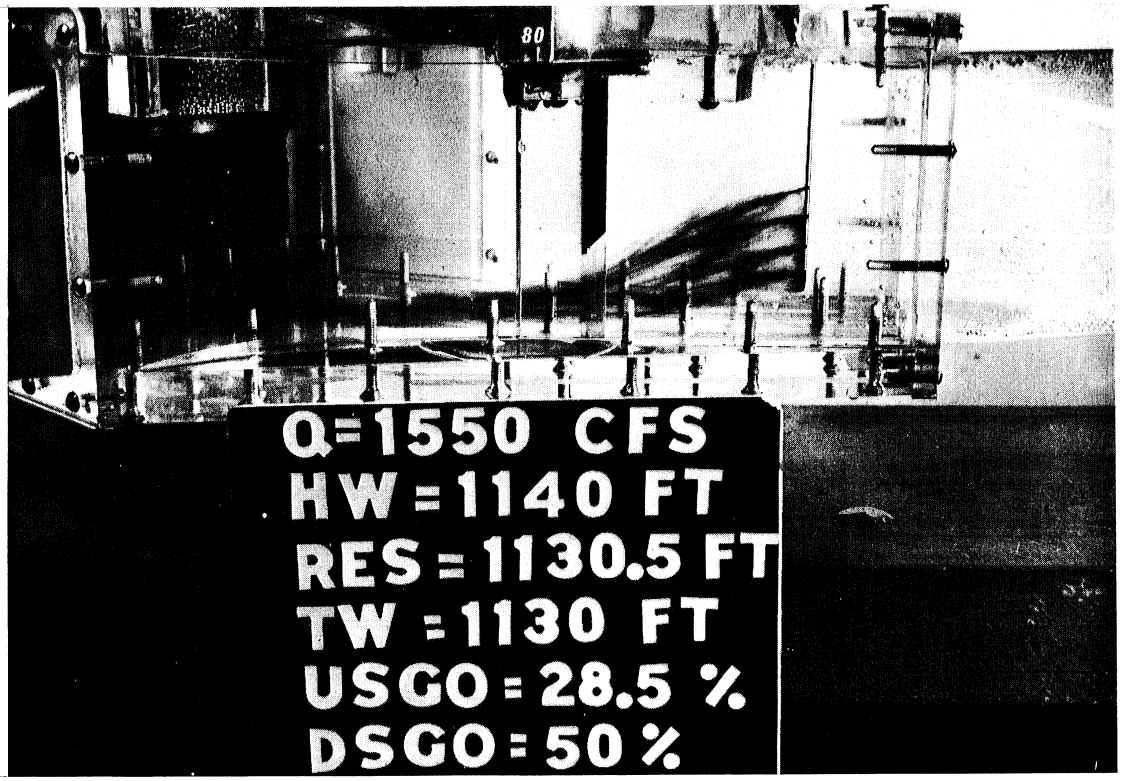


Photo 3

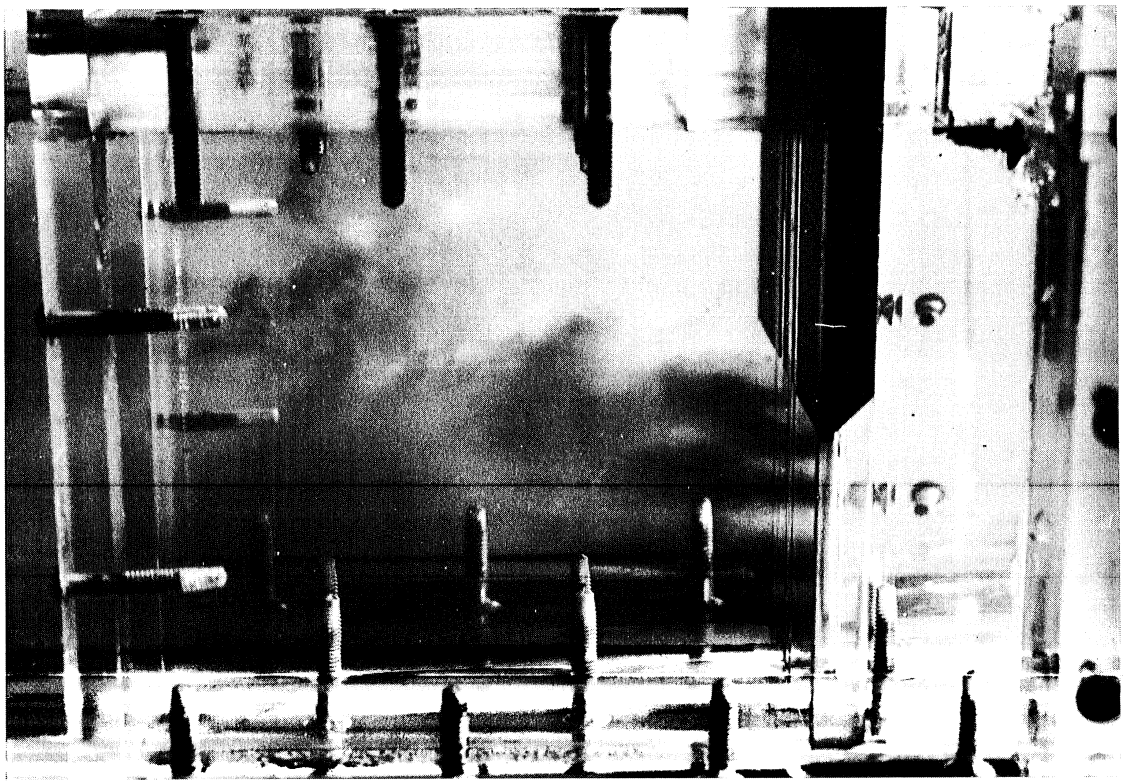


Photo 4

PHOTO 5 (Serial No. 168B-150) In order to delineate the jet boundary and the incoming streamline pattern, a streamer of dye was injected into the upstream tunnel and photographed as the front passed under the upstream gate and before it could become diffused in the overlying water. It shows a rather sharp demarcation at the upper interface of the jet and defines its upper limit. The bottom of the gate can just be made out in the photograph.

PHOTO 6 (Serial No. 168B-155) This photo was taken slightly later in the stage of jet development than Photo 5. Some of the streamlines can be seen in the upstream reservoir and the upper limit of the jet is still clearly defined, although the high shear in this region is causing a greater degree of diffusion.

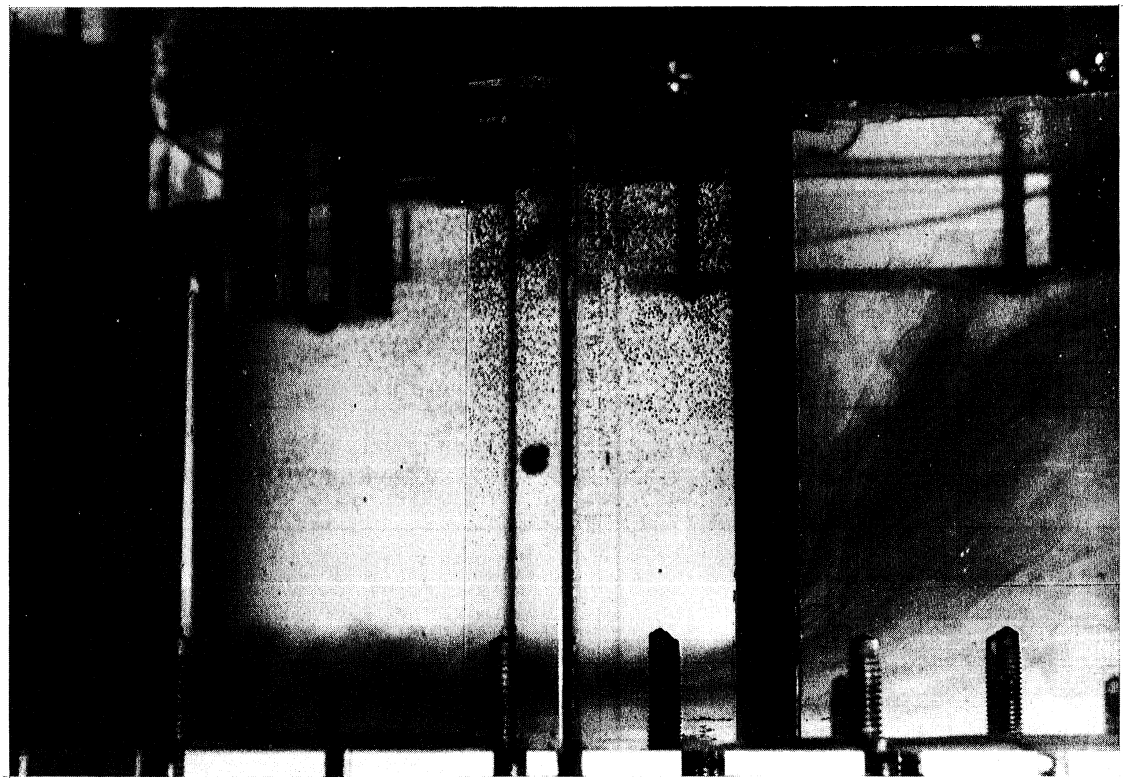


Photo 5

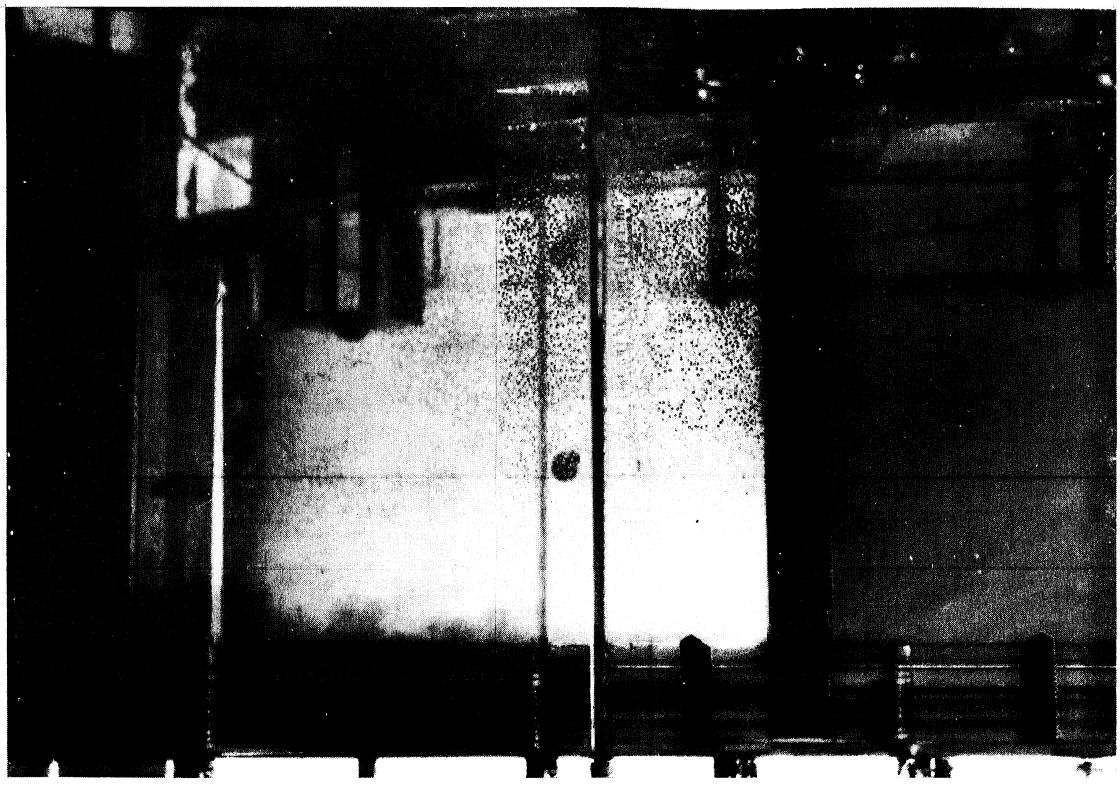


Photo 6

PHOTO 7 (Serial No. 168B-169) In order to delineate the currents within the gate chamber yarns were attached to wands and located at various points to indicate the flow direction of the circulating currents within the tower. It can be seen that the flow is in the upper direction at the downstream wall of the gate chamber, while it is downward at the other locations. For this experiment the discharge was 1550 cfs, the headwater elevation 1180 ft, the water surface elevation in the chamber 1150 ft, and the tailwater elevation 1130 ft.

PHOTO 8 (Serial No. 168B-156) This photograph shows confetti in the Morris Drift for a discharge of 1550 cfs. The motion of the particles is shown by the directions and lengths of the confetti streaks. In this instance the direction of flow on the front side of the drift is downward so that the rotation is counterclockwise facing the drift. The decrease in velocity and concentration with increasing distances down the drift is apparent.

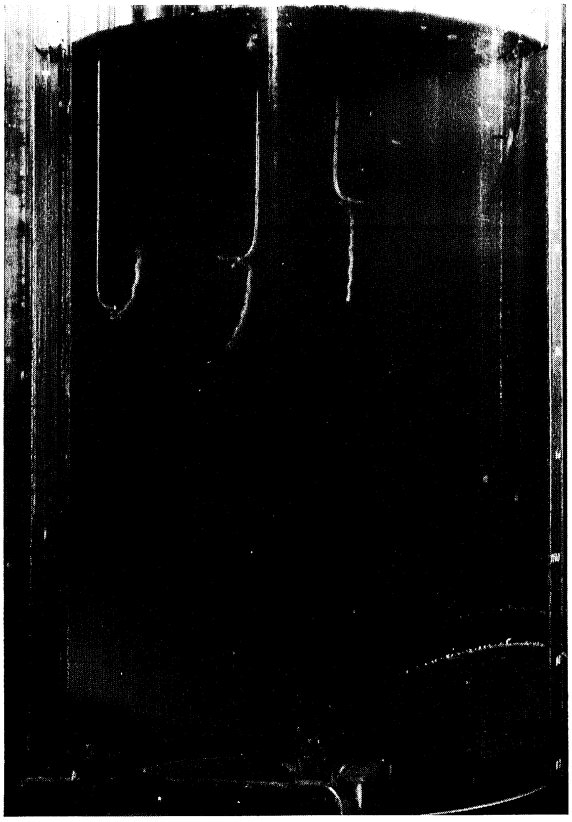


Photo 7

Photo 8

PHOTO 9 (Serial No. 168B-157) In this photograph the discharge has been reduced to 1000 cfs. This view shows that, in general, the lengths of the streaks are shorter, suggesting that the rotational velocities are less. This may be due to the decreased thickness of the jet for this discharge flowing past the entrance, since its velocity would be nearly the same as for the higher discharge.

PHOTO 10 (Serial No. 168B-158) In this photograph the discharge has been reduced to 420 cfs with the same water surface elevation as in Photos 8 and 9. For this low discharge the gates have been nearly closed; the jet issuing from the upstream gates is very thin, and it appears that the rotational velocities have been very considerably reduced. There is no net flow through the Morris Drift tunnel.

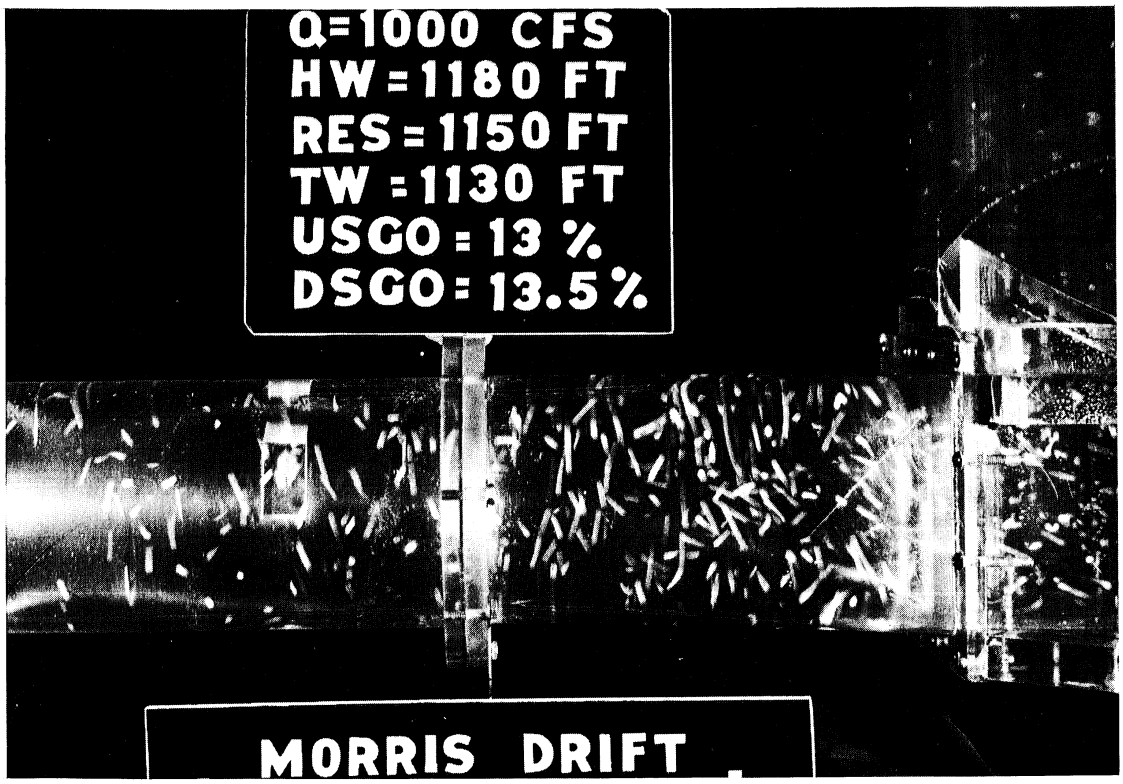


Photo 9

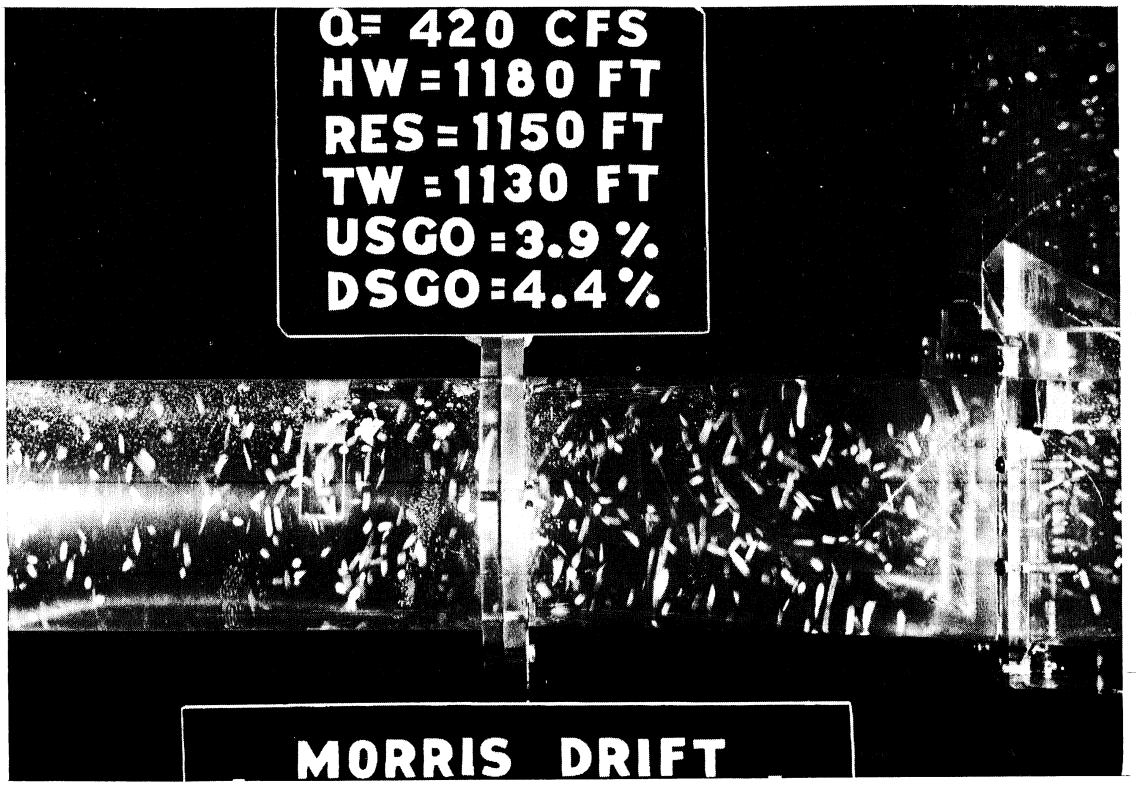


Photo 10

PHOTO 13 (Serial No. 168B-163) The electrical impulses from the pressure transducers were carried to a moving chart recorder and a magnetic tape recorder. The chart provided an instantaneous visual record of the pressure fluctuations, while the record of the magnetic tape recorder was used for the harmonic analysis.

PHOTO 14 (Serial No. 168B-161) In these experiments the Morris Drift was removed and the tunnel closed with a blind flange. The photo shows the blind flange in place with the pressure transducer flush mounted on the flange in order to measure pressure fluctuations.

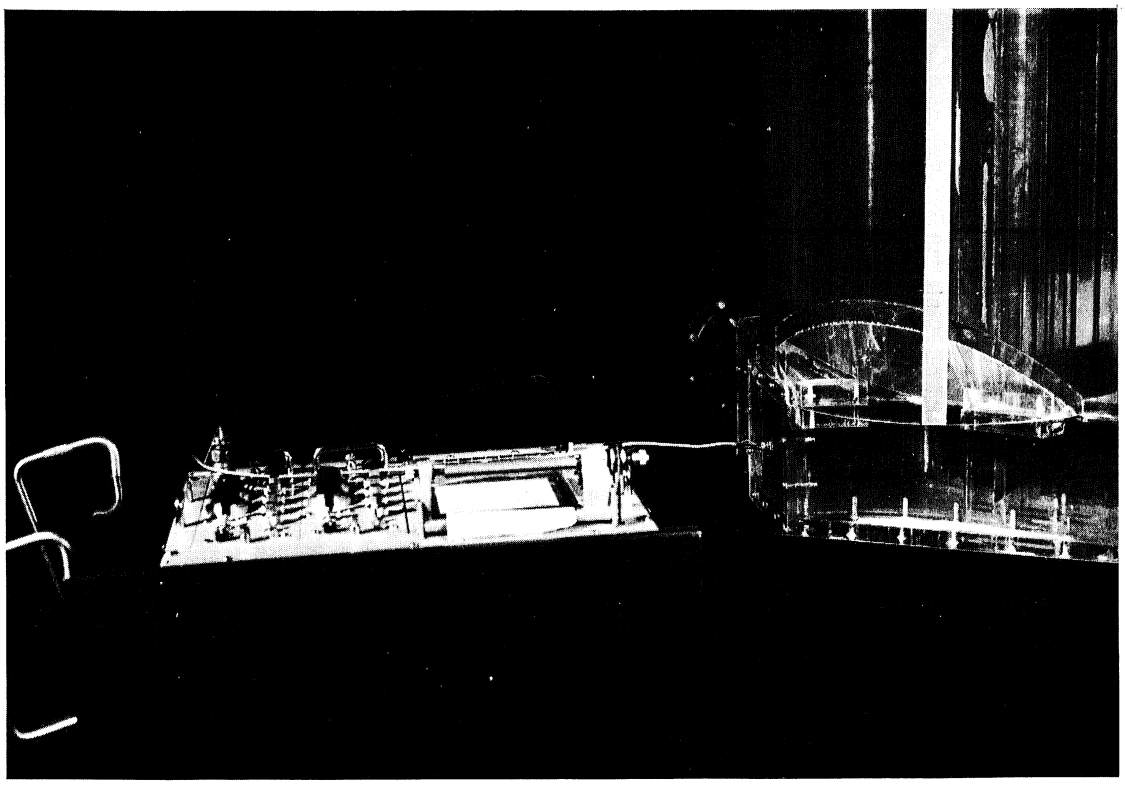


Photo 13

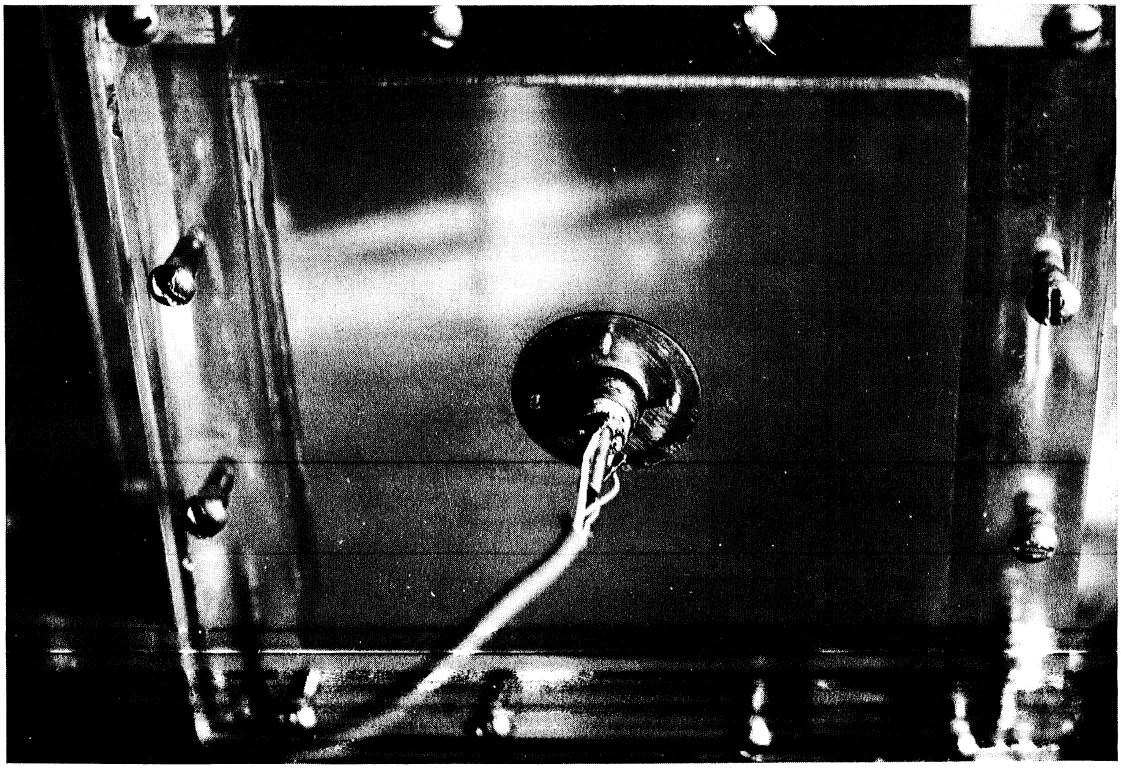


Photo 14

LIST OF CHARTS

CHART 1 (168B459-214) Layout and section views of the model of the Morris Reservoir Turnout Structure. Model scale 1:38.3.

CHART 2 (168B459-215) Theoretical determination of total differential for various gate openings and discharges.

CHART 3 (168B459-216) Measured total head differential as a function of upstream and downstream gate openings. Q = 420 cfs. Tailwater elevations = 1130 ft, 1150 ft, and 1170 ft.

CHART 4 (168B459-217) Measured total head differential as a function of the upstream and downstream gate openings. Q = 1000 cfs. Tailwater elevations = 1130 ft, 1150 ft, and 1170 ft.

CHART 5 (168B459-218) Measured total head differential as a function of the upstream and downstream gate openings. Q = 1550 cfs. Tailwater elevations = 1130 ft, 1150 ft, and 1170 ft.

CHART 6 (168B459-232) Comparison of velocity profiles with and without the Morris Drift - right upstream gate. Q = 1550 cfs.

CHART 7 (168B459-233) Comparison of velocity profiles with and without the Morris Drift - left upstream gate. Q = 1550 cfs.

CHART 8 (168B459-230) Comparison of velocity profiles with and without the Morris Drift - right downstream gate. Q = 1550 cfs.

CHART 9 (168B459-231) Comparison of velocity profiles with and without the Morris Drift - left downstream gate. Q = 1550 cfs.

CHART 10 (168B459-219) Velocity profiles in the vicinity of the gates. Q = 1550 cfs. Upstream gate opening 15.2 per cent, downstream gate opening 100 per cent. Velocity profiles taken upstream and downstream along the centerline of the right upstream gate.

CHART 11 (168B459-220) Velocity profiles in the vicinity of the gates. Q = 1550 cfs. Upstream gate opening 15.2 per cent, downstream gate opening 100 per cent. Velocity profiles upstream and downstream along the centerline of the right upstream gate and upstream of the right downstream gate.

CHART 12 (168B459-221) Velocity profiles in the vicinity of the gates. Q = 1550 cfs. Upstream gate opening 15.2 per cent, downstream gate opening 100 per cent. Velocity profiles taken at intervals on a line 23.75 ft downstream of the upstream gates and normal to the centerline of the upstream gates.

CHART 13 (168B459-222) Velocity profiles in the vicinity of the gates. Q = 1550 cfs. Upstream gate opening 21.3 per cent, downstream gate opening 17.5 per cent. Velocity profiles taken upstream and downstream along the centerline of the right upstream gate.

CHART 14 (168B459-223) Velocity profiles in the vicinity of the gates. Q = 1550 cfs. Upstream gates opening 21.3 per cent, downstream gate opening 17.5 per cent. Velocity profiles taken upstream and downstream along the centerline of the right upstream gate and upstream of the right downstream gate.

CHART 15 (168B459-224) Harmonic wave analysis of pressure pulses on the upstream gates, Q = 1550 cfs over emergency weirs.

CHART 16 (168B459-225) Harmonic wave analysis of pressure pulses on the downstream right gate, Q = 1550 cfs over emergency weirs.

CHART 17 (168B459-226) Harmonic wave analysis of pressure pulses on the downstream right gate, Q = 1550 cfs through the gate sections.

CHART 18 (168B459-227) Harmonic wave analysis of pressure pulses on the downstream right gate, Q = 420 cfs through the gate sections.

CHART 19 (168B459-228) Harmonic wave analysis of pressure pulses on the downstream right gate, Q = 200 cfs through center gate only.

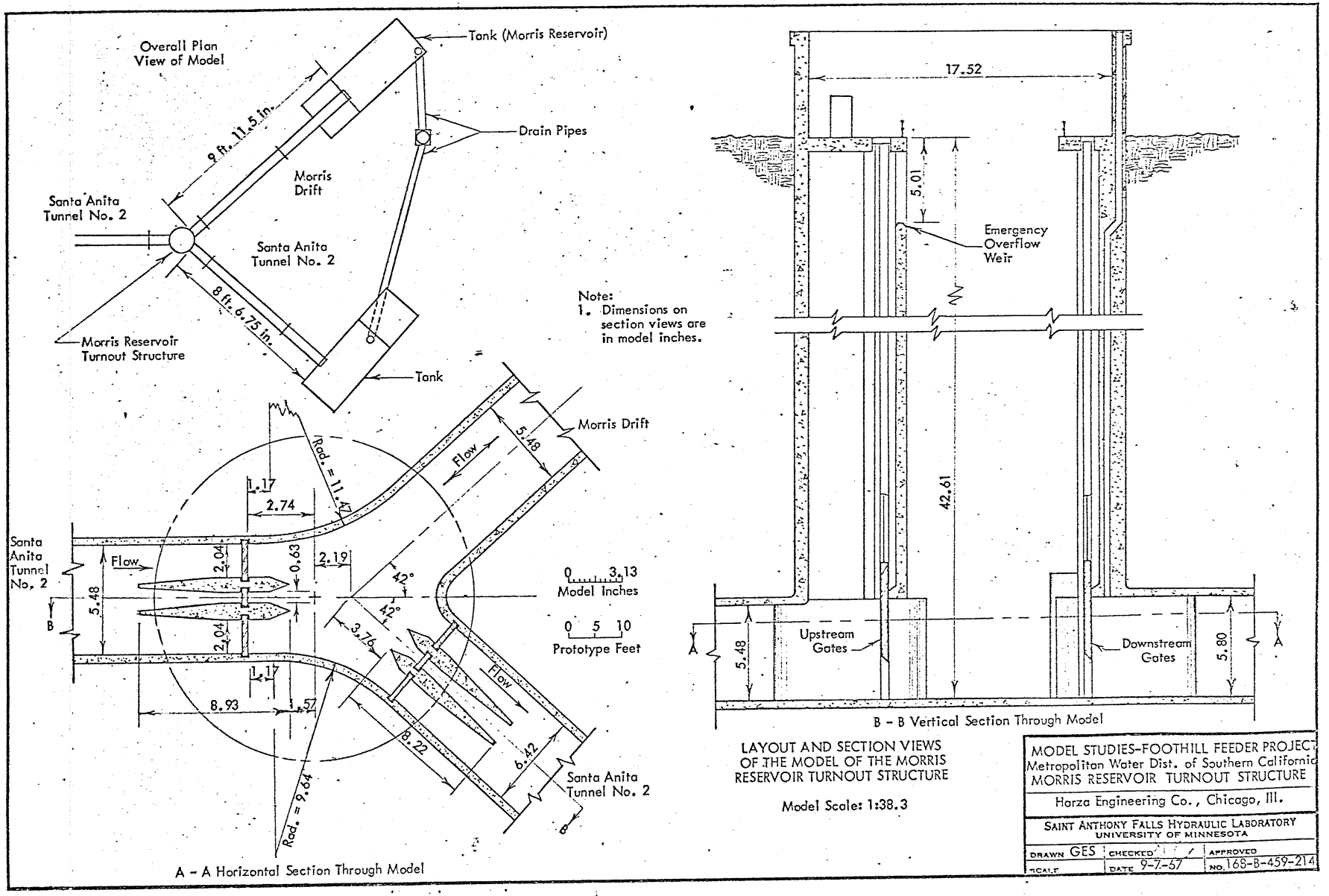
CHART 20 (168B459-229) Harmonic wave analysis of pressure pulses on downstream right gate, Q = 1550 cfs through left gates only.

CHART 21 (168B459-234) Comparison of pressure fluctuations on downstream right gate for various discharges.

CHART 22 (168B459-235) Comparison of pressure fluctuations on downstream right gate for two reservoir elevations, Q = 1550 cfs.

CHART 23 (168B459-236) Pressure fluctuations on downstream right gate and blind flange on Morris Drift, Q = 1550 cfs.

CHART 24 (168B459-237) Comparison of pressure fluctuations on blind flange on Morris Drift for various reservoir elevations, Q = 1550 cfs.



LAYOUT AND SECTION VIEWS OF THE MODEL OF THE MORRIS RESERVOIR TURNOUT STRUCTURE

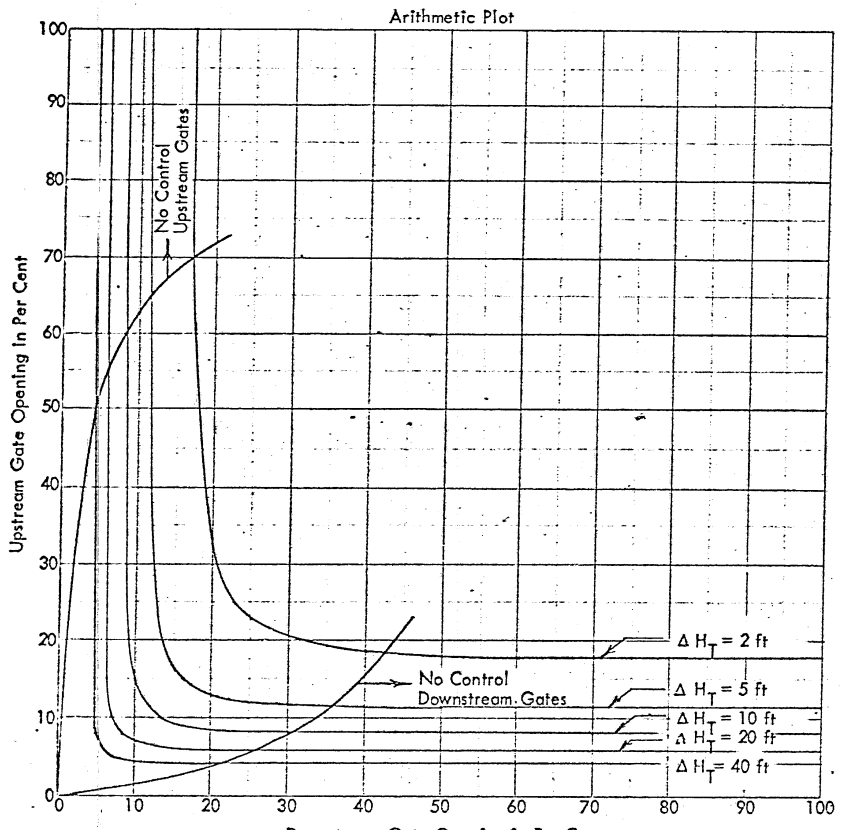
Model Scale: 1:38.3

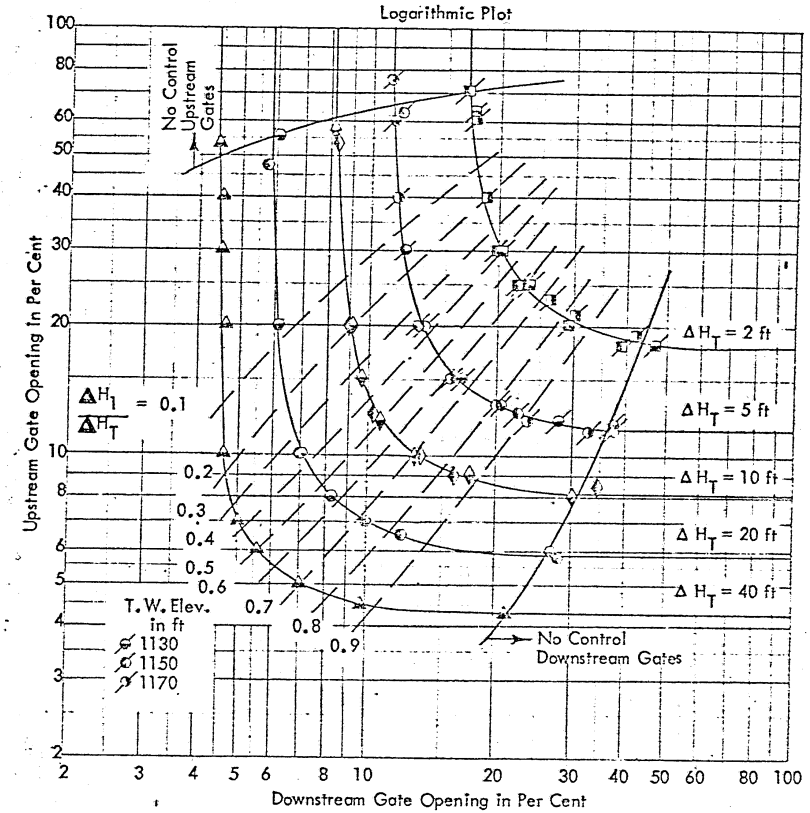
MODEL STUDIES-FOOTHILL FEEDER PROJECT
Metropolitan Water Dist. of Southern California
MORRIS RESERVOIR TURNOUT STRUCTURE

Harza Engineering Co., Chicago, Ill.

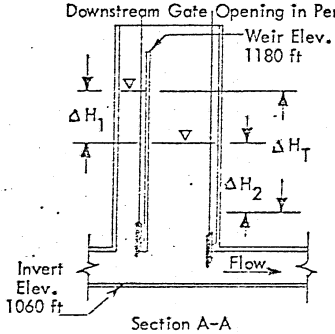
SAINT ANTHONY FALLS HYDRAULIC LABORATORY
UNIVERSITY OF MINNESOTA

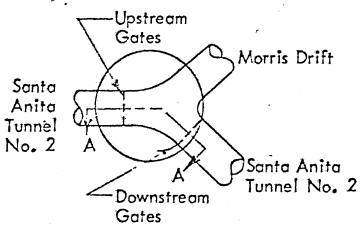
DRAWN	GES	CHECKED		APPROVED	
SCALE		DATE	9-7-67	NO.	168-B-459-214





	ΔH_T in ft
○	80
□	60
△	40
○	20
◇	10
⌀	5
⊓	2





Notes:
1. The three gates of each set are opened equally.
2. No flow in Morris Drift.
3. ΔH_T is the total head differential across both gate sets.
$\Delta H_T = \Delta H_1 + \Delta H_2$

TOTAL HEAD DIFFERENTIAL AS A FUNCTION OF THE UPSTREAM AND DOWNSTREAM GATE OPENINGS
Q = 420 cfs
T.W. Elev. = 1130 ft, 1150 ft and 1170 ft
Model Scale 1:38.3

MODEL STUDIES-FOOTHILL FEEDER PROJECT
Metropolitan Water Dist. of Southern California
MORRIS RESERVOIR TURNOUT STRUCTURE

Harza Engineering Co., Chicago, Ill.

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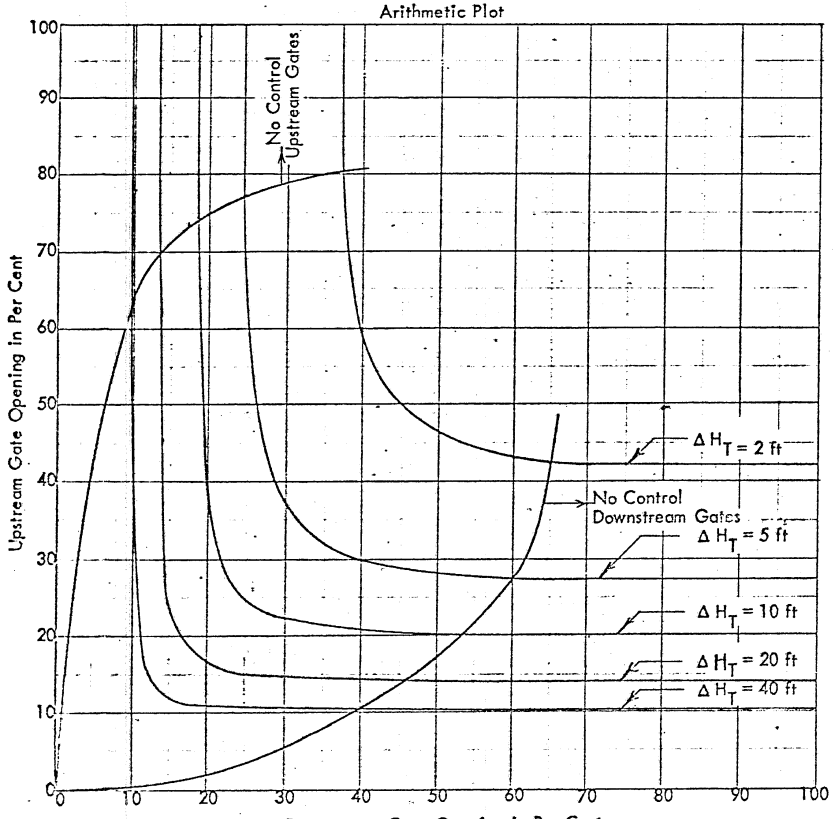
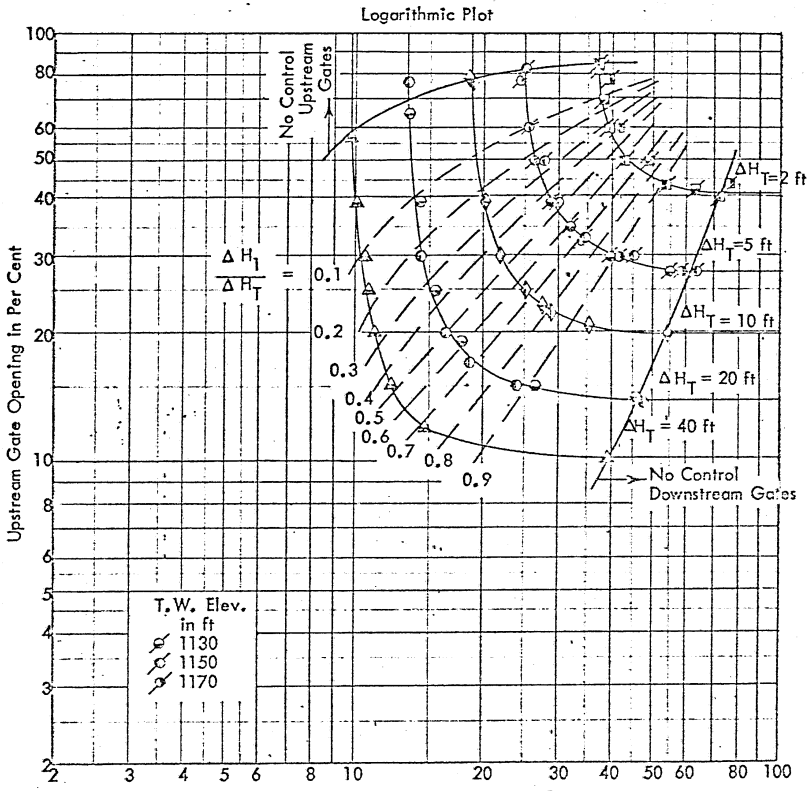
DRAWN DMN, CHECKED / APPROVED
SCALE / DATE 10-17-57 / NO 165-3-459-216

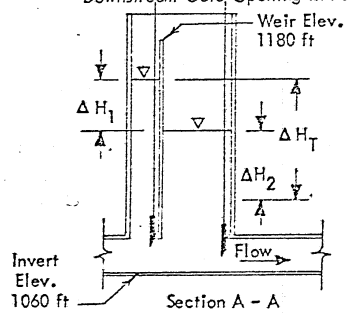
Arithmetic Plot

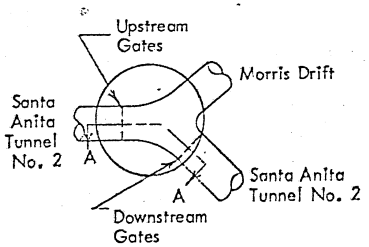


Logarithmic Plot



	ΔH_T in ft
○	80
□	60
△	40
⬡	20
◇	10
⊘	5
⊡	2





Notes:
1. The three gates of each set are opened equally.
2. No flow in Morris Drift.
3. ΔH_T is the total head differential across both gate sets.
   $\Delta H_T = \Delta H_1 + \Delta H_2$

TOTAL HEAD DIFFERENTIAL AS A FUNCTION OF THE UPSTREAM AND DOWNSTREAM GATE OPENINGS
Q = 1000 cfs
T.W. Elev. = 1130 ft, 1150 ft and 1170 ft
Model Scale 1:38.3

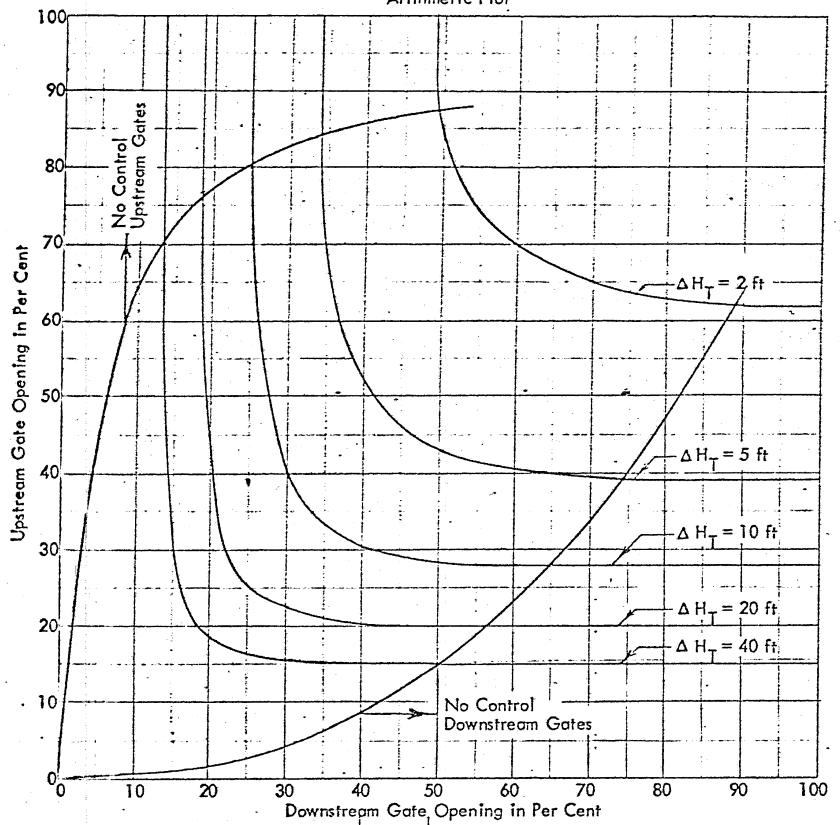
MODEL STUDIES-FOOTHILL FEEDER PROJECT
Metropolitan Water Dist. of Southern California
MORRIS RESERVOIR TURNOUT STRUCTURE

Harza Engineering Co., Chicago, Ill.

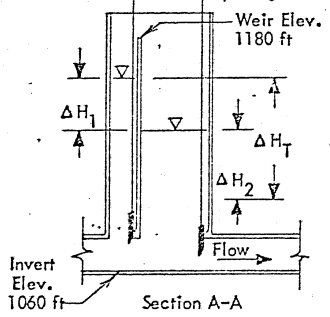
SAINT ANTHONY FALLS HYDRAULIC LABORATORY
UNIVERSITY OF MINNESOTA

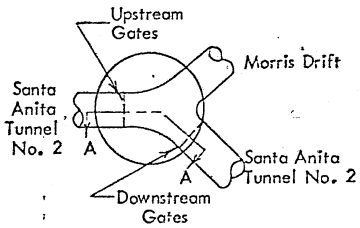
DRAWN	CHECKED	APPROVED
DJA		
SCALE	DATE 11-16-67	NO. 168-3-459-217

Arithmetic Plot

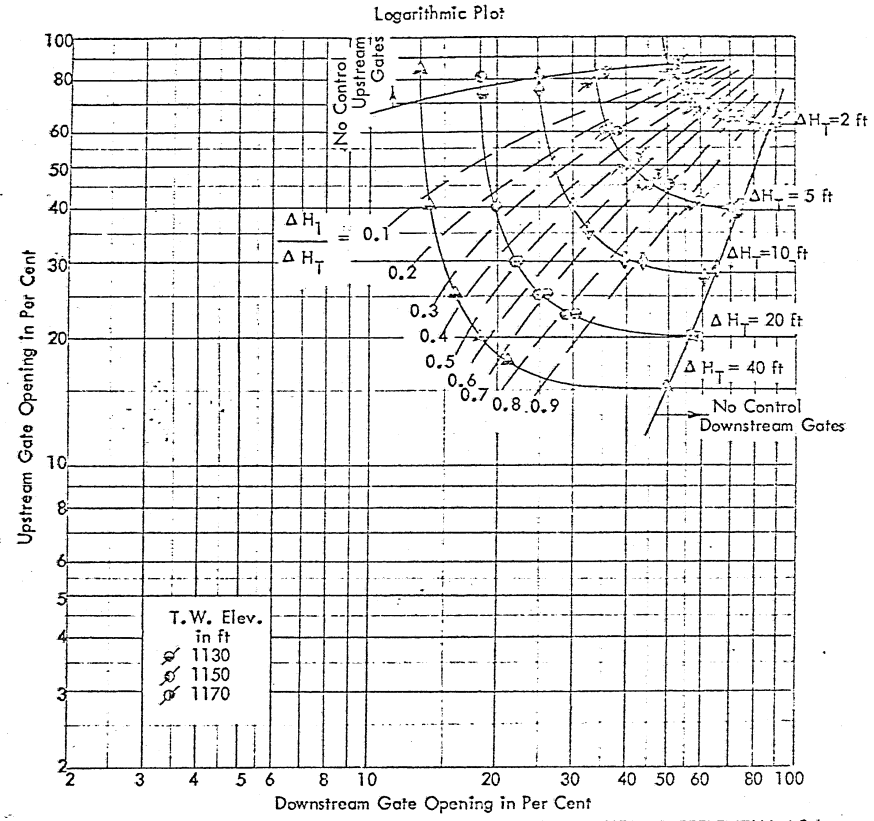


	ΔH_T in ft
○	80
□	60
△	40
⬡	20
◇	10
⌀	5
⌐	2





Logarithmic Plot



Notes:
1. The three gates of each set are opened equally.
2. No flow in Morris Drift.
3. ΔH_T is the total head differential across both gate sets.
   $\Delta H_T = \Delta H_1 + \Delta H_2$

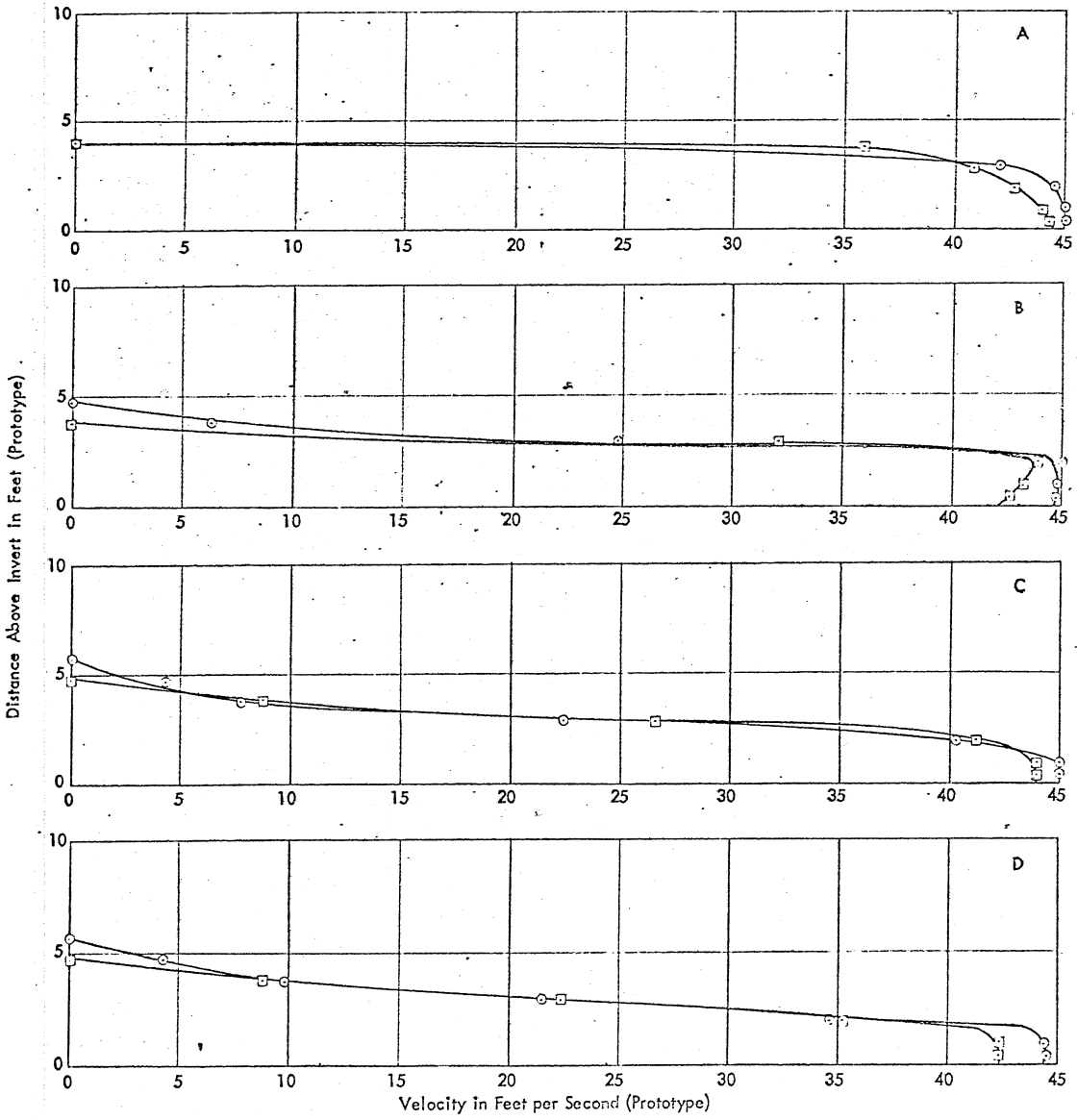
TOTAL HEAD DIFFERENTIAL AS A FUNCTION OF THE UPSTREAM AND DOWNSTREAM GATE OPENINGS
Q = 1550 cfs
T.W. Elev. = 1130 ft, 1150 ft and 1170 ft
Model Scale 1:38.3

MODEL STUDIES-FOOTHILL FEEDER PROJECT
Metropolitan Water Dist. of Southern California
MORRIS RESERVOIR TURNOUT STRUCTURE

Harza Engineering Co., Chicago, Ill.

SAINT ANTHONY FALLS HYDRAULIC LABORATORY
UNIVERSITY OF MINNESOTA

DRAWN DMN CHECKED APPROVED
SCALE DATE 10-17-67 NO. 00-5-45-215



○ With Morris Drift

□ Without Morris Drift

Notes:

1. Center gates closed, outer gates of each set opened equally.
2. Velocities were measured using specially calibrated pitot tubes.
3. Profiles were taken at successive points on the centerline downstream of the right upstream gate as follows:

Profile	Location – distance downstream of gate feet prototype
A	0
B	5.75
C	11.50
D	17.25

COMPARISON OF VELOCITY PROFILES WITH AND WITHOUT MORRIS DRIFT – RIGHT UPSTREAM GATE

Q = 1550 cfs
HW = 1180 ft.
RES = 1150 ft.
TW = 1130 ft.

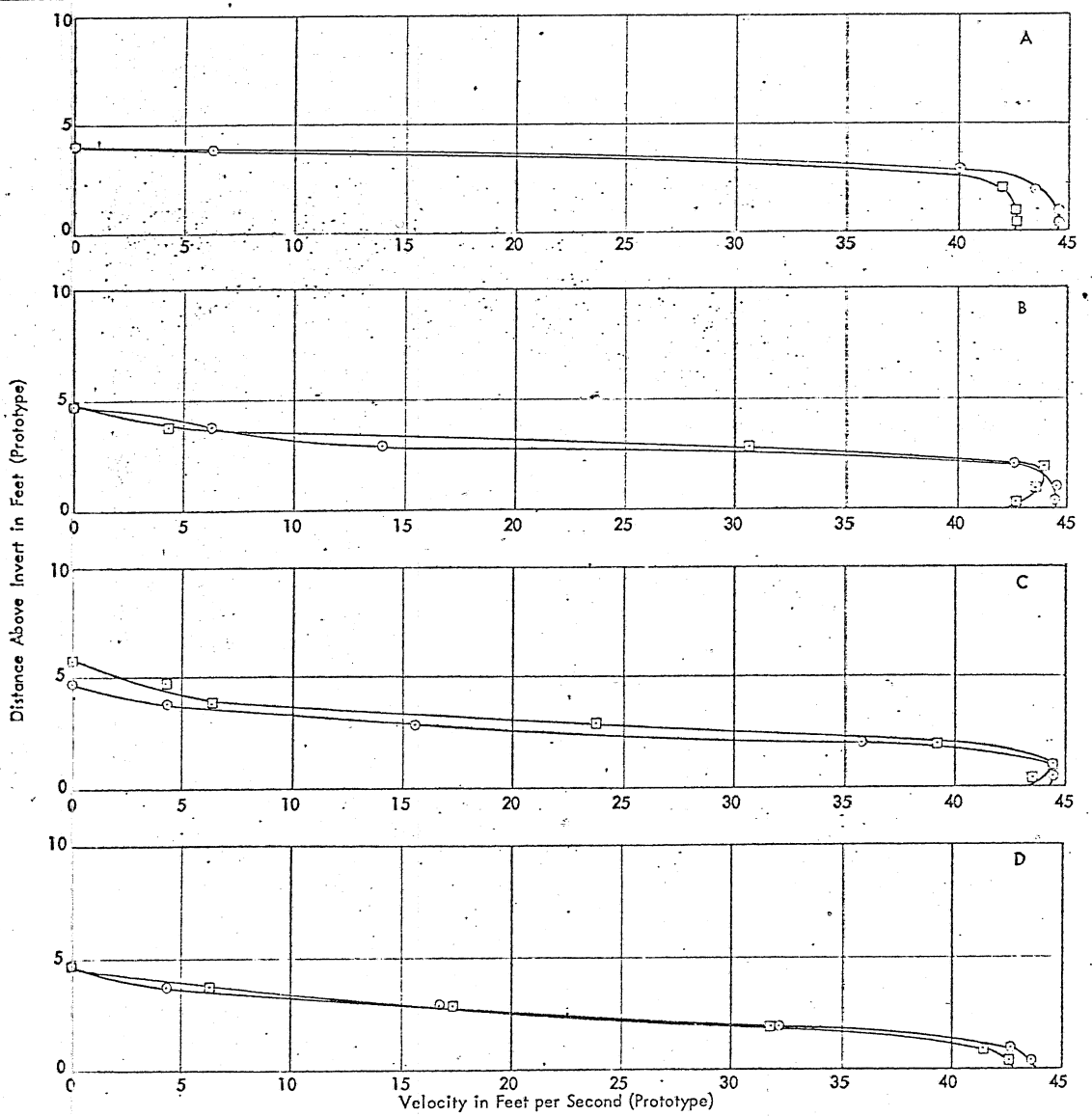
USGO = 21.6 %
DSGO = 21.6 %
(Center Gates Closed)
Model Scale 1:38.3

MODEL STUDIES–FOOTHILL FEEDER PROJECT
Metropolitan Water Dist. of Southern California
MORRIS RESERVOIR TURNOUT STRUCTURE

Harza Engineering Co., Chicago, Ill.

SAINT ANTHONY FALLS HYDRAULIC LABORATORY
UNIVERSITY OF MINNESOTA

DRAWN DMN | CHECKED | APPROVED
SCALE | DATE 2-8-68 | NO. 1633-459-202



○ With Morris Drift

□ Without Morris Drift

Notes:

1. Center gates closed, outer gates of each set opened equally.
2. Velocities were measured using special, calibrated pitot tubes.
3. Profiles were taken at successive points on the centerline downstream of the left upstream gate as follows:

Profile	Location – distance downstream of gate feet prototype
A	0
B	5.75
C	11.50
D	17.25

COMPARISON OF VELOCITY PROFILES WITH AND WITHOUT MORRIS DRIFT – LEFT UPSTREAM GATE

Q = 1550 cfs
HW = 1180 ft.
RES = 1150 ft.
TW = 1130 ft.

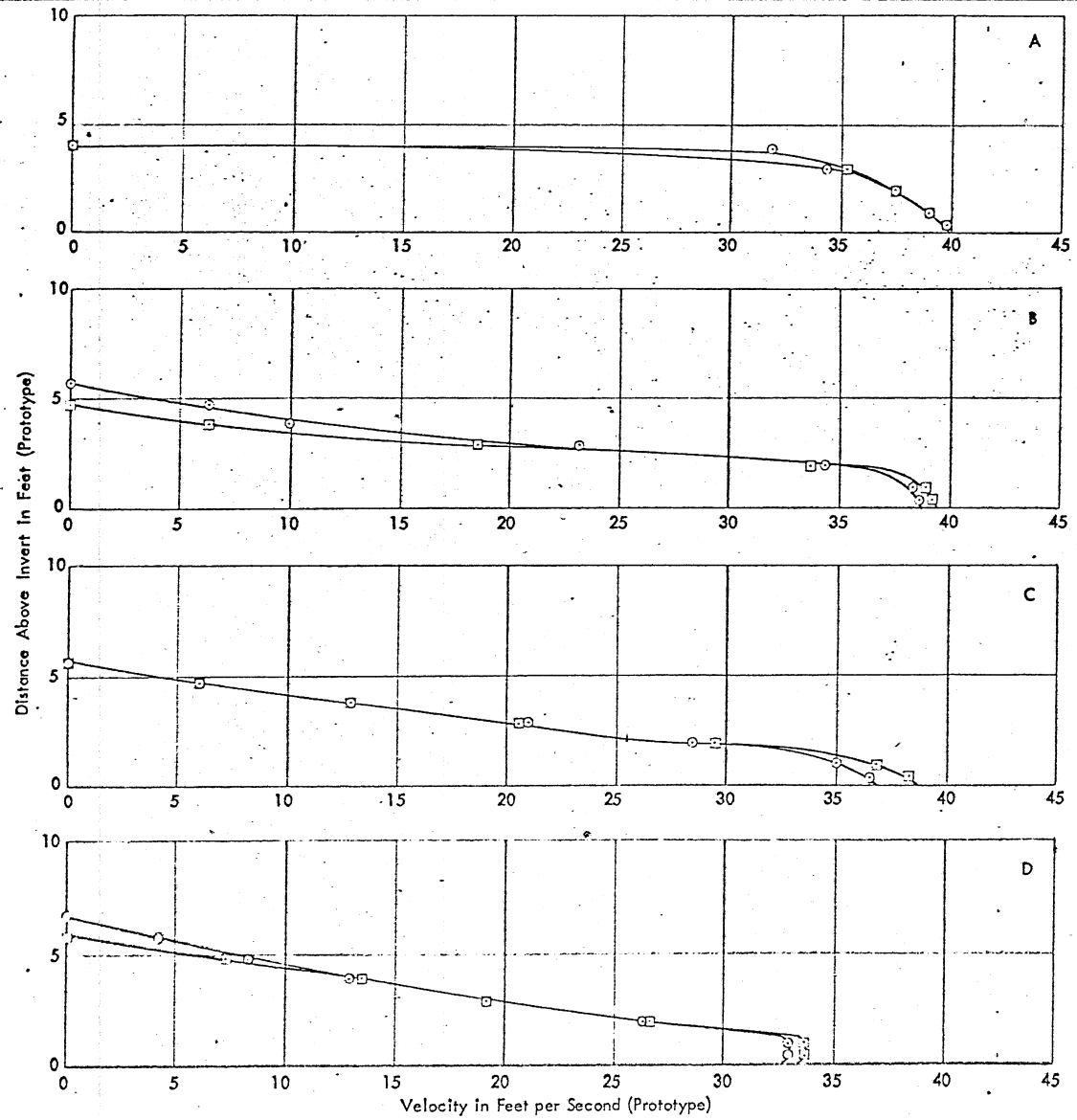
USGO = 21.6 %
DSGO = 21.6 %
(Center Gates Closed)
Model Scale 1:38.3

MODEL STUDIES–FOOTHILL FEEDER PROJECT
Metropolitan Water Dist. of Southern California
MORRIS RESERVOIR TURNOUT STRUCTURE

Harza Engineering Co., Chicago, Ill.

SAINT ANTHONY FALLS HYDRAULIC LABORATORY
UNIVERSITY OF MINNESOTA

DRAWN GES | CHECKED | APPROVED
SCALE | DATE 2-9-48 | NO. 1653-459-233



○ With Morris Drift

□ Without Morris Drift

Notes:

1. Center gates closed, outer gates of each set opened equally.
2. Velocities were measured using special, calibrated pitot tubes.
3. Profiles were taken at successive points on the centerline downstream of the right downstream gate as follows:

Profile	Location – distance downstream of gate feet prototype
A	0
B	5.75
C	11.50
D	17.25

COMPARISON OF VELOCITY PROFILES WITH AND WITHOUT MORRIS DRIFT – RIGHT DOWNSTREAM GATE

Q = 1550 cfs
HW = 1180 ft.
RES = 1150 ft.
TW = 1130 ft.

USGO = 21.6 %
DSGO = 21.6 %
(Center Gates Closed)
Model Scale 1:38.3

MODEL STUDIES–FOOTHILL FEEDER PROJECT
Metropolitan Water Dist. of Southern California
MORRIS RESERVOIR TURNOUT STRUCTURE

Harza Engineering Co., Chicago, Ill.

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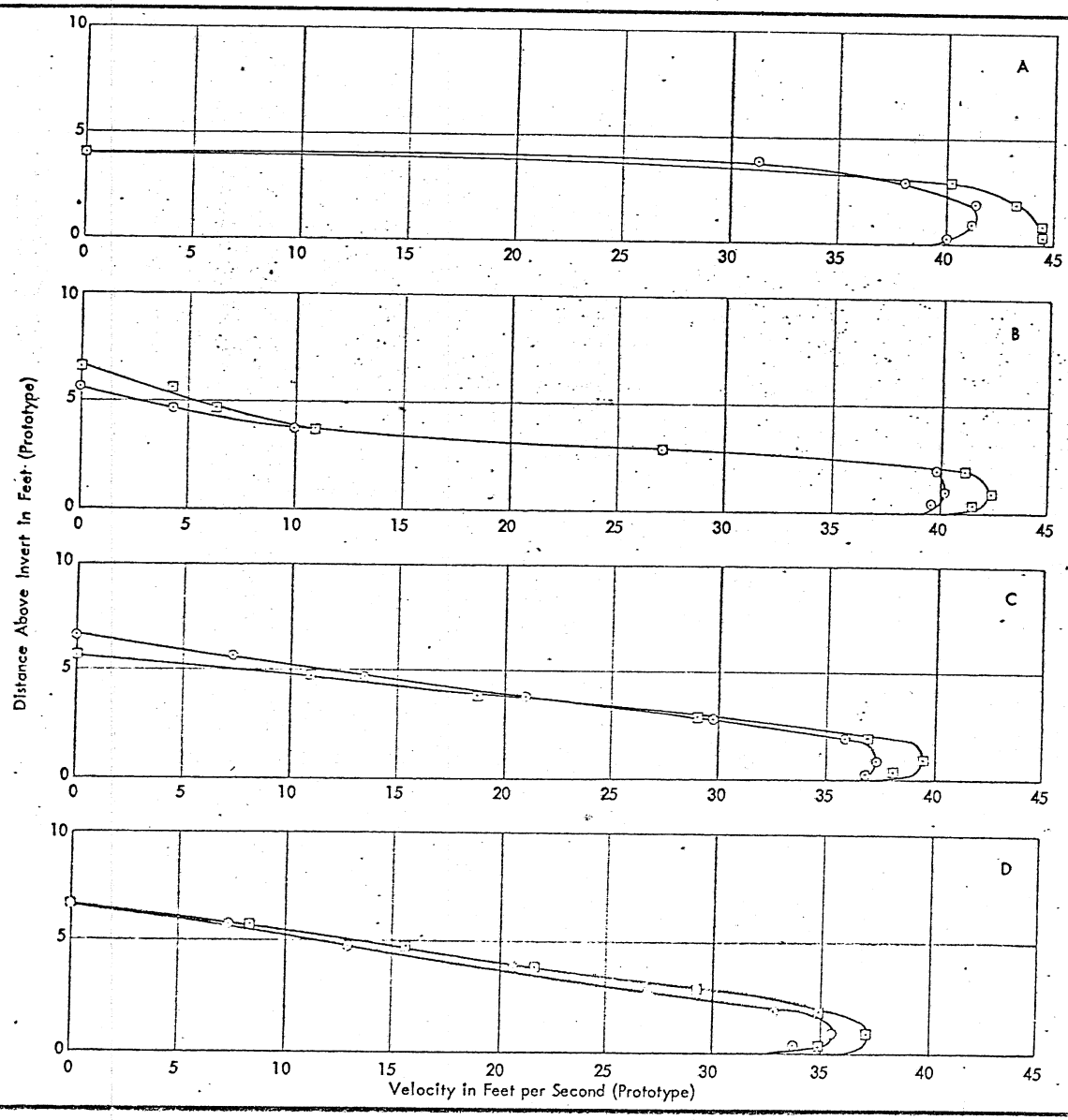
UNIVERSITY OF MINNESOTA

DRAWN DMN	CHECKED	APPROVED
SCALE	DATE 2-8-68	NO. 168B-459-230



○ With Morris Drift

□ Without Morris Drift

Notes:

1. Center gates closed, outer gates of each set opened equally.
2. Velocities were measured using special, calibrated pitot tubes.
3. Profiles were taken at successive points on the centerline downstream of the left downstream gate as follows:

Profile	Location – distance downstream of gate feet prototype
A	0
B	5.75
C	11.50
D	17.25

COMPARISON OF VELOCITY PROFILES WITH AND WITHOUT MORRIS DRIFT – LEFT DOWNSTREAM GATE

Q = 1550 cfs
HW = 1180 ft.
RES = 1150 ft.
TW = 1130 ft.

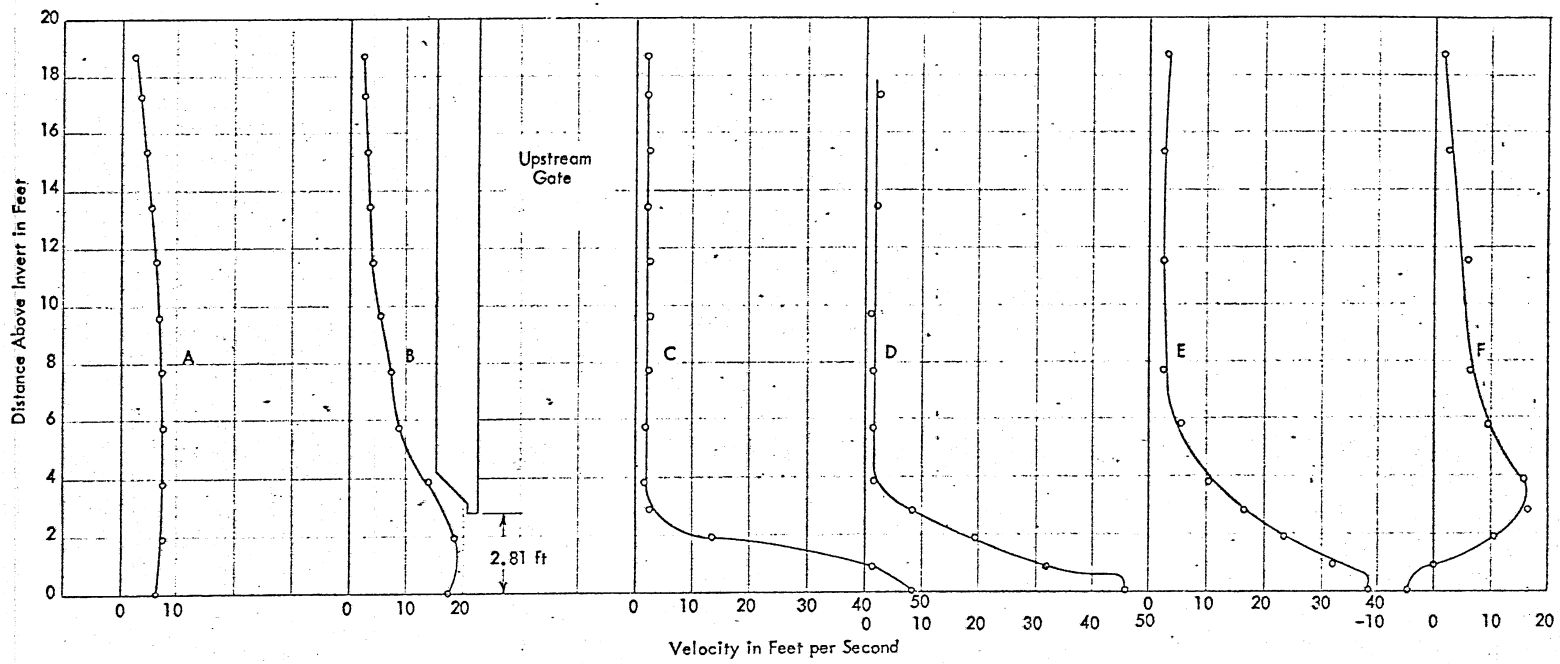
USGO = 21.6 %
DSGO = 21.6 %
(Center Gates Closed)
Model Scale 1:38.3

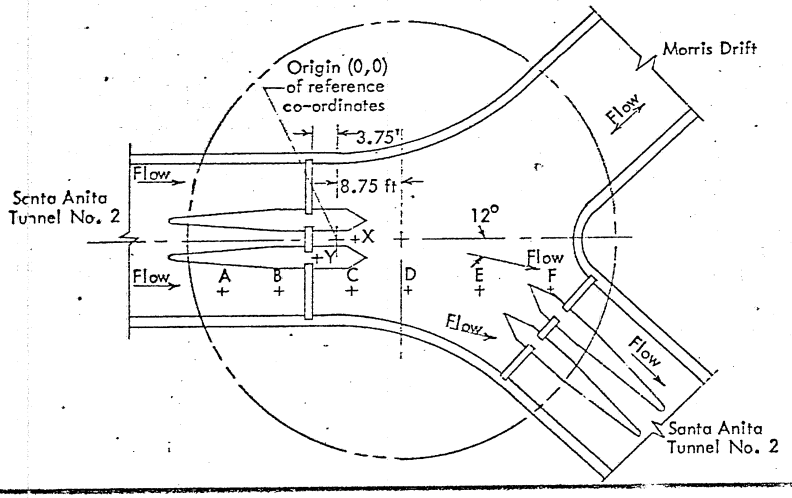
MODEL STUDIES–FOOTHILL FEEDER PROJECT
Metropolitan Water Dist. of Southern California
MORRIS RESERVOIR TURNOUT STRUCTURE

Harza Engineering Co., Chicago, Ill.

SAINT ANTHONY FALLS HYDRAULIC LABORATORY
UNIVERSITY OF MINNESOTA

DRAWN DMN	CHECKED	APPROVED
SCALE	DATE 2-8-58	NO. 1068-459-231





Notes:
1. See sketch for location of the origin (0,0) of the reference co-ordinate system.
2. No flow in Morris Drift.
3. The three gates of each set are opened equally.

Position	X in Feet	Y in Feet
A	-16	+7
B	-8	+7
C	+2	+7
D	+10	+7
E	+20	+7
F	+30	+7

VELOCITY PROFILES IN THE VICINITY OF THE GATES

Q = 1550 cfs
H.W. Elev. = 1170 ft
Res. Elev. = 1131 ft
T. W. Elev. = 1130 ft
Upstream Gate Opening = 15.2%
Downstream Gate Opening = 100%
Model Scale = 1:38.3

MODEL STUDIES-FOOTHILL FEEDER PROJECT
Metropolitan Water Dist. of Southern California
MORRIS RESERVOIR TURNOUT STRUCTURE

Horza Engineering Co., Chicago, Ill.
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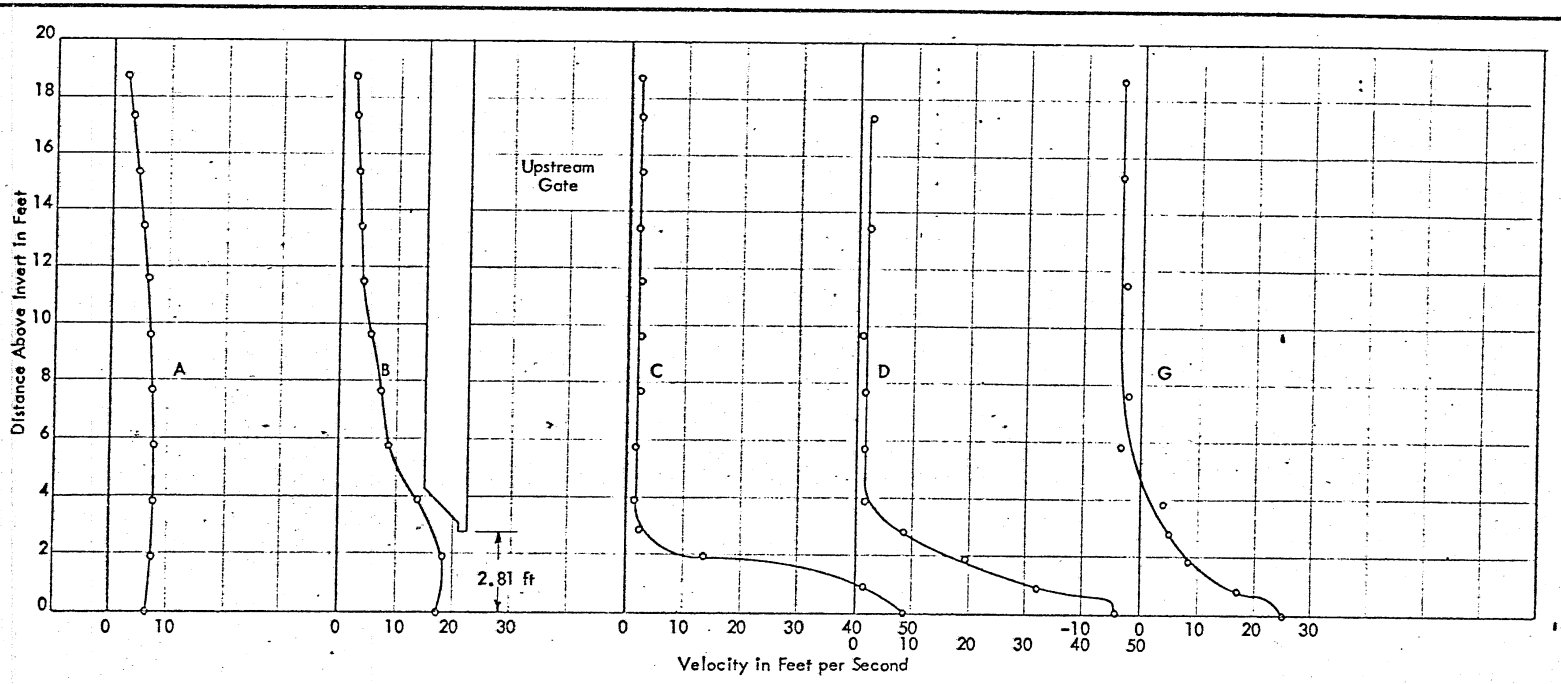
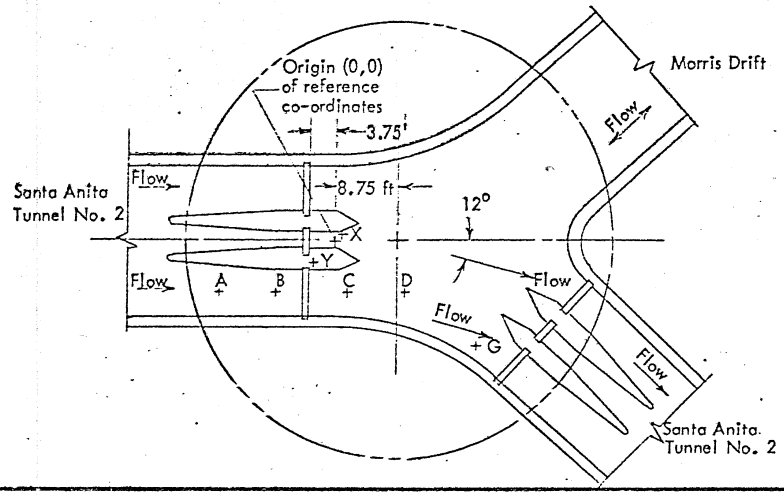
UNIVERSITY OF MINNESOTA

DRAWN GES	CHECKED	APPROVED
SCALE	DATE 11-28-67	NO. 169-B-459-219

CHART 11





Notes:
1. See sketch for location of the origin (0,0) of the reference co-ordinate system.
2. No flow in Morris Drift.
3. The three gates of each set are opened equally.

Position	X in Feet	Y in Feet
A	-16	+7
B	-8	+7
C	+2	+7
D	+10	+7
G	+20	+14

VELOCITY PROFILES IN THE VICINITY OF THE GATES

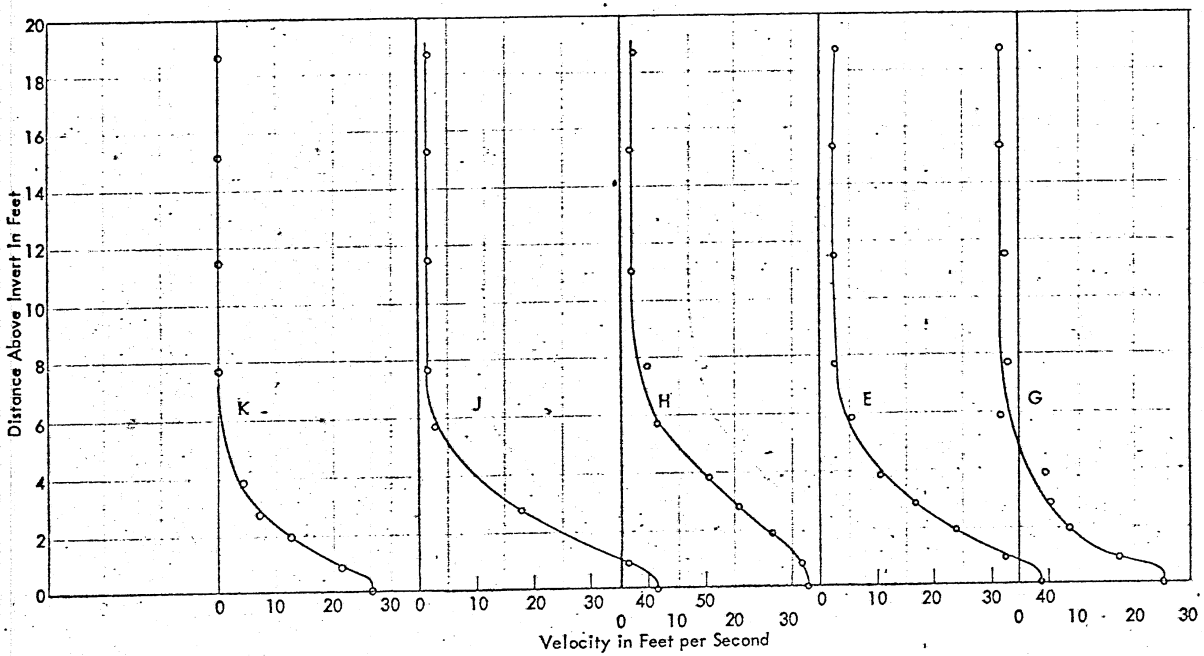
Q = 1550 cfs
H.W. Elev. = 1170 ft
Res. Elev. = 1131 ft
T.W. Elev. = 1130 ft
Upstream Gate Opening = 15.2%
Downstream Gate Opening = 100%
Model Scale = 1:38.3

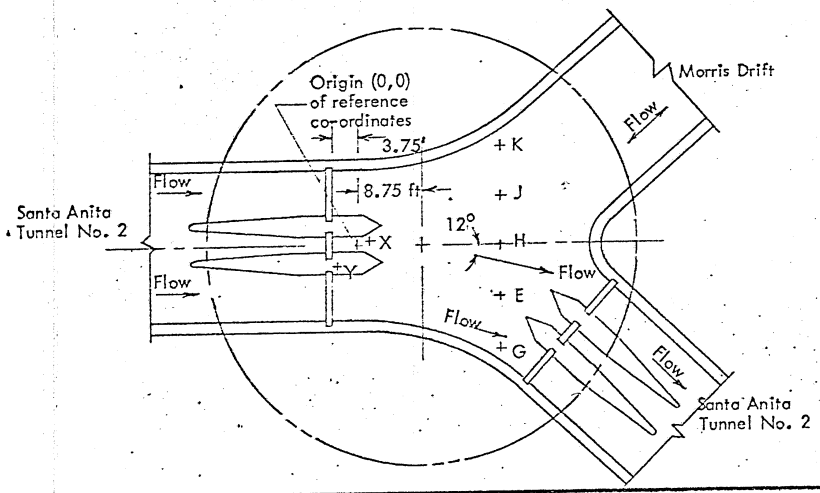
MODEL STUDIES-FOOTHILL FEEDER PROJECT
Metropolitan Water Dist. of Southern California
MORRIS RESERVOIR TURNOUT STRUCTURE

Harza Engineering Co., Chicago, Ill.

SAINT ANTHONY FALLS HYDRAULIC LABORATORY
UNIVERSITY OF MINNESOTA

DRAWN GES	CHECKED	APPROVED
SCALE	DATE 11-28-67	NO. 168-B-459-220





Notes:
1. See sketch for location of the origin (0,0) of the reference co-ordinates.
2. No flow in Morris Drift.
3. The three gates of each set are opened equally.

Position	X in Feet	Y in Feet
K	20	-14
J	20	- 7
H	20	0
E	20	7
G	20	14

VELOCITY PROFILES IN THE VICINITY OF THE GATES
Q = 1550 cfs

H.W. Elev. = 1170 ft
Res. Elev. = 1131 ft
T.W. Elev. = 1130 ft
Upstream Gate Opening = 15.2%
Downstream Gate Opening = 100%
Model Scale = 1:38.3

MODEL STUDIES-FOOTHILL FEEDER PROJECT
Metropolitan Water Dist. of Southern California
MORRIS RESERVOIR TURNOUT STRUCTURE

Harza Engineering Co., Chicago, Ill.

SAINT ANTHONY FALLS HYDRAULIC LABORATORY
UNIVERSITY OF MINNESOTA

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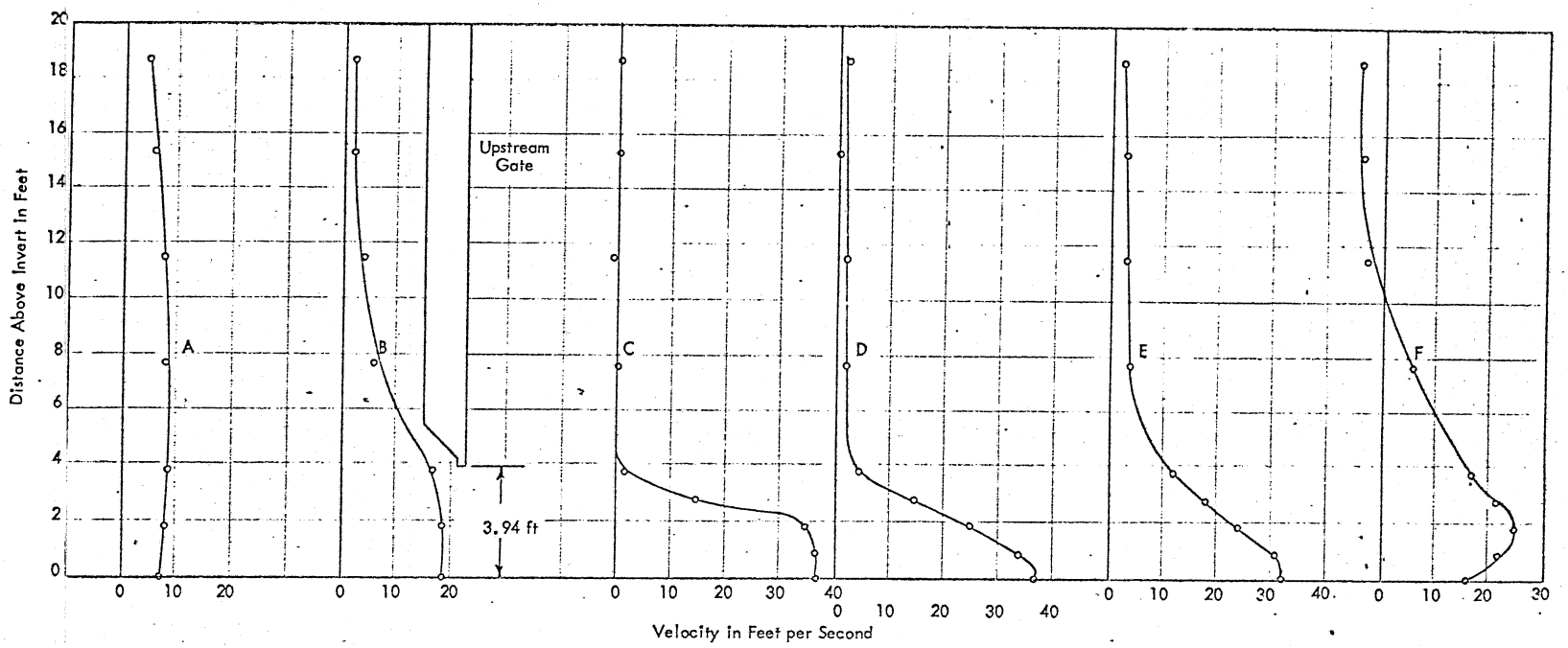
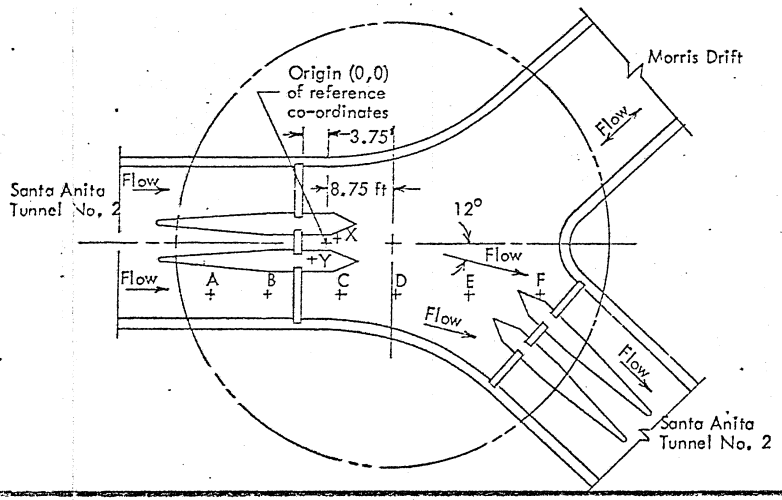
SCALE	DATE 11-28-67	NO. 165-B-459-221





Notes:
1. See sketch for location of the origin (0,0) of the reference co-ordinate system.
2. No flow in Morris Drift.
3. The three gates of each set are opened equally.

Position	X in Feet	Y in Feet
A	-16	+7
B	-8	+7
C	+2	+7
D	+10	+7
E	+20	+7
F	+30	+7

VELOCITY PROFILES IN THE VICINITY OF THE GATES

Q = 1550 cfs
H.W. Elev. = 1170 ft
Res. Elev. = 1150 ft
T.W. Elev. = 1130 ft
Upstream Gate Opening = 21.3%
Downstream Gate Opening = 17.5%
Model Scale = 1:38.2

MODEL STUDIES-FOOTHILL FEEDER PROJECT
Metropolitan Water Dist. of Southern California
MORRIS RESERVOIR TURNOUT STRUCTURE

Harza Engineering Co., Chicago, Ill.

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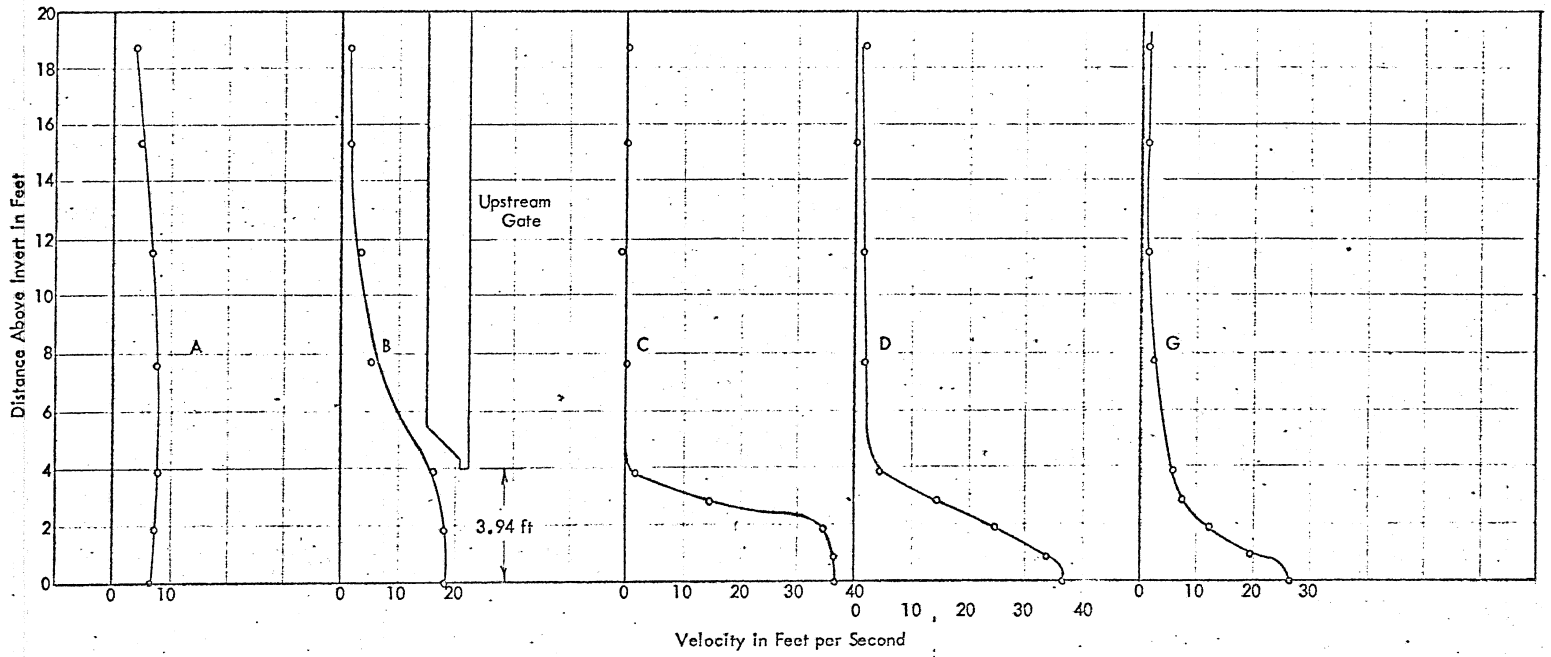
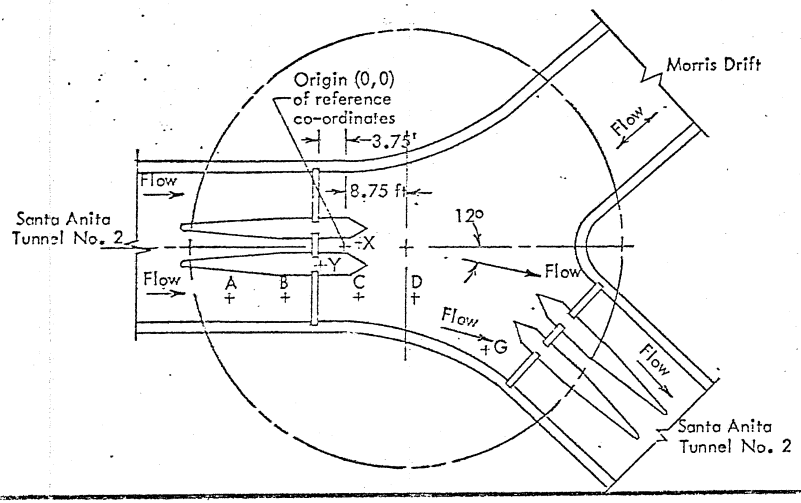
UNIVERSITY OF MINNESOTA

DRAWN GES | CHECKED | APPROVED
SCALE | DATE 11-28-67 | NO. 163-B-459-22





Notes:
1. See sketch for location of the origin (0,0) of the reference co-ordinate system.
2. No flow in Morris Drift.
3. The three gates of each set are opened equally.

Position	X in Feet	Y in Feet
A	-16	+7
B	-8	+7
C	+2	+7
D	+10	+7
G	+20	+14

VELOCITY PROFILES IN THE VICINITY OF THE GATES

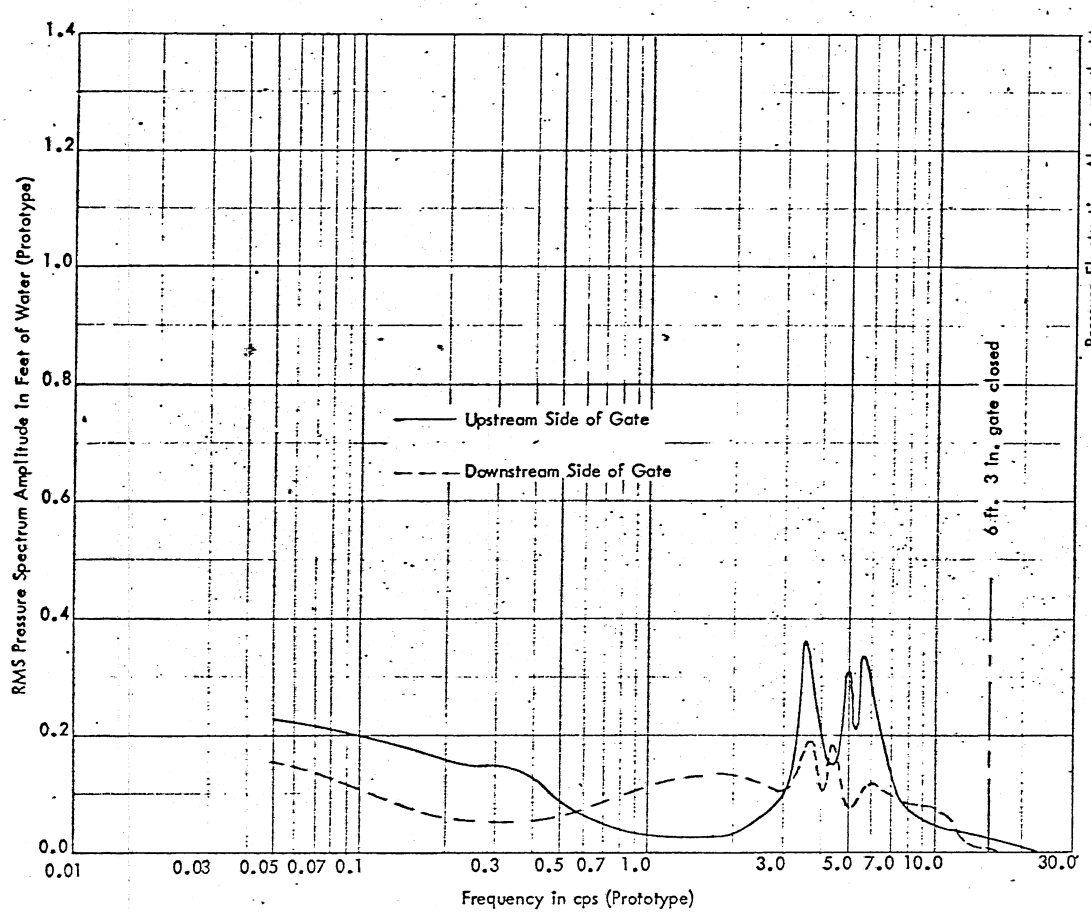
Q = 1550 cfs
H.W. Elev. = 1170 ft
Res. Elev. = 1150 ft
T.W. Elev. = 1130 ft
Upstream Gate Opening = 21.3 %
Downstream Gate Opening = 17.5%
Model Scale = 1:38.3

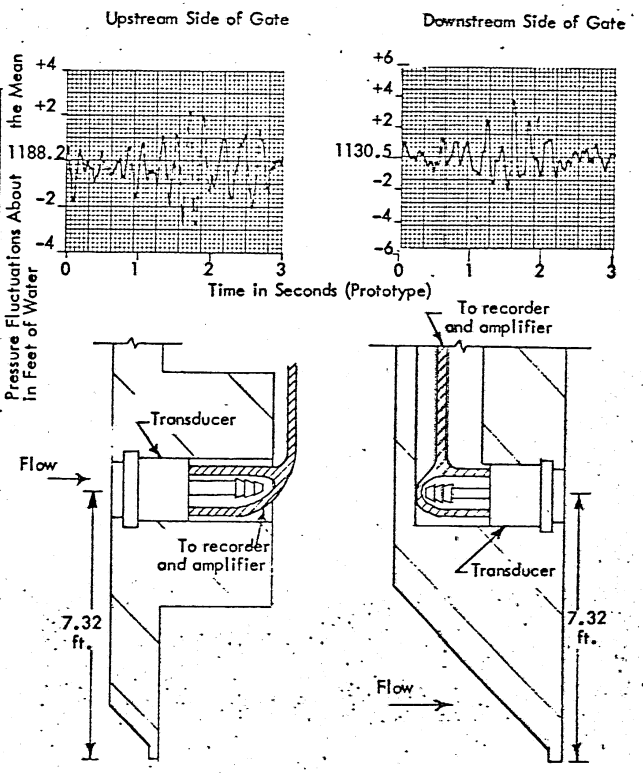
MODEL STUDIES-FOOTHILL FEEDER PROJECT
Metropolitan Water Dist. of Southern California
MORRIS RESERVOIR TURNOUT STRUCTURE

Harza Engineering Co., Chicago, Ill.

SAINT ANTHONY FALLS HYDRAULIC LABORATORY
UNIVERSITY OF MINNESOTA

DRAWN DMN | CHECKED | APPROVED
SCALE | DATE 11-28-67 | NO. 168-B-459-22





Typical Record of Pressure Fluctuations and Sketches showing Transducer Locations in Gate

HARMONIC WAVE ANALYSIS OF THE PRESSURE PULSES OCCURRING ON THE UPSTREAM GATES

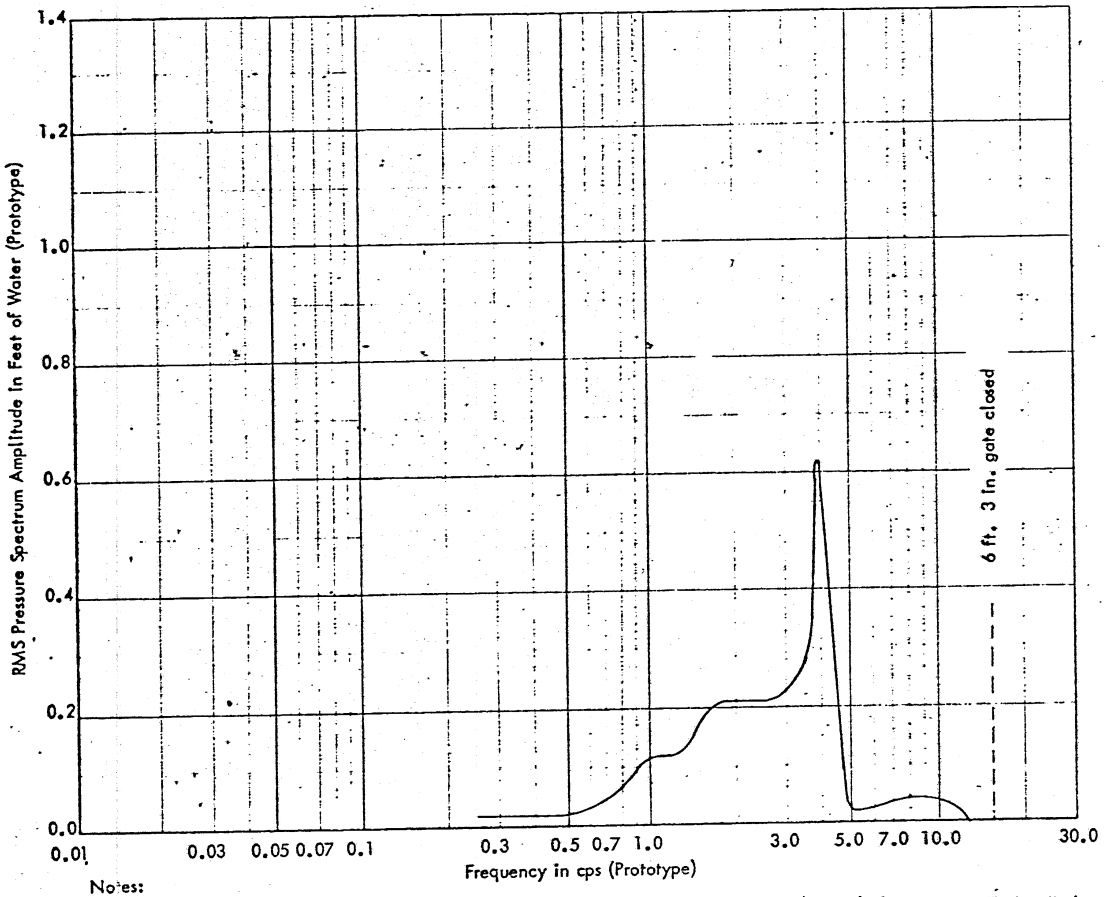
Q = 1550 cfs
HW = 1188 ft.
RES = 1130.5 ft.
TW = 1130 ft.

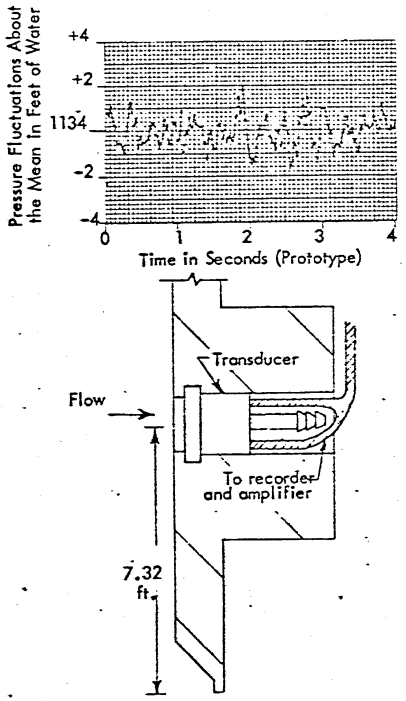
USGO = 0%
DSGO = 100%
Model Scale 1:38.3

Notes:

1. Transducers used were 2.5 psi C.E.C., flush mounted type.
2. Upstream gates closed, downstream gates completely open, no flow in Morris Drift.
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 that shown (above right). The graph above shows the RMS value of the amplitudes of the pressure pulses occurring with the indicated frequencies.
5. Dashed line on graph indicates natural frequency of the gate as designed by Harza Engineering Co. and shown on Harza drawings. 380-SKC-165 and 166.
6. Entire discharge was passed over the emergency weir.

MODEL STUDIES-FOOTHILL FEEDER PROJECT
Metropolitan Water Dist. of Southern California
MORRIS RESERVOIR TURNOUT STRUCTURE
Harza Engineering Co., Chicago, Ill.
SAINT ANTHONY FALLS HYDRAULIC LABORATORY
UNIVERSITY OF MINNESOTA
DRAWN DMN | CHECKED | APPROVED
SCALE | DATE 12-19-67 | NO 1688-459-224





Typical Record of Pressure Fluctuations and Sketch showing Transducer Location in Gate

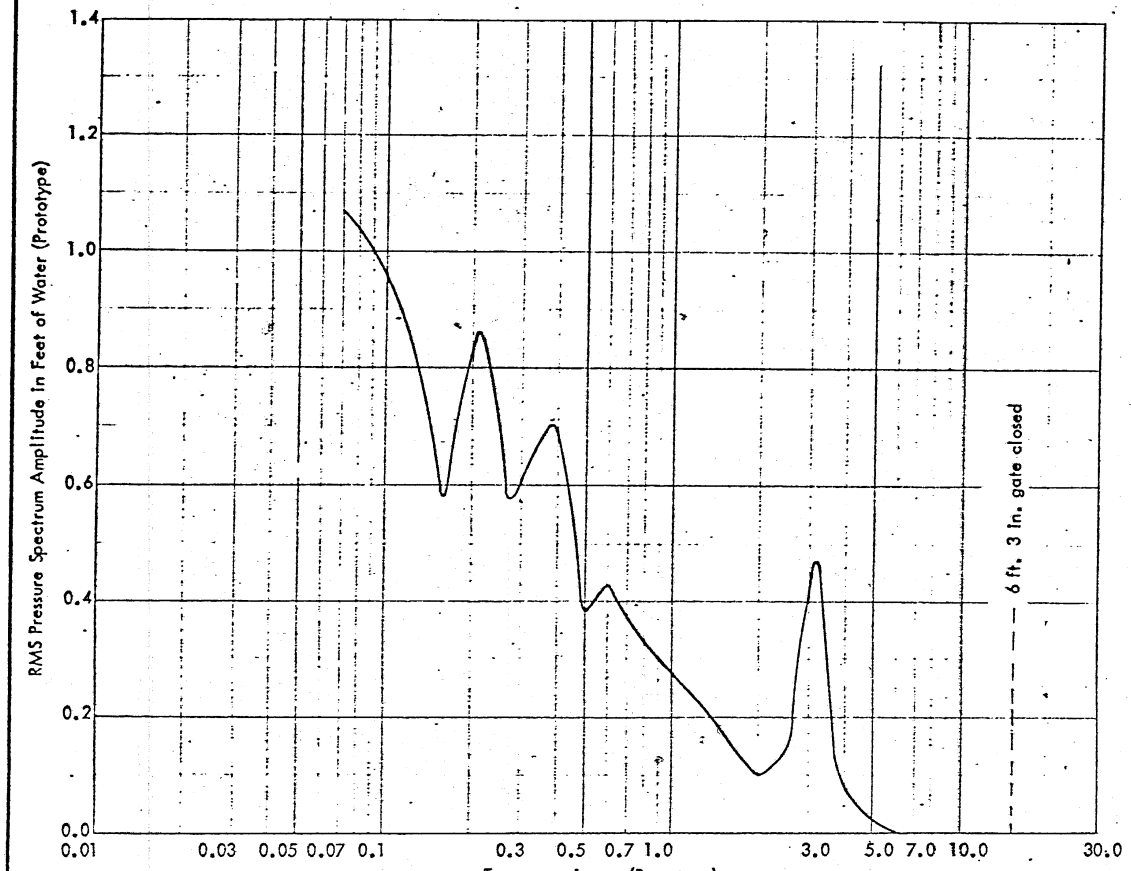
HARMONIC WAVE ANALYSIS OF THE PRESSURE PULSES OCCURRING ON THE DOWNSTREAM RIGHT GATE

Q = 1550 cfs
HW = 1188 ft.
RES = 1134 ft.
TW = 1130 ft.
USGO = 0%
DSGO = 37.8 %
Model Scale 1:38.3

Notes:

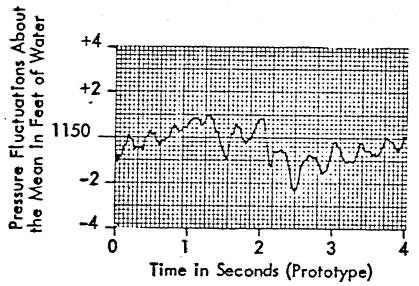
1. Transducers used were 2.5 psi C.E.C., flush mounted type.
2. Upstream gates closed, downstream gates open 37.8 %, no flow in Morris Drift.
3. The transducers were mounted so as to record fluctuating pressures 7.32 ft. above the bottom of the gate.
4. The spectrum was obtained by analysis of records similar to that shown (above right). The graph above shows the RMS value of the amplitudes of the pressure pulses occurring with the indicated frequencies.
5. Dashed line on graph indicates natural frequency of the gate as designed by Harza Engineering Co. and shown on Harza drawings. 380-SKC-165 and 166.
6. Entire discharge was passed over the emergency weir.

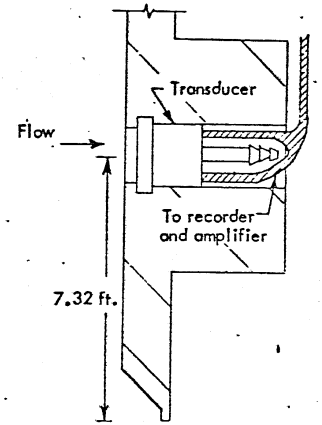
MODEL STUDIES-FOOTHILL FEEDER PROJECT
Metropolitan Water Dist. of Southern California
MORRIS RESERVOIR TURNOUT STRUCTURE
Harza Engineering Co., Chicago, Ill.
SAINT ANTHONY FALLS HYDRAULIC LABORATORY
UNIVERSITY OF MINNESOTA
DRAWN DMN | CHECKED | APPROVED
SCALE | DATE 12-19-67 | NO. 1688-459-225



Notes:

1. Transducers used were 2.5 psi C.E.C., flush mounted type.
2. Upstream gates open 16%, downstream gates open 17%, no flow in Morris Drift.
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 that shown (above right). The graph above shows the RMS value of the amplitudes of the pressure pulses occurring with the indicated frequencies.
5. Dashed line on graph indicates natural frequency of the gate as designed by Harza Engineering Co. and shown on Harza drawings. 380-SKC-165 and 166.



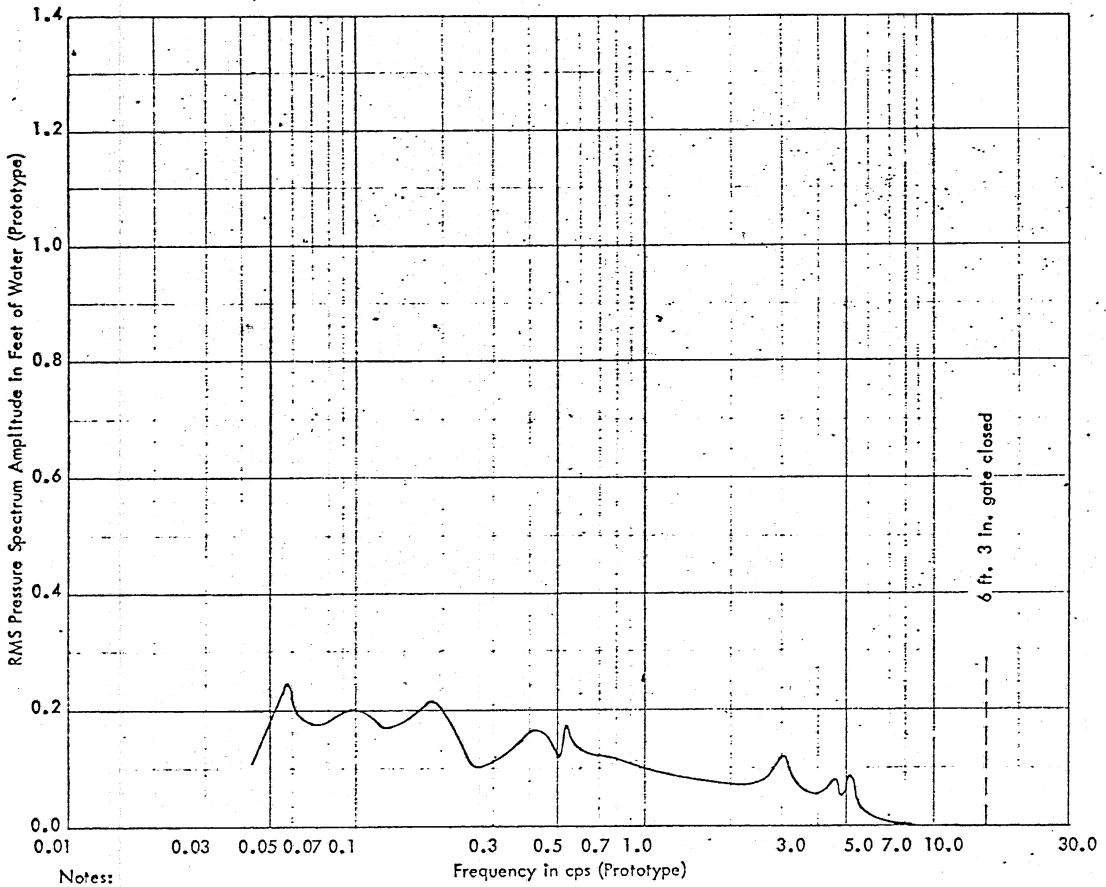


Typical Record of Pressure Fluctuations and Sketch showing Transducer Location in Gate

HARMONIC WAVE ANALYSIS OF THE PRESSURE PULSES OCCURRING ON THE DOWNSTREAM RIGHT GATE

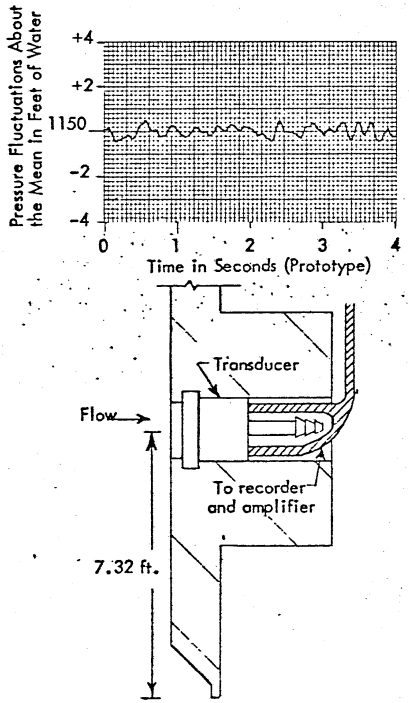
Q = 1550 cfs
HW = 1180 ft.
RES = 1150 ft.
TW = 1130 ft.
USGO = 16%
DSGO 17%
Model Scale 1:38.3

MODEL STUDIES–FOOTHILL FEEDER PROJECT
Metropolitan Water Dist. of Southern California
MORRIS RESERVOIR TURNOUT STRUCTURE
Harza Engineering Co., Chicago, Ill.
SAINT ANTHONY FALLS HYDRAULIC LABORATORY
UNIVERSITY OF MINNESOTA
DRAWN DMN | CHECKED | APPROVED
SCALE | DATE 12-14-67 | NO. 168B-459-226



Notes:

1. Transducers used were 2.5 psi C.E.C., flush mounted type.
2. Upstream gates open 3.9%, downstream gates open 4.4%, no flow in Morris Drift.
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 that shown (above right). The graph above shows the RMS value of the amplitudes of the pressure pulses occurring with the indicated frequencies.
5. Dashed line on graph indicates natural frequency of the gate as designed by Harza Engineering Co. and shown on Harza drawings. 380-SKC-165 and 166.

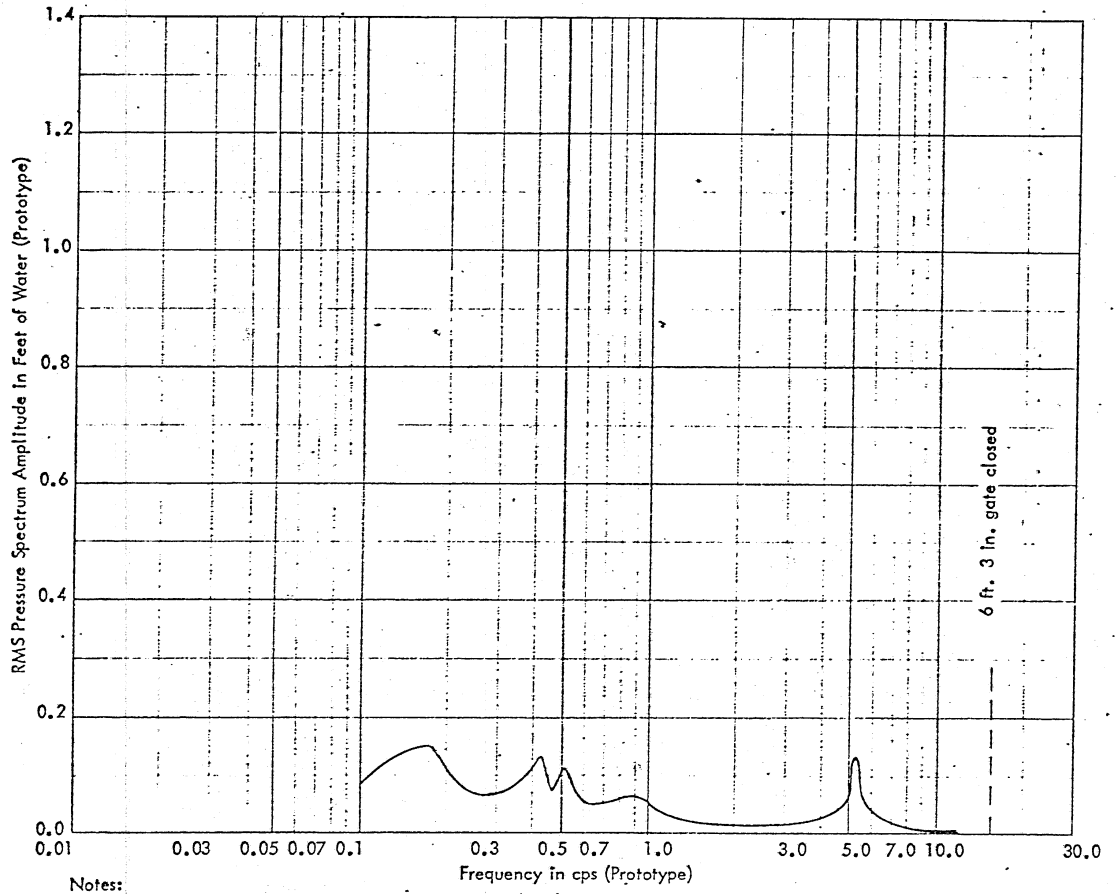


Typical Record of Pressure Fluctuations and Sketch showing Transducer Location in Gate

HARMONIC WAVE ANALYSIS OF THE PRESSURE PULSES OCCURRING ON THE DOWNSTREAM RIGHT GATE

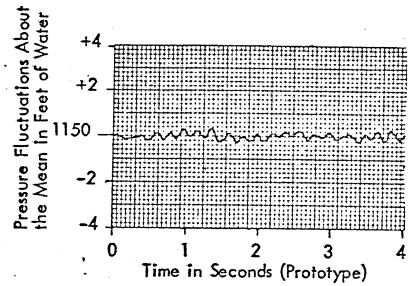
Q = 420 cfs
HW = 1180 ft.
RES = 1150 ft.
TW = 1130 ft.
USGO = 3.9%
DSGO = 4.4%
Model Scale 1:38.3

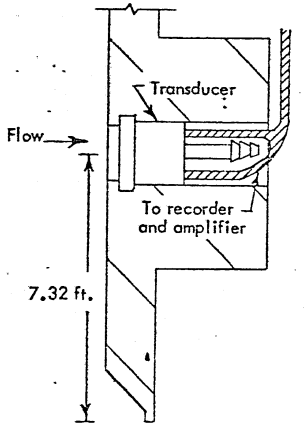
MODEL STUDIES-FOOTHILL FEEDER PROJECT
Metropolitan Water Dist. of Southern California
MORRIS RESERVOIR TURNOUT STRUCTURE
Harza Engineering Co., Chicago, Ill.
SAINT ANTHONY FALLS HYDRAULIC LABORATORY
UNIVERSITY OF MINNESOTA
DRAWN DMN | CHECKED | APPROVED
SCALE | DATE 12-19-67 | NO 168B-459-227



Notes:

1. Transducers used were 2.5 psi C.E.C., flush mounted type.
2. Upstream gate open 15.8%, downstream gate open 18.1% (center gates only), no flow in Morris Drift.
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 that shown (above right). The graph above shows the RMS value of the amplitudes of the pressure pulses occurring with the indicated frequencies.
5. Dashed line on graph indicates natural frequency of the gate as designed by Harza Engineering Co. and shown on Harza drawings. 380-SKC-165 and 166.



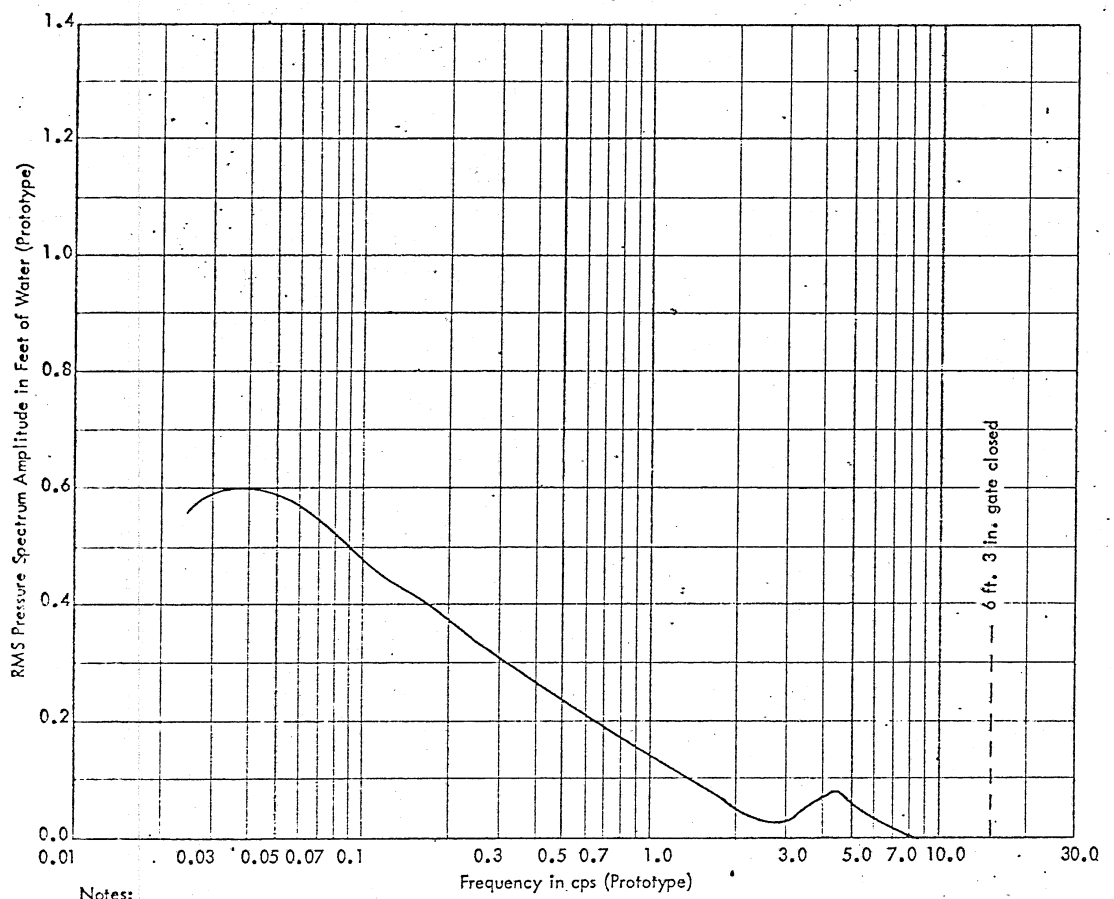


Typical Record of Pressure Fluctuations and Sketch showing Transducer Location in Gate

HARMONIC WAVE ANALYSIS OF THE PRESSURE PULSES OCCURRING ON THE DOWNSTREAM RIGHT GATE

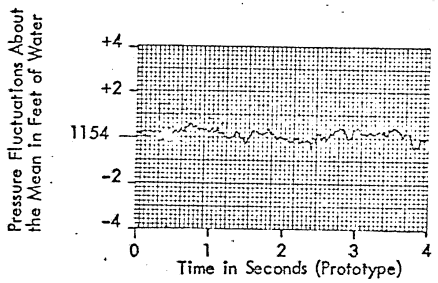
Q = 200 cfs
HW = 1180 ft.
RES = 1150 ft.
TW = 1130 ft.
USGO = 15.8% (Center Gate Only)
DSGO = 18.1% (Center Gate Only)
Model Scale 1:38.3

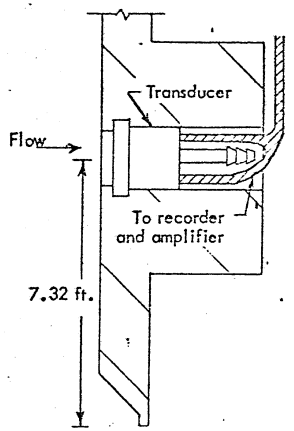
MODEL STUDIES-FOOTHILL FEEDER PROJECT
Metropolitan Water Dist. of Southern California
MORRIS RESERVOIR TURNOUT STRUCTURE
Harza Engineering Co., Chicago, Ill.
SAINT ANTHONY FALLS HYDRAULIC LABORATORY
UNIVERSITY OF MINNESOTA
DRAWN DMN CHECKED APPROVED
SCALE DATE 12-19-67 NO 1692-459-228



Notes:

1. Transducers used were 2.5 psi C.E.E., flush mounted type.
2. Upstream gate open 33.5°/o, downstream gate open 34.5°/o (Left gates only), no flow in Morris Drift.
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 the records similar to that shown (above right). The graph above shows the RMS value of the amplitudes of the pressure pulses occurring with the indicated frequencies.
5. Dashed line on graph indicates natural frequency of the gate as designed by Harza Engineering Co. and shown on Harza drawings. 380-SKC-165 and 166.



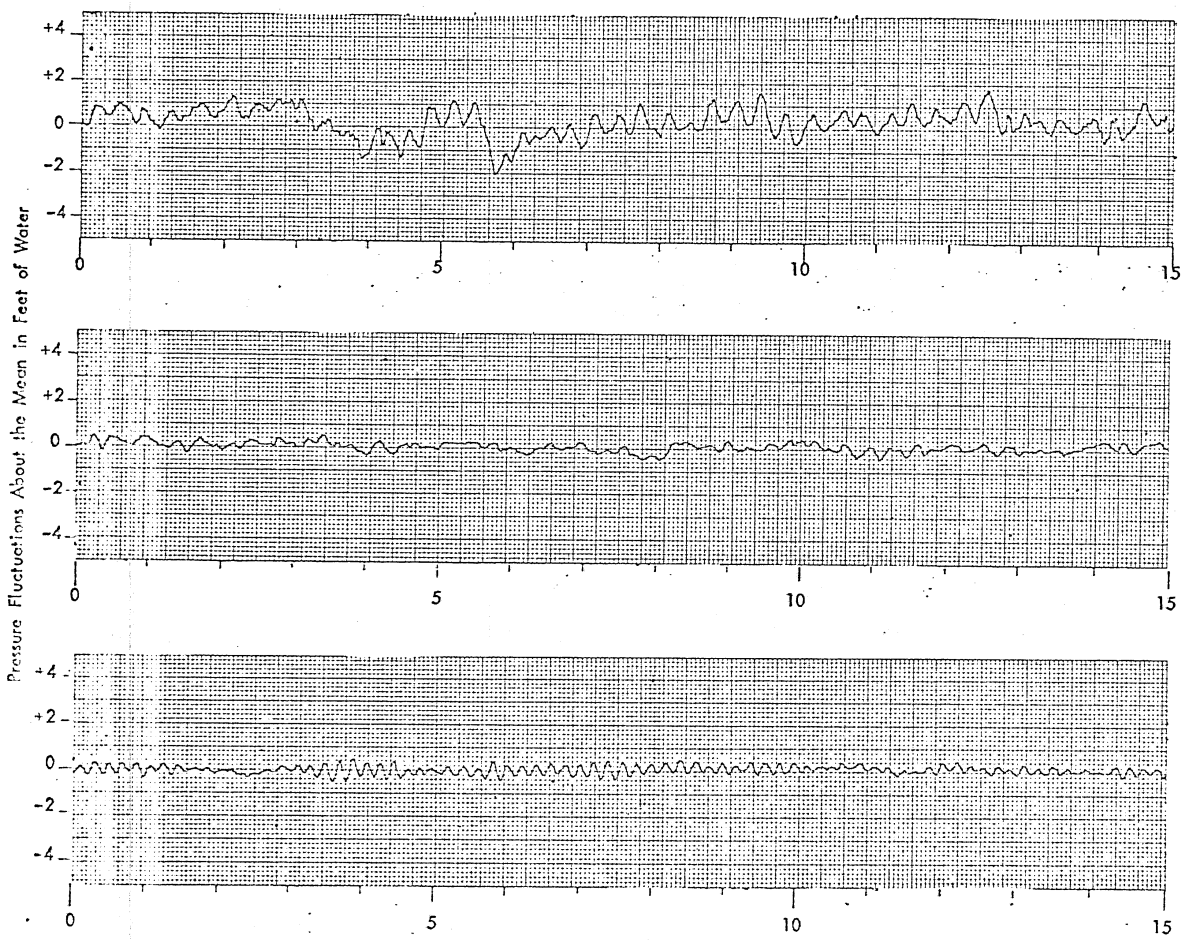


Typical Record of Pressure Fluctuations and Sketch showing Transducer Location in Gate

HARMONIC WAVE ANALYSIS OF THE PRESSURE PULSES OCCURRING ON THE DOWNSTREAM RIGHT GATE

Q = 1550 cfs
HW = 1180 ft.
RES = 1154 ft.
TW = 1130 ft.
USGO = 33.5°/o (Left Only)
DSGO = 34.5°/o (Left Only)
Model Scale 1:38.3

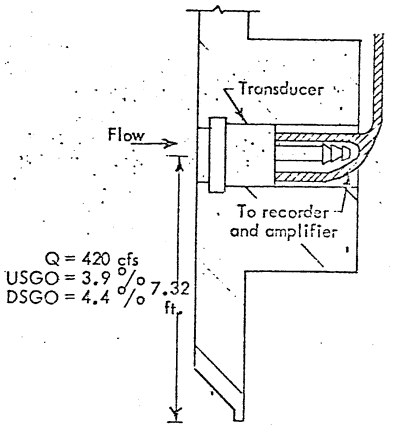
MODEL STUDIES-FOOTHILL FEEDER PROJECT
Metropolitan Water Dist. of Southern California
MORRIS RESERVOIR TURNOUT STRUCTURE
Harza Engineering Co., Chicago, Ill.
SAINT ANTHONY FALLS HYDRAULIC LABORATORY
UNIVERSITY OF MINNESOTA
DRAWN DMN | CHECKED | APPROVED
SCALE | DATE 12-19-67 | No 1698-459-229



Q = 1550 cfs
USGO = 16 %
DSGO = 17 %

Q = 420 cfs
USGO = 3.9 %
DSGO = 4.4 %

Q = 200 cfs
USGO = 15.8 %
DSGO = 18.1 %
(Center Gates Only)



Sketch showing transducer location in the gate

COMPARISON OF PRESSURE FLUCTUATIONS ON THE DOWNSTREAM RIGHT GATE FOR VARIOUS DISCHARGES

HW = 1180 ft.
RES = 1150 ft.
TW = 1130 ft.
Model Scale 1:38.3

Notes:

1. Transducer used was a 2.5 psi C.E.C., flush mounted type.
2. Pressure fluctuations are shown with reference to gage zero which corresponds to a reservoir elevation of 1150 ft.

MODEL STUDIES–FOOTHILL FEEDER PROJECT
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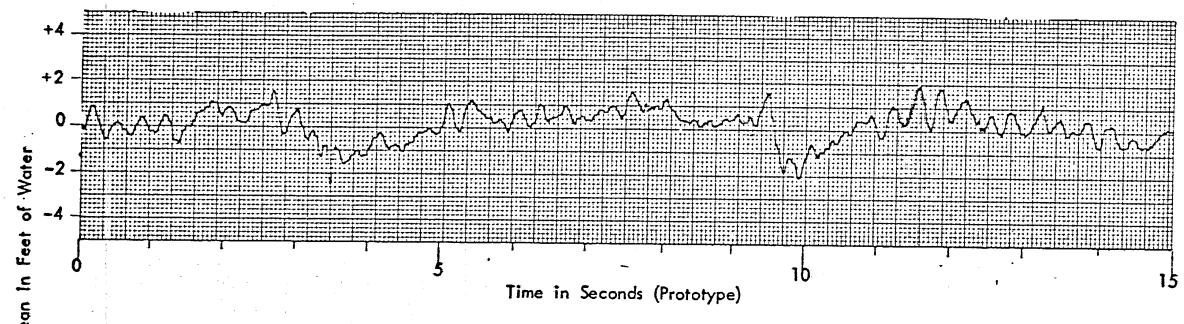
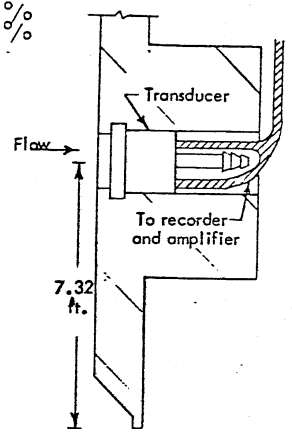
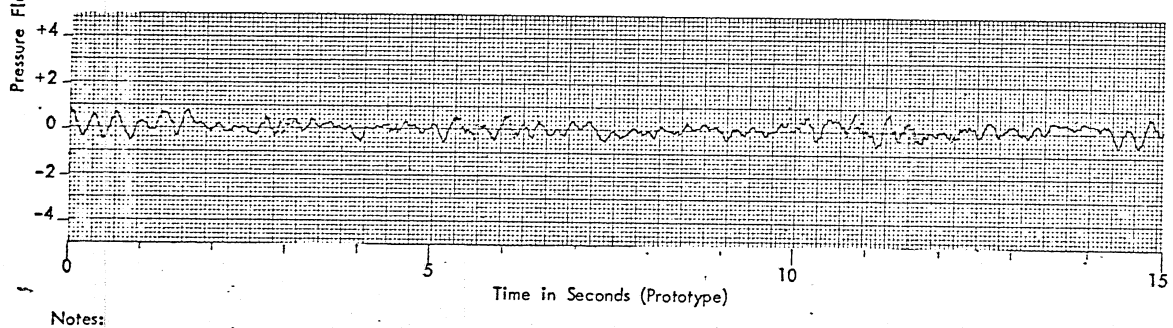


RES = 1150
USGO = 16 %
DSGO = 17 %



Sketch showing transducer location in the gate

Pressure Fluctuations About the Mean In Feet of Water



RES = 1170
USGO = 24 %
DSGO = 13 %

COMPARISON OF PRESSURE FLUCTUATIONS ON THE DOWNSTREAM RIGHT GATE FOR TWO RESERVOIR ELEVATIONS

Q = 1550 cfs
HW = 1180 ft.
TW = 1130 ft.
Model Scale 1:38.3

Notes:

1. Transducer used was a 2.5 psi C.E.C., flush mounted type.
2. Pressure fluctuations are shown with reference to gage zero which corresponds to the reservoir elevations listed.

MODEL STUDIES–FOOTHILL FEEDER PROJECT
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Harza Engineering Co., Chicago, Ill.

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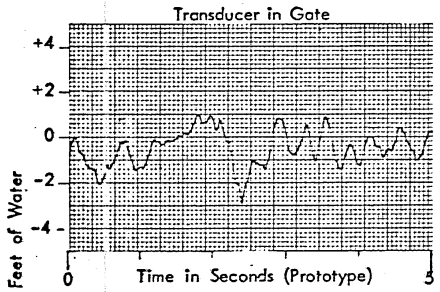
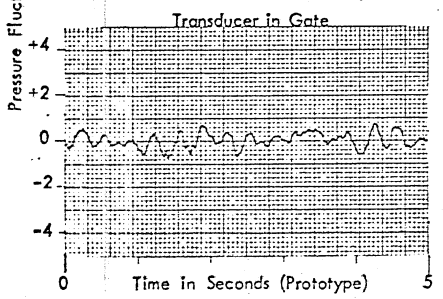
SCALE DATE 2-8-63 NO 1498-459-235

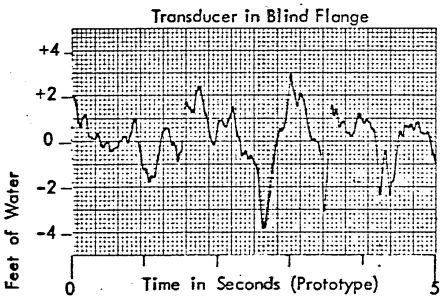


(A)
RES = 1150 ft.
USGO = 16%
DSGO = 17%

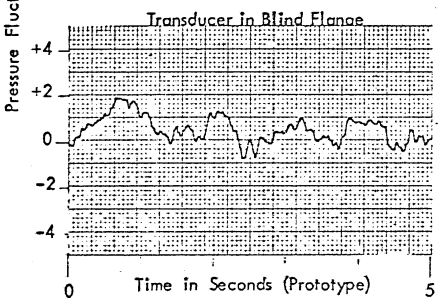


(B)
RES = 1170 ft.
USGO = 24%
DSGO = 13%

Pressure Fluctuations About the Mean in Feet of Water



(C)
RES = 1150 ft.
USGO = 21.6%
DSGO = 21.6%
(Center Gates Closed)



(D)
RES = 1170 ft.
USGO = 33.6%
DSGO = 15.5%
(Center Gates Closed)

Pressure Fluctuations About the Mean in Feet of Water

Notes:

1. Transducers used were 2.5 psi C.E.C., flush mounted type.
2. The transducer in the gate was mounted on the centerline 7.32 ft. above the gate lip.
3. The transducer in the blind flange was mounted at the center.
4. Pressure fluctuations are shown with reference to gage zero which corresponds to the reservoir elevations listed.
5. Comparison of tape A to tape B and of tape C to tape D should be made.

PRESSURE FLUCTUATIONS
ON DOWNSTREAM RIGHT
GATE AND BLIND FLANGE
ON MORRIS DRIFT

Q = 1550 cfs
HW = 1180 ft.
TW = 1130 ft.
Model Scale 1:38.3

MODEL STUDIES–FOOTHILL FEEDER PROJECT
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MORRIS RESERVOIR TURNOUT STRUCTURE

Harza Engineering Co., Chicago, Ill.

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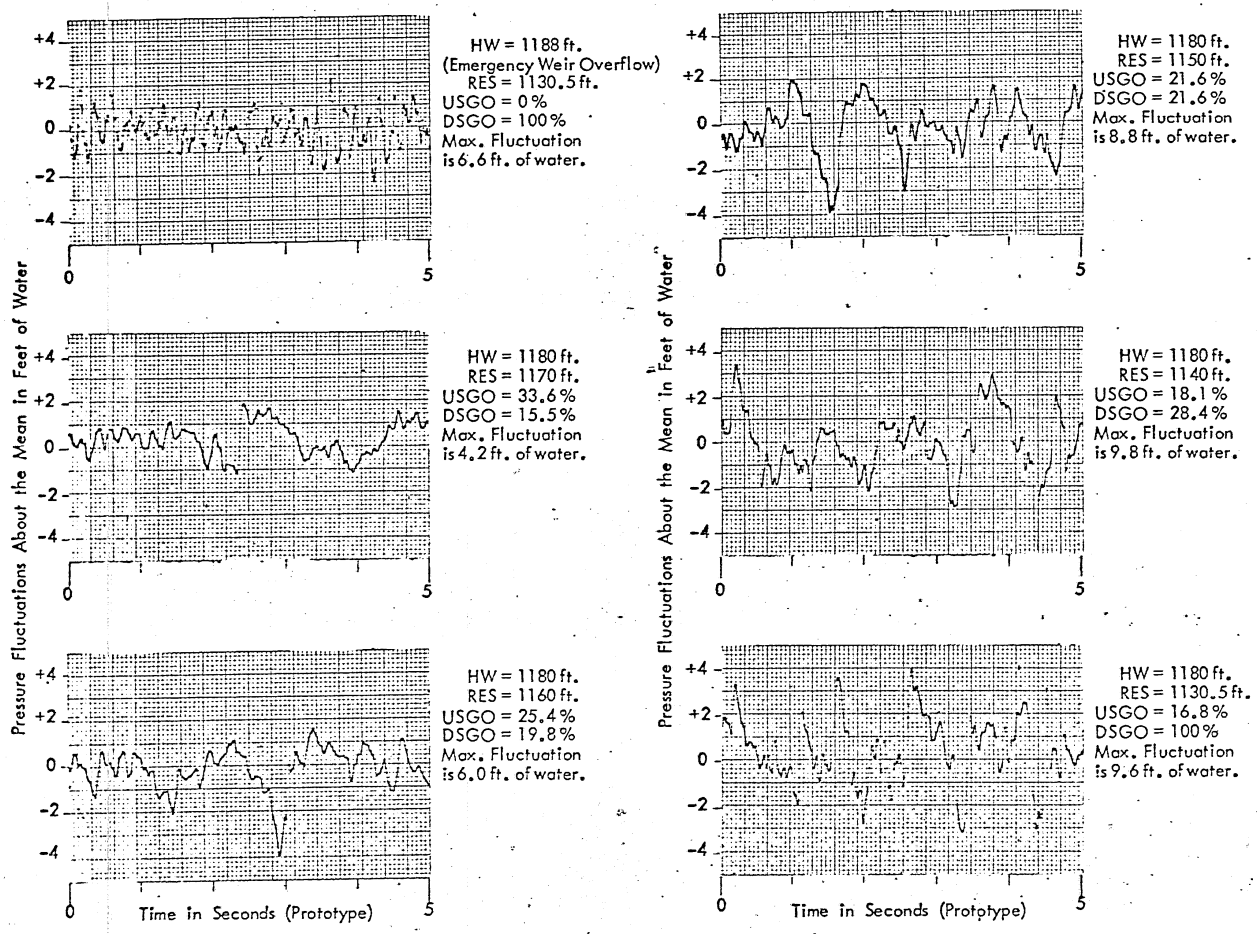

Notes:

1. Transducer used was a 2.5 psi C.E.C., flush mounted type.
2. The transducer was mounted at the center of the blind flange.
3. Pressure fluctuations are shown with reference to gage zero which corresponds to the reservoir elevations listed.
4. Maximum fluctuations listed are those found when examining data from entire test run.

COMPARISON OF THE PRESSURE FLUCTUATIONS ON THE BLIND FLANGE ON MORRIS DRIFT FOR VARIOUS RESERVOIR ELEVATIONS

Q = 1550 cfs
Model Scale 1:38.3

MODEL STUDIES-FOOTHILL FEEDER PROJECT
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SCALE	DATE 2-8-68	NO. 1688-459-237