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Chute Spillway Aerators - McPhee Dam Model/Prototype Comparison

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Abstract

In 1983 a decision was made to include aeration in the chute spillway at McPhee Dam in southwest Colorado to prevent possible cavitation damage to the chute floor near the stilling basin. Model studies were conducted to develop the design of the aerator in 1984 and field tests were conducted to compare to model measurements in 1987. This paper describes the measurements taken and compares model and prototype results.

Introduction

McPhee is the main storage and regulation reservoir in the Dolores Project in southwest Colorado. The dam is an earthfill structure 82.3 m high and 396 m wide at the crest. The chute spillway and stilling basin are located in the right abutment of the dam. The chute is 18.3 m wide, 303 m long and drops 90 m in elevation from the maximum water surface to the stilling basin. The stilling basin is a combined hydraulic jump/flip bucket energy dissipator. At a flow of about 425 m^3/s the jump will wash out of the stilling basin and the flow will flip into a plunge pool downstream from the basin. Figure 1 is a section through the spillway.

A model study was conducted before the dam was constructed to develop the design of the spillway [Pugh, 1981]. This study included the approach channel, the chute, the stilling basin, and the exit channel in a 1:36 scale model. When the spillway was completed, the surface tolerances required to prevent cavitation damage during high releases were not obtained. A decision was made to include aeration to prevent cavitation damage and to minimize future maintenance costs associated with maintaining close surface tolerances. A prototype test was run upon completion of the spillway modifications.

Model Study

Since the 1:36 scale model was still available, it was modified to study the addition of aeration. Initially, two aeration devices were located at stations 13+99 and 15+94. Figure 2 shows the model operating with two aerators and the prototype operating at 142 m^3/s.

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Subsequently, additional analysis of the spillway indicated that one aeration device located at station 15+29 would provide adequate aeration to prevent cavitation damage.

The aeration device location was determined by the cavitation potential and the geometry of the spillway. The cavitation potential is determined by analysis of the flow with a computer program [Falvey, 1989]. The program indicated that the major cavitation potential is in the lower part of the chute where the cavitation index drops as low as 0.135. The aeration device was located where the minimum cavitation index is 0.195, this location is above the point where damage would be expected. The ramp angle was chosen to throw the jet onto the last vertical curve in the spillway to minimize impact pressures and splash. This design allowed 1.52 m of freeboard on the chute walls for the maximum flow depth of 1.66 m, to allow for bulking. The aeration consists of a ramp at a 6.4° angle with the chute floor. The ramp, at station 15+29, is 0.91 m high and 7.8 m long. A ramp without a slot in the chute floor was chosen since there was adequate freeboard available and a slot would require cutting into the chute floor, thus destroying the continuity of the reinforcing steel. Air vent openings (0.91 m by 1.22 m) were cut into the side walls at the downstream end of the ramp, and towers (1.22 m by 1.22 m) were placed on the outside of the walls to provide the air. Figure 3 shows the configuration of the aeration device. The exact location of the ramp was determined by the location of the structural panel in the approximate location desired. The entire ramp, ports, and towers were contained within one panel to facilitate construction.

Model Measurements

Measurements taken in the model included:

(1) Piezometric pressure profiles upstream and downstream from the ramp and on the downstream side of the ramp.

(2) Cavity length under the jet at the sides and the center of the chute.

(3) Flow profiles along the side walls.

(4) Air demand through the air vents.

(5) Pictures and video tape at various flows.

Previous studies [Pinto, 1982] have shown that a model scale of 1:10 to 1:15 is needed to overcome surface tension and viscous effects which limit air entrainment in a scale model. Pinto found that model air demand was considerably less than prototype measurements. Therefore, additional turbulence was induced (as suggested by Pinto) in the 1:36 scale McPhee model by placing 16-gauge wire mesh screen (about 3 mm per square) - 150-mm long - on the ramp. The screen ended 50 mm upstream from the end of the ramp. This screen was large enough to increase the turbulence on the bottom of the flow nappe, yet not large enough to significantly increase the flow depth. This increased the air demand in the model by 40 to 100 percent over the air demand without induced turbulence (fig. 4). The jet trajectory length was also influenced by the induced turbulence. With the increased turbulence, the cavity length downstream from the ramp was reduced by 30 to 40 percent in the model (fig. 5). Figure 6 shows the aerator operating at 940 m^3/s (note the turbulent flow entraining air on both the upper and lower surfaces of the jet). The model results are compared to prototype measurements in a subsequent section of this paper.

Prototype Tests

Field tests of the aeration ramp on the McPhee Dam spillway were performed in May 1987. The tests, which were designed to verify operation of the spillway and to evaluate the effectiveness of the aeration ramp, were limited to a maximum discharge of 142 m^3/s due to downstream channel capacity. The observations and data collected were important in the verification of hydraulic and numerical model results, even though the maximum discharge tested was only about 15 percent of the maximum design capacity.

The tests consisted of measurements and observations at three spillway discharges, 28 m^3/s, 71 m^3/s, and 142 m^3/s (fig. 7). Quantities which were measured included air demand through the vents and pressure distribution on the downstream side of the ramp beneath the jet. Observations of the jet trajectory length and details about the free surface aeration on the chute were recorded for each flow.

Measurements were accomplished with electronic instrumentation and data acquisition equipment. Due to the remote location, power was provided with a portable generator.

Air demand through each vent was measured by placing an orifice plate over the duct entrance and measuring the pressure drop across the plate with a differential pressure transducer. The orifice and duct configuration were modeled just prior to the test at a scale of 1:7.5 at the Bureau of Reclamation's hydraulic laboratory in an air test facility. With given tap locations, the coefficient of discharge, C_D for the orifice and duct combination was determined. A scaled ladder was included in the model and its effect is shown in figure 8.

The pressure distribution beneath the jet was measured with five static pressure transducers, mounted flush on an aluminum plate which was secured in the chute, figure 9. The flow observations were aided by the installation of a staff gauge mounted on the chute wall at the downstream end of the ramp, and also by lines painted on the chute walls every 3.05 m downstream from the ramp.

Each of the three test discharges were maintained for about 1 hour. The readings from the electronic instruments were taken with a computer controlled A to D scanner and a magnetic tape recorder. Flow observations were noted and video and still photographs were used to further document the test.

Model-Prototype Comparison

Common measurements between the model and the prototype included:

(1) Air demand

(2) Jet trajectory length

(3) Air pressure downstream from the ramp

A comparison between model and prototype air demand is shown on figure 4. The model air demand was increased considerably by increasing the turbulence; however, the prototype air demand was still higher. If the prototype measurements are projected to the design flow, the maximum air demand would be $\beta = 0.20$, resulting in a maximum air velocity in the vents of 63 m/s.

The jet trajectory length was close to the prototype observations before turbulence was added to the model. After turbulence was induced on the bottom of the nappe, the trajectory length was reduced in the model due to additional losses at the air water interface and reduced cavity pressures (fig. 5).

The pressure distribution under the nappe at the ramp is the driving force for pulling air in through the vents. Thus, it is important in any type of model (physical or mathematical) to reproduce the proper pressure distribution.

The air pressure downstream from the ramp was higher in the model than in the prototype. The pressure under the nappe was essentially atmospheric before turbulence was induced. After the turbulence was added, the model pressures near the side walls dropped to -0.11 m of water at a flow of 142 m^3/s. The pressure at the center of the ramp was -0.03 m. The field measurements and model pressures are shown on figure 10.

Conclusions

The use of chute spillway aerators has become increasingly popular in the past few years. Numerous model studies have been performed along with a few cases of prototype measurements. Although all the details of how and why the aerators are successful in mitigating cavitation damage are not yet understood, our ability to model the devices is improving. Air demand for small models (scales less than 1:15) can be brought closer to simulating prototype air demands by inducing extra turbulence in the model. Turbulence measurements in both the model and prototype are needed to determine the turbulence levels in the model that would correctly scale prototype air demands. Jet trajectory lengths and undernappe pressure distributions are also closely tied to the air demand. The induced turbulence in the model causes the undernappe pressures to more closely approach the prototype values. However, the jet trajectory in the model is reduced by inducing turbulence and moves further away from the prototype values.

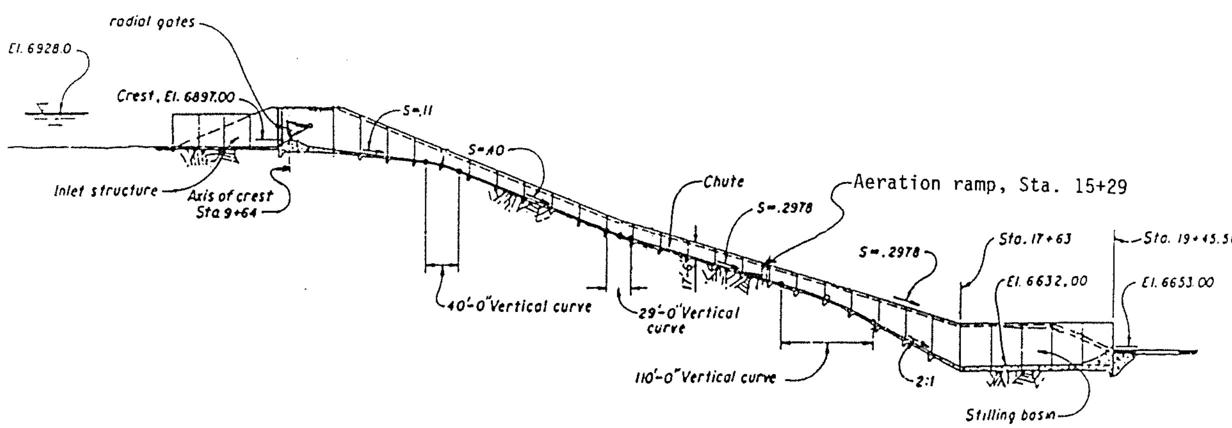


Figure 1. - Section through the spillway (1 ft = ~~0.3028~~ 0.3048 m).

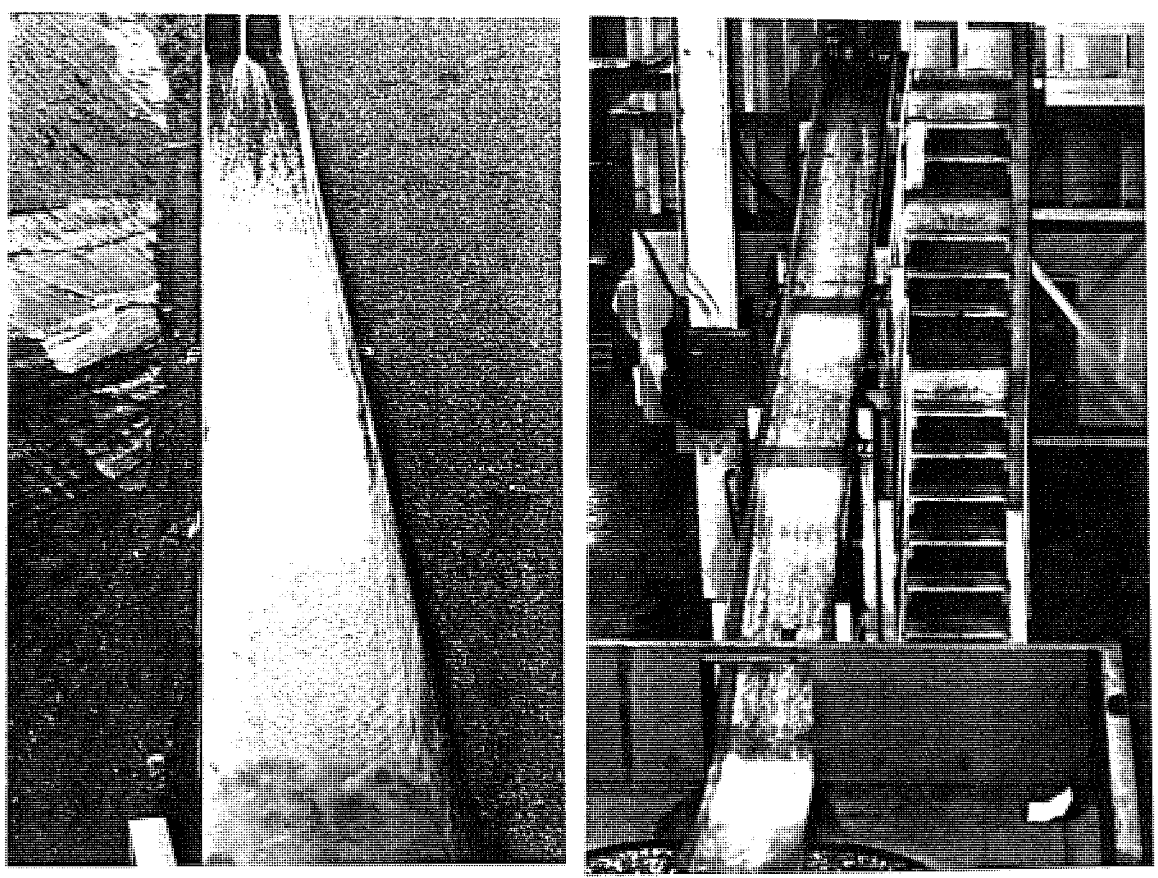


Figure 2. - Prototype and model operating at 142 m^3/s.

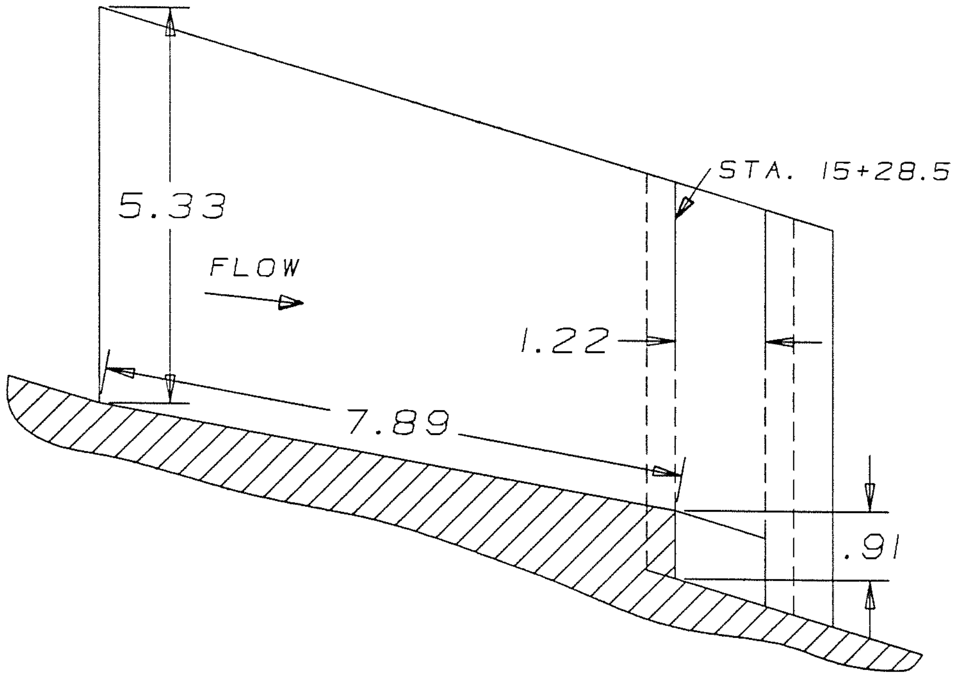


Figure 3. - Configuration of aerator.

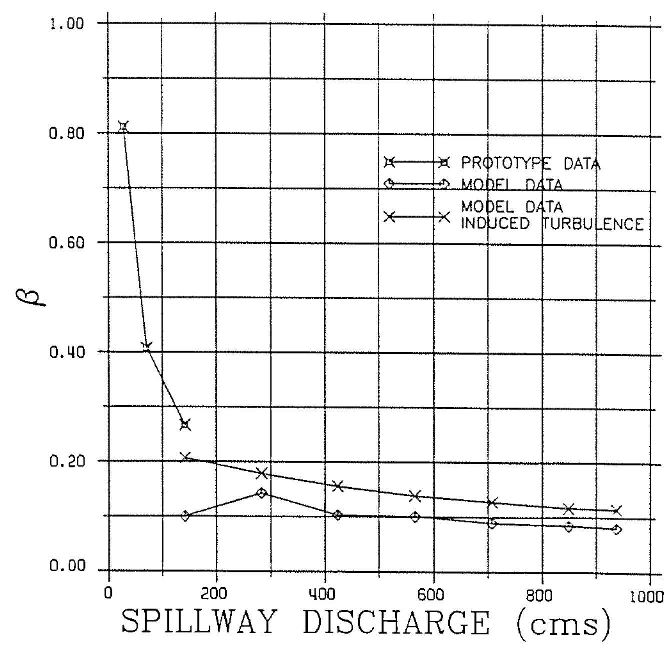


Figure 4. - Model and prototype air demand.
($\beta = Q_{air}/Q_{water}$)

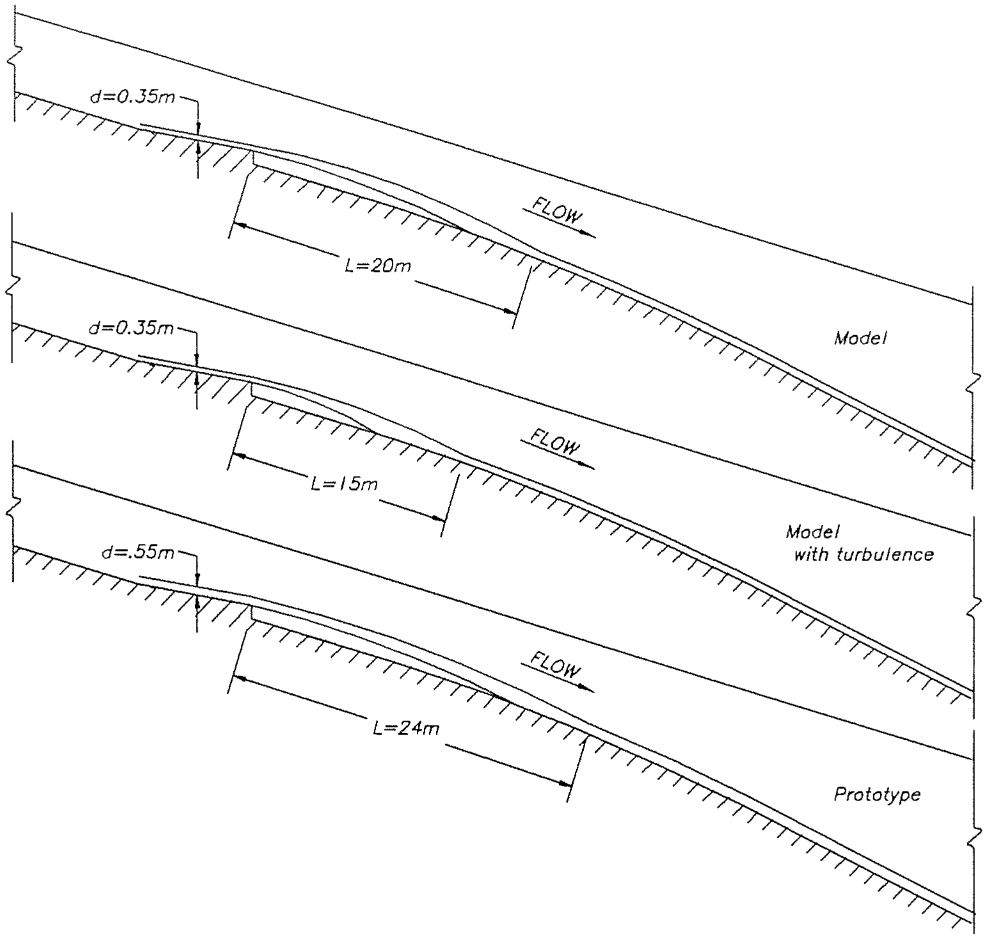


Figure 5. - Cavity lengths model and prototype at 142 m^3/s.

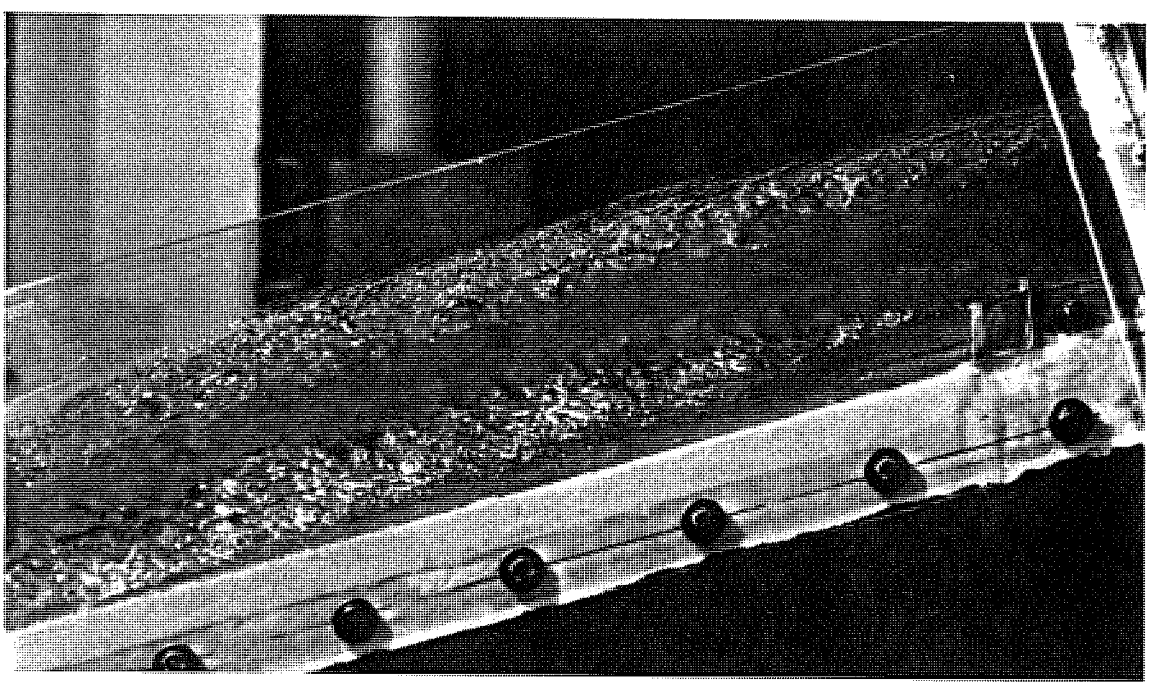
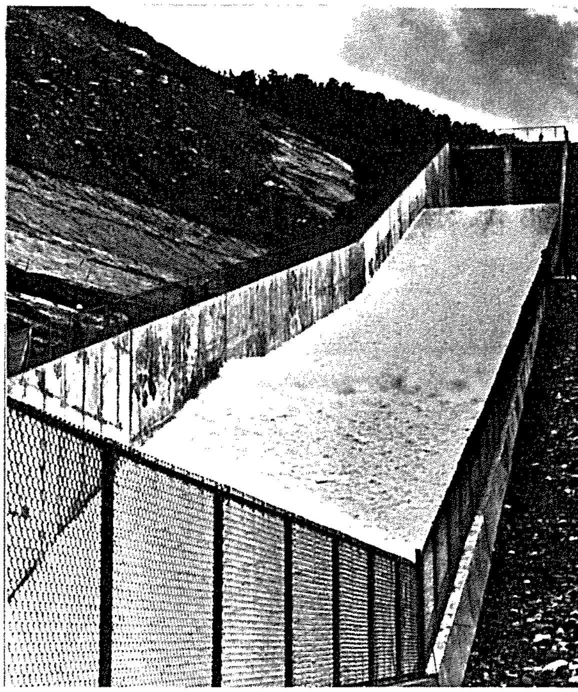
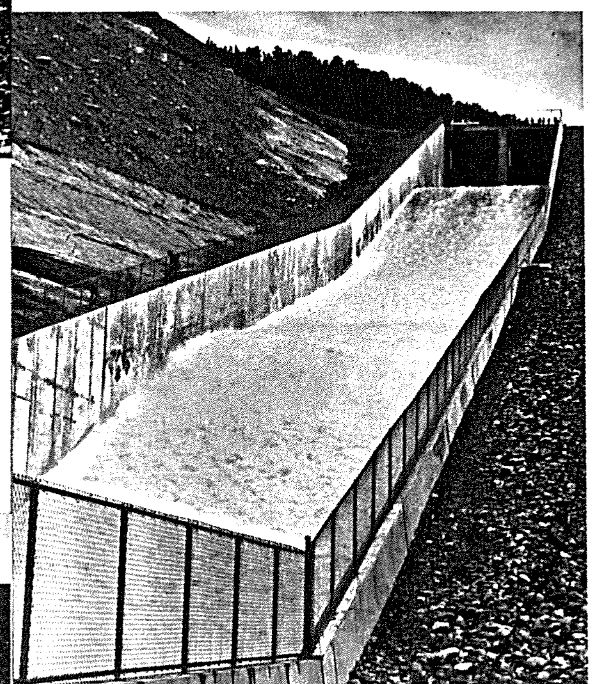


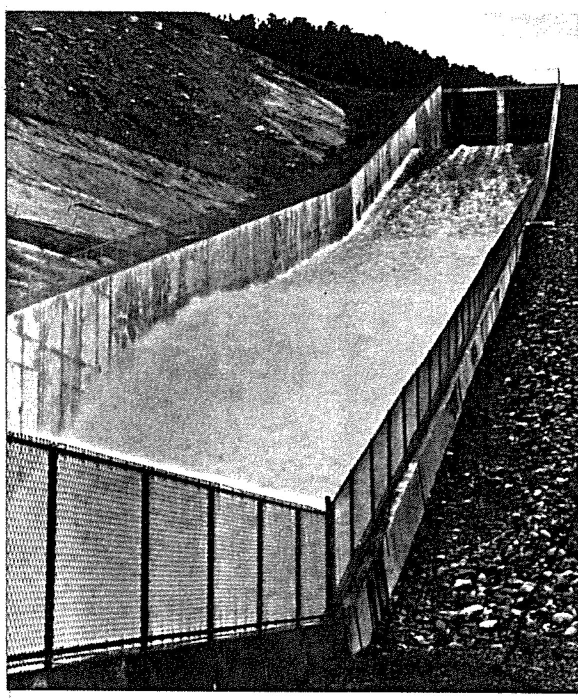
Figure 6. - Model aerator at 940 m^3/s.



a. 28 m^3/s.



b. 71 m^3/s.



c. 142 m^3/s.

Figure 7. - Prototype test flows.

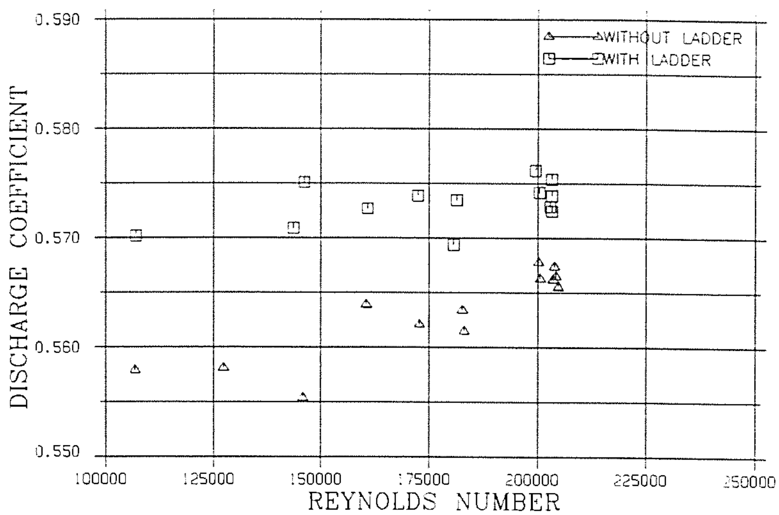


Figure 8. - Discharge coefficient for orifice and duct configuration.

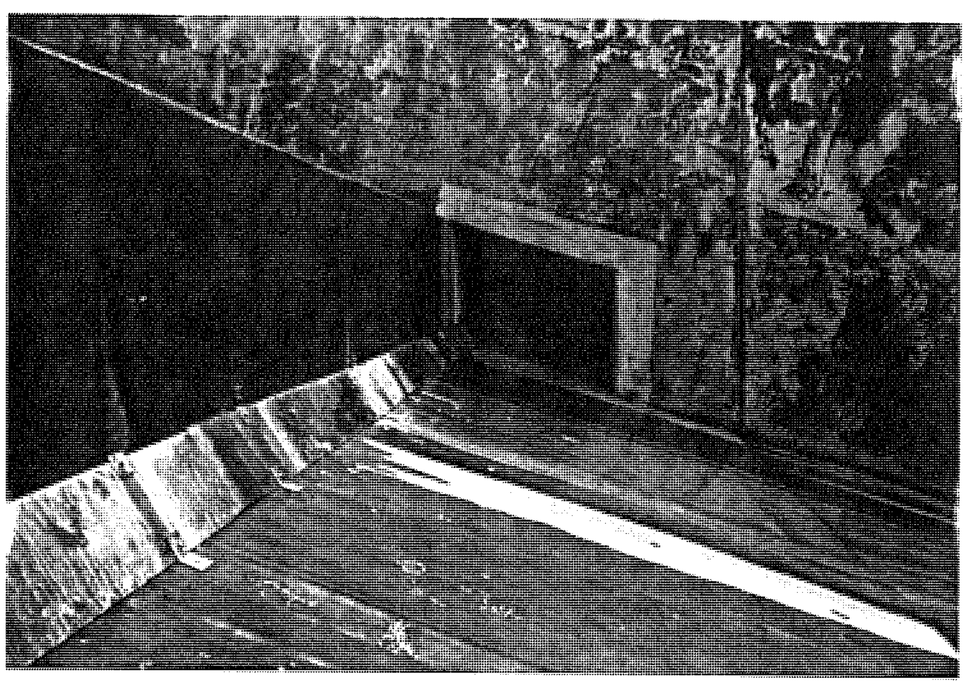


Figure 9. - Pressure transducer mounting at ramp.

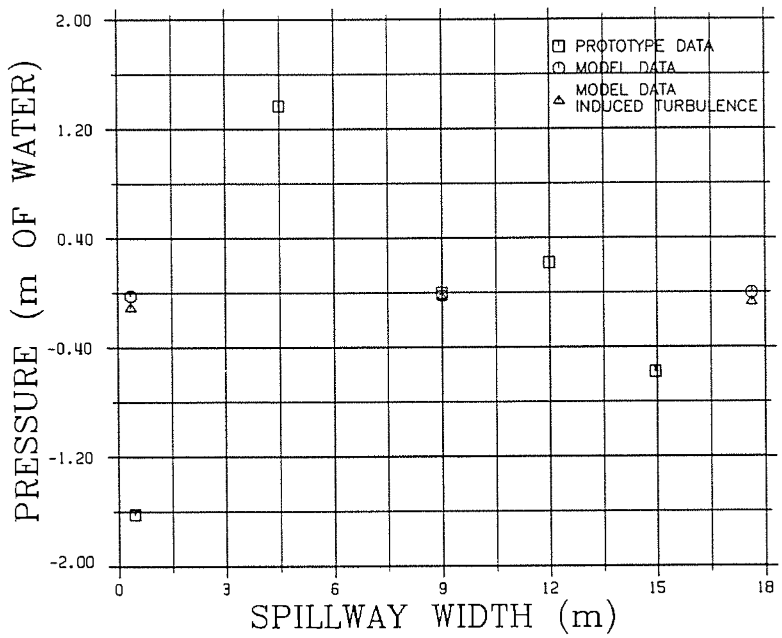


Figure 10. - Model and prototype pressure distribution downstream from ramp.

Bibliography

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2. Pinto, N. L. de S., Neidert, S. H., "Model Prototype Conformity in Aerated Spillway Flow," Cranfield, England, International Conference on Hydraulic Modeling of Civil Engineering Structures, BHRA, Paper E6, 1982, pp. 273-284.

3. Pugh, C. A., "Hydraulic Model Studies of McPhee Dam Spillway," Bureau of Reclamation, GR-81-2, Denver, Colorado, March 1981.