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Glen Canyon Dam Spillway Tests
Model-Prototype Comparison

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Abstract: Between August 1983 and August 1984, model and prototype tests were run on the left spillway of Glen Canyon Dam. The tests were used to design and evaluate the performance of the aeration slots constructed in the 41-ft (12.5-m) diameter tunnel spillways. Several parameters, including: air velocities in the aeration slot and pressures (static and dynamic) throughout the tunnels' vertical bend section were measured for comparison of model and prototype data. A computer-based data acquisition system was used for both the model and prototype tests.

Introduction

During the summer of 1983, the tunnel spillways at Glen Canyon Dam experienced major cavitation damage [1]. As part of the tunnel repair, an aeration slot was constructed in each tunnel. The aeration slots were designed to reduce the potential for cavitation damage by entraining air into the flow which reduces the sonic velocity and in turn the impact pressures as the bubbles implode. Design parameters were set through computer modeling and research on a 1:42.8 scale hydraulic model at the Bureau of Reclamations' Engineering and Research Center [4]. The aeration slot design is similar to the ones previously constructed in the spillway tunnels of Yellowtail Dam (1968) and Flaming Gorge Dam (1982). The prototype tests were used to evaluate the aerator design and its potential to reduce cavitation damage.

Instrumentation and Data Acquisition

Similar instrumentation and computer data acquisition systems were used in the laboratory and field environments.

Static pressures in the model were measured with piezometer taps and water columns; in the prototype, sealed absolute pressure transducers were used. Dynamic pressure fluctuations were measured with identical flush mounted piezoelectric pressure transducers in both the model and prototype. Air velocities in the model were measured with a hot-wire anemometer and with pitot-static probes in the prototype.

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The computer data acquisition system for both tests featured:

- System controller (desktop calculator with disk drives)
- Scanner
- High-speed digital voltmeter
- Anti-aliasing analog filters
- Spectrum analyzer

The sampling and recording of the various instrument outputs was controlled by the desktop calculator through software. The scanner performed the switching function between instruments, allowing the high-speed digital voltmeter to measure each output. The analog filters were used to prevent aliasing of digital data taken at fast rates while measuring the dynamic pressure fluctuations. The spectrum analyzer was used as a second method for obtaining frequency information from the dynamic pressure fluctuations. All data were recorded on magnetic disks for future analysis.

Testing

Testing covered a wide range of flow conditions. A limit of 50,000 ft^3/s (1415.8 m^3/s) for spillway discharge was established for the prototype test, so several flows ranging up to this point were run. During the peak flows the left spillway discharged 50,000 ft^3/s (1415.8 m^3/s), the outlet works discharged 4,000 ft^3/s (113.3 m^3/s), and the powerplant operated at 21,000 ft^3/s (594.7 m^3/s), Figure 1. In addition, a 48-hr-long prototype test at a spillway discharge of 20,000 ft^3/s (566.3 m^3/s) was run to evaluate the aeration slots effect in reducing cavitation [2]. Additional model tests were run to duplicate the exact prototype test conditions.

Results and Discussion

Due to some problems with instrumentation before the prototype test, the results are limited in some areas. However, the two pitot-static tubes measuring air velocity in the aeration slot were operational, along with two static pressure transducers at Stas. 24+60 and 25+80 and three dynamic pressure transducers at Stas. 24+20, 25+80, and 26+60.

Comparison of model and prototype average air velocities in the aeration slot is shown in Figure 2. As can be seen, the model data indicates much less air demand than the prototype. This can be partially explained through understanding the air entrainment mechanism. Primary aeration takes place as the flow passes over the elevated ramp, causing a separation from the tunnel boundary. Air is pulled into the cavity created beneath the jet and is entrained into the flow when the jet returns to the tunnel boundary. Secondary air entrainment occurs on all surfaces of the free jet, through shear drag pulling air into the flow.

The fine scale tubulence level can control the amount of air that a flow can entrain. Typical Froude law scaling does not allow proper modeling of the fine scale turbulence in a flow, hence, the discrepancy between the model and prototype data. Froude based models cannot be used to predict air demands when turbulence is a major factor in the entrainment mechanism, such as is with free jets. Some researchers, [3], have been successful in predicting air demands with large models; however, this is mainly due to Reynolds numbers and turbulence levels beginning to approach prototype values. The scale ratio required to accurately predict turbulence induced air demands has not been established at this time.

Static pressure measurements, although somewhat limited, show good conformance between model and prototype data, see Figure 3. As expected, model data can be used to predict prototype static pressure levels.

Dynamic pressure fluctuations must be dealt with in a different manner. The frequency of the fluctuations as well as the amplitudes must scale. Comparison of pressure versus time traces for model and prototype appear similar; however, the amplitudes of the fluctuations do not scale. This is because the frequency behaves as a dependent variable, not allowing separate scaling of amplitudes. Figures 4a and 4b show frequency spectrums of the dynamic pressure fluctuations at Sta. 24+20 for a range of flows in the model and the prototype. No conformance exists in either frequency or amplitude. Basic trends in the prototype spectrums show an increase in spectral power at low frequencies for increases in discharge. The model spectrums do not follow this trend and in addition show a peak in the spectral power due to bubble dynamics at scaled prototype frequencies of 120-180 Hz (800-1200 Hz model). Reasons for the non-conformance are not fully understood at this point.

Conclusions

The outcome of model and prototype data measurements was as expected. Static pressure measurements compared well. However, the aeration parameters and the dynamic pressure fluctuations showed little or no conformance. This is largely due to the limitations of a Froude scaled model in accurately representing turbulence properties.

The prototype tests were invaluable for evaluation of parameters which are not easily modeled. The prototype data can also be used in evaluating theoretical approaches.

The aeration slots constructed at Glen Canyon Dam performed satisfactorily, with the left spillway tunnel exhibiting no cavitation damage. Based on previous experience at Glen Canyon Dam in 1980 and 1983, damage would have been expected during the 1984 test without the aeration slot.

Appendix

[1] Burgi, P. H., Bruce, M. Moyes, and Thomas W. Gamble, "Operation of Glen Canyon Spillways - Summer 1983," Proceedings of the 1984

ASCE Hydraulics Division Specialty Conference, Coeur d'Alene, Idaho, August 14-17, 1984.

[2] Falvey, H. T. "U.S.B.R Engineering Monograph on Cavitation," to be published.

[3] Pinto, Nelson L. de S., and Sinildo H. Neidert, "Model Prototype Conformity in Aerated Spillway Flow," International Conference on Hydraulic Modeling of Civil Engineering Structures, BHRA Fluid Engineering, Paper E.6, 22-24.09.83, Coventry, England.

[4] Pugh, C. A., "Modeling Aeration Devices for Glen Canyon Dam." USBR publication, to be published.

Note: 1 ft = 0.3048 1 lb/in^2 = 6.89 KPa

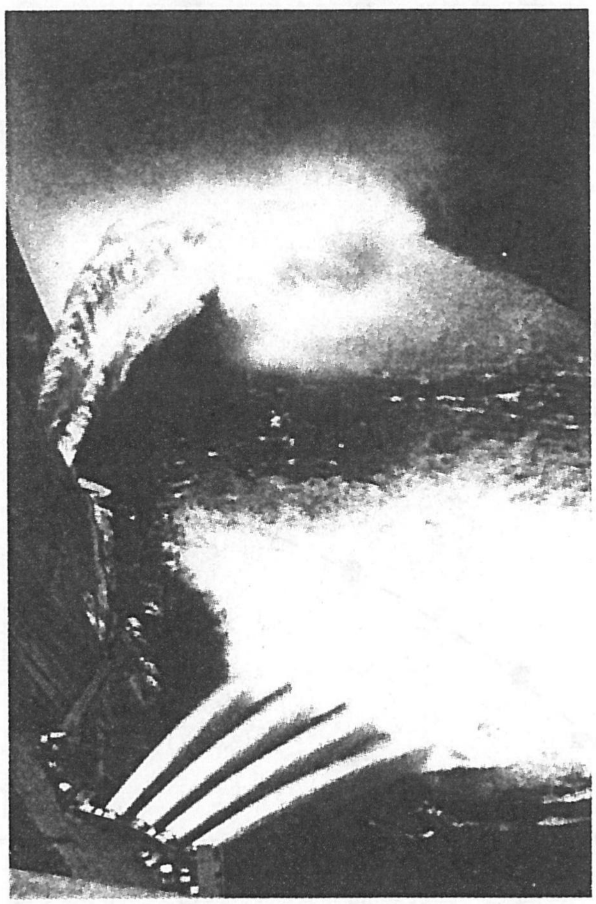

Figure 1. - Prototype test at Glen Canyon Dam: left spillway discharging 50,000 ft^3/s (1415.8 m^3/s).

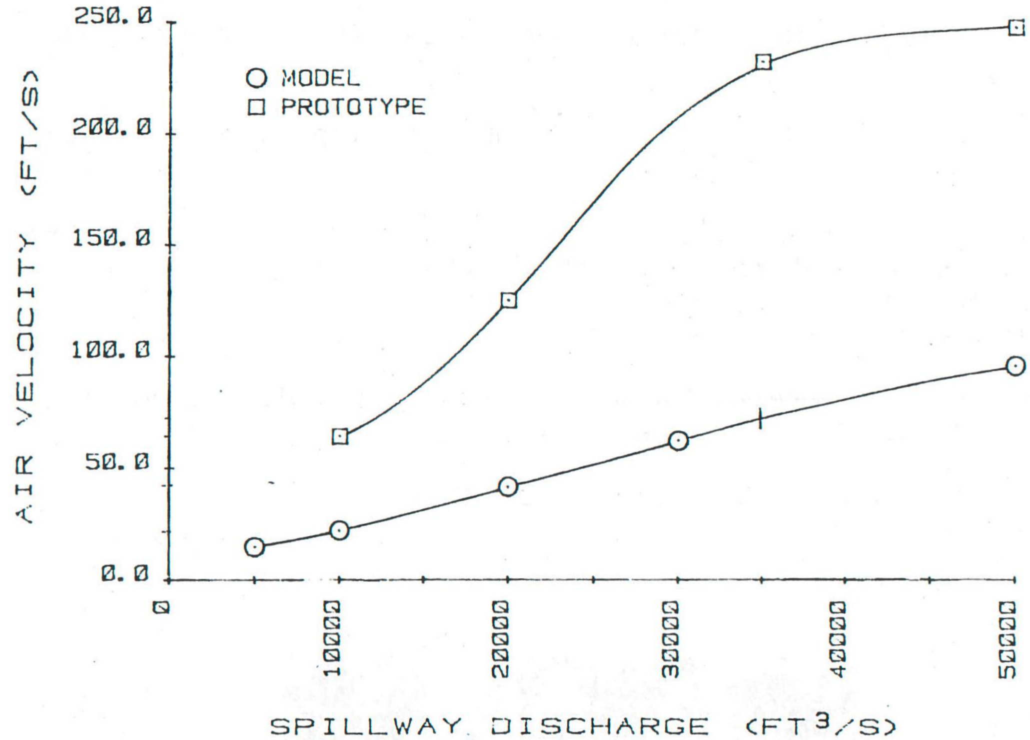

Figure 2. - Model-prototype comparison of air velocities measured in the air slot.

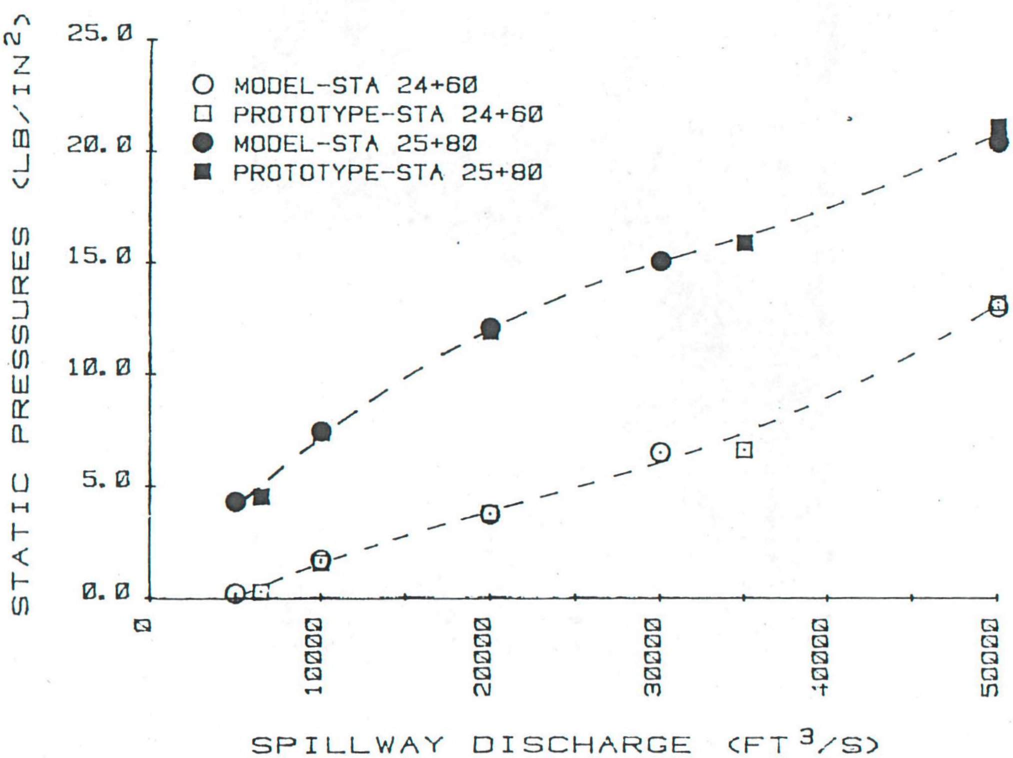

Figure 3. - Model-prototype comparison of static pressures in the vertical bend section, Sta. 24+60 and 25+80.

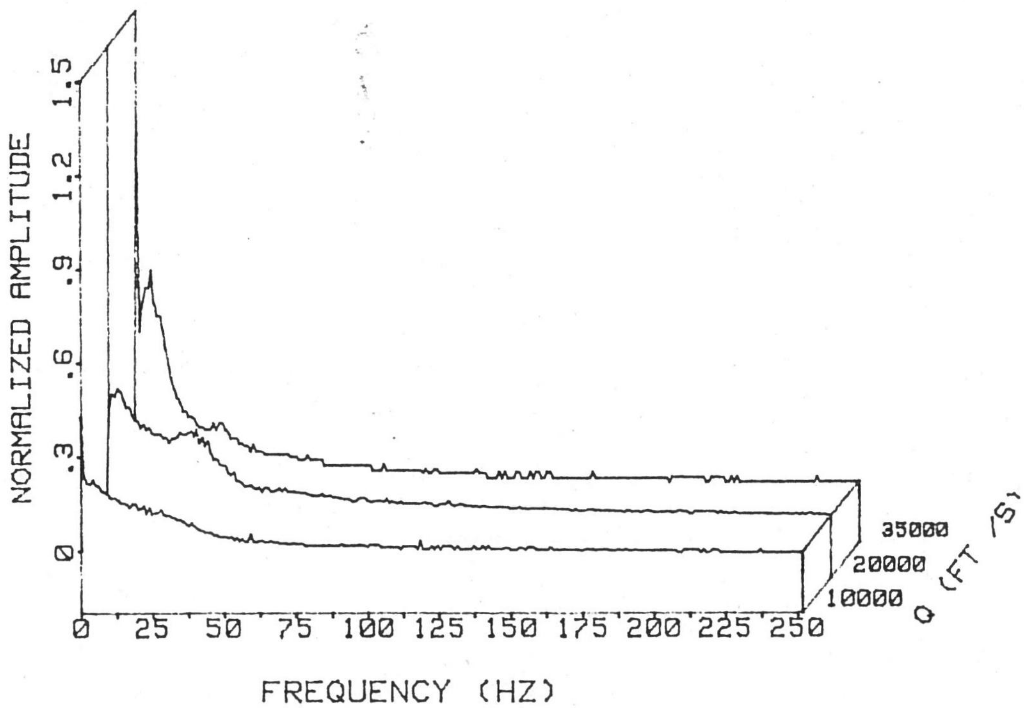

Figure 4a. - Prototype spectrums of dynamic pressure fluctuations at Sta. 24+20.

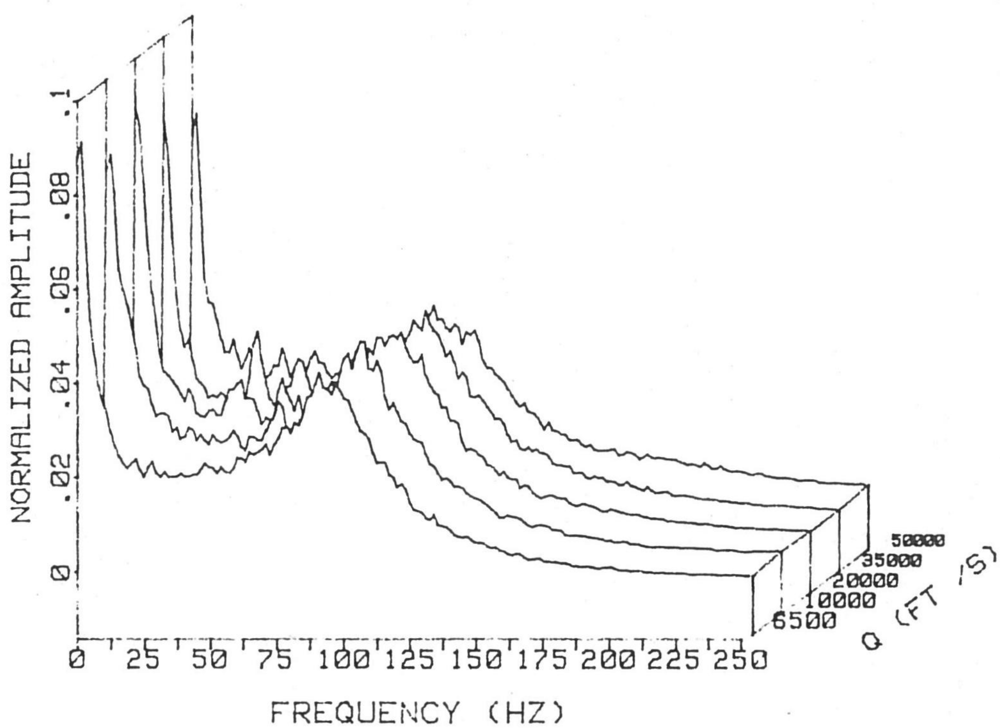

Figure 4b. - Model spectrums of dynamic pressure fluctuations at Sta. 24+20, (scaled to prototype values).