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HYDRAULIC MODEL STUDY RESULTS

HOOVER DAM TUNNEL SPILLWAYS

BY

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Memorandum
Head, Design Section 1

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Head, Hydraulic Structures Section

Hydraulic Model Study Results for the Hoover Dam Tunnel Spillways

PURPOSE

The model study was performed to develop an aeration device for the Hoover Dam tunnel spillways. The Arizona spillway, modeled at a 1:52.174 scale, included the side channel spillway entrance in the reservoir and the full length of the tunnel, including the flip bucket at the tunnel exit. The results from the Arizona spillway are valid for the Nevada spillway as well because the geometries are similar except for a horizontal bend downstream of the vertical bend in the Nevada spillway. The dimensions and location of the aeration device, the tunnel discharge capacity with and without the flip bucket, and pressures in the tunnel and flip bucket caused by a transient hydraulic jump were determined during the study.

OBSERVATIONS OF THE TUNNEL FLOW CONDITIONS

Initial model tests revealed flow conditions that would affect the aeration device design. They were (1) a rough water surface and spiraling flow in the sloping portion of the tunnel caused by flow exiting from the side channel spillway, (2) a hydraulic jump in the tunnel due to the decreased flow area at the flip bucket, and (3) pressure flow in the tunnel near the design discharge. The typical turbulent flow condition upstream of the aeration device is seen on figure 1. The energy dissipation which occurred in the side channel spillway produced a spiraling flow down the center of the tunnel and a very rough water surface. These conditions made it necessary to develop a tunnel aeration device different from previously designed air slots.

The tunnel area constriction at the flip bucket produced three different flow phases - free flow until the discharge is greater than 135,000 ft^3/s, a transient hydraulic jump in the tunnel for discharges between 135,000 and 185,000 ft^3/s, figure 2, and pressure flow at higher discharges. With the hydraulic jump in the tunnel extremely high pressure fluctuations were measured. The initial aeration device reduced the pressure fluctuations by producing a freer water surface for the full length of the near horizontal tunnel. This aerator, however, became submerged as the jump traveled upstream. Further refinement of the aerator design reduced the pressure fluctuations at the flip bucket and increased the discharge before the aerator was submerged by the hydraulic jump.

AERATOR DESIGN

The location of the aerator is determined by a computer program that, among other parameters, calculates the flow sigma or cavitation index. This index defines the location of incipient cavitation where aeration must be provided to protect the flow surface downstream. The aerator should be located where the cavitation index is not less than 0.20 to prevent cavitation damage from occurring downstream where the index is smaller. The location and configuration of the recommended aerator for the tunnel is shown on figure 3.

This design was dictated by the poor flow conditions produced by the side channel spillway and the flip bucket. The design consists of two separate sections meeting at invert station 8+75.13 in the conical section of the tunnel and forming an 8-foot offset away from the flow. The first section, a ramp, beginning at invert station 8+64.04, forms a 10° angle with the 50° sloping tunnel, is 17.26 feet long and 3 feet high at the invert. The design radius of the original tunnel should be 25.46 feet at station 8+75.13 with the end of the ramp formed by a 24.08-foot radius returning to the original tunnel lining above the springline, 35° either side of the crown. The second section forms the aerator vent and transition to the original tunnel surface. This section begins at station 8+75.13 with a 5-foot concentric offset away from the original tunnel surface, returning on a 1:5 slope in a length of 25 feet. This ramp and combined vent and transition replace the traditional "slot" design and prevent the aeration area from filling with water under free flow conditions.

This aeration ramp design provided excellent aeration under the jet. No outside vent for aeration should be required in the prototype. Figure 4 shows the aeration ramp and the aerated jet.

TUNNEL DISCHARGE CAPACITY

The spillway tunnel without the flip bucket will pass the maximum discharge of 200,000 ft^3/s under free flow conditions. However, with the present flip bucket configuration, the tunnel discharge should be limited to 135,000 ft^3/s to avoid the transient hydraulic jump, figure 2. As the discharge approaches the design discharge, the tunnel becomes pressurized and acts as a submerged drop-inlet spillway with a reduced discharge capacity, figure 5. The maximum discharge at reservoir elevation 1232 under pressurized flow is 191,000 ft^3/s; with free flow conditions, the maximum discharge is about 203,000 ft^3/s. The areation ramp was in place during the calibration but had a negligible effect on the discharge capacity.

PRESSURES MEASURED AT THE FLIP BUCKET

The flow constriction produced by the flip buckets in both tunnel spillways (figure 6) should be alleviated. This constriction causes a severely limited range of satisfactory operation. When the transient hydraulic jump formed in the tunnel, high pressure fluctuations and vibrations immediately became evident. These pressures were due to the explosive decompression of air pockets trapped along the tunnel crown as they were released from the end of the tunnel. Magnitude and frequencies of the pressures were measured using pressure transducers located at station 26+77 on the flip bucket ramp and tunnel crown. The pressures on the crown and invert were essentially the same. Data were taken for prototype discharges of 145,000 and 175,000 ft^3/s. A typical strip chart record (Q = 145,000 ft^3/s) of the pressures is shown on figure 7.

The pressure data taken from the strip charts are presented in terms of instantaneous peak, average, and observed frequently occurring peak values. Minimum pressures in each case reached vapor pressure. For a discharge of 145,000 ft^3/s, the average pressure was 177 feet with instantaneous peaks of 470 feet. A discharge of 175,000 ft^3/s produced an average pressure of 230 feet with instantaneous peaks of 500 feet. These high magnitude peak pressures did not occur often; therefore, a more reasonable peak pressure was chosen from the recorded data for purposes of evaluation. Frequently occurring peak pressures were 300 and 400 feet for discharges of 145,000 and 175,000 ft^3/s, respectively. These values occurred with an average frequency of 0.1 to 0.4 Hz and should be considered when evaluating the stability of the tunnel lining near the flip bucket.

These poor flow conditions and high pressure fluctuations could be alleviated by any of the following flip bucket modifications or operating procedures:

a. Remove the flip buckets and replace them further downstream so they will be located outside of the tunnel enclosure and allow a free flow surface for the full range of discharges.

b. Remove a portion of the tunnel crown above both flip bucket ramps. (This section should be about 35 feet long but has not been accurately determined in the model.)

c. Remove a portion of the tunnel crown on the Nevada spillway (where the tunnel crown is exposed) allowing passage of 200,000 ft^3/s through that spillway while limiting the Arizona spillway to 135,000 ft^3/s. This would allow passage of 83 percent of the maximum spillway discharge.

d. If no modification is made to the flip buckets, do not operate either spillway with more than 135,000 ft^3/s without completely analyzing the stresses on the tunnel lining and ensuring its integrity.

Thomas J. Rhone

Attachments

Copy to: D-220 (Quint)
D-1531 (PAP file)
D-1610 (Markwell)
D-3210

KLHouston:flh

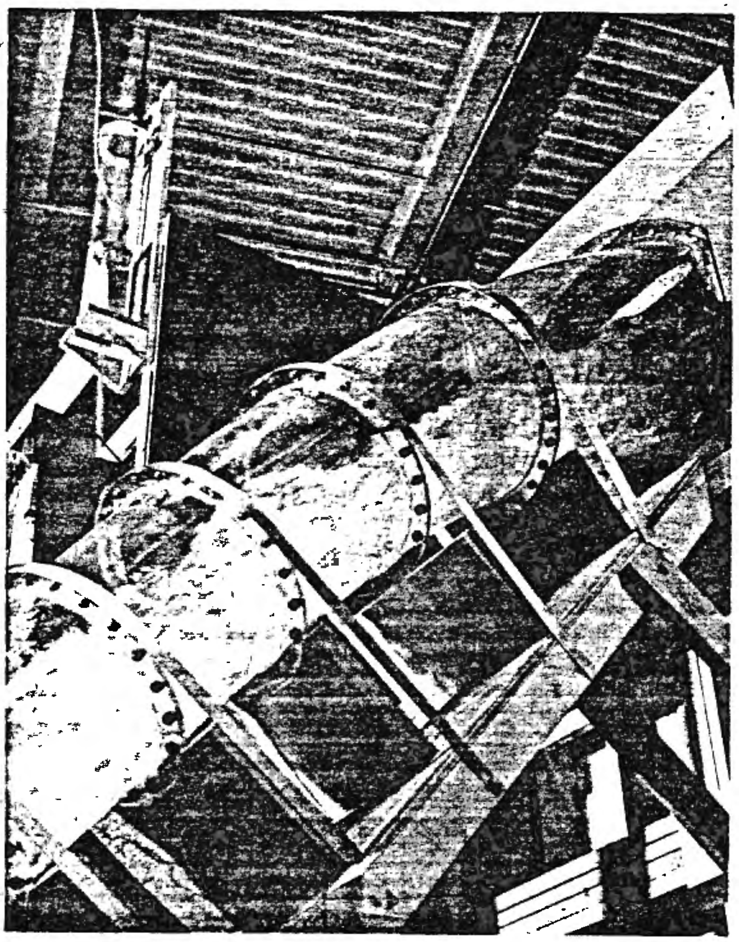

Figure 1. - Spiraling flow in tunnel upstream of aeration ramps caused by flow exiting from the side channel spillway.

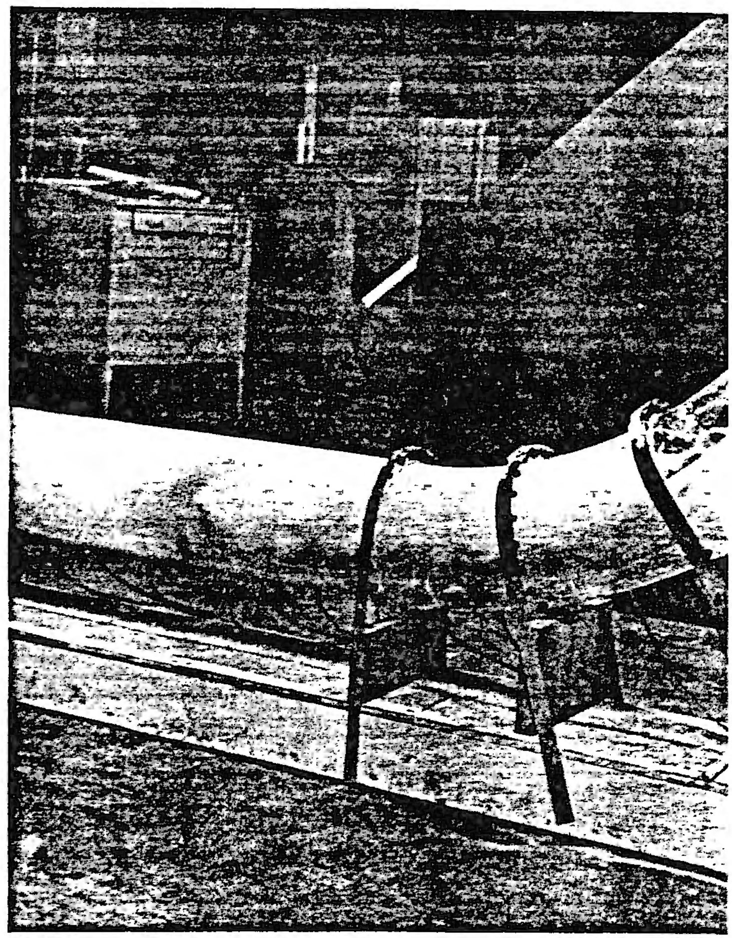

Figure 2. - Transient hydraulic jump formed in tunnel for discharges greater than 135,000 ft^3/s.

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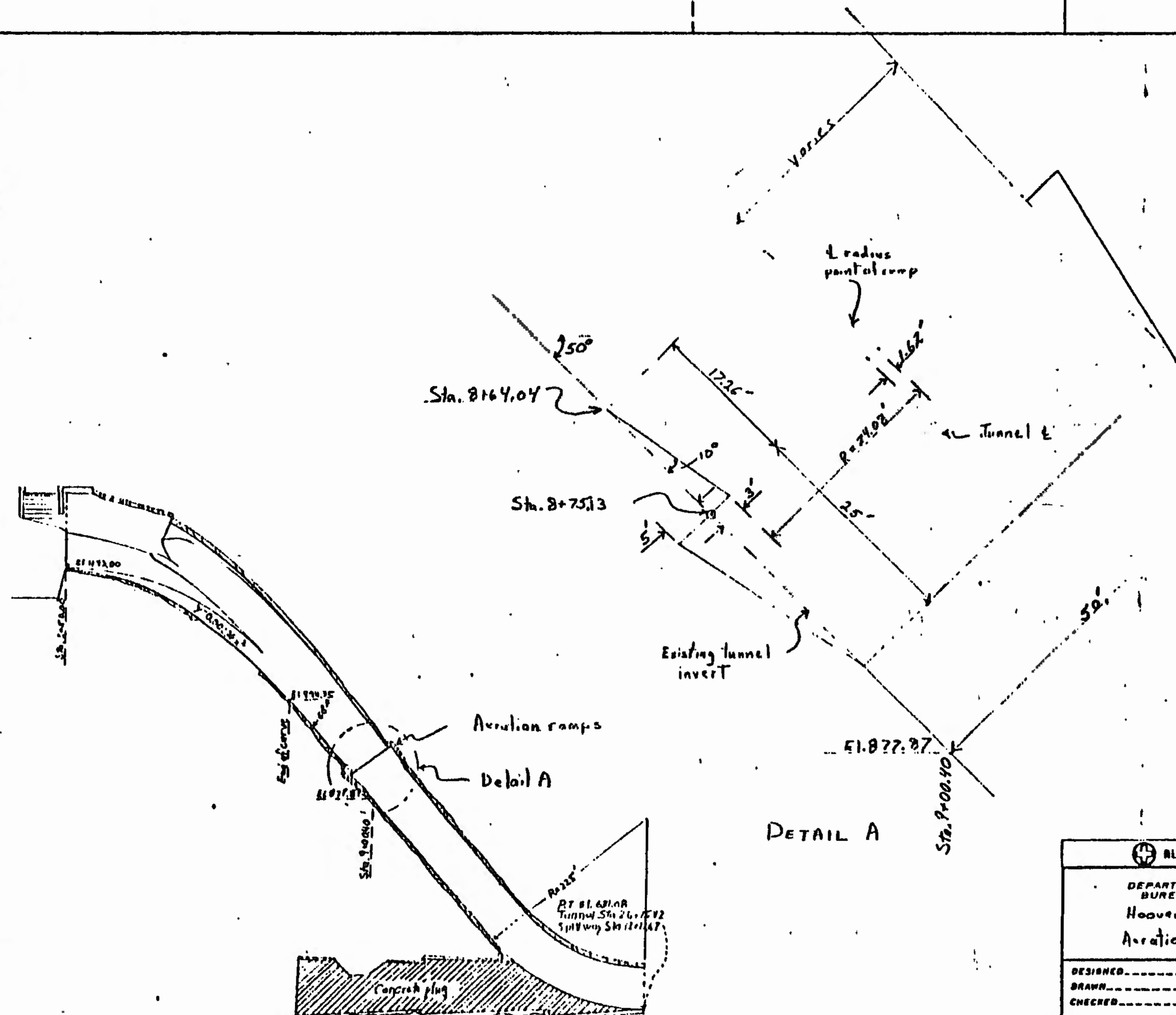

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UNITED STATES
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Hoover Dam Arizona Spillway
Aeration device design

DESIGNED.................SUBMITTED.................
DRAWN.................RECOMMENDED.................
CHECKED.................APPROVED.................

Figure 3

10½" x 15"

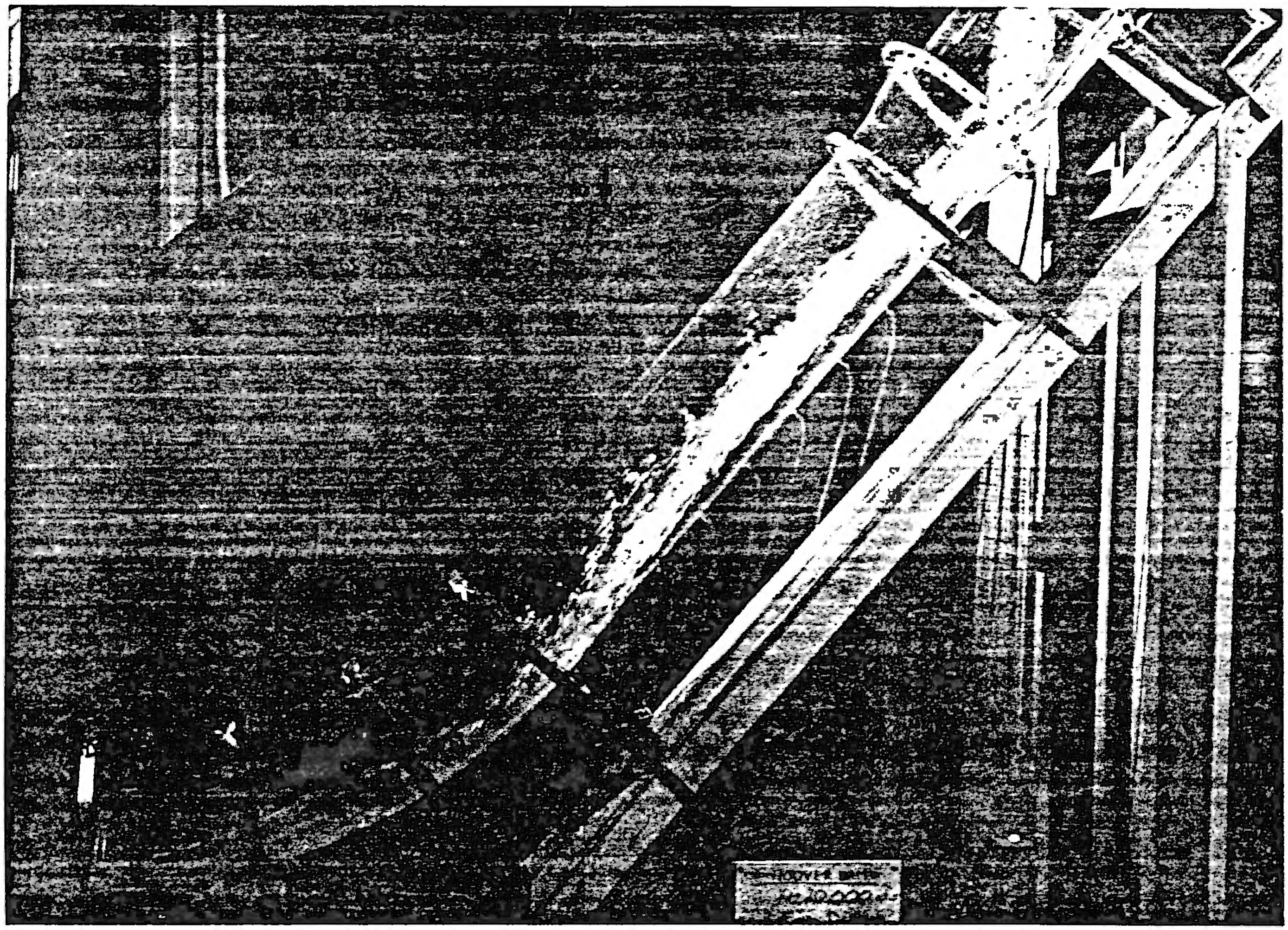

Figure 4. - Flow trajectory of 20,000 ft^3/s through the aeration ramps.

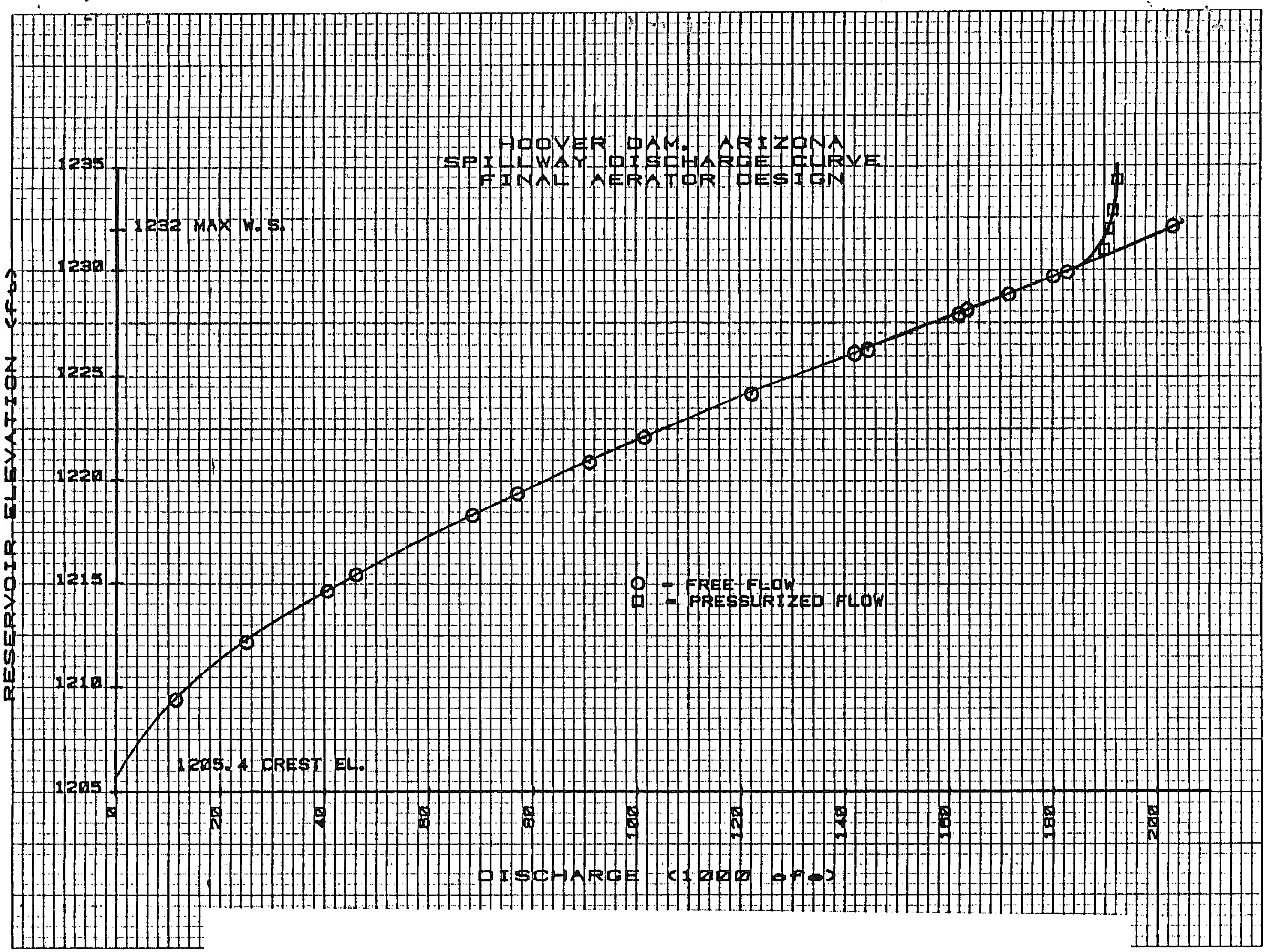

Figure 5. - Discharge curve for the Hoover Dam Arizona spillway with the aeration device installed.

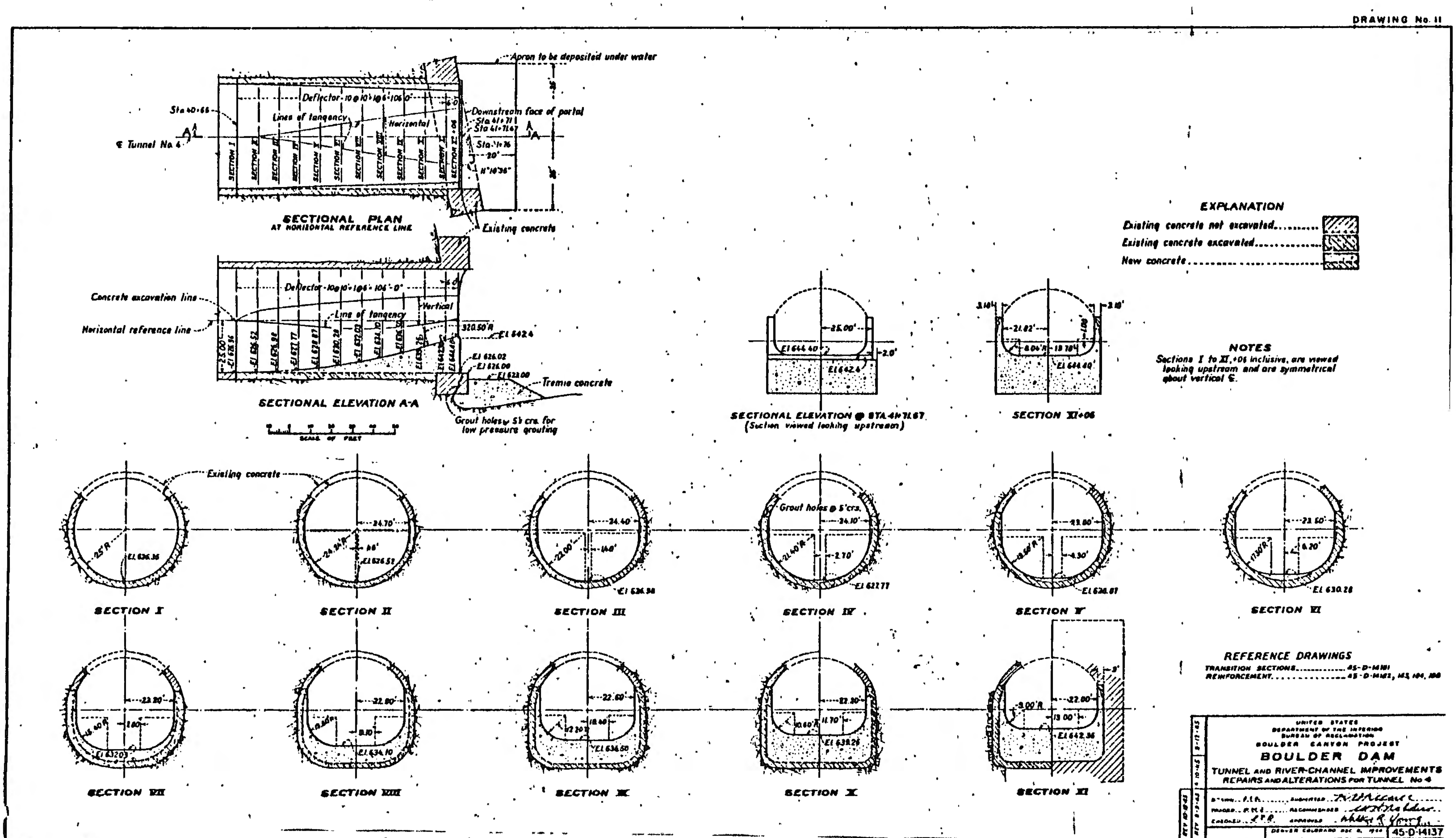

Figure 6. - Sectional plan and elevation of the flip buckets for both the Arizona and Nevada spillways.

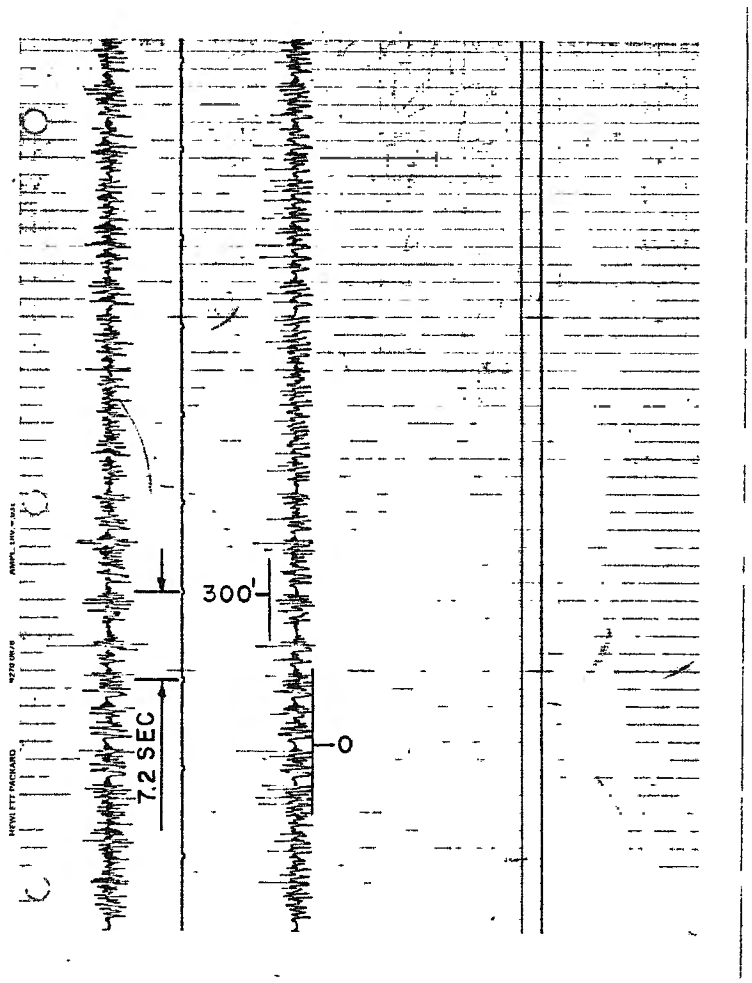

Figure 7. - Typical strip chart record of pressures at the flip bucket for a discharge of 145,000 ft^3/s.