UNCONTROLLED OGEE CREST RESEARCH

An ogee crest is a common control structure shape for service spillways, including morning glory inlets, side channel inlets, and controlled and uncontrolled overfall chutes. Consequently, the ogee crest has received much attention by researchers and its hydraulic characteristics are well understood.

The discharge over an uncontrolled ogee crest is influenced by a number of factors:

- Actual crest shape with respect to ideal nappe shape
- Ratio of actual head to design head
- Height of crest apex above the entrance channel invert
- Approaching flow velocity
- Downstream apron interference or tailwater submergence
- Upstream face slope

Thorough discussions of ogee crest design can be found in design manuals prepared by Reclamation (1987) and COE (Corps of Engineers) (1952).

Hydraulic Design Considerations

Uncontrolled ogee spillway profiles are traditionally constructed to match the lower nappe surface produced by flow over a fully ventilated sharp-crested weir. Reclamation (1948) and many other researchers have measured lower nappe profiles and have developed design criteria for ogee crest geometry. A properly designed and constructed ogee crest shape will result in a discharge coefficient of 3.90 at design head, while atmospheric pressure is maintained on the spillway surface. However, for heads greater than the design head subatmospheric pressure develops on the spillway crest, resulting in suction which pulls water over the crest and causes the discharge coefficient to increase.

Understanding that improved spillway efficiency is possible by operating at heads greater than the design value has led Reclamation and COE to routinely "underdesign" ogee crests for heads equal to 75 percent of the maximum expected head.

The upper limit of increasing discharge capacity is reached when the nappe is susceptible to springing free from the crest. Research by Cassidy (1970) indicates that nappe separation may occur for heads greater than three times the design head. However, ongoing hydraulic model studies by Reclamation indicate that under ideal entrance conditions (i.e. no contractions) discharge coefficients continue to increase for heads five times the design head. However, this condition is extremely unstable and nappe separation can occur from very small surface disturbances. Conditions such as flow contractions, offsets, or gate slots that will allow aeration may cause the nappe to prematurely spring free from the crest. If the air source is interrupted the nappe will reattach and may result in an oscillatory condition.

Current Reclamation Research

Background

In many instants dam owners are confronting the requirement to pass increased flows as a result of a revised PMF (Probable Maximum Flood) estimates. This issue is raising new questions on how far can we stretch existing design limits. When addressing this problem a commonly asked question by many dam owners is; can I safely pass more flow through an existing Ogee crest spillway if the head is raised above original design limits. This question has been the subject of several site specific model investigations at Reclamation (Vermeyen, 1991, Dodge, 1989, Houston, 1987, Johnson, 1987). The latest case study by Vermeyen investigated an ogee crest design desired to operate at 5 times design head (h_d) under PMF conditions. A general rule of thumb used within Reclamation is to limit the operation of ogee crests to heads less than $3*h_d$. This criteria is largely used to prevent the flow from springing free of the crest. However, flow detachment is highly dependent on approach geometry and therefore $3*h_d$ is not considered absolute. A literature search on this subject has revealed very limited data (pressures or discharge coefficients) for head to design head ratios (h/h_d) greater than 3 and no data above a value of 4. To improve our knowledge of ogee crest flow at high heads the Hydraulics Branch initiated a small research study to collect additional data.

Research Program

The goal of this research effort was to extend the data limits for discharge coefficients and minimum-surface-pressures for uncontrolled ogee crests at h/h_d ratios greater than 4. A 1:20 scale ogee crest with a design head of 2.5 ft, was used. The ogee crest was mounted in a 3-foot-wide horizontal flume with straight approach conditions and a free overfall downstream. The crest was tested for heads up to 7 times the design head. It was difficult to prevent the nappe from detaching from the crest for heads greater than 5 times the design head. Even small offsets in the flume walls were sufficient to pipe air beneath the nappe resulting in flow separation. However, by eliminating the wall offsets testing of h/h_d ratios from 5 to 7 were achieved. Nappe separation was also artificially induced for h/h_d ratios greater than 3 by inserting a flow splitter into the nappe which created a path for air entrainment. When the aeration path was removed the nappe would immediately reattach to the crest for h/h_d ratios less than 5.

Discharge Coefficients

Discharge coefficients were calculated using equation 1. where; h is the total head on the crest in ft (includes velocity head, $V^2/2g$), L is the crest length in ft, and Q is the flow rate in ft^3/sec. Discharges were measured using venturi flow meters and the total head was measured using a

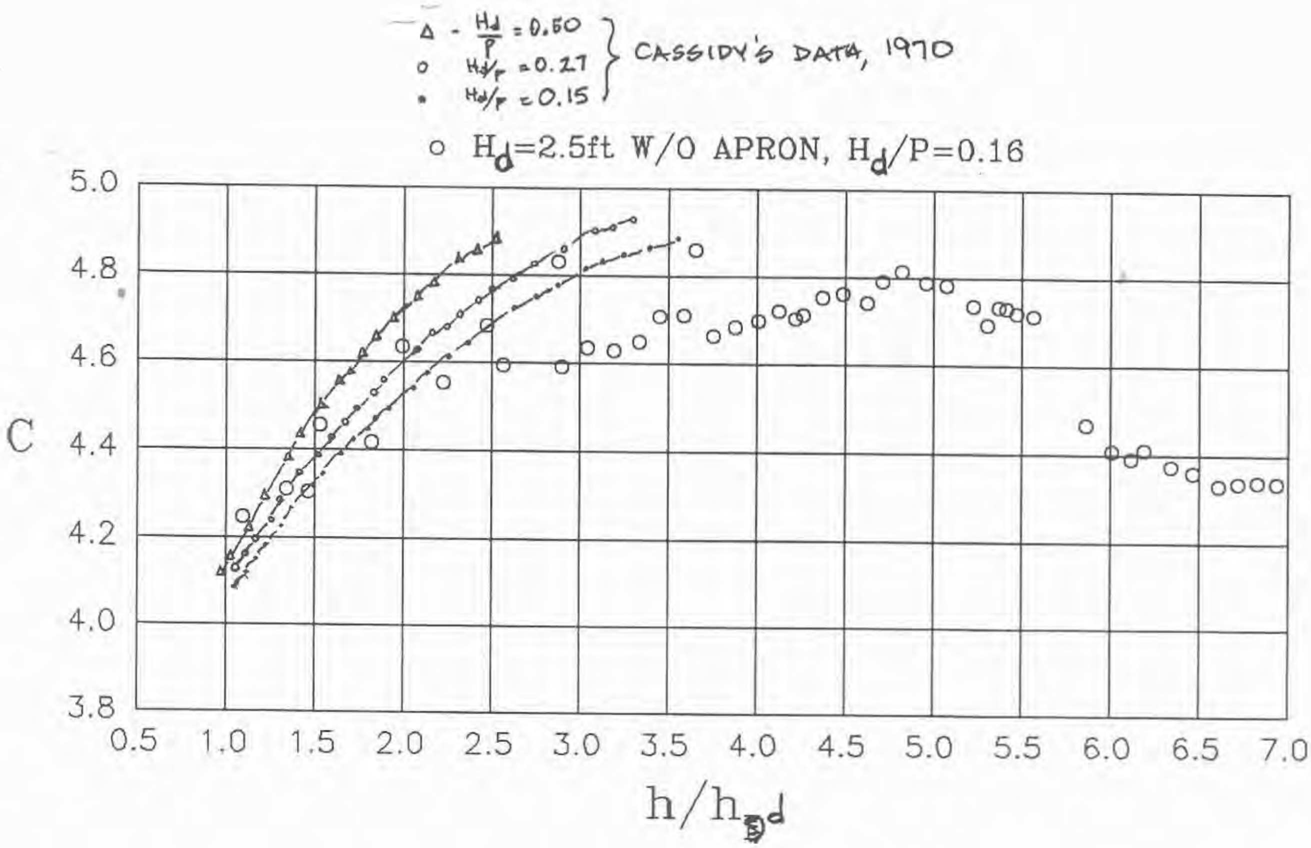

Figure 1. Discharge Coefficients for Several Ogee Crest Designs.

point gage.
In general, discharge coefficients increased with increasing discharge for h/h_d ratios up to 5.

$$C = \frac{Q}{L * h^{3/2}} \tag{1}$$

The maximum discharge coefficient (C) was 4.8 and it dropped to 4.3 for h/h_d equal to 6.50 and C remained near 4.3 for higher discharges, see figure 1. For h/h_d greater than 7 the nappe would not remain attached to the crest. The reduced discharge coefficient was caused by a decrease in the minimum pressure profile which became rather uniform when compared to the spike-shaped pressure profile for lower heads, as shown in figure 2. This phenomenon was also observed in a hydraulic model study of spillway modifications for Chili Bar Dam (Dodge and Mefford, 1990). The change in pressure distribution may be caused by reduced streamline curvature as the ogee begins to operate like a sharp-crested weir.

Minimum Surface Pressures

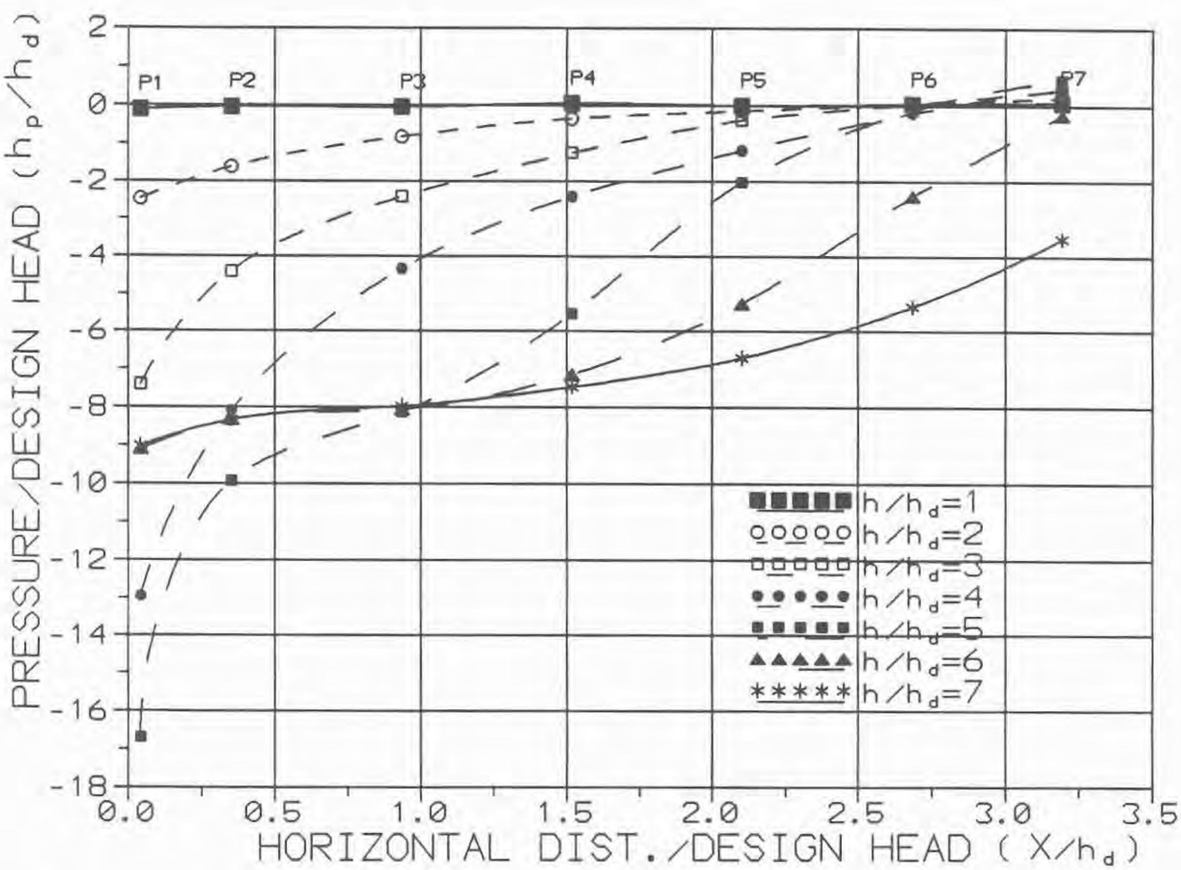

Figure 2. Pressure Distribution on Ogee Crest. *Note the change in pressure profile shape as head increases* (h/h_d *greater than 5).*

Surface pressure heads (h_p) were measured using eight piezometer taps connected to glass tube manometers. The piezometer taps were located along the ogee crest centerline. The minimum surface pressure on the ogee crest usually develops just upstream the crest apex. Theoretically the minimum pressure is atmospheric at the design head and becomes negative for increasing heads. Downstream of the crest apex the pressure recovers toward atmospheric pressure.

Cassidy (1970) proposed a relationship (equation 2) which relates the discharge with the crest height, P, and minimum negative pressure head, $-p_{min}$. Cassidy's results (figure 3) showed that this relationship is independent of the design head to crest height ratio, h_d/P. Therefore, an equivalent relationship in terms of minimum negative pressure head, $-h_{min}$ is given in equation 3. This relationship can be used to determine the unit discharge for a given minimum pressure head. Results from Reclamation's research agree very well and extend the results presented by Cassidy in figure 3.

$$\frac{L}{Q}\left(\frac{-p_{min}}{\gamma}\right)^{\frac{3}{2}} = \phi_1\left(\frac{h_d}{P}, \frac{-p_{min}}{\gamma h}\right) \tag{2}$$

$$\frac{(-h_{min})^{\frac{3}{2}}}{q} = \phi_2\left(\frac{-h_{min}}{h}\right) \tag{3}$$

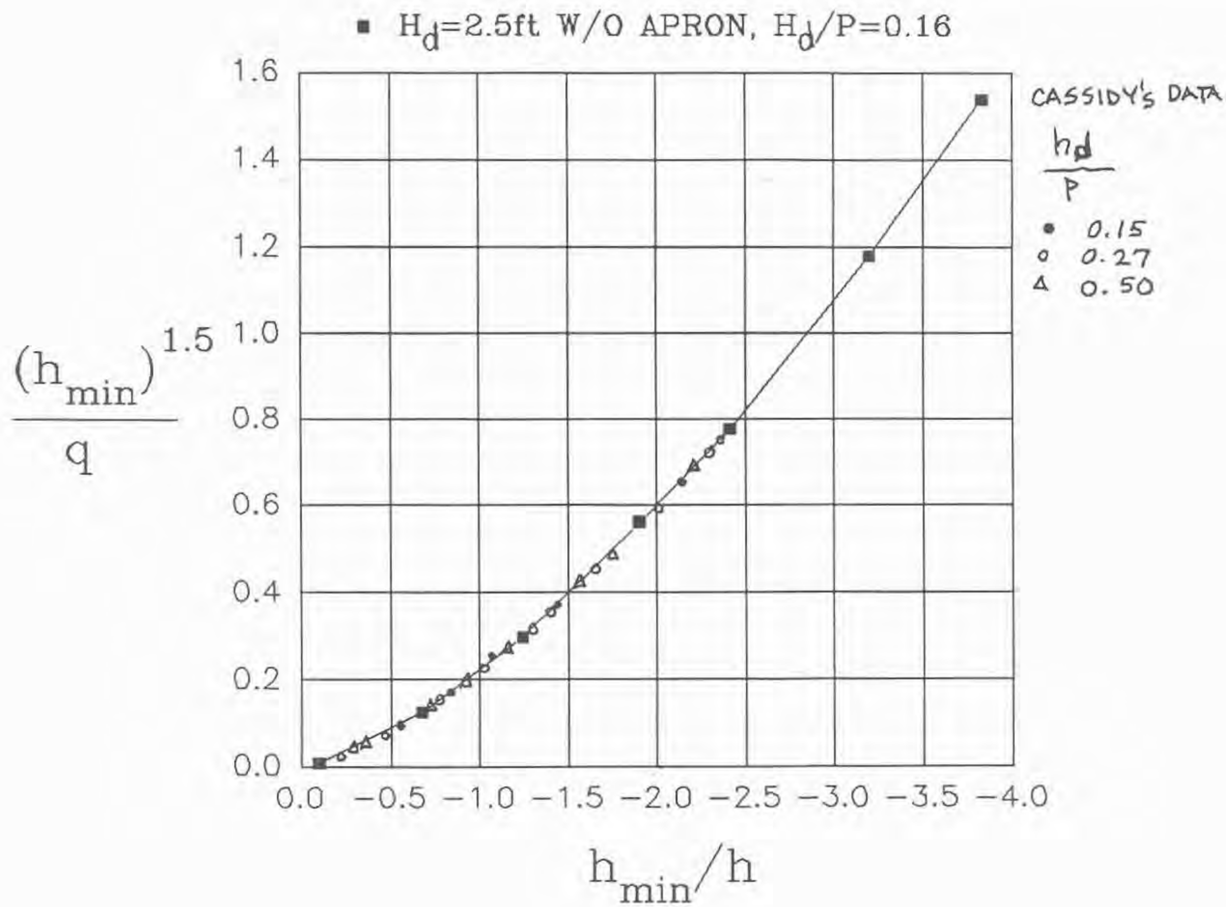

Figure 3. Discharge - Minimum Pressure Characteristics of Ogee Crest.

Cassidy also outlined a procedure in which an uncontrolled ogee crest spillway is designed for a minimum pressure equal to vapor pressure, or the pressure at which cavitation will initiate.

This design procedure maximizes the spillway's discharge efficiency and produces a smaller crest structure. However, the spillway may be unstable because of greater overturning and uplift moments associated with reduced weight.

Conclusions

This research has been productive in extending the discharge coefficient and minimum pressure data sets for an uncontrolled ogee crest for heads in excess of five times the design head. The test results agree well with previous data collected by Cassidy (1970) and Maynord (1985). However, more information is necessary to fully understand the hydraulics of the nappe separation and when it can be expected to occur or how we might design a spillway section to suppress separation. Likewise, cavitation and its effects on the discharge coefficient is also left to be studied.

The advantages to designing uncontrolled ogee crests based on a minimum pressure criteria are as follows:

- A smaller structure can adequately pass the design flood when compared to the standard 75% "underdesign" crest.
- The spillway crest can be set at a higher elevation and still provide discharge capacity to maintain the original maximum pool elevation for a given inflow hydrograph.
- An engineer can chose which minimum pressure is acceptable and design the ogee crest accordingly.
- An engineer can determine the discharge capacity of an existing ogee crest for heads up to 5 times the design head.
- An engineer can estimate the cavitation potential of an existing ogee crest for heads up to 5 times the design head.

Additional Research

Additional research is planned for a 1:20 scale ogee crest with a design head of 4.5 feet. The activities will be similar to those outlined above and will provide additional data for evaluation and verification of these results. Another area of interest is the effect of channel geometry downstream of the crest on flow detachment from the crest. It would also be interesting to examine the two 1:20 scale ogee crests in Reclamation's cavitation facility to determine cavitation characteristics of ogee crests at high heads.

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