PAP-587

DESIGN OF HIGH CAPACITY SPILLWAYS FOR RITSCHARD DAM, COLORADO

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Abstract

A hydraulic model investigation was conducted by the Bureau of Reclamation to assist in designing the hydraulic structures associated with Ritschard Dam. Ritschard Dam will have a labyrinth emergency spillway and ogee service spillway, both of which are expected to convey flows beyond the limits of contemporary design criteria. Preliminary flume studies were conducted on sections of the labyrinth and ogee crests to determine discharge coefficients and surface pressure distributions (ogee only). Ritschard Dam model was used to determine if the ogee and labyrinth spillways could, in combination, convey the peak outflow associated with the probable maximum flood.

Introduction

The proposed site for Ritschard Dam is located in Grand County, Colorado, about 4 miles north of Kremmling, on Muddy Creek, a tributary to the Colorado River. The project owner is the Colorado River Water Conservation District, a water policy and water development body for western Colorado. Ritschard Dam will provide storage for 60,000 acre-feet of water for both the western slope of Colorado and Denver Metropolitan Area. The final Environmental Impact Statement was issued in 1990 and construction is planned to begin in 1992.

Ritschard dam will be an earth embankment structure, 1,900-ft long and 120-ft high. The dam will be constructed with both a service and emergency spillway located in the right abutment. The service spillway consists of a 153-ft-long, uncontrolled ogee crest and reinforced concrete chute (fig. 1). The emergency spillway has a labyrinth weir as the control structure and an unlined rock spillway channel. Combined spillway capacity will be sufficient to pass the probable maximum flood (PMF) peak outflow of 77,000 ft^3/s.

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During the preliminary design phase three emergency spillway designs were considered: a 700-ft-wide open cut, a 500-ft-wide ogee crest, and the 275-ft-wide labyrinth weir. However, due to width constraints at the site, the labyrinth was the preferred alternative. A labyrinth weir consists of several lengths of linear sharp-crested weir, which form several cycles of trapezoidal or triangular planforms. For an equivalent width the labyrinth weir has a longer crest length than a linear weir; consequently, for a given crest shape and head, the discharge capacity per unit width is greatly increased. This increased length is commonly expressed as a length magnification ratio (l/w): where l is the labyrinth weir length and w is the spillway width.

Spillway Design

The ogee crest design was based on methods described in Reclamation's "Design of Small Dams" (USBR, 1987). The initial design discharge was selected as the peak outflow for the 100-yr flood, 6,500 ft^3/s. The resulting design head (H_o) was 2.5 ft. This value is much less than the 14 ft of head on the crest during the PMF. The resulting head on crest (H_e) to design head ratio (H_e/H_o) was 5.6, which is substantially greater than the value of 1.6 which is the maximum for which discharge coefficients have been reported (USBR, 1987).

The Ritschard Dam labyrinth spillway design was based on previous hydraulic model study results for the two-cycle labyrinth spillway recently constructed at Hyrum Dam, Utah (Houston, 1983,1984). The geometric parameters for the labyrinth are essentially the same as the Hyrum design, except that nine cycles were necessary to pass the design discharge. Also, the downstream apexes were designed to include bridge support piers. Because the piers obstruct the majority of the apex width, it was concluded that the apexes would not contribute to the effective weir length. By removing downstream apexes the l/w ratio was reduced from 5.0 to an approximate value of 4.7. In addition, the design head to weir height ratio (H_o/P), for Ritschard's labyrinth was equal to 0.9, which is greater than the maximum value of 0.5 for which Hyrum model data were available.

Because both of these spillways are expected to operate safely for heads extending beyond values determined by contemporary design practice, it was decided to perform a hydraulic model study to verify the performance for each spillway crest.

Experimental Setup

The experimental phase of this study consisted of tests on 1:20 scale, two-dimensional models for both the labyrinth weir and ogee crest. A 1:45 scale, three-dimensional model was also constructed to investigate the overall performance of the waterways and the natural channel downstream of the dam.

Similitude and Test Discharges - Flow over a spillway crest results in substantial horizontal and vertical velocity components; therefore, undistorted models were used for this investigation. All models were scaled using Froude law relationships to ensure flow similarity. The Froude number was chosen because the hydraulic performance of the model/prototype structures are primarily dependent on gravitational and inertial forces.

Testing Flume - The sectional model studies were conducted in a 3-ft-wide by 2-ft-high by 60-ft-long horizontal flume. Water is supplied to this facility through a 12-in-diameter pipe.

The inflow passes through a gravel-filled baffle to equally distribute the flow and dampen any wave action. Each of the sectional models was installed at the downstream end of the flume, along with short sections of the spillway chutes.

The Sectional Models - Two sectional models were tested in the flume:

- **Model 1** - A 1:20 scale model of two-cycles of the labyrinth weir.

- **Model 2** - A 1:20 scale model of 60 ft of the ogee crest. The crest was equipped with eight piezometer taps located along the crest centerline to measure surface pressures.

Measurements - Model heads on the spillway crests were measured by a point gage to the nearest thousandths of a foot. For each model the point gage was located 10 ft upstream from the spillway crest. Approach velocity head was calculated using the flow depth measurement and continuity. Permanently installed Venturi flowmeters were used to obtain flow rates in the flume. Each Venturi was volumetrically calibrated, which resulted in accuracies within ± 1 percent of total flow. Ogee crest surface pressures were measured to the nearest hundredth of a foot using water manometers.

Sectional Model Tests and Results

The head-discharge relationship for the labyrinth weir sectional model indicated that the discharge capacity was lower than values predicted using the Hyrum model study results (fig. 2). Typically, labyrinth head-discharge curves are presented in dimensionless form. The labyrinth discharge (Q_L) is divided by a linear sharp-crested weir discharge (Q_N) for identical heads to obtain a discharge magnification ratio - Q_L/Q_N. The head (H) on the crest is divided by the crest height (P) to obtain a dimensionless head value - H/P. The disparity between these two curves was due to the addition of bridge piers to the downstream apexes. This resulted in an effective weir length that varied depending on the H/P ratio. For increasing H/P ratios the piers further restrict flow over the apex, thereby reducing the effective weir length. But, for design purposes, Q_L was calculated using a fixed weir length which excluded the downstream apexes. As a result, it is very difficult to compare the two head-discharge curves because of variations in effective length. It should be noted that for increasing H/P values discharge magnification decreases similar to Hyrum because of nappe interference at the upstream apexes and nappe submergence.

A head-discharge relationship was developed for the ogee crest sectional model for heads up to 15 ft. These data indicated that the discharge coefficients (calculated using $Q=C_d*L*H_e^{1.5}$) began to decrease for heads greater than 8 ft (fig. 3). This outcome can be explained using pressure head profiles measured for several heads. A properly designed ogee crest will develop atmospheric surface pressures for a head equal to its design head or at a head to design head ratio (H_e/H_o) of 1.0 (fig. 4). For operating heads larger than design, subatmospheric pressures develop over the crest which increases the discharge coefficient. Reclamation has published (USBR, 1987) design information which shows a 7 percent increase in discharge coefficient for a H_e/H_o ratio of 1.6. However, model data indicated that coefficients continue to increase for H_e/H_o values up to 3.2 (H_e and H_o equal to 8 and 2.5 ft, respectively). The pressure head profile for H_e/H_o of 3.0 illustrates the large subatmospheric pressures which occur on the ogee crest and result in a coefficient of 4.28. However, as heads continue to increase there is an upper limit to coefficient magnification. For H_e/H_o of 6.0 the subatmospheric pressure heads were greatly reduced in magnitude, as was the area over which it acts, resulting in a coefficient of 3.67. Consequently, the ogee crest was redesigned so that the discharge coefficient would increase over the entire range of heads. The revised design head of 4.5 ft was established by dividing the maximum head of 14 ft by the "effective" H_e/H_o ratio of 3.2.

Ritschard Dam Model Study

A hydraulic model was constructed to 1:45 scale. The model contained a curved approach channel to the spillways, both the service and emergency spillway chutes, energy dissipation basin, a portion of the dam and the natural topography of Muddy Creek and its floodplain (fig. 1). The model was used to investigate overall spillway performance. This included: detailed studies of approach channel influences on head-discharge relationships for the ogee crest and labyrinth weir, spillway flow conditions, surface pressures on the ogee crest, and stilling basin efficiency.

Model Tests and Results

A head-discharge curve was developed for the entire range of reservoir elevations. The 9-cycle labyrinth weir and 153-ft-wide ogee crest performed very well for all approaching flow conditions. The combined spillway capacity was sufficient to pass the PMF peak discharge of 77,000 ft^3/s. Observations indicated that the bridge piers have little hydraulic effect other than reducing the overall labyrinth weir length as discussed in a previous section.
Ogee crest discharge measurements, for a design head of 4.5 ft, confirmed that discharge coefficients increased over the entire range of reservoir heads. Likewise, surface pressure data were collected at five piezometer locations on the ogee crest, and these data did not indicate a reduction in discharge coefficient due to reduced subatmospheric pressures. These results confirm that the "effective" H_e/H_o ratio of 3.2, used to redesign the ogee crest, was a practical criterion for developing an efficient ogee crest design for high heads.

Conclusions

Ritschard Dam model studies provide additional information which extends the design criteria for labyrinth weirs and ogee crests operating at heads in excess of their design values. However, these conclusions are specific to this particular study, and additional research should be conducted to further generalize these results.

References

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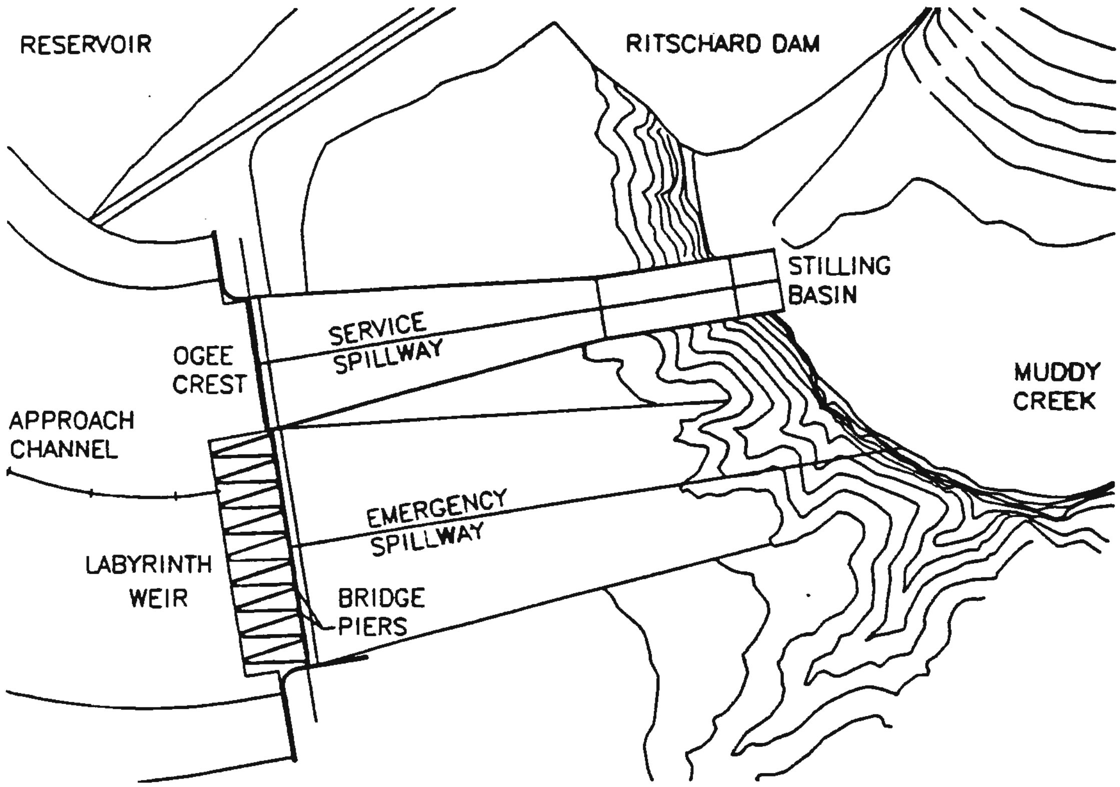

Figure 1. - Plan view of Ritschard Dam Model.

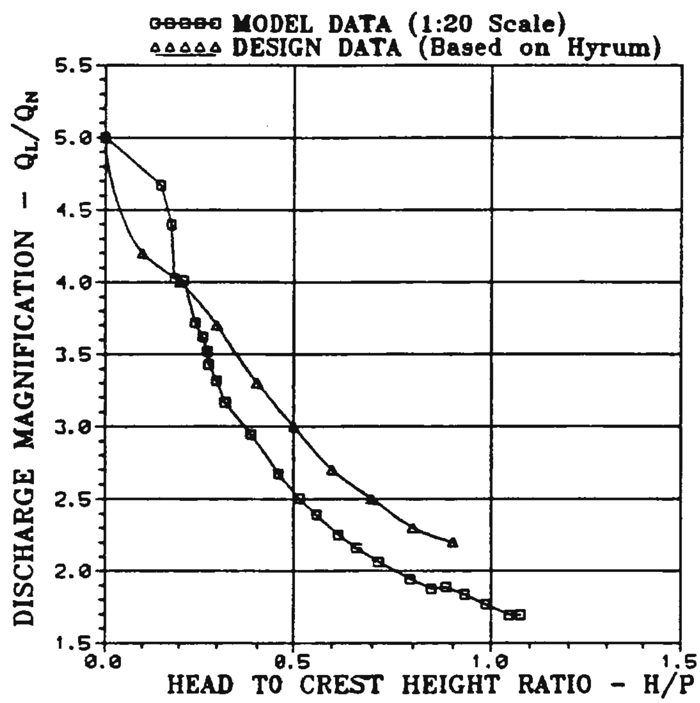

Figure 2. - Dimensionless head-discharge relationship for labyrinth weir sectional model (two cycles).

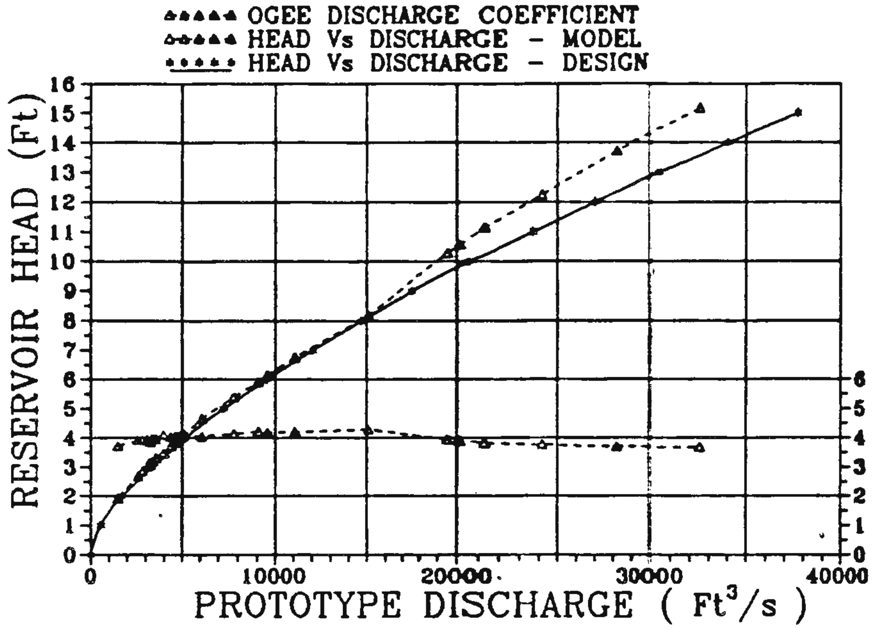

Figure 3. - Head-discharge relationship for ogee crest sectional model (H_0=2.5 ft).

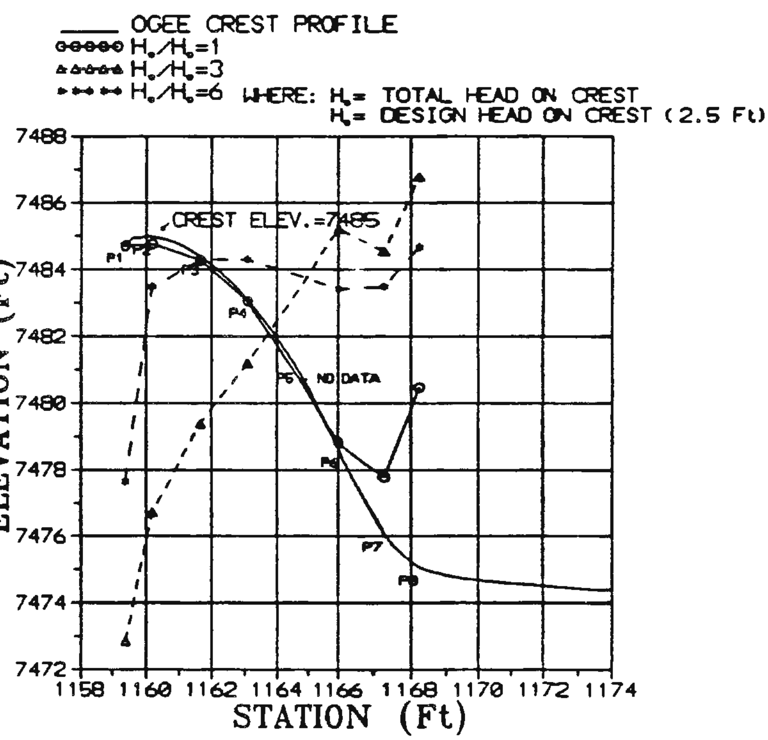

Figure 4. - Pressure head profiles for 1:20 scale ogee crest.

SI Conversions

hectares = 0.4047 acres
meters = .3048 feet
m^3 = 0.0283 ft^3