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Basic Design of Replogle Flumes

Replogle flumes are widely recommended flow measurement structures for most open channel applications in irrigation canals.

The Cal Poly Irrigation Training and Research Center (ITRC) has used the basic design promoted by Dr. John Replogle for over 20 years. Replogle flumes are particularly well suited for use in irrigation canals and have major advantages over all other known weirs and flumes (e.g., Parshall flumes, sharp-crested weirs, cutthroat flumes).

Replogle flumes, technically known as *broad-crested weirs*, belong to the family of *long-throated flumes*. One of the most important benefits is the ability to place a Replogle flume into an existing control section, thereby greatly reducing the cost of a new measurement device.

In general, the term broad-crested weir refers to a structure in which a contraction of the flow is created by raising the channel floor. This contraction produces flow at critical depth resulting in a predictable and unique head-discharge relationship over the entire range of flow rates. When the contraction is produced by a combination of raising the channel bottom and narrowing the width of the channel, the term flume is used.

Examples of Replogle flumes are shown in **Figure 1**.

Figure 1. Replogle flumes in irrigation canals

To facilitate accurate flow measurement, this paper describes specific design and construction considerations applicable to Replogle flumes in irrigation applications. A design example is provided to illustrate these concepts.

WinFlume Software

One of the primary advantages of the Replogle flume is the capability to custom design and calibrate structures for unique operational and site requirements using the Windows-based computer program WinFlume. The current version of the program can be downloaded free-of-charge from the Bureau of Reclamation's web site at http://www.usbr.gov/wrrl/winflume/.

The reader is encouraged to refer to the recent publication *Water Measurement with Flumes and Weir* (ILRI pub. 58, 2001) by Clemmens, Wahl, Bos, and Replogle for comprehensive information on design, calibration, construction, and operation issues.

Design Considerations

The following is a short summary of important design and related construction issues relevant to accurate flow measurement using Replogle flumes in irrigation canals. These recommendations are applicable to most installations and are intended to simplify the design process using WinFlume.

- Definition of the existing channel conditions. The first design step is to select the proper site and determine the field conditions under which the flume must operate. The following characteristics of the installation should be established through site surveying and a thorough review of the conditions at high and low flows:
  - Range of flows to be measured
  - Freeboard requirement at maximum flow
  - Access to the site for construction and subsequent measurement
  - Influence of any downstream control structures, if any
  - Uniform flow, Froude number
  - Lining material and material used for flume construction (roughness coefficient)
  - Cross-sectional dimensions and side slope

  For design purposes, it is usually necessary to measure the cross section of the canal at about four locations, including the site where the flume will be, one upstream of the site about 50 ft, and two downstream at about 50 ft intervals. The survey data required at each location includes top of left bank, top of left concrete, invert at left toe, invert at centerline, invert at right toe, top of right concrete, and top of right bank.

  In addition, the water level elevation in the canal should be surveyed at 100 ft intervals, for approximately 200 ft upstream and 300 ft downstream of the proposed site. This needs to be done at the maximum and minimum flows, with estimates made of the approximate flow rates.

  The upstream and downstream channels should be investigated for possible flow restrictions including culverts, check structures, turnouts, etc. that might affect flows. The size and locations of these structures should be obtained.

  It is critical that the backwater effects, if any, of downstream control structures are evaluated at the proposed flume location. To determine the potential impacts from submergence, the water level at the nearest downstream control structure should be raised to its highest point, while at low flow conditions, and then survey data of the water level obtained at the flume site.

- Recommended site conditions. For accurate flow measurement, it is important to take into account the following:
  - The Froude number should not exceed 0.5 in the approach channel and for a distance upstream of 30 times the maximum head reading, H_{1max}.

    $$Fr = \frac{v}{\sqrt{gA/w}}$$

    where, v = velocity (feet per second)
    A = area (feet^2)
    w = top width (feet)
  - Note H_{1max} is the sill-referenced energy head at maximum flow. Preferably the Froude number should be closer to 0.2.
  - The channel upstream of the flume should be straight and uniform for a distance of at least 30 times H_{1max}.
  - There should be no flow of highly turbulent water (e.g., undershot gates, drop structures, hydraulic jumps, etc.) in the upstream channel for a distance from the approach channel of 30 H_{1max}.
  - If there is a bend close to the structure (closer than 30 H_{1max}), the water surface elevations at the two sides are likely to be different. Reasonably accurate measurements can be made with about 3% added error if the upstream straight channel is at least 6 H_{1max}. It is best to measure the water level on the inner bend of the channel.

- Method of contraction. The designer's objective is to have the least expensive design (usually the simplest shape to construct) that meets the operating criteria. For existing lined trapezoidal irrigation canals, the best choice in terms of cost and performance is often to construct a broad-crested weir using a bottom-only contraction (**Figure 2**).

Figure 2. Trapezoidal Replogle flume in existing concrete lined canal

Another option is to provide additional side contraction by having vertical walls through the section as shown in **Figure 3** (rectangular cross-section).

Figure 3. Rectangular Replogle flume with tapered entrance and smooth rounded edges (Truckee-Carson Irrigation District)

The shape and cross-sectional dimensions of the approach, control, and tailwater sections are defined in the WinFlume program using the *Flume Geometry and Dimensions Form*. Elevation and length dimensions of the structure are edited on the bottom profile drawing within this screen. Information about the channel geometry and sizes can also be entered using the *Section Shape and Dimensions Form*.

- Suggested flume dimensions. Following the generally recommended guidelines, the length of the approach channel, converging transition, throat, and diverging transition depend on the value of the sill-referenced energy head (H_1) at maximum flow. The gage station should be located at a distance between two and three times H_{1max} from the leading edge of the sill. The length of the converging transition is similarly related to the sill height above the approach channel invert (p_1) such that it is between 2.4 p_1 to 4.5 p_1. In most cases the slope of the ramp in the converging section should be set at 3:1 (horizontal:vertical). For accuracy, the throat length (L) should be selected so that the ratio of H_{1max} to the throat length is in the range of 0.070 to 0.70.

- Head loss design criteria. The main tradeoff in designing Replogle flumes is between having enough contraction to avoid submergence, but not so much contraction to infringe on the freeboard and possibly overtop the canal banks. Assuming other design criteria do not control the flume design (e.g., the Froude number at maximum flow), the amount of contraction in Replogle flume designs is determined by the sill height. During design investigation, one should begin with an initial sill height of half the normal flow water depth. Using the WinFlume program, the sill height can be incrementally increased while checking for adequate submergence protection in the tailwater channel.

- All flume designs should have a downstream ramp. The ramps can either be 6:1 full ramps or 6:1 truncated ramps.

- The bottom of the flume should be painted with ablative (anti-fouling) paint to inhibit vegetative growth.

- Head measurement method. For applications where the flume will be used for control purposes, water level (head) must be measured very accurately using electronic sensors (including redundant units). The expected accuracy of current electronic water level sensors is about ± 1/16 inch. While the WinFlume program estimates the combined error due to the accuracy of the rating table and the potential errors related to head measurement (depending on the chosen method), users are cautioned not to make unrealistic assumptions in the determination of expected errors in the design review which may result in impractical design criteria.

- Flush pipe. A flush pipe(s) is required under the length of the structure to prevent pooling when the canal is drained. All flume designs (above 5 cubic feet per second) should have a 4-inch PVC or steel pipe installed to drain the upstream section of the canal. Larger flume designs require relatively larger drain pipe diameters (e.g., 12-inch). The pipe should be installed flush to the concrete.

- Staff gage. A metal or plastic staff gage should be securely installed to the upstream wall. The WinFlume program can be used to print full-scale gages with controls for adjusting the display format. The gage should read directly in terms of the discharge flow rate (cubic feet per second), so everyone will easily know the flow rate upon observation.

- Verification of as-built dimensions. The dimensions of the flume must be precisely measured after construction. The WinFlume design program should then be re-run using the actual "as-built" dimensions, and the proper discharge tables should be generated by WinFlume.

Replogle Flume Design Example

To illustrate the proper design techniques summarized in this paper, the design for a Replogle flume in a medium-sized, earthen lateral (**Figure 4**) is described. The minimum and maximum flow rates at this location are 5 and 90 cubic feet per second, respectively.

Figure 4. Location for new Replogle flume in an earthen lateral

The constructed flume is shown in **Figure 5**.

Figure 5. Constructed rectangular Replogle flume

The final design output from WinFlume is shown in **Figure 6**. The sill crest is 1.8 ft above the existing invert of the channel. The design utilizes a rectangular cross-section to simplify the design and minimize construction costs. The width of the flume was matched to the existing bottom of the channel at 8.2 ft.

The plan view of the flume design is shown in **Figure 7**. Note the entrance has tapered walls with rounded corners.

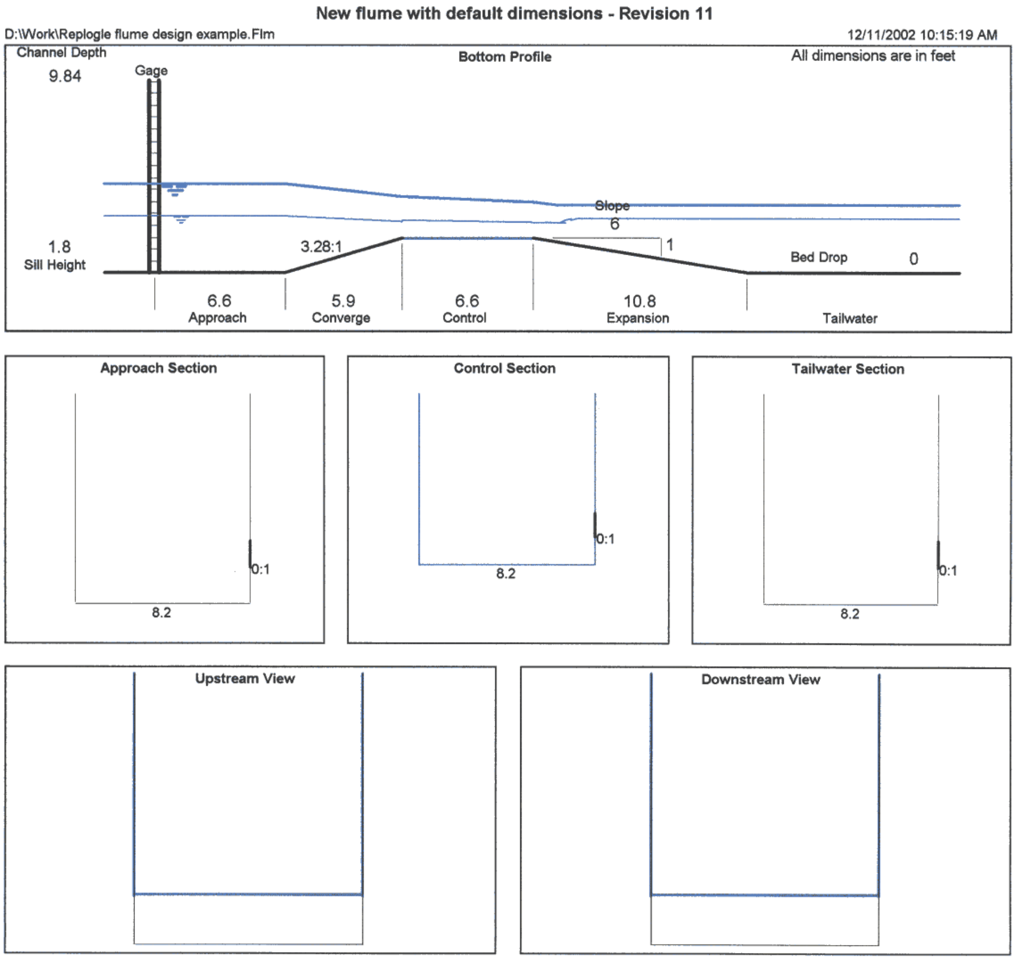

Figure 6. Profile drawing from WinFlume showing dimensions of final design. sill height = 1.8 ft, sill width = 8.2 ft.

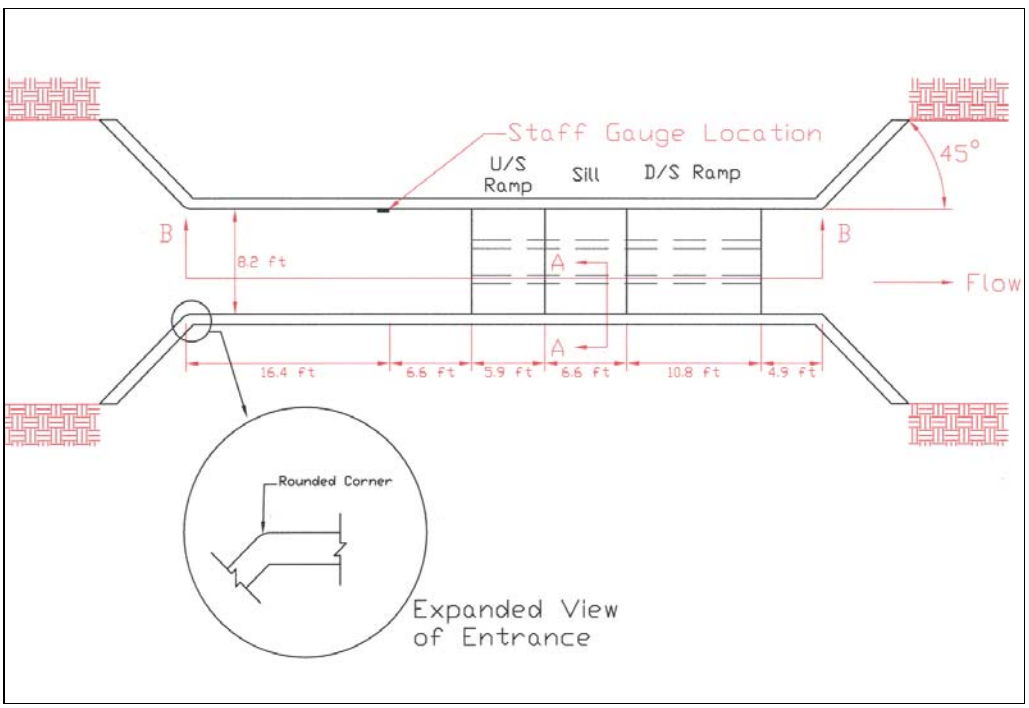

Figure 7. AutoCAD plan view drawing of rectangular Replogle flume installation with recommended entrance and exit conditions

Benefits

Irrigation districts and agricultural water users have benefited from more accurate flow measurement and the cost savings associated with Replogle flumes. There are numerous advantages to properly designed and constructed Replogle flumes including:

- ✓ Minimal head loss required
- ✓ Economical construction techniques
- ✓ Adaptable to existing control sections
- ✓ Variety of construction materials
- ✓ Rating table accuracy of ±2%
- ✓ Choice of various shapes and configurations
- ✓ Calibration based on the as-built dimensions
- ✓ User-friendly software WinFlume
- ✓ Proven track record
- ✓ Accurate over the entire flow range
- ✓ Minimal problems with trash and debris
- ✓ Ability to pass sediment

For Further Information

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