SLUICING FLUMES FOR GAUGING SEDIMENT-LADEN RIVERS

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Summary

This article describes in detail the progress made in identifying and developing a type of flow-measuring flume for stream-flow gauging and hydrological data collection in sediment-carrying rivers and streams.

The sluicing flume that was designed is less capable of silting up and losing its calibration than its counterparts of standard sharp-crested compound weir design. The laboratory work described here led to a refinement in the design in the form of a short flume set into the lowest section of a compound Crump weir gauging installation. Critical flow occurs near the exit of this flume, and it is not affected by high tailwater levels, up to a modular ratio of near unity.

The design also includes sloping wing walls with tapered noses at the entrance section. These are effective in aiding the discharge of bed load from the head pool before it can settle out at or near the flume. The sluicing flume has been built as a prototype gauging weir, according to the optimal dimensions determined on the scale models in the laboratory. An actual hydrological gauging weir has thus been installed on a river, and its performance so far has been good.

1. Introduction

In water-scarce, semiarid regions, the accurate assessment of available water resources is of the utmost importance. Hydrological measurements must be reliable so that the planning of projects using those limited water resources will be sound. Any data inaccuracies, whether accidental or systematic, could lead eventually to gross errors and inadequacies in providing sustainable life support systems based on available water supplies.

Hydrological measuring weirs are designed to be as accurate as possible, based on refined hydraulic principles. A major obstacle in establishing stable, reliable hydrologic data collection systems may be the presence of vast amounts of sediment in the flow being gauged. The very act of impeding the flow by the construction of a fairly low weir to act as a control point with a unique rating curve is also the cause of sediment deposition in the head waters of such a weir. The tractive effort, or stream power, and therewith the stream capability of transporting the sediment onward, is reduced in the deeper pool ahead of the weir (see *Water Data Collection Systems for Surface Water* and *Sediment Phenomena*).

The sediment, mainly its bed-load component, thus tends to settle out, causing shoaling ahead of the measuring weir, which then alters its calibration progressively with time. An error is gradually introduced, the measured flow deviating from the actual flow due to the increased velocity of approach, associated with the shoaling of the head pool to the weir.

Stage-measuring devices would therefore tend to record too-low head values (reduced by the increased velocity of approach head), and therefore the actual discharge would tend to be underestimated by a considerable percentage. Alternately, the shoaling of the head pool may be so excessive that upstream water levels may be raised at the gauging point ahead of the weir.

Should anticipatory corrections be made to compensate either way for an estimated degree of sediment-caused shoaling and such shoaling not occur, or the trend be reversed due to scouring during the rising stage of the flood or freshet, as often happens, the possibility of an overcorrection could lead to an erroneous estimation of the discharge.

In headwaters of streams, particularly in mountainous catchments, volumetric calibration, such as made possible by the filling of a reservoir farther downstream, is generally not possible; hence considerable uncertainty exists as to the margin of error in hydrological data as obtained from sediment-prone measuring weirs. As a result, planning needs to allow generously for possible gross or systematic errors in the hydrological data so obtained, which could be wasteful (see *Dams, Reservoirs, and Water Transfers*).

In an effort to overcome some of these problems by discouraging the sediment from settling out in head pools or the throats of measuring flumes and weirs, the *sediment sluicing flume* was developed. Through the combined efforts of various organizations pursued over a number of years in applied research studies in a hydraulic laboratory and a number of decades of field experience, a practical and reliable solution to the problem of sediment interference at weirs has now been found. This positive result was achieved in the form of the *sluicing flume,* which in principle is a self-cleaning hydrological weir with a stable calibration curve not easily altered by sediment carried in the flow. Figure 1 shows the principle of the sluicing flume as originally conceived, prior to the final refinements carried out after further model testing.

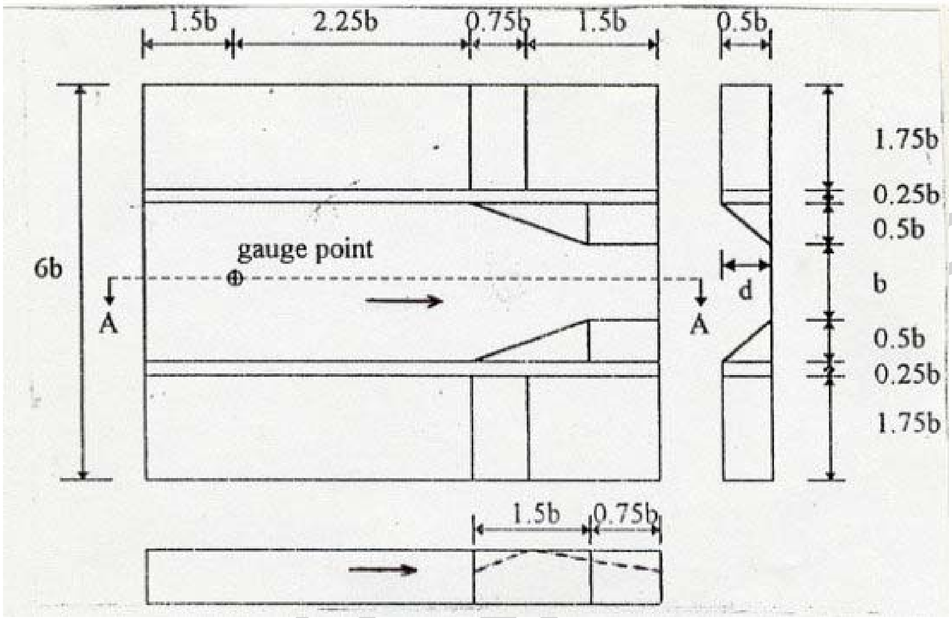

Figure 1. Sluicing flume from a previous study

The sediment sluicing flume uses features of compound weirs, incorporating a lowest-level, parallel-sided channel, set into a stepped array of broad-crested weirs situated between river banks on either side. The unique feature of the sluicing channel is its trapezoidal cross section and the maintenance of critical flow at the throat. The highest flow velocity occurring here is capable of re-suspending any sediment tending to settle out upstream of it. The clearance at the weir of sediment from its lowest point also proceeds upstream and laterally for a sufficient distance to obviate any calibration changes due to shoaling.

With the aid of this self-cleaning sluicing flume, the reliability of hydrological data collected using it, as opposed to conventional sharp-crested weirs, is greatly enhanced. An accurate calculation of the flow passing over the weir is therefore possible. The need for the periodic dredging or re-suspension of the sediment in the head pool, a costly operation at best, now falls away. The margin of uncertainty in data sequences derived from such weirs is thus considerably narrowed down from that for older conventional weirs subject to progressive sedimentation.

In a sensitive life support environment, based on using whatever limited water resources there might be, this greater accuracy is always welcome, as gross mistakes based on freewheeling, overoptimistic estimates (often disregarding all possible sources of error) may be obviated. This article describes in detail the history and development of the sluicing flume.

2. Historical Review

Sluicing flumes were developed and calibrated for use as part of compound flow measuring structures in sediment-transporting rivers. The compatibility of the sluicing flume with new and existing compound weir structures results from

- flume geometries, compatible with three different depth-to-width ratios of the flume,
- calibrating these flumes for use in combination with sharp-crested and Crump weirs of varying length, and
- theoretical calculation of stage-discharge relationships for the flumes as part of compound weir structures.

Ideal flume dimensions for three different depth-to-width ratios were derived from international specifications for flow gauging flumes. Their stage-discharge relationships are determined from basic theory without the need for model testing for cases where flow is contained within the flume. When the flow overtops the side walls, the flume operates as part of a compound weir and model calibration is required.

While tests were still in progress, the first flume based on initial studies was constructed. Although the new structure (at Mpambanyoni in KwaZulu-Natal, South Africa) was an improvement on previous structures with respect to sedimentation in the pool and at the stage-recording position, sedimentation problems within the flume after a flood were experienced. This provided valuable calibration data for simulating the sedimentation process in the model and led to proposals to change the flume layout. Various proposals for reducing the sediment deposition in the flume were tested. These model tests showed that the length reduction of the flume walls was most effective in reducing the sedimentation.

After a satisfactory solution was found, the flumes with the shortened walls were calibrated. Calibration tests showed theory that had been developed for the longer flumes could also be used for the shorter flumes with minor adjustments to the discharge coefficients.

Final calibration tests were conducted with the optimized flume. Much higher discharges were used, and the stage at indentations in the flume wall to reduce the risk of sediment entering the measuring system was recorded. The final tests provided accurate calibration data for the behavior of the flumes under high flow conditions with high tailwater levels. The study led to the recommendation that the three flumes shown in Figure 2 be used.

3. Characteristics of Sluicing Flumes

The main characteristics of these flumes are:

- The flumes possess good sediment-handling characteristics. If sediment levels in the head pool are above the flume invert, sedimentation in the flume would still occur during the falling stage of a flood. These deposits are removed during the rising stage of the next flood.
- The gauge position remains practically sediment free, and the narrow control section of the flume remains totally free of sediment. The flume will provide accurate flow measurement even if some sediment deposits may be present in it.
- The flumes possess stable calibration characteristics that are insensitive to variations in the adjoining weir structure. This allows combining a flume with a variety of adjoining sharp-crested and Crump weir configurations, without the need for model-test calibration to be made in each case.
- The gauging position is inside the flume. When the flow is confined to within the flume, the gauged water level is converted to a flow rate by using standard theory. Calibration is therefore not affected by sedimentation in the pool upstream of the flume. At higher flows when the abutment walls are overtopped, the recorded water level is first converted to a corresponding energy level in the upstream pool. This relationship is not affected by sediment deposition in the upstream pool and leads to a more accurate estimate of the upstream energy level than in the case where pool water level is gauged directly, especially where pool depths are affected by sedimentation.
- The flume becomes drowned with high downstream water levels, but the modular limit for all three flume configurations tested is 0.8, and flow gauging for the flume is possible up to 95% drowning.
- The length of the flume structure in the direction of flow is relatively short. Although shorter than recommended in the literature, the flumes show stable calibration characteristics. They will be easy to construct and have better sediment-handling characteristics than longer flumes.

Model tests were performed extensively at the Civil Engineering Department's hydraulic laboratory of the University of Stellenbosch during the development of the recommended flume configurations. Valuable field inputs were also obtained throughout the study from the Department of Water Affairs and Forestry and were incorporated in the model tests. The result is three recommended flume configurations. The calibration curves for any flume and weir combination can be derived analytically by means of calculation procedures having a sound theoretical basis. It is expected that flow measurement having less than 5% error will be possible over a wide range of flows (see *Hydraulic Methods and Modeling*).

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Biographical Sketches

J.M. Jordaan is a retired civil engineer with experience in hydraulic structures design for the Department of Water Affairs and Forestry in Pretoria, South Africa

Albert Rooseboom is professor of hydraulic engineering in the Civil Engineering Department of the University of Stellenbosch, South Africa. An authority on sediment transport and reservoir sedimentation, he has published a number of papers and research reports in these and related fields. He is a member of the International Association for Hydraulic Engineering and Research (IAHR) and a fellow of the South African Institution of Civil Engineers (SAICE), and is a registered professional engineer in South Africa. He graduated from the University of Stellenbosch and received a doctorate from the University of Pretoria, and he also obtained the diploma of hydraulic engineering from the Delft Technical University in The Netherlands. He is a member of the South African National Committee on Large Dams. His previous assignments over long periods were with the Department of Water Affairs and the University of Pretoria, where he was professor in the Civil Engineering Department. He is a council member of the Water Research Commission of South Africa, and a founder and senior partner of the engineering consulting firm Sigma Beta Incorporated in South Africa.