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Flow measurement using circular sharp-crested weirs

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ABSTRACT

Circular sharp-crested weirs are used as a flow-measuring device in open channels, reservoirs or tanks. The theoretical discharge equation of a circular thin weir ends up the complete elliptic integrals of the first and second kinds that are not very suitable for practical purposes due to their complexity. No *simple* and *accurate* equation is available in the technical literature up until now for the theoretical discharge of this weir. In current research, a simple and accurate theoretical discharge equation has been presented. The maximum percentage error of this equation compared to accurate numerical integration results is less than 0.08%. Also using experimental data, a suitable discharge coefficient equation is presented thus actual discharge can be computed via proposed equations. Moreover, an equation has been derived for the determination of the time required to empty a reservoir or tank by a circular sharp-crested weir.

1. Introduction

The flow measurement in open channels via weirs of various shapes has been a classical topic of interest to many practicing engineers. The flow rate as a function of water or liquid head, has been presented in many standard civil, mechanical and chemical engineering text books for simple weir geometries, such as rectangular, triangular (V-notch), trapezoidal and parabolic [1,2]. The mathematical nature of the governing equations in these weirs is very simple and theoretical discharge equation across these weirs can be derived easily. On the other hand, in some weirs such as circular sharp-crested ones, because of their specified geometry the derivation of the theoretical discharge equation is not very simple.

A circular (flow control) section placed in a vertical thin (metal) plate, which is located at right angle to the sides and bottom of a straight approach channel, is defined as a circular thin plate weir [3]. When the driving head over the weir crest exceeds the diameter of the weir, the weir is expected to behave like an orifice. Circular weirs have the advantage that the crest can be turned and beveled precisely in a lathe [4]. Moreover, the weir crest in this case does not have to be leveled, and hence the point of zero flow is readily determined [4].

In wells pumping the pump discharge is usually measured by an orifice which is installed to the end of the discharge pipe. The flow is determined by an orifice device in which the downstream head is constant (atmospheric pressure). While the pipe is not running full, the orifice acts as a circular thin weir and it is important to know the discharge under these conditions [4]. Also in a fishway where the discharge from it is to be carried into a pipe to a power canal, the flow has to be measured. The circular orifice in the end of the pipe would be running partly full most of the time, and thus becomes a circular weir [4]. Circular weirs have been in use for many years in some laboratories to measure the flow through hydraulic models and other devices.

Circular sharp-crested weirs, in practice, are fully contracted so that the bed and sides of the approach channel should be sufficiently distant from the control section to have no influence on the development of the nappe as shown in Fig. 1. The fully contracted weir may also be placed in a non-rectangular approach channel provided that the general installation conditions mentioned by Bos [3] are considered.

Dodge [5] obtained the theoretical discharge equation for circular sharp-crested weirs as an infinite series (Reported by Stevens [4]). This solution needs many terms to reach an acceptable accuracy. Stevens [4] probably was the first who obtained functional relationship between the water head and theoretical discharge in terms of the complete elliptic integrals of the first and second kinds. This complex equation requires a series of substitutions thus it is not very suitable for practical purpose. Stevens [4] also tabulated his solution. Discharge equation has also been developed for elliptical weir [6]; this study is only a generalization of Stevens' result for circular weir. Since there is not a simple and accurate theoretical discharge *equation* in the available technical literature, the current research is conducted to achieve a precise and simple formula for flow through sharp edged circular weirs. Then this equation is modified by a discharge coefficient equation obtained via laboratory experiments.

2. Proposed discharge equation

Referring to Fig. 1 and based on energy equation assuming a negligible approach velocity head, the theoretical discharge over

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