The LayFlat Gate for Flow Regulation and Measurement – Development and Experience in Large Scale Installations

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ABSTRACT

This paper describes the development of the LayFlat gate and its use in large-scale flow regulating and measurement applications. The development work required the design and construction of FlowLab, a large-scale facility for testing and calibration of prototype LayFlat gates. With this facility, testing of gates under both drowned and undrowned operation has been carried out at flow rates up to 80ML/d. These tests have identified the important operating characteristics of the gates and have enabled the development of a calibration algorithm, linking the flow rate to upstream and downstream water levels, gate angle, and gate length. These large gates have been successfully applied in irrigation and other water supply situations where accurate flow control and measurement are required. Even larger gates capable of flow control and measurement up to 800ML/d are currently in development. The extension of the calibration characteristics of the gates developed and tested in FlowLab to these larger gates is presented. The calibration algorithm was shown to predict the flow rate with an accuracy of ±4.01% for unsubmerged gates and ±4.80% for submerged gates at one standard deviation (68% probability).

INTRODUCTION

With the current emphasis on re-establishing environmental flows to natural waterways, there is a need to accurately measure flow rates within the waterways. There are a number of methods of achieving this, including the use of calibrated flow control structures.

Recently overshot gates, such as the LayFlat gate, have become increasingly popular for controlling water levels in open channels. To a large extent, this popularity is due to the ability of such gates to handle flow surges with limited change in water level and to the ease for operators in understanding the hydraulic behaviour of the gates.

The basic layout of a LayFlat gate is simple. It comprises a rectangular panel that is hinged at the bottom of the canal. Typically, two cables connect the top of the panel to a hoisting mechanism that can be used to raise and lower the gate to the desired height to control the upstream depth for various flow rates.

With the increasing emphasis on water accounting, in addition to water level control, operators need to be able to determine the flow rate at each gate. Over a large range of gate angles, the LayFlat gate operates essentially as a sharp-crested weir. In principle, then, a modified form of the standard sharp-crested weir formula can determine the flow rate. Modification is required to account for differences in the discharge coefficient resulting from operational changes to the gate angle.

The LayFlat gate has been developed by AWMA Pty Ltd. A range of full-scale gates of different sizes has been tested at flow rates up to 80ML/d. These tests have been undertaken in FlowLab, a full-scale testing facility located at Cohuna. Within this facility, the flow rate is measured with electro-magnetic flow meters to an accuracy of ±0.5%, permitting a high degree of accuracy in the calibration of the full-scale gates.

In this extended abstract, a brief description of the development of a calibration and prediction algorithm is presented first. A full analysis of all of the test data is then presented in summary form, together with assessments of uncertainty. The extension of the present work to predict the characteristics of gates up to 800ML/d is then discussed.

CALIBRATION AND PREDICTION ALGORITHM

The standard theoretical analysis for a sharp-crested weir yields the equation:

$$Q = C_e \frac{2}{3}\sqrt{2g}Bh^{3/2} \qquad (1)$$

where Q is the flow rate

C_e is the effective discharge coefficient
g is gravitational acceleration
B is the gate width
h is the head on the gate, where h is defined by the following equation:

$$h = L_{up} - H_{gate}$$

where L_{up} is the upstream water level in metres referenced to the gate hinge.
H_{gate} is the height of the gate lip in metres referenced to the gate hinge.

The gate height in a Layflat gate will need to be calculated as a function of a position sensor output and a polynomial equation with custom coefficients. The gate must be surveyed and the data fed into a regression calculator to determine the coefficients. This process is described in detail in the document “**Layflat Gate Commissioning.doc”.**

As shown by Kindsvater and Carter (1959), the effective discharge coefficient for a vertical sharp-crested weir is given by the equation:

$$C_e = b + m\frac{h}{p} \tag{2}$$

where p is the height of the gate crest above the channel bottom
b is a base coefficient
m is an empirical constant, of, experimentally determined, value 0.075

Wahlin and Replogle (1994) extended the theory to sloping overshot weirs by rewriting Equation (1) as:

$$Q = C_a C_e \frac{2}{3}\sqrt{2g}Bh^{3/2} \tag{3}$$

where C_a is a correction factor for gate angle.

From their model tests, Wahlin and Replogle (1994) determined that:

$$C_a = 1.0333 - 0.003848\theta - 0.000045\theta^2 \tag{4}$$

where θ is the gate angle in degrees

Equations (2) to (4) comprise the equation set for the solution for undrowned LayFlat gates.

For submerged gates, Equation (3) is rewritten as:

$$Q = C_{df} C_a C_e \frac{2}{3}\sqrt{2g}Bh^{3/2} \tag{5}$$

where C_{df} is a drowned flow reduction factor

Villemonte (1947) expressed C_{df} by the equation:

$$C_{df} = A\left[1 - \left(\frac{h_2}{h_1}\right)^{1.5}\right]^n \tag{6}$$

where h_1 is the upstream measured head
h_2 is the downstream measured head
A and n are empirical constants

Again, from their extensive model tests, Wahlin and Replogle (1994) determined that:

$$A = -0.0013\theta + 1.0663 \qquad \text{for } \theta < 60^0 \qquad (7)$$

$$A = 1.0 \qquad \text{for } \theta > 60^0 \qquad (7a)$$

$$n = 0.1525 + 0.006077\theta - 0.000045\theta^2 \qquad (8)$$

TEST DATA AND ANALYSIS

The characteristics of the LayFlat gates tested are presented in Table 1. A total of 163 tests of unsubmerged gates were undertaken and 128 tests of submerged gates.

The data for unsubmerged gates were first analysed in calibration mode to examine any variations in the computed value of the base discharge coefficient, *b*. Only unsubmerged data were used for this calibration run because the submerged data analysis includes an additional empirical relationship, which could bias the results.

Table 1: Characteristics of Tested Gates

Gate ID	Gate Length (m)	Gate Width (m)	W/L Ratio	Flow Range (ML/d)
1	1.464	1.210	0.827	10-70
2	1.567	1.553	0.991	10-59
3	1.515	1.832	1.209	10-68
4	1.152	1.230	1.068	15-71
5	0.979	1.525	1.558	15-74
6	1.163	1.850	1.591	17-81
7	1.302	1.545	1.187	17-84
8	0.755	1.546	2.048	14-55
9	1.983	1.235	0.623	27-72

Despite the range of gate geometric characteristics indicated in Table 1, remarkably little variation in the base discharge coefficient was discerned across all unsubmerged tests. An average value of xxxx with a standard deviation of 0.0255 was noted.

In prediction mode, the algorithm was used to predict the flow rate for all unsubmerged and submerged gate tests, using the average base coefficient value. The results are summarized in Figure 1 (unsubmerged tests) and Figure 2 (submerged tests).

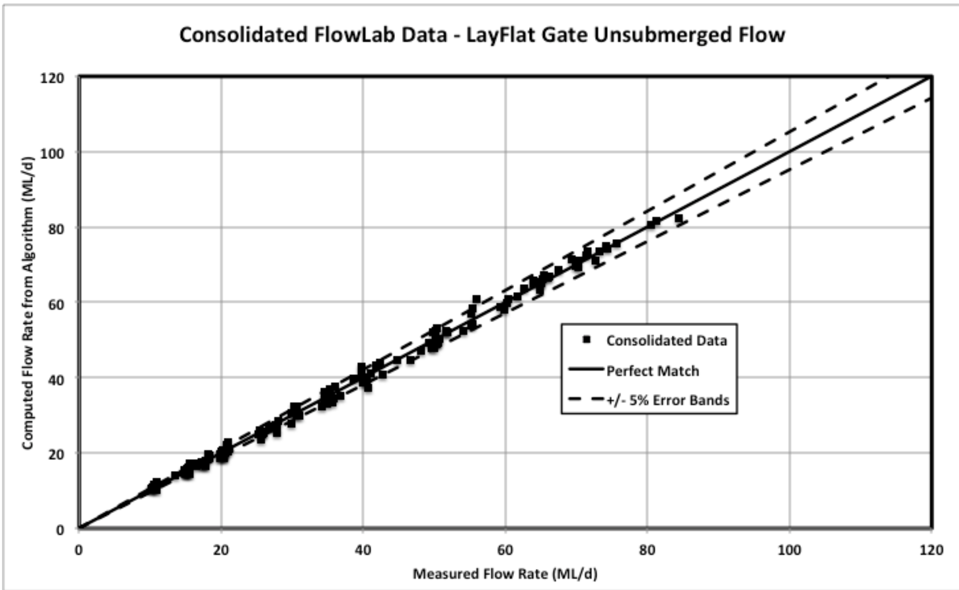

Figure 1: Comparison of Measured and Computed Flow Rates for Unsubmerged Gate Tests with +/-5% Error Bands

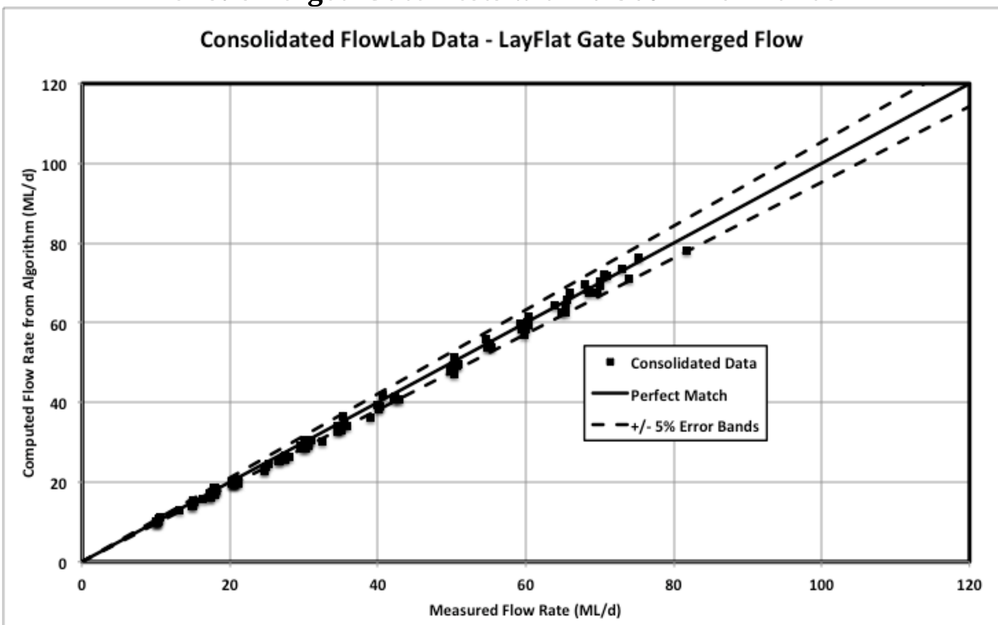

Figure 2: Comparison of Measured and Computed Flow Rates for Submerged Gate Tests with +/-5% Error Bands

Both graphs indicate a close comparison between computed and measured flow rates across the full range of gates and flow rates tested. An analysis of the errors indicated that, at one standard deviation (68% probability), the uncertainty was ±4.01% for unsubmerged tests and ±4.80% for submerged tests.

EXTRAPOLATION OF TEST RESULTS

Model tests are routinely used to predict the performance of prototype structures. The theory of hydraulic models indicates that, for open channel structures, Froude Number similarity provides the appropriate scaling conditions.
The Froudian similarity law for flow rate is given by:

$$\lambda Q = \lambda L^{2.5} \tag{9}$$

where λ means "the scale of" (model to prototype)
Q is the flow rate
L is a typical length

Keller (1998, 2010) has examined the issue of scale effect in hydraulic model studies and has demonstrated that, for hydraulic structures, provided the model Reynolds Number is sufficiently large, scale effects are negligible, even for prototype structures twenty times larger than the corresponding model.

In the present situation, the Reynolds Numbers for the tests carried out in FlowLab are very large and the results may confidently be extrapolated to much larger geometrically similar gates. Adopting a very conservative approach, the results obtained in FlowLab have been extrapolated through length scales of 2 and 3. In this way, the performance of larger but geometrically similar LayFlat gates can be predicted up to flow rates of 1,200ML/d.

CONCLUSIONS

Nine prototype LayFlat gate structures have been tested and calibrated in the FlowLab facility at Cohuna. These structures were of different sizes and geometries with ratios of width to length varying from 0.623 to 2.048. The extensive testing comprised a total of 163 tests of unsubmerged gates and 128 tests of submerged gates at flow rates up to 81ML/d.

On the basis of established theory for overflow sharp-crested weirs, a theoretical analysis of the LayFlat gate was undertaken. Testing with unsubmerged gates yielded a single base discharge coefficient value of 0.6131 with a standard deviation of 0.0255.

This coefficient was utilized in a full calibration of all gates which showed that the prediction algorithm predicted the flow rate with an accuracy of ±4.01% for unsubmerged tests and ±4.80% for submerged tests at one standard deviation (68% probability).

Using established modeling theory, the test results were conservatively extrapolated to gates with dimensions two times and three times the sizes of the tested gates. This extended the effective flow range to 1,200ML/d.

It should be noted that these uncertainty limits apply to the range of gate geometries tested (width to length ratios of 0.623 to 2.048) and to single gates. Installations comprising multiple gates may introduce small additional uncertainties due to slightly different approach conditions. For such installations, it is suggested, conservatively, that the uncertainty limits be increased to ±5% for unsubmerged gates and ±6% for submerged gates at one standard deviation.

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