ASFM Measurement In An Open Spillway

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ABSTRACT

Inadequate spillway capacity is one of the major reasons for dam failure in embankment dams. New Swedish guidelines for the design flood, adopted in 1990, have led to an extensive work with upgrading of the discharge capacity in a number of dams.

A large number of dams have such a spillway design that they do not easily allow for accurate theoretical calculations of the discharge capacity due to e.g. oblique inflow conditions, head losses in the adjacent spillway area and uneven water levels in front of the spillway openings.

Hydraulic models have been the traditional way to determine the discharge capacity in those cases where a theoretical approach is judged to give an uncertain result. In some cases even a hydraulic model is suspected to give an uncertain result, e.g. when friction losses play an important role in the discharge capacity.

For these reasons, a requirement exists to develop a field measurement method to determine spillway capacity. A test with an Acoustic Scintillation Flow Meter to directly measure discharge was made at the Mellanfallet Dam on the river Dalalven in Sweden in August 1999.

New Swedish Guidelines

In 1985, the same year the work started with the new Swedish guidelines, heavy rain and overtopping of the dam crest caused dambreak in Noppikoski dam. The major cause of the dambreak was a jammed spillway gate that couldn't be opened. Hydrological simulations showed that the dam was in danger of overtopping even if the gate had been opened. The Noppikoski case has been reported by Enfors & Eurenius, 1988.

The new Swedish guidelines were adopted in 1990 and preliminary calculations have, in some cases, substantially increased the design flood. Only a few power plants have so far been subject to more detailed investigations. The new guidelines are described by Bergström

Examples are given by Yang, 2000 in which the increase in design flood for Bergeforsen dam in river Indalsälven is almost 50 % from 2300 to 3400 m^3/s.

Determination Of Spillway Capacity

Equal important to determine the design flood is the determination of the real discharge capacity in a dam's spillway.

So far hydraulic models have been the predominant tools to determine spillway capacity especially when the probability for a successful determination with a theoretical approach is low.

In the last few years, new techniques with field measurements and mathematical modelling have increased the possibilities to determine discharge capacities with high accuracy.

When it comes to field measurement, it is of course only possible to measure on existing structures but it is an important tool to verify old discharge capacity curves with unknown origin and to compare, and in some cases to verify, the results from hydraulic models.

Mathematical modelling has in recent years become a serious alternative to hydraulic models. In a comprehensive Swedish study, mathematical modelling of spillway discharge capacity for six different spillways was compared in a blind test to corresponding hydraulic modelling in a flume. The result showed good agreement, except for some cases, with those exceptions being due to the mathematical model describing the flow situation and not weaknesses in the program code.

In the same study a theoretical approach was made to determine the discharge capacity. The results from that test showed, in many cases, substantial deviations from the correct value. This study is described by Cederström.

Hydraulic model tests are judged to have a maximum error in discharge capacity of about 3 to 4% in a well-designed model. The accuracy is suspected to perhaps be lower if inertia and gravitational forces do not solely govern the discharge capacity, as it should in a true Froude model. This could be the case if friction losses and the development of the boundary layer in the approaching flow to the spillway affect the discharge capacity.

Discharge Measurement With An Acoustic Scintillation Flow Meter (ASFM).

Acoustic scintillation drift is a technique for measuring flows in a turbulent medium, such as water or air, by analyzing the variations (with position and time) of sound which has passed through it. Scintillation in this context refers to random variations in the intensity of the sound caused by the variations in the refractive index of the water produced by the turbulence, which is always present in any natural flow. The ASFM measures the speed of the current from the transverse drift of the acoustic scintillation’s observed across two relatively closely spaced propagation paths. The method has been used for many years to measure winds in the atmosphere and ionosphere (Ishimaru, 1978; Lawrence, Ochs & Clifford, 1972; Wang, Ochs & Lawrence, 1981), more recently for measuring currents and turbulence in ocean channels (Clifford & Farmer, 1983; Farmer & Clifford, 1986; Farmer, Clifford & Verrall, 1987; Lemon & Farmer, 1990) and in hydroelectric plants (Birch & Lemon, 1993; Lemon, 1995; Lemon & Bell, 1996); its derivation is well-established.

The ASFM measures the lateral (i.e. along-path) average of the component of the flow perpendicular to the acoustic path. It is therefore well suited for collecting data for discharge measurements, since the product of the path length with the lateral average of the normal component of flow gives the element of discharge at the depth of the path. Sampling at several levels in the vertical and integrating then gives the discharge.

Mellanfallet

Mellanfallet dam is situated on the river Dalälven at Älvkarleby hydro power station. The original dam, built in 1910-1915, was completely rebuilt in 1987-1988.

The dam has six gated spillway openings and the discharge capacity has been determined in a hydraulic model.

Upstream of the spillway the water is shallow and the remains of the old dam is still present. The old dam was used as a cofferdam and it was not possible to completely remove it. It is possible that friction losses and singular losses from the cofferdam could affect the spillway capacity. It was not possible to calibrate the hydraulic model, as the model tests were done before the new dam was built.

Vattenfall found that this spillway would serve as an ideal test site. The left spillway was chosen because a discharge capacity curve, exclusively for this spillway opening, had been determined in the model tests.

Mellanfallet dam has a highest regulated water level of +22.5 m.s.l. but normally during operation the water level is roughly +22.0 m.s.l. The spillway opening is 10 m wide and the sill is at +18.5 m.s.l.

The spillway crest curvature looks more like a broad crested weir than a WES-profile and this could also affect the accuracy of the model tests. Friction losses and the boundary layer could develop in a different manner in the model compared to the prototype.

In August 1999 a serious attempt to measure the spillway discharge was made at Mellanfallet dam with the ASFM method from ASL Environmental Sciences

The measurement plane was roughly 0.15 m in front of the spillway opening and the measurement was made with nine levels of ultrasonic beams. The base of the measurement frame was at the elevation +18.15 m.s.l., the vertical sides of the frame were formed by H-beams fastened to the needle guidance rails used for temporary closure.

The distance between the vertical beams was 11.0 m.

The ultrasonic transducers were mounted on the H-beam with the transmitters on one side and the receivers on the other as shown schematically in Figure 1. The open side of the H-beam was covered with a protective aluminium plate with holes for the transducers. Nine acoustic levels (transducers RX1 through RX9 and TX1 through TX9), in the entrance to the spillway, were mounted on the two vertical H-beams. These eighteen transducers were cabled to the surface to six pressure cases (RX and TX) which, in turn were cabled to the surface data acquisition and control system (SPS). Levels one, two and three were cabled to the first set of pressure cases (RX and TX), levels four five and six were cabled to the second set of pressure cases and levels seven, eight and nine were cabled to the third set. MSL indicates the expected mean water surface elevation. Figure 2 shows a photograph of the spillway in operation with the ASFM system installed.

During an initial test, prior to the installation of the transducers, it was found that the contraction around the H-beams was so severe that the water level dropped below the level of the highest transducer levels and entrained air to levels further down. This entrained air, significantly impeded the transmission of the high frequency sound making measurements on the upper levels impossible.

In order to improve the flow situation around the H-beams, semi circular plates were mounted between the upstream part of the H-beam and the dam wall. This improved the flow situation but not enough for a successful set of full measurements with the water level still dropping below the upper level and entrained air reaching down several levels at large gate openings.

Test Procedure

The test was performed with three gate openings, 0.5m, 1.0 m and fully open gate. At each of the nine paths, the ASFM measured the lateral average of the flow velocity. The discharge is computed by integrating the horizontal component of those velocities between the sill, at the base of the frame and the water surface.

The presence of the free surface meant that to obtain an accurate discharge, the surface elevation had to be measured across the opening. The average elevation of the profile was then used as the upper limit for the integration of the horizontal velocities. Flow velocities at the surface were also

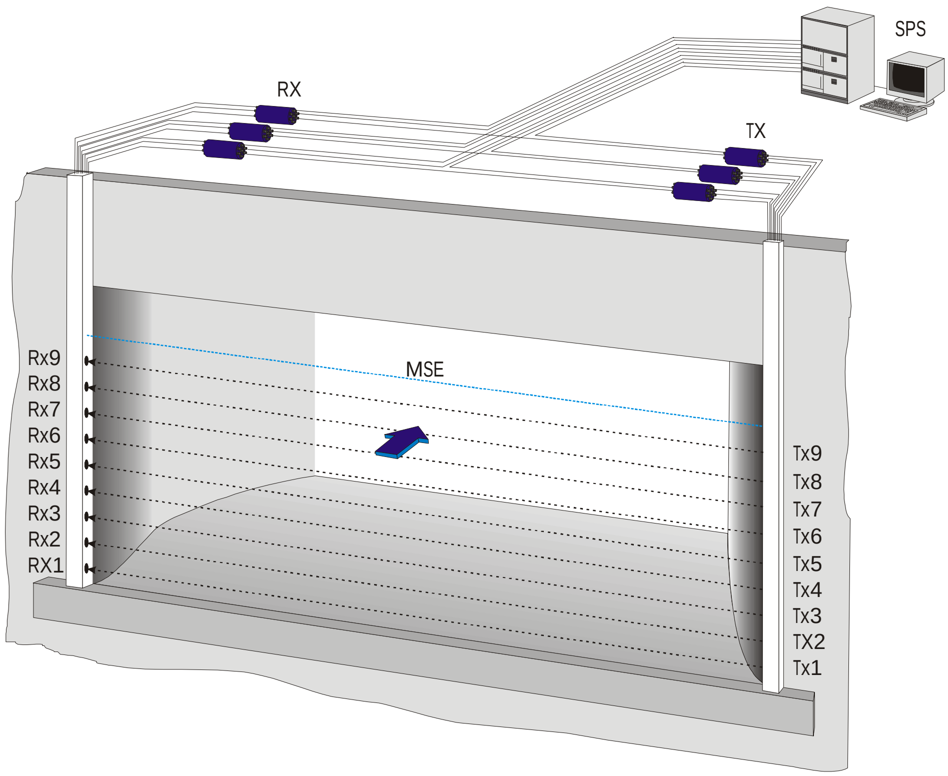

Figure 1: The above figure shows a schematic of the Acoustic Scintillation Flow Meter and the deployment arrangement in the spillway.

Figure 2: Photograph of the flow situation at the spillway inlet

measured with a current meter and the average was used for the horizontal component of velocity at the upper boundary.

Results

Despite the installation of the semi-circular plates, the vortices formed by the flow contraction around the H-beams caused air entrainment down past the upper pair of transducers at full gate opening, so that no acoustic signals were received on that level. Intermittent effects of the air entrainment were apparent at the next three levels below, causing severe signal interference, so that insufficient data could be obtained to make a discharge computation.

Only at the lowest gate opening (0.5 m) were the entrainment effects small enough so that usable data could be obtained; in that case a discharge of 23.6 m^3/sec was measured, which compares favourably with the expected value. Figure 3 shows the horizontal velocities, including the surface measurement at the 4.25m elevation.

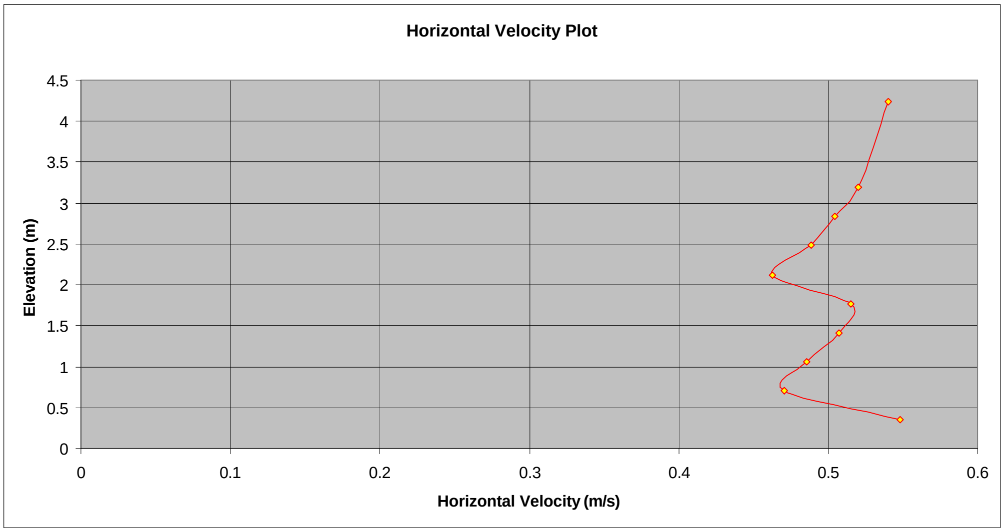

Figure 3: Horizontal velocity plot (vertical profile) for 0.5m gate opening. The measurement at the 4.25m elevation was taken at the surface with a current meter for extrapolation purposes.

Conclusions

The ASFM technique shows promise for directly measuring spillway capacity, but the method of mounting the sensors must be improved so that vortex formation and the introduction of air in front of the sensor faces is prevented. Otherwise, as was seen at Alvkarleby, it is not possible to measure the maximum discharge capacity, which is the quantity of interest. Methods to improve the sensor installation are presently being studied, with the intention that a new test can be performed to measure the maximum discharge.

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