Vortices at intakes

By J. L. Gordon*

This article describes the development of design criteria to avoid vortices at low-head intakes, based on a study of 29 existing hydroelectric intakes

FOR A CONVENTIONAL hydroelectric intake, with a deck slab set above water level, the cost of the intake structure increases with increasing depth of gate sill below water level. For maximum economy the gate sill should be set as high as possible. However, with gate sills at a shallow depth, there is a danger of vortices forming, which may entrain air, thus reducing the efficiency of the turbine. The problem then becomes one of establishing the gate sill at as high a level as possible for economy, but below the level at which vortices are produced for hydraulic efficiency.

There are very few published reports on experiences with vortices at intakes, and in particular there appear to be few data published on just what can be regarded as the submergence required to avoid vortices. Model studies can be undertaken, but on a small intake the cost of a model study may exceed the cost of the intake structure. Several model studies have been undertaken by Anwar[1] and Denny[2], however there is the suspicion that a considerable scale effect may be involved, since viscosity and the forces governing entrainment of air are important, as acknowledged by Lawton[3].

The experience gained from a study of the flow at intakes which have been designed by Montreal Engineering Co Ltd, of Canada, in the past 20 years is included in this article. The study was prompted by the observation of a vortex at low reservoir drawdown on one of the intakes. Of the 29 intakes studied, four were found to have vortices at low reservoir levels. All intakes studied have the same general configuration as shown in Fig. 1, and their characteristics are all within the following limits:

	Lowest	Highest
Velocity at gate V	3·41ft/s	22·2ft/s
Submergence s	4·5ft	67·0ft
Gate height d	4·2ft	26·0ft
Gate width w	4·2ft	22·0ft
d/w ratio	0·9	1·5

The factors which appear to affect the formation of a vortex are: the geometry of the approach flow to the intake; the velocity at the intake; the size of the intake and the submergence.

It is obvious that an intake with the flow approaching from the side (as shown in Fig. 2) will be more prone to vortices than one with a symmetrical approach. However this effect is difficult to measure, particularly since the geometry of the intake approach channel is probably unique to each intake. Accordingly, it was decided to concentrate on investigating the effects of velocity, intake size, and submergence on vortex formation.

In order to derive an empirical equation for submergence, it was assumed that the submergence S was a function of a velocity and a dimension as shown by the following equation:

$$S = C\,V^n\,d^m \qquad (1)$$

where C is a coefficient.

For simplicity it was decided to measure velocity at the gate and use the height of the gate as the dimension

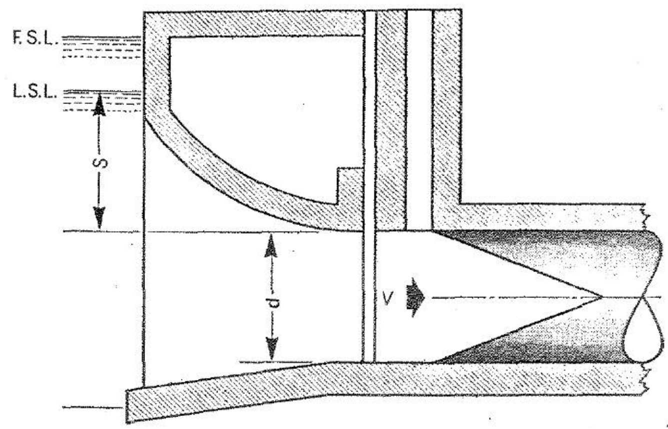

Fig. 1. General configuration of an intake

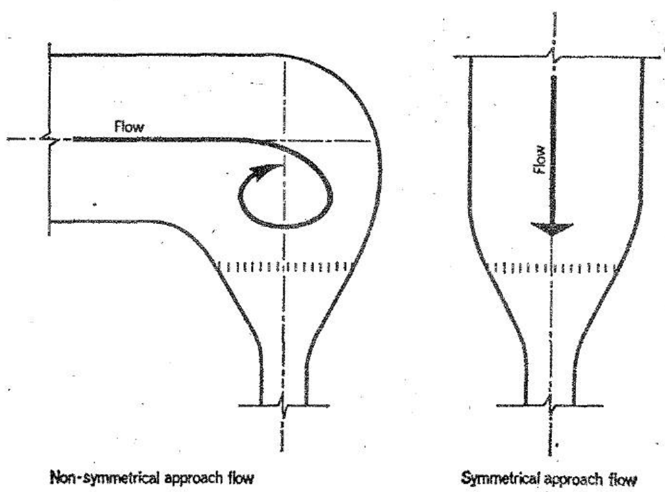

Fig. 2. Intake with flow approaching from the side

function d. The submergence could be measured either from the top of the gate or from the gate centreline. However, after several trials using various values for the exponents n and m it became apparent that a better relationship could be obtained when submergence was measured from the top of the gate as shown in Fig. 1. The trial and error procedure indicated that a reasonable relationship could be obtained with the exponent $n=1$ and $m=\frac{1}{2}$ which produces the equation:

$$S = C\,V\,(d)^{\frac{1}{2}} \qquad (2)$$

and the chart shown on Fig. 3.

The effect of the direction of the approach flow could not be clearly evaluated in this brief study. However, until more data become available, we intend to design

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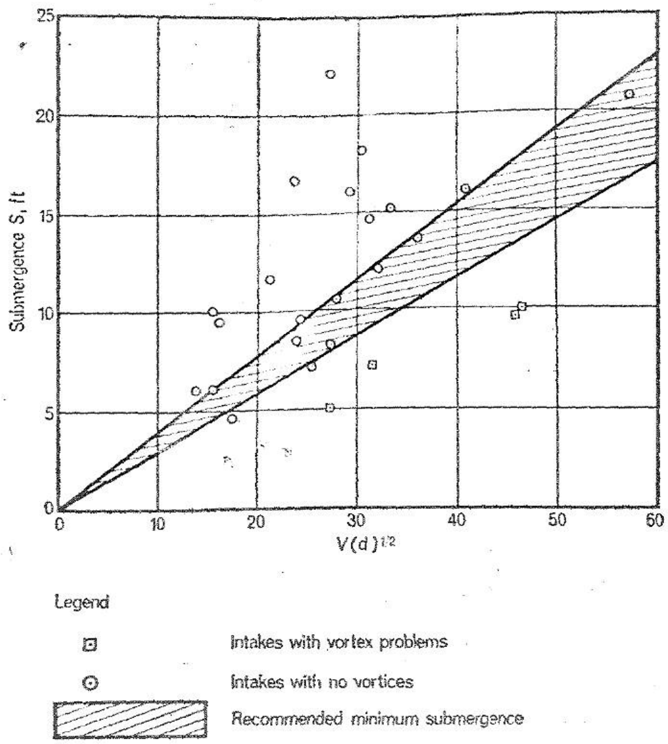

Fig. 3. Minimum submergence limits for intakes with both symmetrical- and lateral-approach flows

intakes which have a symmetrical approach flow with a submergence of at least:

$$S=0{\cdot}3\ V(d)^{\frac{1}{2}} \quad .. \quad (3)$$

which corresponds with the lower limit of the shaded area on Fig. 3, and for intakes with a lateral approach flow the minimum submergence will be increased to:

$$S=0{\cdot}4\ V(d)^{\frac{1}{2}} \quad .. \quad (4)$$

which corresponds with the upper limit of the shaded area on Fig. 3.

Some confirmation of the foregoing submergence criteria can be obtained from Lennart[4], who gives data on several intakes in Sweden which exhibit vortices. At the Atorp power plant, Lennart reports that "a rather strong surging vortex arose. This sucked down trash towards the racks." The submergence of the intake at Atorp corresponds to approximately $S=0{\cdot}1\ V(d)^{\frac{1}{2}}$ with the unit at full load. Lennart further reports that "at lower discharges the eddy zone decreased correspondingly and at about $15m^3/s$ it became imperceptible". At this lower flow the effective submergence increases to $S=0{\cdot}3\ V(d)^{\frac{1}{2}}$.

For the Hammarforsen intake, also reported by Lennart, strong vortices were evident at a submergence equivalent to $S=0{\cdot}28\ V(d)^{\frac{1}{2}}$, and the flow approached the intake at an angle of at least 30-45° from the perpendicular to the front of the intake. It would be interesting to know if these vortices disappeared when the flow was reduced, increasing the effective submergence to $S=0{\cdot}4\ V(d)^{\frac{1}{2}}$.

An idea of the scale effect can be obtained by comparing the submergence criteria with the results obtained by Denny[2] from model experiments. Fig. 4 shows the intakes plotted on the chart developed by Denny (Fig. 13a in Ref. 2). All the intakes, with one exception, plot in the region where vortices could be expected from model studies, whereas experience indicates that only four have encountered troublesome vortices. A partial explanation may be in the definition of "vortex problems". For hydro-intakes the development of small surface riffles or swirls is of no concern, provided the swirls do not

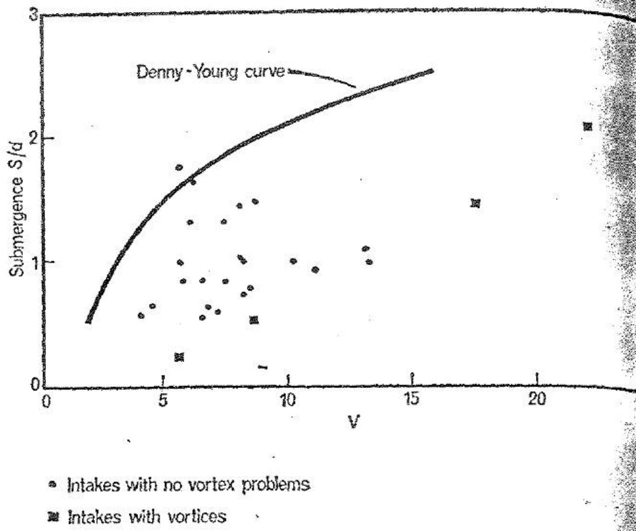

Fig. 4. Intakes plotted on a chart developed by Denny

develop into vortices which draw air into the pipeline. Once air is entrained vortices become a problem.

In conclusion, it is apparent that further research is required into the factors which affect vortex formation. Due to the scale effect, this could best be undertaken on several existing hydro intakes where the flow and the reservoir low supply level can be varied as necessary.

References

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