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Chute spillway concrete volume. - 1998

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Abstract

A formula has been developed to predict the volume of concrete required in a chute spillway, based on only two parameters, the spillway capacity and chute length. The quality of the rock foundation also has an influence. The formula is based on an analysis of 16 existing spillways.

Many hydropower projects include a chute spillway for discharge of flood waters. Their shapes are varied. Many have a chute narrower than the upstream gated control structure; in others the chute width equals the gated section width, and in a few the chute widens to spread the impact of the flip bucket jet over a larger area.

The preliminary design of such structures is often somewhat arbitrary, with the concrete thickness in the chute slab and walls based more on guesswork than on a detailed analysis. The result can lead to a gross underestimation of the concrete volume and hence the cost.

Over the years, the author has managed to collect data on 16 chute spillways, and recently analysed the data in an attempt to develop an empirical formula for the concrete volume to provide an aid in the design process. The formula which has been developed is a function of only two parameters, namely the spillway capacity and the chute length. In the formula, the terms have the following definitions:-

Vc = concrete volume in cubic metres, representing the total volume of concrete in the upstream control structure and the spillway chute, down to and including the flip bucket, but not any concrete within an energy dissipa tion basin below the chute.

Qc = spillway capacity in cubic metres per second.

L = slope length of the chute in metres, from gate face to the downstream end of the flip bucket.

The analysis is based on data for the most common type of spillway chute, where the chute is carved into one of the dam abutments or is located in an adjacent valley and where the height of the control structure ogee does not exceed a few metres. The basic data for the 16 spillways are shown in Table 1, and the results of the analysis are shown in Figure 1.

A first attempt to develop a formula was based on concrete volume, as a function of flow times chute length. However, this correlation resulted in a very wide scatter of the points, with the spread on volume being 1:4, too wide a range to be of practical use. A detailed examination of the plotted data and the spillway statistics indicated that the formula should have two components, one for the control structure volume, and another for the chute volume.

Previous work by the author had shown that for a free standing intake structure located within the upstream slope of an embankment dam, the intake concrete volume could be accurately expressed by the following formula:-

$$Vi = 15\,Qi \quad m^3 \quad (1)$$

where

Vi = intake concrete volume in cubic metres

Qi = intake capacity in cubic metres per second.

Based on this experience, it was reasoned that the first term in the formula, for the control structure concrete volume, should be a simple multiple of the spillway capacity.

As for the second term, representing the chute volume, the author has developed formulae for powerhouse concrete volume [1], wherein it was found that the concrete volume could be expressed as a function of the runner diameter raised to the

Table 1. Chute spillway characteristics.

Project no, name	Concrete vol. $V m^3$	Flow $Q m^3/s.$	Length L.m	$10Q + Q^{0.33}L^{1.2}$ (for Figure 2)
1 McKay	2,200	285	91	4,300
2 Echo	2,300	430	104	6,200
3 Pocaterra	2,573	146	130	3,200
4 Taylor Park	3,300	285	230	7,300
5 Guernsey	7,080	1,485	178	20,400
6 Duncan	14,000	1,685	335	29,300
7 Boysen (1)	15,000	571	122	8,300
8 Arrowrock	19,500	1,140	249	19,100
9 Tieton	26,700	860	366	19,700
10 Brazeau	30,600	1,850	305	30,000
11 Mica	47,400	4,250	580	75,100
12 La Grande 2	84,000	15,430	91	160,000
13 La Grande 3 (2)	88,000	9,700	105	103,000
14 Portage Mtn.	102,440	9,740	701	151,000
15 Tres Marias	145,000	8,700	600	130,000
16 Itiapu (2)	1,030,000	62,000	540	693,000

(1) Volume includes energy dissipator.
(2) Volume includes two dividing walls in chute.

power of 2.4. From this precedent, it was reasoned that chute concrete volume should be a function of:-

$Qs^{0.33}$, to obtain a function in metres, multiplied by
L to obtain a function in metres squared, all raised to some power.

The formula would then have the following form:-

$$Vs = a\,(bQs + Qs^{0.33}L^{x})^{y} \quad m^3 \tag{2}$$

where a,b,x and y are unknown values to be determined by trial and error. After a few iterations, the following formula was developed:-

$$Vs = k(10Qs + Qs^{0.33}L^{1.2})^{1.08} \qquad m^3 \tag{3}$$

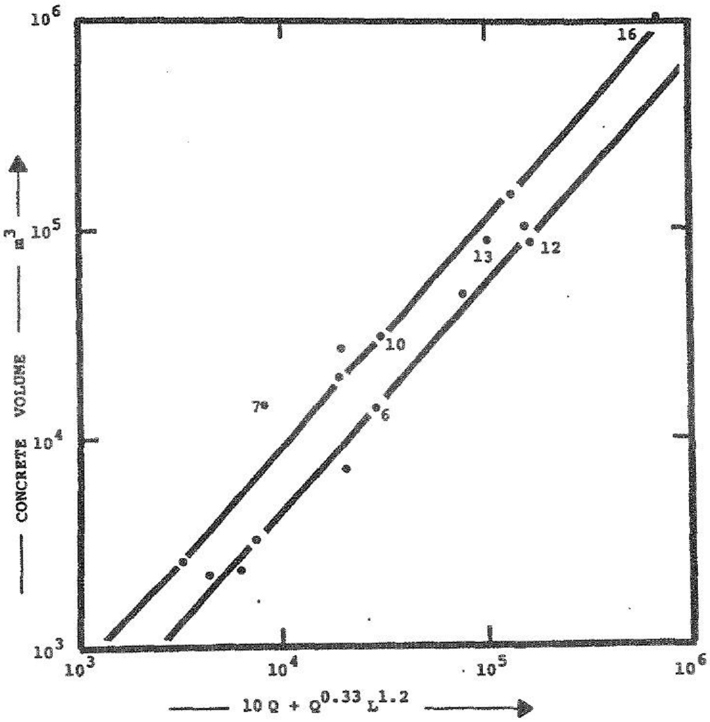
with k having a range of values from 0.22 to 0.44, which may depend on the strength and competence of the rock foundation, as will be discussed later.

In Figure 1, (spillways with comments are identified by number) it will be noted that a few spillways plot outside the two parallel lines. The reason for this is known for some, as follows:-
Boysen is above the lines, because concrete in the stilling basin is included in the total.
La Grande 2 is below the lines, because there is no flip bucket at the end of the chute, which discharges into a long unlined rock channel.
Itiapu is above the lines, because the chute has two internal walls, required to guide the flow in the wide concrete chute, all built on a foundation of nearly horizontal strata of grained basalt interlaid with breccia and agglomerate [2].

As mentioned previously, the range in value for k may be due to the effect of the foundation strength, or the competence of the rock foundation. Unfortunately, data on rock strength was not included in the spillway statistics, hence this conclusion is only tentative, being based on the following observations.

The thickness of the concrete slab and walls in the chute can vary from less than one half metre in a chute founded on competent rock, as at Duncan Lake in British Columbia, where the chute rests within a trench carved into the excellent hard scis-

Figure 1. Chute spillway characteristics.



tose and limestone rock in the left abutment [3]. Duncan plots on the lower line. On the other hand Brazeau, in Alberta, has a chute spillway founded on poor sandstone and shale, and in the upper reaches on over-consolidated glacial till, with free-standing walls on either side. Brazeau plots on the upper line, and the average concrete slab-wall thickness exceeds one metre. Chutes with slab-wall thicknesses of over 2m have been built, as at Petenwell on the Wisconsin River (US), where the chute is founded on sand [4].

Hence, there is some evidence to indicate that the value of k is influenced by the quality of the foundation. If this is the case, the question can be asked: why does the La Grande 3 spillway, which is founded on the same excellent quality rock as that at La Grande 2, plot 55% above the lower line? The answer lies in the design of the spreading chute which has a flip bucket width wider than that of the control structure, and two internal guide walls to direct flow towards the wide flip bucket, all required to spread the impact of the water jet flowing off the flip.

Equation 4 will be most useful in computer programs designed to estimate quantities and the cost of a hydro site quickly, and as a benchmark for comparing quantities in a feasibility study. For example, in a preliminary feasibility study of the Gull Island project in Labrador, the 16,500m³ capacity, 152m long, chute spillway, founded on excellent quality granite rock, should have a concrete volume of just over 100,000m³ according to Equation 4, with a k factor of 0.22. The estimated volume was about 72,500m³, perhaps on the low side. If more data were available on rock quality, it may be possible to develop a relationship for k as a function of rock compressive strength or some other parameter. Unfortunately, data on spillway chute concrete volume, capacity, chute length and rock quality is rarely if ever published. If readers of this paper are interested and could forward pertinent data to the author, an update of this paper could be forthcoming sometime in the future.

References

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