U. S. Department of Agriculture
Soil Conservation Service
Engineering Division
Design Branch

May 11, 1973

DESIGN NOTE NO. 15*

Subject: Submerged Weir Flow

Weir flow over a drop spillway is either free flow or submerged flow. Free (unsubmerged weir) flow exists when the tailwater surface is at or below the crest of the weir. Submerged weir flow exists when the tailwater surface is above the crest of the weir. The depth of submergence is the difference in elevation between the downstream water surface and the crest of the weir.

For free flow conditions the discharge through the weir is independent of the tailwater elevation and the depth at the weir is usually taken as critical depth. For submerged weir flow, the discharge may or may not be independent of the tailwater elevation. When the depth of submergence is 0.7 of the critical depth or less, the discharge is usually taken as equal to the free discharge. For greater submergence, the discharge is determined by both the headwater and tailwater depths (see Fig. 1).

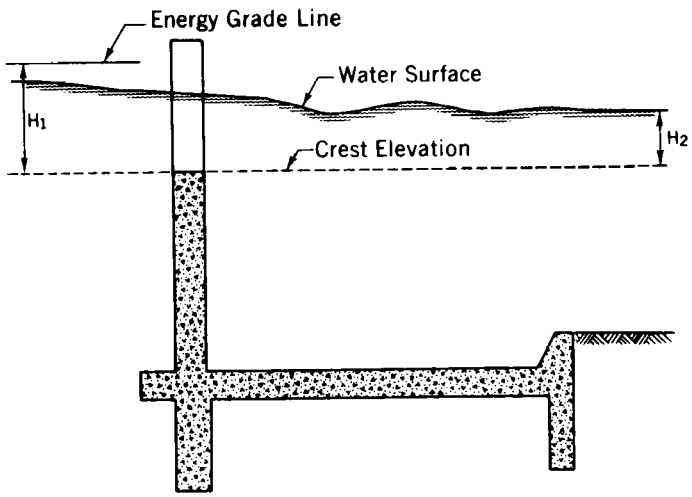


Fig. 1

H_1 ≡ Specific energy head at crest of weir, ft

H_2 ≡ Submergence over the crest = difference in elevation between tailwater and crest of weir, ft

*Prepared by H. J. Goon of the Design Unit, Design Branch, Hyattsville, Maryland.

$L \equiv$ Length of weir, ft

$C \equiv$ Discharge coefficient for free flow

$Q_f \equiv$ Discharge for free flow $= C\ L\ H_1^{3/2}$, cfs

$q_f \equiv$ Discharge for free flow per foot length of weir $= \frac{Q_f}{L}$, cfs/ft

$Q_s \equiv$ Discharge for submerged flow, cfs

$q_s \equiv$ Discharge for submerged flow per foot length of weir $= \frac{Q_s}{L}$, cfs/ft

The discharge for submerged flow is taken as

$$Q_s = R\ Q_f$$

$$q_s = R\ q_f$$

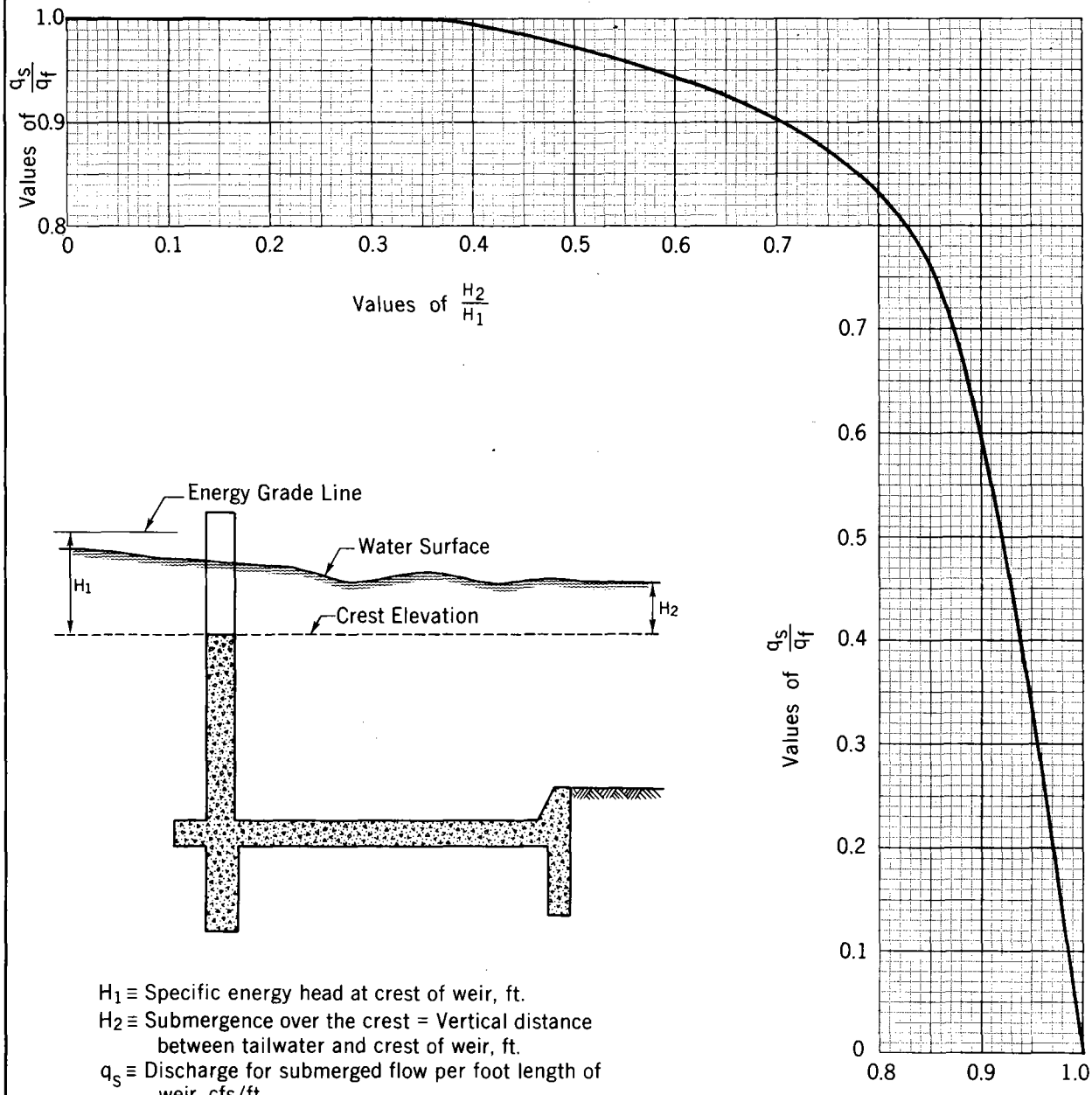
where R is assumed to be a function of submergence ratio, $\frac{H_2}{H_1}$.

Figure 3.4, page 3.17 of NEH-11, Drop Spillways, gives the relation between R and $\frac{H_2}{H_1}$. This figure was prepared by analyzing available test data of submerged flow over several types of weirs and earth embankments. The data indicate a wide band of values of R for given values of the submergence ratio. Therefore, precise results should not be expected from Figure 3.4. If precise results are necessary, a search of literature for discharge data from appropriate weirs or a model study is required.

Figure 3.4 is reproduced on Sheet 1 of ES-207. Observe that when q_s and H_2 are given, H_1 can not be explicitly evaluated from Sheet 1, ES-207. Although H_1 may be solved by cut-and-try methods, it is desirable to transform the graph of Sheet 1, ES-207 into a form such that H_1 can be explicitly evaluated. The transformed graph is given in Sheet 2 of ES-207. Thus

1. when H_1 and q_s are given, Sheet 1 is used to determine H_2 (see Example 1, Sheet 3 of ES-207).
2. when q_s and H_2 are given, H_1 can be explicitly evaluated from Sheet 2, ES-207. (See Example 2).
3. when H_1 and H_2 are given, either Sheet 1 or Sheet 2 may be used to determine q_s.

DROP SPILLWAYS: Relation Between Submergence and Discharge
Given H_1 and q_s, determine H_2



$H_1 \equiv$ Specific energy head at crest of weir, ft.

$H_2 \equiv$ Submergence over the crest = Vertical distance between tailwater and crest of weir, ft.

$q_s \equiv$ Discharge for submerged flow per foot length of weir, cfs/ft.

$q_f \equiv$ Discharge for free flow per foot length of weir, cfs/ft. $= 3.1\ H^{3/2}$

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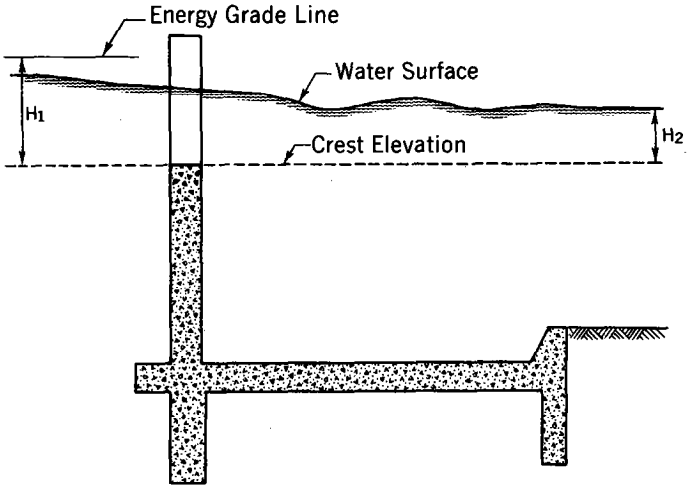
DROP SPILLWAYS: Relation Between Submergence and Discharge
Given H_2 and q_s, determine H_1



$H_1 \equiv$ Specific energy head at crest of weir, ft.
$H_2 \equiv$ Submergence over the crest = Vertical distance between tailwater and crest of weir, ft.
$q_s \equiv$ Discharge for submerged flow per foot length of weir, cfs/ft.

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DROP SPILLWAYS: Relation Between Submergence and Discharge Examples

Example 1

Given: A drop spillway with submerged flow

Discharge coefficient, $C = 3.1$

Specific energy head, $H_1 = 4.20$ ft

Length of weir, $L = 19$ ft

Discharge, $Q_s = 480$ cfs

Determine: Submergence over the crest, H_2

Solution: $Q_f = 3.1\ L\ H_1^{3/2} = 3.1(19)(4.20)^{3/2} = 507$ cfs

$$\frac{q_s}{q_f} = \frac{Q_s}{Q_f} = \frac{480}{507} = 0.947$$

$$\frac{H_2}{H_1} = 0.585 \text{ (Sheet 1, ES-207)}$$

$$H_2 = 0.585(4.20) = 2.46 \text{ ft}$$

Example 2

Given: A drop spillway with submerged flow

Length of weir, $L = 19$ ft

Discharge, $Q_s = 480$ cfs

Submergence over the crest, $H_2 = 2.46$ ft

Determine: Specific energy head, H_1

Solution: $$q_s = \frac{Q_s}{L} = \frac{480}{19} = 25.3 \text{ cfs/ft}$$

$$\frac{q_s^{2/3}}{H_2} = \frac{(25.3)^{2/3}}{2.46} = \frac{8.62}{2.46} = 3.50$$

$$\frac{H_1}{H_2} = 1.71 \text{ (Sheet 2, ES-207)}$$

$$H_1 = 1.71(2.46) = 4.20 \text{ ft}$$

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