# The discharge and run off calculation of weirs under the consideration of dynamic flows

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Keywords: calculation formula, weirs, flow dynamics

## 1 Situation

To calculate the discharged flow masses of a combined overflow site it must be possible, to do so in order to the known geometric parameters of the spillway site and the interceptors in combination with the monitored water levels up and downstream next to the site. This calculations should be solvable on all hydraulic situations even on rapidly unsteady varied flows like the submerged jet stream, the undular jump or the free or suppressed overfall.
Generally this fundamental proposal must be true for any shape of the spillway as well as for the small-crested weir.

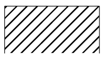
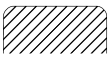
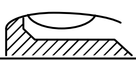
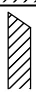
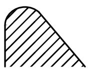
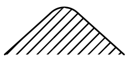
| **Shape of the crest** | | μ |
|---|---|---|
|  | broad-crested weir | 0,49-0,51 |
|  | broad-crested weir, chamfered | 0,50-0,55 |
|  | drum gate: perfect round-crested weir | 0,65-0,73 |
|  | sharp-crested weir with full aeration under the nappe | 0,64 |
|  | round-crested weir with a slope on the down-stream side | 0,75 |
|  | round-crested weir with a slope on both sides | 0,79 |

**Figure 1: μ-factors of the free overfall**

The calculation of the free or suppressed overfall masses in Germany usually is done on constant discharge coefficients within the POLENI-equation, for ex. the μ-factor in figure 1 or the characteristic lines in figure 2. The planning engineer must be sure that the recommended functions satisfy his demands. In opposite

of this the typical designed weirs of sewer systems,

- the small-crested weir or
- the round-crested weir

are not included in the given functions. For the high number of sites built in this kind of weirs it is necessary to offer dimensioning formula of this weir shapes to engineers.

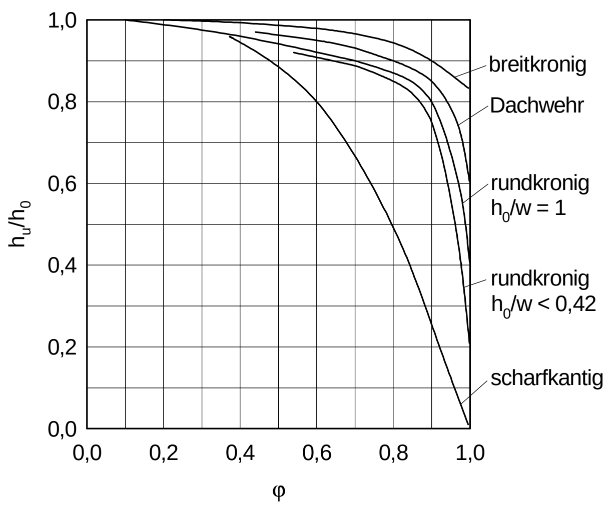


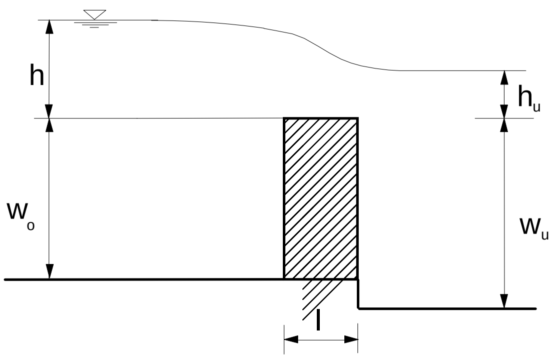

**Figure 2: φ- factor of the suppressed overfall**

In the standard guideline in Germany of dimensioning sewers and buildings inside the sewer systems (ATV-A 111, 1994), a constant $\mu = 0,5$ is given for all weirs except the sharp-crested weir. It is necessary to realise dynamic coefficients to represent the behaviour of the flows at the weir sites.

## 2 The Calculation of the Overflow Spillway shown at the Small-Crested Weir

### 2.1 Basic hydraulic Aspects

The geometric and hydraulic situation of the small-crested weir is given in fig. 3.




| | | |
|---|---|---|
| $w_o$ : | [m] | upstream height of the weir |
| $w_u$ : | [m] | downstream height of the weir |
| l : | [m] | length of the crest of the weir |
| h : | [m] | upstream velocity head |
| $h_u$ : | [m] | downstream water level |

**Figure 3: Overflow at the small-crested weir**

The overflow will be calculated with the formula of POLENI (1):

$$Q = \frac{2}{3} \cdot \mu \cdot \varphi \sqrt{2g} \cdot b \cdot h^{3/2} \qquad (1)$$

IF

$$C_h = \frac{2}{3} \sqrt{2g} \cdot \mu = 2{,}953 \cdot \mu \qquad (2)$$

THEN

$$Q = C_h \cdot \varphi \cdot b \cdot h^{3/2} \qquad (3)$$

| | | | |
|---|---|---|---|
| with | b : | [m] | width of the weir crest |
| | $\mu$ : | [-] | factor for free overfall |
| | $C_h$ : | $[m^{1/3} * s^{-1}]$ | discharge coefficient on free overfall |
| | $\varphi$ : | [-] | reducing factor for suppressed overfall, for free overfall $\varphi = 1$ |

## 2.2 Aspects of the free overflow

Small-crested weirs hydraulically can be situated between the sharp-crested weir and the broad-crested weir. If the spillway is low, the shape of the spillway and the corresponding water levels are typically the same as of the broad-crested weir. For the calculation the discharge coefficient $C_h$ is small.
If the spillway is high, the shape of the spillway is typically the same as of the small-crested weir.
Dimensionally correct the following conditions can be shown

$$C_h = f\left(\frac{h}{w_0}; \frac{h}{l}\right) = 2{,}953 \cdot \mu_1 \cdot \mu_2 \qquad (4)$$

$\mu_1$ stands for the small-crested weir spillway pattern and is described by the well known weir formula of REHBOCK (5)

$$\mu_1 = 0{,}6034 + 0{,}0813 \cdot \frac{h}{w_0} \qquad (5)$$

$\mu_2$ stands for the broad-crested weir spillway pattern and is investigated by the author (6)

$$\mu_2 = 1 - 0{,}2 \cdot e^{-0{,}6\left(\frac{h}{l}\right)^{3{,}06}} \qquad (6)$$

The overflow spillway of the free overfall then is calculated as

$$Q = 2{,}953 \cdot \mu_1 \cdot \mu_2 \cdot b \cdot h^{3/2} \qquad (7)$$

The influence of the broad-crested weir is given by the factor $m_2$ , which gives at maximum a 20% overflow reduction compared to the sharp-crested weir.

If the inlet site of the small-crested weir will be chamfered or round-crested equation (7) will be extended by the factors

- $\mu_3$ for the chamfer of the small crest or
- $\mu_4$ for the circular shape of the small crest.

Both factors are formulated on mathematically investigated equations like the equation of $\mu_2$.

## <u>2.3 Aspects of the suppressed overfall</u>

For the small-crested weir is not included in the figures 1 or 2 the engineer usually uses the equation given for the sharp-crested weir instead. The difference of spillway masses is not small if a free overfall is taken into account but if a suppressed overfall is given, the difference can be more than 100%.

This can be said for obviously a small-crested weir within a range of hydraulic overflow situations can be described like a broad crested weir. The suppressed overfall starts approximately within the **$h_u/h$** -interval

$$0{,}80 < \mathbf{h_u/h} < 0{,}87$$

In comparison to the characteristic curve of the sharp-crested weir (figure 2) there is a significant deviation.

Long experimental series of model tests on the whole range of weir types between the sharp-crested and the broad-crested weir and their analysis three different possibilities to explain the relationship of the parameters:

$$\varphi = f\left(\frac{h_u}{h}; \frac{h}{h_u + w_u}\right) \tag{8}$$

$$\varphi = f\left(\frac{h_u}{h}; \frac{h_u}{h_u + w_u}\right) \tag{9}$$

$$\varphi = f\left(\frac{h_u}{h}; \frac{l}{h}\right) \tag{10}$$

Definitive important is the influence of $w_u$ on the formula because the suppressed overfall is influenced by the downstream hydraulic situation.

In the following figures 4 and 5 the relationship given in the equations (8) and (10) are shown while the mathematical analysis of (8) is given in equation (11).

$$\varphi = \exp^{a} \cdot \left[ \arctan\left( C \cdot \left( \frac{1 - \frac{h_u}{h}}{\frac{h}{h_u + w_u}} \right) \right) \right]^{b} \tag{11}$$

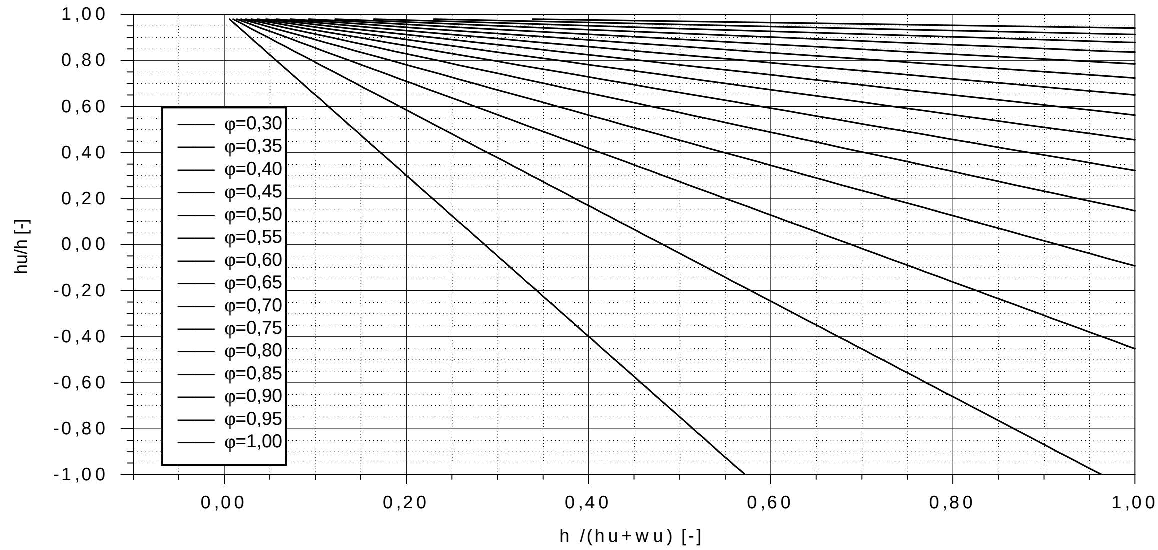



**Figure 4:** $\varphi = f\left(\frac{h_u}{h}; \frac{h}{h_u + w_u}\right)$

The constants a, b and c represent the different **$l/w_0$** - intervals. Graphically during the interval of 0,25 < **$l/w_0$** < 0,35 figure 4 represents equation (11).

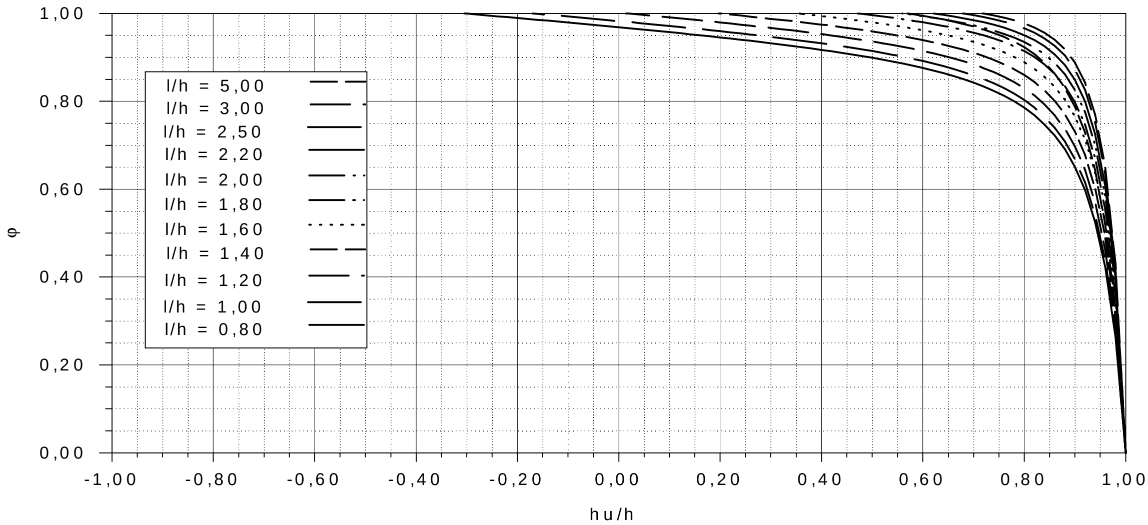



**Figure 5:** $\varphi = f\left(\frac{h_u}{h}; \frac{l}{h}\right)$

In the same interval of $0{,}25 < \mathbf{l/w_0} < 0{,}35$ equation (10) is shown in figure 5. The mathematical model is not given in this paper. In total 10 of this diagrams are investigated referring to 4 different $\mathbf{l/w_0}$ - intervals.

Figure 5 shows a separate φ - curve classified by an overflow spillway Q respectively the corresponding l/h . Therefor it can not be accepted to describe the imperfect overfall at a special type of weir by a single graph referring to figure 2.

Using special software it is possible to calculate 16 different types of weirs, including the small-crested weir under the conditions of

- the perfect overfall,
- the imperfect overfall,
- slanting weirs,
- sluice gates.

## 3 Conclusion

With the given formula the small-crested weir now can be designed according to the geometry of the inflow and under the conditions of different velocity heads and the length of the crest. In case of the suppressed overfall there is a deviation up to 100% compared to the calculation of the small-crested weir like a sharp-crested weir. The small-crested weir now can be used as a measuring weir. The developed dimensional exact calculation formula of the small-crested weir supports a significant reduction of the length of the weir crest.

## 4 Literature: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