Vertical gates for distribution of irrigation water

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VERTICAL GATES FOR DISTRIBUTION OF IRRIGATION WATER

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ABSTRACT

Vertical slide gates with undershot flow are used in irrigation systems as head regulators and offtake structures.
The gates are located in a rectangular canal section. The weir abutments are vertical and rounded off to eliminate flow separation.
The number of gates in a structure may vary from one to four or more. If two or more gates are combined in one single structure, intermediate piers are provided and are also rounded off.
The gates can be raised and lowered in vertical slots.
There are mainly two advantages of the vertical slide gate:
- the double function as a discharge regulating and measuring structure
- the low sensitivity for a small change in head.

The purpose of this paper is to underline the function of discharge measurement using vertical slide gates, and to formulate the limits of application.
Attention is given to the different types of flow: gate flow and venturi flow.
For gate flow a distinction is made between free flow and submerged flow, and between two-dimensional flow and three-dimensional flow.
The recommendations given in this paper are based upon theoretical equations and a number of model studies carried out by Delft Hydraulics and by the Agricultural University in The Netherlands.

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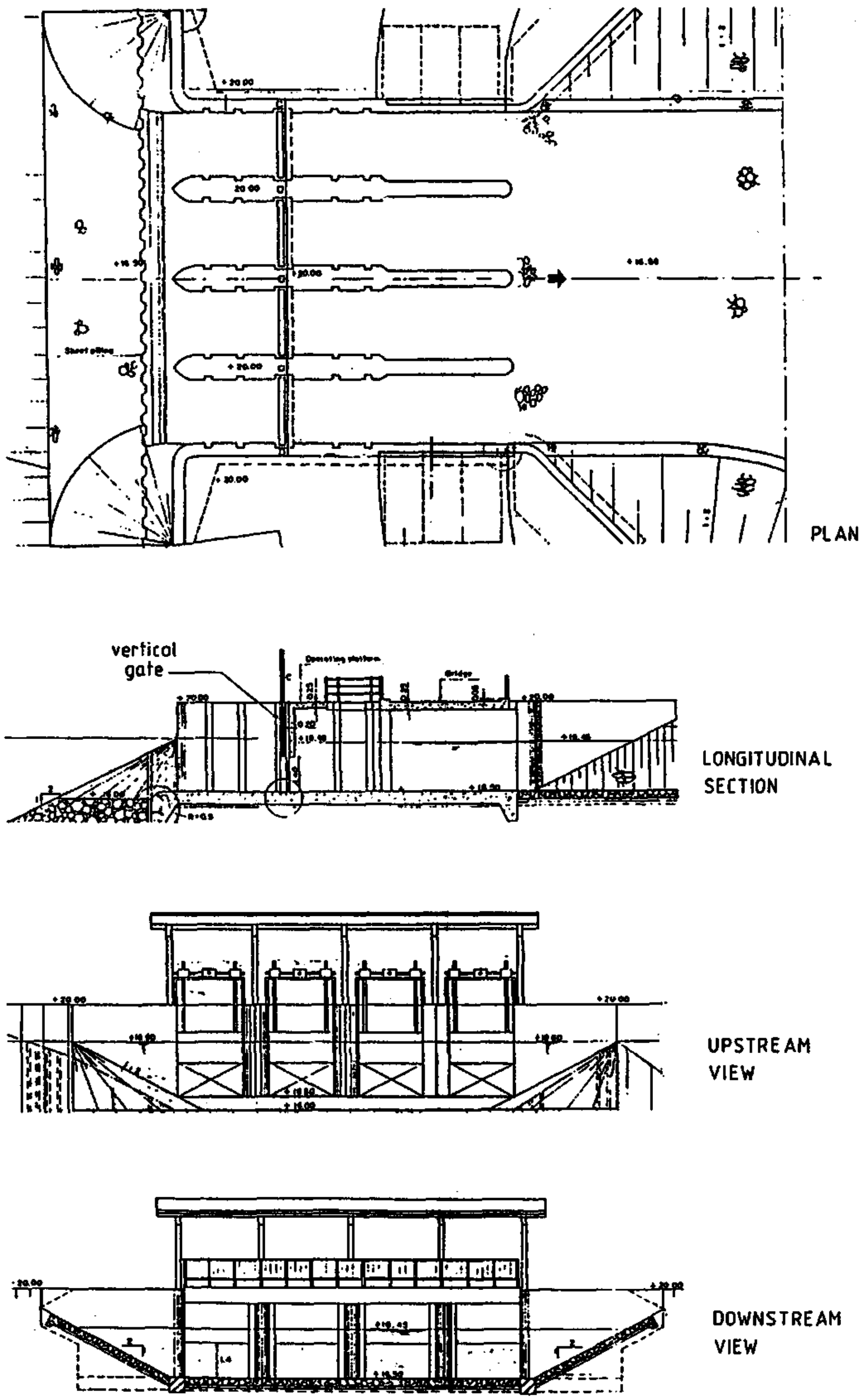

Fig. 1: Gated intake structure.

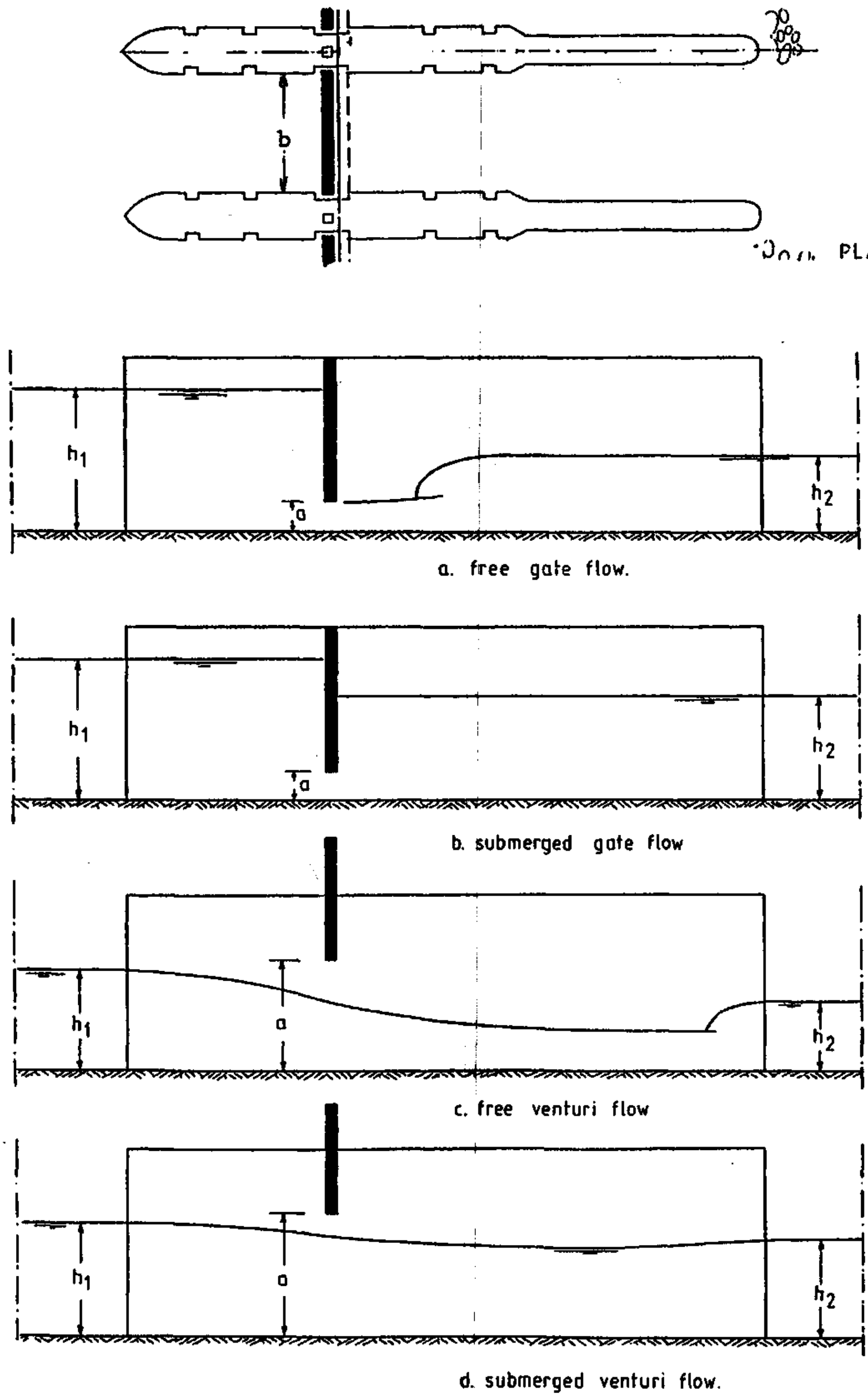

Fig. 2: Different flow types in a gated intake structure.

By application of the equations 3, 4 and 5 the discharge relation can be calculated for two-dimensional flow.

Garbrecht [4] gives the following equation for two-dimensional flow under a sharp-edged gate (d = 0)

$$Q = (0.9146 \sqrt{h_1/a} - 0.2321) \;.\; a \sqrt{ga} \;.\; b \qquad (6)$$

which is in fairly good agreement with the equations 3, 4 and 5.

Conclusion: the determination of discharge for two-dimensional free flow under a vertical gate can be done with fairly high accuracy, provided the rounding of the bottom edge is well defined, and $h_1/a \geq 2$.

2.2. <u>Limit between free flow and submerged flow</u> (Fig. 6)

The limit at which the hydraulic jump will submerge the free jet is also called the modular limit. The equation reads:

$$h_2/a = C_C/2 \; [\sqrt{1+16(H_1/aC_C - 1)} - 1] \qquad (7)$$

where

h_2 = downstream waterlevel, related to the sill level (m)

H_1 = upstream energy head, related to the sill level (m)

assuming $H_1 \approx h_1$ values of h_2/a can be calculated.

Figure 6 gives the limit between free flow and submerged flow for the extreme C_C-values

C_C = 0.611 sharp edged bottom, d = 0

C_C = 0.990 rounded edge, d > 4.7 a

Both modular limits are related to two-dimensional flow.

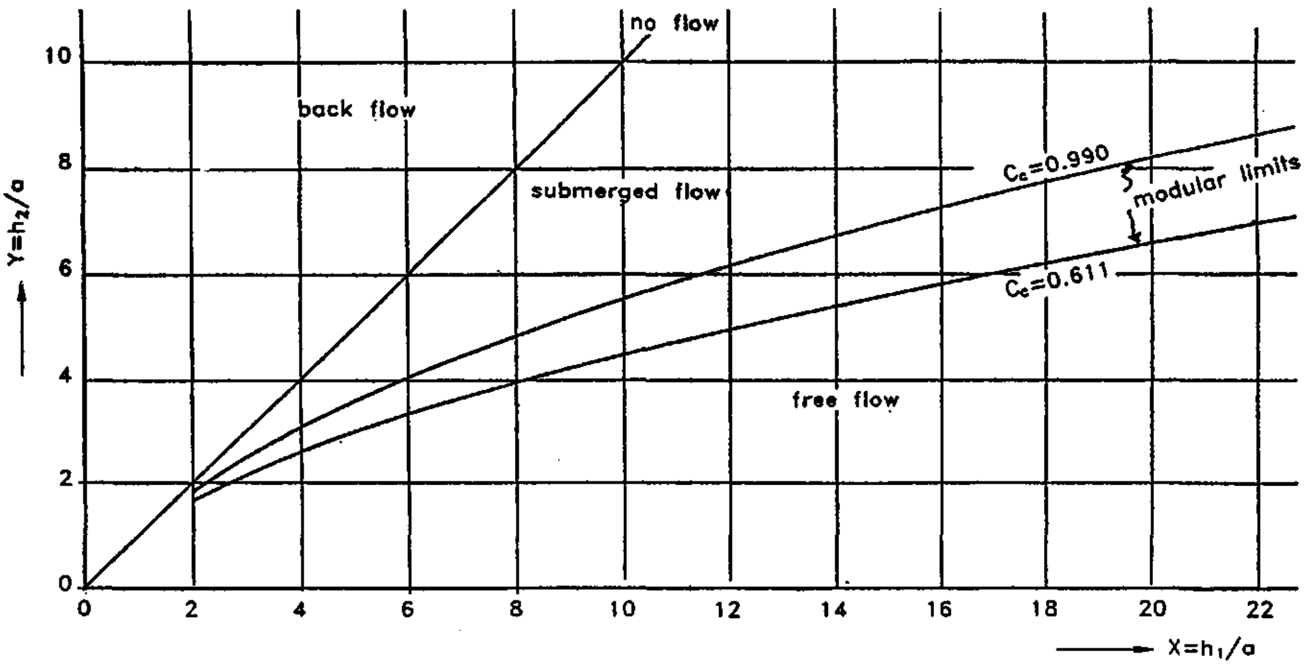

Fig. 6: Limit between free flow and submerged flow.

2.3. Determination of discharge for submerged flow (Figures 7 and 8)

The variety in discharge equations is now about as numerous as the variety in authors. All equations apply to two-dimensional flow.
The accuracy of the equations depends primarily on the difference in head h_1-h_2:

$Q = f(h_1/a, h_2/a, \text{shape of bottom edge})$

The shape of the bottom edge is given by the diameter d of the circular rounding of the bottom edge, from which the contraction coefficient C_c is calculated with equation 5.

Four of the many equations for submerged flow are listed below.

- $Q = C_2 \cdot a \cdot b \cdot \sqrt{2gh_1}$ (8)

  The equation is used for free flow by various authors. A number of authors, among whom Kolkman [5], apply the same equation for submerged flow.
  The discharge coefficient C_2 is a function of h_1/a, h_2/a and C_c. h_2 is the downstream head at a certain distance behind the gate.
  Figure 7 gives the discharge coefficient C_2 for the vertical sharp-edged gate.

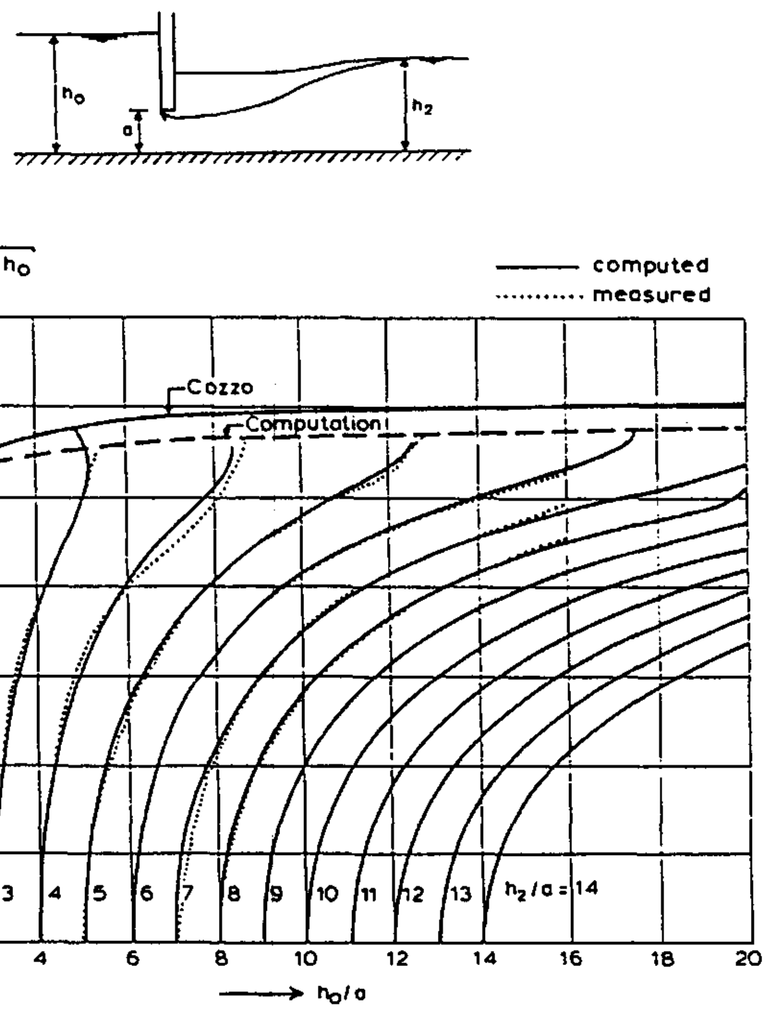

Fig. 7: Discharge coefficient for submerged two-dimensional flow through a sharp-edged plane gate.

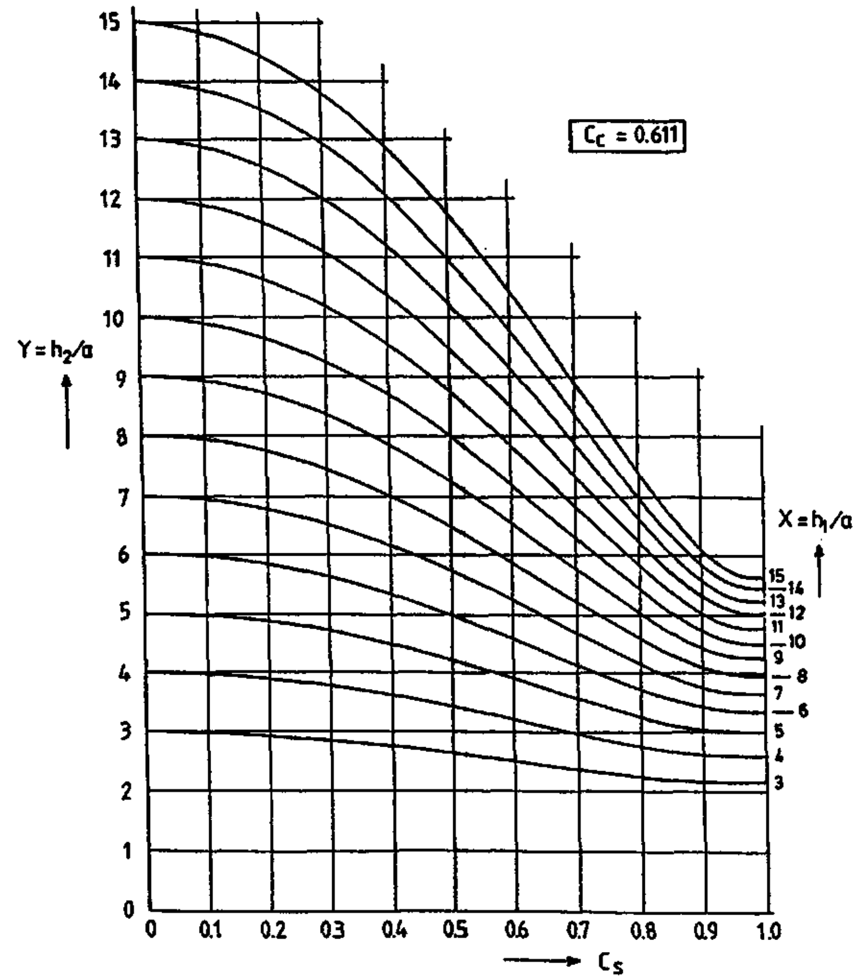

Fig. 8: Coefficient C_s for submerged gate flow.

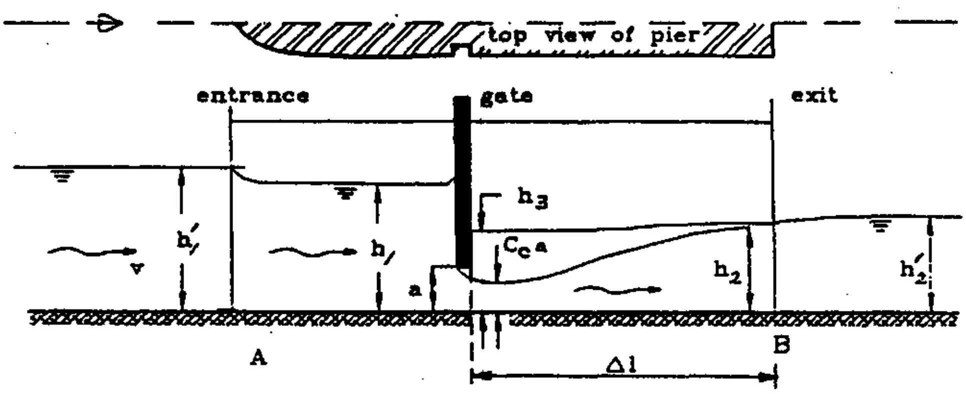

Fig. 9: Loss of head for three-dimensional gate flow.

In most of the gated intake structures the length of the intermediate piers will be determined by factors as:
- overall stability of the structure
- minimum length for energy dissipation downstream of the gate
- costs of construction.

The designer will tend to minimize the length of piers and abutments. For those relatively short piers the flow conditions between the piers will not be suitable to measure the h_1 and h_2 waterlevels. The velocity distributions in the h_1 and h_2 sections are expected to be far from normal: in the h_1 section three-dimensional effects are present, whereas in the h_2 section energy will not be dissipated completely. Therefore the waterlevels are measured in sections upstream and downstream of the structure, h_1' and h_2' respectively.
But now the flow through the structure can be seen as a chain of discontinuities (Fig. 9), for each of which an equation can be set up relating waterlevels and discharge. In this approach no interactions between the sections are introduced.
In general terms the total loss of head over the intake structure can be expressed as follows:

$$h_1' - h_2' = (h_1'-h_1) + (h_1-h_2) + (h_2-h_2') \tag{13}$$

where the partial losses are as follows:

- entrance: $h_1' - h_1 = (1 + \xi_i) \cdot (v_1)^2/2g - (v_1{}^1)^2/2g$ (14)
  where ξ_i is the entrance loss coefficient
- gate : $h_1 - h_2$ which is assumed to be the headloss due to two-dimensional gate flow (par. 2)
- exit : $h_2 - h_2' = (v_2{}^1)^2/2g + (\xi_o - 1).(v_2)^2/2g$ (15)
  where ξ_o is the exit loss coefficient.

In this approach the two-dimensional relation $h_1 - h_2 = f(Q,a)$ can be transformed in a three-dimensional relation $h_1' - h_2' = f(Q,a)$.
Kolkman [5] presented a numerical procedure to compute this type of relations. In practice, however, the computed relation may deviate from the real situation due to one or more of the following uncertainties:
- difficulties in a clear description of the bottom-edge rounding d, resulting in inaccuracies of the C_C-value
- inaccuracy of the estimated loss coefficients ξ_1 and ξ_2
- interaction between the different losses: entrance, gate and exit
- incorrect location of the h_1 and h_2 measuring points.

It is therefore recommended - especially in those cases where the intermediate piers are short or where the flow velocities v_1 and v_2 are fairly high - to calibrate the structure. Calibration can be carried out in the field or by carrying out a hydraulic model investigation.

In very few cases the intermediate piers are so long that the flow conditions in the area between the piers are suitable for measuring h_1 and h_2 (in both sections two-dimensional flow with a normal velocity distribution).
In those cases the three-dimensional effects are kept outside of the measuring section.
Now discharges can be determined from two-dimensional flow equations (section 2).

In conclusion the following methods for the determination of discharges for three-dimensional gate flow are recommended:

piers	method	head sections	conditions	approximate error X	
				free flow	subm.flow
long	1. 2-dimensional flow equations (par. 2)	h_1 h_2	a, c	5%	10%
	2. numerical procedure 3-dimensional flow	h_1' h_2'	a, b, c	10%	15%
short	3. model calibration	h_1' h_2'	-	5%	10%
	4. field calibration	h_1' h_2'	-	10%	15%

conditions: a = clear description of bottom-edge rounding;
b = interaction of losses negligible;
c = correct locations of head sections.

4. Limits of application

For a correct operation of intake structures with vertical undershot gates, the following limits of application must be met:

1. The shape of the upstream bottom edge shall be well defined, so as to determine the correct value of the contraction coefficient C_C.
2. The bottom of the undershot gate is truly horizontal.
3. To prevent air entraining vortices immediately upstream of the gate, the bottom of the gate must be submerged with $h_1/a \geq 2$.
4. For accurate discharge measurements the structure shall be equipped with waterlevel recorders upstream and downstream of the structure, and with a device indicating the gate opening height. The locations of the recorders shall not be affected by high turbulence or other irregularities of the water surface.
5. For structures with two or more gates it is recommended to operate all gates under exactly the same opening height a for the following reasons:
   - different heights a make the determination of the total discharge complicated and less accurate
   - using all the gates the velocity distribution over the full width of the canal is more uniform, upstream as well as downstream of the structure, resulting in lower maximum flow velocities.
6. Concrete or masonry abutments shall be well finished, and the roundings of abutments and piers shall be at least R = b/8 for moderate approach velocities and R = b/4 for high velocities, to prevent additional losses.
7. It is strongly recommended to design intake structures in such a way that only one flow type will occur: free flow or submerged flow. This will be achieved by selecting the bottom elevation of the sluice gate sufficiently high (for free flow) or low (for submerged flow) in relation to the downstream waterlevel.

5. Conclusions and recommendations

1. Intake structures provided with vertical slide gates are fairly popular structures in irrigation systems for two reasons:
   - the double function as discharge regulating and measuring structure
   - the low sensitivity for a small change in head.

   The ratio h_1/a identifies the type of flow:

$h_1/a \leq 1.25$	venturi flow (which should be prevented)
$1.25 < h_1/a < 2.00$	gate flow with possible air entrainment (not recommended)
$h_1/a \geq 2.00$	gate flow (recommended range)

2. Determination of discharge for two-dimensional gate flow can be carried out with fairly good accuracy:

type of flow	determination of discharge	approximate error X
free flow	equations 3, 4 and 5	5%
submerged flow	equation 8 and Fig. 7	10%

   The limit between free flow and submerged flow is expressed by equation 7 or Figure 6.
3. Determination of discharge for three-dimensional gate flow is more complicated.
   The three-dimensional effects depend mainly on the length and shape of the intermediate piers. The following methods can be applied:

length of piers	method	approximate error X	
		free flow	subm. flow
long	1. two-dimensional flow equations	5%	10%
short	2. numerical procedure three-dimensional flow	10%	15%
	3. model calibration	5%	10%
	4. field calibration	10%	15%

4. The limits of application for a correct operation of gated intake structures have been mentioned in section 4.
5. Further investigation is recommended as for the following aspects:
   - equations 11 and 12 need to be verified with experimental data of sharp edged gates and round edged gates so as to find reliable dimensionless parameters for the determination of discharge for two-dimensional submerged flow
   - the numerical procedure as proposed by Kolkman for the determination of three-dimensional flow should be worked out and verified with experimental data.

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