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Hydrometry — Fishpasses at flow measurement structures

Hydrométrie — Échelles à poissons auprès des structures mesurant le débit

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Foreword

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International Standards are drafted in accordance with the rules given in the ISO/IEC Directives, Part 2.

The main task of technical committees is to prepare International Standards. Draft International Standards adopted by the technical committees are circulated to the member bodies for voting. Publication as an International Standard requires approval by at least 75 % of the member bodies casting a vote.

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ISO 26906 was prepared by Technical Committee ISO/TC 113, *Hydrometry*, Subcommittee SC 2, *Flow measurement structures*.

Introduction

Flow gauging structures are commonly used for the measurement of open channel flows. To operate satisfactorily, these structures require a head difference to be generated between the upstream and downstream water levels. At structures designed to operate in the modular flow range, an upstream head measurement is used to interpret flow rates. At structures designed to operate in both the modular and drowned flow ranges, the upstream head measurement is augmented by a second measurement which senses tailwater conditions. The former type tends to require higher head losses over the structure.

In recent years, greater emphasis has been placed on environmental issues, including the free migration of fish in watercourses. It is acknowledged that flow measurement structures, with their requirement for a head loss between upstream and downstream conditions, may inhibit the movement of fish. It has become important, therefore, to consider ways of aiding fish migration without seriously affecting flow measurement accuracy.

Hydrometry — Fishpasses at flow measurement structures

1 Scope

This International Standard specifies requirements for the integration of fishpasses with flow measurement structures. It identifies those fishpasses which have satisfactory hydrometric calibration data and gives methods for computing combined flows and uncertainties.

NOTE Measurement structures and fishpasses have inherently different hydraulic performance criteria. Water measurement structures perform better with uniform flow patterns; conversely, fish passage performance is improved by the variability of the flow conditions that allow fish and other aquatic inhabitants to select the passage conditions that best meet their mode of movement. This International Standard does not suggest that the fishpasses discussed are the preferred methods of passage or that they are good enough that passage performance can be sacrificed to obtain a single structure that does both.

2 Normative references

The following references are indispensable for the application of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 772, *Hydrometry — Vocabulary and symbols*

ISO 14139, *Hydrometric determinations — Flow measurements in open channels using structures — Compound gauging structures*

3 Terms and definitions

For the purpose of this document, the terms and definitions given in ISO 772 apply.

4 Symbols

Where a symbol applies to a particular type of fishpass, it is indicated as follows.

[L] indicates applicable to the Larinier super-active baffle fishpass (see 7.2)

[PT] indicates applicable to the pool type fishpass with V-shaped overfalls (see 7.3)

[PO] indicates applicable to the Dutch pool and orifice fishpass (see 7.4)

Symbol	Term	Unit
a	height of baffle [L]	m
b	orifice width [PO]	m
b	crest breadth measured at transverse section of upstream baffle [L]	m
B	width of fishpass [L]	m
B	pool width [PT and PO]	m
B_2	width of the non-aerated nappe [PT]	m
C	characteristic discharge coefficient [PO]	
C_{de}	dimensionless coefficient of discharge [L]	
C_D	characteristic discharge coefficient [PT]	
C_V	coefficient for the approach velocity [PT]	
D	longitudinal spacing of transverse baffles [L]	m
D	pipe diameter [PO]	m
g	acceleration due to gravity [All]	m/s^2
h_{max}	maximum head	m
h_v	orifice height [PO]	m
h_1	upstream gauged head relative to transverse section of upstream baffle [L]	m
h_1	upstream head [PT]	m
h_2	downstream head [PT]	m
H_1	upstream total head relative to transverse section of upstream baffle [L]	m
H_1	upstream total head [PT]	m
H_{1e}	effective upstream total head relative to transverse section of upstream baffle [L]	m
k_h	head correction factor taking into account fluid property effects [L]	m
l	pool length [PT]	m
L	crest length [PT]	m
L	pool length [PO]	m
n	number of partitions [PO]	
n_l	length scale factor [PO]	
n_V	flow velocity scale [PO]	
n_Q	discharge scale [PO]	
n_ℓ	scale factor for length dimensions [PT]	
P	height of the top baffle [L]	m
P	pool depth [PT]	m
Q	discharge [All]	m^3/s
Q_d	design discharge [PT and PO]	m^3/s
S	bed slope of fishpass [PO and L]	
U	burst velocity of fish [PO]	m/s
v	flow velocity [PT and PO]	m/s
v_1	velocity of approach at tapping location [L]	m/s
$\bar{V}$	mean flow velocity [PO]	m/s
W_{L1}	upstream water level [PO]	m
W_{L2}	downstream water level [PO]	m
X	distance to h_1 measurement section [PT]	m
X_C	uncertainty in C_D [PT]	%
X_Q	uncertainty in measured or calculated discharge [PT and PO]	%
Y_d	downstream water depth, related to upstream bed level [PO]	m
Y_0	upstream water depth, related to upstream bed level [PO]	m

α	angle of V-shape [PT]	deg
δ_h	error in measurement of h_1 [PT]	m
Δh	drop over the fishpass for modular flow [PT]	m
$\overline{\Delta h}$	head drop per pool [PO]	m
$\overline{\Delta h_d}$	design head drop per pool [PO]	m
Δt	pool drop [PT]	m

5 Principle

The discharge over a flow measurement structure is a function of the upstream head (plus a measure of the downstream head in the case of those structures designed to operate in the drowned flow range). When a fishpass is placed alongside a flow gauging structure, an additional flow path is created. In certain circumstances, where the fishpass has a well-defined hydrometric calibration, total flows and uncertainties may be calculated. Thus the fishpass becomes an integral part of the flow measurement system. This document provides the necessary design and performance information for this type of arrangement.

6 Installation

NOTE General requirements of combined flow measurement structure/fishpass installations are given in the following clauses.

6.1 Requirements for gauging structure/fishpass installations

NOTE Requirements for the installation of gauging structures are given in the appropriate International Standard (see Clause 2 and the Bibliography). There is much in common between the different structures and the requirements, which can also be applied to flow measurement structure/fishpass installations, and are summarized in the following clauses.

6.1.1 Selection of site

6.1.1.1 A preliminary survey shall be made of the physical and hydraulic features of the proposed site, to check that it conforms (or may be made to conform) to the requirements necessary for measurement by a weir.

6.1.1.2 Particular attention shall be paid to the following features in selecting the site:

— availability of an adequate length of channel of regular cross-section;

— the existing velocity distribution;

— the avoidance of a steep channel, if possible;

— the effects of any increased upstream water level due to the measuring structure;

— conditions downstream, including such influences as tides, confluences with other streams, sluice gates, mill dams and other controlling features which might cause submerged flow;

— the impermeability of the ground on which the structure is to be founded, and the necessity for piling, grouting or other sealing, in river installations;

— the necessity for the use of flood banks to confine the maximum discharge to the channel;

— the stability of the banks and the necessity for trimming and/or revetment in natural channels;

— the clearance of rocks or boulders from the bed of the approach channel;

— the effect of wind; wind can have a considerable effect on the flow in a river or over a weir, especially when these are wide and the head is small and when the prevailing wind is in a transverse direction.

6.1.1.3 If the site does not possess the characteristics necessary for satisfactory measurement, the site shall be rejected unless suitable improvements are practicable.

6.1.1.4 If an inspection of the stream shows that the existing velocity distribution is regular, then it may be assumed that the velocity distribution will remain satisfactory after the construction of a weir.

6.1.1.5 If the existing velocity distribution is irregular and no other site for a gauge is feasible, due consideration shall be given to checking the distribution after the installation of the weir and to improving it if necessary.

6.1.1.6 Several methods are available for obtaining a more precise indication of irregular velocity distribution. Velocity rods, floats or concentrations of dye can be used in small channels, the latter being useful in checking conditions at the bottom of the channel. A complete and quantitative assessment of velocity distribution may be made by means of a current metre or acoustic Doppler profiler.

6.1.2 Installation conditions

6.1.2.1 The complete installation consists of an approach channel, the flow measurement/fishpass structures and a downstream channel. The conditions of each of these three components affect the overall accuracy of the measurements.

6.1.2.2 Installation requirements include such features as the quality of the structures, the cross-sectional shape of channel, channel roughness and the influence of control devices upstream or downstream of the structures.

6.1.2.3 The distribution and direction of velocity, determined by the features outlined in 6.1.1, have an important influence on the performance of the flow measurement structure and the fishpass.

6.1.2.4 Once an installation has been constructed, the user shall prevent any change which could affect the flow characteristics.

6.1.3 Upstream channel

6.1.3.1 At all installations the flow in the upstream channel shall be smooth, free from disturbance and shall have a velocity distribution as normal as possible over the cross-sectional area. This can usually be verified by inspection or measurement. In the case of natural streams or rivers this can only be attained by having a long, straight upstream channel free from projections either at the side or on the bottom. Unless otherwise specified in the appropriate clauses, the following general requirements shall be complied with.

6.1.3.2 The altered flow-conditions due to the construction of the structure(s) might have the effect of building up shoals of debris upstream of the structure, which in time might affect the flow conditions. The likely consequential changes in the water level shall be taken into account in the design of the structures.

6.1.3.3 In an artificial channel the cross-section shall be uniform and the channel shall be straight for a length equal to at least five times its breadth.

6.1.3.4 In a natural stream or river the cross-section shall be reasonably uniform and the channel shall be straight for such a length as to ensure regular velocity distribution.

6.1.3.5 If the entry to the upstream channel is through a bend or if the flow is discharged into the channel through a conduit of a smaller cross-section, or at an angle, then a longer length of straight approach channel may be required to achieve a regular velocity distribution.

6.1.3.6 There shall be no baffles in the upstream channel, which are nearer than five times the maximum head to the point of head measurement.

6.1.3.7 Under certain conditions, a standing wave may occur upstream of the installation, for example if the approach channel is steep. Provided this wave is at a distance of not less than 30 times the maximum head upstream, flow measurement will be feasible, subject to confirmation that a regular velocity distribution exists at the structure.

6.1.4 Downstream channel

6.1.4.1 The channel downstream of the structure is of no importance to flow measurement if the gauging structure or gauging structure/fishpass installation has been so designed that the flow is modular under all operating conditions. A downstream gauge shall be provided to measure tailwater levels to determine if and when submerged flow occurs.

6.1.4.2 In the event of the possibility of scouring downstream, which may lead to the instability of the structure, particular measures to prevent this happening may be necessary.

6.1.4.3 A separate head gauge to indicate downstream conditions and a second stilling well shall be fitted if the flow measurement structure is designed to operate in the drowned condition or if there is a possibility that the structure may drown in the future.

6.1.4.4 The circumstances described in 6.1.4.3 may arise if the altered flow conditions, due to the construction of the structure, have the effect of building up shoals of debris immediately downstream of the structure or if river works are carried out downstream at a later date.

6.1.4.5 For optimum fishpass performance the jet of water issuing into the downstream channel shall be discernable to the fish amongst all the other competing flows and from as far away as possible. Care shall be taken to avoid the jet being masked by cross-flows or turbulence in the receiving water. Further details, which specifically relate to the fishpass, are given in 6.2.3.

6.1.5 Flow measurement and fishpass structures

6.1.5.1 The flow measurement structure should comply with the requirements given in the appropriate International Standard (see Bibliography).

6.1.5.2 The fishpass shall comply with the requirements of Clause 7. The quality of construction, particularly at the upstream entry, should match that of the flow measurement structure (see Bibliography).

6.1.6 Maintenance

6.1.6.1 Maintenance of the flow measurement structure, the fishpass and the approach channel is important to secure accurate continuous measurements of discharge.

6.1.6.2 It is essential that the approach channel to flow measurement structure/fishpass installations be kept clean and free from silt and vegetation. The float well and the entry from the upstream channel shall also be kept clean and free from deposits.

6.1.6.3 The flow measurement structure and the fishpass shall be kept clean and free from clinging debris and care shall be taken in the process of cleaning to avoid damage to the weir or fishpass.

6.1.7 Measurement of head

6.1.7.1 When a fishpass is set alongside a flow measurement structure, an additional flow path is created and the fishpass flow needs to be evaluated with a similar precision to that of the gauging structure itself. The following are the two ways of doing this.

— Head gauges are placed at both the fishpass and the gauging structure, and the two flows are determined separately and then combined to give the total river flow. This method requires more computing and telemetry but is reliable, particularly where the upstream entry to the fishpass is remote from the gauging structure.

— Head gauges are placed only at the gauging structure and the flow at the fishpass is determined by transferring the single measured head to the fishpass using the established principles which apply to compound weirs. This method is more economical and is particularly useful where the upstream entry to the fishpass is close to the gauging structure.

6.1.7.2 Head gauges shall be designed and installed in accordance with the relevant International Standard (see Bibliography for gauging structures and this International Standard for fishpasses).

6.1.7.3 Head gauges shall be zeroed to the crest of flow measurement weirs or to the invert level of flumes. Accuracy in zeroing gauges is very important at low flows.

6.2 Requirements specific to the fishpass

6.2.1 General

The swimming performance of fish depends on many factors, including:

— species;

— individual size and ability;

— water temperature;

— water depth;

— water velocity;

— water quality;

— turbulence;

— motivation;

— migration period.

It is thus a complex subject with many variations. The data available are variable in both quantity and quality, and are complex to interpret. Furthermore, the effectiveness of a fishpass in terms of ease of passage depends on a suitable match between the type of fishpass, the specific hydraulic conditions within the fishpass and the particular species of fish wishing to migrate. It is not within the scope of this International Standard to cover this complex subject in detail. Instead, basic requirements which apply to a range of species of fish and a range of types of fishpass are identified to help those designing flow measurement structure/fishpass installations.

6.2.2 Guidelines for basic parameters of fishpasses

Guidelines for maximum water velocities within, head drops across and lengths of fishpasses are given in Table 1.

Table 1 — Guidelines for maximum water velocities within, head drops across and lengths of fishpasses

Pass parameters		Species			
		Coarse fish	Brown trout	Sea trout	Salmon
Pool pass	Max. velocity (m/s)	1,4 to 2,0	1,7 to 2,4	2,4 to 3,0	3,0 to 3,4
	Max. head drop (m)	0,1 to 0,2	0,15 to 0,3	0,3 to 0,45	0,45 to 0,6
Baffled pass	Max. velocity (m/s)	1,1 to 1,3	1,2 to 1,6	1,3 to 2,0	1,3 to 2,0
	Length of pass (m)	8 to 10	8 to 10	10 to 12	10 to 12

6.2.3 Location and attraction flows

6.2.3.1 General

In many respects, the most significant problem in passing fish, either upstream or downstream, is that of attracting the fish into the fishpass facility.

6.2.3.2 Location

For those fish travelling upstream, the exit from the fishpass to the downstream reach shall be located as far upstream as possible and shall be near one of the banks wherever practicable since this is the preferred migration route for many species. This location facilitates monitoring and maintenance. Security risks may need to be addressed. See also 6.2.4 and 6.2.5.

6.2.3.3 Attraction flows

The jet of water issuing from the fishpass shall be discernible to the fish. Exit velocities shall be in excess of 0,75 m/s and preferably in excess of 1,5 m/s for salmonids.

The discharge through the fishpass shall be large enough to attract fish towards the downstream entrance. There are various criteria for this including:

— 1 % to 5 % of the river flow during the migration period (larger watercourses);

— 5 % to 10 % of the annual daily flow of the river (smaller watercourses);

— a flow equal to the river flow which is exceeded 97 % of the time.

The discharge through the fishpass and the velocity of the outflow shall be determined in relation to the specific circumstances, and the specific species and size of fish which need to be conveyed.

6.2.4 Downstream entry/exit to fishpass

Fish normally find their way to the most upstream point. The downstream entrance to the fishpass shall therefore be located at the most upstream position which is easily accessible to the fish, for example close to the downstream truncation of a gauging structure. The downstream entry to the fishpass shall not be in areas of either re-circulating flows or highly turbulent flows. A vertical slot entry shall be installed such that a significant jet of water flows from the fishpass over a range of river flows.

6.2.5 Upstream exit/entry from fishpass

The upstream exit from the fishpass shall not be located where there is a danger of fish being immediately swept back downstream. A submerged orifice exit will help to minimize the ingress of floating and demersal trash. The size of the orifice shall be large enough to avoid significant head losses which would complicate flow measurement. The edges of the orifice shall be rounded to minimize head losses.

7 Fishpass performance

7.1 General

7.1.1 Types

There are many different types of fishpass. Generally, they form variations on the themes of steps, slopes or lifts.

The step approach involves splitting the height to be passed into a series of small drops with various forms of traverse separating resting pools. The slope approach involves spilling water down relatively steep slopes where various forms of baffles are used to dissipate energy and slow down the water velocity. To these can be added fish lifts, diversion or by-pass channels that may vary from the totally artificial to the “natural stream-mimicking” type and many adaptations to ease the passage of fish, including adaptations to the flow measurement structure itself.

7.1.2 Fishpasses with interconnected pools

Fishpasses with interconnected pools are perhaps the oldest type of pass in use. They are generally applicable for most fish species, are extensively used throughout the world and in most cases require low maintenance. They can frequently change direction, even very sharply, and therefore may be integrated into some locations much more easily than some other types of pass. The connection between the pools may take one of several forms including simple over-falls, a variety of notches, vertical slots, or orifices. There may also be a combination of these.

Constraints on the use of these fishpasses include the height between each pool and the need for little turbulence within the pools to provide the fish with resting areas during transit.

This International Standard includes two types of fishpass which fit into the interconnected pools category:

— the pool-type fishpass with V-shaped overfalls;

— the Dutch pool and orifice fishpass.

7.1.3 Fishpasses with continuous energy dissipation

7.1.3.1 General

The two best known fishpasses with continuous energy dissipation along their length are:

a) the Denil fishpass, developed by a Belgian engineer;

b) the Larinier fishpass, first developed in France.

In both cases, fish should pass the length of any one flight in a single attempt. Therefore the length of flight should be limited.

Accurate information on the hydraulic performance of Denil fishpasses is not yet available.

7.1.3.2 Larinier super-active baffle fishpasses

This type of pass, developed in France by Larinier and Miralles, is being widely used in Europe. It is suitable not only for large migratory salmonids such as salmon and sea trout, but also for an extensive range of other species including coarse fish. Fish exploit the heterogeneity of microvelocities in this type of fishpass.

It is a relatively wide and shallow type of fishpass (in comparison with a Denil fishpass), and only has baffles on the bed of the pass. Channel width is only limited by site conditions and not by hydraulic operating characteristics as is the case for other types of baffled fishpass. A significant advantage of this type of fishpass is that major attraction flows can be created, by juxtaposing multiple ‘units’ of pass in to a very wide channel.

One specific fishpass of the continuous energy dissipation type is included in this International Standard, i.e. the Larinier super-active baffle fishpass with 100 mm high baffles.

7.1.4 The three types of fishpass included in this International Standard have all been subjected to rigorous hydrometric testing in large-scale laboratory facilities to determine coefficients of discharge. The Larinier super-active baffle fishpass with 100 mm high baffles has been calibrated using volumetric measurement facilities for every individual flow rate. The pool-type fishpass with V-shaped overfalls and the Dutch pool and orifice fishpass have been calibrated against a secondary flow measurement device with volumetric checks at intervals.

Pending further rigorous studies the coefficient of discharge for the three types of fishpasses, at the 95 % confidence level, shall be taken as follows:

— the Larinier super-active baffle fishpass with 100 mm baffles is1 %;

— the pool-type fishpass with V-shaped overfalls is 2 %;

— the Dutch pool and orifice fishpass is 2 %.

7.2 Larinier super-active baffle fishpass with 100 mm baffles

7.2.1 Description

The super-active Larinier fishpass with 100 mm baffles is shown in Figure 1.

This fishpass has the following features:

— width of one unit, $B = 6a = 600$ mm;

— width of echelon section of baffles, $B/2 = 300$ mm;

— height of baffles, $a = 100$ mm;

— longitudinal slope of unit, $S = 15$ %.

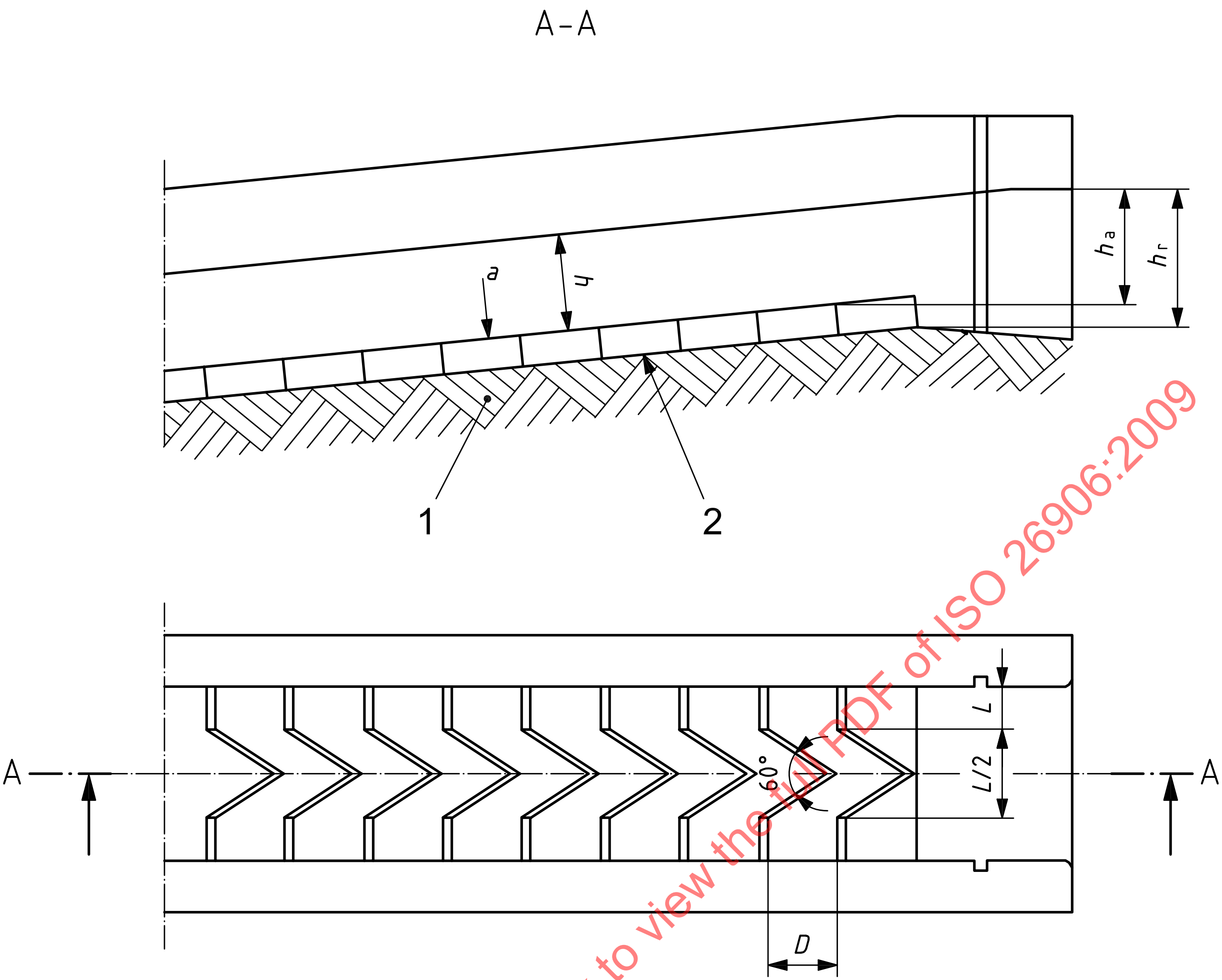
Larinier fishpass units shall be juxtaposed in multiples of 1,0, 1,5, 2,0, 2,5, etc. when larger fishpass flows are required.

7.2.2 Limitations

7.2.2.1 The upper and lower limits for flows (heads) which provide satisfactory flow conditions for fish migration are as follows:

— minimum upstream head, $h_1 = 0{,}18$ m (0,087 m^3/s per Larinier unit or 0,145 m^3/s per metre width);

— maximum upstream head, $h_1 = 0{,}60$m (0,498 m^3/s per Larinier unit or 0,830 m^3/s per metre width).



Plan view

Key

$L = 6a$

$D = 2{,}60a$

1 channel slope S

2 invert of the fishpass

Figure 1 — Larinier super-active baffle fishpass with 100 mm high baffles

7.2.3 Modular flow calibration

7.2.3.1 Discharge equations

The modular flow equation for the Larinier fishpass is calculated using Equation (1):

$$Q = b\, C_{\text{de}}\, (g)^{0,5}\, (H_{1\text{e}})^{1,5} \tag{1}$$

where

$$H_{1\text{e}} = H_1 - k_\text{h} = h_1 + (v_1)^2/2g - k_\text{h} \tag{2}$$

where

b is the crest breadth measured at transverse section of upstream baffle, in metres;

C_{de} is the dimensionless coefficient of discharge;

g is the acceleration due to gravity, in metres per second squared;

h_1 is the upstream gauged head relative to transverse section of upstream Larinier baffle, in metres;

H_1 is the upstream total head relative to transverse section of upstream Larinier baffle, in metres;

H_{1e} is the effective upstream total head relative to transverse section of upstream Larinier baffle, in metres;

k_h is the head correction factor taking into account fluid property effects, in metres;

Q is the flow, in cubic metres per second;

v_1 is the velocity of approach at tapping location, in metres per second.

7.2.3.2 Coefficient of discharge

The coefficient of discharge is shown in Figure 2.

The following simplified values of C_{de} shall be used in Equation (1):

Phase 1 (0,02 m $< h <$ 0,08 m)

$$C_{de} = 0{,}50 + 2{,}50\,(h - 0{,}02) \qquad (3)$$

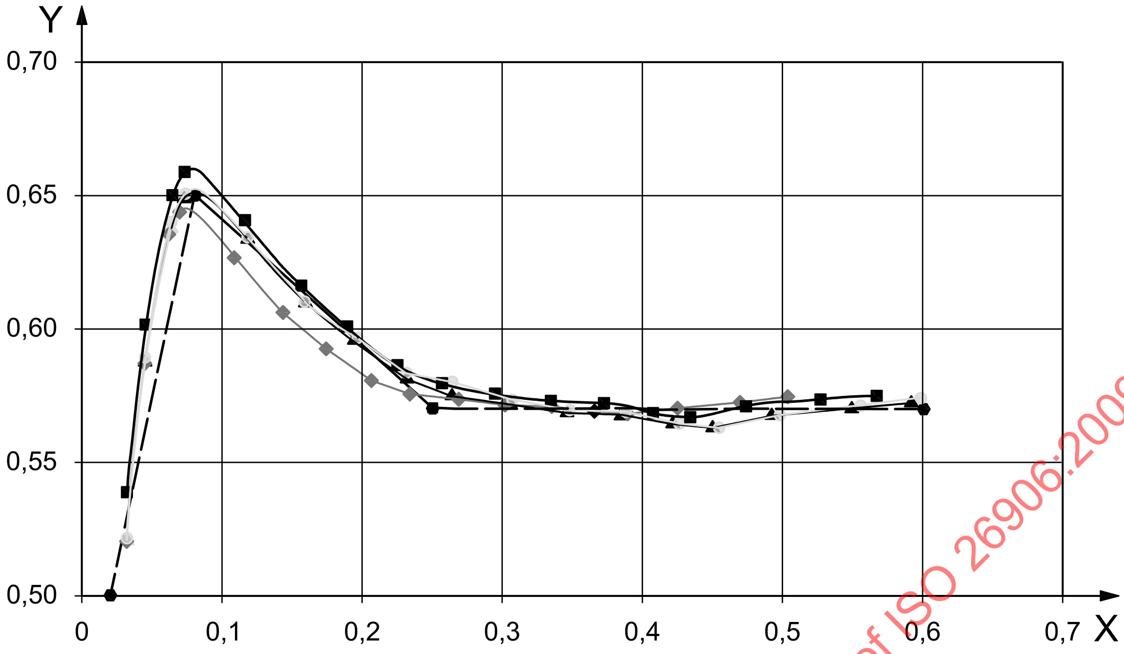
Phase 2 (0,08 m $< h <$ 0,25 m)

$$C_{de} = 0{,}65 - 0{,}47\,(h - 0{,}08) \qquad (4)$$

Phase 3 ($h >$ 0,25 m)

$$C_{de} = 0{,}57 \qquad (5)$$

The value of k_h used in Equation (2) should be zero.



Key

U/S gauge at 0,5h_{max}
U/S gauge at 1,0h_{max}
U/S gauge at 1,5h_{max}
U/S gauge at 2,0h_{max}
Phase 1 simplification
Phase 2 simplification
Phase 3 simplification

X head, expressed in metres
Y coefficient of discharge

Figure 2 — Coefficient of discharge for super-active Larinier fishpass

7.2.4 Modular limit

The modular limit of the Larinier fishpass varies with head (flow). The modular limit is the ratio of the downstream to upstream heads at which there is a reduction from the modular flow of one percent. Equation (6) shall be used to determine its value.

$$\text{Modular limit} = (20 + 6\,h_1 / P)\ \% \qquad (6)$$

where

P is the height of the top baffle, in metres (0,1 m in this case).

7.3 Pool-type fishpass with V-shaped overfalls

7.3.1 Description

7.3.1.1 The pool-type fishpass with V-shaped overfalls is used throughout the Netherlands, especially in small rivers. The pool-type fishpass with V-shaped overfalls is sometimes in the river itself, but is most often found in a bypass channel parallel to the main river.

7.3.1.2 The design discharge of the standard type is $Q_d = 2$ m^3/s. By scaling down and scaling up the standard type the range of design discharges is $0{,}35 < Q < 5{,}50$ m^3/s.

7.3.1.3 The fishpass consists of a series of pools, separated by overfalls at equal distances. The pool length, $l = 7{,}50$ m. Each of the overfalls is built up from a sheet piling covered by a batten. The view of the overfalls from upstream is v-shaped with tan $(\alpha/2) = 7$. As a consequence the main flow in a pool occurs in its centre, while along both banks weak eddies are present, so creating rest places for the migrating fish. The highest flow velocities are found above and immediately downstream of the crest of the overfall.

7.3.1.4 The number of overfalls/pools depends on the maximum head difference between the water levels upstream and downstream of the fishpass and the desired drop, Δt, between adjacent pools. In the standard type, $\Delta t = 0{,}25$ m. The overfalls have a width, B, which extends from bank to bank in the standard type, or they have a width of at least half the width of the channel. For the standard type, $B = 10$ m and the pool depth, $P = 0{,}40$ m.

7.3.1.5 The layout of the fishpass is shown in Figure 3. The most important dimensions are the pool length, $l = 7{,}50$ m and the pool drop, $\Delta t = 0{,}25$ m. A submergence ratio, $h_2/h_1 \approx 0{,}5$, is assumed to be attractive for most migrants (h_1 is the upstream head over the crest, h_2 is the downstream head). Pool drops, $\Delta t > 0{,}25$ m may result in low or even negative h_2/h_1 values presenting a wide area of air pockets beneath the nappe. The pool length, $l = 7{,}50$ m, is sufficient to avoid short cutting from one pool to the next one (dissipation of an adequate proportion of the kinetic energy). Four different standard types are presented, which are shown in Figure 4.

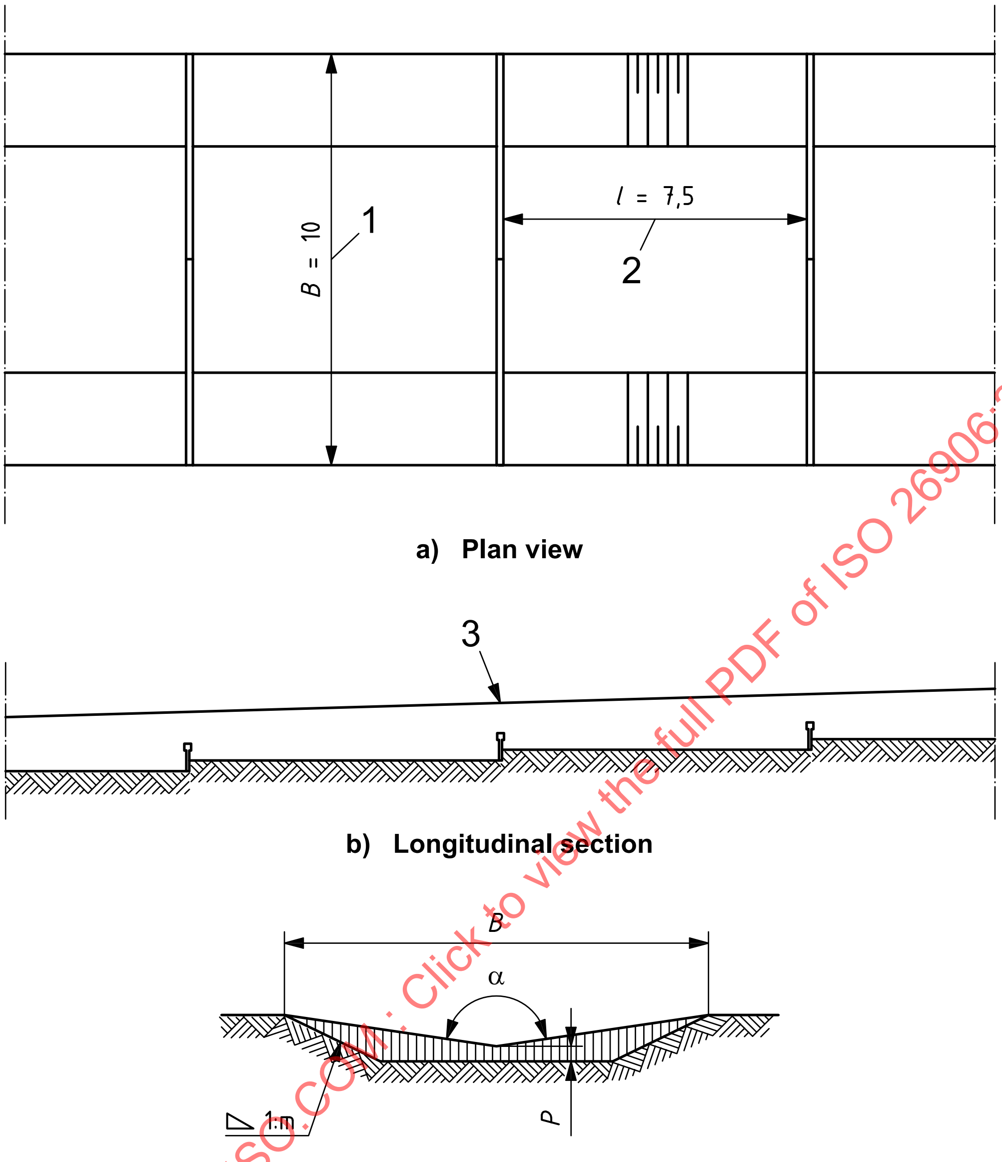
7.3.1.6 Pool-type fishpasses with V-shaped overfalls are designed for a certain design discharge, Q_d. For type 1 and a design discharge, $Q_d = 2$ m^3/s, the width of the non-aerated nappe is about 3,30 m (submergence ratio $h_2/h_1 = 0{,}5$). For $Q > Q_d$ the flow velocities will be high, and for $Q > Q_d$ the non-aerated part of the nappe may become too small (air pocket too wide). The fishpass shall be situated such that the migrating fish species are attracted to find its forebay or tailbay by existing currents.

7.3.1.7 It is recommended to measure the discharge over the first (the highest situated) overfall for the following reasons.

— The best approach conditions and a stable water surface in the forebay are present. The head h_1 shall be measured at a distance $X \geqslant 3\ h_{max}$ upstream from the first overfall;

— The risk of submerged flow is minimized.

Dimensions in metres



a) Plan view

b) Longitudinal section

c) Front (upstream) view

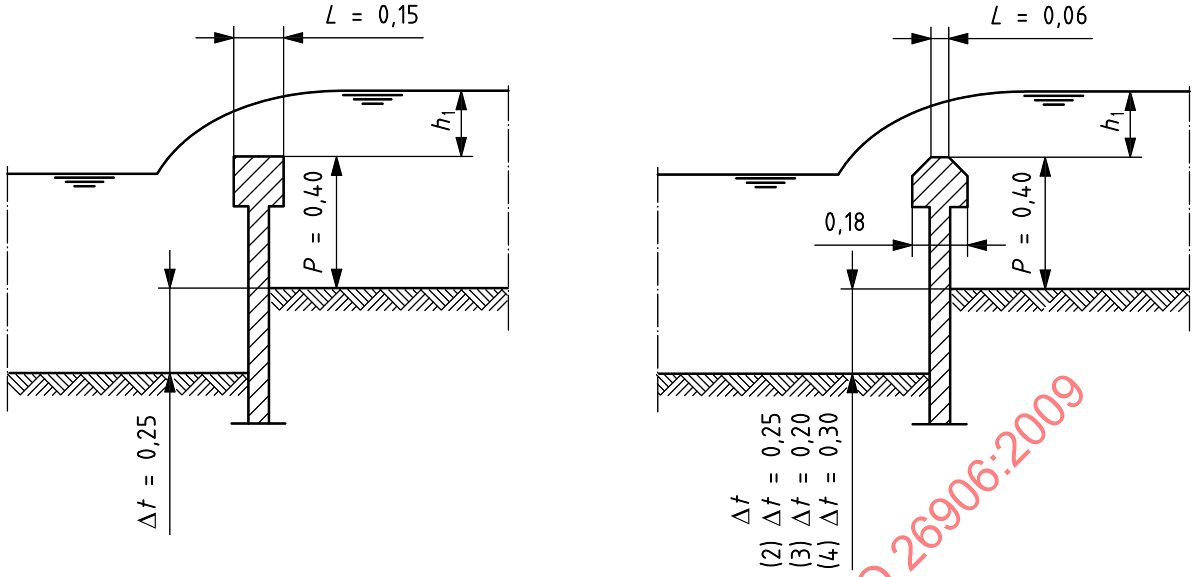
Key

1 pool width

2 pool length

3 bank level

Figure 3 — Layout of the pool-type fishpass with V-shaped overfalls



Type	Crest shape	Crest length L m	Pool drop Δt m
1	rectangular	0,15	0,25
2	bevelled	0,06	0,25
3	bevelled	0,06	0,20
4	bevelled	0,06	0,30

Figure 4 — Cross-sections of overfalls 1, 2, 3 and 4

7.3.2 Determination of discharge under free flow conditions

7.3.2.1 Discharge equation

The modular flow for the pool-type fishpass with V-shaped overfalls, is calculated using Equation (7):

$$Q = \left(\frac{4}{5}\right)^{5/2} \times \left(\frac{g}{2}\right)^{1/2} \times \tan\left(\alpha/2\right) \times C_D \times C_V \times h_1^{2,50} \tag{7}$$

where

Q is the discharge, in cubic metres per second;

g is the acceleration due to gravity, in metres per second squared;

α is the angle of V-shape, in degrees;

C_D is the characteristic discharge coefficient;

C_V is the coefficient for the approach velocity;

h_1 is the upstream head with respect to the lowest crest elevation.

The velocity of approach coefficient is defined as $C_V = (H_1/h_1)^{5/2}$

where

H_1 is the upstream total head with respect to the lowest crest elevation, $H_1 = h_1 + v^2/2g$, in metres;

v is the mean flow velocity in the approach channel, in metres per second.

In many situations the approach channel (the forebay) will be relatively wide and deep, resulting in low velocities, so that $H_1 \approx h_1$ and $C_V = 1$.

For tan $(\alpha/2) = 7$ the Equation (7) can be rewritten as Equation (8):

$$Q = 8{,}87 \times C_D \times C_V \times h_1^{2{,}50} \quad (8)$$

7.3.2.2 Coefficient of discharge

The coefficients of discharge are shown in Figure 5 for the four standard types.

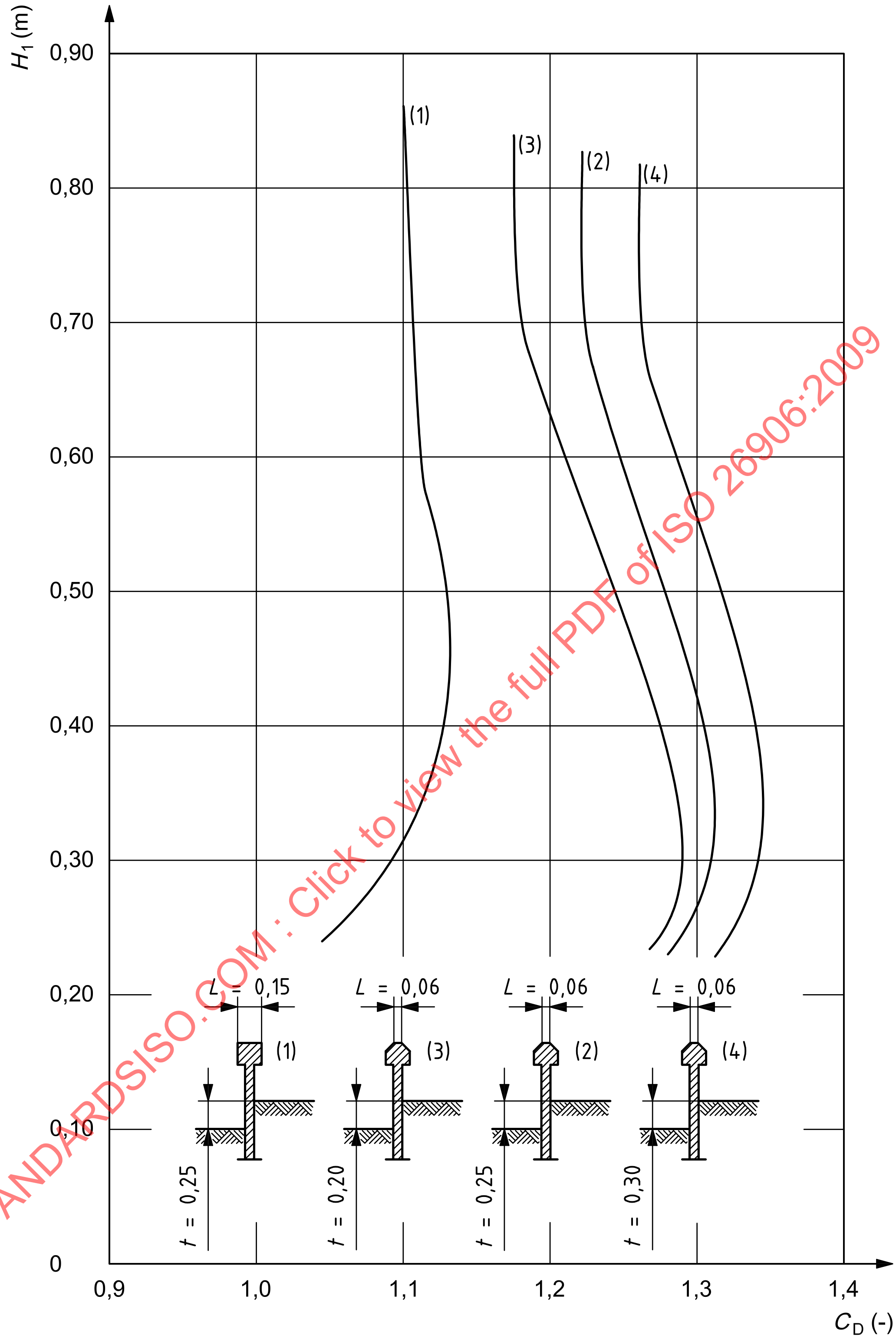


Figure 5 (*continued*)

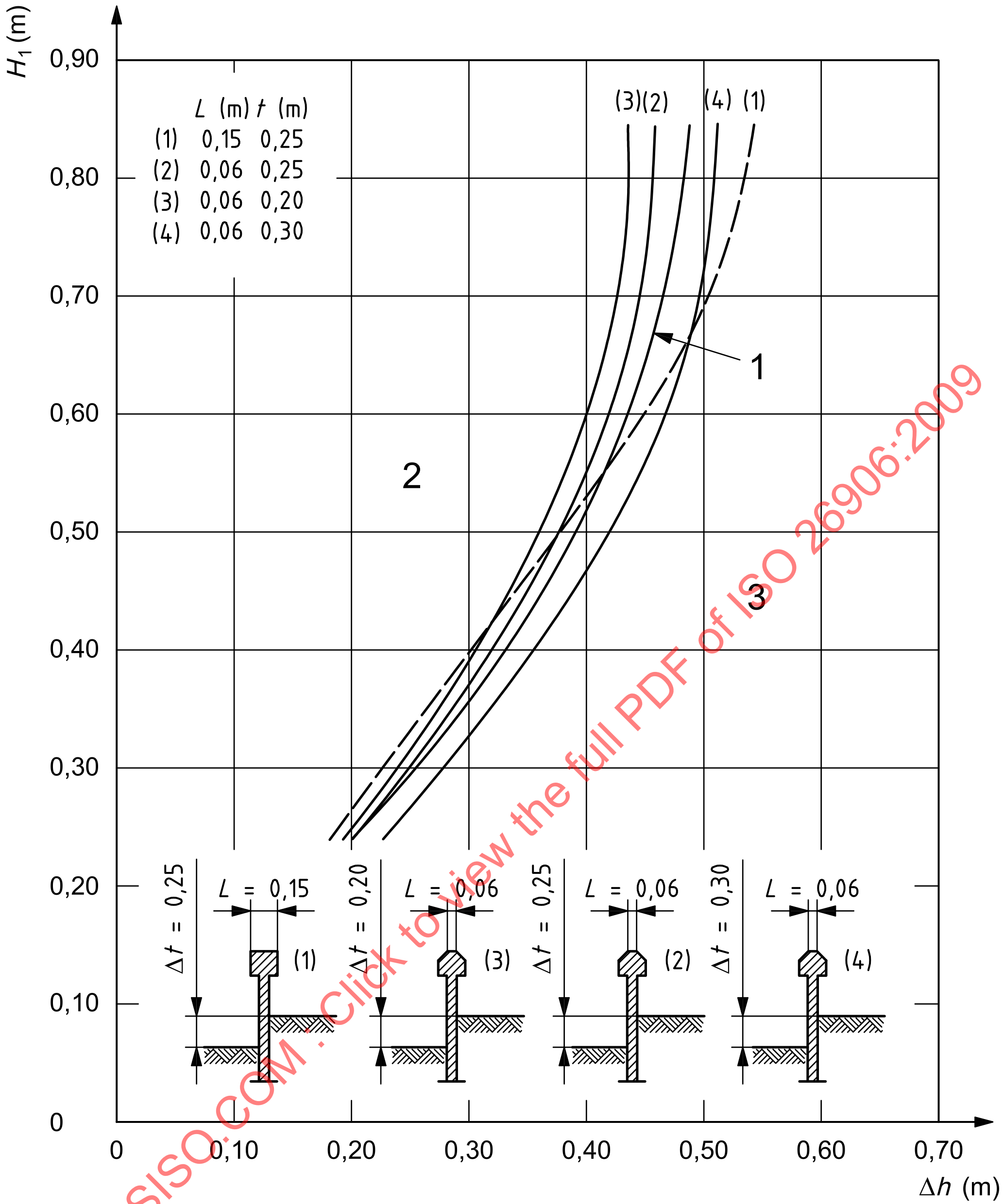
Type	Crest shape	Crest length L m	Pool drop Δt m
1	Rectangular	0,15	0,25
2	Bevelled	0,06	0,25
3	Bevelled	0,06	0,20
4	Bevelled	0,06	0,30

NOTE The given relation is only valid for the standard design as shown in Figures 3 and 4. For alternative designs, scaled up or down from the standard design, the reader has to adapt Figure 5.

Figure 5 — Discharge coefficient C_D

7.3.3 Modular limit

If the tail water level of the fishpass starts rising, then the lowest situated overfalls will be submerged. The highest situated overfall, in use as flow measurement structure, becomes submerged as soon as the minimum required drop, Δh, is exceeded. The drop, Δh, is defined as the difference between the water levels in the fore bay and the tail bay of the fishpass. The modular limits shown in Figure 6 shall be applied for the four standard types. The modular limit for this fishpass is defined as the submergence for which the deviation between the submerged flow calculated with the free-flow head discharge equation and the real flow is 2 % (instead of the usual 1 %).



Key

1 average modular limit

2 submerged flow

3 free flow

NOTE The given relation is only valid for the standard design as shown in Figures 3 and 4. For alternative designs, scaled up or down from the standard design, the reader has to adapt Figure 6.

Figure 6 — The modular limit

7.3.4 Determination of discharge under submerged flow conditions

There is no information about a flow reduction factor for submerged flow.

7.3.5 Limitations

In the interest of a correct determination of discharge, the following limitations shall be taken into account.

— The working range for this fishpass (suitable conditions for fish migration) is 0,5 $Q_d < Q < 2Q_d$.

— To be sure of modular flow, the modular limit in Figure 6 shall not be exceeded.

7.3.6 Scaling up to standard design

In case the desired design discharge should be less or more than $Q_d = 2$ m^3/s for the standard types as presented in 7.3.1, then it is possible to scale down or to scale up the standard design, taking into account the scale rules. Table 2 gives a review of 11 designs, scaled down and scaled up from the standard design of type 1 (the rectangular crest shape).

Table 2 — Dimensions and characteristics of eleven different designs of standard type 1

Design no.	Design discharge Q_d m^3/s	Dimensions optimum design m					Width of non-aerated nappe B_2 m	Max velocities m/s	
		Pool drop Δt	Pool length l	Pool width B	Pool depth P	Crest length L		Downstream of the crest	Pool
1	0,35	0,125	3,75	5,00	0,20	0,075	1,65	1,74	0,53
2	0,56	0,15	4,50	6,00	0,24	0,090	1,98	1,91	0,58
3	0,82	0,175	5,25	7,00	0,28	0,105	2,31	2,06	0,63
4	1,14	0,200	6,00	8,00	0,32	0,120	2,64	2,21	0,67
5	1,54	0,225	6,75	9,00	0,36	0,135	2,97	2,34	0,71
6	2,00	0,25	7,50	10,00	0,40	0,150	3,30	2,47	0,75
7	2,54	0,275	8,25	11,00	0,44	0,165	3,63	2,59	0,78
8	3,15	0,30	9,00	12,00	0,48	0,180	3,96	2,70	0,82
9	3,85	0,325	9,75	13,00	0,52	0,195	4,29	2,81	0,85
10	4,64	0,35	10,50	14,00	0,56	0,210	4,62	2,92	0,88
11	5,51	0,375	11,25	15,00	0,60	0,225	4,95	3,02	0,92

Similar tables can be made for the standard types 2, 3 and 4.

7.4 Dutch pool and orifice fishpass

7.4.1 Description

7.4.1.1 The Dutch pool and orifice fishpass is a vertical slot fishpass in which the slots have been closed at the top. The orifices are placed alternately to the right and to the left. The dimensions are comparatively small, as well as the total drop over the structure (most times less than 1 m) and the design discharge, which may vary as follows: $0{,}050 < Q_d < 0{,}150$ m^3/s. The fishpass is mainly intended for freshwater fish with a burst velocity, not exceeding $u = 1{,}00$ m/s. The following are the advantages of the pool and orifice fishpass.

— As a result of its small dimensions, the fishpass is a compact structure which does not occupy too much space.

— The mean velocities are identical in all the orifices and are independent of the total drop over the structure. This is not the case with vertical slot fishpasses.

— The fishpass is not very susceptible to floating debris.

7.4.1.2 The layout of the Dutch pool and orifice fishpass is shown in Figure 7. Figure 8 gives the front (upstream) view of a transition and the position of the orifice. The fishpass has the following features:

a) the pool width is B = 1,20 m and pool length L = 0,80 m;

b) the design head drop per pool is $\overline{\Delta h_d} = 0{,}05$ m;

c) the number of partitions (orifices), n, depends on the total drop $Y_0 - Y_d$ over the structure and the design head drop per pool: $n = (Y_0 - Y_d) / \overline{\Delta h_d}$;

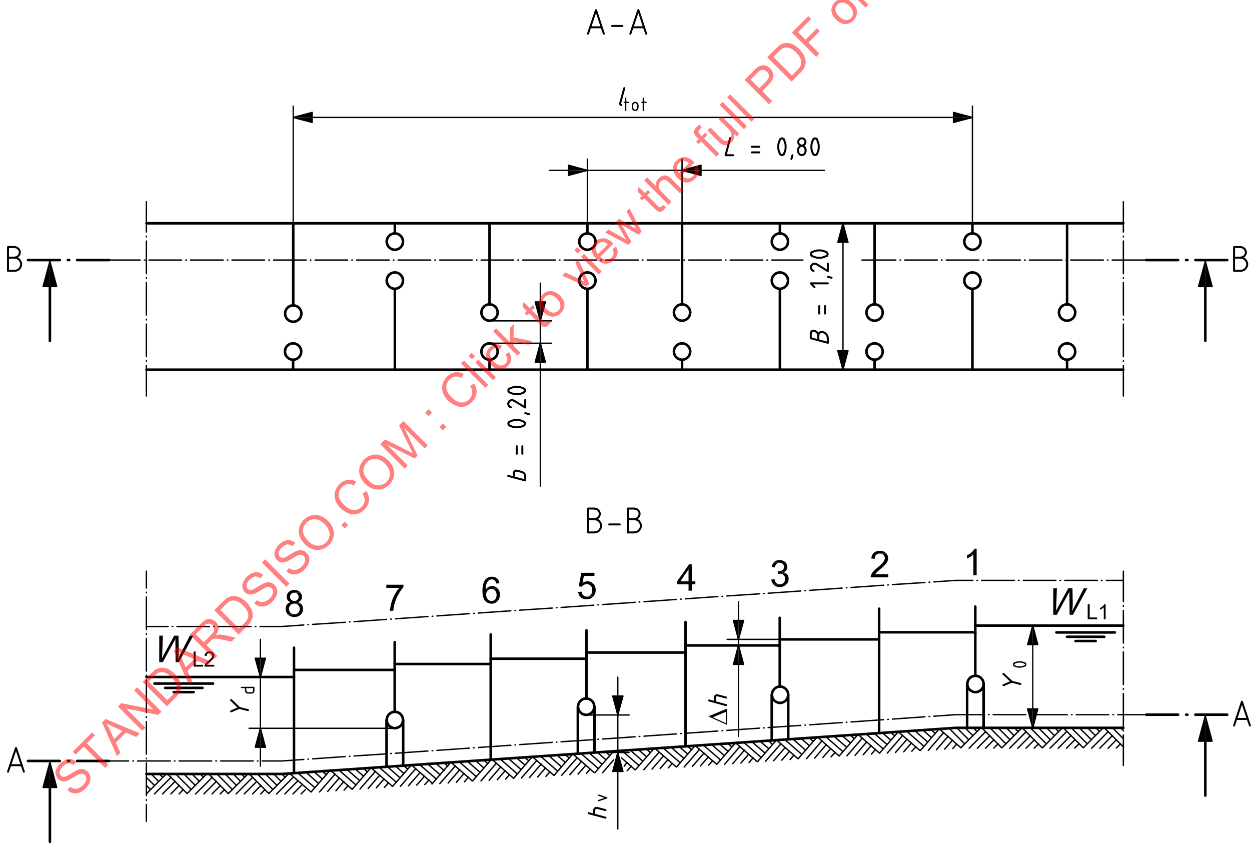
d) the orifice width is b = 0,20 m and orifice height $0{,}30 < h_v < 0{,}60$ m;

e) the orifices are rounded off with pipes D = 0,09 m, in order to minimize the risk of blockage by floating debris and placed in the transition perpendicular to the longitudinal axis of the fishpass;

f) the bed slope of the fishpass is $S = \overline{\Delta h_d} / L = 0{,}062\,5$;

g) the bed consists of a smooth concrete layer.

Dimensions in metres



Key

l_{tot} total length of fishpass

Figure 7 — Standard design of the Dutch pool and orifice fishpass

Dimensions in metres

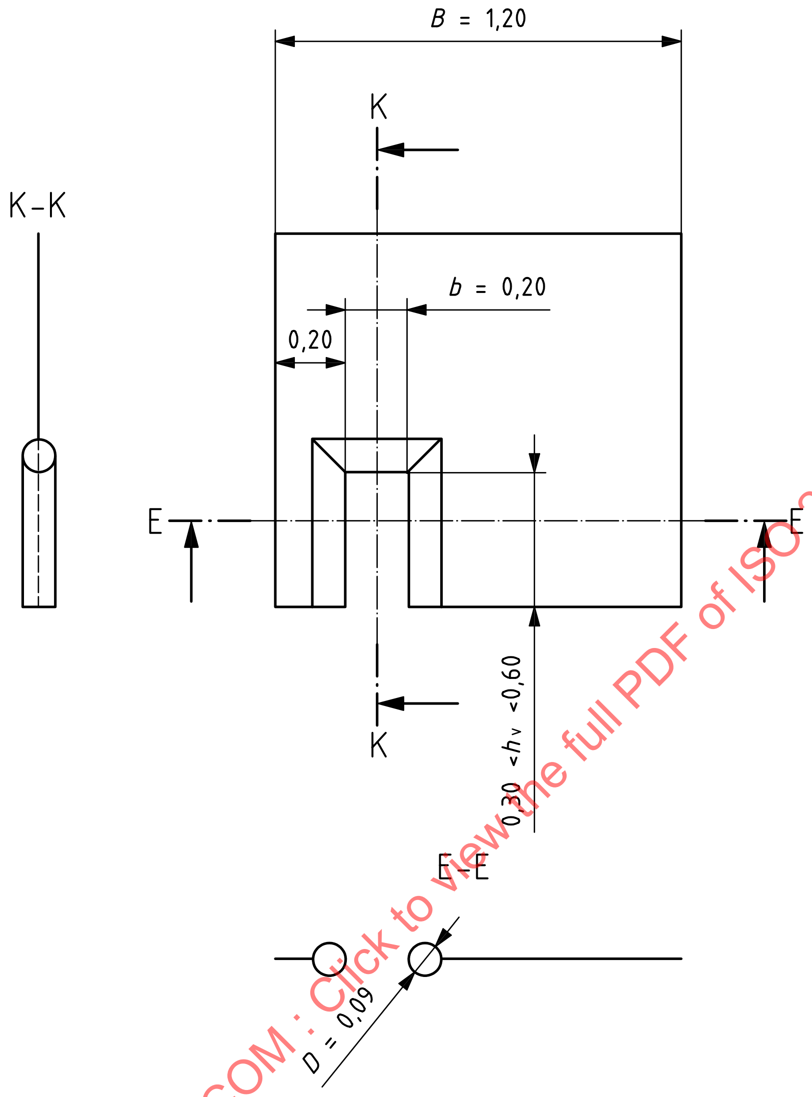


Figure 8 — Front (upstream) view of a transition and the position of an orifice in the transition

7.4.2 Determination of discharge

7.4.2.1 Discharge equation

The flow in the Dutch pool and orifice fishpass is subcritical flow throughout the structure. Therefore, a modular limit is out of order, and there is submerged flow under all circumstances.

The discharge is given by Equation (9):

$$Q = C \times b \times h_v \times \sqrt{2g \times \overline{\Delta h}} \qquad (9)$$

where

Q is the discharge, in cubic metres per second;

C is the characteristic discharge coefficient;