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Hydrometry — Fishpasses at flow measurement structures

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National foreword

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Foreword

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The committee responsible for this document is ISO/TC 113, *Hydrometry*, Subcommittee SC 2, *Flow measurement structures*.

This second edition cancels and replaces the first edition (ISO 26906:2009), which has been technically revised.

Introduction

Flow gauging structures are commonly used for the determination 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, that create high velocities may inhibit the movement of fish. It has become important, therefore, to consider ways of aiding fish migration without significantly 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 Flow measurement structures and fishpasses have inherently different hydraulic performance criteria. Flow 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 fish passage or that they are good enough that passage performance can be sacrificed to obtain a single structure that meets both the fish passage and flow measurement requirements.

2 Normative references

The following documents, in whole or in part, are normatively referenced in this document and are indispensable for its application. 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 and the following apply.

3.1
fish pass design range
range of flows within which fish require passage

Note 1 to entry: This may be defined on an annual or a seasonal basis, e.g. for spawning.

Note 2 to entry: In some countries the design range is determined in terms of flow statistics. For example, the design range for coarse fish in the UK is usually between the estimated mean daily flow that is exceeded 95 % of the time and the mean daily flow that is exceeded 20 % of the time. While for migratory salmonids including sea trout and salmon, it is 95 % and 90 % to 10 % respectively.

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)
[D]	indicates distance between baffles in a Larinier Fish Pass
[S]	indicates the Slope of the Larinier Fish Pass in degrees

Symbol	**Term**	**Unit**
a	height of baffle [L]	m
a_{fp}	proportion of total flow through fish-pass [L]	
b	orifice width [PO]	m
b	crest breadth measured at transverse section of upstream baffle [L]	m
b_{fms}	proportion of total flow through flow measuring structure [L]	
B	total width of fishpass channel [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]	$\mathrm{m/s^2}$
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
$H_{1\mathrm{e}}$	effective upstream total head relative to transverse section of upstream baffle [L]	m

Symbol	**Term**	**Unit**
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
$\underline{L}$	width of one unit of Larinier fishpass [L]	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 above the upstream bed [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
u^*C_{De68}	standard uncertainty in discharge coefficient C_D [L, PT and PO]	%
u^*_b	uncertainty in the gauging structure breadth measurement [L, PT and PO]	%
$u(E)$	absolute uncertainty in gauge/head zero [L, PT and PO]	m or mm
u^*_{H1e}	uncertainty in the total head measurement [L, PT and PO]	%
u_{h1}	absolute uncertainty in the measured upstream head [L, PT and PO]	m or mm
U^*_{fp}	overall uncertainty in fish pass flow [L, PT and PO]	%
U^*_{fms}	overall uncertainty in flow measurement structure [L, PT and PO]	%

Symbol	Term	Unit
U^*_c	combined overall uncertainty in fish pass and flow measurement structure flows [L, 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
$\overline{\Delta h_\mathrm{d}}$	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 non-modular 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 International Standard provides the necessary design and performance information for this type of arrangement.

6 Installation

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

6.1 Requirements for gauging structure and fishpass installations

NOTE Requirements for the installation of measuring 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 and 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 flow determination by a structure, or combination of structures.

6.1.1.2 Particular attention shall be paid to the following features when investigating a site:

- at existing measurement locations the type(s), state of repair and hydraulic performance of existing structures shall be assessed;
- availability of an adequate length of channel of regular cross-section;

- availability of an adequate width of cross sectional area outside the channel to install a bypass channel if required. The banks of the river need to be low enough to install a bypass channel that is not overdeep;
- 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 uniform, then it may be assumed that the velocity distribution will remain satisfactory after the construction of a structure.

6.1.1.5 If the existing velocity distribution is irregular and no other site for a measurement 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 non-uniform 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 meter or acoustic doppler current profiler.

6.1.2 Installation conditions

6.1.2.1 The complete installation consists of an approach channel, the flow measurement and 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, particularly the accumulation of sediment or debris within the fishpass.

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 uniform 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. It is recommended that wherever possible the approach shall be straight for a distance of five times the channel width upstream of the head measuring section. Unless otherwise specified in the appropriate clauses, the following general 6.1.3.2 to 6.1.3.8 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 and sediment upstream of the structure, which in time might affect the flow conditions. Changes in upstream bed level at the head measuring section may result in significant changes in the distance between the bed elevation and the crest of the structure (P value) which can affect the stage-discharge relationship due to the resultant variations in the velocity head.

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 upstream of the head monitoring point. This also applies to the approach to the fishpass.

6.1.3.4 In a natural stream or river, the cross-section shall be reasonably uniform and the channel shall be straight for a length equal to at least five times its breadth upstream of the head monitoring point

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 submerged entrance of a smaller cross-section, or at an angle, then a longer length (say 10 channel widths) 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.

6.1.3.8 Stop log slots, and/or fish observation camera housings shall be designed so as not to create disturbances and irregular velocity distributions in the approach channel to the flow measuring structure, or in specific components thereof, e.g. fish pass in separate channel. For example, where cameras may be fixed in slots/compartments in the approach channel walls then the slot/compartment should be protected with a transparent cover set flush with the channel wall.

6.1.4 Separate channel

6.1.4.1 For some fish passes, or at some sites, separate channels may be required to facilitate the movement of fish into or out of the fish pass, These will help minimize the operational and maintenance requirements such as the removal of debris and create a more favourable hydraulic conditions for flow determination purposes. For example, the performance of Larinier fish passes as flow measurement structures is very dependent on the crests being kept clear of trash/debris and this should be considered when developing the design. A separate channel with a deflector/boom or submerged entrance should be considered. It is recommended that the upstream exit of the separate fishpass channel is set laterally to the line of the river to help reduce trash ingress.

6.1.4.2 Where a separate channel is required, an additional head measurement device will be required in the approach channel to the fish pass at the recommended distance upstream for the type of structure or fish pass concerned. The water level sensing device and the supporting arrangement shall be installed in accordance with the appropriate hydrometric standards and the manufacturer's guidance.

6.1.5 Downstream channel

6.1.5.1 The channel downstream of the structure is of no importance to flow measurement if the measuring structure or gauging structure 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. The downstream conditions will affect the location of the downstream entrance to the fishpass and its performance. See 6.2.3.

6.1.5.2 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.

6.1.5.3 A downstream water level sensor shall be installed if there is a possibility that the structure may become non-modular in the future or if it is required to assess the modular limit.

6.1.5.4 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.

6.1.5.5 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.

6.1.5.6 Prior to the design of a fishpass at an existing flow gauge, it is recommended that a downstream water level sensor is installed for a period of time in order to gain a record of water levels across the appropriate fish migration window. This is important because the downstream level record is essential to ensure the correct design of the fish pass.

6.1.6 Flow measurement and fishpass structures

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

6.1.6.2 The fishpass shall conform to with the requirements of Clause 7.

6.1.7 Maintenance

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

6.1.7.2 It is essential that the approach channel to flow measurement structure and fishpass installation need to be kept clean and free from silt, debris and vegetation. The float well and the entry from the upstream channel shall also be kept clean and free from deposits.

6.1.7.3 The flow measurement structure and 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.

6.1.7.4 The provision of remote surveillance cameras is recommended in order to reduce manpower operating resource requirements.

6.1.8 Measurement of head

6.1.8.1 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 measuring structure itself. The following are the two ways of doing this.

6.1.8.2 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 computation and instrumentation but is reliable, particularly where the upstream entry to the fishpass is remote from the gauging structure.

6.1.8.3 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. This method should not be used when the fish pass channel is totally separated and has an orifice or boom at the upstream end. Checks shall be undertaken to ensure that there is no significant water level difference between the main structure head measuring point and the level upstream of the fish pass. If the level difference is consistently greater than 3 mm, consideration should be given to installing a separate water level sensor in the fish pass.

6.1.8.4 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).

6.1.8.5 Head gauges shall be zeroed to the crest of horizontal flow measurement weirs or to the invert level of flumes and v-shaped weirs Accuracy in zeroing gauges is very important, particularly for low flow determination. The gauge zero should be established to within no greater than 2 mm of the weir crest or structure invert level. See 7.2 for details of the gauge zero of a Larinier fishpass.

6.2 Requirements specific to the fishpass

6.2.1 General

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

- 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 (ms^{-1})	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 (ms^{-1})	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 fish pass design is creating both upstream and downstream conditions, to attract fish into the fish pass.

6.2.3.2 Location

For those fish travelling upstream, the entrance to the fishpass in 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. 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 ms^{-1} and preferably in excess of 1,5 ms^{-1} 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 the following:

- 5 % to 10 % of the competing river flow across the fish migration window;
- a starting flow of 5 % to 10 % of the annual daily flow of the river in the fish pass at a river flow exceeding 95 % of the time;
- a starting 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 underwater 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.

Velocities in the upstream channel exit from the fish pass shall not exceed the upper limit of velocity for the target fish species. The following velocities should be used as a guideline unless other specific limitations are required:

- the mean approach velocity in the exit must be no more than 1,0 ms^{-1} for migratory salmonids, 0,70 ms^{-1} for grayling and brown trout, and 0,5 ms^{-1} for coarse fish.

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 transverse 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 the following:

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 any one flight should be limited. Flights may be interspersed with rest pools to increase the overall head to be overcome. Where required, rest pools shall be of sufficient size to provide satisfactory hydraulic conditions for the target species.

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

7.1.3.2 Larinier super-active baffle fishpasses

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

7.1.4 Calibration and discharge coefficient

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 baffle sizes between 75 mm and 150 mm 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 uncertainties for the three types of fishpasses, at the 68 % confidence level, shall be taken as follows:

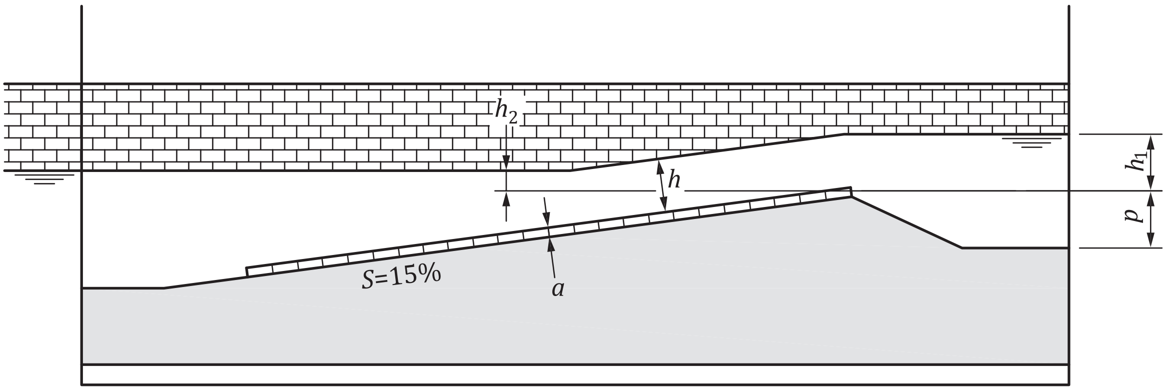
- the Larinier super-active baffle fishpass is 1 %;
- the pool-type fishpass with V-shaped overfalls is 1 %;
- the Dutch pool and orifice fishpass is 1 %.

7.2 Larinier super-active baffle fishpass with baffle sizes between 75 mm and 150 mm

7.2.1 Description

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.

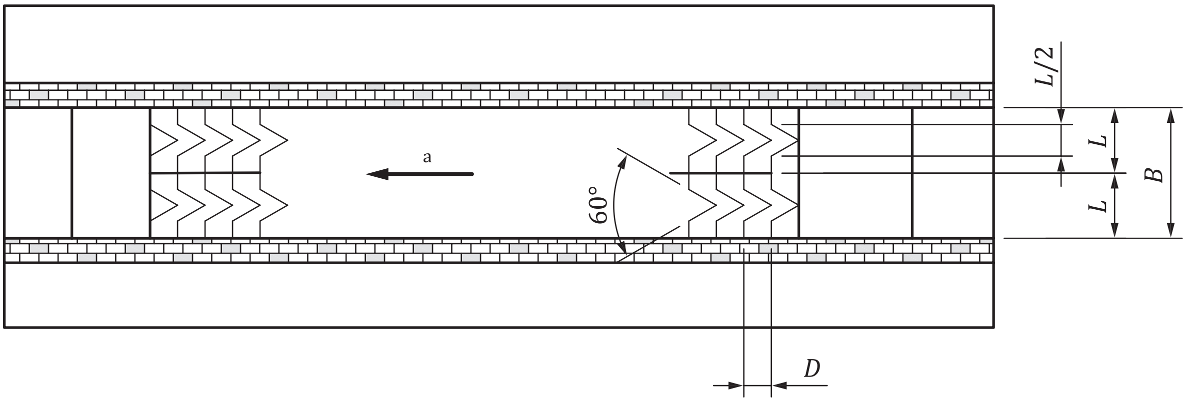
It is a relatively wide and shallow type of fishpass (in comparison with a Denil fishpass), and only has baffles on the bed of the pass. Channel width is only limited by site conditions and not by hydraulic operating characteristics as is the case for other types of baffled fishpass. A significant advantage 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. This fishpass can have baffle heights (a) of between 75 mm and 150 mm .The super active Larinier fishpass is shown in Figures 1 and 2.



Key

a	height of baffle
h	depth of water in the fishpass
h_1	upstream head
p	crest height of upstream baffle relative to upstream bed level

Figure 1 — Larinier super-active baffle Fishpass. Profile



Key

B	full channel width
D	distance between baffles. Front face ds baffle to ds face of upper one = 2,6*a
L	width of one Larinier unit
a	Direction of flow.

Figure 2 — Twin Larinier baffle example. Plan

7.2.2 The following features apply to the range of baffle sizes from 75 mm to 150 mm

— Height of baffles, a = any value in the range (75 mm < a < 150 mm);

Width of one unit, $L = 6a$ where a = height of baffle. For example, if the baffle height a = 100 mm then L = 600 mm. If a = 150 mm, then L = 900 mm.

Width of echelon section of baffles, $L/2$;

— Longitudinal slope of unit, S = 15 % or 1:6,67 or 8,53°

— Distance between baffles = 2,60a. For example, for a 100 mm baffle D = 260 mm, for a 150 mm baffle D = 390 mm.

- Larinier fishpass units shall be juxtaposed in multiples of 1,0, 1,5, 2,0, 2,5 etc. when larger fishpass flows are required.
- A separator plate equal in height and thickness to the baffle shall separate each unit where juxtaposed units are used.

7.2.3 Limitations

7.2.3.1 Fish passage limitations. The upper and lower limits for flows (heads) which provide satisfactory flow conditions for fish migration are as follows:

- the minimum depth for hydraulic operation as a fish pass is $1{,}15 * a$, e.g. for a 100 mm baffle = 0,115 m, for a 150 mm baffle = 0,172 5 m. This depth is less than the upstream head on the fishpass;
- for coarse fish, trout and grayling, the minimum water depth in the pass h = 0,10 m;
- for sea trout, the minimum water depth in the pass h = 0,15 m;
- for salmon, the minimum water depth in the pass h = 0,20 m;
- for coarse fish, trout and grayling, the maximum depth h_1 = 0,50 m;
- for sea trout and salmon, the maximum depth $h_1 = 6 * a$, e.g. for 100 m baffle = 600 mm, for 150 mm baffle = 0,90 m.

7.2.3.2 Hydrometric flow range limitations. The upper and lower limits which provide accurate flow data:

- minimum upstream head, h_1 = 0,03 m,
- maximum upstream head, h_1 = 0,90 m, and
- maximum value of h_1/P to avoid high Froude numbers and waves in the approach flow = 3,0.

The head (h_1) is measured relative to the transverse part of the top baffle, i.e. the cease to flow level

The difference between the height of the top baffle (transverse) elevation and the upstream bed level (P value) shall be a minimum of 0,15 m for hydrometric purposes. For fish passage purposes, it should be sufficient to maintain the required depths and velocities for fish passage in the upstream exit channel.

It is recommended that the upstream slope of the fish pass should be 1:2, i.e. the same as a horizontally crested triangular profile weir, see ISO 4360.

The location of the first Larinier baffle will be set at the apex of the 1:2 slope upstream slope and the 15 % downstream slope.

The minimum number of baffles required for flow determination is 4.

The baffles shall be made from material of sufficient strength and durability to withstand the hydraulic and other watercourse conditions, e.g. flood flows, suspended sediment and debris. Also it is important that the material used is rigid and maintains its shape. Suitable materials include stainless steel, galvanised mild steel, and marine grade aluminium. HDPE may be suitable in certain circumstances provided that the anticipated conditions will not be too harsh, for example where they are well protected from debris of large sediment load in off-main watercourse fish pass. Some Larinier fish passes have also been used as canoe passes. In such circumstances, HDPE baffles may be preferred.

The baffles shall be 12 mm thick with a fully radiused top edge

The maximum range of the Larinier fish pass is currently 0,9 m. Therefore, the wing walls should be at least 0,9 m above the elevation of the top baffle. The upper recommended head of 0,9 m is the limit of investigation and as such the limit of the theoretical rating. However, it may be possible to extend the rating above this range particularly if gauging is undertaken to assist with this and the wingwalls are built sufficiently high.

7.2.4 Modular flow calibration

7.2.4.1 Discharge equations

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

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

where

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

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;
$H_{1\mathrm{e}}$	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.

7.2.4.2 Coefficient of discharge

The coefficient of discharge is shown in Figure 3.

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

Phase 1 ($0{,}03\ \mathrm{m} \le h_1 < 0{,}08\ \mathrm{m}$)

$$C_{\mathrm{de}} = 0{,}50 + 2{,}50\,(h_1 - 0{,}02) \tag{3}$$

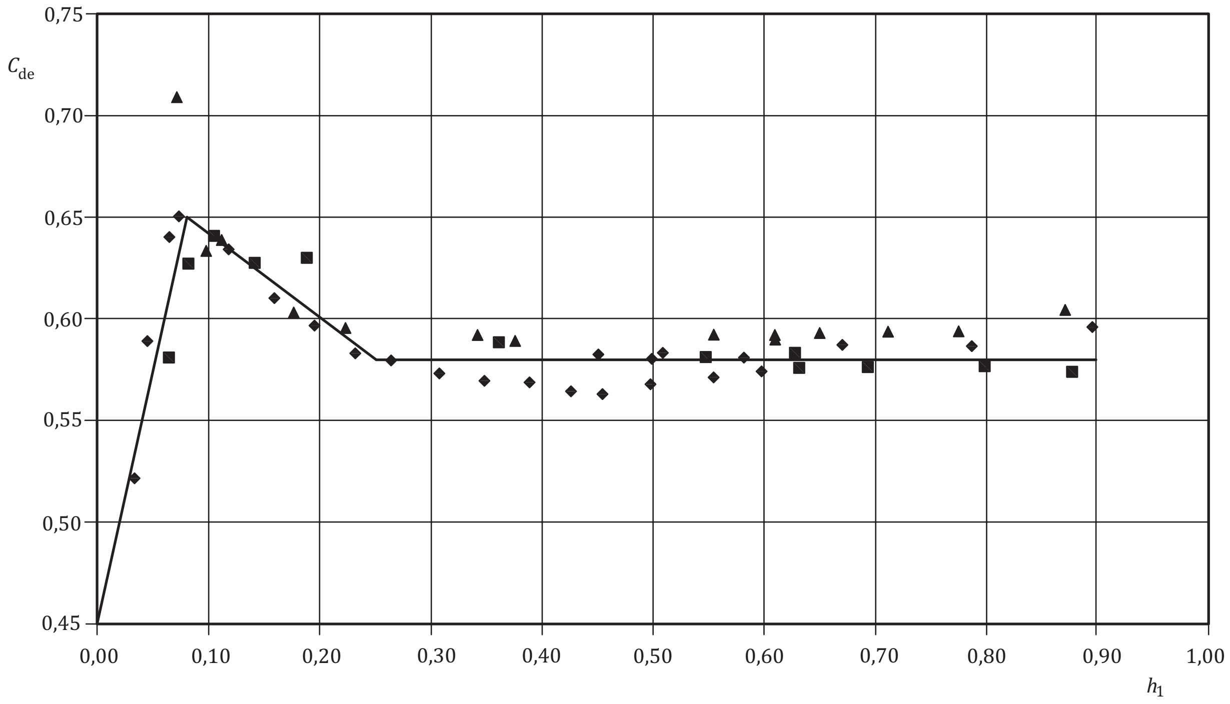
Phase 2 ($0{,}08\ \mathrm{m} \le h_1 < 0{,}25\ \mathrm{m}$)

$$C_{\mathrm{de}} = 0{,}65 - 0{,}41\,(h_1 - 0{,}08) \tag{4}$$

Phase 3 ($0{,}25\ \mathrm{m} \le h_1 < 0{,}90\ \mathrm{m}$)

$$C_{\mathrm{de}} = 0{,}58 \tag{5}$$

The value of k_{h} used in Formula (2) should be zero.



Key

◆	100 mm baffles
■	150 mm baffles
■	75 mm baffles
—	recommended coefficients

Figure 3 — Coefficient of discharge for super-active Larinier fishpass

7.2.5 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, expressed as a percentage, at which there is a reduction from the modular flow of one percent. Formula (6) shall be used to determine its value.

$$\text{Modular limit} = (20 + 60\,h_1)\ \% \tag{6}$$

where

h_1 is the upstream head in metres.

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.

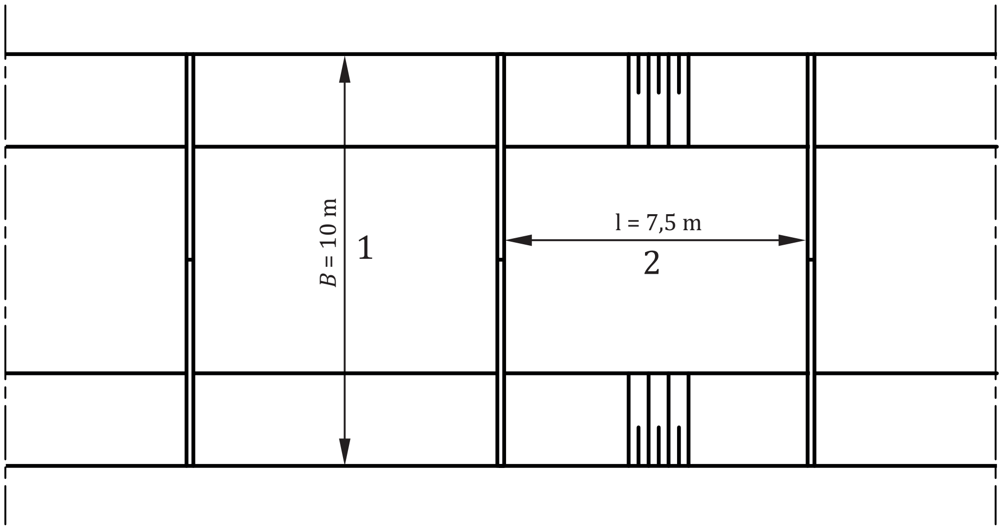
7.3.1.5 The layout of the fishpass is shown in Figure 4. The most important dimensions are the pool length, $l = 7{,}50$ m, and the pool drop, $\Delta t = 0{,}25$ m. A submergence ratio, h_2/h_1 approximately 0,5 for each weir crest, is assumed to be attractive for most migrants (h_1 is the upstream 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 5.

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, $Q_\mathrm{d} = 2$ m^3/s, the width of the non-aerated nappe is about 3,30 m (submergence ratio $h_2/h_1 = 0{,}5$). For $Q > Q_\mathrm{d}$, the flow velocities will be high and for $Q > Q_\mathrm{d}$, 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.

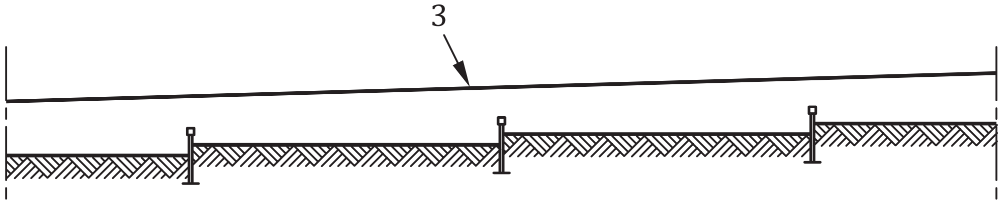
7.3.1.7 It is recommended to measure the discharge over the first (the highest situated) overfall for the following reasons.

- The best approach conditions and a stable water surface in the forebay are present. The head, h_1, shall be measured at a distance, $X = 3\ h_\mathrm{max}$, upstream from the first overfall.
- The risk of submerged flow is minimized.

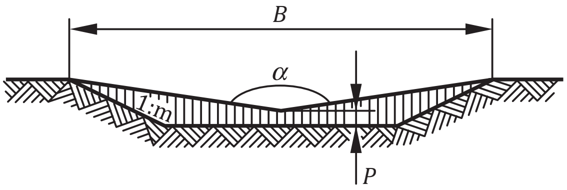
Dimensions in metres



a) Plan view



b) Longitudinal section



c) Front (upstream) view

Key

1 pool width

2 pool length

3 bank level

Figure 4 — Layout of the pool-type fishpass with V-shaped overfalls

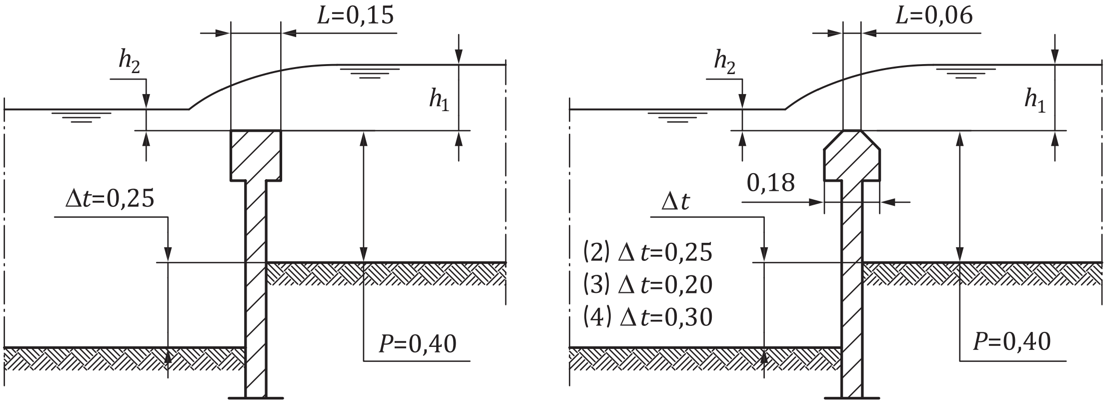


Figure 5 — Cross-sections of overfalls 1, 2, 3 and 4

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

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 Formula (7):

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

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 $C_{\mathrm{V}} = (H_1/h_1)^{5/2}$

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 approximately h_1 and $C_V = 1$.

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

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

7.3.2.2 Coefficient of discharge

The coefficients of discharge are shown in Figure 6 for the four standard types.

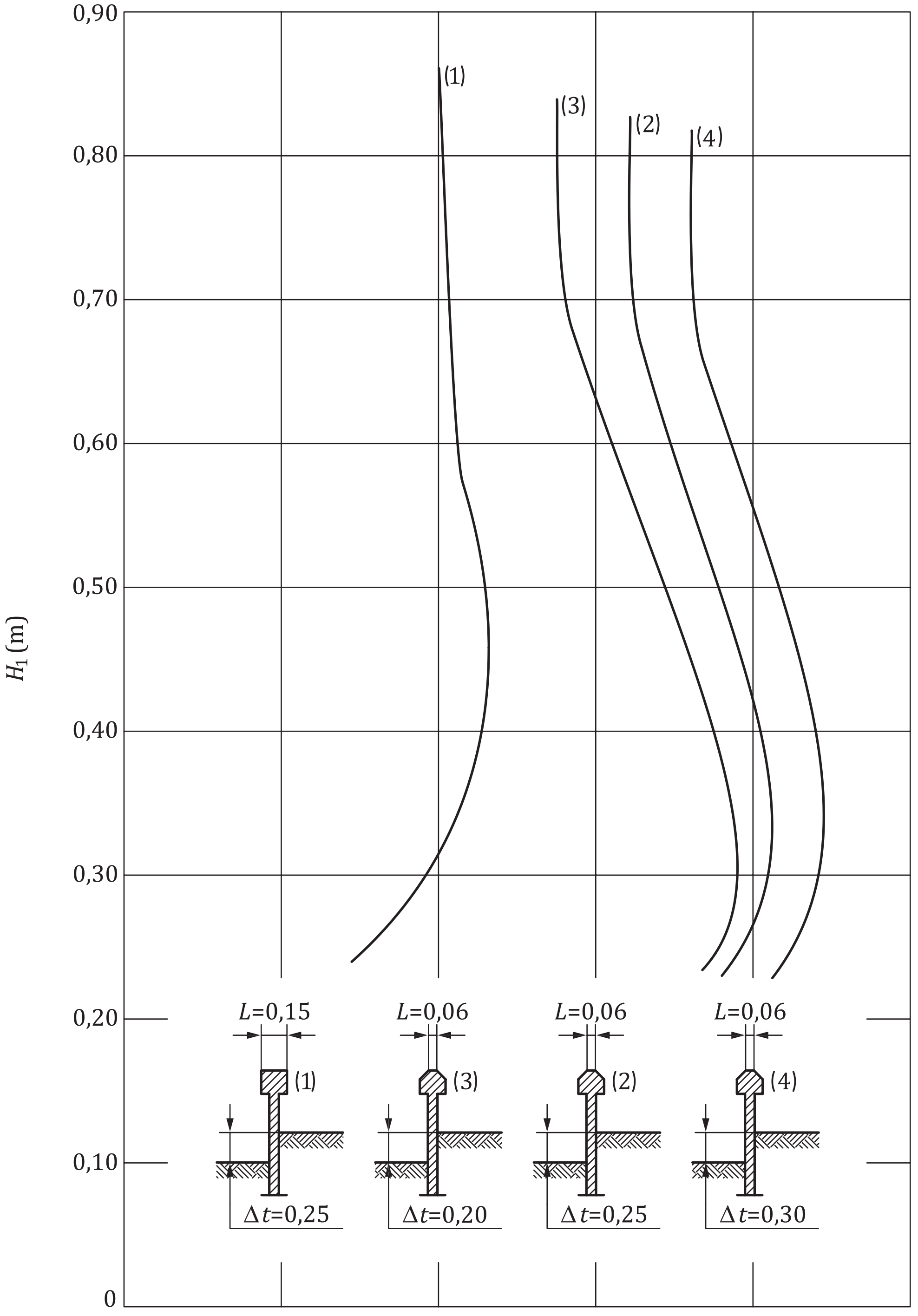


Figure 6 — Discharge coefficient C_D

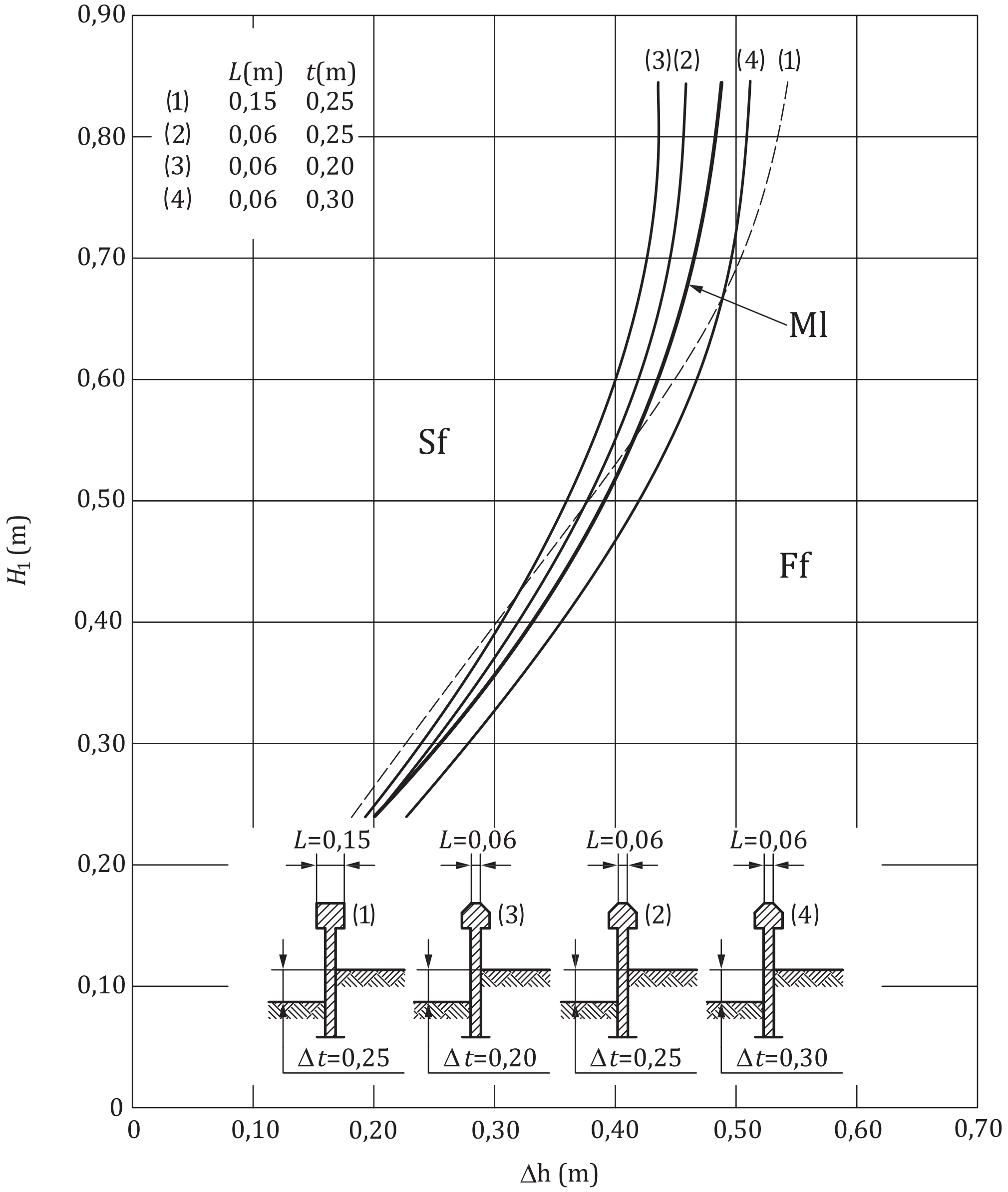
Type	Crest shape	Crest length L m	Pool drop Δt m
1	Rectangular	0,15	0,25
2	Bevelled	0,06	0,25
3	Bevelled	0,06	0,20
4	Bevelled	0,06	0,30

NOTE The given relation is only valid for the standard design as shown in Figures 4 and 5.

7.3.3 Modular limit

The modular limit is the ratio of the downstream to upstream total head values when the discharge is reduced by one percent from the unrestricted modular flow value.

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 7 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

Ml	modular limit (average of all four designs)
(1), (2), (3), (4)	modular limits of each design
Sf	zone of submerged flow
Ff	zone of free flow

NOTE The curves shown are only valid for the standard design as shown in Figures 4 and 5.

Figure 7 — 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 7 shall not be exceeded.

7.3.6 Scaling up to standard design

In case the desired design discharge should be less or more than $Q_d = 2\ \text{m}^3/\text{s}$ 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 11 different designs of standard type 1

Design no.	Design discharge	Dimensions optimum design m					Width of non-aerated nappe	Max velocities m/s	
		Pool drop	Pool length	Pool width	Pool depth	Crest length		Downstream of the crest	Pool
	Q_d m^3/s	Δt	l	B	P	L	B_2 m		
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: $0,050 < Q_d < 0,150\ \text{m}^3/\text{s}$. 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 8. Figure 9 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 $\overline{\Delta h_d} = 0{,}05\ \text{m}$;

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: $n = (Y_0 - Y_d) / \overline{\Delta h_d}$;

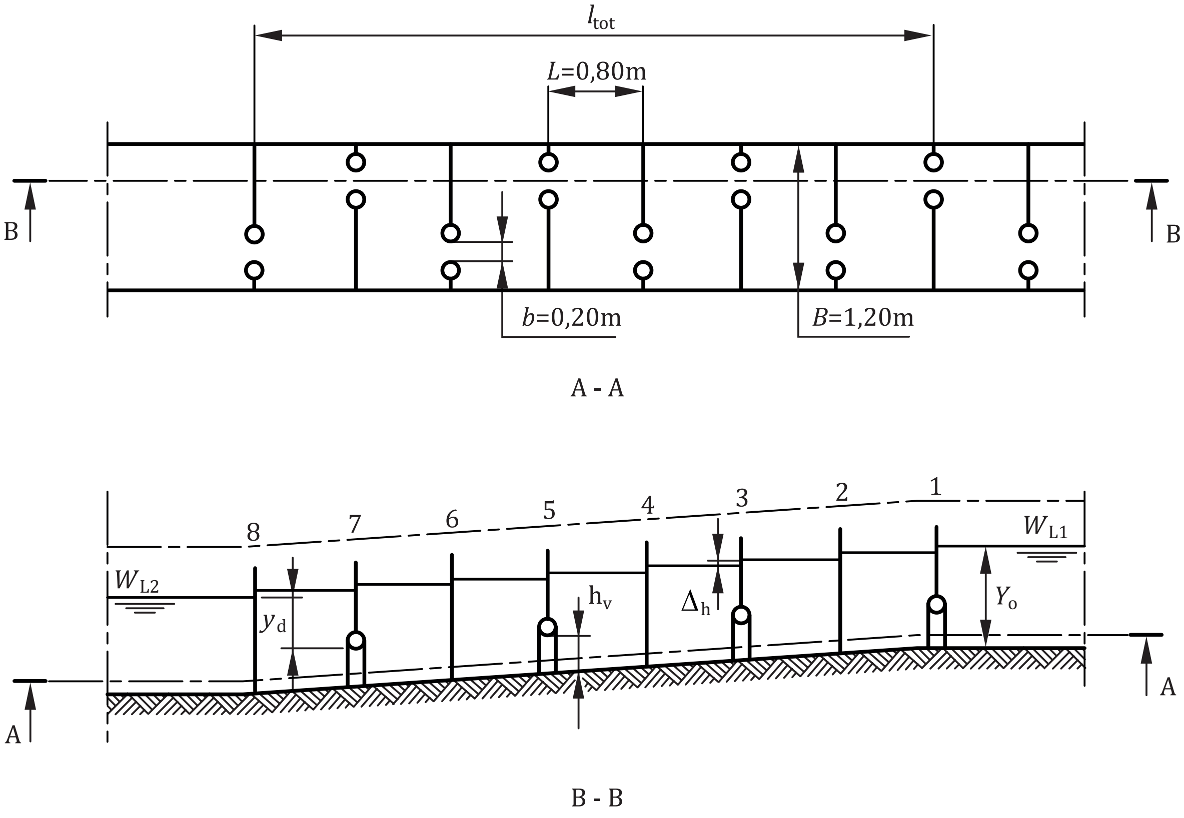
d) the orifice width is b = 0,20 m and orifice height $0{,}30 < h_v < 0{,}60$ m;

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 $S = \overline{\Delta h_d} / L = 0{,}0625$;

g) the bed consists of a smooth concrete layer.

Dimensions in metres



Key

l_{tot} total length of fishpass

A - A = Plan view

B - B = Profile

Figure 8 — Standard design of the Dutch pool and orifice fishpass

Dimensions in metres

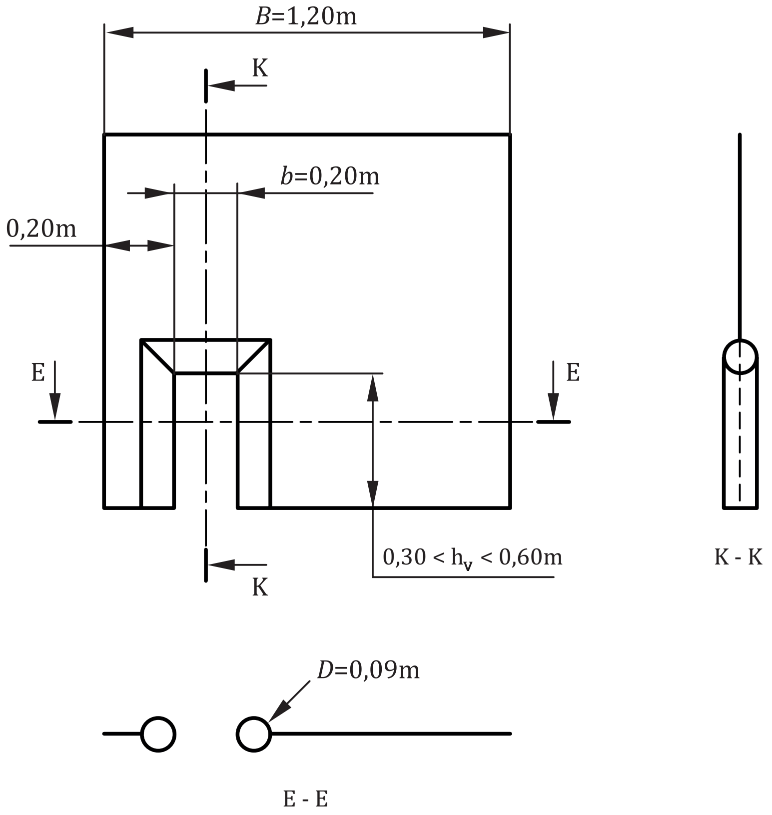


Figure 9 — Front (upstream) view of a transition and the position of an orifice in the transition

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.

The discharge is given by Formula (9):

$$Q = C \times b \times h_\text{v} \times \sqrt{2g \times \overline{\Delta h}} \tag{9}$$

where

Q	is the discharge, in cubic metres per second;
C	is the characteristic discharge coefficient;
b	is the orifice width, in metres;
h_v	is the orifice height in metres;
g	is the gravitational acceleration, in metres per second squared;
$\overline{\Delta h}$	is the average head drop per pool, in metres.

$$\overline{\Delta h} = \left(Y_0 - Y_\mathrm{d}\right) / n \tag{10}$$

Y_0 is the upstream water depth related to upstream bed level, in metres;

Y_d is the downstream water depth related to upstream bed level, in metres;

n is the number of partitions.

The design discharge is calculated using Formula (11):

$$Q_\mathrm{d} = C \times b \times h_\mathrm{v} \times \sqrt{2g \times \overline{\Delta h_\mathrm{d}}} \tag{11}$$

where

$\overline{\Delta h_\mathrm{d}}$ is the design head drop per pool if the average water level slope in the fishpass equals the designed bed slope.

This situation is also called “uniform flow”.

The rating curve has been established for the standard design (Figure 7) with four orifice heights in the range 0,30 < h_v < 0,60 m and a smooth bed, sloping with S = 0,062 5. Investigations during the model tests examined the sensitivity of C to changes in the following parameters: number of partitions n, bed roughness and non-uniform flow (average water level slope deviates from S = 0,062 5).

7.4.2.2 Coefficient of discharge

The coefficient of discharge is shown in Table 3.

Table 3 — Coefficient of discharge $C = f\,(Y_0, h_\mathrm{v})$

Water depth	***C*-values for four orifice heights h_v**			
Y_0 m	h_v = 0,30 m	h_v = 0,40 m	h = 0,50 m	h_v = 0,60 m
0,60	0,905	0,871		
0,70	0,926	0,915	0,849	
0,80	0,934	0,935	0,900	0,844
0,90	0,932	0,939	0,924	0,903
1,00	0,926	0,937	0,931	0,922
1,10	0,918	0,933	0,930	0,930
1,20	0,909	0,927	0,928	0,932

Using the C-values of Table 3, the rating curve $Q = C \times b \times h_\mathrm{v} \times \sqrt{2g \times \overline{\Delta h}}$ can be established. Strictly speaking, Table 3 is valid for a smooth bed, a standard pool length L = 0,80 m and for uniform flow $\overline{\Delta h_\mathrm{d}} = 0{,}05\,\mathrm{m}$.

The effects of a deviating number of partitions n, a rough bed and non-uniform flow are as follows:

- C is independent from the number of partitions n, provided $n \geq 4$;
- the difference between C-values for a smooth bed and a gravel bed is < ± 1 %;
- the difference between C-values for uniform flow and non-uniform flow is < ± 1 % in the range $0{,}8\,\overline{\Delta h_\mathrm{d}} < \overline{\Delta h} < 1{,}25\,\overline{\Delta h_\mathrm{d}}$.

7.4.2.3 Limitations

In the interest of a correct determination of discharge, the following limitations shall be taken into account. There is a free choice for the following parameters:

- orifice height, h_v. Standard values are 0,30 m, 0,40 m, 0,50 m and 0,60 m;
- the number of partitions, n, depending on the total head drop over the structure $n = \left(W_{\mathrm{L}1} - W_{\mathrm{L}2}\right) / \overline{\Delta h_\mathrm{d}}$, provided $n \overset{\star}{=} 4$;
- upstream water depth, Y_0, depending on the channel's bed level. $Y_0 > h_\mathrm{v} + 0{,}30$ m is recommended, in order to prevent the development of a vortex in front of the first orifice;
- in case of a gravel bed, the position of the gravel in the surrounding of the orifices should be stable;
- the total drop over the fishpass $Y_0 - Y_\mathrm{d} = W_{\mathrm{L}1} - W_{\mathrm{L}2}$ may deviate from the design values, taking into account $0{,}8\,\overline{\Delta h_\mathrm{d}} < \overline{\Delta h} < 1{,}25\,\overline{\Delta h_\mathrm{d}}$.

7.4.3 Scaling up the standard design

7.4.3.1 In case the desired design discharge $Q_\mathrm{d} < 0{,}050\ \mathrm{m^3/s}$ or $Q_\mathrm{d} > 0{,}150\ \mathrm{m^3/s}$, then it is possible to scale down or to scale up the standard design.

7.4.3.2 The standard design of the Dutch pool and orifice fishpass is characterized by the standard sizes B, L, b, D and $\overline{\Delta h_\mathrm{d}}$, resulting in about $\overline{V} = 0{,}92\ \mathrm{m/s}$ through the orifices. Any of these parameters can be scaled up (or down) by scaling up (or down) the complete standard design as described in Figures 8 and 9, taking into account the scale rules:

- length scale n_ℓ, valid for B, L, b, D and $\overline{\Delta h_\mathrm{d}}$ and h_v;
- the bed slope of the fishpass remains the same, $S = 0{,}062\,5$;
- flow velocity scale $n_\mathrm{v} = (n_\ell)^{0{,}5}$;
- discharge scale $n_\mathrm{Q} = (n_\ell)^{2{,}5}$.

7.4.3.3 In many situations, it becomes difficult or even impossible to scale up the water depth Y_0 since both the upstream water level and bed level have fixed values. In that case, application of the scale rules is not 100 % correct:

- the scales n_v and n_Q are slightly affected by the discharge coefficient C, which is a function of Y_0.

7.4.3.4 It is therefore recommended to carry out the scaling-up techniques as follows:

- in situations where Y_0 can be scaled up with the factor n_ℓ, the scale factors n_v, and n_Q are 100 % correct;
- if it is impossible to scale up Y_0, then C, $\overline{V}$ and Q should be calculated, based on the new partly up scaled dimensions.

The recommended scaling-down/scaling-up factor is $0{,}75 < n_\ell < 1{,}33$.

8 Computation of discharge

8.1 Principles

This International Standard concerns fish-passes which are placed alongside flow measurement structures. As such, they constitute an integral part of the flow measurement system and accurate determination of that part of the total flow taken by the fish-pass is essential if overall flow measurement accuracy is to be maintained.

In some cases, the design incorporates an upstream head measurement gauge at both the fishpass and the gauging structure. Here the two flows shall be determined separately and aggregated to determine the total river flow. The data presented in this International Standard provide the means for determining fishpass flows for the three types of fishpass covered. Flow over the measuring weir is determined using the appropriate International Standard for that type of weir (see Clause 2 and Bibliography).

In other cases, there is only one upstream head gauge, usually located at the flow measurement structure. The total head level at the flow measurement structure is then assumed to apply to the fishpass and total flows are determined by regarding the fishpass as one section of a compound flow measurement structure (see ISO 14139). Uncertainty calculations follow the detailed method described in ISO 14139, which is essential for those designing flow measurement structure/fishpass installations.

8.2 Details

8.2.1 Where there are two sets of head gauges, separate calculations shall be performed for the fishpass and the gauging structure. For the fishpass, the calculation methods given in Clause 7 shall be used. For the flow measurement structure, the calculation methods given in the appropriate International Standard in the Bibliography shall be used. In choosing the most appropriate flow measurement structure, ISO 8368 may be of value. See the Bibliography for details.

8.2.2 Where there is only one head measurement at the flow measurement structure/fishpass installation, the system shall be regarded as a compound flow measurement structure in terms of operation (see ISO 14139). The measurement of head shall be carried out at the flow measurement structure and the appropriate head to be applied to the fishpass shall be deduced in accordance with ISO 14139.

9 Uncertainties in flow determination

9.1 General

9.1.1 This clause provides information for the user of this International Standard to state the uncertainty of a discharge determination obtained for a fish pass which can be used to determine flow or a combination of a fish pass and other flow measurement structures.

NOTE In accordance with former practice in hydrometry, the expression for uncertainty is continued to be expressed at the 95 % confidence level for the discharge coefficient and the determined flow rate.

The ISO/IEC Guide 98-3 (referred to hereafter as the GUM) and ISO/TS 25377 (referred to hereafter as the HUG) operate using standard uncertainties (i.e. at the 68 % confidence level). In accordance with the HUG, the uncertainty of a flow determinations using a fish pass weir are estimated as a combined uncertainty, calculated from the various component uncertainties. The HUG requires final resultant uncertainty of measurement to be expressed at the 95 % confidence level since this is normal hydrometric practice. Nevertheless, in the first instance the standard uncertainty is estimated. Some components of uncertainty are expressed at the 95 % confidence level while others are standard uncertainties, i.e. those derived from Type A and B methods (see A.5 and A.6). Those at the 95 % confidence level shall be converted to the 68 % confidence level by dividing them by the coverage factor, $k = 2$ at the 95 % confidence level. Having so combined these components to determine the standard uncertainty, this result is now multiplied by the coverage factor ($k = 2$) to express the uncertainty at the 95 % confidence level.

9.1.2 Annex A provides an introduction to measurement uncertainty based on the GUM and the HUG. Flow determinations in hydrometry are dependent on measurements using various techniques. Annex B which is taken from the HUG provides guidance on the sample values for a variety of hydrometric measurement techniques. These are presented in tabular form with uncertainty estimates ascribed to each technique for the purpose of illustration only. These sample values shall not be interpreted as norms of performance. The uncertainties expressed in Table B.1 are at the 68 % confidence level.

9.1.3 A measurement result comprises:

a) an estimate of the measured value, with

b) a statement of the uncertainty of the measurement.

9.1.4 A statement of the uncertainty of a fish pass used as a flow measurement structure can be considered to have three separate components of uncertainty:

a) uncertainty of the measurement of head in the channel (u^*h_{1e}),

b) uncertainty of the measurement of the dimensions of the structure (u^*b), and

c) uncertainty of the discharge coefficient stated in 7.1 from laboratory calibration of the flow structure being considered (u^*C_{De}).

9.1.5 Guidance on the estimation of measurement uncertainty associated with items a) and b) of 9.1.4 is provided in Annex A.

These values are for illustrative purposes only, and they should not be interpreted as norms of performance for the types of equipment listed. In practice, uncertainty estimates shall be taken from test certificates for the equipment, preferably obtained from a laboratory with accreditation to ISO/IEC 17025 or sound hydrometric experience including independent, *in situ* check measurements.

9.2 Combining uncertainties

Refer to A.7.

The extent to which each flow formula parameter contributes to the flow measurement uncertainty, *U(Q)* is derived by analytical solution using partial differentials of the discharge formula.

$$Q = JC_{De}g^{0,5}H_{1e}^{1,5} \tag{12}$$

where

J a numerical constant not subject to error.

Uncertainties in g, the acceleration due to gravity, may be ignored.

The effect on the value Q due to small dispersions of ΔC_{De}, Δm and Δh_1 is:

$$\Delta Q = J\sqrt{g}\left(\frac{\partial Q}{\partial C_{De}}\Delta C_{De} + \frac{\partial Q}{\partial b}\Delta b + \frac{\partial Q}{\partial h}\Delta h_{1e}\right) \tag{13}$$

Where the partial differentials are the sensitivity coefficients referred to in A.7 and the HUG that relate to the discharge equation. ΔQ is the resultant dispersion of Q due to small dispersions of ΔC_{de}, ΔC_{dr}, Δm and Δh_1. Evaluating the partial differentials the relationship can be written:

$$\frac{\Delta Q}{Q} = \frac{\Delta C_{De}}{C_{De}} + \frac{\Delta b}{b} + 1{,}5\frac{\Delta h_{1e}}{h_{1e}} \tag{14}$$

In uncertainty analysis, the values $\frac{\Delta Q}{Q}$, $\frac{\Delta C_{De}}{C_{De}}$, $\frac{\Delta b}{b}$ and $\frac{\Delta h_{1e}}{h_{1e}}$ are referred to as dimensionless standard uncertainties and are given the notation $u^*(Q)$, $u^*(C_{De})$, $u^*(b)$ and $u^*(h_{1e})$. Since the uncertainties of C_{De}, b

and h_{1e} are independent of each other, probability requires summation in quadrature rather than a simple summation. The standard uncertainty of the discharge measurement can be estimated thus:

$$U^* = \sqrt{u(C_{De})^2 + u^*(b)^2 + \left[1{,}5u^*(h_{1e})\right]^2} \tag{15}$$

9.3 Uncertainty in the discharge coefficient $u^*(C_{De})_{68}$ for the fish-pass

Guidance on the possible uncertainties in the discharge coefficients for the fish-passes covered in this International Standard is contained in 7.1.

9.4 Uncertainty in the effective head

The uncertainty in effective total head can be considered to consist of four components:

a) the uncertainty in the actual head measurement i.e. instrument uncertainty;

b) uncertainty in the gauge zero;

c) uncertainty in the head correction factor k_h. The absolute standard uncertainty is usually taken as 0,1 mm which can be assumed to be negligible relative to the first two uncertainties and for most practical applications can be ignored;

d) uncertainty in the estimation of total head using the iterative process. If sufficient iterations are used in the computation, the uncertainty in the estimation of total head is negligible and can be ignored.

Therefore, if uncertainties in the head correction factor and the iterative process are ignored, the uncertainty in the total head can be estimated as follows:

$$u^*_{He} = 100\frac{\sqrt{u(h_1)^2 + u(E)^2}}{h} \tag{16}$$

where

$u(h_1)$and $u(E)$ are the absolute, standard uncertainties in the instrument and the stage zero respectively in the same units as the stage (h_1).

Therefore, the uncertainty in the effective head can be assumed to be a combination of the instrument and gauge zero uncertainties. An example of the computation of the uncertainty in the effective total head is contained in Clause 10. In addition, reference should also be made to Annexes A and B.

9.5 Uncertainty budget

9.5.1 General

In reports, an uncertainty budget table may be presented (or referenced) to provide the following information for each source of uncertainty:

a) the method of evaluation (from Annex A);

b) the determined value of relative standard uncertainty $u^*(C_{De})$, $u^*(b)$, and $u^*(h_{1e})$, including the datum uncertainty of $u^*(h_{1e})$;

c) the relative sensitivity coefficients. The sensitivity coefficient is a measure of the impact of the individual component uncertainty on the overall uncertainty. For horizontal structures such as a horizontal crested fish pass, the head measurement has an exponent value β = 1,5. Therefore, the sensitivity is 1,5 since any error in the head measurement, results in a larger uncertainty in the discharge due to the impact of the exponent on the discharge computation.

The values for each source are then applied to give the combined standard uncertainty, *U*(Q)*. A coverage factor $k = 2$ is then applied to define the uncertainty at the 95 % level of confidence.

It is customary to present these steps in tabular form with one row for each source and a column for each of the items a) to c) above.

The table may include where appropriate the critical thinking behind the subjective allocation of uncertainty to the quantities m and h_1. This section of the table may be replicated for a range of values of h_1 to determine a relationship between *U*(Q)* and h_1.

9.5.2 Compound structures – sources of uncertainty

The sources of uncertainty in flow determination at flow measurement structures are as given in the uncertainties sections of the International Standards relating to the appropriate type of structure. Where installations incorporate two sets of head measurements, the uncertainties for the fishpass and the flow measurement structure shall be computed separately. The overall uncertainty for the fishpass/flow measurement structure installation shall be obtained as the root mean square of the two individual uncertainties, but weighted in accordance with the proportion of flow through each structure as follows.

$$U_c^* = \sqrt{\left(a_{fp} \times \left(U_{fp}^*\right)^2 + b_{fms} \times \left(U_{fms}^*\right)^2\right)} \tag{17}$$

where

U_c^* combined uncertainty for the site i.e. fish pass plus flow measuring structure;

a_{fp} proportion of flow through fish pass (as a decimal fraction);

U_{fp}^* uncertainty in flow in fish pass/device A, (as a %);

b_{fms} proportion of flow through flow measurement structure (as a decimal fraction);

U_{fms}^* uncertainty in flow through flow measurement structure (as a %).

Where installations incorporate only one set of head gauges at the flow measurement structure, additional uncertainties arise due to the method used for estimating water levels or total head levels at the fishpass. Available evidence is limited, but it suggests that the percentage uncertainty in flow associated with transposing upstream water levels or total head levels is random, with a magnitude within the range of 2,5 % at the 68 % confidence level. In particular cases, more reliable estimates can be made of this value by making field or laboratory observations. For cases involving drowned flow, little information is available about the additional uncertainty in discharge associated with estimating downstream water levels or total head levels. A value of 5 % at the 95 % confidence level shall be assumed until further evidence becomes available.

Annexes A and B provide an introduction to the measurement of uncertainty.

10 Example

10.1 Installation

In this example, the installation comprises the following:

- a flat-V weir built in accordance with ISO 4377, has crest slopes of 1:10, a crest elevation of 100,25 mAD and a crest breadth 10,00 m;

- a twin unit super-active Larinier fishpass, with elevation of the transverse section of the uppermost baffle 100,25 mAD and width 1,20 m;
- a channel bed level of 100,0 mAD both upstream and downstream of the gauging structure/fishpass installation.

One head measurement is provided at the flat-V weir. There is no head measurement at the fishpass This is not recommended. Whenever possible, the Larinier Fish Pass should have its own dedicated head measuring device.

In this example, the following uncertainties in measurement are assumed:

a) uncertainty in cross slope of the flat-V weir of 0,2 % at 68 % confidence level;

b) assume uncertainty in head measurement at the flat-V weir = 2 mm at 68 % confidence level;

c) assume uncertainty in head measurement gauge zero = 1 mm at 68 % confidence level;

d) uncertainty in coefficient of discharge for flat-V weir of = 2,9 %;

e) uncertainty in the crest breadth of the Larinier fishpass = 3 mm at 68 % confidence level;

f) uncertainty in the coefficient of discharge of the Larinier fishpass = 1 % at 68 % confidence level;

g) additional uncertainty due to the transfer of head to the ungauged fishpass = 2,5 % at 68 % confidence level.

10.2 Flow conditions

In this example, the gauged head at the flat-V weir is 0,400 m (100,650 mAD) and the observed tailwater level is 100,40 mAD (0,150 m above the flat-V weir and the fishpass).

10.3 Computation of discharge

10.3.1 Modularity

The submergence ratio at the flat-V weir is given by:

$$\text{Submergence ratio} = (0{,}150\ /\ 0{,}400) \times 100 = 38\ \% \qquad (18)$$

The submergence ratio at the fishpass is given by:

$$\text{Submergence ratio} = (0{,}150\ /\ 0{,}400) \times 100 = 38\ \% \qquad (19)$$

ISO 4377 gives the modular limit of the flat-V weir as 70 % and Formula (6) gives a modular limit of 44 % for the fish-pass under these particular flow conditions. Therefore, the gauging structure/fishpass installation is operating under modular flow conditions.

10.3.2 Flow over the flat-V weir

Using ISO 4377, the flow over the flat-V weir is computed as 1,587 m^3s^{-1}. The upstream gauged head, h_1, is 0,400 m. The upstream total head, H_1, is 0,403 m. A Coriolis Coefficient of 1,2 was used in the calculation of total head as recommended in ISO 4377 for design purposes.

10.3.3 Flow through the fish-pass

Using Formulae (1) and (5)

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

Phase 3 (0,25 m ≤ h_1 < 0,90 m)

$$C_{\mathrm{de}} = 0,58$$

The flow through the fish pass is

$$Q = 1,2 \times 0,58 \times (9,81)^{0.5} \times (0,403)^{1.5} = 0,558\ \mathrm{m^3 s^{-1}}.$$

10.3.4 Total flow

The total flow through the gauging structure and fish-pass installation is:

$$\text{Total flow} = 1,587 + 0,558 = 2,145\ \mathrm{m^3 s^{-1}} \qquad (20)$$

10.3.5 Uncertainty in flow through the fish-pass

The Larinier fish-pass has a near horizontal crest at the top baffle and hence the hydraulic performance approximates to a two-dimensional weir, such as the Crump weir (see ISO 4360). Uncertainties for the fishpass are calculated according to the methods described in this International Standard. The individual uncertainties are as follows:

a) uncertainty in discharge coefficient (u^*C_{De}) = 1 % at 68 % conf. level (see 7.1);

b) uncertainty in the breadth of the fish pass $\left(u^*{}_b\right) = \dfrac{u_b}{h_1} \times 100 = \left(5/1200\right) \times 100$

= 0,42 % at 68 % confidence level;

c) uncertainty in head [Formula (16)] = $u^*_{He} = 100 \dfrac{\sqrt{u(h_1)^2 + u(E)^2}}{h}$

$$= 100 \times \frac{\sqrt{2^2 + 1^2}}{400} = 0,56\%\ \text{at } 68\%\ \text{confidence level}.$$

<u>Overall uncertainty for estimated flow through the fish-pass</u>

Uncertainty in estimated fish pass flow Formula (15)

$$U^*_{fp} = \sqrt{u(C_{De})^2 + u^*(b)^2 + \left[1,5u^*(h_{1e})\right]^2}$$

$$U^*_{fp} = \sqrt{1^2 + 0,42^2 + 1,5^2 \times 0,56^2}$$

= 2,13 % at 68 % confidence level.

As noted previously, for this example, there is no separate head measuring section for the fish pass (this should be avoided whenever possible and a separate head measuring point and approach section is strongly recommended). Therefore, an additional 2,5 % uncertainty at the 68 % confidence level has been allowed for. Combining the uncertainties in quadrature, the overall estimated adjusted uncertainty for the fish pass flow is determined as follows:

$$U^*_{fpadj} = \sqrt{2{,}13^2 + 2{,}5^2} = 3{,}3\% \text{ at } 68\% \text{ confidence level}$$

In order to estimate uncertainty at 95 % confidence level, coverage factor k = 2.

Overall uncertainty through fish pass $\left(U^*_{95fp}\right)$ = standard uncertainty × k

= 3,3 × 2 = 6,6 % at 2SD/95 % confidence level

10.3.6 Uncertainty in flow over the flat-V weir

Using the methodology stated in ISO 4377, the standard uncertainty in the flow over the flat-V weir has been estimated to be 1,98 % at the 68 % confidence level.

10.3.7 Uncertainty in total flow

The overall uncertainty in the determination of discharge can be estimated using Formula (17).

Proportion of total flow in fish pass (a_{fp}) = 0,558/2,145 = 0,26

Proportion of total flow through Flat-V weir (b_{fms}) = 1,587/2,145 = 0,74

Combined overall standard uncertainty is given by:

$$U^*_c = \sqrt{\left(a_{fp} \times \left(U^*_{fp}\right)^2 + b_{fms} \times \left(U^*_{fms}\right)^2\right)}$$

$$= \sqrt{0{,}26 \times 3{,}3^2 + 0{,}74 \times 1{,}98^2}$$

= 2,4 % at 1SD/68 % confidence level

Overall combined uncertainty at 95 % confidence level = standard uncertainty × k

= 2,4 × 2 = 4,8 %

10.3.8 Reduction in overall uncertainty if second head gauge were to be installed upstream of the fish-pass

A second head gauge would remove the uncertainty in transposing heads from the gauging weir to the fish-pass. In this case, the overall uncertainty would be calculated using the uncertainty in the fish-pass without the additional 2,5 % uncertainty due to fact there is no separate water level measurement in the approach to the fish-pass. The estimated uncertainty assuming a separate head measurement was available for the fish-pass, is calculated as follows:

$$\text{Overall uncertainty} = \sqrt{0{,}26 \times 2{,}13^2 + 0{,}74 \times 1{,}98^2}$$

= 2,0 % at 1SD/68 % confidence level

Overall combined uncertainty at 95 % confidence level = standard uncertainty × k

= 2,0 × 2 = 4,0 %

Annex A
(informative)

Introduction to measurement uncertainty

A.1 General

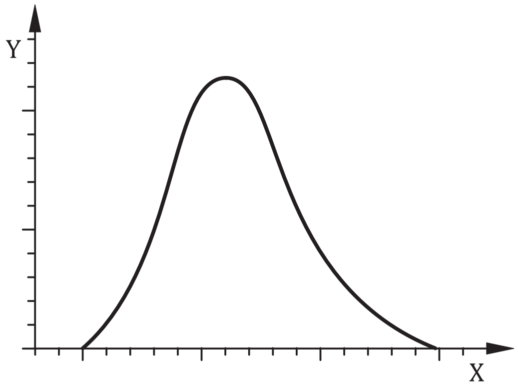
Results of measurements or analysis cannot be exact. The discrepancy between the true value, which is unknowable, and the measured value is the measurement error. The concept of uncertainty is a way of expressing this lack of knowledge. For example, if water is controlled to flow at a constant rate, then a flow meter will exhibit a spread of measurements about a mean value. If attention is not given to the uncertain nature of data, incorrect decisions can be made which have financial or judicial consequences. A realistic statement of uncertainty enhances the quality of information, making it more useful.

The uncertainty of a measurement represents a dispersion of values that could be attributed to it. Statistical methods provide objective values based on the application of theory.

Standard uncertainty is defined as:

Standard uncertainty equates to a dispersion of measurements expressed as a standard deviation.

From this definition, uncertainty can be readily calculated for a set of measurements.

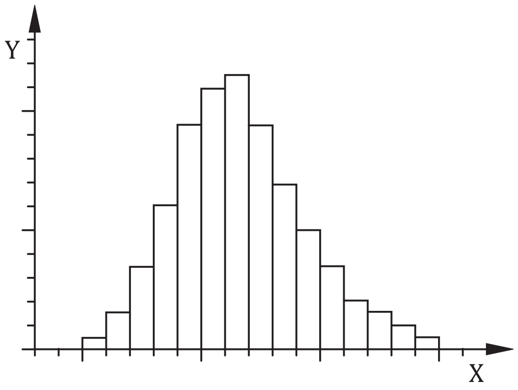


Key

X flow value

Y probability

Figure A.1 — Pictorial representation of some uncertainty parameters — Probability density function

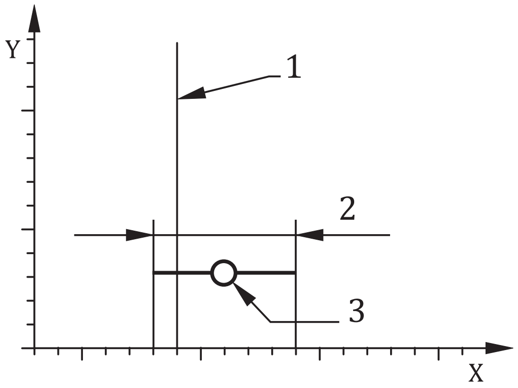


Key

X flow value

Y number of samples

Figure A.2 — Pictorial representation of some uncertainty parameters — Histogram



Key

1 limit

2 standard deviation

3 mean value

X flow value

Y number of samples

Figure A.3 — Pictorial representation of some uncertainty parameters — Standard deviation of the sampled measurements

Figure A.1 shows that if repeated measurements of a steady flow are made, these follow a probability density function whose shape resembles the plot shown in the figure.

Figure A.2 shows sampled flow measurements, in the form of a histogram.

Figure A.3 shows standard deviation of the sampled measurements compared with a limiting value. The mean value is shown to exceed the limiting value but is within the band of uncertainty (expressed as the standard deviation about the mean value).

A.2 Confidence levels and coverage factors

For a normal probability distribution, analysis shows that 68 % of a large set of measurements lies within one standard deviation of the mean value. Thus, standard uncertainty is said to have a 68 % level of confidence.

However, for some measurement results, it is customary to express the uncertainty at a level of confidence which will cover a larger portion of the measurements: for example at a 95 % level of confidence (see Figure A.6). This is done by applying a factor, the coverage factor k, to the computed value of standard uncertainty.

For a normal probability distribution, 95,45 % (effectively 95 %) of the measurements are covered for a value of $k = 2$. Thus, uncertainty at the 95 % level of confidence is twice the standard uncertainty value.

In practice, measurement variances rarely follow closely the normal probability distribution. They may be better represented by triangular, rectangular or bimodal probability distributions and only sometimes approximate to the normal distribution.

So a probability distribution shall be selected to model the observed variances. To express the uncertainty of such models at the 95 % confidence level requires a coverage factor that represents 95 % of the observations. However, the same coverage factor, $k = 2$, is used for all models. This simplifies the procedure while ensuring consistency of application within tolerable limits.

A.3 Random and systematic error

The terms “random” and “systematic” have been applied in hydrometric standards to distinguish between a) random error that represent an inherent dispersion of values under steady conditions, and b) systematic errors that are associated with inherent limitations of the means of determining the measured quantity.

A difficulty with the concept of systematic error is that systematic error cannot be determined without pre-knowledge of true values. If its existence is known or suspected, then steps shall be taken to minimize such error either by recalibration of equipment or by reversing its effect in the calculation procedure. At which point, systematic error contributes to uncertainty in the same way as random components of uncertainty.

For this reason, the GUM does not distinguish between the treatment of random and systematic uncertainties. Generally, when determining a single discharge, random errors dominate and there is no need to separate random and systematic errors. However, where (say) totalized volume is established over a long time base, the systematic errors, even when reduced, can remain dominant in the estimation of uncertainty.

A.4 Measurement standards

The GUM and the HUG provide rules for the application of the principles of measurement uncertainty: in particular on the identification of components of error, the quantification of their corresponding uncertainties and how these are combined using methods derived from statistical theory into an overall result for the measurement process.

The components of uncertainty are characterized by estimates of standard deviations. There are two methods of estimation:

a) **Type-A estimation** (by statistical analysis of repeated measurements from which an equivalent standard deviation is derived).

   This process may be automated in real-time for depth or for velocity measurement.

b) **Type-B estimation** (by ascribing a probability distribution to the measurement process).

   This is applicable to:

1) human judgement of a manual measurement (distance or weight),

2) manual readings taken from instrumentation (manufacturer's statement), or

3) calibration data (from manufacturer).

A.5 Evaluation of Type-A uncertainty

Defined in A.1, the term "standard uncertainty" equates to a dispersion of measurements expressed as a standard deviation. Thus, any single measurement of a set of n measurements has by definition an uncertainty:

$$u(x)=t_\mathrm{e}\sqrt{\frac{1}{n-1}\sum_{i=1}^{n}(x_i-\overline{x})^2} \qquad \text{(A.1)}$$

where $\overline{x}$ is the best estimate of the true mean:

$$\overline{x}=\frac{1}{n}(x_1+x_2+.....x_n) \qquad \text{(A.2)}$$

and t_e is a factor derived from statistical theory to account for the increased uncertainty when small numbers of measurements are available refer to Table A.1.

If, instead of a single measurement from the set, the uncertainty is to apply to the mean of all n values, then:

$$u(\overline{x})=\frac{t_\mathrm{e}}{\sqrt{n}}\sqrt{\frac{1}{n-1}\sum_{i=1}^{n}(x_i-\overline{x})^2} \qquad \text{(A.3)}$$

For continuous measurement, Type-A evaluations may be derived as a continuous variable from the primary measurement, i.e. from water level or water velocity.

By taking average values over large numbers, n, of measurements, the uncertainty of the mean value $u(\overline{x})$ is reduced by a factor of $\frac{1}{\sqrt{n}}$ compared to the uncertainty $u(x)$ of an individual measurement. For this reason, monitoring equipment should specify measurement performance in terms including both $u(\overline{x})$ and $u(x)$ to show the extent to which averaging is applied.

Table A.1 — t_e factors at 90 %, 95 % and 99 % confidence levels

Degrees of freedom[a]	Confidence level % 90	95	99
1	6,31	12,71	63,66
2	2,92	4,30	9,92
3	2,35	3,18	5,84
4	2,13	2,78	4,60
5	2,02	2,57	4,03
10	1,81	2,23	3,17
15	1,75	2,13	2,95
20	1,72	2,09	2,85
25	1,71	2,06	2,79
30	1,70	2,04	2,75
40	1,68	2,02	2,70
60	1,67	2,00	2,66
100	1,66	1,98	2,63
Infinite	1,64	1,96	2,58

[a] In general, the number of terms in a sum minus the number of constraints on the terms of the sum (GUM).

A.6 Evaluation of Type-B uncertainty

A.6.1 General

When there is no access to a continuous stream of measured data or if a large set of measurements is not available, then the type-B method of estimation is used to:

a) assign a probability distribution to the measurement process to represent the probability of the true value being represented by any single measured value,

b) define upper and lower bounds of the measurement, and then

c) determine a standard uncertainty from a standard deviation implied by the assigned probability distribution.

The Type-B methods allow estimates of upper and lower bounding values to be used to derive the equivalent standard deviation.

Four probability distributions are described in the GUM and in A.6.2 to A.6.5.

A.6.2 The triangular distribution

The triangular distribution is represented in Figure A.4.

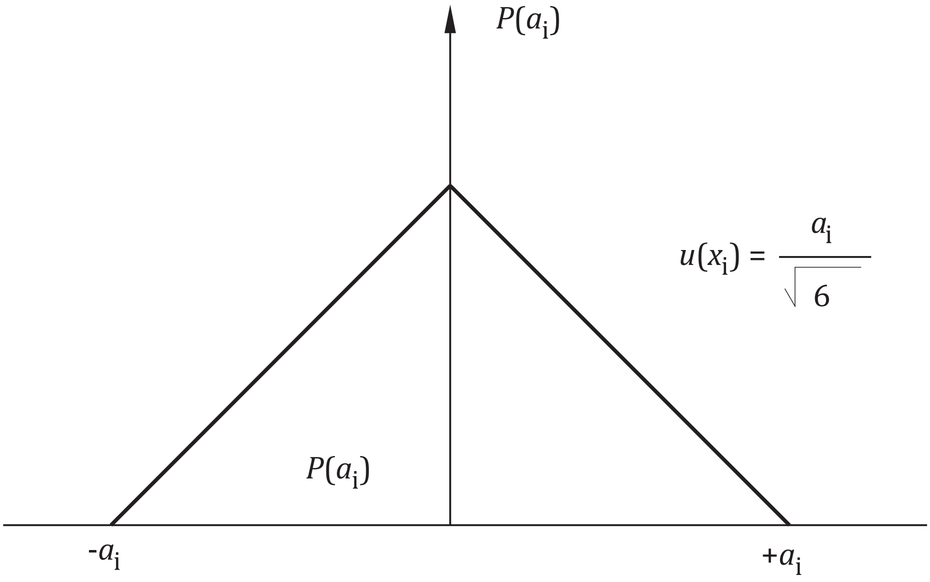


Figure A.4 — The triangular distribution

$$u(a_{\text{mean}}) = \frac{1}{\sqrt{6}} \frac{(a_{\max} - a_{\min})}{2} \tag{A.4}$$

This usually applies to manual measurements where the mean value is most likely to be closer to the true value than others between the discernible upper and lower limits of the measurement.

A.6.3 The rectangular distribution

The rectangular distribution is represented in Figure A.5.

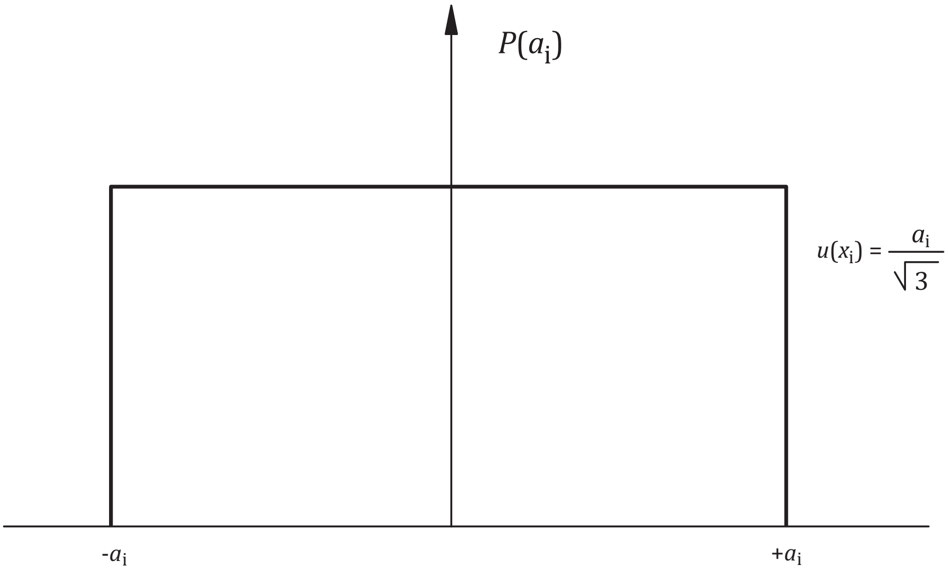


Figure A.5 — The rectangular distribution

$$u(a_{\mathrm{mean}}) = \frac{1}{\sqrt{3}} \frac{(a_{\mathrm{max}} - a_{\mathrm{min}})}{2} \tag{A.5}$$

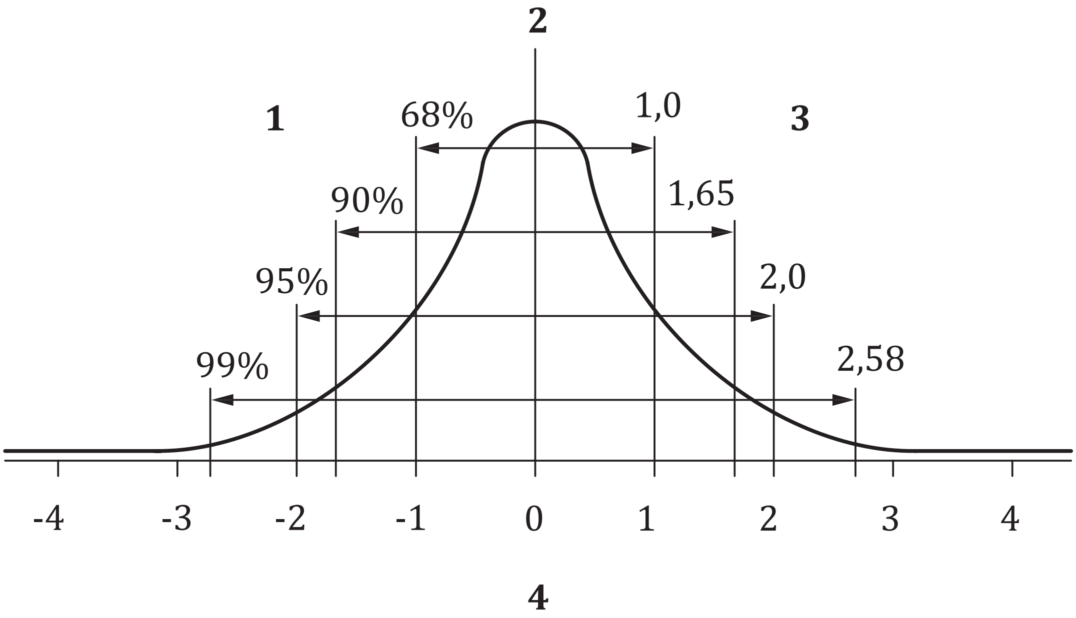
This probability distribution is usually applied to the resolution limit of the measurement instrumentation (i.e. the displayed resolution or the resolution of internal analogue/digital converters).

However, this is not the only source of uncertainty of measurement equipment. There may be uncertainty arising from the measurement algorithm used and/or from the calibration process.

If the equipment measures relative values, then there will also be uncertainty in the determination of its datum.

A.6.4 The normal probability distribution

The normal probability distribution is represented in Figure A.6.



Key

1 percent of readings in bandwidth
2 probability
3 coverage factor
4 standard deviations

Figure A.6 — The normal probability distribution

$$u(x_{\mathrm{mean}}) = \frac{u(\mathrm{specified})}{k} \tag{A.6}$$

where k is the coverage factor applying to the specified uncertainty value.

These are uncertainty statements based on “off-line” statistical analysis, usually as part of a calibration process where they have been derived using a Type-A process. When expressed as standard uncertainty, the uncertainty value is to be used directly with an equivalent coverage factor of $k = 1$.

A.6.5 The bimodal probability distribution

The bimodal probability distribution is represented in Figure A.7.

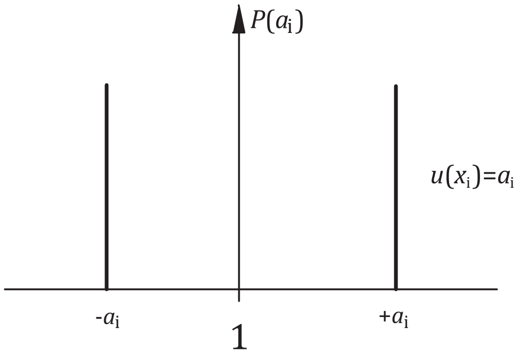


Figure A.7 — The bimodal probability distribution

$$u(a_{mean}) = \frac{(a_{\max} - a_{\min})}{2} \tag{A.7}$$

Measurement equipment with hysteresis can only exhibit values at the upper and lower bounds of the measurement.

An example of this is the float mechanism where friction and surface tension combine to cause the float to move in finite steps.

A.7 Combined uncertainty value, u_c

For most measurement systems, a measurement result is derived from several variables. For example, flow measurement, Q, in a rectangular channel can be expressed as a function of independent variables:

$$Q = b \times h \times \bar{V} \tag{A.8}$$

where

b is the channel width;

h is the depth of water in the channel;

$\bar{V}$ is the mean velocity.

These three components are measured independently and combined to determine a value for Q.

Just as b, h and $\bar{V}$ are combined to determine the value Q, so each component of uncertainty shall be combined to determine a value for $u_c(Q)$. This is done by evaluating the sensitivity of Q to small change, Δ, in b, h or V. Thus:

$$\Delta Q = \frac{\partial Q}{\partial b}\Delta b + \frac{\partial Q}{\partial h}\Delta h + \frac{\partial Q}{\partial \bar{V}}\Delta \bar{V} \tag{A.9}$$

where the partial differentials, $\frac{\partial Q}{\partial b}$, $\frac{\partial Q}{\partial h}$ and $\frac{\partial Q}{\partial \bar{V}}$ are sensitivity coefficients. For the formula $Q = b \times h \times \bar{V}$, this is equal to:

$$\frac{\Delta Q}{Q} = \frac{\Delta b}{b} + \frac{\Delta h}{h} + \frac{\Delta \bar{V}}{\bar{V}} \tag{A.10}$$

In uncertainty analysis, the values $\frac{\Delta Q}{Q}$, $\frac{\Delta b}{b}$, $\frac{\Delta h}{h}$ and $\frac{\Delta \bar{V}}{\bar{V}}$ correspond to dimensionless standard uncertainties. They are given the notation $u_c{}^*(Q)$, $u^*(b)$, $u^*(h)$ and $u^*(\bar{V})$.

Since the uncertainties of b, V and h are independent of each other, probability considerations require summation in quadrature.

$$u_c^*(Q) \cong \sqrt{u^*\left(\bar{V}\right)^2 + u^*\left(b\right)^2 + u^*\left(h\right)^2} \tag{A.11}$$

Annex B
(informative)

Performance guide for hydrometric equipment for use in technical standards

For guidance on the origins and use of Table B.1, reference should be made to ISO/TS 25377.

Table B.1 — Performance guide for hydrometric equipment for use in technical standard examples

Measurement technologies		**Comment**	**Symbol**			**NORMS OF MEASUREMENT PERFORMANCE FOR USE IN WORKED EXAMPLES** **Installed equipment to have corresponding values certified by manufacturer**									
				Uncertainty options		**Nominal rating of the measurement equipment**					**Corresponding measurement uncertainty** **(68 % confidence level)**				
Velocity (continuous)				A[d]	B	Minimum	25 %	50 %	75 %	Maximum	Minimum	25 %	50 %	75 %	Max.
Point Velocity	Propeller	Calibration certificate	*u(V)*	YES	Rectangular	0,080 m/s	0,750 m/s	1,50 m/s	2,250 m/s	3,000 m/s	0,000 5 m/s	0,010 m/s	0,022 m/s	0,030 m/s	0,040 m/s
	Electro-magnetic	Calibration certificate	*u(V)*	YES	Rectangular	0,080 m/s	0,750 m/s	1,550 m/s	2,250 m/s	3,000 m/s	0,0005 m/s	0,010 m/s	0,018 m/s	0,025 m/s	0,025 m/s
Path velocity	Transit time ultrasonics	Sonic velocity Path angle	*u(V)*	YES	Rectangular	0,030 m/s	0,250 m/s	0,250 m/s	0,750 m/s	1,000 m/s	0,003 m/s	0,005 m/s	0,007 m/s	0,007 m/s	0,010 m/s
	Ultrasonic Doppler	Particle-dependent low velocity resolution	*u(V)*	YES	Rectangular	0,030 m/s	0,250 m/s	0,250 m/s	0,750 m/s	1,000 m/s	0,003 m/s	0,005 m/s	0,007 m/s	0,007 m/s	0,010 m/s
	Echo correlation	Particle-dependent	*u(V)*	YES	Rectangular	0,030 m/s	0,250 m/s	0,250 m/s	0,750 m/s	1,000 m/s	0,003 m/s	0,005 m/s	0,007 m/s	0,007 m/s	0,010 m/s
Section velocity	Electro-magnetic	To be calibrated *in situ*	*u(V)*		Rectangular	0,030 m/s	0,250 m/s	0,250 m/s	0,750 m/s	1,000 m/s	0,003 m/s	0,005 m/s	0,007 m/s	0,007 m/s	0,010 m/s
Water level (continuous)[a]															
Relative datum (to be applied to all methods)		Manual process	*u(E)*		Triangular or Rectangular	Not applicable	0,500 m	1,000 m	1,500 m	2,000 m	0,001 m	0,001 m	0,001 5 m	0,001 5 m	0,001 5 m

Table B.1 *(continued)*

Measurement technologies		**Comment**	**Symbol**			**NORMS OF MEASUREMENT PERFORMANCE FOR USE IN WORKED EXAMPLES** **Installed equipment to have corresponding values certified by manufacturer**									
				Uncertainty options		**Nominal rating of the measurement equipment**					**Corresponding measurement uncertainty** **(68 % confidence level)**				
Velocity (continuous)				A[d]	B	Minimum	25 %	50 %	75 %	Maximum	Minimum	25 %	50 %	75 %	Max.
In-contact methods	Encoder/ float system[b]	Requires regular maintenance	$u(R)$		Bimodal	applicable	extension 1,250 m	extension 2,500 m	extension 3,750 m	extension 5,000 m	0,001 5 m	0,002 0 m	0,002 0 m	0,002 5 m	0,002 5 m
	Pressure transducer	Datum value drift	$u(h_1)$		Rectangular	0,010 m	0,500 m	1,000 m	1,500 m	2,000 m	0,002 m	0,002 m	0,002 5 m	0,002 5 m	0,003 0 m
	Ultrasonic	Surface wave effects	$u(h_1)$	YES	Rectangular	0,050 m	0,500 m	1,000 m	1,500 m	2,000 m	0,001 m	0,001 m	0,001 5 m	0,001 5 m	0,001 5 m
Non-contact methods	Air-ranging ultrasonic[b]	Surface wave effects Air temperature[c]	$u(R)$	YES	Rectangular	Range 0,300 m	Range 1,250 m	Range 2,500 m	Range 3,750 m	Range 5,000 m	0,002 m	0,004 m	0,010 m	0,025 m	0,060 m
	Pulse echo radar	Surface wave effects	$u(R)$		Rectangular	Range 0,300 m	Range 1,250 m	Range 2,500 m	Range 3,750 m	Range 5,000 m	0,002 m	0,004 m	0,010 m	0,025 m	0,060 m
Cross-section profile (distance measurement)															
	Natural channels	Sonar or dip gauging / GPRS (General Packet Radio Services) or tracking	$u(B)$		Rectangular	0,500 m	5,000 m	10,000 m	15,000 m	20,000 m	0,002 m	0,020 m	0,060 m	0,100 m	0,200 m
	Man-made channels	Manual measurement	$u(B)$		Triangular or rectangular	Not applicable	0,500 m	1,000 m	1,500 m	2,000 m	0,001 m	0,001 m	0,001 5 m	0,001 5 m	0,001 5 m

Table B.1 *(continued)*

Measurement technologies	Comment	Symbol			NORMS OF MEASUREMENT PERFORMANCE FOR USE IN WORKED EXAMPLES Installed equipment to have corresponding values certified by manufacturer									
			Uncertainty options		Nominal rating of the measurement equipment					Corresponding measurement uncertainty (68 % confidence level)				
Velocity (continuous)			A[d]	B	Minimum	25 %	50 %	75 %	Maximum	Minimum	25 %	50 %	75 %	Max.

Many of the values presented in this table are provisional. They are intended to be norms of performance for the technology. Values are to be defined by consensus between users and should be representative of the broad range of equipment available. A formal testing programme may be required to establish the table entries.

[a] Percentage uncertainty for head measurement cannot be specified by the equipment manufacturer. It shall be derived from a relationship of the form $u^*(h) = \sqrt{\frac{u(E)^2 + u(h_1)^2}{h}}$ where $u(E)$ is the uncertainty of the relative datum.

[b] $u^*(h) = \sqrt{\frac{u(E)^2 + u(R)^2}{h}}$ where $u(R)$ is the uncertainty of the range/extension.

[c] The performance figures assume precise compensation for the effects of temperature on sonic velocity. This formula is a practical approximation:

$\text{sonic velocity} = 20,08\sqrt{\text{absolute temperature of air}}$.

[d] If the unsteady conditions exist, a time-dependent component of uncertainty shall be defined. Instrumentation without this capability shall require a manufacturer's statement of uncertainty relating to unsteady conditions.

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[3] ISO 3846, *Hydrometry — Open channel flow measurement using rectangular broad-crested weirs*

[4] ISO 4359, *Flow measurement structures — Rectangular, trapezoidal and U-shaped flumes*

[5] ISO 4360, *Hydrometry — Open channel flow measurement using triangular profile weirs*

[6] ISO 4374, *Liquid flow measurement in open channels — Round-nose horizontal broad-crested weirs*

[7] ISO 4377, *Hydrometric determinations — Flow measurement in open channels using structures — Flat-V weirs*

[8] ISO 8333, *Liquid flow measurement in open channels by weirs and flumes — V-shaped broad-crested weirs*

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