International Standard

ISO 19234

Hydrometry — Low cost baffles to aid fish passage on triangular profile gauging weirs

Hydrométrie — Chicanes à faible coût pour faciliter le passage des poissons par les déversoirs à profil triangulaire

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Foreword

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The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular, the different approval criteria needed for the different types of ISO document should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see www.iso.org/directives).

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For an explanation of the voluntary nature of standards, the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the World Trade Organization (WTO) principles in the Technical Barriers to Trade (TBT), see www.iso.org/iso/foreword.html.

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

This first edition cancels and replaces (ISO/TR 19234:2016), which has been technically revised.

The main changes are as follows:

— this document has been restructured;

— low-cost baffles on flat-V weirs have been included.

Any feedback or questions on this document should be directed to the user's national standards body. A complete listing of these bodies can be found at www.iso.org/members.html.

Introduction

Flow gauging structures such as triangular profile weirs are commonly used for the measurement of open channel flows. This document applies to weirs operating under modular flow conditions, with flow passing through critical depth. To operate under these conditions, such weirs require a sufficient head difference to be generated between upstream and downstream. At structures operating in the modular flow range, flow rate is solely a function of the upstream head.

In recent years, greater emphasis has been placed on environmental issues, including the free migration of fish in watercourses. It is acknowledged that the head drop required to achieve modular flow can inhibit the movement of fish. It has become important, therefore, to consider ways of aiding fish migration without significantly affecting flow measurement accuracy.

Applied research has shown that baffles of suitable form and placement on the downstream face of triangular profile weirs can partially mitigate fish passage impacts while retaining the gauging function.

NOTE The coefficient of discharge of the weir would normally remain the same although it is an option to recalibrate the coefficient to take into account the placement of baffles.

The baffle system described in this document was adapted from an optimal solution for aiding fish passage[1][2] on non-gauging sloping weirs commonly used for other purposes (e.g. abstraction, flow diversion, power generation, navigation).

The following Excel[1)] spreadsheet tools can be used to design the layout of the baffles according to this document:

— Crump weir spreadsheet (LCB placement sheet for Crump weirs 2023.xlsm);

— Flat-V weir spreadsheet (LCB placement sheet for flat-V weirs 2023.xlsx).

The spreadsheet tools are available at: https://standards.iso.org/iso/19234//ed-1/en/

1) Excel is the trademark of a product supplied by Microsoft. This information is given for the convenience of users of this document and does not constitute an endorsement by ISO of the product named. Equivalent products may be used if they can be shown to lead to the same results.

Hydrometry — Low cost baffles to aid fish passage on triangular profile gauging weirs

1 Scope

This document specifies how to integrate baffles to aid the passage of fish on the downstream face of triangular profile weirs that conform to ISO 4360 (including Crump weirs) and ISO 4377 (flat-V weirs).

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 772, *Hydrometry — Vocabulary and symbols*

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

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

3 Terms and definitions

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

ISO and IEC maintain terminology databases for use in standardization at the following addresses:

— ISO Online browsing platform: available at https://www.iso.org/obp

— IEC Electropedia: available at https://www.electropedia.org/

3.1
anguillid
eel and lamprey
long and cylindrical body-shaped species including eel (*Anguilla anguilla*) and lamprey *(Lampetra fluviatillis* and *Petromizon marinus*)

3.2
non-migratory salmonid
fish of the family Salmonidae that migrates solely in freshwater including brown trout (*Salmo trutta*) and grayling (*Thymallus thymallus*)

3.3
coarse fish
non-salmonid fish found in freshwater habitats

3.4
Crump weir
weir with a triangular profile in the streamwise direction and a horizontal crest in the transverse direction used for gauging

Note 1 to entry: This weir was named after the inventor E.S. Crump. The upstream slope is 1:2 and downstream slope is 1:5 (see ISO 4360).

3.5
anadromous
living and migrating between the sea and freshwater

3.6
flat-V weir
triangular profile weir (3.15) with a transverse V-shaped crest used for gauging

Note 1 to entry: The upstream slope is 1:2 and downstream slope is 1:5 (parallel to the centreline). The cross-slopes can be between 1:10 and 1:40 (see ISO 4377).

3.7
low-cost baffle
LCB
low-cost deflector attached to the downstream face of the structure to aid fish passage

Note 1 to entry: These are low-cost baffles in comparison to having to incorporate a formal fish pass in a gauging weir.

Note 2 to entry: These are perpendicular to the downstream slope of the weir. The geometry of the baffle is precisely described in Figure 4.

3.8
migratory salmonid
fish of the family Salmonidae that migrates between the sea and fresh water including salmon (*Salmo salar*) and sea trout (*Salmo trutta*)

3.9
modular flow
flow that is independent of variations in tailwater level

3.10
plunging flow
flow passing an obstruction that is directed towards the floor and defined as

$$H_2/H_1 \leq 0{,}50$$

where

H_1 is the depth of water on the upstream side of baffle relative to the base of the baffle;

H_2 is the depth of water on the downstream side of baffle relative to the base of the baffle.

Note 1 to entry: Unstable flow conditions can occur for ratios of H_2/H_1 between 0,51 to 0,59.

3.11
potamodromous
living and migrating solely in freshwater

3.12
reflection
change in direction of the position of the gaps in the baffles

3.13
streaming flow
flow passing an obstruction that remains at or near the surface and defined as

$$H_2/H_1 \geq 0{,}60$$

where

H_1 is the depth of water on the upstream side of baffle relative to the base of the baffle;

H_2 is the depth of water on the downstream side of baffle relative to the base of the baffle.

Note 1 to entry: Unstable flow conditions can occur for ratios of H_2/H_1 between 0,51 to 0,59.

3.14
structural head difference
SHD
difference in elevation (in metres) between the invert (lowest level) of the crest of the *triangular profile weir* (3.15) and the downstream water surface at a flow exceeded 95 % of the time

Note 1 to entry: See Figure 3 an illustration of structural head difference.

3.15
triangular profile weir
weir with a triangular profile in the streamwise direction

Note 1 to entry: This includes *Crump weirs* (3.6) and *flat-V weirs* (3.8).

3.16
V_{full}
flow that just fills the whole width of a flat-V weir at the crest

4 Symbols

a	baffle width	m
b	breadth of the weir crest perpendicular to the flow direction	m
c	gap offset distance immediately downstream from the reflection (see Figure 6)	m
d	distance between baffles, centre to centre along the slope (see Figure 6) (a * suffix indicates the dimension in plan view)	m
d_L	intermediate variable used in the Crump weir spreadsheet for calculating cutting lengths for the baffles – left-hand-side baffle	—
d_R	intermediate variable used in Crump weir spreadsheet for calculating cutting lengths for the baffles – right-hand-side baffle	—
f	offset distance between the position of gaps in successive baffles (see Figure 6)	m
h	gauged head relative to the crest elevation (upstream head is implied if no subscript is used); for flat-V weirs, the crest elevation is taken from the invert of the V	m
H	total head, energy head, relative to crest elevation; for flat-V weirs, the crest elevation is taken from the invert of the V	m
H_1	depth of water on the upstream side of baffle relative to the base of the baffle	m
H_2	depth of water on the downstream side of baffle relative to the base of the baffle	m
L	for Crump weirs, this is the distance from the crest to the base of the upstream face of the first baffle along the slope (in plane view); for flat-V weirs, this distance is the smallest distance to the base of the upstream face of the first baffle (see Figures 6 and 7 for clarity) (a * suffix indicates the dimension in plan view)	m

L_1	distance from the crest to the centre of the first baffle along the slope (only relevant to Crump weirs)	m
L_2	rounded up value of L_1 (only relevant to Crump weirs)	m
L_a	maximum apron length	m
p	height of the weir crest above the upstream bed level	m
q	gap width	m
Q_{nn}	flow that is exceeded for *nn* % of the time	m^3/s
R	radius	mm
T	height of the first baffle	m
T_s	height of subsequent baffles used in the Crump weir spreadsheet	m
V_{full}	flow that fills the whole width of the flat-V weir at the crest	m^3/s
z_L	intermediate variable used in the Crump weir spreadsheet to determine local coordinates (left-hand-side) for determining the gap location	—
z_R	intermediate variable used in the Crump weir spreadsheet to determine local coordinates (right-hand-side) for determining the gap location	—
Δ_x	axis in the direction of the flow (perpendicular to the crest) used in the Crump weir spreadsheet	—
Δ_y	axis in the direction perpendicular to the face of the crest (vertical upwards) used in the Crump weir spreadsheet	—
Δ_z	axis in the direction along the crest used in the Crump weir spreadsheet	—

5 Principles

5.1 General principles

Baffles are placed in horizontal parallel rows on the downstream sloping face of the weir. There is a gap in each row of baffles that runs at an angle progressively across and down the weir face. This forms an oblique flow path that can be reflected from side to side in narrower channels forming a V-shaped pattern in plan view (as shown in Figures 1 and 2). The baffles retard flow, maintain a consistent depth of water, and substantially reduce the acceleration of the water on the downstream face of the weir. The oblique flow path formed by the gaps provides a passage route for fish with greater flow depth and lower velocities than over the baffles. The baffles also spread the dissipation of flow energy over the length of the downstream slope of the weir, creating a series of small hydraulic jumps and reducing the intensity of a final hydraulic jump at the junction with the tailwater pool.

The solution creates conditions that fish can exploit to find passage over a wide range of flows. Fish can exploit the low velocity flow path, or, when flow tops the baffles, they can swim straight up the slope, taking advantage of the lower velocities created by the baffles. However, if the top baffle is too close to the weir crest, it can affect gauging performance.

For the application of this document, users shall either apply ISO 4360 (including Crump weirs) or ISO 4377 (flat-V weirs).

5.2 Crump weirs — Structures that conform to ISO 4360

Baffles are placed in rows that are parallel to the crest on the downstream sloping face of the weir. See Figure 1.

a) Baffles in the dry (viewed from upstream during construction)

b) Baffles in operation before maintenance has been carried out (viewed from upstream)

NOTE The figure shows Jessops Weir on the River Asker, Dorset, United Kingdom.

Figure 1 — Crump weir

Although the weir in Figure 1 is a Crump weir, it no longer has a gauging function. Therefore, the first baffle has been placed closer to the crest than this document allows. The downstream slope of this crest is sufficiently long for more than one reflection and the flow path of the water where the gaps are located is evident when the baffles are in operation.

The distance from the weir crest to the upstream side of the first baffle is of critical importance. The distance to the first baffle is determined by the range of flow rates for which modular flow is required at the gauge. The distance can be determined by using the low-cost baffle placement tool. The spreadsheet tool is available at: https://standards.iso.org/iso/19234//ed-1/en/

The baffle solution was tested in a laboratory with structures that operate up to a maximum head of 0,49 m at field scale. The dimensions and location of the baffles are determined (see Figure 6) so that they do not reduce the coefficient of discharge of the weir by more than 1 %[3][4].

5.3 Flat-V weirs — Structures that conform to ISO 4377

Baffles are placed in parallel rows on the downstream sloping face of the flat-V weir, along the contours of the weir so that each baffle top is level in the horizontal plane. There are gaps in each row of baffles that run at an angle progressively across and down the weir face. This oblique flow path can be reflected from side to side (see Figure 2).

a) Bird's eye view (including installation of a most downstream baffle to take truncation into account)

b) Downstream view of weir showing baffles in operation

NOTE Figure 2 a) shows Lea Bridge Weir, on the River Cuckmere, East Sussex, United Kingdom. Figure 2 b) shows Isfield Gauging Station on the River Uck, East Sussex, United Kingdom.

Figure 2 — Flat-V weir

The distance between the weir crest and the base of the first baffle downstream of the crest is of critical importance, and for flat-V weirs this is fixed (refer to Figure 7 and Table 5). It is fixed at 918 mm measured downslope from the crest (900 mm measured in plan) for a flow range up to V_{full}.

The recommended arrangement of baffles has a single central gap in the most upstream baffle and symmetrical gaps on either side of the weir centre in ensuing baffles. In the case of flat-V weirs, all gaps are set at 250 mm except for the upstream central gap (see Figure 7 and Table 5).

The development of an appropriate baffle solution for these weirs was based on computational fluid dynamics, laboratory investigations and field observations. Comparisons were made between the coefficients of discharge obtained up to a maximum head of 0,3 m at field scale with various baffle arrangements and those of the plain flat-V weir, for head over the weir up to the highest level of the V crest. The configuration (in Figure 7 and Table 5) was shown to be suitable from both fish and hydrometric viewpoints. The spreadsheet tool is available at: https://standards.iso.org/iso/19234//ed-1/en/

The dimensions and location of the baffles are determined in such a manner so that they do not reduce the coefficient of discharge of the flat-V weir by more than 1,6 %.

There are additional benefits of baffles on flat-V weirs. They prevent flow convergence on the weir by straightening the flow, and they also mitigate the formation of large eddies that would otherwise be formed downstream of the weir. These features, in themselves, can otherwise confuse fish migrating upstream and significantly reduce or prevent their ability to pass such structures.

5.4 Suitability for fish species

The baffle system was initially developed for Crump-like weirs with the objective of providing an effective aid to fish passage at sites where there are high velocities and shallow flows. These conditions are typically found on sloping weirs, such as triangular profile style weirs, where they frequently compromise or prevent passage by fish. For weirs where gauging is not required, the size of the first baffle is smaller and can be placed such that the first and second baffle are level with the crest. Therefore, the distance of the first baffle to the crest is closer than that being required in this document for active gauging weirs. The baffle concept was further developed to include flat-V weirs.

The baffles aid passage for a wide range of species and sizes of fish by attenuating velocity, increasing water depth on the weir, and providing a low velocity streaming flow access route across and up the weir face for smaller fish. Streaming flow is more conducive than plunging flow for fish passage. Evidence suggests that many of the species of fish living in rivers can exploit the baffles to gain passage where otherwise it would be difficult or impossible. They do this in different ways. Smaller species and individuals exploit the low velocity flow path through the gaps in the baffles and larger fish tend to swim over the baffles when there is sufficient depth of water.

Powerful swimming fish that include anadromous fish such as salmon (*Salmo salar*) and sea trout (*Salmo trutta*), as well as weaker swimming potamodromous fish which include brown trout (*Salmo trutta*), grayling (*Thymallus thymallus*) and coarse fish, have been shown to pass over weirs using this type of baffle installation on Crump weirs. It is anticipated that similar hydraulic conditions generated on a flat-V weir will also improve the passage of fish in the same manner.

Adult migratory salmonids, including sea trout as small as 290 mm and salmon as large as 1 200 mm, have been shown by video observation to successfully pass over a non-gauging Crump-like weir (1:5 slope) 2,8 m high that was previously impassable[5]. In this case, because Jessop's Weir (River Asker, Dorset, United Kingdom) was a non-gauging weir, the first two baffles are level with the crest. The first baffle is 120 mm in height and 600 mm from the crest and the second baffle is 200 mm in height and 1 000 mm from the crest.

At the other end of the fish size scale, brown trout of 80 mm to 298 mm have demonstrated passage efficiencies of 67 % in one year and 82 % in the next year over a 1,60 m high, 1:4,2 sloping weir that was previously impassable[6]. A 50 % probability of passage (P50) was attained by brown trout at a length of 113 mm, and a 90 % probability of passage (P90) by fish at a length of 222 mm on this non-gauging Crump-like weir retrofitted with low-cost baffles. At the site (Swanside Beck, Yorkshire, United Kingdom), the first and second baffle are level with the crest. These efficiencies were also attained despite the last baffle and the downstream end of the weir being elevated above the downstream water level which would make it more difficult for fish to pass.

Trials at Brimpton Gauging Weir (River Enborne, Berkshire, United Kingdom) with potamodromous coarse fish have indicated that a range of species and sizes of fish have successfully used baffles retrofitted to Crump gauging weirs. At this site which has a 0,7 m head drop over a 1:5 sloping Crump weir[7], chub (213 mm to 489 mm), dace (*Leuciscus leuciscus*, 198 mm to 206 mm) and roach (*Rutilus rutilus,* 240 mm to 244 mm) successfully passed low-cost baffles at efficiencies of 54 %, 33 % and 50 %, respectively. At Trent at Stoke-on-Trent Gauging Station (River Trent, Staffordshire, United Kingdom) with a head drop of 0,56 m, 1:5 slope, and also retrofitted with baffles[8], chub (*Leuciscus cephalus,* 225 mm to 400 mm), dace (145 mm to 280 mm) and roach (145 mm to 290 mm) passed at efficiencies of 56 %, 57 % and 66 %, respectively. At the same site, brown trout (210 mm to 400 mm) passed at an efficiency of 81 %. It should be noted that the near crest baffle was a smaller baffle (120 mm) and further from the crest (1 220 mm) than this document would require.

At Eshton Beck (Yorkshire, United Kingdom), a thin plate gauging station[9] with a compound sloping weir face (3,09 m at 1:9, 4,05 m at 1:51) and with a head drop of 0,59 m, the use of an LCB significantly improved passage efficiency of brown trout (156 mm – 269 mm) by at least 27 % from 64 % to 91 %. It also significantly reduced delay at and time of passage over the obstruction, and it increased the range of flows over which fish passed the weir. The smallest fish that passed (156 mm) ascended on ten occasions, demonstrating the ease of passage provided by the baffles.

The expectation is that most species of coarse fish living in rivers, and certainly most of those above 200 mm in length, are capable of taking advantage of retrofitted baffles to facilitate passage. An exception is possibly perch (*Perca fluviatillis*), for which the limited evidence at Brimpton and Trent at Stoke-on-Trent Gauging Stations sites suggests that they were not successful.

There is currently no evidence to show that smaller species and/or weak swimmers such as loach (*Misgurnus anguillicaudatus),* minnows (*Phoxinus phoxinus*), bullhead (*Cottus gobio*), brook lamprey (*Lampetra planeri*) and small eels *(Anguilla anguilla)* (<300 mm) can make use of an LCB modified weir. Additional facilities can cater for these species but are not addressed in this document.

Fish need to make a considerable effort to pass obstructions and can be at risk of developing an oxygen debt at structures such as sloping weirs, even with baffles to aid passage. Successful passage also depends on the approach conditions being satisfactory and benign so that fish can approach the area of the obstruction with little effort using a sustainable swimming speed, thus saving energy for passage.

6 Installation — General considerations

6.1 Site selection and application

The baffle application described in this document shall be restricted for use on triangular profile flow gauging weirs as set out in ISO 4360 and ISO 4377 on weirs with a 1:5 downslope (20 %, 11,3°).

The technique was originally developed to improve fish passage on non-gauging sloping weirs and also addressed gradients up to 1:4 (25 %, 14,0°). The methodology has been adapted for triangular profile weirs where active gauging continues to be the priority.

Baffles can be fitted to both single and compound triangular profile weirs. In the case of compound structures, the baffles are normally fitted to the lowest weir structure. Where there are two lower weir structures at the same level, consideration should be given to using the structure that has better access for maintenance and/or is least likely to be affected by debris. The hydraulic downstream conditions as a result of installing the baffles shall be taken into consideration.

A preliminary survey shall be made of the physical and hydraulic features of the site, to check that it conforms (or can be made to conform) to the requirements necessary for baffle installation.

Particular attention should be paid to the following features for gauging weirs (see Figure 3):

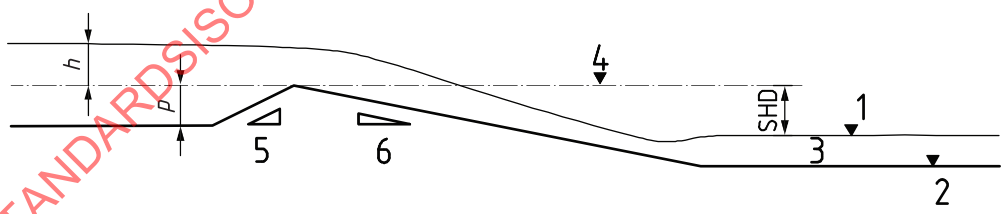
a) The downstream slope is confirmed as being nominally 1:5.

b) The concrete face of the slope should be smooth and in good condition without signs of erosion damage, cracking or leaks.

c) Knowledge of the location and depth of reinforcement bars in the concrete, if present, is required.

d) Where the downstream face is truncated and forms a vertical drop to the downstream stilling basin or river bed, additional works can be required to extend the downstream slope to achieve the appropriate baffle layout.

e) A truncated weir (for hydrometric purposes) may be used downstream of the last baffle where salmonids are the only species present. Where other species are present, the downslope shall continue to the floor from the stilling basin, but may be at a maximum slope of 1:2 beyond the last baffle.



Key

1 downstream water level at Q_{95}
2 downstream bed level
3 stilling basin
4 crest level
5 1:2 slope
6 1:5 slope

Figure 3 — Sketch illustrating the definition of structural head difference

In order to provide suitable approach conditions for fish, a minimum depth and a maximum velocity of water should be provided (see Table 1) as follows.

— The mean approach velocity in the downstream stilling basin or natural river channel shall be no more than the velocity given in Table 1 at Q_{10} for migratory salmonids; Q_{20} for non-migratory salmonids and coarse fish; and Q_{70} for anguillids.

— Where present, the stilling basin shall be a minimum of 3,0 m in length downstream from any truncation or from the bottom of the weir slope.

— Where present, the elevation of the stilling basin should ensure that there is a minimum depth of 0,3 m of water present. In some circumstances, the stilling basin floor may be below the downstream bed level.

— Where no stilling basin is present, there should be a minimum depth of 0,3 m for 3 m distance immediately downstream from any truncation, or from the bottom of the weir slope, and the water velocities should not exceed those given in Table 1.

Table 1 — Maximum acceptable mean approach velocities downstream of the weir for different fish groups

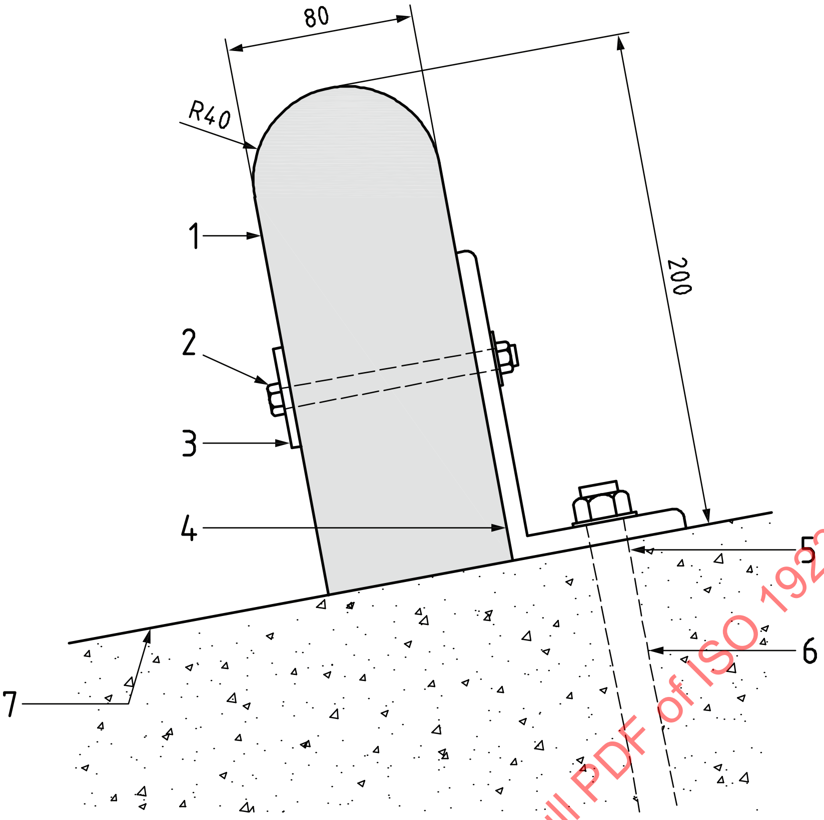
Fish groups	Mean approach velocity in stilling basin m/s
Migratory salmonids	1,0
Non-migratory salmonids	0,7
Coarse fish	0,5
Anguillids	0,3

If the site does not possess the characteristics necessary for satisfactory installation, the site shall be rejected unless suitable practical improvements can achieve those characteristics. In such cases, a conventional fish pass solution can be used.

6.2 Baffle dimensions

The principal baffle dimensions are shown in Figure 4. All baffles shall conform to these dimensions with a tolerance of ±4 mm. All baffles should be 0,20 m high and 0,08 m thick.

The tops of the baffles and the ends of the baffles in any gaps shall be rounded to ensure smooth flow lines and to protect fish.



Key

1 baffle

2 M8 bolt with nut and oversized washer at 300 mm centres

3 40 mm × 4 mm thick galvanised steel plate with elongated holes

4 galvanized steel 125 mm × 65 mm × 8 mm "L" shaped bracket with 18 mm diameter holes for stud fixings

5 hole drilled into existing concrete weir face for chemical resin anchors

6 M16 galvanized studding resin anchor (300 mm long) fixed with a washer and nut at 750 mm apart (end distances 250 mm max.)

7 concrete slope assumed to be in good condition and not in need of any refurbishment, checks required for location of reinforcement bars

Figure 4 — Baffle dimensions and typical fixing arrangements

6.3 Baffle material and construction

An engineering assessment of structural integrity of the weir shall be made to ensure that it is able to support the baffle installation. When fixing the baffles on the weir, interaction with existing reinforcement shall be avoided.

Baffles can be made from hardwood, stainless steel or recycled plastic. The advantage of recycled plastic is that it is robust, waterproof and, once a mould has been fabricated, it is cheap to produce and the baffles are of a consistent quality and dimensions.

Figure 4 shows a typical proven method of fixing the baffles in place by bolting to a suitable steel angle. The angle is normally installed on the upstream side but can be installed on the downstream side of the baffle if required (e.g. to avoid the reinforcement bars). The unit is fixed to the concrete using a suitable anchor bolt. The angle and the bolts shall be of appropriate durability and strength. For example, stainless steel fixings are typically used.

A basic tenet of this system providing a low-cost solution is that there is no need to keep returning to the site to make repairs to the structure and therefore it is important to ensure that the baffles and the mode of fitting are robust.

Any spaces underneath the baffles and at the ends next to the wingwall shall be minimized or filled to prevent leakage.

6.4 Limitations for baffle installations

The following limitations apply:

a) Baffles should not be used on rivers with high levels of large size bed load material.

b) Baffle resilience can be a limitation on rivers that carry high levels of large and/or aggressive bed load material that can damage the baffles and/or cause erosion damage of the concrete weir face leading to them being undermined.

c) Debris material such as trees can catch on [as seen in Figure 1 b)], damage or break the baffles with the consequence of affecting the performance of the structure by changing the discharge coefficient.

d) There is no limit to the maximum width of the weir that baffles can be installed on. However, safe access for maintenance can be a problem on wide structures.

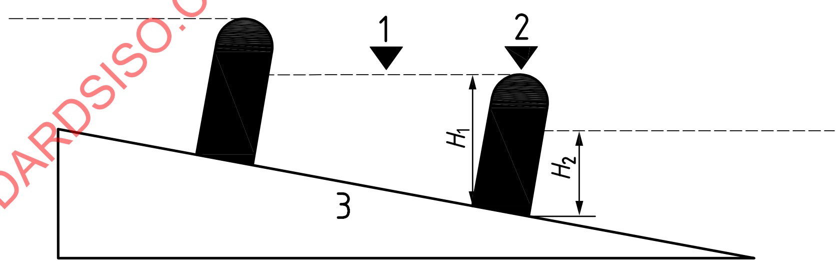
e) While water levels upstream can increase as a result of the added hydraulic roughness of the baffles when operating beyond the designed modular range, this increase is expected to be negligible due to the short length of the downstream face. This is considered not to be of concern from a flooding point of view, but the rating curve of the weir should be checked and recalibrated if needed.

f) Figure 5 shows a visual representation of the definition of H_1 and H_2. The baffle dimensions used on a gauging station are all 0,2 m high and 0,08 m thick (see Figure 4).

g) The water level on the downstream side of the most downstream baffle shall be such that streaming flow occurs in the free gap (for 0,2 m high baffles, this means 0,12 m of water, i.e. $H_2/H_1 \geq 0{,}60$) at Q_{95} exceedance flow (see Figure 5).

h) Maximum SHD values before mitigation using low-cost baffles are given in Table 2.

In addition to these points, there are additional limitations for Crump weirs (see 7.3) and flat-V weirs (see 8.3) that shall be taken into consideration when installing low-cost baffle systems.



Key

1 water level

2 baffle

3 1:5 slope

Figure 5 — Measurements H_1 and H_2

Table 2 — Maximum structural head difference limits before mitigation is recommended

Fish groups	Maximum SHD at Crump weirs m	Maximum SHD at flat-V weirs m
Migratory salmonids	0,5	0,3
Non-migratory salmonids	0,4	0,25
Coarse fish	0,3	0,2

7 Installation at Crump weir — Weirs that conform to ISO 4360

7.1 General baffle arrangements for Crump weirs

This clause describes what is visually shown as the layout for the baffles on the face of the Crump weir (see Figure 6). A worked example is given in Table 3.

The distance (*L*) along the slope to the front face of the first baffle is set in accordance with Formulae (1) and (2) in 7.2. This is based on the maximum head for which modular flow is required. Thereafter, baffles are set at 0,4 m centres (*d*), i.e. 0,32 m from the back face of the upstream baffle to the front face of the next downstream baffle.

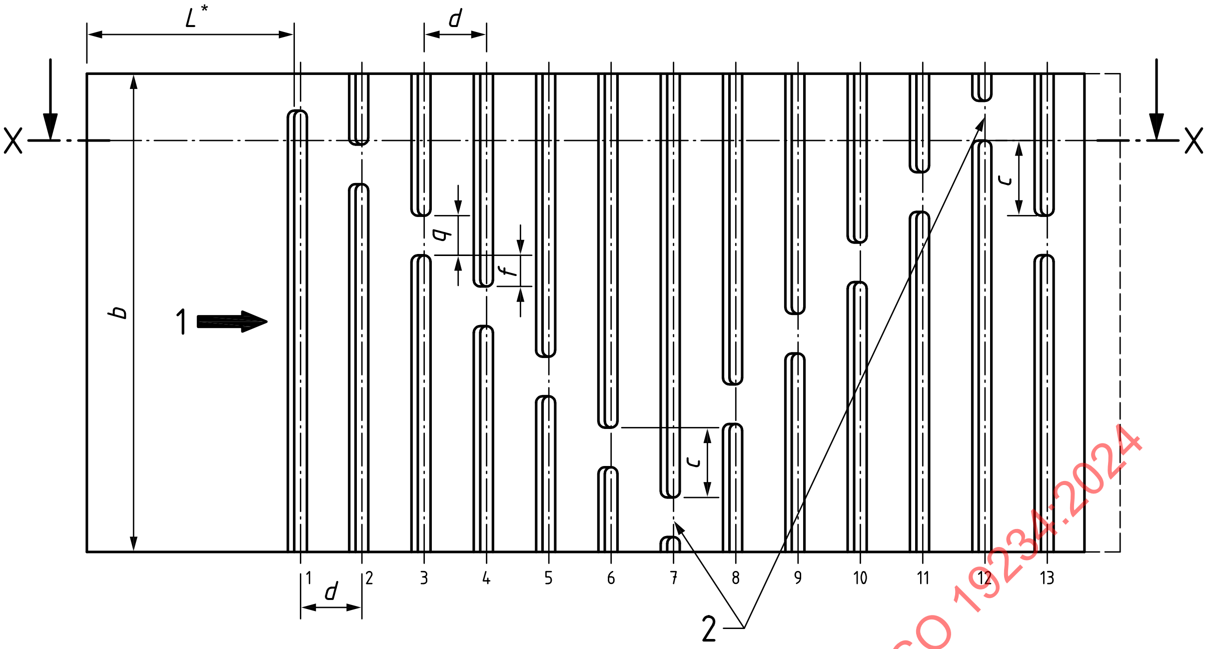
The free gap (*q*) in the baffles is set at the appropriate value, which is 0,25 m for coarse fish, trout and grayling, and 0,3 m for migratory salmonids. The gap at the first and most upstream baffle is set next to either wingwall to enable fish to have the best chance of escaping upstream once out of the direct influence of the baffles. This is because the lowest water velocities are against the wall of the gauge where friction creates a lower velocity boundary stream.

At each successive baffle, the free gap is off-set by a distance (*f*) of 0,2 m in order to create the low velocity oblique flow path across the weir face for smaller individual fish to exploit. The distance of the off-set (*f*) remains the same whether the free gap is set at either 0,25 m or 0,3 m.

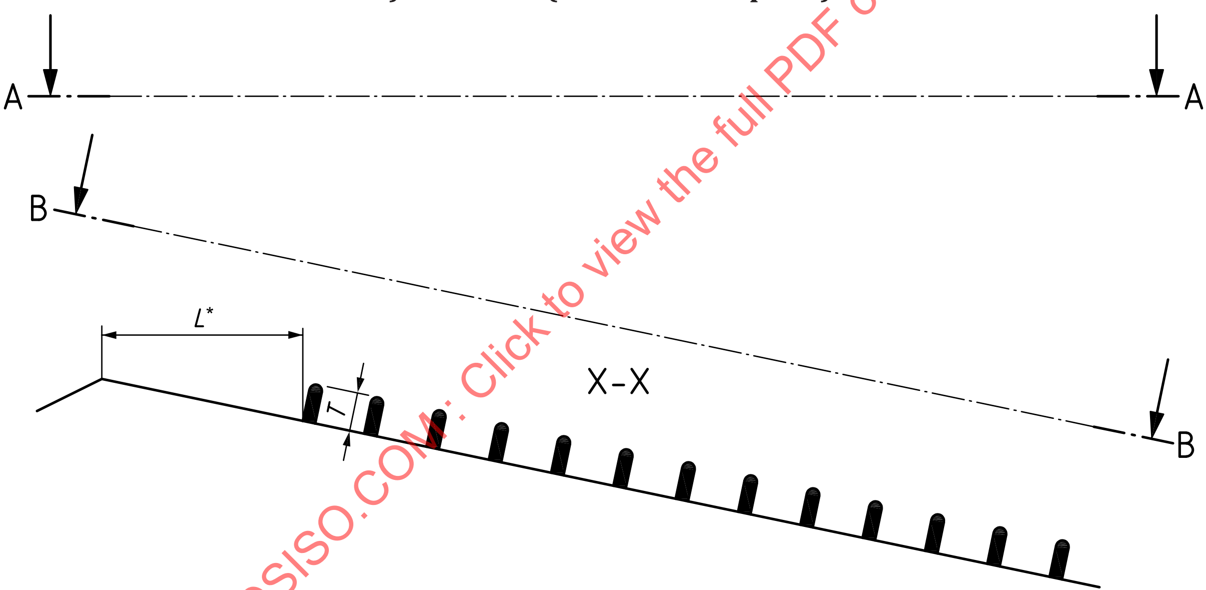
Where the weir has sufficient crest length, i.e. is wide enough, the oblique flow path of free gaps may form one continuous route diagonally across the downstream weir face. The downstream entry point for fish into the low velocity flow path changes with rising river discharge and downstream water level.

Where the weir is not wide enough, the low velocity flow path may be reflected to create a V or W pattern across the slope (one reflection or multiple reflections). At points of reflection, an offset distance (*c*) of 0,48 m (coarse fish) or 0,53 m (migratory salmonids) to the edge of the gap in the next baffle downstream shall be introduced to avoid any “short-circuiting” of the stream flow over the baffles that can occur due to alignment of the gaps in the baffles upstream and downstream from the turning point.

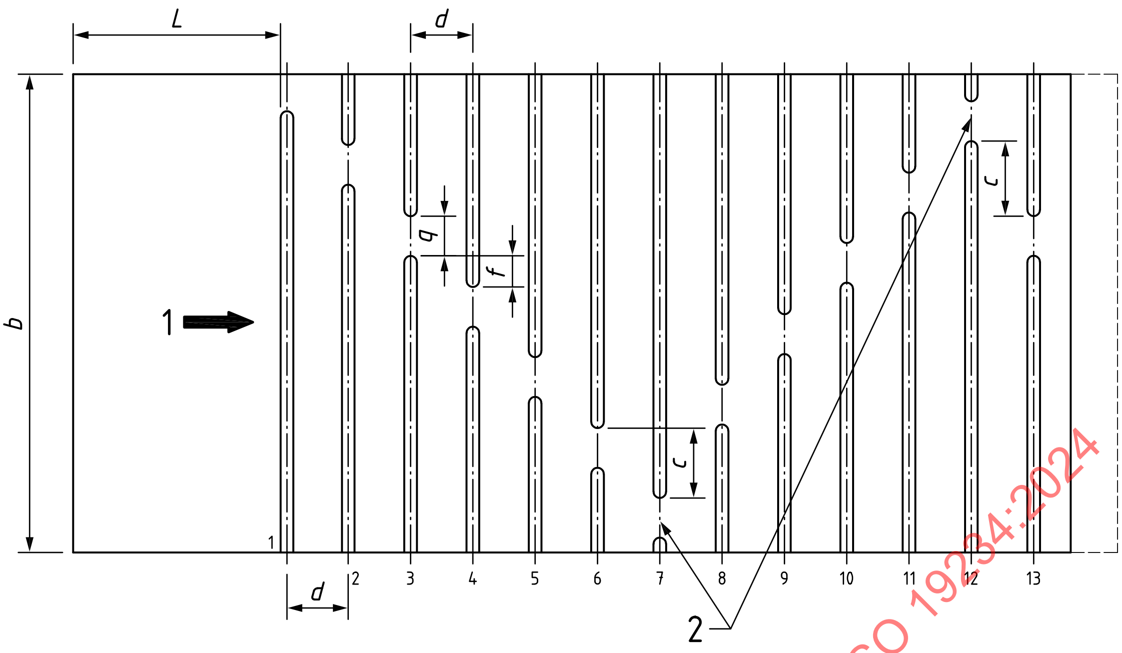
The most downstream baffle is set so that there is a minimum depth of 0,12 m of water on the downstream side of the baffle at a low river discharge equivalent to Q_{95} exceedance, inducing and ensuring a streaming flow ($H_2/H_1 \geq 0{,}60$) through the free gap that acts as an entrance to the low velocity path for the fish. It is unnecessary to provide further baffles beyond this point since they would unnecessarily obstruct the approach to the low velocity path. The baffle arrangement design can be automated by use of the associated spreadsheet tool.



a) Plan view (from A-A viewpoint)



b) Longitudinal section X-X



c) Plane view of arrangement (i.e. parallel to the slope of B-B)

Key

1 flow direction

2 gap

Figure 6 — Crump weir — General arrangement of the baffles

Table 3 — Worked example using the Crump weir tool[a] to illustrate *L* and *d* in plan and plane view with given *h*, *p*, *q*, *b* dimensions

	L mm	*d* mm
Section A-A: dimension in plan	1,296	392
Section B-B: dimension along slope	1,322	400
NOTE Assumptions: h = 500 mm, p = 300 mm, q = 250 mm, b = 4,000 mm an apron length of 10 400 mm.		
[a] https://standards.iso.org/iso/19234//ed-1/en/.		

Within the guidelines in this section, there is some flexibility that can be introduced to the location of the downstream entrance gap by choosing where the reflection occurs, or to which side the most upstream gap is located.

7.2 Location of the first baffle on Crump weirs

A critical dimension for the low-cost baffle design is the distance from the crest of the weir to the first baffle on the downstream slope of the weir. The location shall be close to the crest to minimize velocities during the final stages of fish ascent, but shall also be far enough away that it does not impact the modular flow condition over the triangular profile weir.

Field experience[7] to date has been based on a baffle height of 0,2 m, with the first baffle set no more than 1,24 m downstream from the crest (i.e. crest to baffle face; this is 1,24 m measured along the slope), allowing modular flow for upstream heads (at field scale) up to 0,49 m. Setting the first baffle further downstream than this allows for larger modular flow ranges, but can reduce fish passage efficiency.

Laboratory studies were undertaken to study the relationship between the coefficient of discharge and the size and position of the first baffle relative to the upstream head[3].

Three inter-related variables (as defined in Reference [3]) are considered:

— the total head over the weir up to which accurate modular flow performance is required, H;

NOTE H is not to be confused with H_1 and H_2 (see Figure 5) which are used to define the conditions in the free gap shown as y (in Figure 6).

— distance from the crest line to the front face of the first baffle measured along the slope, L;

— size (height) of the first baffle, T.

The three independent variables all have dimensions of length. The degree to which the baffles affect the coefficient of discharge is presented in terms of the two non-dimensional variables H/L and H/T. Formulae 1 and 2 were developed as part of the laboratory study. They defined the distance from the crest to the first baffle that would cause a reduction of no more than 1 % in the coefficient of discharge for a triangular profile weir.

$$H/L = 0{,}001\,0\,(H/T)^2 - 0{,}002\,6\,H/T + 0{,}417\,9 \qquad (1)$$

At small values of H, it is possible for the crest level of the baffle calculated from Formula (1) to approach and exceed the level of the weir crest. These conditions were not tested in the laboratory and are clearly unacceptable because the flow control can transfer from the weir to the baffle. Formula (2) limits the crest level of the baffle to be below the crest level of the weir:

$$H/L = 0{,}166\,7H/T \qquad (2)$$

Or simplified as Formula (3):

$$L = 6T \qquad (3)$$

Formulae (1) and (2) are dimensionless and apply to any baffle height (T). However, considering work undertaken by References [1], [2] and [7], only 0,2 m high baffles should be used on gauging weirs.

7.3 Limitations for baffle installations on Crump weirs

The following limitations can apply.

a) The maximum SHD across a structure successfully employed to date in the United Kingdom is 2,8 m for migratory salmonids and 0,7 m for coarse fish. It is anticipated that coarse fish passage can be effective up to 1,5 m.

b) The structure should not be less than 1,5 m wide because the increase in uncertainty in the theoretical hydraulic rating becomes unacceptable. It is not practicable to use more than one reflection on weirs less than 3,0 m wide.

c) There are limitations on the width of the structure together with maximum allowable SHD. Guidance is provided in Table 4. The limitation is that only one reflection with 0,25 m or 0,30 m gaps is allowable on small structures. A reflection occurs where the oblique flow path meets, or comes close to meeting, a side-wall and has to turn back across the weir slope. There can be multiple reflections on larger weirs with long downstream slopes. Figure 6 illustrates the meaning of a reflection.

Table 4 — Weir width and structural head difference constraints for Crump weirs

Width of weir m	Maximum SHD m
1,5	0,64
2,0	0,64
3,0	0,96
4,0	1,28

d) A structure with a large modular flow range (experiencing modular flow at high upstream heads) requires the location of the first baffle to be set too far downstream from the crest to make it effective for fish passage. Field experience has shown that Crump weirs with modular flow range of up to 0,5 m of head are able to pass coarse fish with a moderate but acceptable level of efficiency. Higher heads (and associated higher velocities) make weirs less suitable for baffle installation where coarse fish are the target species for improving passage. There is little field experience where salmonids are the only target species, but it is expected that a modular flow range exceeding 0,5 m and up to 0,75 m may be considered for small salmonids (< 0,5 m in length), and up to 1,0 m may be considered for large migratory salmonids (> 0,5 m in length).

e) The gap width (q) should always be set equal to the value specified for the target species: −0,30 m for migratory salmonids or 0,25 m for other species. If the layout causes the gap to be too close to the sidewall or be reduced in width because it reaches the sidewall, then a reflection should be provided so that the desired gap width can be maintained.

f) The distance between the weir crest and the front face of the first baffle downstream of the crest is of critical importance (see Figure 6).

g) The stage at which the modular limit occurs will determine the distance from the crest to the first baffle. However, if the modular range is set too high, the first baffle can be set so far downstream that the target fish are not able to pass over the final section of low depth and high velocity flow.

h) The location of the baffles shall be determined in such a manner so that it does not affect the coefficient of discharge of the Crump weir by more than 1 %. The solution was tested in the laboratory with structures that operate up to a maximum head of 0,49 m at field scale.

8 Installation at flat-V weir — Weirs that conform to ISO 4377

8.1 General baffle arrangements for flat-V weirs

Figures 7 and 8 illustrate the arrangement of baffles on flat-V weirs.

The distance along the centreline slope from the front face of the first baffle to the crest shall be 0,9 m in plan and 0,918 m in the plane of the centreline slope. Thereafter, baffles shall be set at 0,4 m centres (as shown in Figure 8).

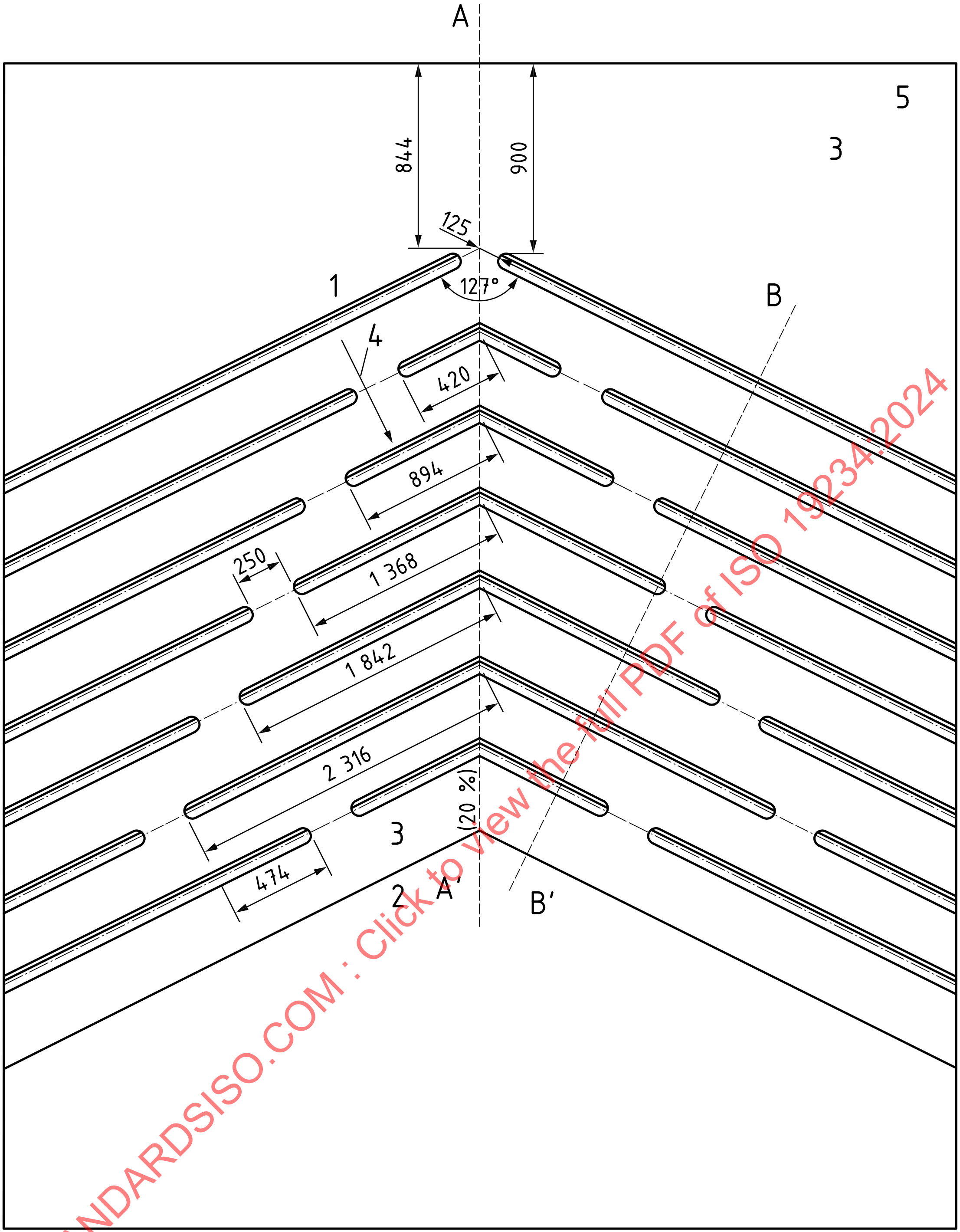
The free gap in the baffles is set at 0,25 m in the plane of the baffles regardless of the fish species groups. The gap at the first and most upstream baffle is set at the centre of the weir to ensure flow stability is maintained and sufficient depth of water during low flow. Due to the three-dimensional nature of the flat-V weir, describing the layout is more complicated than for the Crump weir. Figures 7 and 8 illustrate the arrangements, including the dimensions in both plan view and plane format.

At each successive baffle, the free gap is offset by a distance of 0,474 m to create a deeper, unobstructed oblique flow path across the weir face to serve smaller fish.

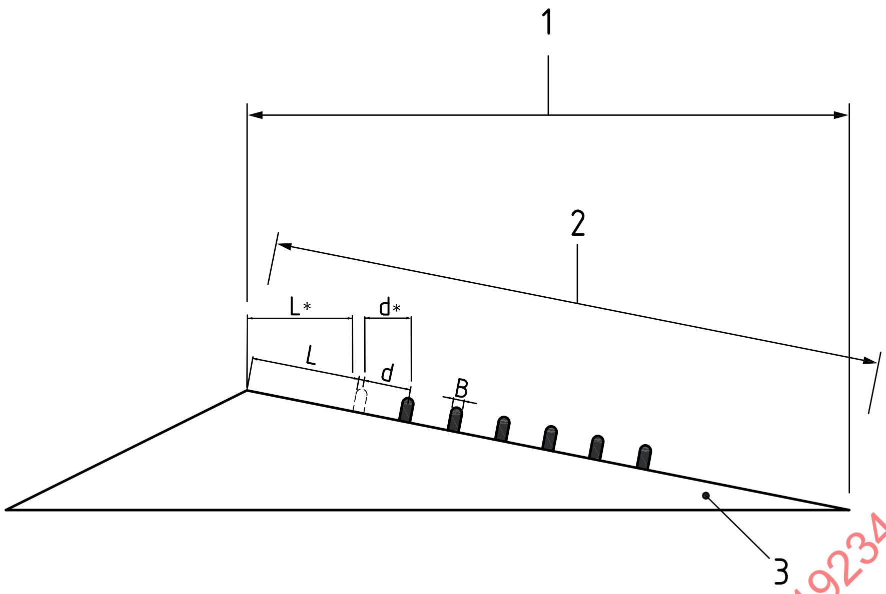
Where the weir has sufficient crest length, i.e. is wide enough, the oblique flow path of free gaps can form one continuous route diagonally across each side of the downstream weir face. The downstream entry points for fish into the low velocity flow path changes with rising river discharge and downstream water level.

Where the weir is not wide enough, the low velocity flow path may be reflected to create a V pattern across each slope. After a reflection, the gap is offset by an additional distance of 0,474 m to the edge of the gap in the next baffle downstream to avoid any “short-circuiting” of the stream flow over the baffles that can occur due to alignment of the gaps in the baffles upstream and downstream from the turning point.

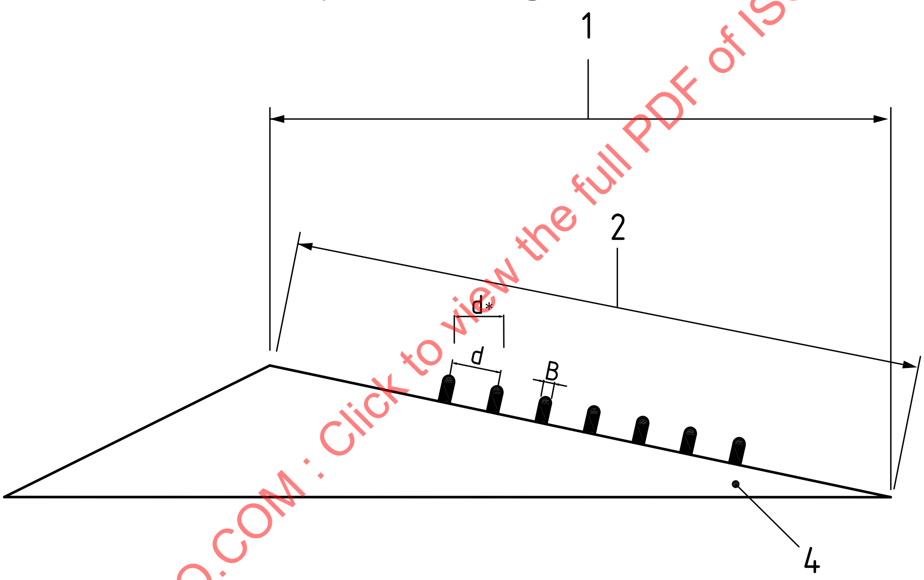
The most downstream baffle is set so that there is a minimum depth of 0,12 m of water on the downstream side of the baffle at a low river discharge equivalent to Q_{95} exceedance, ensuring a streaming flow (H_2/H_1 ≥ 0,60) through the free gap that acts as an entrance to the deeper path for the fish. It is unnecessary to provide further baffles beyond this point since they can obstruct the approach to the low velocity path. The baffle arrangement design can be automated by use of the associated spreadsheet tool.



a) Plan view



b) Section through A-A'



c) Section through B-B'

Key

1 plan view

2 plane view

3 1:5 slope

4 1:4, 47 slope

5 1:10 cross slope

Figure 7 — Flat-V weir baffle arrangement