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Hydrometry — Low cost baffle solution to aid fish passage at triangular profile weirs that conform to ISO 4360

Hydrométrie — Projet de chicane à faible coût pour faciliter le passage des poissons au niveau des déversoirs à profil triangulaire conformes à l'ISO 4360

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Contents

Page

Foreword

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

Introduction

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

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

Hydrometry — Low cost baffle solution to aid fish passage at triangular profile weirs that conform to ISO 4360

1 Scope

This document specifies the requirements for the integration of baffles on the downstream face of triangular profile flow measurement structures to aid the passage of fish.

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*

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 terminological databases for use in standardization at the following addresses:

- ISO Online browsing platform: available at http://www.iso.org/obp
- IEC Electropedia: available at http://www.electropedia.org/

3.1
diadromous fish
fish that migrate between fresh water and sea water to complete their life cycle

3.2
potamodromous fish
fish that migrate wholly within fresh water to complete their life cycle

3.3
baffle
wall or block attached to the downstream face of the structure to aid fish passage

3.4
aerobic swimming
<fish> sustainable swimming using red muscles, which incur no oxygen debt

3.5
anaerobic swimming
<fish> time limited swimming using white muscles, which incur oxygen debt

3.6
riverine species
fish species typically found in and adapted to a flowing water environment

3.7

structural head difference

SHD

difference in elevation between the crest of the triangular profile weir and the downstream water level at a flow equivalent to Q_{95} exceedance

Note 1 to entry: Q_{95} is the flow that is exceeded for 95 % of the time.

Note 2 to entry: See Figure 2.

3.8

streaming flow

flow which occurs when $H_2/H_1 \geq 0{,}60$, where

H_2 is the head on the downstream side of the baffle;

H_1 is the head on the upstream side of the baffle

3.9

plunging flow

flow which occurs when H_2/H_1 is less than 0,50, where

H_2 is the head on the downstream side of the baffle;

H_1 is the head on the upstream side of the baffle

Note 1 to entry: Values between 0,50 and 0,60 can be in hysteresis.

4 Symbols

Symbol	Term	Unit
b	Breadth of the weir crest perpendicular to the flow direction	m
h	Gauged head relative to the crest (upstream head is inferred if no subscript is used)	m
H	Total head relative to the crest level	m
H_1	Head on the upstream side of the baffle	m
H_2	Head on the downstream side of the baffle	m
L	Distance from the crest to the front of the first baffle	m
L_1	Distance from the crest to the centre of the first baffle	m
L_2	’Rounded up’ value of L_1	m
L_a	Maximum apron length	m
Q_{95}	Flow that is exceeded for 95 % of the time	$m^3 \cdot s^{-1}$
T	Height of the first baffle	m
Ts	Height of subsequent baffles	m
c	Slot offset distance immediately downstream from the reflection	m
d	Distance between baffles, centre to centre	m
p	Height of the weir crest above the upstream bed level	m
q	Slot width	m

[a] A spreadsheet tool associated with this document is used to design the layout of the baffles in accordance with this document. A link to the spreadsheet is given. http://standards.iso.org/iso/tr/19234

When opening the spreadsheet, be sure to click on the “Enable Macros “dialogue box.

Symbol	Term	Unit
f	Offset distance between the position of slots in successive baffles	m
SHD	Crest level above Q_{95} downstream water level	m
zL	Intermediate variable used in the spreadsheet[a] to determine local coordinates (left hand side) for determining the slot location	
zR	Intermediate variable used in the spreadsheet[a] to determine local coordinates (right hand side) for determining the slot location	
dL	Intermediate variable used in the spreadsheet[a] for calculating cutting lengths for the baffles – left hand side baffle	
dR	Intermediate variable used in spreadsheet[a] for calculating cutting lengths for the baffles – right hand side baffle	

[a] A spreadsheet tool associated with this document is used to design the layout of the baffles in accordance with this document. A link to the spreadsheet is given. http://standards.iso.org/iso/tr/19234

When opening the spreadsheet, be sure to click on the “Enable Macros “dialogue box.

5 Principles

Baffles are placed in parallel rows on the downstream sloping face of a triangular profile weir. There is a slot in each row of baffles that runs at an angle progressively across and down the weir face. This oblique channel can be reflected from side to side in narrower channels forming a V-shaped pattern in plan view, see Figures 1 and 3. The baffles retard flow, maintain a consistent depth of water, and prevent water velocities increasing down the weir. The oblique channel formed by the slots provides a passage route with greater flow depth and lower velocities than over the baffles. The baffles also break the often significant hydraulic jump that typically occurs down the face of weir and moves it further up the weir face where its intensity is greatly reduced.

The solution creates conditions that fish are able to exploit to find passage over a wide range of flows. Fish may exploit the low velocity channel or, when flow tops the baffles, they may swim straight up the slope, taking advantage of the retarded velocity flows created by the baffles.

The difference in elevation between the invert of the weir crest and the top of the first baffle downstream is of critical importance. The dimensions and location should be determined in such a manner that it does not affect the coefficient of discharge of the triangular profile weir by more than 1 %. The range of level measurement of the gauge will determine the distance of the first baffle downstream from the crest. However if the range is set too high, the first baffle will be set so far downstream that fish will not be able to pass over the final section of low depth and high velocity flow. The solution was tested in the laboratory with structures that operate up to a maximum head of 0,49 m at field scale. It is recommended that the first baffle should not be set any further downstream than a distance equivalent to a maximum head of 0,49 m.

a) Baffles installed on a weir shown under dry conditions

b) Flow condition on a weir with baffles under running condition

Figure 1 — Examples of baffle installations on triangular profile weirs

6 Installation

6.1 Site selection and application

6.1.1 Restriction

The baffle application is restricted to the use

- on two dimensional triangular profile flow gauging weirs as set out in ISO 4360;
- on weirs with a downslope 1:5 (Vertical: Horizontal) (20 % gradient in percentage or 11,31 degrees slope with horizontal).

6.1.2 Background

The technique was originally developed to improve fish passage on triangular profile gauging weirs but also addressed gradients up to 1:4 (25 %, 14 degrees) 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.

6.1.3 Preliminary survey

A preliminary survey should 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.

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

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

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

d) The mean approach velocity in the downstream stilling basin or natural river channel should be no more than those given in Table 1 at Q_{10} for migratory salmonids; Q_{20} for brown trout, grayling, and coarse fish; and Q_{70} for eels.

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

f) Where present, the stilling basin should have a minimum depth of 0,3 m below tail river bed level.

g) 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 (d) above.

h) Where the downstream face is truncated and forms a vertical drop to the downstream stilling basin or river bed, additional works may be required to extend the downstream slope to achieve the appropriate baffle layout [see (i) below].

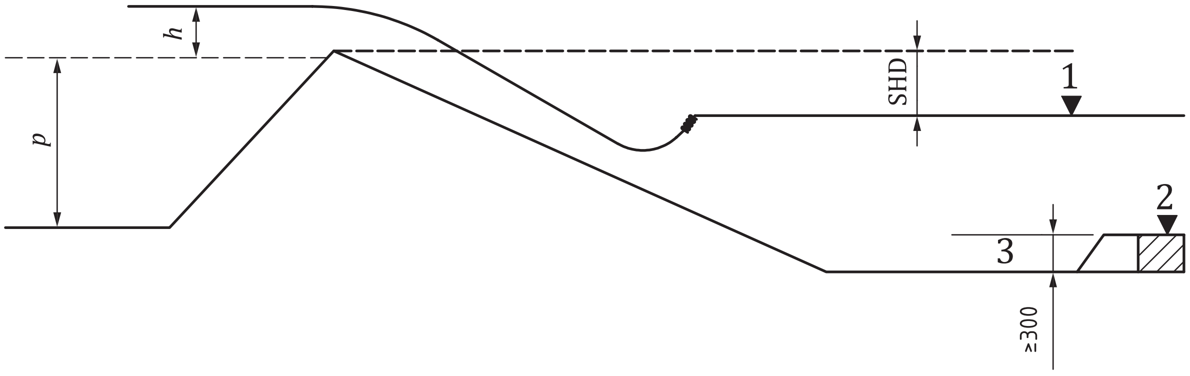
i) A truncated weir (for hydrometric purposes) may be used downstream of the last baffle where salmonids are the only species present. Where other species are present, the downslope should continue to the floor from the stilling basin, but may be at a maximum slope of 1:2 beyond the last baffle.

j) The water level on the downstream side of the most downstream low cost baffle should be such that streaming flow occurs in the free slot (for 0,2 m baffles this means 0,12 m of water, i.e. $H_2/H_1 \geq 0{,}60$) at Q_{95} exceedance.

Table 1 — Maximum acceptable mean approach velocities in the stilling basin for different fish species

	Migratory salmonids	Brown trout and graylings	Coarse fish	Eels
Mean approach velocity in stilling basin, m/s	1,0	0,7	0,5	0,3

If the site does not possess the characteristics necessary for satisfactory installation, the site should be rejected unless suitable improvements are practicable to achieve those characteristics.



Key

1 downstream water level at Q_{95}

2 downstream bed level

3 stilling basin

Figure 2 — Sketch illustrating the definition of structural head difference (SHD)

6.1.4 Limitations

a) Baffles are not recommended to be used on rivers with high levels of large size bed load material. Baffle resilience may be a limitation on rivers that carry high levels of large and aggressive bed load material, for example large cobbles, that might damage the baffles.

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

c) The maximum structural head difference (SHD) across a structure successfully employed to date is 2,8 m for migratory salmonids and 0,7 m for coarse fish. It is anticipated that coarse fish passage will be effective up to 1,5 m.

d) The structure should not be less than 1,5 m wide. Ideally the structure should not be less than. 3 m wide since the fish passage experience to date is based on structures not less than 3 m wide. It is not practicable to use more than one reflection on weirs less than 3 m wide.

e) There are limitations on the width of structure together with maximum allowable structural head difference (SHD). Guidance is provided in Table 2. The limitation is that only one reflection with 0,25 m or 0,3 m slots is allowable on small structures. A reflection occurs where the oblique channel meets, or comes close to meeting, a side-wall and turns back across the weir slope. There may be multiple reflections on larger weirs with long downstream slopes. Figure 3 indicates the meaning of a reflection.

Table 2 — Baffle width and structural head drop constraints

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

f) The slot width (*q*) should always be set equal to the value specified for the target species (250 mm or 300 mm). If the layout would cause the slot 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 slot width can be maintained.

g) 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 structures with modular flow range of up to 0,5 m are able to pass coarse fish species 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 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).

6.2 General arrangement

The baffles used on a gauging station are all 0,2 m high and 0,08 m thick, Figure 5. The distance *(L)* to the front face of the first baffle is set in accordance with Formulae (1) and (2) below. 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.

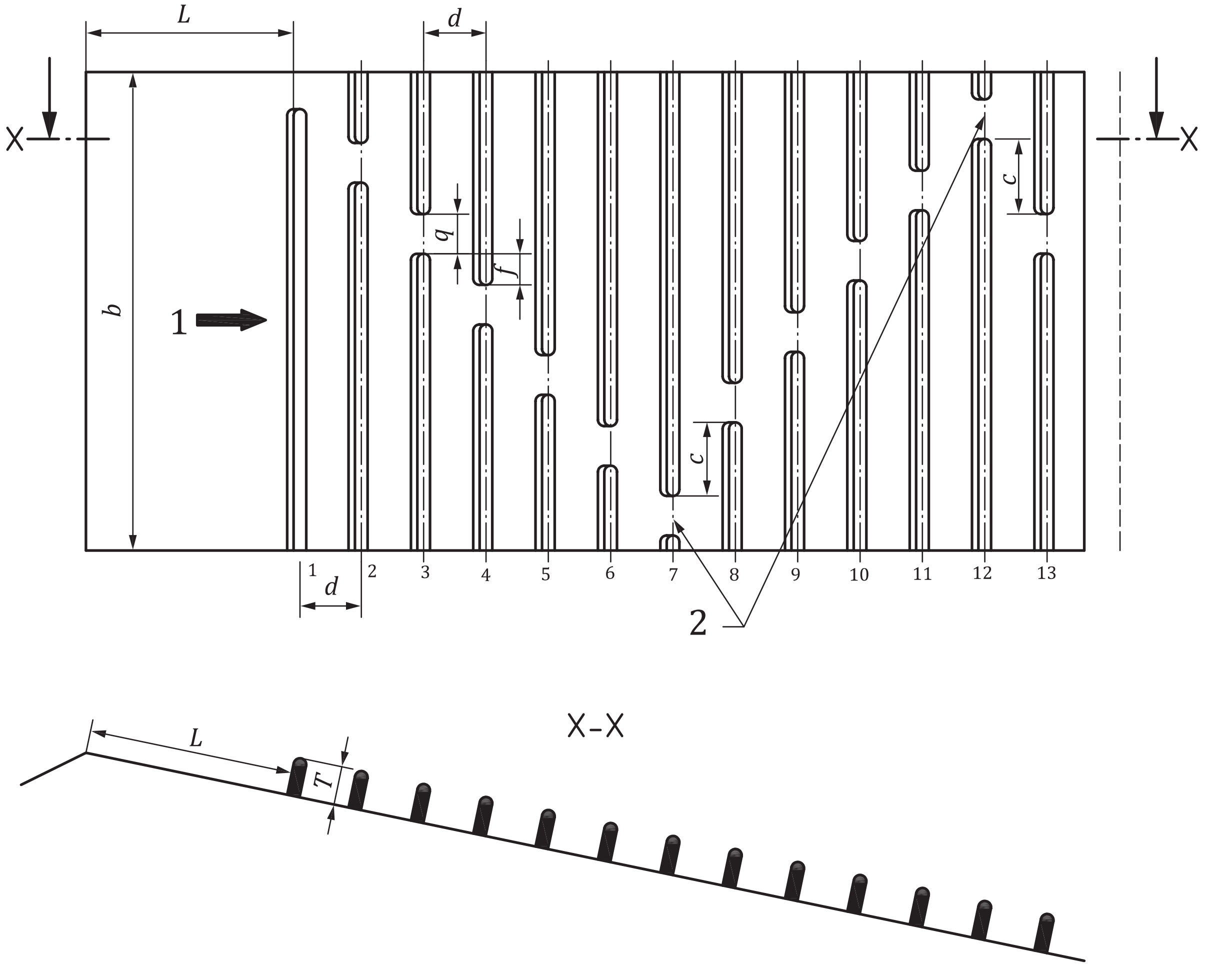
The free slot (q) in the baffles is set at the appropriate value, which is 0,25 m for coarse fish, trout and grayling, and 0,3 m for migratory salmonids. The slot at the first and most upstream baffle is set next to either wingwall to enable fish to have the best chance of escaping upstream once out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

At each successive baffle, the free slot is offset by a distance (f) of 0,2 m in order to create the low velocity oblique channel across the weir face for smaller individual fish to exploit. The distance of the off-set (f) remains the same whether the free slot width 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 channel of free slots may form one continuous channel diagonally across the downstream weir face. The downstream entry point for fish into the low velocity channel will change with rising river discharge and downstream water level.

Where the weir is not wide enough, the low velocity channel may be reflected to create a V or W pattern across the slope (one reflection or multiple reflections). At points of reflection, it is necessary to use an offset distance (c) of 0,48 m (coarse fish) or 0,53 m (migratory salmonids) to the edge of the slot in the next baffle downstream. This avoids any ‘short-circuiting’ of the stream flow over the baffles that might occur due to alignment of the slots in the baffles upstream and downstream from the turning point

The most downstream baffle is set so that there is a minimum water depth of 0,12 m 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 slot that acts as an entrance to the low velocity channel for the fish. It is unnecessary to provide further baffles beyond this point since they would unnecessarily obstruct the approach to the low velocity channel. The baffle arrangement design can be automated by use of the associated spreadsheet tool. See http://standards.iso.org/iso/tr/19234



Key

1 flow

2 reflection

Figure 3 — General arrangement of the baffles

6.3 Suitability for fish species

The baffle system was developed with the objective of providing a moderately effective aid to fish passage at sites where there are high velocities and shallow flows. These are typically found on sloping weirs, such as triangular profile style weirs that seriously compromise or prevent passage by fish.

The baffles aid passage for a wide range of species and sizes of fish by attenuating velocity increase, maintaining water depth on the weir, and providing a low velocity streaming flow access route across and up the weir face for smaller fish. Evidence suggests that many the riverine species of fish 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 channel through the slots in the baffles and larger fish swim over the baffles.

Powerful swimming fish that include diadromous species such as salmon and sea trout as well as potamodromous species that include trout have been shown to pass over weirs using baffle installations.

Migrating salmonids including sea trout as small as 290 mm and salmon up to 1 200 mm have been shown to successfully pass an otherwise impassable sloping weir (1:5 slope) 2,8 m high that was previously impassable. It has also been noted that salmonids and brown trout (around 150 mm to 300 mm) have successfully passed over a weir fitted with baffles that was previously impassable. Brown trout 80 mm to 298 mm were monitored passing a low cost baffle weir with 24 % gradient on the river Ribble River tributaries with up to 82 % efficiency. There was a 50 % probability of passage for brown trout at 113 mm, and 90 % probability of passage for brown trout at 222 mm [4].

Trials with potamodromous coarse fish species have indicated that a range of species and sizes of fish have successfully used baffles with a 0,7 m head drop over a triangular profile weir[5]. Chub (213 mm to 489 mm), dace (198 mm to 250 mm), and roach (175 mm to 290 mm) have all successfully passed low cost baffles at various efficiencies ranging from 33 % to 66 %, but generally more than 50 %. Brown trout (210 mm to 400 mm) have passed at an efficiency of more than 80 %. The expectation is that most species of riverine coarse fish, and certainly those above 200 mm in length, will be capable of using baffles to gain passage. An exception is for perch for which the limited evidence suggests that they were not successful.

There is currently no evidence to show that smaller species and/or weak swimmers such as loach, minnows, bullhead, brook lamprey, and small eels (< 300 mm) can make use of such a facility.

Fish may make a considerable effort to pass obstructions and will usually be at risk of developing an oxygen debt at structures such as sloping weirs, even with baffles to aid passage. Successful passage will also depend on the approach conditions being satisfactory and benign so that fish may approach the area of the obstruction with little effort using the aerobic swimming, as opposed to utilizing the energetic anaerobic swimming mode required to enable them to pass up over the obstruction.

6.4 Location of the first baffle

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 should be as close to the crest as possible in order to minimize velocities during the final stages of fish ascent, but should also be far enough away that it does not impact the modular flow condition over the triangular profile weir. Field experience to date has been based on a baffle height of 200 mm, with the first baffle set no more than 1,24 m downstream from the crest (i.e. crest to baffle centre), allowing modular flow for upstream heads up to 0,5 m. Setting the first baffle further downstream than this could allow larger modular flow ranges (higher heads), but may reduce fish passage efficiencies.

Laboratory studies were undertaken to establish the distance of the uppermost baffle from the crest as a function of upstream head and baffle size[8].

Three inter-related variables are considered:

- head over the weir up to which accurate modular flow performance is required, H;
- distance from the crest line to the front face of the first baffle, L;
- size (height) of the first baffle, T.

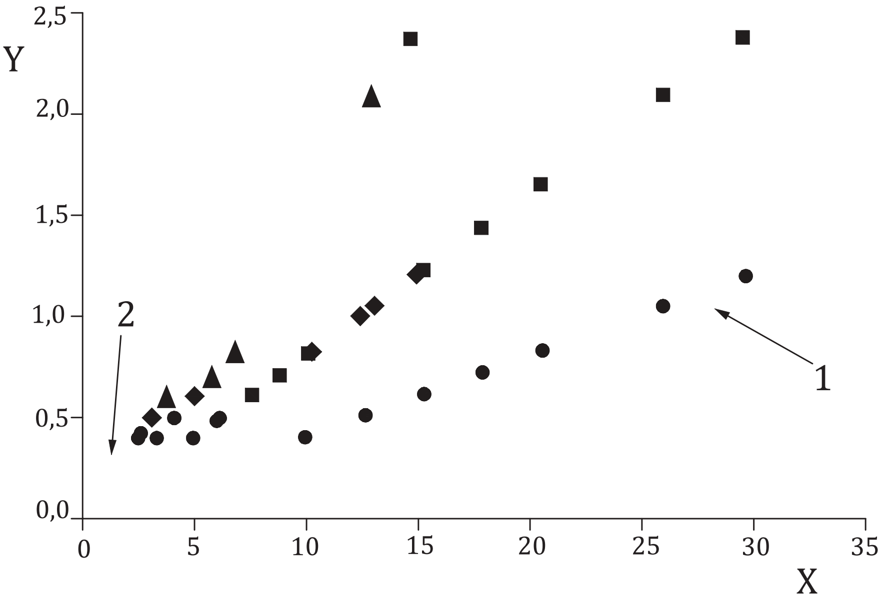
The three independent variables all have dimensions of length. The degree to which the baffles affect the coefficient of discharge is presented in terms of the two non-dimensional variables H/L and H/T, Figure 4. Formulae (1) and (2) were developed as part of the laboratory study. They define the distance from the crest to the first baffle that will cause a reduction of no greater than 1 % in the coefficient of discharge for a triangular profile weir. The first is a polynomial equation fitted to the laboratory results.

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

At low values of H/L and H/T, 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 inadmissible because the flow control would transfer from the weir to the baffle. The linear relationship shown in Formula (2) ensures that the crest level of the baffle is always below the crest level of the weir.

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

Setting the first baffle position using the two equations shown as lines (1) and (2) in Figure 3 will limit the change in the coefficient of discharge of the triangular profile weir to less than 1 %.



Key

X ratio of head over weir to height of first baffle H/T

Y ratio of head over weir to distance to first baffle H/L

● > 0,99

■ 0,98 to 0,99

◆ 0,97 to 0,98

▲ 0,96 to 0,97

0,95 to 0,96

0,94 to 0,95

0,93 to 0,94

NOTE Values shown in the key are observed multipliers on the modular coefficient of discharge. Formulae (1) and (2) are shown as solid lines [8].

Figure 4 — Hydrometric effects of near-crest baffles

Figure 4 shows dimensionless results, suggesting that any value of baffle height (T) could be used. However, considering work undertaken by Rhodes and Servais (2008)[6] and the results of field testing [5], it is recommended that only 200 mm high baffles be used.

6.5 Baffle dimensions

The principle baffle dimensions are shown in the drawing below in Figure 5. All baffles will conform to these dimensions with a tolerance of ± 4 mm. All baffles will be 0,2 m high (T), and 0,08 m thick.

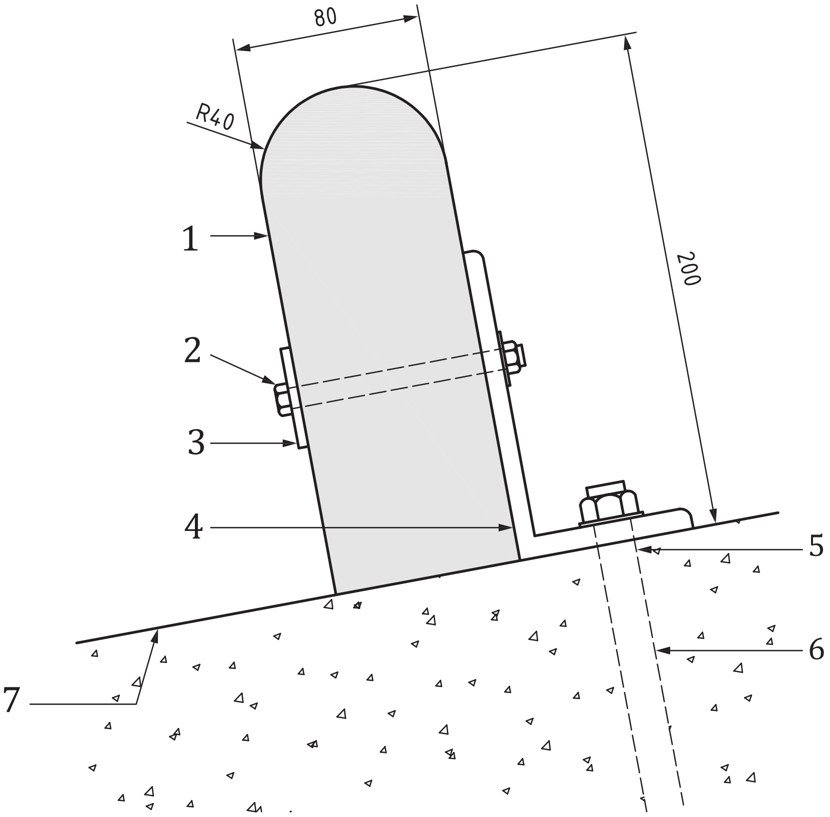
6.6 Baffle material and construction

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 5 shows a typical proven method of fixing the baffles in place by bolting to a galvanised steel angle. The angle could be installed on either the upstream or downstream side of the baffle. The unit is anchored to the concrete using a galvanised steel anchor bolt. The plate and the bolts can also be fabricated from stainless steel for greater longevity.

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; therefore, it is important to ensure that the baffles and the mode of fitting are robust.

It is important that an engineering assessment of structural integrity of the weir is made to ensure that it is able to support the baffle installation.



Key

1 recycled plastic baffle

2 M8 bolt with nut and oversized washer at 300 cm3

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

4 galvanized 125 mm x 65 mm x 8 mm steel unequal angle 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, need to check for location of reinforcement bars

Figure 5 — Baffle dimensions and typical fixing arrangements

7 Maintenance considerations

Following installation of the baffles, it is important that they are maintained to ensure structural integrity and proper hydraulic performance is retained and that debris does not collect on them.

Baffles may become damaged or ripped out following periods of high flow or floods. Routine inspection is recommended after high flow events and any repairs undertaken as necessary.

It is important to ensure debris and weed growth does not build up on the baffles. This will have the effect of increasing the frictional effects on the downstream face of the structure and effectively reducing the modular range of the gauge which will invalidate flow measurement. It may also impair fish passage, particularly if free slots become blocked.

To reduce the necessity to visit the site to monitor debris on the weir, remote monitoring using a camera is highly recommended.

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