
British Standard

Measurement of liquid flow in open channels

Part 4. Weirs and flumes

Part 4D. Compound gauging structures

Mesure de débit des liquides dans les canaux découverts
Partie 4. Déversoirs et canaux jaugeurs
Partie 4D. Structures de jaugeage composites

Fließmessung an offenen Gerinnen
Teil 4. Wehre und Gerinne
Teil 4D. Kombinierte Meßeinrichtungen

Contents

	Page
Foreword	Inside front cover
Committees responsible	Back cover

Methods

1 Scope	1
2 Definitions and symbols	1
3 Characteristics of compound gauging structures	2
4 Installation	2
5 Maintenance	4
6 Measurement of head	4
7 Computation of discharge	5
8 Errors in flow measurement	5

Appendices

A Velocity distribution	7
B Drowned (non-modular) flow	7
C Examples of calculations	14

Tables

1 Values of C_v in terms of $f \left(\frac{h_1}{h_1 + P} \right)$	17
2 Modular discharge (in m ³ /s) are a compound weir per metre of crest in terms of upstream head	18

Figures

1 Examples of velocity profiles in the approach channel	9
2 Example of compound weir design	10
3 Details of crest tappings for triangular profile weirs	11
4 Drowned flow characteristics expressed in terms of h_p/H_1 and H_2/H_1 versus f	12
5 Drowned flow reduction factor f in terms of h_p/h_1 and $\left(\frac{h_1 b}{h_1 + P B} \right)$	13

Foreword

This Part of this British Standard, which is a revision of BS 3680 : Part 4D : 1981, has been prepared under the direction of the Industrial-process Measurement and Control Policy Standards Committee.

A wide variety of weirs and flumes has been designed but only those that have received general acceptance after adequate research and field testing, and that, therefore, do not require in situ calibration, are considered for

inclusion in a compound structure.

Although all types of weirs and flumes can be used in the modular range of flow, only triangular-profile weirs, as described in BS 3680 : Parts 4B and 4G may be used in the drowned range of flow.

Compliance with a British Standard does not of itself confer immunity from legal obligations.

British Standard

Measurement of liquid flow in open channels

Part 4. Weirs and flumes

Part 4D. Compound gauging structures

Methods

1 Scope

This Part of BS 3680 gives the methods of measurement of flow in rivers and artificial channels, using any combination of weirs and/or flumes in a compound structure. For guidance on the selection of weirs and/or flumes, reference should be made to BS 3680 : Part 4H.

Appendix A deals with velocity distribution.

Structures standardized for operation in the drowned (non-modular) flow range and the method computation of flow are described in appendix B.

Appendix C gives examples of calculations.

Compound flow measuring structures without divide piers need in situ or model calibrations and are not covered by this Part of this British Standard.

NOTE. The titles of the publications referred to in this standard are listed on the inside back cover.

2 Definitions and symbols

2.1 For the purposes of this Part of BS 3680, the definitions given in BS 3680 : Part 1 apply.

2.2 The following symbols are used in this Part of BS 3680 with the corresponding units of measurement.

Symbol		Units of measurement
A	area of cross section of flow	m^2
b	crest width	m
B	width of approach channel	m
C_D	coefficient of discharge	non-dimensional
C_v	coefficient of approach velocity	non-dimensional
e	uncertainty in absolute magnitude	non-dimensional
f	drowned flow reduction factor	non-dimensional
g_n	gravitational acceleration (standard value)	m/s^2
h	gauged head	m
H	total head	m
h_p	crest tapping pressure head	m
h_v	velocity approach head	m
L	length of flume throat or weir crest in direction of flow	m
n	number of measurements in a set	non-dimensional
P	height of flume invert or weir crest above mean bed level	m
Q	total discharge	m^3/s
Q_1, Q_2, Q_3	individual section discharges (in general Q_n)	m^3/s
Q_{mod}	total modular discharge	m^3/s
q	discharge per unit width	m^2/s
S_Y	standard deviation of a set of measurements of quantity Y	m
$S_{\bar{Y}}$	estimated standard deviation of mean of several readings of quantity Y	m
$\bar{V}$	mean velocity at cross section	m/s
$\bar{V}_a$	mean velocity in approach channel	m/s

Symbol		Units of measurement
X_Q	percentage uncertainty in total discharge	non-dimensional
$X_{Q,1}, X_{Q,2}, X_{Q,3}^*$	percentage uncertainty in individual section discharges	non-dimensional
X_{tu}	percentage uncertainty in estimating upstream water levels or upstream total head levels	non-dimensional
X_{td}	percentage uncertainty in estimating downstream water levels or downstream total head levels	non-dimensional
X_Y	percentage uncertainty in quantity Y	non-dimensional
α	Coriolis energy coefficient	non-dimensional
Δ	difference in weir crest levels	m
δ^*	boundary layer displacement thickness	m

Suffixes

1	denotes upstream value
2	denotes downstream value

Superscripts

G	refers to gauging section
T	refers to crest tapping section
S	refers to any other section

3 Characteristics of compound gauging structures

A compound gauging structure as covered by this Part of BS 3680 comprises two or more individual structures, operated in parallel and separated by divide piers. The individual structures, which can be used in a compound gauging weir, are covered by BS 3680 : Parts 4A, 4B, 4C, 4E, 4F, 4G and 4I.

In the modular flow range, discharges depend solely on upstream water levels, and a single measurement of upstream head is required. In the drowned flow range, discharges depend on both upstream and downstream water levels, and two independent head measurements are required. These are:

- (a) the upstream head;
- (b) the head developed within the separation pocket that forms just downstream of the crest (see appendix B).

The flow conditions considered are limited to steady or slowly changing flows. The essential parallel flow through the compound structure is ensured by the use of divide piers. The flow is separated by the divide piers into each individual weir or flume. The discharge can be determined through each individual section by a single upstream head measurement in the case of modular flow or by two independent head measurements as required for drowned flow conditions. The summation of the discharges through each of the sections provides the measurement of total flow within the channel.

4 Installation

4.1 Selection of site. A preliminary survey shall be made of the physical and hydraulic features of the proposed site to

check that it conforms (or may be made to conform) to the requirements necessary for measurement using the weir.

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

- (a) the availability of an adequate length of channel of regular cross section;
- (b) the existing velocity distribution;
- (c) the avoidance of channels having gradients greater than 1 in 250;
- (d) the effects of any increased upstream water level due to the measuring structure;
- (e) the conditions downstream, including such influences as tides, confluences with other streams, sluice gates, mill dams and other controlling features that might cause drowning;
- (f) 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;
- (g) the necessity for flood banks to confine the maximum discharge to the channel;
- (h) the stability of the banks, and the necessity for trimming and/or revetment in natural channels;
- (j) the clearance of rocks or boulders from the bed of the approach channel;
- (k) the effects of wind.

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

If the site does not possess the characteristics required for satisfactory measurements, it shall be rejected unless suitable improvements are practicable.

*In cases where the subscript of a symbol also contains a subscript, it is house style to write the second subscript on the same line, after a comma

Thus X_{Q_1} is written $X_{Q,1}$

If a survey of a stream shows that the existing velocity distribution is regular, then it should be assumed that the velocity distribution will remain satisfactory after the weir has been built.

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

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

4.2 Installation conditions

4.2.1 General. The complete measuring installation consists of an approach channel, a measuring structure and a downstream channel. The parameters of each of these three components affect the overall accuracy of the measurements.

Installation requirements include such features as weir finish, the cross-sectional shape of the channel, channel roughness and the influence of control devices upstream or downstream of the gauging structure.

The distribution and direction of velocity have an important influence on the performance of a weir, these factors being determined by the features mentioned in this subclause.

4.2.2 Approach channel. For all installations, the flow in the approach channel shall be smooth, free from disturbance and shall have a velocity distribution as normal as possible over the cross-sectional area (see appendix A); this can usually be verified by inspection or measurement. In the case of natural streams or rivers, this flow can only be attained by having a long, straight approach channel free from projections into the flow. Unless otherwise specified in the appropriate clauses of this standard, the approach channel shall comply with the general requirements outlined in this subclause.

The altered flow conditions due to the construction of the weir may have the effect of building up shoals of debris upstream of the structure, which in time may affect the flow conditions. The likely consequential changes in the water level should be taken into account in the design of gauging stations.

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 width, and more if attainable.

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

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

Baffles shall not be installed closer to the points of measurement than five times the maximum head to be measured.

Under certain conditions, a standing wave may occur upstream of the gauging device, 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 is feasible, subject to confirmation that a regular velocity distribution exists at the gauging station.

If a standing wave occurs within this distance, the approach conditions and/or gauging device shall be modified.

4.2.3 Measuring structure. The structure shall be rigid, watertight and capable of withstanding flow conditions without distortion or fracture. It shall be at right angles to the direction of flow and shall have the dimensions specified in the relevant British Standard(s) for the type of measuring structure(s) chosen.

For the purposes of this standard, a compound flow measuring structure consists of a series of individual weirs or flumes, which are disposed across the width of an open channel. The individual sections of the compound structure shall be separated by divide piers such that each section can be treated as a simple weir or flume, thus minimizing three-dimensional flow conditions. The computation of discharge for individual sections can therefore be based on established discharge equations (see the references in appendix B).

The divide piers that separate individual sections of the compound structure shall be at least 0.3 m thick to avoid sharp curvatures at their upstream noses (cutwaters), which can be semi-circular or semi-elliptical.

To minimize cross flows at the cutwaters of the divide piers and subsequent flow separation, the difference in levels between adjacent crests (weirs) or inverts (flumes) shall not exceed 0.5 m.

NOTE 1. Flow conditions at and near the cutwaters of the divide piers will be improved if the upstream bed levels bear a similar relationship to crest or invert levels at each individual section of the compound structure (see figure 2). This minimizes the variations in velocity across the width of the approach channel.

The compound flow measuring structure shall be capable of withstanding flood flow conditions without damage from outflanking or from downstream erosion. The structure and the immediate approach channel can be constructed in concrete with a smooth cement finish or surfaced with a smooth non-corrodible material.

NOTE 2. In laboratory installations, the finish should be equivalent to rolled sheet metal or plated, sanded and painted timber.

The surface finish is particularly important near the crest or throat invert, but can be relaxed a distance along the profile of $0.5H_{\max}$ upstream and downstream of the crest or throat. Details of tolerances for the finish and alignment of individual weirs or flumes are given in the appropriate Part of this British Standard.

A typical design for a compound measuring structure is shown in figure 2.

NOTE 3. The lengths of the divide piers are not crucial but they should extend preferably from the upstream recording section to the downstream limit of individual weirs or flumes.

The height of the divide piers should normally be the same as the vertical side walls. If less, then errors will arise in the computation of discharge when water levels exceed the height of the divide piers. These errors will depend on the dimensions of the compound structure and the actual height of the divide piers.

4.2.4 Downstream conditions. Conditions downstream of the structure are important in that they control the tail-water level. This level is one of the factors that determine whether modular or drowned flow conditions will occur at the weir. It is essential, therefore, to calculate or observe stage-discharge relations covering the full discharge range, and to make decisions regarding the type of weir and its required geometry in the light of this evidence.

When making these calculations or observations particular care shall be taken to ensure that influences that may be periodic or seasonal such as tides are taken into account.

NOTE. Confluences with other streams, sluice gates, mill dams and other features such as weed growth may also influence tail-water levels.

If the downstream channel is erodible, the extent of protective works necessary to dissipate the additional energy generated by the structure shall be taken into account in the assessment of the site.

5 Maintenance

Maintenance of the measuring structure and the approach channel is important to secure accurate continuous measurements.

It is essential that the approach channel to weirs be kept clean and free from silt and vegetation as far as practicable, and for at least the distance specified in 4.2.2. The stilling well and the entry from the approach channel shall also be kept clean and free from deposits.

The weir structure shall be kept clean and free from clinging debris and care shall be taken in the process of cleaning to avoid damage to the crest.

NOTE. The presence of divide piers between weir sections will inevitably increase maintenance requirements for the structure, particularly if floating debris is prevalent.

6 Measurement of head

6.1 General. The head upstream of the measuring structure may be measured by a hook-gauge, point-gauge or staff-gauge where spot measurements are required, or by a recording-gauge where a continuous record is required; in many cases it is preferable to measure heads in a separate stilling well to reduce the effects of water surface irregularities.

The discharges given by the working equation in the appropriate standard for the particular structure are volumetric figures, and the liquid density does not affect the volumetric discharge for a given head provided that the operative head is gauged in liquid of identical density. If the gauging is carried out in a separate well, a correction for the difference in density may be necessary if the temperature in the well is significantly different from that of the flowing liquid. However, it is assumed in this standard that the densities are equal.

6.2 Stilling well. It is usual to measure the upstream head in a stilling well to reduce the effects of water surface irregularities.

NOTE 1. When this is done, it is also desirable to measure the head in the approach channel as a check from time to time.

Where the structure is designed to operate in the drowned flow range (triangular-profile and flat-V weirs only) a separate gauge well is required to record the piezometric head developed within the separation pocket which forms immediately downstream of the crest.

The gauge well shall be vertical and of sufficient height and depth to cover the full range of water levels and shall have a minimum height of 0.6 m above the maximum water level expected. The gauge well shall be connected to the appropriate head measurement position by means of a pipe or a slot.

Both the well and the connecting pipe shall be watertight and, where the well is provided for the accommodation of the float of a level recorder, it shall be of adequate size and depth to give clearance around and beneath the float at all stages. The float shall be not nearer than 0.075 m to the wall of the well.

The pipe shall have its invert not less than 0.06 m below the lowest level to be gauged.

The pipe connection to the upstream head measurement position shall terminate flush with the boundary of the approach channel and preferably at right angles thereto. The approach channel boundary shall be plain and smooth (equivalent to carefully finished concrete) within a distance of 10 times the diameter of the pipe from the centreline of the connection. A pipe that is oblique to the wall is acceptable only if it is fitted with a removable cap or plate, and set flush with the wall, through which a number of holes are drilled. The edges of these holes shall not be rounded or burred.

Where the individual section of the compound structure is a two-dimensional triangular-profile weir the pipe connection to the head measurement position for the separation pocket head shall be as given in BS 3680 : Part 4B.

Where the individual section of the compound structure is a flat-V or triangular-profile weir, the pipe connection to the head measurement position for the separation pocket head shall be as given in BS 3680 : Part 4G.

Adequate additional depth shall be provided in the well to avoid the danger of floats grounding either on the bottom or on any accumulation of silt or debris.

The diameter of the connecting pipe or width of slot shall be sufficient to permit the water level in the well to follow the rise and fall of head without appreciable delay, but shall be as small as possible, consistent with ease of maintenance, to damp out oscillations due to short period waves.

NOTE 2. No firm rule can be laid down for determining the size of the connecting pipe, because this is dependent on the circumstances of the particular installation, e.g. whether the site is exposed and thus subject to waves and whether a large diameter well is required to house the floats of recorders.

It is preferable to make the connection too large rather than too small, because a restriction can easily be added later if short period waves are not adequately damped out. A 100 mm diameter pipe is usually suitable for a flow measurement in the field, as compared with the 3 mm diameter pipe that is appropriate for precision head measurement with steady flows in the laboratory.

6.3 Zero setting. Accurate initial setting of the zeros of the head measuring devices with reference to the level of the crest, or invert, and regular checking of these settings thereafter, is essential if overall accuracy is to be attained.

A means of checking the zero setting of the head-measuring devices shall be provided, consisting of a datum related to the level of the weir.

A zero check based on the level of the water when the flow ceases is liable to serious errors from surface tension effects and shall not be used.

NOTE. As the size of the weir and the head on it reduces, small errors in construction and in the zero setting and reading of the head-measuring device become of greater importance.

6.4 Location of head measurement section(s). The upstream head shall be measured at any one of the individual sections of the compound structure but preferably at the section measuring the lowest crest or invert. The tapping shall be in the vertical side wall if the individual section is adjacent to the bank, or in the divide pier if the individual section is mid-stream. In this latter case the divide piers shall extend at least $H_{\max}$ upstream of the head measurement position.

The distance of the head measurement section from crest or invert is usually expressed as a multiple of the maximum total head with a value appropriate to the individual section of not less than two. For precise locations for each type of structure, see the appropriate Part of this British Standard.

The presence of divide piers is not considered to have a significant influence, and the position of the head measurement section need only satisfy the requirements noted in this subclause.

If a triangular profile or flat-V weir is used as one of the individual sections of the compound structure, and it is designed to operate in the non-modular (drowned) flow range, then a separate crest tapping and associated gauge well shall be provided (see BS 3680 : Parts 4B and 4G).

7 Computation of discharge

7.1 Modular flow conditions. Modular flow calibrations are based on measurements of upstream water levels. Where a single (non-compound) structure is used, the recorded water level is used directly in the computation of discharge. However, it is not usually economic to measure water levels upstream of each individual section of a compound weir, and hence it is necessary to make assumptions about the relationships between flow conditions at the various sections when calculating the total flow.

Research has shown that the total head level can be assumed constant over the full width of a compound measuring structure and that it can be obtained by adding to the observed water level the velocity head appropriate to the individual section at which the water level is observed. Thus the basis of the method of computing the total discharge over a compound structure is to calculate the total head level at the individual section at which the water level is measured, as if it were a simple non-compound structure, and to use the same value of total head level to calculate individual discharges at other sections. Successive approximation or coefficient of velocity techniques are applied at the section of the structure where the water

level is recorded to convert gauged heads to total heads. Discharge equations in terms of total heads are used at other sections of the compound structure and no conversions are required. An example calculation is given in appendix C.

7.2 Non-modular (drowned) flow conditions. When a compound structure is designed to operate in the non-modular flow range, a triangular-profile or flat-V weir with a crest tapping shall be used in those sections of the compound weir that are likely to drown.

Upstream total heads are determined as for the modular flow case but discharges at those individual sections of the compound structure that are drowned are obtained by considering both the upstream total head and the crest tapping pressure. An example calculation is given in appendix C.

8 Errors in flow measurement

8.1 General. The total uncertainty of any flow measurement can be estimated if the uncertainties from various sources are combined. The assessment of these contributions to the total uncertainty will indicate whether the rate of flow can be measured with sufficient accuracy for the purpose in hand. This clause is intended to provide sufficient information for the user of this standard to estimate the uncertainties of measurements of discharge.

The error is the difference between the true rate of flow and that calculated in accordance with the equations in the appropriate standard for the particular structure used for calibrating the measuring structure (which is assumed to be constructed and installed in accordance with this standard). The term 'uncertainty' is used here to denote the deviation from the true rate of flow within which the measured flow is expected to lie some 19 times out of 20 (with 95 % confidence limits).

8.2 Sources of error. The sources of error in the discharge measurement for each individual section of the compound structure are as given in the errors sections of the Parts of this British Standard relating to the appropriate type of structure (see B.1). Additional errors arise due to the method used for estimating water levels or total head levels at individual sections, when (as is usual) these are not measured separately at each section. Available evidence is limited, but it suggests that the percentage uncertainty in discharge, X_{tu} , associated with transposing upstream water levels or total head levels is random, with a magnitude within the range of 5 %. 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 possible value of X_{td} , the additional uncertainty in discharge associated with transposing downstream water levels or total head levels, which is likely to be of the order of 10 %.

8.3 Kinds of error

8.3.1 Errors can be classified as random or systematic the former affecting the reproducibility (precision) of measurement and the latter affecting its true accuracy.

8.3.2 The standard deviation of a set of n measurements of a quantity, Y , under steady conditions can be estimated from the equation:

$$S_Y = \left(\frac{\sum_1^n (Y_1 - \bar{Y})^2}{n-1} \right)^{1/2} \quad (1)$$

where $\bar{Y}$ is the arithmetic mean of the n measurements.

The standard deviation of the mean is then given by the equation:

$$S_{\bar{Y}} = \frac{S_Y}{\sqrt{n}} \quad (2)$$

and the uncertainty of the mean is twice $S_{\bar{Y}}$ (for 95 % probability)*. This uncertainty is the contribution of the observation of Y to the total uncertainty.

8.3.3 A measurement can also be subject to systematic error; the mean of very many measured values would thus still differ from the true value of the quantity being measured. An error in setting the zero of a water level gauge to invert level, for example, produces a systematic difference between the true mean measured head and the actual value. As repetition of the measurement does not eliminate systematic errors, the actual value can only be determined by an independent measurement known to be more accurate.

8.4 Errors in coefficient values and errors in measurement.

These errors are dealt with in the error clauses of the appropriate Parts of this British Standard relating to the individual sections of the compound measuring structure (see B.1).

8.5 Combination of uncertainties to give overall uncertainty in total discharge

8.5.1 For the section at which the upstream water level is measured, the percentage uncertainty $X_{Q,1}$ † in the section

flow Q_1 is calculated by reference to the Part of this British Standard appropriate to that type of weir or flume (see B.1).

8.5.2 The percentage uncertainties, $X_{Q,2}, X_{Q,3} \dots$, in the section flows, $Q_2, Q_3 \dots$, for other sections are similarly computed, assuming the same uncertainty on water level measurement (not percentage) as in 8.5.1. Uncertainties due to transferring water levels or heads are ignored at this stage of the calculation.

8.5.3 The uncertainty in the total flow, Q , is the weighted mean of the uncertainties for the flows, Q_i , in the individual sections, with the inclusion of terms for the uncertainty of transposing water levels or heads, estimated from the equation:

$$X_Q = \pm \frac{1}{Q} \{ \sum_1^n Q_i \sqrt{(X_{Q,i})^2 + X_{tu}^2 + X_{td}^2} \} \quad (3)$$

8.5.4 If no sections of the weir are submerged, then X_{td} is omitted in all cases, and X_{tu} is omitted for any sections at which the upstream water level is measured.

8.5.5 If the weir is submerged, then X_{td} is omitted for any sections at which the crest pressure is measured, but included for any other sections. For cases of submergence it does not follow automatically that X_{tu} is to be omitted at sections where the upstream water levels are measured. A transfer of upstream heads as well as downstream heads may be involved in assessing crest pressures at such sections.

8.6 Presentation of results. Although it is desirable, and frequently necessary, to list total random and total systematic uncertainties separately, a simpler presentation of results may be required.

For this purpose, random and systematic uncertainties may be combined as described in BS 5844.

* This factor of 2 assumes that n is large. For $n = 6$ the factor is 2.6, for $n = 8$ it is 2.4; for $n = 10$ it is 2.3; for $n = 15$ it is 2.

† All uncertainties have a plus or minus value.

Appendix A

Velocity distribution

An even distribution of velocity over the cross section of the approach channel in the region of the gauging station is necessary for high accuracy of measurement of discharge by means of weirs, notches and flumes. This is because the recommended coefficients are empirical values obtained by various investigations and were usually obtained under ideal laboratory conditions. These involved either the use of screens to ensure an approximately uniform velocity over the cross section, or a long straight approach channel conducive to the establishment of a normal distribution of velocities.

Normal velocity distribution is defined as the distribution of velocities attained in a channel over a long uniform straight reach. A characteristic feature of flow in such a channel is that the velocity is at maximum at about 0.6 of the depth above invert, with the average velocity occurring at about 0.4 of the depth above invert.

Any deviation from the ideal conditions of either very uniform velocity or a normal velocity distribution may lead to errors in flow measurement, but quantitative information on the influence of velocity distribution is inadequate to define the acceptable limits of departure from the ideal distributions. With the uncertainties on discharge coefficients quoted in the relevant Parts of this British Standard (see B.1) in mind, figure 1 provides some guidance on the type of velocity distribution and evenness thereof that are acceptable in practice.

In figure 1 different patterns of isovels are shown. These isovels are contours of equal velocity in the direction of flow.

The percentage difference in the value of α left and α right is shown in figure 1. Figure 1(c) shows the extreme value for the departure from ideal approach conditions for the uncertainties quoted in the relevant Parts of this British Standard (see B.1) and this percentage difference may be regarded as the maximum permissible. This distribution gives a Coriolis energy coefficient of 1.44.

Appendix B

Drowned (non-modular) flow

B.1 General. Structures that are standardized for operation in the modular and non-modular flow ranges are as follows:

(a) *Modular flow range*

BS 3680 :	Part 4A	thin-plate weirs
	Part 4B	triangular-profile weirs
	Part 4C	flumes
	Part 4E	rectangular broad-crested weirs
	Part 4F	round-nose horizontal crest weirs
	Part 4G	flat-V weirs
	Part 4I	V-shaped broad-crested weirs

(b) *No-modular (drowned) flow range*

BS 3680 :	Part 4B	triangular-profile weirs
	Part 4G	flat-V weirs

These weirs may be used in the non-modular flow range if a crest tapping is provided. They are commonly used as one or more of the sections of a compound structure, the method of operation being described in B.2.

B.2 Non-modular flow compound 2-dimensional triangular-profile weirs with 1:2 and 1:5 slopes

B.2.1 Method of operation. If a weir complying with BS 3680 : Part 4B is to be used for gauging in the non-modular range, a crest tapping should be provided together with a separate gauge well in addition to the other requirements for gauging within the modular range. Double gauging with this type of structure will give reliable flow recording in the non-modular range. The modular discharge coefficient is approximately constant throughout its range. In the non-modular range the reduction factor $f = Q/Q_{mod}$ is uniquely related to the ratio h_p/H_1 where h_p is the crest tapping pressure head and H_1 is the upstream total head.

Essentially, the crest tapping removes the difficulty of obtaining accurate reading of the downstream water level where some degree of turbulence is invariably present.

Allowing a 1 % uncertainty in the modular discharge value, drowning is considered to take place where h_p/H_1 exceeds 0.24.

For the purpose of checking, at the design stage, whether this type of weir is likely to drown, the submergence ratio at the modular limit is approximately 0.75.

For compound triangular-profile weirs designed to operate in the non-modular range it is normal practice to fit a crest tapping to the lowest crest only. This represents a compromise between accuracy and practicability.

It is recommended that, in cases of doubt as to whether or not a weir may become non-modular, a crest tapping should be provided together with a separate gauge well.

A typical design for a compound structure of this type and crest tapping details are given in figures 2 and 3 respectively.

B.2.2 Computation of non-modular flows

B.2.2.1 General. Two methods for the computation of non-modular discharge for a triangular-profile weir complying with BS 3680 : Part 4B are described in this subclause. They are the:

- successive approximation method;
- coefficient of velocity method.

Examples of these methods, as applied to a compound weir, are given in appendix C. For non-modular flow the standard discharge equation is modified to $Q = C_D \sqrt{(g_n)} b f H_1^{3/2}$, where f is the drowned flow reduction factor.

B.2.2.2 Successive approximation method. The basis of the successive approximation method is to calculate the total head at the section of the weir at which the head is measured (gauging section) as if it were for a single weir, and to use the same value to calculate the individual discharge of each other section of the weir. On the assumption that a crest tapping is fitted to the lowest crest only, it is then necessary to determine if and to what degree the other crest(s) is/are drowned by reference to the ratio of downstream to upstream total head (H_2/H_1) calculated from the single reading of the crest tapping.