Design Manual for Roads and Bridges

Drainage
Design

CD 521
Hydraulic design of road edge surface water channels and outlets

(formerly HA 37/17, HA 78/96, HA 113/05, HA 119/06)

Version 1.1.0

Summary
This document gives requirements and guidance for the design of road edge surface water channels and outlets, combined channel and pipe systems for surface water drainage, and grassed surface water channels on motorways and all-purpose trunk roads.

Application by Overseeing Organisations
Any specific requirements for Overseeing Organisations alternative or supplementary to those given in this document are given in National Application Annexes to this document.

Feedback and Enquiries
Users of this document are encouraged to raise any enquiries and/or provide feedback on the content and usage of this document to the dedicated National Highways team. The email address for all enquiries and feedback is: Standards_Enquiries@highwaysengland.co.uk

This is a controlled document.

Contents

Latest release notes

Document code	Version number	Date of publication of relevant change	Changes made to	Type of change
CD 521	1.**1**.0	November 2021	Core document	Incremental change to requirements
Incremental changes to some requirement clauses, one equation amendment and numerous editorial amendments.				

Previous versions

Document code	Version number	Date of publication of relevant change	Changes made to	Type of change
CD 521	1	March 2020		
CD 521	0	August 2019		

Foreword

Publishing information

This document is published by National Highways.

This document supersedes HA 37/17, HA 78/96, HA 113/05, and HA 119/06, which are withdrawn.

Contractual and legal considerations

This document forms part of the works specification. It does not purport to include all the necessary provisions of a contract. Users are responsible for applying all appropriate documents applicable to their contract.

Introduction

Background

This document provides requirements for and advice on the design of surface water channels and their outlets, including combined channels and pipes, and grassed channels.

This document represents the combination of four previous advice documents HA 37/17, Hydraulic Design of Road-Edge Surface Water Channels, HA 78/96, Design of Outfalls for Surface Water Channels, HA 113/05, Combined Channel and Pipe System for Surface Water Drainage, and HA 119/06, Grassed Surface Water Channels for Highway Runoff.

The superseded advice documents referenced above contained duplicate information, which is resolved or removed from this amalgamated document.

The document compliments and expands on the information provided in MCHW HCD Series B [Ref 13.N] and MCHW HCD Series F [Ref 14.N] drawings.

Assumptions made in the preparation of this document

The assumptions made in GG 101 [Ref 10.N] apply to this document.

Guidance is given on the basic assumption that work will be constructed in accordance with the Manual of Contract Documents for Highways Works (MCHW).

Mutual Recognition

Where there is a requirement in this document for compliance with any part of a "British Standard" or other technical specification, that requirement may be met by compliance with the Mutual Recognition clause in GG 101 [Ref 10.N].

Abbreviations and symbols

Abbreviations

Abbreviation	Definition
DMRB	Design Manual for Roads and Bridges
FEH	Flood Estimation Handbook
HCD	Highway Construction Details
MCHW	Manual of Contract Documents for Highways Works
SHW	Specification for Highways Works
SuDS	Sustainable Drainage Systems

Symbols

Symbol	Definition	Units
A	Cross-sectional area of flow	m^2
A_p	Cross-sectional area of post	m^2
b	Effective cross-fall of channel	-
b_1	Slope of side of channel remote from carriageway (1 unit vertical: b1 units horizontal)	-
b_2	Slope of side of channel adjacent to carriageway (1 unit vertical: b2 units horizontal)	-
b_3	Transverse slope of carriageway adjacent to channel (1 unit vertical: b3 units horizontal)	-
B	Surface width of flow	m
B_c	Channel width	m
B_b	Base width of channel	m
B_d	Surface width of flow for channel-full conditions	m
B_s	Surface width of flow in surcharged channel neglecting the width of surcharge on hard-strip or hard shoulder	m
B_t	The surcharged width of the channel at the downstream end of the transition	m
c	Variable coefficient used in calculating the surface flow width of dished surface water channels	-
$\overline{C}$	Average plan width of the cutting	m
C_d	Drag coefficient	-
D	Diameter of pipe	m
E	Top width of flow in weir collecting channel	m
F_d	Non-dimensional number representing channel-full flow conditions	-
F_s	Non-dimensional number representing surcharged channel conditions	-
g	Acceleration due to gravity	m/s^2

Symbols (continued)

Symbol	Definition	Units
G_g	Width of outlet grating	m
G_m	Factor for channel shape	-
H	Grass height	m
Hc	Horizontal cover around pipe	m
H_g	Length of outlet grating	m
I	Mean rainfall intensity	mm/hr
J	Design flow depth in weir collecting channel	m
K	Hydraulic conveyance factor	$m^{\frac{8}{3}}$
L	Length of road that can be drained between two adjacent outlets on a continuous slope, or the distance between a point of zero slope and the downstream outlet	m
L_1	Length of surface water channel upstream of the intermediate channel	m
L_2	Length of surface water channel downstream of the intermediate outlet	m
L_a	Length of angled part of weir outlet	m
L_A	Maximum allowable spacing between the last intermediate outlet and the terminal outlet	m
L'_A	Actual spacing between adjacent outlets	m
L_B	Length of road that can be drained when bypassing is permitted	m
L_c	Length of road that can be drained when N=1 year	m
L_{cum}	Cumulative drainage length	m
L_{ip}	Average length between posts	m
L_p	Maximum length of road that can be drained by a section of internal pipe	m
L_r	Length of straight part of weir outlet parallel to the carriageway	m
L_s	Maximum length of road that can be drained under surcharge conditions	m
L_{SB}	Maximum length of road that can be drained under surcharge conditions where bypassing is permitted	m
L_t	Length of transition for weir outlet	m
L_T	Maximum total length of road that can be drained	m
L'_T	Total length of road drained by this section of combined channel	m
L_w	Total length of weir outlet	m
m	Shape characteristic parameter	-
m_g	Coefficient relating the grass type	-
N	Return period	years
N_1	Number of intermediate outlets in combined system	-
n	Manning's roughness coefficient	$s/m^{\frac{1}{3}}$
n_c	Manning roughness coefficient of the carriageway	$s/m^{\frac{1}{3}}$

Symbols (continued)

Symbol	Definition	Units
n_{ip}	Manning roughness coefficient of the internal pipe	s/m$^{\frac{1}{3}}$
n_p	Additional roughness coefficient due to posts	s/m$^{\frac{1}{3}}$
P	Wetted perimeter	m
$PIMP$	Percentage of impervious areas	%
PR	Percentage run-off from the whole catchment	-
Q	Flow rate	m^3/s
Q_c	Design capacity of a surface water channel just flowing full	m^3/s
Q_d	Approach flow for channel full conditions	m^3/s
Q_i	Flow intercepted by outlet	m^3/s
Q_p	Flow rate from the upstream internal pipe	m^3/s
Q_s	Maximum flow capacity under surcharge conditions	m^3/s
Q_t	$Q_p + Q_s$	m^3/s
r	Hydraulic radius factor (flow width/wetted perimeter)	-
R	Hydraulic radius of flow	m
S	Longitudinal gradient of a channel (vertical fall per unit distance measured along the channel)	m/m
S_e	Effective value of S for channels with non-uniform slope	m/m
S_j	Local gradient determined at eleven equally-spaced points; j = 1 to 11	m/m
S_1	Gradient at the upstream end	m/m
S_{11}	Gradient at the outlet	m/m
$SOIL$	Indices related to the infiltration potential of the soil	-
T	Storm duration	minutes
T_c	Critical storm duration	minutes
U	Vertical cover above and below the pipe	m
$UCWI$	Urban catchment wetness index	-
V	Velocity	m/s
W	Width of the impermeable part of the catchment	m
W_e	Effective catchment width	m
X	Factor for use in the calculation of the shape factor for surcharged surface water channels	-
y	Design depth of flow in surface channel - measured from the centre line of the surface water channel invert	m
y_1	Depth of channel from lower edge of carriageway to centre line of invert	m
y_2	Depth of channel from top edge of carriageway to centre line of invert	m
y_3	Overall depth of surcharged channel to centre line of invert	m
Z	Head of water above pipe invert	m

Symbols (continued)

Symbol	Definition	Units
α	Run-off coefficient of the cutting	-
η	Efficiency	-
η_d	Efficiency of outlet for channel-full conditions	-
η_s	Efficiency of outlet for surcharged conditions	-
η_D	Efficiency of outlet grating with diagonal bar pattern	-
η_L	Efficiency of outlet grating with longitudinal bar pattern	-
θ	Angle of weir outlet	-
ϕ	Surcharge factor (ratio between drainage length for surcharged channel and drainage length for channel just flowing full)	-
2minM5	Depth of rainfall occurring at a particular geographical location in a storm with T = 2 minutes and N = 5 years	mm

Terms and definitions

Terms

Term	**Definition**
Combined (surface water) channels	A combined surface water channel and pipe system consisting of a single unslotted unit, with flow discharged from the channel into the internal pipe via gully gratings located over a shallow chamber
Environmental protection agency	The legislative body responsible for managing the quality of water bodies and flood risk in public watercourses.
Fin drain	A planar geocomposite arrangement designed to remove sub-surface water from beneath the pavement.
Grassed surface water channel	Triangular or trapezoidal cross section channel, formed from turf or seeded topsoil over a compacted subsoil, located near the edge of the carriageway, used to collect, convey and provide a degree of water quality treatment to surface water
Grating	Inlet cover with openings or bars NOTE: Grating can be steel or concrete.
Gully	A chamber at the roadside connected to a drainage system to receive surface water NOTE: The chamber is usually surmounted by a surface grating.
Intermediate outlet	An outlet used to remove water part way along a surface water channel to maintain channel capacity NOTE: Flow from the intermediate outlet is conveyed via a carrier pipe or ditch to a suitable discharge point.
Outfall	Point at which a drainage system discharges into a watercourse or sewer NOTE: Usually, but not always, at the highway boundary.
Source protection zones	These are for groundwater sources such as wells, boreholes and springs used for public drinking water supply. NOTE 1: These zones show the risk of contamination from any activities that can cause pollution in the area. NOTE 2: The closer the activity, the greater the risk. NOTE 3: The maps show three main zones (inner, outer and total catchment) and a fourth zone of special interest, which we occasionally apply, to a groundwater source.
Surface water	Rainfall that collects on the surface of the ground (such as on the road or verge) and has not percolated through the surface
Surface water channel	Triangular, trapezoidal or rectangular cross section channel, formed from asphalt or concrete, located near the edge of the carriageway, used to collect and convey surface water from the road

Terms (continued)

Sustainable drainage systems (SuDS)	Approaches to manage surface water that take account of water quantity (flooding), water quality (pollution), biodiversity (wildlife and plants), and amenity are collectively referred to as sustainable drainage systems (SuDS).
Terminal outlet	An outlet located at the low/end point of a channel to collect flow carried along the channel NOTE 1: Flow from the terminal outlet is conveyed to a suitable discharge point.
Vegetated drainage system	Systems used to convey, store and treat highway runoff NOTE 1: They are described as vegetated drainage systems because they contain a significant element of vegetation and they are designed for use especially in highway drainage networks. NOTE 2: They are similar to systems described elsewhere as sustainable drainage systems (SuDS).

1. Scope

Aspects covered

1.1 This document shall be used for:

1) the hydraulic design of concrete, asphalt, and grassed surface water channels;
2) the hydraulic design of outlets from triangular and trapezoidal surface water channels;
3) the hydraulic and structural design of combined channel and pipe systems; and,
4) the structural design of grassed surface water channels.

NOTE This document does not cover the structural design of concrete and asphalt surface water channels or outlets and their chambers.

Associated documents

1.2 This document shall be read in conjunction with:

1) CG 501 [Ref 3.N];
2) CD 524 [Ref 6.N];
3) CG 502 [Ref 20.N];
4) CD 377 [Ref 16.N];
5) CD 532 [Ref 21.N];
6) CD 527 [Ref 18.N]

Implementation

1.3 This document shall be implemented forthwith on all schemes involving highway drainage on the Overseeing Organisations' motorway and all-purpose trunk roads according to the implementation requirements of GG 101 [Ref 10.N].

Use of GG 101

1.4 The requirements contained in GG 101 [Ref 10.N] shall be followed in respect of activities covered by this document.

2. Surface water channel systems

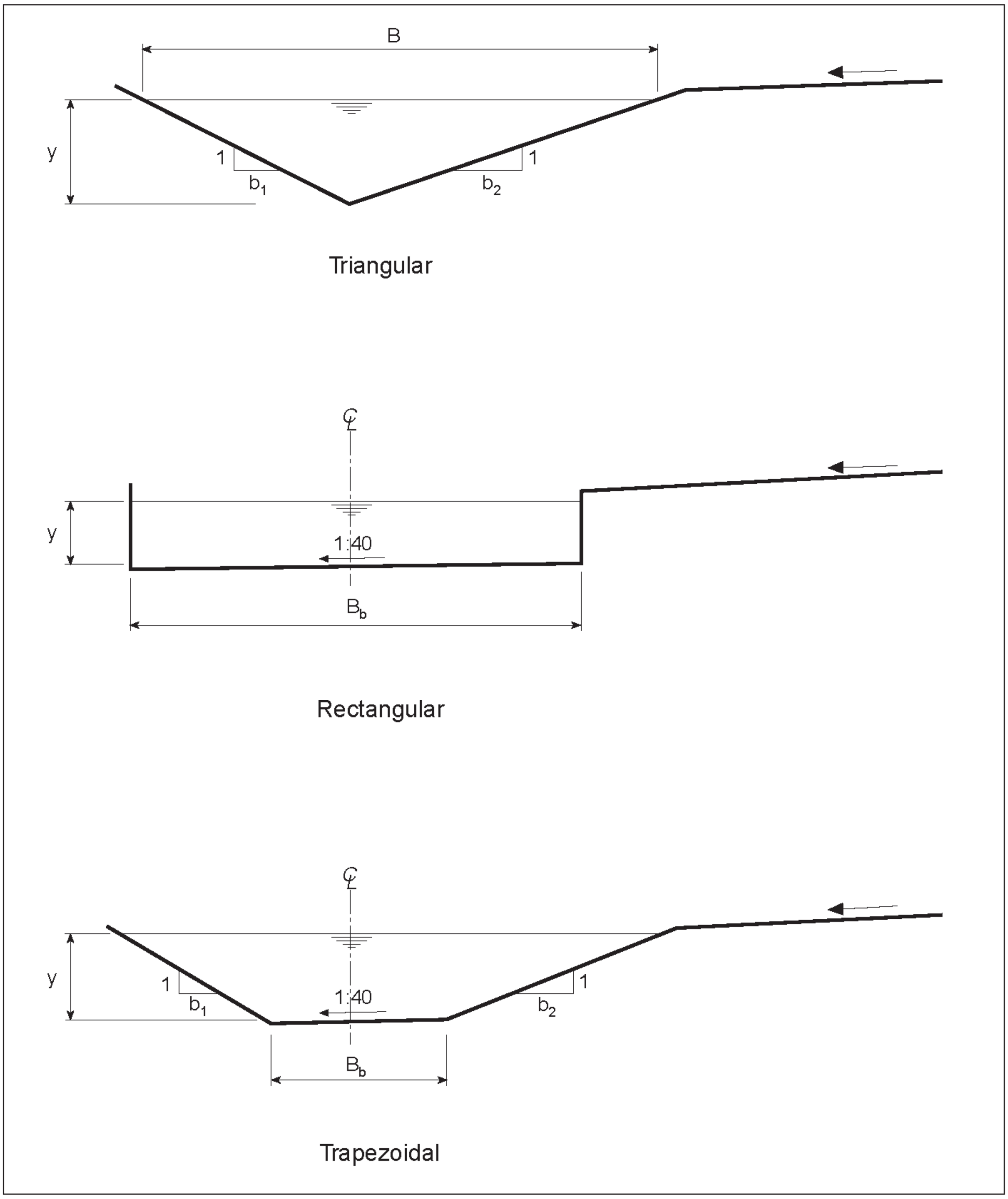
General

2.1 The longitudinal gradient of a surface water channel shall be the same as the longitudinal gradient of the pavement being drained.

Surface water channel (concrete or asphalt)

2.2 Concrete or asphalt surface water channels shall be triangular, rectangular or trapezoidal in accordance with Figure 2.2.

Figure 2.2 Channel cross sections



NOTE 1 *For additional details of cross sectional shapes of channels refer to Appendix H.*

NOTE 2 *For further details of surface water channel profiles, dimensions and application see CD 524 [Ref 6.N].*

2.3 When using a concrete or impermeable asphalt pavement, there shall be no step between the inner edge of the channel and the top edge of the carriageway.

NOTE *Where porous asphalt surfacing is used, a step can be necessary to allow water to drain from the permeable layer.*

2.3.1 The vertical distance between the top of the porous asphalt layer and the invert of the channel should not exceed 150 mm.

NOTE *Refer to CD 236 [Ref 16.I] for further information on use of porous asphalt.*

Combined surface water channel and pipe (concrete)

2.4 The combined surface water channel and pipe system shall consist of a single unslotted unit, with flow discharged from the channel into the internal pipe via gully gratings located over a shallow chamber.

NOTE *Examples of intermediate outlets with inline and offline gratings are shown in Figure 2.4Na and Figure 2.4Nb.*

Figure 2.4Na Example of intermediate outlet with inline grating

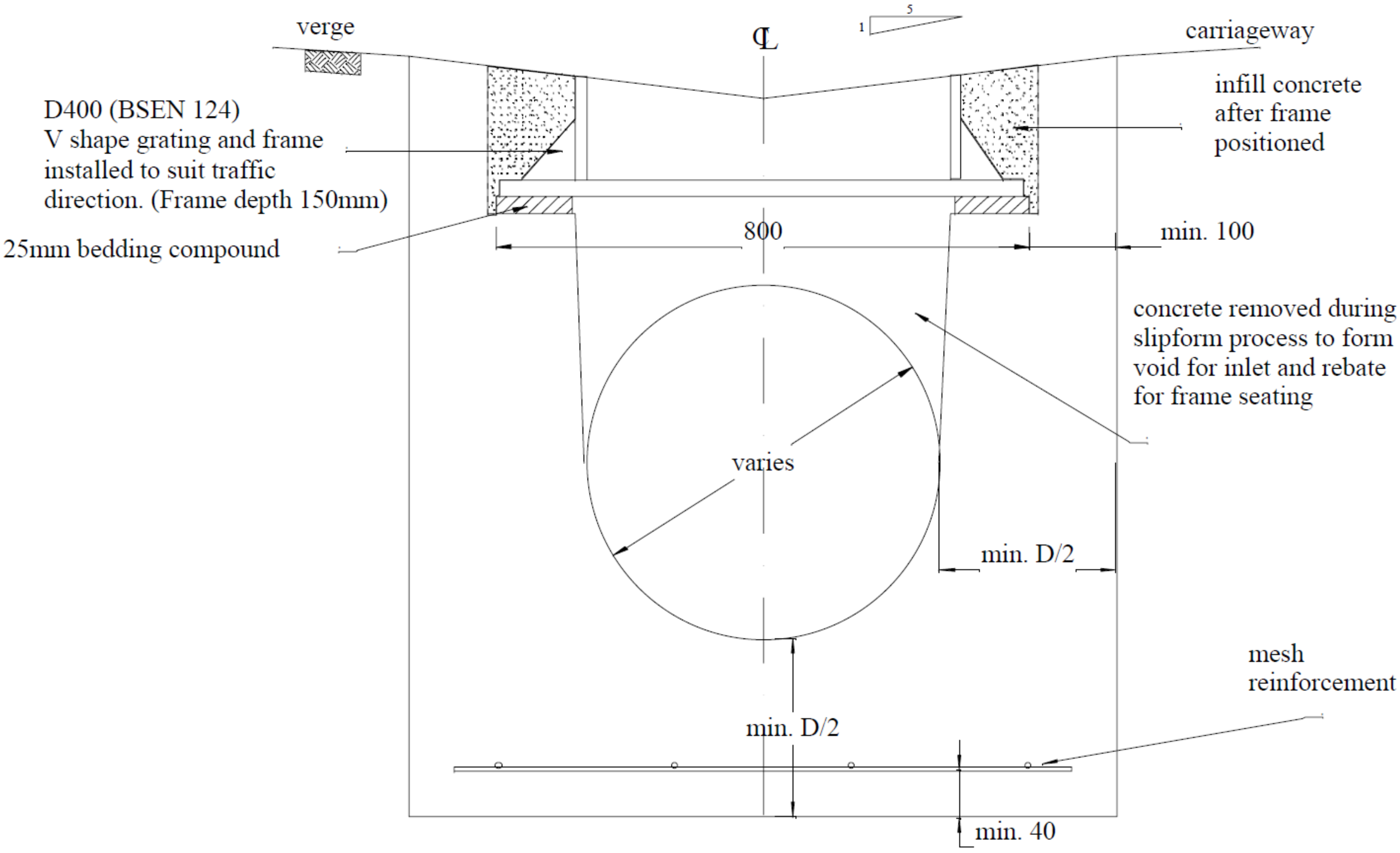
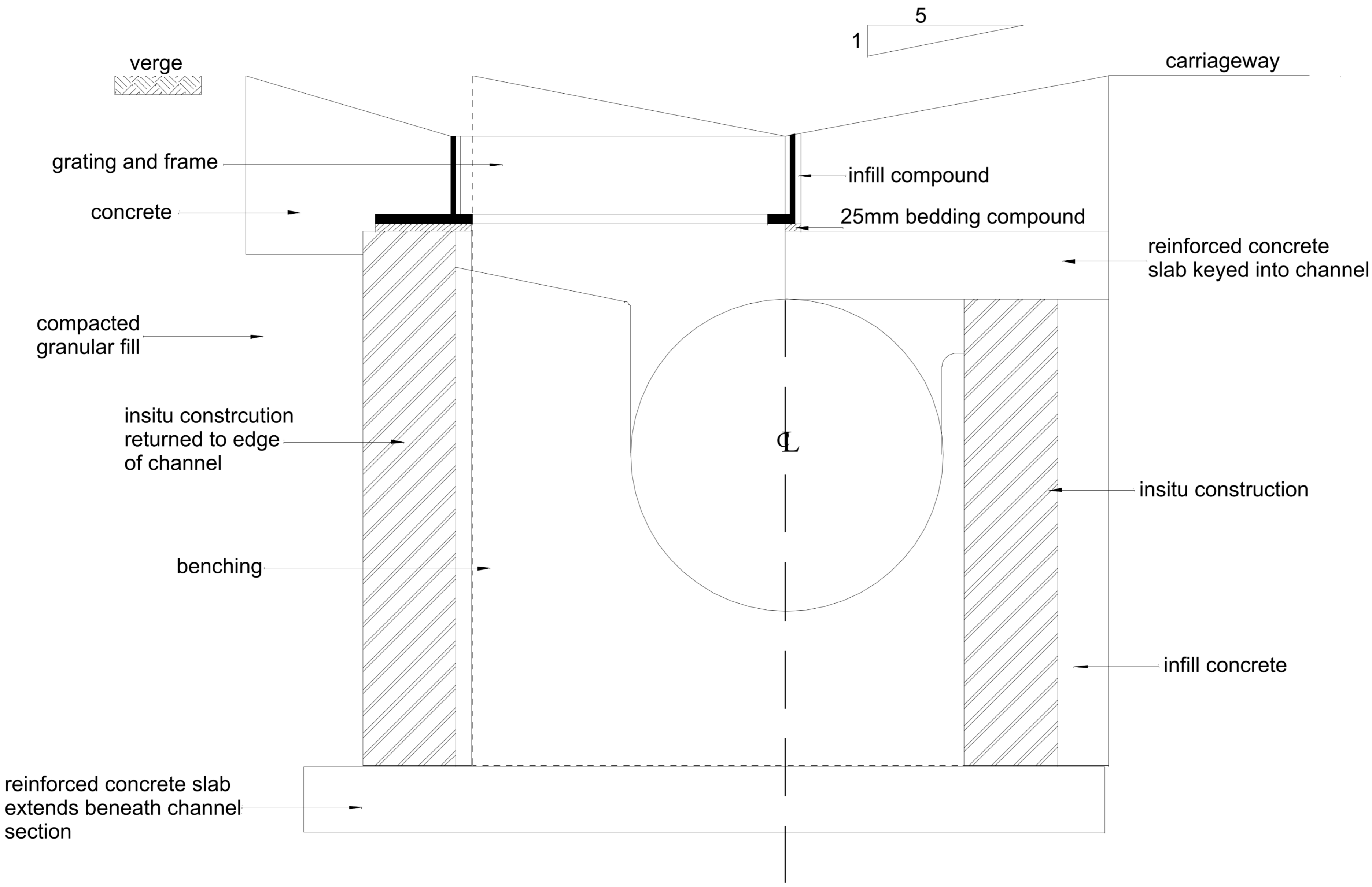


Figure 2.4Nb Example of intermediate outlet with offline grating



2.5 The surface water channel part of the combined channel and pipe system shall be triangular, trapezoidal or rectangular in shape.

2.6 The internal pipe shall be unlined and formed as a cylindrical void below the invert of the channel.

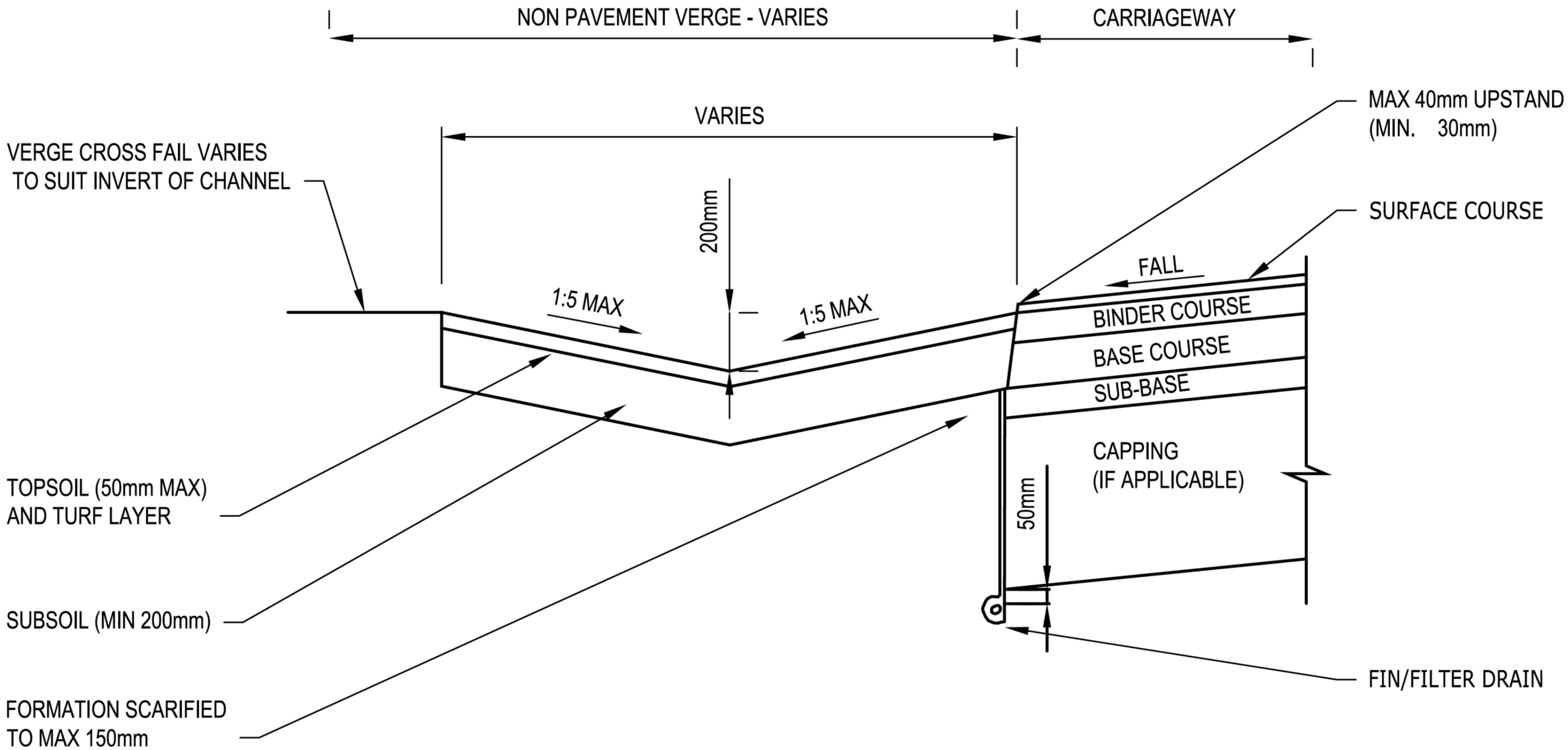
2.6.1 The cylindrical void may be produced by an inflated flexible tube.

Surface water channel (grassed)

2.7 Grassed surface water channels shall be triangular or trapezoidal in cross section.

NOTE *Typical cross sectional arrangements of grassed surface water channels are shown in Figure 2.7N and Appendix L.*

Figure 2.7N Typical cross section of triangular grassed surface water channel



3. Influencing factors

Health and safety

General

3.1 The position of surface water channels in relation to the pavement edge shall follow the guidance provided in CD 524 [Ref 6.N].

3.2 Vehicle restraint systems shall be located outside the extent of the drainage channel.

NOTE 1 Fixed obstructions in a drainage channel, such as a longitudinal line of posts for a vehicle restraint system, can reduce its flow capacity.

NOTE 2 Refer to CD 377 [Ref 16.N] and CD 127 [Ref 1.N] for additional requirements affecting the combined layout of vehicle restraint systems and surface water channels, and other drainage infrastructure.

3.3 Where located adjacent to the hardstrip or hard shoulder and in front of a vehicle restraint system, the side slopes of surface water channels, including channel outfalls, shall be 1:5 (vertical : horizontal) for triangular channels and 1:4.5 for trapezoidal channels.

3.4 For both triangular and trapezoidal surface water channel terminations, the end ramp shall not exceed 1:4.

3.4.1 Where vehicle restraint systems are needed for other reasons and where located behind a vehicle restraint system, the side slopes of surface water channels, including channel outfalls, may exceed 1:4.

3.5 Weir outlets shall be used on motorways and all-purpose trunk roads which exceed longitudinal falls of 1:50 (2%).

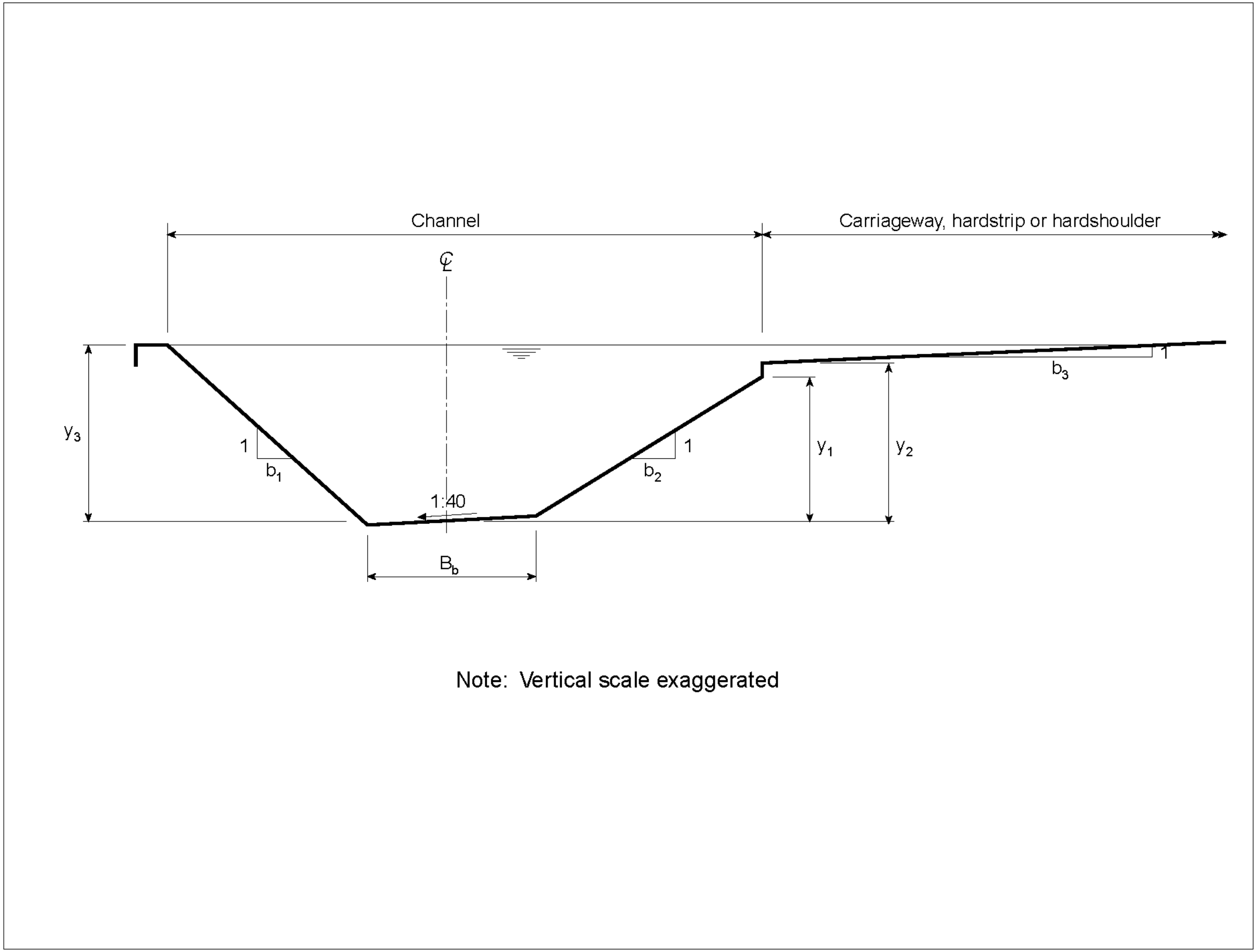
3.6 Weir outlets shall only be used where located behind a vehicle restraint system.

3.7 Gully gratings used for outlets in surface water channels shall meet the geometrical, structural and loading requirements of BS EN 124:1994 [Ref 9.N] and BS 7903 [Ref 8.N].

Surface water channel (concrete or asphalt) and combined surfaced water channel and pipe

3.8 Surface water channels shall be limited to a maximum design depth of flow (dimension y_1 in Figure 3.8) of 150 mm where located adjacent to the hardstrip, hard shoulder or at the edge of the carriageway and in front of the vehicle restraint system, where one is provided.

Figure 3.8 Cross section of surcharged trapezoidal channel



3.9 All rectangular channels, or triangular and trapezoidal channels with a design depth of flow greater than 150 mm, shall only be used when a vehicle restraint system is provided between the channel and the carriageway.

NOTE A surface water channel on its own does not require the protection of a vehicle restraint system.

3.10 All rectangular channels, or triangular and trapezoidal channels with a design depth of flow greater than 150 mm, shall be located outside of the working width behind the vehicle restraint system.

3.10.1 All rectangular, or triangular and trapezoidal channels with a design depth of flow up to 150 mm, may be located in the working width behind the vehicle restraint system.

NOTE Surface water channel depth is limited to mitigate the risk of vehicles overturning due to the channel being too low relative to the vehicle restraint system.

3.11 Where a combined surface water channel and pipe is installed adjacent to the hardstrip or hard shoulder and is not protected by a vehicle restraint system, the combined surface water channel and pipe shall meet the loading requirements specified in MCHW Series 1100 [Ref 12.N] and BS EN 1433 [Ref 4.N].

Grassed surface water channels

3.12 Grassed surface water channels shall be limited to a maximum design depth of flow of 200 mm where located adjacent to the hardstrip or hard shoulder or at the edge of the carriageway and in front of the vehicle restraint system, where one is provided.

3.13 A grassed surface water channel shall only be used on an embankment where the width of the channel is greater than, or equal to, the height of the embankment.

NOTE Grassed surface water channels are only used on embankments where the width of the channel is greater than, or equal to, the height of the embankment due to the risk of percolation destabilising the embankment slope.

3.14 Triangular and trapezoidal grassed surface water channels greater than 200 mm deep, shall only be used when a vehicle restraint system is provided between the channel and the carriageway and when a vehicle restraint system is required for other reasons.

3.15 Triangular and trapezoidal grassed surface water channels greater than 200 mm deep, shall not be located in the working width behind the vehicle restraint system into which the vehicle restraint system can deflect upon vehicle impact.

3.15.1 Triangular and trapezoidal grassed surface water channels up to 200 mm deep, may be located in the working width behind the vehicle restraint system.

NOTE Surface water channel depth is limited to mitigate the risk of vehicles overturning due to the channel being too low relative to the vehicle restraint system.

Environmental

General

3.16 Assessment of pollution impacts from road runoff shall be determined in accordance with LA 113 [Ref 17.N].

3.16.1 The selection of surface water channel type should be based upon the need to mitigate pollution impacts from road run off as determined by LA 113 [Ref 17.N].

NOTE Information regarding the environmental benefits associated with grassed surface water channels is included in Appendix A and CD 532 [Ref 21.N].

Grassed surface water channels

3.17 Measures necessary to protect ground water from road run off due to infiltration through a grassed surface water channel shall be determined as part of an environmental assessment undertaken in accordance with LA 113 [Ref 17.N].

3.17.1 When a grass surfaced water channel is selected for use with an impermeable membrane (to protect receiving ground water), the membrane should be installed below the subsoil to retain moisture to maintain grass growth.

3.17.2 The impermeable membrane should extend over sub-surface drainage.

NOTE Refer to Figure 2.7N for a typical cross section of a triangular grassed surface water channel.

3.18 Grassed surface water channels shall be a minimum of 150 mm deep to ensure effective conveyance.

Structural

General

3.19 Surface water channel loading requirements shall be based upon the loading classes given in BS EN 124:1994 [Ref 9.N].

Combined surface water channel and pipe (concrete)

3.20 The maximum pipe size for unreinforced mass concrete combined channel and pipe sections with a loading class of C250 and D400, shall be 300 mm (D_{max}), with a minimum vertical cover (U_{min}) of D/2, and a minimum horizontal cover (Hc_{min}) of D/2.

3.21 The maximum pipe size for light mesh reinforced concrete combined channel and pipe sections with a loading class of D400, shall be 400 mm (D_{max}), with a minimum vertical cover (U_{min}) of D/2, and a minimum horizontal cover (Hc_{min}) of D/2.

3.21.1 Light mesh should consist of welded mesh formed of mild steel bars with:

1) maximum spacing between bars of 200 mm; and,
2) a minimum area of steel perpendicular to the longitudinal centre-line of the pipe of 385 mm^2 per metre run of pipe.

3.22 The maximum pipe size for heavier mesh reinforced concrete combined channel and pipe sections with a loading class of D400, shall be 500 mm (D_{max}), with minimum vertical cover (U_{min}) of D/2, and a minimum horizontal cover (Hc_{min}) of D/2.

3.22.1 Heavier mesh should consist of a welded mesh formed of mild steel bars with:

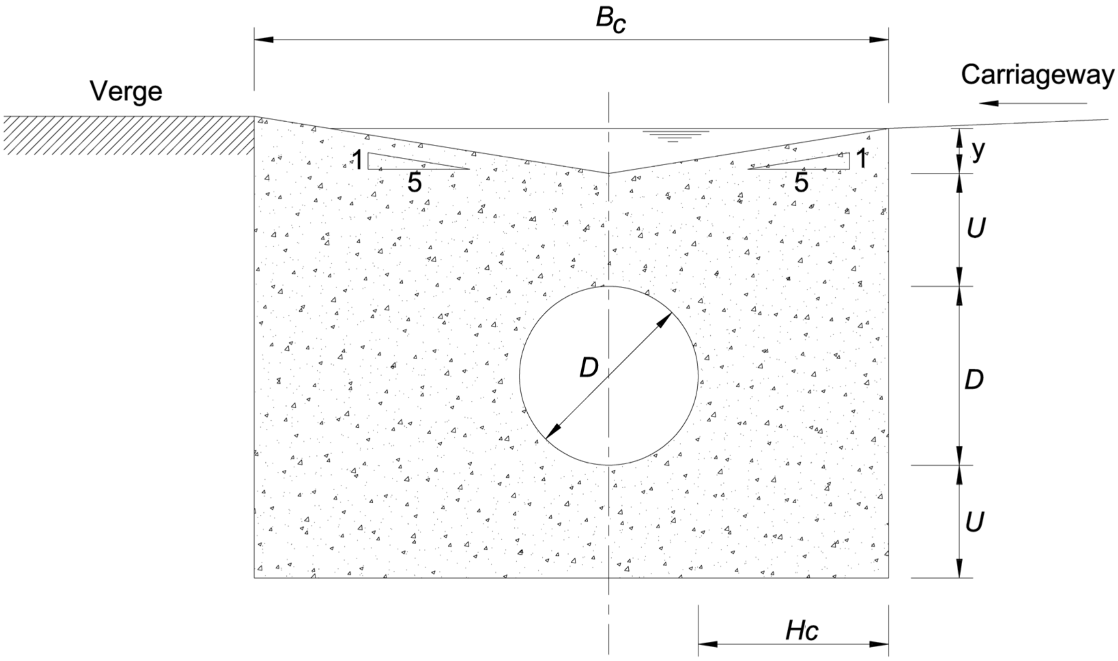
1) maximum spacing between bars of 100 mm for bars placed perpendicular to the line of the pipe;
2) maximum spacing between bars of 200 mm for those places parallel to the line of the pipe; and,
3) the minimum area of steel perpendicular to the longitudinal centre-line of the pipe of 1100 mm^2 per metre run of pipe.

3.23 The geometric limits, D_{max}, U_{min} and Hc_{min} shall be deemed to meet the requirements of load class D400 (BS EN 124:1994 [Ref 9.N]) without the need for structural testing.

NOTE 1 The dimensions corresponding to a loading class of D400 in BS EN 124 (BS EN 124:1994 [Ref 9.N]) were established from structural tests (HRW SR 624 [Ref 2.I]).

NOTE 2 The geometric parameters D, U and Hc are shown in the typical cross section of a triangular combined surface water channel and pipe system in Figure 3.23N2.

Figure 3.23N2 Typical cross section of triangular combined surface water channel and pipe system



3.24 Both light and heavier mesh shall be placed horizontally in the base of the combined channel and pipe block such that the bars run parallel and perpendicular to the line of the pipe.

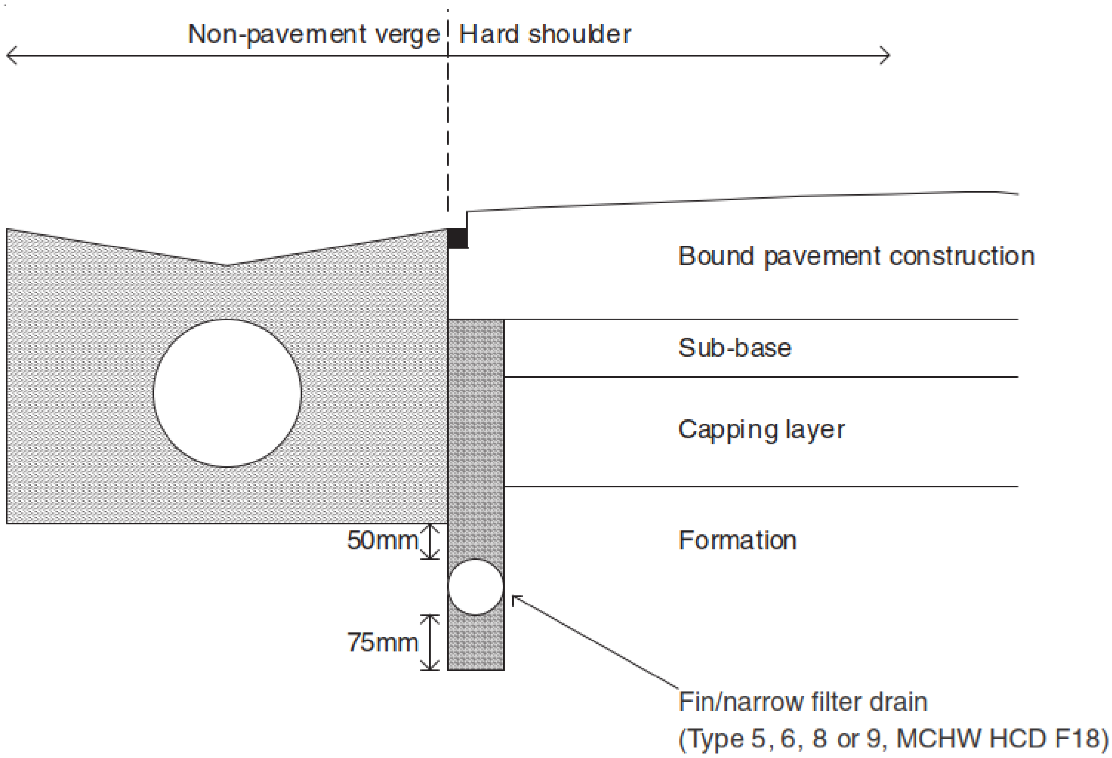
3.25 Concrete cover to the mesh reinforcement shall not be less than 40 mm.

3.25.1 Where mesh reinforcement is used, the ends of the bars may be left flat.

3.26 Where combined surface water channel and pipe systems are used, the sub-surface drain shall be located between the pavement foundation construction and the channel.

NOTE Figure 3.26N shows a typical example of sub-surface drainage for a combined channel and pipe system.

Figure 3.26N Typical example of sub-surface drainage for combined channel and pipe system



3.26.1 Where a combined channel and pipe system is used, the calculated flow capacity of the sub-surface drainage pipe should be increased by 20%.

3.26.2 Where a type 5 or 6 fin drain is used, the geotextile should be fixed to the side of the channel.

3.26.3 Where a fin drain is used, the top of the fin drain pipe should be a minimum of 50 mm below the bottom of the capping layer or the base of the channel, whichever is the lower.

NOTE 1 The location of the sub-surface drainage renders this less accessible due to intermediate chambers being too shallow for connection from the fin drain. Therefore the diameter of the pipe is sized to accommodate some build-up of sediment during the life of the system.

NOTE 2 Due to the depth of a combined surface water channel and pipe system a Type 10 filter drain MCHW HCD Series F [Ref 14.N] cannot be used.

Grassed surface water channels

3.27 Outlets from grassed surface water channels shall have a transition zone in the form of an apron surrounding them constructed from concrete or plastic blocks.

NOTE 1 Figures 3.27N1a and 3.27N1b show a plan view of a typical intermediate and terminal outlet for a grassed surface water channel, including apron (see also Figure 3.28N1):

Figure 3.27N1a Typical intermediate outlet arrangement (plan view) for grassed surface water channel

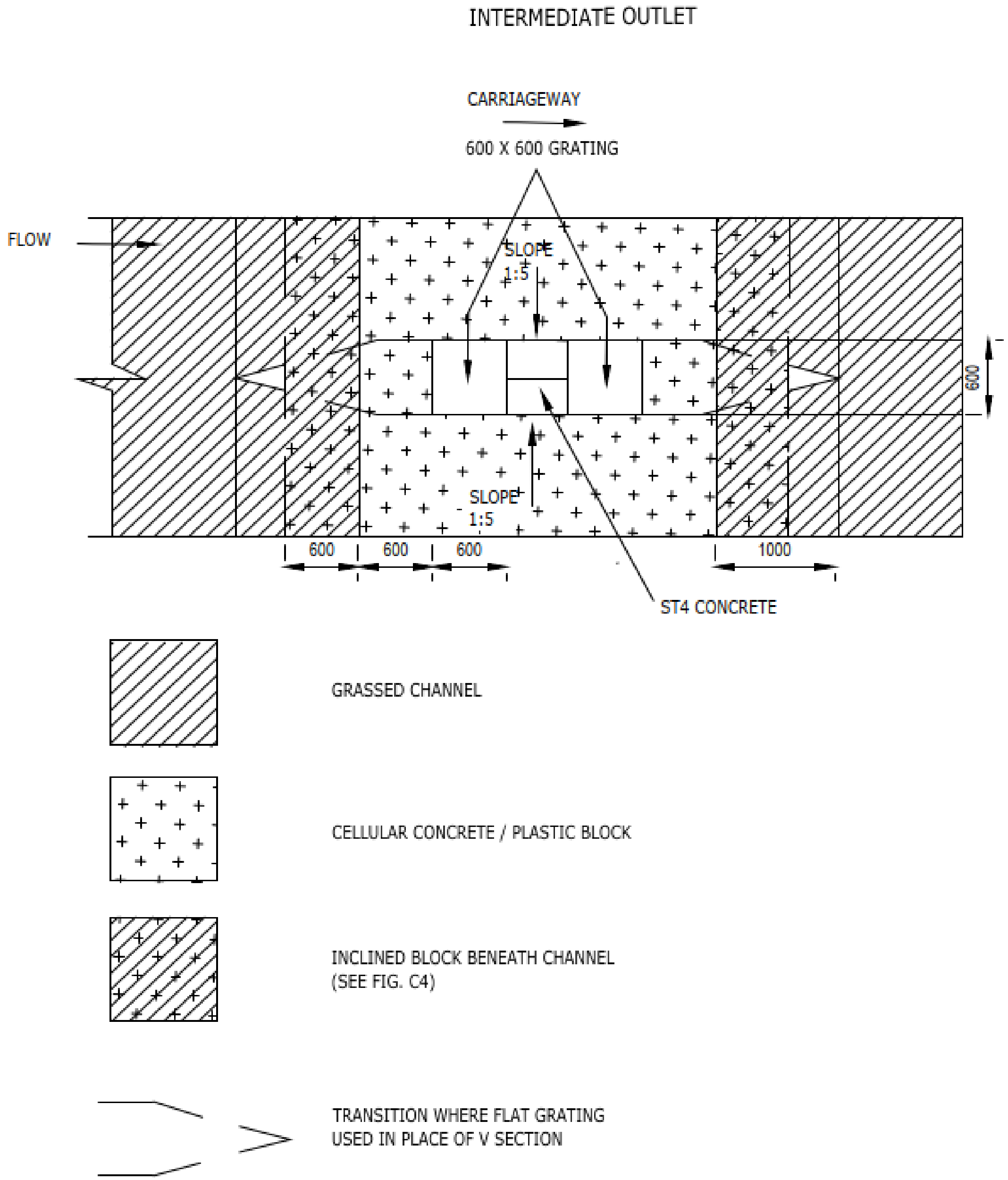
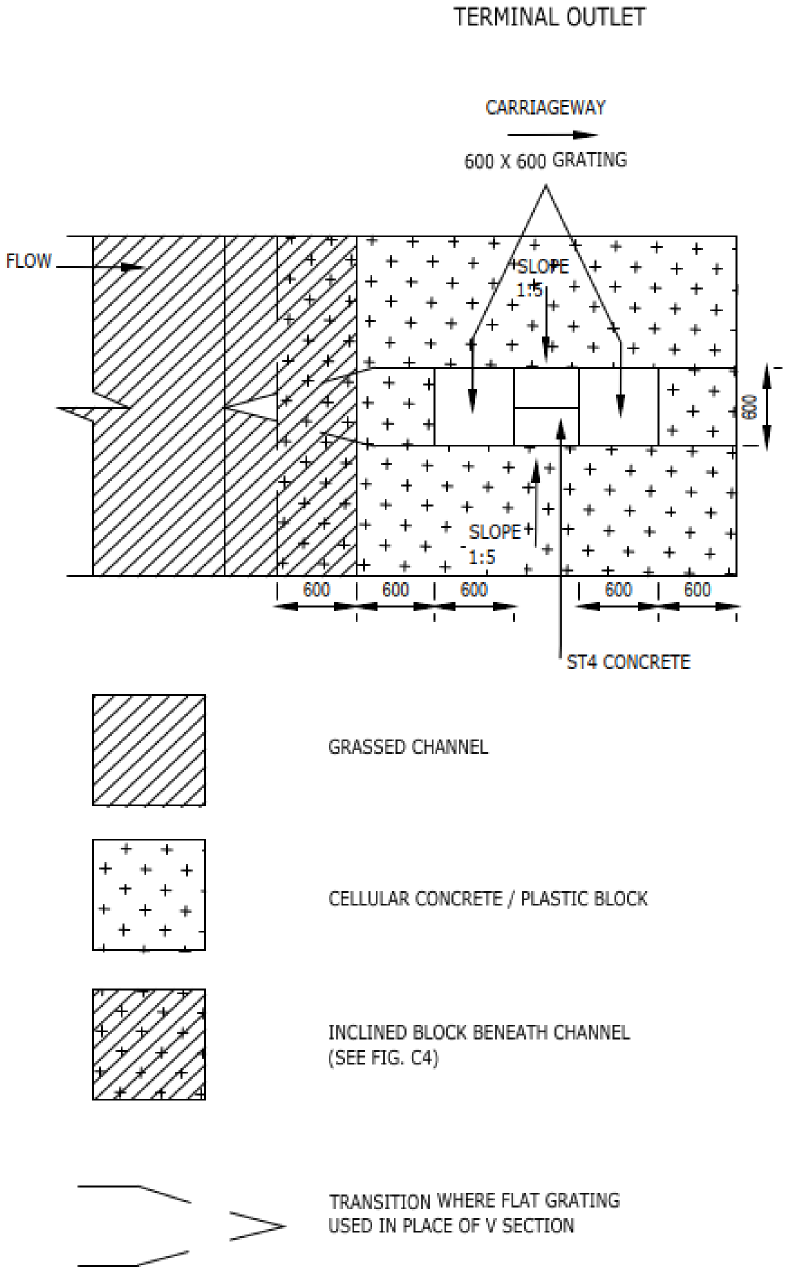


Figure 3.27N1b Typical terminal outlet arrangement (plan view) for grassed surface water channel

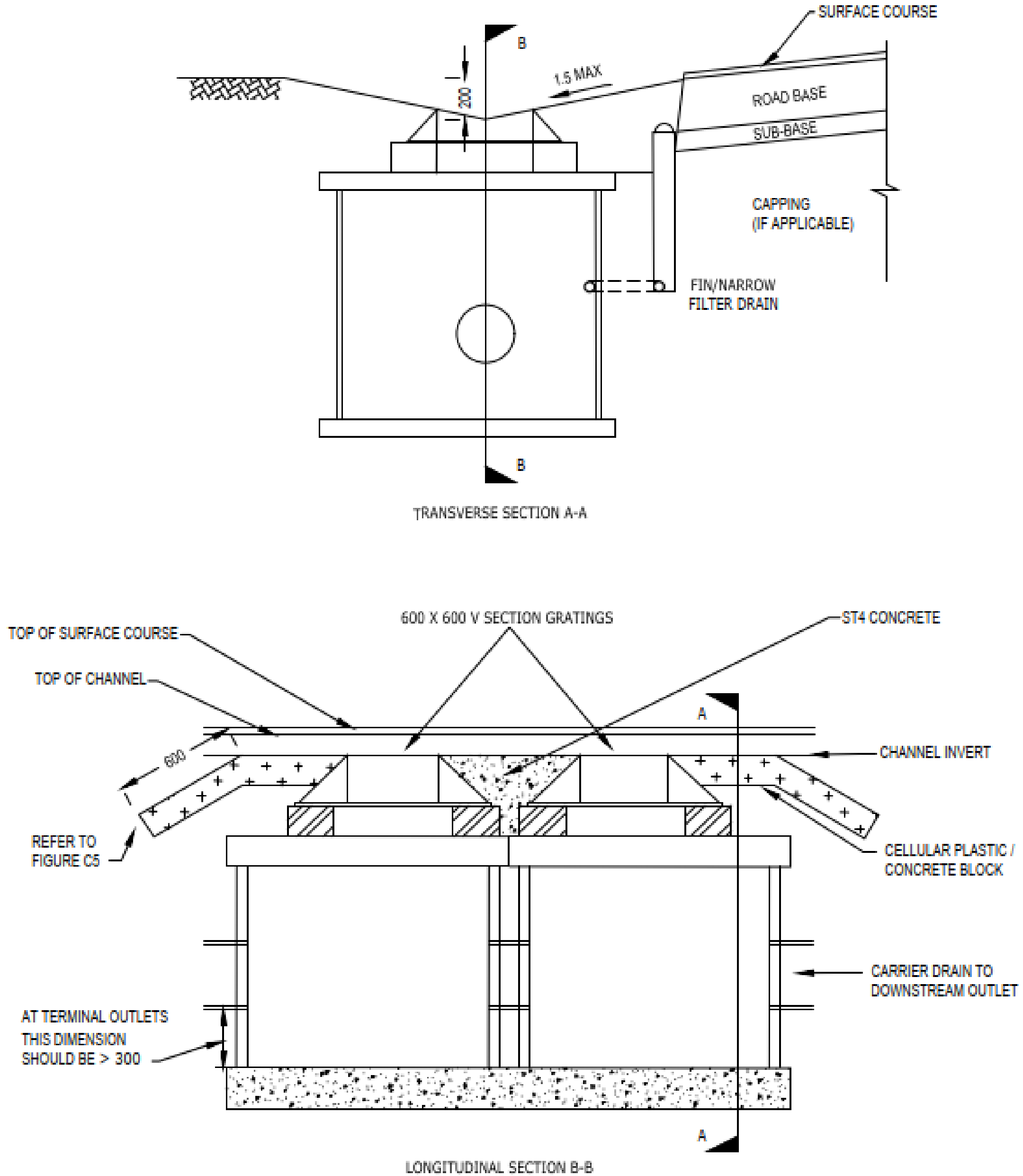


NOTE 2 *The outlets from the grassed surface water channel form a solid obstruction within an area of comparatively soft channel construction. Any vehicle wheel that impacts with the outlet structure or, if travelling at a high velocity, the vehicle itself could be damaged.*

3.28 The outlet apron concrete or plastic blocks shall incorporate holes for topsoil and grass growth, and be inclined to slope downwards from the edge of the outlet to below the channel.

NOTE 1 *Figure 3.28N1 shows a cross section through a typical grassed surface water channel outlet arrangement:*

Figure 3.28N1 Cross sections through typical grassed surface water channel outlet arrangement



NOTE 2 *The design of the apron absorbs much of the energy and protects both the vehicle and the structure.*

3.29 Where vehicle access across grassed surface water channels to communications equipment or other infrastructure for routine maintenance is required, particularly where there is only a 1 metre wide hardstrip, the channel shall be locally reinforced.

3.29.1 Locally reinforcing the channel in the vicinity of the communications equipment may take the form of a 200 mm thick layer of Type 1 sub-base on compacted formation, overlain by a 50 mm thick layer of hydro-seeded topsoil and erosion control matting.

Figure 3.29.1 Example of hydro-seeded trapezoidal grassed surface water channel shortly after construction (Photo courtesy of Norfolk County Council & Balfour Beatty)

NOTE *The suggested approach to locally reinforce the channel can be taken when early erosion control is important to prevent the loss of topsoil, and encourage the establishment of vegetation.*

3.29.2 Local reinforcement of the channel in the vicinity of the communications equipment may include reinforcing mats within the topsoil and grass roots, or proprietary grass surface reinforcement products.

Figure 3.29.2 Photograph showing an example of a grass reinforcing mat

3.30 Cohesive subsoil shall not be used in the construction of grassed surface water channels due to poor performance when driven over.

3.31 Where there is percolation through the bed of the surface water channel, flows shall be intercepted by a sub-surface drainage system before reaching the unbound pavement layers.

3.31.1 A Type 5 or 6 fin drain with a double cuspated core should be installed to provide sub-surface drainage, with the top of the fin drain located above the top of the pavement sub-base level.

3.31.2 Where a fin drain is installed, no part of the drain should protrude into the grassed topsoil.

Construction aspects

3.32 Where in-line outlets are proposed for a combined channel and pipe system, the channel shall have a minimum of 100 mm of concrete surround to the grating(s) frames (see Figure 2.4Na which shows a typical example).

3.33 Where intermediate outlet chambers are proposed for a combined channel and pipe system, the depth of concrete benching shall not be less than 75% of the diameter of the incoming pipe.

NOTE 1 Benching is normally constructed to the soffit level of the incoming pipe to fully contain flow, however vertical space between the underside of the cover slab and the pipe can be limited.

NOTE 2 Appendix M includes details on construction related aspects of combined channel and pipe systems, and grassed surface water channels.

Maintenance

3.34 Where long sections of barrier can impede maintenance of the grass, grassed surface water channels shall not be used.

NOTE *Appendix K includes details on maintenance related aspects of combined channel and pipe systems, and grassed surface water channels.*

4. Design process

Step 1: Selection of channel type

New highway construction

4.1 Where a surface water channel is located within the central reserve and a carrier drain is proposed, or an outfall is within the maximum length of road that can be drained by a channel, then a concrete, asphalt or grassed surface water channel shall be used.

4.2 Where a surface water channel is located within the verge or central reserve and there is no carrier drain proposed, or an outfall is not within the maximum length of road that can be drained by a channel, then a combined concrete channel and pipe shall be used.

4.3 Where a surface water channel is located within the verge and there is a proposed carrier drain, or an outfall is within the maximum length of road that can be drained by a channel, then a concrete, asphalt, or grassed surface water channel shall be used.

4.4 Where a surface water channel is located within the verge on an embankment (fill) and there is a proposed carrier drain, or an outfall is within the maximum length of road that can be drained by a channel, then a concrete, asphalt, or lined grassed surface water channel shall be used.

Existing highway

4.5 Where a surface water channel is located within the central reserve and an existing carrier drain is present, or an outfall is within the maximum length of road that can be drained by a channel, then a concrete, asphalt or grassed surface water channel shall be used.

4.6 Where a surface water channel is located within the verge or central reserve and there is no existing carrier drain present, or an outfall is not within the maximum length of road that can be drained by a channel, then a combined concrete channel and pipe shall be used.

4.7 Where a surface water channel is located within the verge and there is an existing carrier drain, or an outfall is within the maximum length of road that can be drained by a channel, then a concrete, asphalt, or grassed surface water channel shall be used.

4.8 Where a surface water channel is located within the verge on an embankment (fill) and there is an existing carrier drain, or an outfall is within the maximum length of road that can be drained by a channel, then a concrete, asphalt, or lined grassed surface water channel shall be used.

Step 2: Determine design inputs

4.9 Prior to commencing the calculations the following design inputs shall be determined:

1) storm return period;
2) rainfall;
3) catchment width;
4) channel geometry;
5) channel gradient; and,
6) channel roughness.

Step 3: Carry out calculations

4.10 Upon completion of the design inputs in step 2, the calculations shall be carried out in accordance with requirements of Section 5, as noted below:

1) length of road to be drained;
2) surface water channel design flow;
3) surcharged surface water channels;

4) hydraulic design of outlets; and,

5) drainage capacity of internal pipe for combined channels.

NOTE *Due to the nature of the calculations, there can be the need for some iteration, hence the work flow is not always linear and can need some earlier steps to be revisited.*

5. Design of surface water channels and associated outlets and pipes

Design inputs

Storm return period

5.1 Where surcharging is permitted, a surface water channel shall be designed to flow full for a storm with a return period of N = 1 year, and a check undertaken to ensure that a surcharged surface water channel does not overflow in a storm with a return period of N = 5 years.

5.1.1 Reference should be made to CG 501 [Ref 3.N] regarding the need to design surface water channels for storms of return periods higher than N = 1 year and N = 5 years.

NOTE 1 The maximum permissible widths of flooding are stated in CG 501 [Ref 3.N] as 1.0 m for all-purpose roads and 1.5 m for motorways.

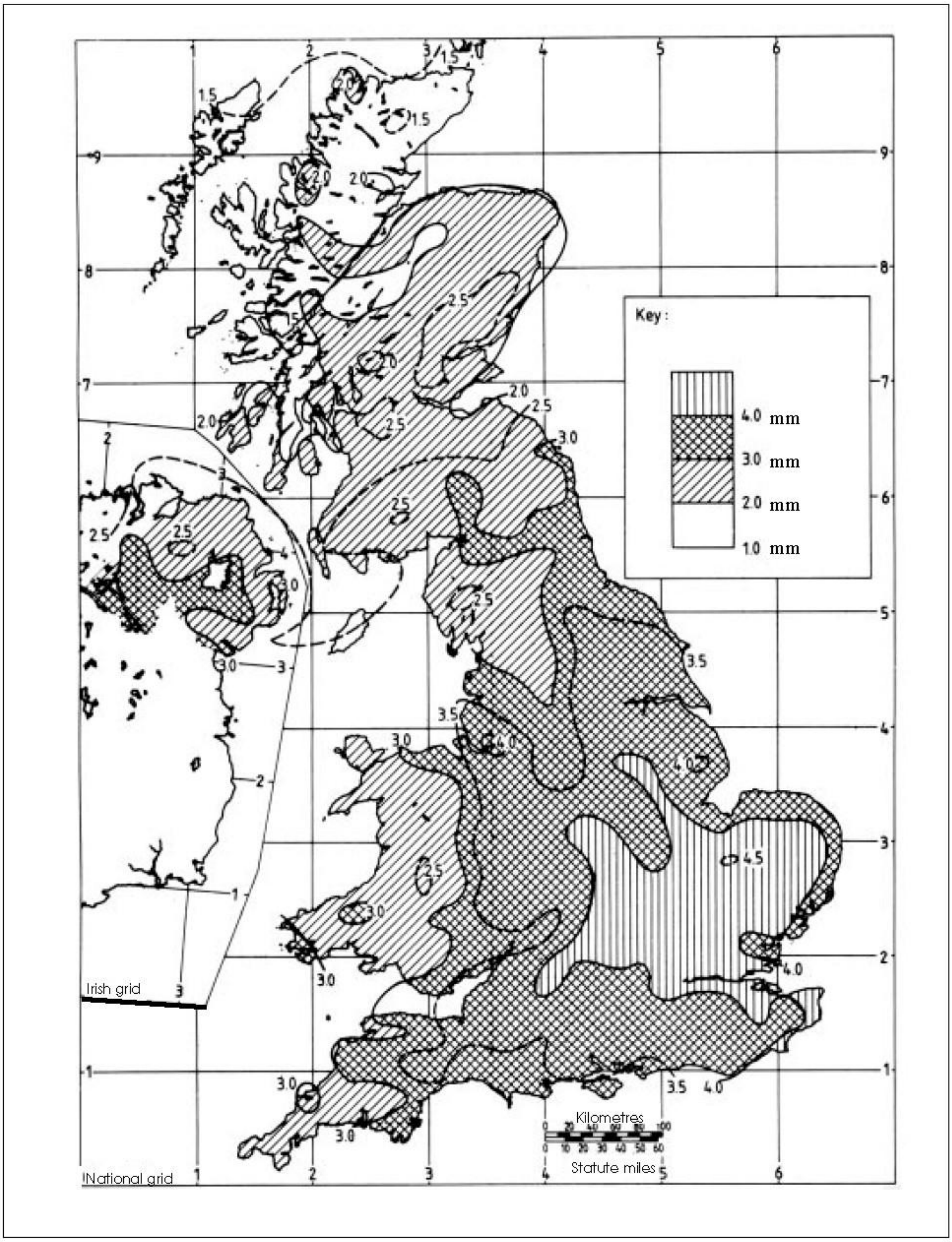
NOTE 2 The type of channel geometry shown in Figure H.1 and H.2 (see Appendix H) allow storms of higher return period to be accommodated without causing water to encroach beyond the edge of the hardstrip or hard shoulder. Further details on design depth dimensions is also provided.

5.2 Where surcharging is not permissible in the central reserve then the surface water channel shall be designed to flow full for a storm with a return period of N = 5 years to prevent water from encroaching on to the adjacent lane or overflowing on to the opposite carriageway.

Rainfall

5.3 The baseline value of 2minM5 for schemes in the UK shall be obtained from Figure 5.3 (taken from BS EN 12056-3 2000 [Ref 7.N]).

Figure 5.3 Values of 2minM5 rainfall depth for UK (reproduced from BS EN 12056-3: 2000 by permission British Standard Institution)



5.4 The baseline value of 2minM5 shall be increased to allow for the effects of climate change over the lifetime of the development by the percentage stated in CG 501 [Ref 3.N].

NOTE Further information relating to rainfall data, rainfall intensity and storm duration can be found in

Appendix E.

Catchment width

5.5 The effective catchment width W_e shall equal all impermeable surfaces draining to the surface water channel (including the surface water channel) plus an allowance (if necessary) for runoff from a cutting.

5.5.1 Minor local variations in W_e may be allowed for by using an average width, calculated by dividing the total effective area draining to an outlet by the drainage length L .

5.5.2 It should be assumed that 100% run-off occurs from concrete and black-top surfaces.

5.6 Field data shall be used to identify the amount of runoff from a cutting.

5.6.1 In the absence of suitable field data, W_e should be calculated from:

Equation 5.6.1 Effective width of a catchment

$$W_e = W + \alpha\overline{C}$$

where:

W_e	effective catchment width (m)
W	width of the impermeable part of the catchment (m)
α	run-off coefficient of the cutting
$\overline{C}$	average plan width of the cutting (m)

NOTE Details of the derivation of Equation 5.6.1 are given in Appendix C.

5.6.2 Values of the run-off coefficient coefficient α may be estimated from:

Table 5.6.2 Run-off coefficients for cuttings

Soil type	**Antecedent wetness**	α
High permeability	low medium high	0.07 0.11 0.13
Medium permeability	low medium high	0.11 0.16 0.20
Low permeability	low medium high	0.14 0.21 0.26

5.6.3 Appropriate choices of antecedent wetness for Northern Ireland, Scotland, Wales and English counties may be chosen from Table 5.6.3.

Table 5.6.3 Antecedent wetness categories

Low	Medium	High
Bedfordshire Buckinghamshire Cambridgeshire Essex Greater London Hertfordshire Norfolk Rutland Suffolk	Berkshire Cleveland Derbyshire Durham East Sussex Hampshire Hereford & Worcester Humberside Isle of Wight Kent Leicestershire Lincolnshire North Yorkshire Northamptonshire Northumberland Nottinghamshire Oxfordshire Shropshire South Yorkshire Staffordshire Surrey Tyne & Wear Warwickshire West Sussex West Yorkshire	Northern Ireland Scotland Wales Avon Cheshire Cornwall Cumbria Devon Dorset Gloucestershire Greater Manchester Lancashire Merseyside Somerset Wiltshire

NOTE *The basis of the data in Tables 5.6.2 and 5.6.3 is explained in Appendix C.*

Channel geometry

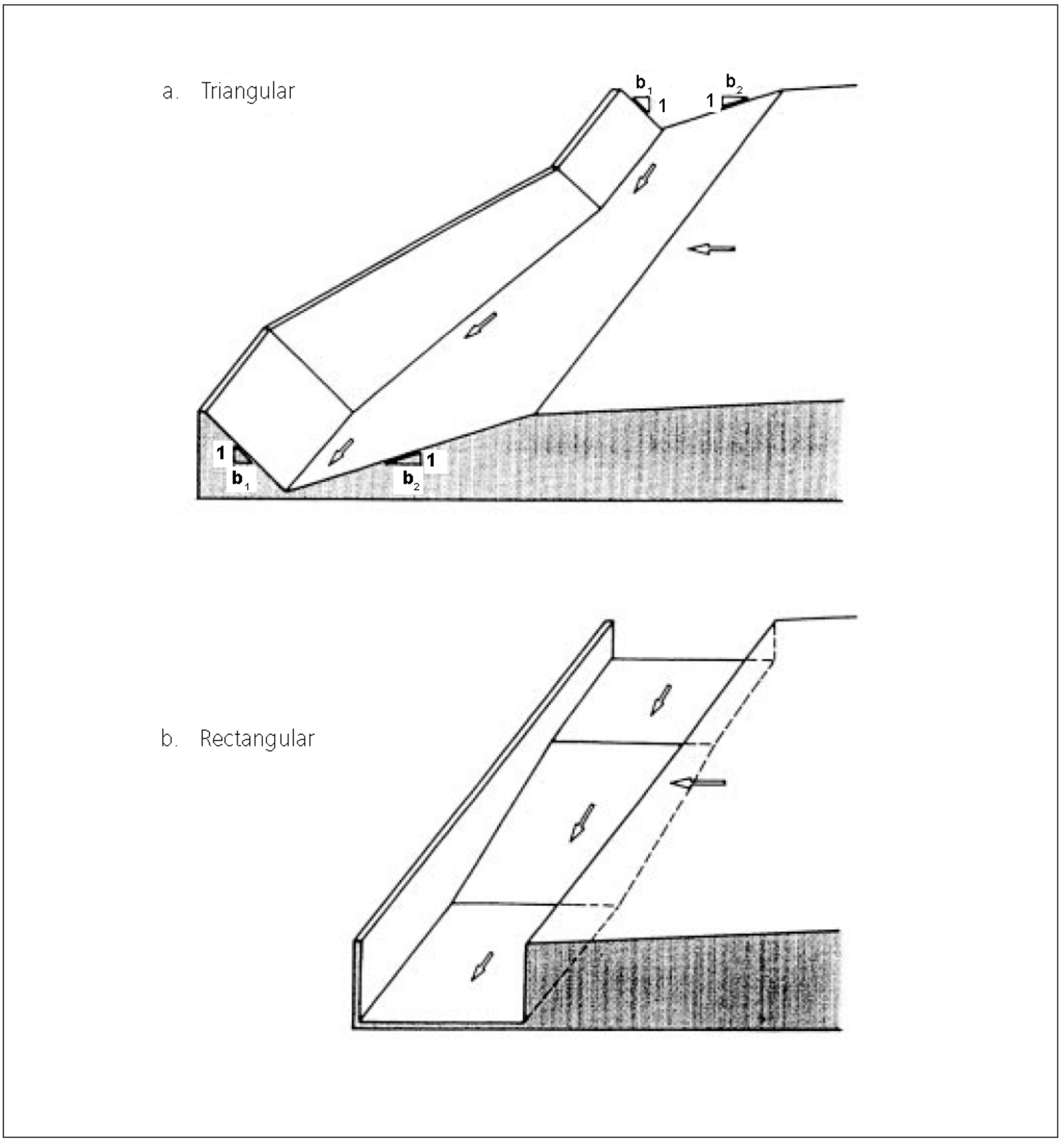
5.7 Where an increase in the size of a surface water channel is desired part way along a drainage length, transitions shall be gradual in order to minimise energy losses.

5.7.1 Where the invert is lowered, the length of the transition should not be less than 15 times the change in depth.

5.7.2 The side of a surface water channel at a transition should not diverge outwards from the longitudinal centre-line at an angle greater than 1:3 in plan.

5.7.3 Transitions for triangular and rectangular surface water channels shown in Figure 5.7.3 should be used.

Figure 5.7.3 Transitions for triangular and rectangular surface water channels



NOTE *In the case of a triangular profile, it is possible to deepen the channel without altering the cross-falls b_1 and b_2, and similarly a rectangular channel can be deepened while keeping the width B_b constant.*

5.8 The base of trapezoidal and rectangular surface water channels shall fall away from the carriageway edge at 1:40.

NOTE *The channel base cross-fall is needed to provide self-cleansing characteristics that are similar to those of conventional kerbed channels.*

5.9 The factor G_m for the surface water channel shape shall be calculated using Equation 5.9.

Equation 5.9 Factor for channel shape

$$G_m = 2.90 \times 10^6 (2.65 - m)$$

where:

G_m	factor for channel shape
m	shape characteristic parameter

5.10 The shape characteristics can be expressed in terms of a parameter which shall be defined using Equation 5.10.

Equation 5.10 Shape characteristic parameter m

$$m = \frac{By}{A} - 1$$

where:

m	shape characteristic parameter (-)
B	surface width of flow (m)
y	design depth of flow (m)
A	cross-sectional area of flow (m^2)

NOTE 1 The effect on flow capacity of a base section cross-fall for trapezoidal or rectangular surface water channels is very small and can be neglected.

NOTE 2 For a triangular profile m = 1, and for a rectangular profile m = 0. Trapezoidal channels can have values of m between 0 and 1.

5.11 For dished surface water channels, the surface flow width shall be calculated using Equation 5.11.

Equation 5.11 Surface flow width for dished surface water channels

$$B = cy^m$$

where:

B	surface width of flow (m)
c	variable coefficient (-)
y	design depth of flow (m)
m	shape characteristic parameter (-)

5.12 The effective cross-fall of the surface water channel shall be defined using Equation 5.12.

Equation 5.12 Effective cross-fall of a surface water channel

$$b = b_1 + b_2$$

5.13 The hydraulic radius R shall be calculated using Equation 5.13.

Equation 5.13 Hydraulic radius

$$R = \frac{A}{P}$$

where:

A	cross sectional area of flow (m^2)
P	wetted perimeter of flow (m)

5.14 The hydraulic-radius factor for a trapezoidal surface water channel shall be calculated using Equation 5.14.

Equation 5.14 Hydraulic radius factor for a trapezoidal surface water channel

$$r = \frac{B_b + (b_1 + b_2)y}{B_b + \left[\left(1 + {b_1}^2\right)^{\frac{1}{2}} + \left(1 + {b_2}^2\right)^{\frac{1}{2}}\right]y}$$

where:

b_1	slope of side of channel remote from carriageway (1 unit vertical: b_1 units horizontal)
b_2	slope of side of channel adjacent to carriageway (1 unit vertical: b_2 units horizontal)
B_b	base width of channel (m)

NOTE 1 For a wide shallow surface water channel, r tends towards unity.

NOTE 2 The effect of the base section cross-fall on flow capacity is very small and can be neglected.

5.15 The hydraulic-radius factor for a triangular surface water channel shall be calculated using Equation 5.15.

Equation 5.15 Hydraulic radius factor for a triangular surface water channel

$$r = \frac{b_1 + b_2}{\left(1 + {b_1}^2\right)^{\frac{1}{2}} + \left(1 + {b_2}^2\right)^{\frac{1}{2}}}$$

NOTE A triangular surface water channel with one side vertical can be catered for by putting b_1 = 0.

5.16 The hydraulic-radius factor for a rectangular surface water channel shall be calculated using Equation 5.16.

Equation 5.16 Hydraulic radius factor for a rectangular surface water channel

$$r = \frac{B_b}{B_b + 2y}$$

where:

B_b	base width of channel (m)
y	design depth of flow (m)

NOTE The effect of the base section cross-fall on flow capacity is very small and can be neglected.

Gradient

5.17 Where the gradient of a surface water channel (or pipe) varies with distance, an equivalent value of uniform slope shall be calculated using Equation 5.17.

Equation 5.17 Equivalent value of slope

$$S_e = 400\left[S_1^{-\frac{1}{2}} + S_{11}^{-\frac{1}{2}} + 2\sum_{j=2}^{j=10} S_j^{-\frac{1}{2}}\right]^{-2}$$

where:

S_e	equivalent value of uniform slope
S_j	local gradient determined at eleven equally-spaced points (j = 1 to 11)
S_1	gradient at the upstream end
S_{11}	gradient at the outlet

5.17.1 Where the longitudinally-varying gradient is locally zero (but not adverse) at the upstream or downstream end of a surface water channel or pipe, the zero value should be replaced in Equation 5.17 by the following.

Equation 5.17.1a Approach to amend zero values of S1

$$S_1 = \frac{S_2}{9}$$

Equation 5.17.1b Approach to amend zero values of S11

$$S_{11} = \frac{S_{10}}{9}$$

5.17.2 Where the gradient becomes zero at an intermediate point between the upstream and downstream ends of a length of the surface water channel, an outlet should be placed at the intermediate point and the surface water channel designed as two separate lengths.

Roughness

5.18 The hydraulic resistance of a surface water channel used in design shall depend upon its surface texture, the standard of construction, and the presence of deposited sediment.

5.18.1 Manning's roughness coefficients n given in Table 5.18.1 should be used for design of concrete or asphalt surface water channels.

Table 5.18.1 Values of Manning's roughness coefficents for surface water channels

Channel type	Condition	n
Concrete	Average	0.013
Concrete	Poor	0.016
Asphalt	Average	0.017
Asphalt	Poor	0.021

NOTE Further information about the factors influencing the hydraulic resistance is given in Appendix D.

5.19 For grassed surface water channels, the Manning's roughness coefficient shall be calculated using Equation 5.19.

Equation 5.19 Manning's roughness coefficent for grassed surface water channels

$$n = \frac{0.05}{1 - \frac{m_g H}{R^{\frac{5}{3}} S^{\frac{1}{2}}}}$$

where:

H	grass height (assume H = 0.05m for fescues-dominated mixture and 0.075m for perennial rye grass-dominated mixture)
m_g	coefficent relating to grass type ($m_g =$ 0.0048 for perennial rye grass and 0.0096 for fescues-dominated mix.)

NOTE 1 Values of n are typically within the range 0.05 to 0.1.

NOTE 2 Alternative approaches to calculate n are detailed in Appendix D.

NOTE 3 Information on grass selection is provided in Appendix J.

Calculations

Length of road to be drained by a surface water channel

5.20 The maximum length of road that can be drained by a section of surface water channel shall be calculated using Equation 5.20.

Equation 5.20 Length of road that can be drained by a surface water channel

$$L = G_m \frac{S^{\frac{1}{2}}}{n} (ry)^{\frac{2}{3}} (N - 0.4)^{-0.362} \left[\frac{A}{W_e(\text{2minM5})} \right]^{1.62}$$

where:

L	length of road/ surface water channel between two adjacent outlets on a continuous slope, or the distance between a point of zero slope and the downstream outlet (m)
G_m	factor for channel shape (-)
S	longitudinal gradient of the surface water channel (m/m)
r	hydraulic-radius factor (-)
y	design depth of flow (m)
N	design return period (years)
W_e	effective width of the catchment (m)
A	cross-sectional area of flow (m^2)
2minM5	rainfall depth occurring in 2 minutes with return period of 5 years (mm)

NOTE 1 Equation 5.20 is valid for all types of triangular, rectangular or trapezoidal channel provided the cross-sectional shape factors b_1, b_2 and B_b (as appropriate - see Figure 2.2) do not vary with the depth of flow or with distance along the drainage length.

NOTE 2 The effect of a base section cross-fall for trapezoidal or rectangular surface water channels on flow capacity is very small and can be neglected.

NOTE 3 The total length of road that can be drained by a combined channel and pipe system is a function of both channel and pipe capacity. Refer to the drainage capacity of internal pipes section.

NOTE 4 Use of Equation 5.20 to determine the maximum length of road to be drained does not take account of bypassing at outlets.

5.20.1 Where a symmetrical triangular surface water channel is desired then the length of road that can be drained may be calculated using Equation 5.20.1.

Equation 5.20.1 Length of road that can be drained by a symmetrical triangular surface water channel

$$L = 1.56 \times 10^6 \frac{(By)^{2.29}}{(B^2+4y^2)^{\frac{1}{3}}} \frac{S^{\frac{1}{2}}}{n} \frac{(N-0.4)^{-0.362}}{[W_e(\text{2minM5})]^{1.62}}$$

where:

B	surface width of flow (m)
y	design depth of flow (m)

5.21 Where the size of a triangular surface water channel for a given length of road needs to be determined, the design depth of flow shall be calculated using Equation 5.21.

Equation 5.21 Depth of flow for triangular surface water channel

$$y = 2.60 \times 10^{-2} \left(\frac{nL}{S^{\frac{1}{2}}}\right)^{0.256} r^{-0.171} (N-0.4)^{0.093} \left[\frac{W_e(\text{2minM5})}{b}\right]^{0.415}$$

where:

b	effective cross fall ($= b_1 + b_2$)
y	design depth flow (m)
n	Manning's roughness coefficient
L	length of road to be drained (m)
S	longitudinal gradient of the surface water channel (m/m)
r	hydraulic radius factor (-)
N	design return period (years)

NOTE Equation 5.21 is valid for all types of triangular surface water channel provided the cross-sectional shape factors b_1 and b_2 do not vary with the depth of flow or with distance along the drainage length.

5.22 Where the size of a rectangular surface water channel for a given length of road needs to be determined, the design depth of flow shall be calculated using Equation 5.22.

Equation 5.22 Depth of flow for rectangular surface water channel

$$y = 9.75 \times 10^{-4}\left(\frac{nL}{S^{\frac{1}{2}}}\right)^{0.437}\left(1+\frac{2y}{B_b}\right)^{0.292}(N-0.4)^{0.158}\left[\frac{W_e(\text{2minM5})}{B_b}\right]^{0.708}$$

where:

y	design depth of flow (m)
n	Manning roughness coefficient (s/m$^{\frac{1}{3}}$)
L	length of road to be drained (m)
S	longitudinal gradient of the surface water channel (m/m)
B_b	base width of the channel (m)
N	design return period (years)
W_e	effective width of the catchment (m)
2minM5	rainfall depth occurring in 2 minutes with return period of 5 years (mm)

NOTE 1 To determine the design depth of flow, the unknown flow depth appears on both sides of Equation 5.22 and some iteration is needed to find the solution.

NOTE 2 Equation 5.22 is valid for rectangular surface water channels provided the cross-sectional shape factor B_b does not vary with the depth of flow or with distance along the drainage length.

NOTE 3 The effect of a base section cross-fall for rectangular surface water channels on flow capacity is very small and can be neglected.

5.23 For trapezoidal channels, flow depth, y , shall be determined using the following design procedure:

1) make an initial estimate of the size and shape of channel needed;
2) calculate the flow area A and the hydraulic-radius factor r ;
3) determine the values of the shape characteristic parameter m , and the factor of channel shape G_m ;
4) calculate the length L of road that can be drained and compare with the required length; and,
5) revise the channel geometry and repeat steps (1) to (4) until the required drainage length is achieved.

NOTE No general equation for directly determining flow depth, y , in trapezoidal channels can be obtained because different solutions are possible depending on the chosen values for base width and side slope.

5.24 Where a trapezoidal channel size varies part way along the length, the design of the smaller, upstream channel shall be checked to ensure that it has the capacity to drain the length of road upstream of the transition point.

5.24.1 The capacity of the larger, downstream channel should be similarly checked using the overall length of road draining to the outlet.

5.24.2 The larger downstream channel should be designed assuming a drainage length 5% greater than the actual length draining to the outlet.

NOTE For transitions in trapezoidal surface water channels, it is not possible to keep all the shape factors b_1, b_2 and B_b constant. For this reason, the drainage length used when designing the downstream length of the surface water channel is 5% greater than the actual length draining to the outlet.

Surface water channel design flow

5.25 The flow rate of the surface water channel shall be calculated from the Manning resistance equation in Equation 5.25.

Equation 5.25 Manning resistance equation

$$Q = \frac{AR^{\frac{2}{3}}S^{\frac{1}{2}}}{n}$$

where:

Q	flow rate (m^3/s)
A	cross sectional area of flow (m^2)
R	hydraulic radius of flow (m)
S	longitudinal gradient of channel (m/m)
n	Manning's roughness coefficient

5.25.1 The design flow for a trapezoidal channel should be calculated using Equation 5.25.1.

Equation 5.25.1 Design flow for a trapezoidal channel

$$Q = \frac{S^{\frac{1}{2}}}{n}\left[\frac{(2B_b + by)^5}{32(B_b + by)^2}r^2y^5\right]^{\frac{1}{3}}$$

where:

B_b	base width of channel (m)
b	effective cross-fall
y	design depth of flow (m)
r	hydraulic-radius factor

5.25.2 The design flow for a triangular channel should be calculated using Equation 5.25.2.

Equation 5.25.2 Design flow for a triangular channel

$$Q = \frac{bS^{\frac{1}{2}}}{n}\left[\frac{r^2y^8}{32}\right]^{\frac{1}{3}}$$

5.25.3 The design flow for a triangular channel of symmetrical cross-section may be calculated using Equation 5.25.3.

Equation 5.25.3 Design flow for a symmetrical triangular channel

$$Q = 0.315\frac{(By)^{\frac{5}{3}}}{(B^2 + 4y^2)^{\frac{1}{3}}}\frac{S^{\frac{1}{2}}}{n}$$

where:

B	surface width of flow (m)
y	design depth of flow in the symmetrical triangular channel (m)

5.25.4 The design flow for a rectangular channel should be calculated using:

Equation 5.25.4 Design flow for a rectangular channel

$$Q = \frac{B_b S^{\frac{1}{2}}}{n} \left[r^2 y^5\right]^{\frac{1}{3}}$$

where:

B_b	base width of channel (m)
y	design depth of flow (m)

Surcharged surface water channels

5.26 An estimate of the length of road that can be drained, and the flow along a surcharged channel shall be obtained using equations set out in Section 5 of this document.

5.26.1 The cross sectional area, hydraulic-radius factor and shape factor for an equivalent surface water channel should be defined using equations set out in Section 5 of this document.

5.26.2 An alternative approach for estimating the maximum flow capacity of a symmetrical triangular surface water channel under surcharged conditions may be estimated from Equation 5.26.2.

Equation 5.26.2 Maximum flow for symmetrical triangular surface water channels

$$Q_s = 1.575 \phi Q_c$$

where:

Q_s	maximum flow capacity under surcharge conditions when N=5 years (m^3 /s)
Q_c	design capacity of a surface water channel just flowing full when N=1 year (m^3 /s)
ϕ	surcharge factor (ratio between drainage length for surcharged channel and drainage length for channel just flowing full)

NOTE *ϕ can be estimated using Figure F.1 or F.2., or Table F.1 in Appendix F.*

5.26.3 An alternative approach for estimating the maximum length of road that can be drained by a symmetrical triangular surface water channel under surcharged conditions may be estimated from Equation 5.26.3.

Equation 5.26.3 Maximum length of road that can be drained by a symmetrical triangular surface water channel

$$L_s = \phi L_c$$

where:

L_s	maximum length of road that can be drained under surcharge conditions when N=5 years (m)
L_c	length of road that can be drained when N=1 year (m)

NOTE 1 *This simplified method provides an estimate of L_s that tends to be conservative.*

NOTE 2 *ϕ can be estimated using Figure F.1 or F.2 or Table F.1 in Appendix F.*

5.27 The cross-sectional area of the surcharged surface water channel shall be calculated using Equation 5.27.

Equation 5.27 Surcharged cross sectional area

$$A = \frac{1}{2}\left[(b_1 + b_2)y_3^2 - b_2(y_3 - y_1)^2 + b_3(y_3 - y_2)^2 + 2B_b y_3\right]$$

where:

y	design depth of flow (m)
y_1	depth of channel from lower edge of carriageway to centre line of invert (m)
y_2	depth of channel from top edge of carriageway to centre line of invert (m)
y_3	overall depth of surcharged channel to centre line of invert (m)
b_3	transverse slope of carriageway adjacent to channel (1 unit vertical: b3 units horizontal)

NOTE 1 Equation 5.27 is defined for a trapezoidal surface water channel, but can be applied to the case of a triangular surface water channel (with B_b = 0) or a rectangular surface water channel (with b_1 =0= b_2).

NOTE 2 Where the surface water channel can be constructed without a step between the inner edge of the channel and the top edge of the carriageway, $y_2 = y_1$.

5.28 The hydraulic-radius factor for an equivalent surcharged surface water channel shall be calculated using Equation 5.28.

Equation 5.28 Surcharged hydraulic-radius factor

$$r = \frac{b_1 y_3 + b_2 y_1 + b_3(y_3 - y_2) + B_b + (y_2 - y_1)}{(b_1^2 + 1)^{\frac{1}{2}} y_3 + (b_2^2 + 1)^{\frac{1}{2}} y_1 + (b_3^2 + 1)^{\frac{1}{2}} (y_3 - y_2) + B_b + (y_2 - y_1)}$$

NOTE Equation 5.28 is defined for a trapezoidal surface water channel, but can be applied to the case of a triangular surface water channel (with B_b = 0) or a rectangular surface water channel (with b_1 =0= b_2).

5.29 The shape factor for the equivalent surcharged surface water channel shall be calculated using Equation 5.29.

Equation 5.29 Shape factor for the equivalent surcharged surface water channel

$$m = \frac{1}{2}\left[X - 1 + \left(X^2 + \frac{14}{3}X + 1\right)^{\frac{1}{2}}\right]$$

NOTE Values of m for equivalent surface water channels can be greater than unity.

5.30 X for an equivalent surcharged surface water channel shall be calculated using Equation 5.30.

Equation 5.30 Value of X

$$X = \frac{K}{y_3^{\frac{2}{3}} A}$$

where:

K	= Hydraulic conveyance factor

5.31 The hydraulic conveyance factor for an equivalent surcharged surface water channel shall be calculated using Equation 5.31.

Equation 5.31 Surcharged hydraulic conveyance factor

$$K = \frac{3}{8}\left[(b_1 + b_2)y_3^{\frac{8}{3}} - b_2(y_3 - y_2)^{\frac{8}{3}} + \left(\frac{n}{n_c}\right)b_3(y_3 - y_2)^{\frac{8}{3}} + \frac{8}{3}B_b y_3^{\frac{5}{3}}\right]$$

where:

n_c = Manning roughness coefficient of the carriageway

NOTE Equation 5.31 is defined for a trapezoidal surface water channel, but can be applied to the case of a triangular surface water channel (with B_b = 0) or a rectangular surface water channel (with b_1 =0= b_2).

Design of channel outlets

5.32 The channel outlet design methods shall apply to symmetrical triangular channels with cross-falls of 1:5 and also to channels with trapezoidal cross section and cross-falls of 1:4.5 or 1:5.

5.32.1 Channel outlets should be designed as either intermediate or terminal according to their position along the channel.

5.32.2 The design methods may be used for three alternative geometries of outlet:

1) in-line outlet, where the water is collected symmetrically from either side of the channel invert;
2) off-line outlet, where the channel is widened away from the carriageway and the outlet is off-set from the centre-line of the channel; and,
3) weir outlet, which is appropriate for steep slopes (typically > 1:50) where the water is directed towards a side weir and collecting channel.

5.32.3 Where longitudinal gradient, S , of roads and channels is steeper than 1:50, grassed surface water channels should not be used.

NOTE 1 The design procedure involves selecting the type of outlet (in-line, off-line or weir outlet) and the number of gratings needed to achieve the required hydraulic performance. The number of gratings can vary from one to three depending on the channel type and amount of flow approaching the outlet.

NOTE 2 The geometry of each type of outlet is shown in Figures H.5 to H.10 (see Appendix H). The size of the gratings is related to the size of the channel.

NOTE 3 The channel outlet design methods were developed from laboratory tests as detailed in HR Wallingford Report SR 406 (1996) and supported by experimental testing and analysis detailed in HRW SR 406 [Ref 17.I] and HRW SR 585, [Ref 1.I].

5.33 The outlet design shall be based on a minimum waterway area (defined as the total area of openings) of $0.44G_g^2$, where G_g is the width of the grating.

5.34 The in-line outlet geometry for triangular channels shall consist of pairs of gratings positioned on the side slopes of the channel.

5.35 The spacing between pairs of in-line gratings in triangular channels shall not be less than $1.7G_g$ (see Figure H.5 in Appendix H).

5.36 The size of gratings for in-line outlets in triangular channels shall be chosen so that the ratio of width G_g over the depth of channel y_1 is within the following limits:

Equation 5.36 Outlet grating size limits

$$4.5 \leq \frac{G_g}{y_1} \leq 5.1$$

NOTE The lower limit corresponds to the minimum width of grating required to achieve the required hydraulic performance. The upper limit corresponds to the widest grating that can be installed in the channel.

5.37 The off-line outlet geometry for triangular channels shall be as shown in Figure H.6 (see Appendix H).

NOTE In the arrangement for Figure H.6, the side slope on the road side is extended below the invert of the channel to produce a ponding effect over the gratings which increases the efficiency of the outlet.

5.38 The spacing between pairs of off-line gratings in triangular channels shall not be less than $1.25G_g$.

5.39 The width of gratings for off-line outlets in triangular channels shall be determined by Equation 5.39.

Equation 5.39 Width of gratings for outlets in triangular channels

$$\frac{G_g}{y_1} \geq 4.5$$

5.40 The in-line outlet geometries for trapezoidal channels shall be as shown in Figures H.7 and H.9 (see Appendix H).

5.41 The width of gratings for in-line outlets in trapezoidal channels shall be determined by Equation 5.41.

Equation 5.41 Width of gratings for in-line outlets in trapezoidal channels

$$\frac{G_g}{y_1} = 3.0$$

5.42 The off-line outlet geometries for trapezoidal channels shall be as shown in Figures H.8 and H.10 (see Appendix H).

5.43 The width of gratings for offline outlets in trapezoidal channels shall be determined by Equation 5.43.

Equation 5.43 Width of gratings for off-line outlets in trapezoidal channels

$$\frac{G_g}{y_1} \geq 4.0$$

5.44 The required length H_g of each outlet grating for triangular and trapezoidal channels shall be given by: $H_g \geq G_g$

5.45 The hydraulic design of intermediate outlets shall be based on the design curves shown in Figures H.11 to H.22 (see Appendix H), which give the numbers of gratings needed to achieve the required performance at the outlet for channel full and surcharged conditions.

5.45.1 The design of triangular channels should be based on the use of either one, two or three pairs of gratings (see Figures H.11 to H.14 in Appendix H).

5.45.2 The design of trapezoidal (higher capacity) channels should be based on the use of either two or three pairs of gratings (see Figures H.15 to H.22 in Appendix H).

5.45.3 Outlets should be designed for channel-full conditions (i.e. the 1 year return period event) and the performance checked for surcharged flow conditions using Figures H.12, H.14, H.16, H.18, H.20 and H.22 (see Appendix H), which corresponds to a width of surcharging of 1 m.

NOTE The design curves show the variation in efficiency of each outlet with the flow conditions.

5.46 When referring to the design curves, a non-dimensional number shall be used to represent flow conditions, defined as F_d for channel full and F_s for surcharged channel, determined by Equations 5.46a to 5.46f.

Equation 5.46a Triangular channel full

$$F_d = \frac{28.6 Q_d}{B_d^{2.50}}$$

Equation 5.46b Triangular channel surcharged

$$F_s = \frac{24.6 Q_s}{B_s^{2.50}}$$

Equation 5.46c Trapezoidal channel full (1:4.5 side slope)

$$F_d = \frac{25.6 Q_d}{B_d^{2.50}}$$

Equation 5.46d Trapezoidal channel (1:4.5 side slope) surcharged

$$F_s = \frac{22.2 Q_s}{B_s^{2.50}}$$

Equation 5.46e Trapezoidal channel (1:5 side slope) full

$$F_d = \frac{29.8 Q_d}{B_d^{2.50}}$$

Equation 5.46f Trapezoidal channel (1:5 side slope) surcharged

$$F_s = \frac{25.5 Q_s}{B_s^{2.50}}$$

where:

Q_d	is the approach flow (in m^3/s) corresponding to channel full conditions (i.e. flow depth y_1)
Q_s	is the approach flow (in m^3/s) corresponding to surcharged channel conditions (i.e. flow depth y_3)
B_d	is the surface width of the flow (in m) for channel full conditions
B_s	is the surface width of the flow (in m) in a surcharged channel neglecting the width of surcharge on the hard strip or hard shoulder - see Figures H.1 and H.2

5.46.1 Calculation of the flow rate for channel-full conditions, Q_d , and surcharged channel conditions, Q_s , should be based on Manning's resistance equation, as set out in Equation 5.25.

5.46.2 When checking for surcharged conditions, an estimate of flow rate Q_s may be taken from Figure H.3 for triangular channels and H.4 for trapezoidal channels (see Appendix H).

NOTE The curves in Figure H.3 and H.4 in Appendix H are based on 1 m width of surcharging of the carriageway at cross-falls of 1:30, 1:40 and 1:60. The value of Q_s/Q_d can be read from the curves and, with Q_d calculated using Manning's resistance equation, the value of Q_s can be determined.

5.47 Values of outlet efficiency, η_d for channel-full and η_s for surcharged conditions, shall be determined from design curves H.11 to H.22 in Appendix H.

5.47.1 The efficiency of an outlet may be defined as the ratio of the flow intercepted by the outlet, Q_i , to the total flow approaching it, expressed by Equations 5.47.1a and 5.47.1b.

Equation 5.47.1a Outlet efficiency for channel full

$$\eta_d = \frac{Q_i}{Q_d}$$

Equation 5.47.1b Outlet efficiency for surcharged conditions

$$\eta_s = \frac{Q_i}{Q_s}$$

5.48 Intermediate outlets operating under channel-full conditions shall not be designed for efficiencies of less than 80%.

NOTE Although outlet efficiencies of 100% can be considered desirable, more economic designs can be achieved by allowing a certain amount of flow to by-pass intermediate outlets.

5.48.1 Outlet gratings for grassed surface water channels should be designed on 100% efficiency.

NOTE Velocities in grassed channels are low in comparison with concrete, so even under surcharged conditions, the volume of flow bypassing the gratings would be minimal.

5.49 When by-pass flow is allowed in the design of an intermediate outlet (that is when efficiencies are lower than 100%) a reduction in the spacing of the outlets, or an increase in channel capacity, shall be made to allow for additional flow by-passing the upstream outlet.

5.49.1 Where flow bypassing at intermediate outlets is permitted, the distance between outlets should be reduced to ηL , where η is the collection efficiency of the upstream outlet, and L is the length of road that could be drained if there were no bypassing at the upstream outlet.

5.49.2 Where flow bypassing at intermediate outlets is permitted, the downstream channel size may be increased so that it is able to drain a length, provided other design requirements in this document are met:

Equation 5.49.2 Length of road to be drained, for use in channel design where bypassing is permitted at intermediate outlets

$$L_B = L + \frac{1}{2}(1-\eta)L_U$$

where:

L_U	length of surface water channel upstream of the intermediate channel
L	length of surface water channel downstream of the intermediate outlet
L_B	the length of road that can be drained where bypassing is permitted
η	collection efficiency of outlet (efficiency of 80% corresponds to η =0.8)

5.50 Terminal outlets shall be designed to achieve minimum efficiencies of 97.5%.

5.50.1 For the design of terminal outlets values of F_d and F_s should be calculated using equations set out in section 5.46 of this document.

5.50.2 The value of F_d should be compared with the limiting values given in Table G.1 (for triangular channels) or Tables G.2 and G.3 (for trapezoidal channels) (see Appendix G for Tables).

5.50.3 The type of outlet selected should have a limiting value of F_d that is not less than the calculated value.

NOTE The values presented in Tables G.1, G.2, and G.3 for terminal outlets correspond to efficiencies of 97.5%.

5.51 Where a longitudinal bar pattern grating is used, an adjustment to the calculated efficiencies for both intermediate and terminal outlets shall be made.

5.51.1 Where η_D is the efficiency corresponding to a diagonal bar pattern, the efficiency η_L corresponding to a longitudinal bar pattern should be estimated by Equation 5.51.1.

Equation 5.51.1 Efficiency of logitudinal bar grating

$$\eta_L = 0.5 + 0.5\eta_D$$

NOTE 1 The design curves shown in Figures H.11 to H.22 (see Appendix H) are based on tests carried out with gratings having a diagonal bar pattern. Comparing the performance of gratings equivalent in terms of overall size and waterway area, longitudinal bars are more efficient that diagonal bars.

NOTE 2 Where the outlet is located adjacent to the carriageway and in front of any vehicle restraint system, use of a longitudinal bar pattern grating can present a hazard to cyclists and provide a lower skidding resistance than diagonal bars.

5.52 Where it is not possible to achieve minimum efficiencies of 80% for intermediate outlets and 97.5% for terminal outlets (for both in-line and off-line arrangements) a weir outlet shall be used.

NOTE 1 The flow collecting efficiency of an outlet decreases as the steepness of the surface water channel (steeper than 1:50) and velocity of flow within it are increased.

NOTE 2 A weir outlet functions by gradually directing water away from the carriageway and discharging it over a side weir into a collecting channel (see Figures H.23 and H.24 in Appendix H for layout).

5.53 Where a weir outlet is used, a vehicle restraint system shall be installed along the carriageway side of the collecting channel (see layout in Figure H.23 in Appendix H).

5.54 The procedure for designing weir outlets shall be as set out in the flow charts shown in Figures H.26 (for triangular channels), H.27 and H.28 (for trapezoidal channels), set out in Appendix H.

5.55 The total length, L_w , of the weir outlet shall comprise a straight length, L_r , parallel to the edge of the carriageway and a length, L_a , at an angle to the carriageway (see Figure H.24 in Appendix H).

5.56 L_r shall be equal to B_t , the surcharged width of the channel at the downstream end of the transition, so that in Equation 5.56:

Equation 5.56 Weir outlet geometry

$$\frac{L_w}{B_t} = 1 + \frac{1}{\tan\theta}$$

5.56.1 The values of the ratio $\frac{L_w}{B_t}$ and θ should be obtained from Figure H.25 in Appendix H and are dependent on the non-dimensional number, F_d , set out in section 5.46 of this document, which is calculated for design flow conditions in the upstream surface water channel.

5.56.2 The straight and angled portions of the weir outlet, L_r and L_a respectively, should be joined by a curved side transition with its upstream end at the mid-point of length L_r .

5.57 For triangular channels, in the transition section upstream of the weir outlet, the cross-falls and overall depth of the channel shall remain constant.

5.58 The triangular cross-section shape of the upstream channel shall transition to a trapezoidal cross-section in order to reduce the depth of flow approaching the weir outlet.

5.58.1 For triangular channels with side slopes of 1:5, the length, L_t , of the transition and the base width, B_b , at the downstream end should be determined by Equations 5.58.1a and 5.58.1b.

Equation 5.58.1a Weir outlet transition length - triangular channel 1:5 side slopes

$$L_t = 25y_1$$

Equation 5.58.1b Weir outlet base width - triangular channel 1:5 side slopes

$$B_b = 5y_1$$

where:

y_1	is the design flow depth in the surface water channel upstream of the transition (see Figure H.1 in Appendix H)

5.59 For trapezoidal channels, in the transition section upstream of the weir outlet, the cross-falls and overall depth of the channel shall remain constant but base width increased (from a value of $2y_1$ at the upstream end) in order to reduce design flow depth approaching the weir outlet.

5.59.1 For trapezoidal channels with 1:4.5 side slopes, the length, L_t , of the transition and the base width, B_b , at the downstream end should be determined by Equations 5.59.1a and 5.59.1b.

Equation 5.59.1a Weir outlet transition length - trapezoidal channel 1:4.5 side slopes

$$L_t = 25y_1$$

Equation 5.59.1b Weir outlet base width - trapezoidal channel 1:4.5 side slops

$$B_b = 7y_1$$

5.59.2 For trapezoidal channels with 1:5 side slopes, the length, L_t , of the transition and the base width, B_b , at the downstream end should be determined by Equations 5.59.2a and 5.52.2b.

Equation 5.59.2a Weir outlet transition length - trapezoidal channel 1:5 side slopes

$$L_t = 30y_1$$

Equation 5.59.2b Weir outlet base width - trapezoidal channel 1:5 side slopes

$$B_b = 8y_1$$

5.60 Where a weir outlet is used, the collecting channel into which flow is discharged shall be deep enough to allow the outlet to discharge freely when the surface water channel is flowing under surcharged conditions.

5.60.1 The design flow depth, J (in m), of the receiving channel may be estimated from Equation 5.60.1.

Equation 5.60.1 Weir outlet collecting channel depth

$$J = 4.82\left(E^4\frac{Q^4}{A^5}\right)$$

where:

E	is the top width of flow (in m) and no less than 0.5m
Q	is the design rate of flow (m^3/s)
A	is cross sectional area of flow (m^2)

5.60.2 The overall depth of the channel should be determined by adding 0.15 m to the value of J .

5.61 A chamber shall be located below or immediately adjacent to an outlet (in-line, off-line or weir collection channel) to enable flow from the surface water channel to be conveyed to a suitable discharge point.

NOTE 1 *Possible configurations of outlet chambers are shown in Section 2, Figures 2.4Na and 2.4Nb (combined surface water channel and pipe), Section 3, Figures 3.28N1 and 3.29N1 (surface water channel - grassed), and Appendix I, Figures I.1 to I.5.*

NOTE 2 *Where a combined channel and pipe system is used, and in the case of an intermediate weir outlet, flow from the collecting channel can be discharged into the internal pipe of the combined system via a covered chamber formed on the line of the surface water channel and downstream of the weir outlet.*

5.62 The outgoing chamber pipe shall be designed so that the water level in the chamber is not within 150 mm of the underside of the gratings when the outlet is receiving flow from the channel under surcharged conditions.

5.62.1 The height, Z (in m), of the water surface in the chamber above the invert of the outgoing pipe may be estimated from Equations 5.62.1a and 5.62.1b.

Equation 5.62.1a Height Z for surface water channel outlets

$$Z = \frac{D}{2} + 0.23\frac{Q_s^2}{D^4}$$

where:

D	is the diameter of the pipe (in m)
Q_s	is the flow rate (in m^3/s) in the chamber corresponding to surcharged conditions in the surface water channel

Equation 5.62.1b Height Z for combined surface water channel and pipe outlets

$$Z = \frac{D}{2} + 0.23\frac{Q_t^2}{D^4}$$

where:

Q_t	is $Q_s + Q_p$ (from Equation 5.73.1a)

5.62.2 The gradient and diameter of the outgoing pipe may be determined from standard flow tables or resistance equation so that the pipe is just flowing full under surcharged channel conditions.

5.62.3 Where the chamber below the outlet is designed to trap sediment, the outgoing pipe from the chamber may be connected directly to a carrier pipe by means of a 45 degree junction without the need for a chamber at the junction position.

Drainage capacity of internal pipe for combined channels

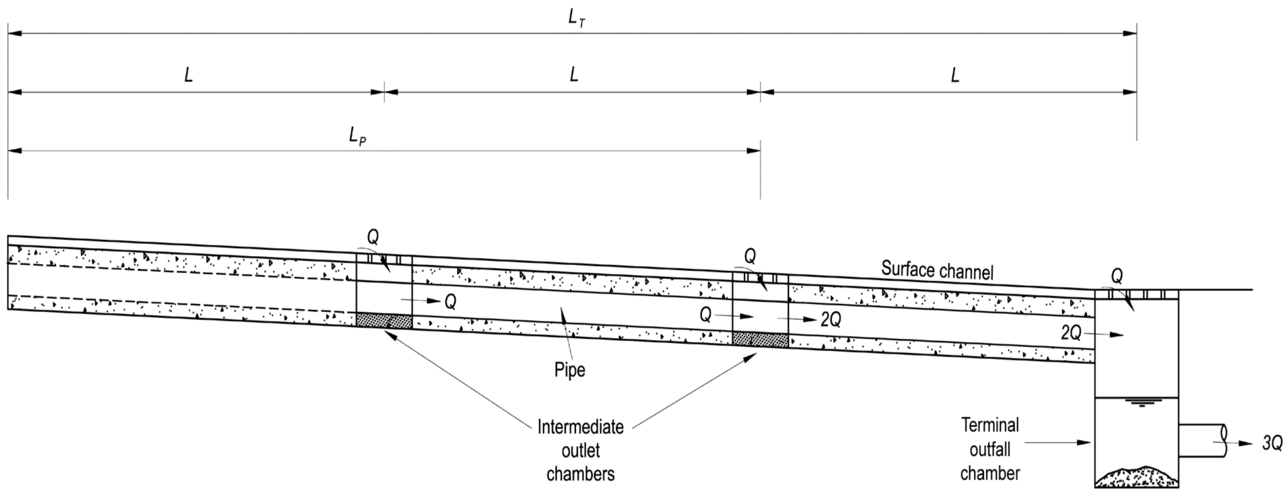
5.63 A combined surface water channel and the internal pipe shall have the same longitudinal gradient as the pavement being drained.

NOTE *Any increase in flow capacity gained by constructing the pipe at a steeper gradient relative to the surface of the road could be small and outweighed by the increased cost and difficulty of construction.*

5.64 Where the section of road has a constant longitudinal gradient, the following outline design procedure shall be followed:

1) assume a suitable size and cross-sectional geometry for the surface water channel and determine the length of road that can be drained, L ;
2) assume a suitable diameter of internal pipe and determine the length of road that can be drained by the pipe, L_p , before it reaches its maximum flow capacity;
3) determine the maximum total length, L_T , that can be drained by the combined system; and,
4) use L , L_p and L_T to determine the number and location of outlets required along a road drained by a section of combined surface water channel and pipe system.

Figure 5.64 Longitudinal profile of combined surface water channel and pipe system



5.65 The diameter of the internal pipe in a combined surface water channel and pipe system shall be kept constant along a drainage length.

NOTE 1 The diameter of the internal pipe is kept constant in order to simplify the construction process.

NOTE 2 Deposition of sediment at the upstream end where flow rates are low can be accommodated within an oversized pipe without causing surcharging problems at road level.

5.65.1 Any change in pipe size should coincide with the position of an intermediate outlet.

5.66 Where more than one pipe size is used in a combined system, the invert of the outgoing pipe shall not be higher than the invert of the incoming pipe.

5.66.1 Where more than one pipe is used in a combined system, the soffits of the two pipes should be set at the same level.

5.67 When there is significant variation in the longitudinal gradient along the length of pipe, the longitudinal gradient S shall be replaced by the effective longitudinal gradient S_e .

NOTE 1 Refer to the Design inputs, Gradient sub-section, clause 5.17 onwards, for the method to calculate S_e .

NOTE 2 Where the longitudinal profile of the road has been determined in advance of the hydraulic design, the procedure to determine S_e can be iterative.

5.68 Where a drainage length has intermediate crest or sag points, the drainage length shall be divided into separate sub-lengths and the pipe in each sub-length sized separately.

5.69 At intermediate sag points, the flow in the internal pipe shall be discharged via an outfall to a watercourse, or outlet to a toe ditch or separate carrier pipe.

5.70 The maximum length of road that can be drained by an internal pipe shall be determined using Equation 5.70.

Equation 5.70 Drainage length for internal pipes

$$L_p = 8.0 \times 10^6 \frac{R^{\frac{2}{3}} S^{\frac{1}{2}}}{n_{\text{ip}}} (N - 0.4)^{-0.362} \left[\frac{A}{W_e(\text{2minM5})} \right]^{1.62}$$

5.70.1 Where the internal pipe is to be designed to flow full for storms with a return period N of 5 years, the maximum length of road that can be drained should be calculated using Equation 5.70.1.

Equation 5.70.1 Drainage length for internal pipes when N=5 years

$$L_p = 1.24 \times 10^6 \frac{S^{\frac{1}{2}}}{n_{\text{ip}}} \frac{D^{3.91}}{[W_e(\text{2minM5})]^{1.62}}$$

NOTE The maximum flow depths produced by storms with a return period of N = 1 year cannot exceed 60% of the pipe diameter.

5.71 Manning's roughness coefficients for smooth-bore pipes formed in concrete by the slip-forming process given in Table 5.71 shall be used.

Table 5.71 Manning's roughness coefficients for slipformed concrete internal pipes

Condition	n_{ip}
Average	0.014
Poor	0.016

NOTE The 'average' condition assumes that the surface roughness of the pipe walls is equivalent to a value of k_s = 0.6 mm in the Colebrook-White resistance equation (see HRW Tables [Ref 19.N]) but with an additional allowance of Δ n = 0.0025 for energy losses caused by flow entering the pipe at intermediate *outlets. The 'poor' condition assumes a rougher surface finish of k_s = 1.5 mm and a depth of sediment deposit in the invert equal to 5% of the pipe diameter.*

5.71.1 Where the internal pipe is formed by a process other than slip-forming, values of n_{ip} should be assessed taking account of the surface finish of the pipe, the energy losses at intermediate outlets, the existence of joints and the possible presence of sediment deposits.

5.72 Flow capacities of the surface water channel and internal pipe shall be assessed separately.

5.73 The maximum flow capacity of the internal pipe shall be determined from the Manning resistance equation.

5.73.1 For an internal pipe flowing full at its downstream end, the flow capacity and corresponding velocity should be calculated using Equations 5.73.1a and 5.73.1b.

Equation 5.73.1a Capacity of an internal pipe flowing full at its downstream end

$$Q_p = 0.312\frac{D^{\frac{8}{3}}S^{\frac{1}{2}}}{n_{\text{ip}}}$$

Equation 5.73.1b Velocity of an internal pipe flowing full at its downstream end

$$V_p = 0.397\frac{D^{\frac{2}{3}}S^{\frac{1}{2}}}{n_{\text{ip}}}$$

5.74 The velocity of an internal pipe at the downstream end of a drainage length shall not be less than the appropriate value given in Table 5.74.

Table 5.74 Minimum pipe-full velocities for self-cleansing flows

Internal pipe diameter - D (mm)	Minimum velocity - $V_{\min}$ (m/s)
200	0.71
250	0.73
300	0.79
350	0.84
400	0.89
450	0.97
500	1.05

NOTE 1 Interpolation can be used to obtain values of $V_{\min}$ for intermediate pipe sizes.

NOTE 2 Derived from guidance on sediment problems in pipes given in CIRIA R141 [Ref 5.I] and CD 527 [Ref 18.N].

5.75 The maximum total length of road that a section of combined surface water channel and pipe system can drain shall be calculated using Equation 5.75. :

Equation 5.75 Maximum total length of road that can be drained

$$L_T = L_P + L_A$$

where:

L_A	maximum allowable spacing between the last intermediate outlet and the terminal outlet
L_P	maximum length of road that can be drained by a section of internal pipe
L_T	the maximum total length of road that can be drained by a combined channel and pipe system

5.76 The number and positions of outlets along a combined system shall not exceed the calculated maximum values of L_p , L_A and L_T .

5.76.1 Where lengths of road have a constant longitudinal gradient and require equal spacing between adjacent outlets, the following process should be followed:

1) calculate the number of intermediate outlets, N_1 , using Equation 5.76.1a;
2) calculate the actual spacing between adjacent outlets, L'_A , using Equation 5.76.1b, with the last intermediate outlet located at a distance, L_p , from the upstream end of the system;
3) calculate the total length of road drained by this section of combined channel, L'_T (where the terminal outlet can be located) using Equation 5.76.1c.

Equation 5.76.1a Number of intermediate outlets in combined system

$$N_1 = 1 + \text{INTEGER}\left(\frac{L_p}{L}\right)$$

Equation 5.76.1b Actual spacing between adjacent outlets

$$L'_A = \frac{L_p}{N_1}$$

Equation 5.76.1c The total length of road drained by the section of combined channel

$$L'_T = L_p + L'_A$$

NOTE *L'_A is smaller than the maximum allowable value of L_A .*

5.76.2 Where lengths of road have a varying longitudinal gradient, the following process should be followed, starting from the upstream end of the system:

1) calculate the maximum allowable length of road, L_A , that can be drained by the surface channel using the local value of longitudinal gradient, and locate the first intermediate outlet at this point;
2) determine points downstream at which the maximum drainage capacity of the surface water channel is reached and locate intermediate outlets at each point;
3) add together the individual values of channel length, L , to find the cumulative drainage length, L_{cum} , measured from the upstream end of the system;
4) determine the total length of road, L'_T , that can be drained by this section of combined system (this is equal to the first value of L_{cum} that exceeds the maximum drainage length, L_p , of the internal pipe);
5) locate a terminal outlet at this downstream point to discharge all the flow from the combined system to a watercourse, toe ditch or separate carrier pipe.

5.77 The maximum allowable spacing, L_A , between adjacent outlets (or between the upstream end of a combined system and the first outlet) shall be determined by the following criteria:

1) where there is no flow by-passing at upstream outlet: $L_A \leq L$ and $L_A \leq L_S$;
2) where there is flow by-passing at upstream outlet: $L_A \leq L_B$ and $L_A \leq L_{SB}$.

6. Normative references

The following documents, in whole or in part, are normative references for this document and are indispensable for its application. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

Ref 1.N	Highways England. CD 127, 'Cross-sections and headrooms'
Ref 2.N	Highways England. CD 227, 'Design for pavement maintenance'
Ref 3.N	Highways England. CG 501, 'Design of highway drainage systems'
Ref 4.N	BSI. BS EN 1433, 'Drainage channels for vehicular and pedestrian areas - Classification, design and testing requirements, marking and evaluation of conformity (AMD 16109) (AMD Corrigendum 16739)'
Ref 5.N	National Highways. CS 551, 'Drainage surveys'
Ref 6.N	National Highways. CD 524, 'Edge of pavement details'
Ref 7.N	BSI. BS EN 12056-3, 'Gravity drainage systems inside buildings. Roof drainage, layout and calculation' , 2000
Ref 8.N	BSI. BS 7903, 'Guide to selection and use of gully tops and manhole covers for installation within the highway'
Ref 9.N	BS EN 124:1994, 'Gully tops and manhole tops for vehicular and pedestrian areas — Design requirements, type testing, marking, quality control'
Ref 10.N	National Highways. GG 101, 'Introduction to the Design Manual for Roads and Bridges'
Ref 11.N	Highways England. MCHW Series 0500, 'Manual of Contract Documents for Highway Works, Volume 1 Specification for Highway Works. Series 500 Drainage and service ducts.'
Ref 12.N	Highways England. MCHW Series 1100, 'Manual of Contract Documents for Highway Works. Volume 1 Specification for Highway Works. Series 1100 Kerbs, Footways and Paved Areas.'
Ref 13.N	Highways England. MCHW HCD Series B, 'MCHW Volume 3: HCD Section 1 Series B - Edge of Pavement Details'
Ref 14.N	Highways England. MCHW HCD Series F, 'MCHW Volume 3: HCD Section 1 Series F - Drainage'
Ref 15.N	Highways England. MCHW HCD Series G, 'MCHW Volume 3: HCD Section 1 Series G - Loop Detectors'
Ref 16.N	Highways England. CD 377, 'Requirements for road restraint systems'
Ref 17.N	Highways England. LA 113, 'Road drainage and the water environment'
Ref 18.N	Highways England. CD 527, 'Sumpless gullies'
Ref 19.N	Thomas Telford. HR Wallingford and Barr D I H. HRW Tables, 'Tables for the hydraulic design of pipes, sewers and channels'
Ref 20.N	Highways England. CG 502, 'The certification of drainage design'
Ref 21.N	National Highways. CD 532, 'Vegetated drainage systems for highway runoff'

7. Informative references

The following documents are informative references for this document and provide supporting information.

Ref 1.I	HR Wallingford. Escarameia M, Todd A J and May R W P. HRW SR 585,, 'Combined surface channel and pipe system: Interim Report'
Ref 2.I	HR Wallingford. May RWP, Todd AJ, Boden DG and Escarameia M. HRW SR 624, 'Combined surface channel and pipe system: Project Report'
Ref 3.I	OECD Symposium on Road Drainage, Bern, Switzerland,. May R W P.. OECD , 'Design of highway drainage channels'
Ref 4.I	HR Wallingford. HRW DE 30, 'Design of highway drainage channels: Preliminary analysis'
Ref 5.I	CIRIA. CIRIA R141, 'Design of sewers to control sediment problems'
Ref 6.I	National Highways. CD 535, 'Drainage asset data and risk management'
Ref 7.I	Institute of Hydrology, UK. Faulkner D. FEH V2, 'Flood Estimation Handbook, Volume 2 Rainfall frequency estimation'
Ref 8.I	Institute of Hydrology UK . Flood SR16, 'Flood Studies Supplementary Report 16'
Ref 9.I	HR Wallingford. Escarameia M and Todd AJ. HRW SR 662, 'Grassed surface water channels for road drainage,'
Ref 10.I	Highway Research Board (USA). Izzard CF and Hicks WI. Highway Research Board, 'Hydraulics of runoff from developed surfaces'
Ref 11.I	Highways England. MCHW HCD NMCS, 'MCHW Volume 3: HCD Section 3 - National Motorway Communications System Installation Drawings'
Ref 12.I	Transport Research Laboratory. HR Wallingford. TRL CR 8, 'Motorway Drainage Trial on the M6 Motorway, Warwickshire' , 1985
Ref 13.I	Science and Practice, CAB International. Adams WA and Gibbs RJ. Adams & Gibbs 1993, 'Natural turf for sports and amenity'
Ref 14.I	Highways England. TD 131, 'Roadside technology and communications'
Ref 15.I	BSI. BS 4449, 'Steel for the reinforcement of concrete. Weldable reinforcing steel. Bar, coil and decoiled product. Specification'
Ref 16.I	Highways England. CD 236, 'Surface course materials for construction'
Ref 17.I	HR Wallingford. Escarameia M and May R W P. HRW SR 406, 'Surface water channels and outfalls: Recommendations on design'
Ref 18.I	National Water Council. Hydraulics Research Ltd.. HRW: Wallingford Procedure, 'The Wallingford Procedure: Design and Analysis of Urban Storm Drainage'
Ref 19.I	The Sports Research Institute, London. Shildrick J. Turfgrass Manual, 'Turfgrass Manual'

Appendix A. Grassed surface water channel - environmental benefits

A1 General

Grassed surface water channels are a vegetated drainage system and may also be considered to be a sustainable drainage system (SuDS), in that they use minimal non-replenishable materials such as quarried stone or oil based products. The system also offers potential environmental benefits not found in most conventional highway drainage techniques.

The visual environment is improved by the apparent reduction in width of the road, which for a rural, dual, all-purpose carriageway can be between 10 and 15%. Replacing the concrete surface water channel by a grassed channel represents a visual 'greening' of the road.

A2 Flow attenuation

The increased surface roughness of the grassed channel in comparison with that of concrete can reduce the corresponding flow velocity. Comparison between average flow velocities in the two types of channel indicates velocities in grassed channels around 25% of those in concrete channels. A reduction in velocity will increase the time of flow within the channel and thereby increase the time of concentration. Consequently, the peak discharge flow rate to a receiving watercourse can be less from the grassed channel.

A3 Sediment deposition

The lower flow velocity generates less energy thereby reducing the sediment transport ability of the channel flow. Sediment can settle in the channel bed and be trapped by the grass blades.

A4 Pollution containment

Sediment is the prime constituent in the transport of heavy metals and polluting materials, such as lead, copper, zinc, and cadmium. Metals are mainly contained in the suspended solids carried along by the channel flow and are removed when the solids are deposited as sediment. Increased sediment deposition can result in less of these pollutants reaching the receiving watercourse.

Appendix B. Worked examples

B1 Determining the length of road that can be drained by a triangular surface water channel

The triangular surface water channel has the following characteristics:

1) symmetrical cross-falls: b_1 = b_2 = 5;
2) channel depths (see Fig 3.8): y_1 = 0.120m, y_3 = 0.145m;
3) longitudinal channel gradient: S = 1/200 = 0.005; and,
4) Manning's roughness coefficient: n = 0.013 (concrete, average condition).

The value of the hydraulic-radius factor corresponding to the design flow depth y_1 is calculated from Equation 5.15 to be:

$$r = \frac{5+5}{2(1+5^2)^{\frac{1}{2}}} = 0.981$$

The width of flow corresponding to the design flow depth y_1 is: B = 10 x 0.120 = 1.200 m

and the corresponding flow area is: $A = \frac{1}{2} \times B \times y_1 = \frac{1}{2} \times$ 1.200 $\times$ 0.120 $=$ 0.072m^2

The shape parameter m of the channel (see Equation 5.10) has a value of:

$$m = \frac{1.200 \times 0.120}{0.072} - 1 = 1.00$$

The width of the two-lane carriageway drained by the channel is 9.300 m (including two 1.000 m-wide hardstrips). The overall width of the channel itself is:

$$B = b_1 y_3 + b_2 y_1 = (5 \times 0.145) + (5 \times 0.120) = 1.325 \text{ m}$$

The road is on embankment and there is no run-off from the verge into the channel. The effective catchment width is therefore:

$$W_e = 9.300 + 1.325 = 10.625 \text{ m}$$

The road is located near Coventry and from Figure 5.3 it is found that the characteristic value of rainfall depth occurring in 2 minutes with a return period of 5 years is:

2minM5 = 4.0 mm

Note: allowance for the effects of climate change contained in CG 501 [Ref 3.N] should be adopted for all new designs.

The channel is to be designed so that the design flow depth y_1 is not exceeded by run-off from storms occurring once every year on average; the design return period is therefore: N = 1 year

The length of road that can be drained by the channel is calculated from Equation 5.20, in which the factor G_m corresponding to the triangular shape of the channel is obtained from Equation 5.9 as: G_m = 2.90 x 10^6 (2.65 - 1.00) = 4.79 x 10^6

The maximum drainage length is therefore:

$$L = 4.79 \times 10^6 \frac{(0.005)^{\frac{1}{2}}}{0.013} (0.981 \times 0.120)^{\frac{2}{3}} \times (1.0 - 0.4)^{-0.362} \times \left[\frac{0.072}{10.625 \times 4.0}\right]^{1.62} = 244 \text{ m}$$

The critical storm duration corresponding to the design flow condition can be estimated from Equation E.2 in Appendix E as:

$$T_c = 0.085 \left[\frac{0.013 \times 244}{0.005^{\frac{1}{2}}}\right] (0.981 \times 0.120)^{-\frac{2}{3}} = 15.9 \text{ minutes}$$

B2 Determining the length of road that can be drained by a surface water channel constructed in a cutting

Consider the same road and channel as worked example B1, but constructed in a cutting which contributes run-off to the channel. The road is located in Warwickshire so from Table 5.6.3 the antecedent wetness is "medium". The soil in the cutting is a fairly heavy clay with a low permeability so from Table 5.6.2 the run-off coefficient is α = 0.21. The average width of the cutting draining to the channel is $\overline{C}$ = 15.0 m. Compared to the example in B1, the effective catchment width is increased to the following value given by Equation 5.6.1: We = 10.625 + 0.21 x 15.0 = 13.775 m.

All the other parameters in Equation 5.20 are unchanged so the revised length of road that can be drained by the channel is:

$$L = 244\left(\frac{10.625}{13.775}\right)^{1.62} = 160m$$

B3 Determining the length of road that can be drained by a trapezoidal channel

The trapezoidal surface water channel has the following characteristics:

1) base width of channel: B_b = 0.300 m;
2) symmetrical cross-falls: b_1 = b_2 = 5;
3) channel depths (see Fig 2): y_1 = 0.150m y_3 = 0.175 m;
4) longitudinal channel gradient: S = 1/200 = 0.005; and,
5) Manning's roughness coefficient: n = 0.013 (concrete, average condition).

The value of the hydraulic-radius factor given by Equation 5.14 for the design flow depth y_1 is:

$$r = \frac{0.300+[(5+5)\times 0.150]}{0.300+\left[2(1+5^2)^{\frac{1}{2}}\times 0.150\right]} = 0.984$$

The width of flow corresponding to the design flow depth y_1 is:

B = 0.300 + (10 x 0.150) = 1.800 m

and the corresponding flow area is:

$$A = B_b y_1 + \tfrac{1}{2}(b_1+b_2)y_1^2 = (0.300\times 0.150) + \left(\tfrac{1}{2}(5+5)\times 0.150^2\right) = 0.158 \text{ m}^2$$

The shape parameter of the channel has from Equation 5.10 the value:

$$m = \frac{1.800\times 0.150}{0.158} - 1 = 0.71$$

The width of four-lane motorway drained by the channel is 17.900 m (including a 3.300-m hard shoulder). The road is on embankment and there is no run-off from the verge into the channel. The effective catchment width is therefore: W_e = 17.900 + 1.925 = 19.825 m

The section of motorway is located near Watford and from Figure 5.3 the characteristic rainfall depth is: 2minM5 = 4.1 mm

Note: the allowance for the effects of climate change contained in CG 501 [Ref 3.N] is to be adopted for all new designs.

The channel is to be designed so that the design flow depth y_1 is not exceeded by run-off from storms with a return period of N = 1 year. The shape factor G_m for the channel is obtained from Equation 5.9 as: G_m = 2.90 x 10^6 (2.65 - 0.71) = 5.63 x 10^6

The maximum length of road that can be drained by the channel is calculated using Equation 5.20:

$$L = 5.63\times 10^6 \frac{(0.005)^{\frac{1}{2}}}{0.013}(0.984\times 0.150)^{\frac{2}{3}} \times (1.0-0.4)^{-0.362}\left[\frac{0.158}{19.825\times 4.1}\right]^{1.62} = 417 \text{ m}$$

B4 Determining the design depth of flow of a rectangular surface water channel

Along part of the motorway considered in worked example B3, superelevation causes run-off to drain from one of the carriageways towards the central reserve. Both sides of the central reserve are protected by safety barriers so it is possible to use a channel of rectangular cross-section in this location. The width of the channel is chosen to be B_b = 1.000 m and it is required to determine the design depth of flow when draining a maximum distance of L = 300 m. The effective catchment width (carriageway + hard shoulder + channel) is: W_e = 17.900 + 1.000 = 18.900 m.

The values of n , S and 2minM5 are as given in worked example B3. Since the channel is not permitted to surcharge on to the carriageway that it drains, it is decided to determine the design depth of flow y of the channel for storms with a return period of N = 5 years (see clause 5.1). The value of y for a rectangular channel is determined from Equation 5.22, but it should be noted that y also appears on the right-hand side of the equation. A short iterative procedure is therefore necessary as illustrated by the following calculations.

Estimate a likely value for the design flow depth, e.g. y = 0.150 m, and substitute this on the right-hand side of Equation 5.22 so that:

$$y = 9.75 \times 10^{-4} \left(\frac{0.013 \times 300}{0.005^{\frac{1}{2}}}\right)^{0.437} \left(1 + \frac{2 \times 0.150}{1.000}\right)^{0.292} (5 - 0.4)^{0.158} \left[\frac{18.900}{1.000} \times 4.1\right]^{0.708} = 0.168 \text{ m}$$

Substituting this calculated value of y on the right-hand side of the equation gives a revised value of y = 0.169 m; one final iteration converges to the solution y = 0.170 m, which is the required design depth of flow in the 1.0 m-wide rectangular channel.

B5 Determining the spacing between the intermediate outlets and the terminal outlet for a grassed surface water channel

It is necessary to determine the spacing between the intermediate outlets and the terminal outlet for a grassed surface water channel that will drain a section of dual, two-lane carriageway near Norwich. The pavement is black top with a cross fall of 1:40 on non-superelevated sections. The width of the carriageway is 9.3 m (including two 1.0 m-wide hardstrips). The longitudinal gradient of the road is 1 in 125, S =0.8%, and is at grade so cannot receive runoff from the adjacent pervious area.

The principal features of the system are as follows:

1) symmetrical triangular channel with crossfalls of 1:5 (vertical : horizontal);
2) design flow depth: y = 0.2 m;
3) corresponding flow width: B = 2.00 m;
4) grass type: perennial ryegrass (which gives m_g = 0.0048 - see clause 5.20); and,
5) average grass height: H = 0.075 m (see clause 5.20).

The grassed surface water channel is to be designed to allow a maximum width of surcharging of 1.0m on the adjacent hardstrip. For a straight section of road, with a crossfall of 1:40, this can be achieved by setting the outer edge of the channel 25 mm above the level at the edge of the hardstrip. Also there is to be an up-stand at the edge of the channel, nominally equal to 40mm. Given that the sides of the channel have crossfalls of 1:5, it follows that the overall width of the channel can be equal to B+(0.065x5) = 2.325 m (applies only to the side of the channel remote from the carriageway).

Using the above information and substituting this into Equation 5.19: n = 0.062

The effective catchment width, W_e , draining to the grassed surface water channel is equal to the width of the carriageway plus the width of the grassed channel, including the additional width due to surcharge: W_e = 9.30 + 2.325 = 11.625 m

The characteristic rainfall depth for the Norwich area is found from the map in Figure 5.3:

2minM5 = 4.0 mm

Note: the allowance for the effects of climate change contained in CG 501 [Ref 3.N] should be adopted for all new designs.

The first step in the hydraulic design is to determine the required spacing between intermediate outlets along the grassed channel. Flows produced by storms with a return period of N = 1 years should be contained within the surface water channel with the flow depth not exceeding y = 0.20 m. Substituting the values in Equation 5.20.1, it is found that the maximum drainage length is: L = 411 m.

The maximum length of road, L_s that the channel can drain to an outlet in the surcharged condition for storms of return period N = 5 years, is determined from Equation 5.26.3 where the value ϕ can be obtained from Table F.1:

where ϕ = 1.4, L_s = 575 m

The maximum flow capacity of the grassed channel when just flowing full at design depth of flow, y = 0.2 m, can be determined from Equation 5.25.3. Q = 0.061 m^3 /s

The maximum flow capacity of the channel under surcharged conditions can be estimated from Equation 5.26.2, where the value of ϕ can be obtained from Table F.1:

where ϕ = 1.4, Q_s = 0.135 m^3 /s

The maximum depth of water in the outlet chamber should not rise to within 150 mm of the underside of the grating under design flow conditions. Assume the outgoing pipe diameter = 300 mm and insert in Equation 5.62.1. Q = 0.061 m^3 /s, Z = 256 mm.

There is no surcharge at design flow, so a 300 mm diameter is adequate.

Under surcharged flow conditions: = 0.135 m^3 /s, Z = 668 mm. Q_s = 0.135 m^3 /s, Z = 668 mm

Therefore, the outgoing pipe invert should be at least 0.818 m (i.e. 0.668 + 0.150) below underside of grating.

B6 Determining the spacing between the intermediate outlets and terminal outlet for a combined surface channel and pipe system

It is required to determine the spacing between the intermediate outlets and terminal outlet for a combined surface channel and pipe system that will drain a section of two-lane, dual carriageway near Norwich. The pavement is black top with a transverse gradient of 1:40 on non-super-elevated sections. The width of carriageway draining to the verge is 9.3,m (including two 1.0,m-wide hardstrips). The section of road under consideration has a longitudinal gradient of S = 0.8% (i.e. 1:125) and is on embankment so the combined system cannot receive run-off from any adjacent pervious areas.

The combined system can be slip-formed in C28/35 mass concrete with light mesh to meet a D400 loading requirement.

The principal features of the system are as follows:

Surface water channel:

1) symmetrical triangular channel with cross-falls of 1:5 (vertical : horizontal);
2) design flow depth: y = 0.120 m;
3) corresponding flow width: B = 1.20m; and,
4) Average roughness condition: from Table 5.18.1 (concrete), n = 0.013.

Internal pipe:

1) diameter: D = 0.400 m;
2) average roughness condition: from Table 5.71, n_{ip} = 0.014.

Overall cross-sectional shape:

1) The surface channel is to be designed to allow a maximum width of surcharging of 1.0 m on the adjacent hardstrip. For a straight section of road with a transverse gradient of 1:40, this can be achieved by setting the outer edge of the channel 25 mm above the level at the edge of the hardstrip. Given that the sides of the channel have cross-falls of 1:5, it follows that the overall width of the concrete unit forming the combined system will be equal to B + 0.125 m = 1.325 m.
2) To meet the structural requirements set out in this document, a minimum concrete cover equal to half the pipe diameter needs to be provided. Therefore, the minimum depth of the concrete block is 0.12 m + 0.20 m + 0.40 m + 0.20 m = 0.92 m (measured from the edge of the hardstrip).

The transverse bars of the mesh need to provide a minimum steel area of 385 mm^2 per metre run of pipe. This can be provided, for example, by 7 mm-diameter, transverse bars located at 100 mm centres.

The effective width of catchment, W_e , draining to the combined channel and pipe system is equal to the width of the carriageway plus the width of the concrete block:

$W_e = 9.30 + 1.325 = 10.625$ m

The characteristic rainfall depth for the Norwich area is found from Figure 5.3 to be:

2minM5 = 4.0 mm

The first step in the hydraulic design is to determine the required spacing between intermediate outlets along the combined system. Flows produced by storms with a return period of N = 1 year should be contained within the surface water channel with the flow depth not exceeding y = 0.120 m. Substituting the above values in Equation 5.20.1, it is found that the maximum drainage length is:

L = 307 m.

If some flow by-passing occurs at an intermediate outlet, the distance that can be drained by the next section of channel will be reduced. Using the design procedures given in section 5 for the hydraulic design of outlets, the selected design of intermediate outlet is calculated to have a collection efficiency of η = 0.90. Assuming that the outlets are equally spaced, the maximum spacing between intermediate outlets allowing for by-passing is found from Equation 5.49.2 to be:

L_{B} = 292 m.

It is also necessary to check that the width of surcharging on the hardstrip will not exceed 1.0 m during storms having a return period of N = 5 years. This can be done using the procedure given in the surcharged surface water channel section of section 5. For a design flow depth in the channel of y = 0.120 m and a road cross-fall of 1:40, Figure F.1 shows that the drainage length factor for surcharged conditions has a value of η = 1.08. From Equation 5.26.3, the maximum possible length of road that can be drained under surcharged conditions is therefore:

$L_s = 1.08 \times 307 = 332$ m.

If the flow collection efficiency of the intermediate outlet under surcharged conditions is η = 0.85, the maximum spacing between intermediate outlets taking account of by-passing is:

$L_{\text{SB}} = 309$ m

The maximum allowable spacing, L_A , between intermediate outlets is the smaller of the two values L_{B} and L_{SB} (see section 5), which is:

$L_A = 292$ m

The next step is to determine the length of road that can be drained by the internal pipe. The pipe should be designed to flow just full for storms with a return period of N = 5 years. Using Equation 5.70.1 and the data given above, it is found that maximum possible length of road that can be drained by the 0.40 m-diameter pipe is:

$L_p = 507$ m.

The flow velocity at the downstream end of the pipe is obtained from Equation 5.73.1b and has the value:

$V_p = 1.38$ m/s.

This will produce satisfactory self-cleansing conditions since it exceeds the minimum velocity of $V_{\min}$ = 0.89 m/s recommended in Table 5.44 for a pipe of 0.40 m diameter.

The maximum total length of road that can be drained by this section of combined surface channel and pipe system (measured from the upstream end to the terminal outlet) is:

$L_T = L_P + L_A = 507 + 292 = 799$ m

In order to achieve a regular spacing between outlets and to simplify the setting-out and construction of the system, it is convenient to adopt the following slightly conservative values:

L'_p = 500 m and L'_A = 250 m

This results in a total drainage length for the section of combined system being considered of:

L'_T = 750 m.

Therefore, two intermediate outlets will be required at chainages of 250 m and 500 m (measured from the upstream end of the system) with a terminal outlet located at a chainage of 750 m.

The dimensions and layouts of the intermediate outlets and the terminal outlet are determined using the recommendations in section 5. Flow from the terminal outlet may be discharged to a watercourse or toe ditch, or to a separate carrier pipe in the verge or central reserve.

The maximum design flow rate discharged from the terminal outlet is assumed to be equal to the sum of the flow rate, Q_p , from the internal pipe and the flow rate, Q_s , from the most downstream section of surface channel when flowing under surcharged conditions. From Equation 5.73.1a:

$Q_p =$ 0.173 m^3/s

and from Equations 5.26.2 and 5.25.3:

$Q_s =$ 0.127 m^3/s

The design rate of flow discharged by the terminal outlet is therefore:

$Q_T = 0.300$ m^3/s

B7 Designing an intermediate in-line outlet in a triangular surface water channel

Site characteristics:

1) cross-falls 1:5;
2) design flow depth 0.120 m;
3) longitudinal channel gradient 1:200 = 0.005;
4) Manning's roughness coefficient (average condition) 0.013; and,
5) adopt an efficiency of 100% for the outlets and a carriageway cross-fall of 1:40.

The flow in the channel is calculated from Equation 5.25 but first it is necessary to calculate the hydraulic radius R using Equation 5.13:

$$R = \frac{A}{P} = \frac{(1.2\times0.12)/2}{2(0.120^2+0.6^2)^{0.5}} = \frac{0.072}{1.224} = 0.0588m$$

The channel-full flow Q_d is then given by:

$$Q_d = \frac{0.072\times0.0588^{\frac{2}{3}}\times0.005^{\frac{1}{2}}}{0.013} = 0.0592m^3/s$$

The flow Q_s for surcharging of 1-m width of the hard-strip or hard-shoulder is determined from Figure H.3. For B_d = 1.2 m, Q_s/Q_d = 1.7 and therefore:

$$Q_S = 1.7 \times 0.0592 = 0.1006m^3/s$$

Then calculate F_d using Equation 5.46a:

$$F_d = \frac{28.6\times0.0592}{1.2^{2.5}} = 1.07$$

Calculate also F_s using Equation 5.46b. It is first necessary to calculate B_s . For a carriageway cross-fall of 1:40, 1 m of surcharging corresponds to 0.025 m of water depth above the channel-full depth, giving a total depth of 0.145 m. Therefore:

$$B_s = 5(0.120 + 0.145) = 1.325m$$

Figures H.11 and H.12 (see Appendix H) are appropriate for the design of in-line intermediate outlets in triangular channels.

As part of the design, channel-full conditions should be assessed using Figure H.11. Adopting an efficiency of 100%, Figure H.11 shows the need for two pairs of gratings installed on the sloping sides of the channel. Figure H.12 shows that two pairs of gratings are also satisfactory for surcharged conditions.

The size of the gratings (G_g is width and H_g is length) is calculated as described in Section 5:

$4.5 \leq G_g/0.120 \leq 5.1$

and $H_g \geq G_g$

Taking the smallest dimensions allowed gives:

$G_g = 0.120 \times 4.5 = 0.540m$

$H_g = G_g = 0.540m$

A commercially available grating, with width and length not smaller than 540 mm, should be chosen. The total waterway area of the slots should not be less than $0.44G_g^2$ or 0.128 m^2 (see Clause 5.33).

As shown in Figure H.5 (see Appendix H), the longitudinal distance between the two pairs of gratings should be at least equal to $1.7 \times 0.540m = 0.918m$ if a grating of width 0.540 m is chosen.

B8 Designing a terminal off-line outlet in a triangular surface water channel

Design with the same site characteristics as in Example B7.

The flow in the channel for channel-full conditions Q_d was calculated to be 0.0592 m^3/s and for surcharged conditions Q_s was found to be 0.1006 m^3/s. The values of F_d and F_s were, respectively, 1.07 and 1.22.

Table G.1 should be consulted for the design of terminal outlets in triangular channels. Checking first for channel-full conditions it can be seen that for an off-line outlet, one single grating could be able to intercept the flow satisfactorily (F_d = 1.2 in Table G1 is bigger than the calculated F_d = 1.07). However, when checking for surcharged conditions, Table G.1 indicates the need for a minimum of two gratings (F_s = 1.0 in the table is smaller than the calculated F_s = 1.22). In this case, two gratings should be used not only to account for floods of higher return period but also for the possibility of partial blockage of the gratings by debris.

The size of the gratings is the same as in example B7. The longitudinal distance between the two gratings should be at least equal to 1.25 x 0.540 m = 0.675 m. The total length of the outlet including one upstream transition of 2.02 m should be equal to or greater than 4.9 m (see Figure H.6 in Appendix H for details of the geometry).

B9 Designing an intermediate off-line outlet in a trapezoidal surface water channel

Site characteristics:

1) cross-falls 1:5;
2) design flow depth 0.150 m;
3) base width 0.300 m;
4) longitudinal channel gradient 1:500 =0.002;
5) Manning's roughness coefficient (average condition) 0.013; and,
6) Adopt an efficiency of 85% for the outlets and a carriageway cross-fall of 1:40.

The flow in the channel is calculated from Equation 5.25 but first it is necessary to calculate the hydraulic radius R using Equation 5.13:

$$R = \frac{A}{P} = \frac{\frac{1}{2}(0.30+1.80)\times 0.15}{0.3+2(0.15^2+0.75^2)^{\frac{1}{2}}} = \frac{0.1575}{1.830} = 0.0861m$$

The channel full flow is then given by:

$$Q_d = \frac{0.1575 \times 0.0861^{\frac{2}{3}} \times 0.002^{\frac{1}{2}}}{0.013} = 0.106m^3/s$$

The flow Q_s for surcharging of 1m width of the hard-strip or hard-shoulder is determined from Figure H.4. For B_d = 1.8 m, Q_s/Q_d = 1.5 and therefore:

Q_s = 1.5 x 0.106 = 0.159 m^3/s

Then calculate F_d using Equation 5.46e:

$F_d = \frac{29.8 \times 0.106}{1.8^{2.5}} = 0.73$

Assuming 0.025 m of surcharging above the channel-full depth of 0.150 m, the surcharged width of the channel is:

$B_s = 0.3 + 5(0.150 + 0.175) = 1.925m$

The corresponding value of F_s is found from Equation 5.46f:

$F_s = \frac{25.5 \times 0.159}{1.925^{2.5}} = 0.79$

Figures H.21 and H.22 are appropriate for the design of off-line outlets in trapezoidal channels with cross-falls of 1:5. For channel-full conditions, Figure H.21 shows that for F_d = 0.73 a minimum of two gratings is required to achieve a collection efficiency of 85%. Checking for surcharged conditions using Figure H.22, it can be seen that for F_s = 0.79 two gratings are also satisfactory and just satisfy the efficiency criterion of 85%.

The dimensions of the gratings are calculated as described in Clauses 5.36 (Equation 5.36) and 5.44:

$Gg \geq 4.0 \times 0.150 = 0.600m$

$H_g \geq 0.600m$

The total waterway area of the slots should not be less than $0.44G_g^2$ or 0.158 m^2 (see Clause 5.33). The layout of the outlet is similar to the one shown in Figure H.10 but with only two gratings. The minimum overall length of the outlet is $6.0G_g$ or 3.60 m including two 0.96 m long transitions.

B10 Designing a terminal outlet for a triangular surface water channel

Site characteristics

1) cross-falls 1:5;
2) design flow depth 0.120 m;
3) longitudinal channel gradient 1:25 = 0.04; and,
4) Manning's roughness coefficient (average condition) 0.013.

The flow in the channel is calculated using Equation 5.25 as in Example B7:

A = 0.072 m^2

R = 0.0588 m

$Q_d = \frac{0.072 \times 0.0588^{\frac{2}{3}} \times 0.04^{\frac{1}{2}}}{0.013} = 0.167m^3/s$

The value of F_d is calculated using Equation 5.46a:

$F_d = \frac{28.6 \times 0.167}{1.2^{2.5}} = 3.03$

From Table G1 (and the flow chart in Figure H.26) it can be seen that, because F_d > 2.30, neither an in-line or an off-line outlet is adequate and therefore a weir outlet is required. Following the procedure in Figure H.26, the first step is the design of the transition section upstream of the weir outlet. Using Equation 5.58.1a, the required length of the transition is:

L_t = 25 x 0.120 = 3.000 m

Over this distance, the triangular profile of the surface water channel is transformed to a trapezoidal shape with the same depth and cross-falls but with a base width given by Equation 5.58.1b of:

B_b = 5 x 0.120 = 0.600 m

Assuming 0.025 m of surcharging above the channel-full depth of 0.120 m, the surcharged width at the downstream end of the transition is:

B_t = 5 x 0.120 + 0.600 + 5 x 0.145 = 1.925 m

The dimensions of the weir outlet are determined from Figure H.25. For a value of F_d = 3.05, this gives:

L_w = 4.15 x 1.925 = 8.0 m

θ = 17.6°.

The straight and angled portions of the weir have the following lengths:

L_r = $B_t \approx$ 2.0 m

$L_a = L_w - L_r =$ 8.0 m - 2.0 m = 6.0 m.

Appendix C. Runoff from cuttings

In the absence of suitable published data, it was decided to use an existing runoff equation to provide a method for estimating runoff from road cuttings. The selected equation was developed during studies for Volume 1 of the Wallingford Procedure HRW: Wallingford Procedure [Ref 18.I] as a means of predicting surface runoff to urban storm sewers in the UK, and has the form:

Equation C.1 Percentage runoff

$$PR = 0.662PIMP + [0.00219(100 - PIMP) \times SOIL \times UCWI]$$

where:

PR	percentage runoff from the whole catchment
$PIMP$	percentage of impervious area
$SOIL$	an indices related to the infiltration potential of the soil
$UCWI$	an index of the urban catchment wetness

A different runoff formula was finally adopted for the Wallingford Procedure, but Equation C.1 is more suitable for application to roads in cuttings.

The effective width W_e of a road in cutting is defined as the equivalent width of road which can produce the same total amount of runoff as a road of width W and a cutting of average width $\overline{C}$. From Equation C.1 it can be shown that:

Equation C.2 Effective catchment width

$$W_e = W + \left(\frac{SOIL \times UCWI}{300}\right)\overline{C}$$

The Flood Studies Supplementary Report 16 Flood SR16 [Ref 8.I] classified UK soils into five SOIL classes, S1 to S5 according to their infiltration potential. These SOIL parameters are between 0.10 and 0.53; the lowest value could apply to a well-drained sandy soil and the highest to a rocky soil on a fairly steep slope. Maps showing regional distributions of SOIL classes are given in volume 5 of FEH V2 [Ref 7.I] and volume 3 of the Wallingford Procedure HRW: Wallingford Procedure [Ref 18.I]; the type of soil in a cutting should, however, be assessed from a site survey since the maps do not identify small local variations. Cuttings for roads are steeper than most natural catchments, and for a given soil type may produce relatively more runoff. Approximate allowance can be made for this by classifying a soil in a category of lower infiltration potential than normal; values of the SOIL parameter for cuttings might therefore be expected to be in the range 0.3 to 0.53.

Design values of UCWI for use with Equation C.1 are given in Volume 1 of the Wallingford Procedure HRW: Wallingford Procedure [Ref 18.I] as a function of the standard average annual rainfall at a site. Representative values for UK regions were obtained by finding the maximum range of UCWI within each region (excluding only peaks in highland areas), and adopting a figure one third of this range below the maximum value. The regions were then grouped into categories of high, medium and low catchment wetness, and an average representative value of UCWI calculated for each group.

The values of the runoff coefficient a in Table 5.5.2 were obtained from Equation C.2 using figures of SOIL = 0.3, 0.47 and 0.53 for soils of high, medium and low permeability, and representative values of UCWI = 71, 107, and 132 for low, medium, and high categories of antecedent wetness.

Site data is to be collected where possible to improve the estimate of runoff from the cuttings.

Appendix D. Roughness

D1 Channel roughness

The Manning resistance equation is appropriate when a flow is rough-turbulent (that is with its resistance mainly determined by the surface texture of the channel). This is likely to be the case in most road drainage channels, except perhaps near the upstream end where the velocity or depth of flow is small and the flow may be smooth-turbulent (that is with its resistance mainly determined by the viscosity of the water). It is often assumed that the roughness coefficient n depends only upon the surface texture of the channel, but experimental evidence indicates that it can vary with the relative depth of flow, the cross-sectional shape of the channel and the intensity of any lateral inflow.

A modified version of Manning's equation for shallow triangular channels was developed by the Highway Research Board [Ref 10.I] and is recommended by the US Federal Highway Administration. The equation has the form in Equation D.1.

Equation D.1 Modified Manning's equation for shallow triangular channels

$$Q = \frac{3}{8}\frac{bS^{\frac{1}{2}}}{n}y^{\frac{8}{3}}$$

where:

Q	flow rate (m^3/s)
b	effective cross-fall of channel (-)
S	longitudinal gradient of channel (m/m)
n	Manning's roughness coefficient
y	design depth of flow (m)

Equation D.1 was obtained by applying Manning's equation to vertical elements in the cross-section and integrating the discharge across the channel; no allowance is made for the resistance of a vertical kerb. It gives capacities that are approximately 20% higher than the conventional version in Equation 5.25.2. Values of n quoted in the literature for triangular channels therefore depend upon which of the two formulae were used to analyse the experimental data.

The conventional form of Manning's equation has been used in this document (that is in Equations 5.25, 5.25.1, 5.25.2, 5.25.3 and 5.25.4) so as to provide a common basis for all shapes of channel. Values of n given in the literature vary typically from 0.010 to 0.017 for concrete channels and from 0.012 to 0.022 for asphalt channels. In Table 5.18.1 the recommended figures for "average" condition are well correlated with the mean of the published values; the figures for "poor" condition are slightly less than the corresponding maximum values.

Factors which can tend to increase the resistance of a channel are lateral inflow from the road surface and the presence of silt and grit in the invert. Data on these effects are not available, but it is probable that at the downstream ends of channels (which are the most critical points) they are not very large in relation to the uncertainties in the basic n values. An "average" value of n = 0.013 for a concrete channel could be appropriate if it has a trowel-type finish, no sharp discontinuities in line or elevation, and is regularly cleaned.

An approximate procedure is given in the surcharged surface water channel section in Section 5 for applying the design method for simple cross-sectional shapes to the case of surcharged compound channels. It was found that a direct solution for compound channels could be obtained only when using a development of the modified Manning's equation in Equation D.1. The relationships in Equations 5.26 to 5.29, between the relevant hydraulic characteristics (flow capacity and storage capacity) for a compound channel and an equivalent "simple" channel, are therefore based on the modified form of Manning's equation.

The location of a longitundinal line of posts within a channel, such as a post-mounted vehicle restraint system, can affect channel capacity and increase the risk of an obstruction or blockage. An estimate of the extra flow resistance produced by a longitudinal line of posts is obtained by considering the drag force acting on each post. The factor of 0.7 in Equation D.2 corresponds to a drag coefficient of C_d = 1.2 with an allowance for the effect of varying water depth between the upstream and downstream ends of a channel. The effect of a longitudinal line of posts on channel capacity can be estimated by increasing the appropriate value of n by np given by:

Equation D.2 Roughness coefficient due to posts

$$n_p = 0.7\left[\frac{1}{gL_ip}\left(\frac{A_p}{A}\right)\right]^{\frac{1}{2}}\left(\frac{ry}{m+1}\right)^{\frac{2}{3}}$$

where:

n_p	additional roughness coefficient due to posts
g	acceleration due to gravity (m/s^2)
L_ip	average length between posts (m)
A_p	cross sectional area of posts (m^2)
A	cross sectional area of flow (m^2)
r	hydraulic radius factor (-)
y	design depth of flow (m)
m	shape characteristic parameter (-)

Allowance need not normally be made for one or two isolated posts located in the channel.

D2 Grassed surface water channels

The Manning's roughness coefficient, n , can alternatively be calculated using the following formulae derived from laboratory tests and validated using field trial data. (See HRW SR 662 [Ref 9.I] and Equation D.3).

Equation D.3 Alternative Mannings equation for grassed surface water channels where VR>0.002

$$n = 0.05 + 0.0048(1+\alpha)\frac{H}{VR}$$

where:

α	runoff coefficient (-)
H	grass height (m)
V	velocity (m/s)
R	hydraulic radius of flow (m)

with α = 0 for Perennial Ryegrass-dominated grass mixtures and α = 1 for Fescues-dominated grass mixtures.

Equation D.3 is applicable for VR>0.002. The great majority of design cases can be in that category. However, where VR<0.002, n can be calculated using the following expression:

Equation D.4 Alternative Mannings equation for grassed surface water channels where VR<0.002

$$n = 0.05 + 2.4(1 + \alpha)H$$

where:

α	runoff coefficient (-)
H	grass height (m)

Appendix E. Rainfall

Kinematic wave theory enables the peak depth of flow at the downstream end of a channel to be determined for a given intensity and duration of rainfall. For design of surface water channels, it was necessary to describe the rainfall characteristics by means of an equation relating mean intensity to the duration and return period of the storm event.

This led to Equation E.1 being developed for predicting the mean rainfall intensity.

Equation E.1 Mean rainfall intensity

$$I = 32.7(N - 0.4)^{0.223}\left\{(T - 0.4)^{0.565}\frac{\text{2minM5}}{T}\right\}$$

To enable this to be produced, relevant information on short-period storms with durations between 1 minute and 10 minutes was provided by the Met Office, and used in the following calculation procedure given in Annex A of BS EN 12056-3 2000 [Ref 7.N]:

1) determine from a map of the UK (reproduced in this document as Figure 5.3) the value of rainfall depth (2minM5) occurring in 2 minutes with a return period of 5 years at the chosen location;
2) calculate (using a table and the value of 2minM5) the rainfall depth for the required duration T but still with a return period of 5 years (that is, TminM5);
3) calculate (using a graph and the value of TminM5) the rainfall depth for the required duration T and return period N (that is, TminMN); and,
4) divide the rainfall depth TminMN by the duration to give the mean intensity I .

Equation E.1 was obtained by curve-fitting the tabular and graphical data corresponding to steps (2) to (4) above. The applicability of the equation to storm duration's greater than 10 minutes was checked using data in Volume II of the Flood Estimation Handbook FEH V2 [Ref 7.I].

The equation was optimised for values of T = 2-20 minutes and N = 1-20 years and tends to overestimate the mean intensity outside these ranges. The recommended upper limits for use of Equation E.1 are T = 30 minutes and N = 50 years.

The validity of kinematic wave theory for flows in shallow drainage channels was checked using measurements from a trial on the M6 motorway TRL CR 8 1985 [Ref 12.I]. More information of kinematic wave theory is given in HR Wallingford HRW DE 30 [Ref 4.I] and May OECD [Ref 3.I].

The intensity of rainfall normally varies with time during a storm, and this affects the way in which a channel responds to run-off. Typical profiles of rainfall intensity in summer and winter storms are given in Volume II of the Flood Estimation Handbook FEH V2 [Ref 7.I] . For impervious surfaces such as roads, the largest flows tend to be produced by heavy short-period storms which occur more frequently in summer than winter. The design method therefore uses what is termed the 50% summer profile, in which the peak intensity at the midpoint of the storm is approximately 3.9 times the average intensity; 50% of summer storms in the UK can be expected to have lower ratios of peak to mean intensities. Data from the M6 motorway TRL CR 8 1985 [Ref 12.I] showed that using the 50% summer profile in the design method gave conservative results.

In the design equations given in Section 5, the critical storm duration has been eliminated as an independent variable and does not need to be determined separately when calculating the length of road that a channel can drain. However, an assessment can be undertaken to check that the critical storm duration is within the recommended upper limit of 30 minutes.

The critical storm duration T_c that gives rise to the design flow conditions in a surface water channel can be estimated from:

Equation E.2 Critical storm duration

$$T_c = 0.085\left(\frac{nL}{S^{\frac{1}{2}}}\right)(ry)^{-\frac{2}{3}}$$

where:

Tc	critical storm duration (minutes)
n	Manning's roughness coefficient
L	length of road/ surface water channel between two adjacent outlets on a continuous slope, or the distance between a point of zero slope and the downstream outlet (m)
S	longitudinal gradient of channel (m/m)
r	hydraulic radius factor (-)
y	design depth of flow (m)

Appendix F. Surcharge factors

Figure F.1 Drainage length factor for triangular channels with surcharged width of Bs = 1 m

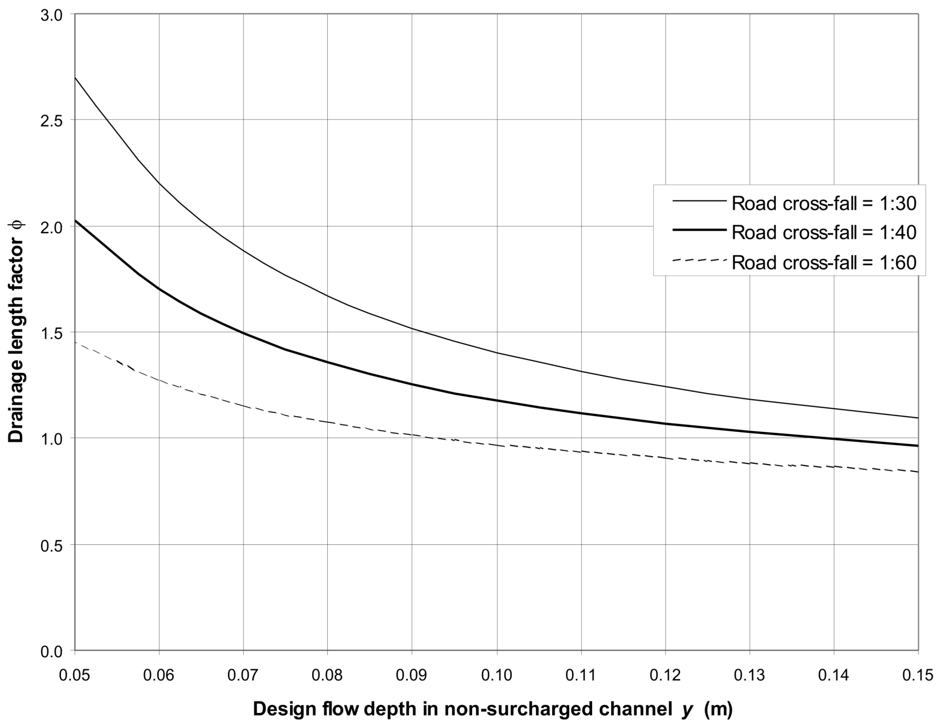


Figure F.2 Drainage length factor for triangular channels with surcharged width of Bs = 1.5 m

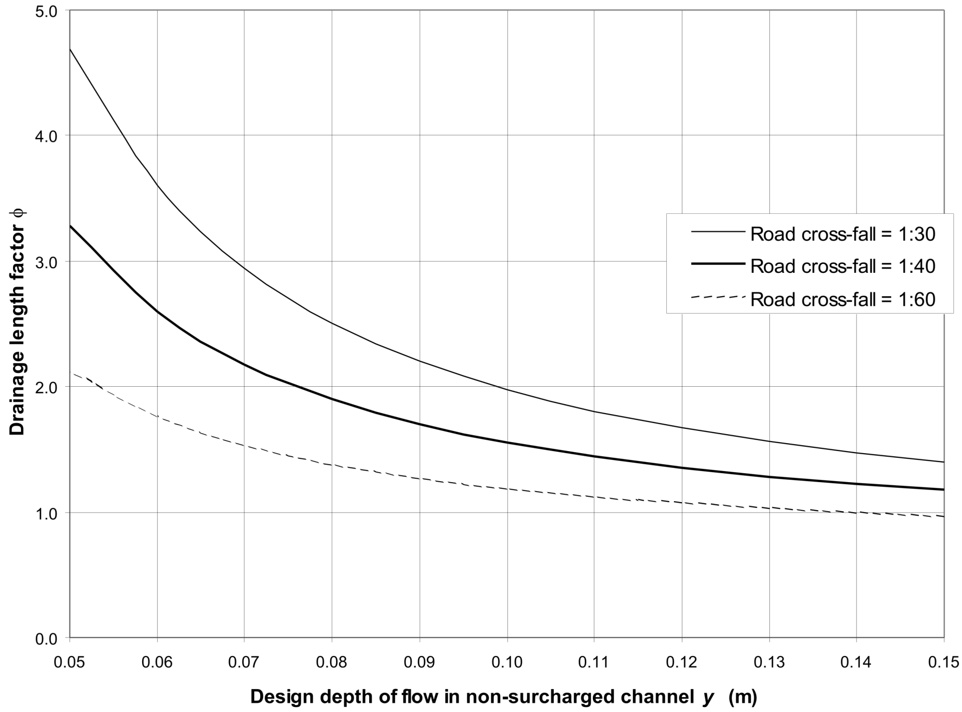


Table F.1 Values of drainage length factor

Road cross-fall	Values of ϕ for B_s =1m	Values of ϕ for B_s =1.5m
1:30	1.5	1.8
1:40	1.4	1.6
1:50	1.2	1.4

Appendix G. Outlet design tables

Table G.1 Triangular channels: Limiting values of Fd and Fs for terminal outlets

Type of outlet	No of gratings (or pairs of gratings)		
	1	2	3
In-line outlet: Channel full (F_d) Surcharged (F_s)	0.95 0.80	2.0 1.8	2.3 2.1
Off-line Outlet: Channel full (F_d) Surcharged (F_s)	1.2 1.0	1.4 1.3	2.0 1.7

Table G.2 Trapezoidal channel with cross-falls of 1:4.5: Limiting values of Fd and Fs for terminal outlets

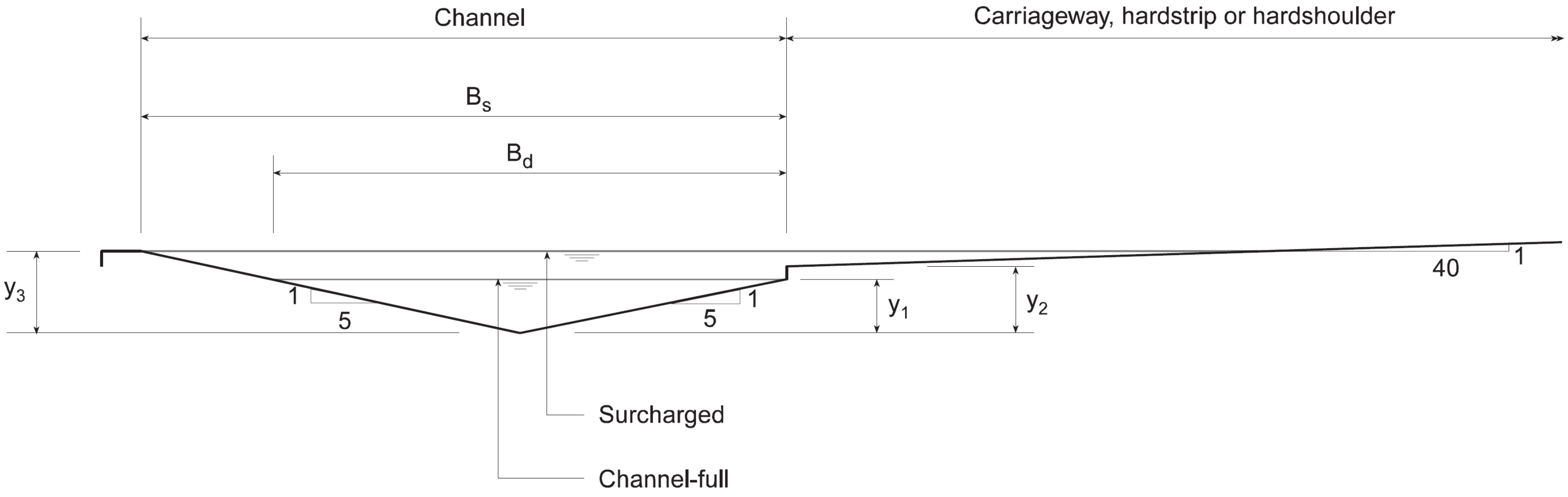
Type of outlet	No of gratings	
	2	3
In-line outlet: Channel full (F_d) Surcharged (F_s)	 0.55 0.40	 0.85 0.75
Off-Line Outlet: Channel full (F_d) Surcharged (F_s)	 1.0 0.9	 1.3 1.2

Table G.3 Trapezoidal channel with cross-falls of 1:5: Limiting values of Fd and Fs for terminal outlets

Type of outlet	No of gratings	
	2	3
In-line outlet: Channel full (F_d) Surcharged (F_s)	 0.45 0.30	 0.65 0.50
Off-line outlet: Channel full (F_d) Surcharged (F_s)	 0.75 0.65	 1.1 1.0

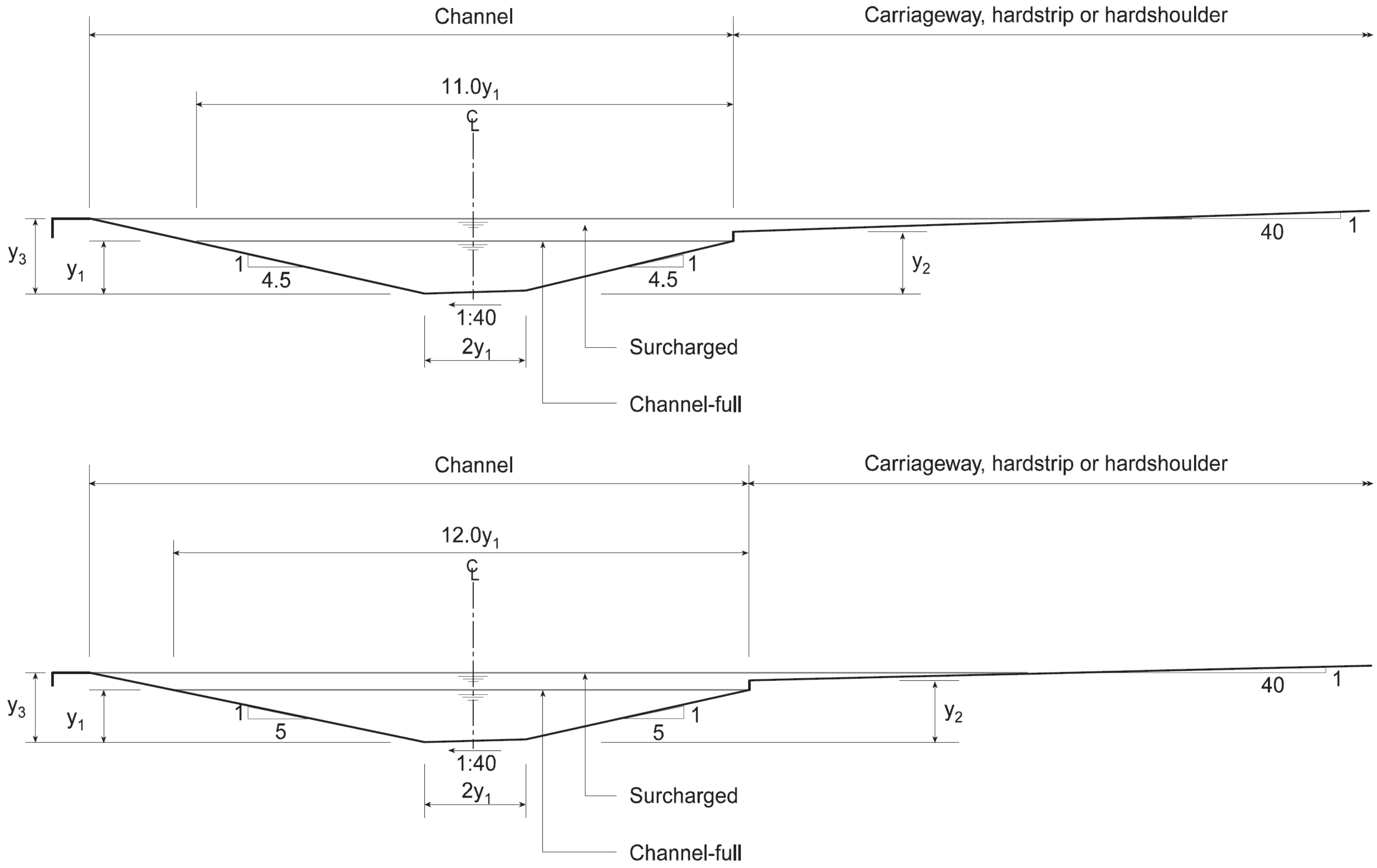
Appendix H. Outlet design figures

Figure H.1 Cross-sectional shape of triangular channel



[N.B. $y_3 = y_2$ in central reserve]

Figure H.2 Cross-sectional shape of trapezoidal channel



[N.B. $y_3 = y_2$ in central reserve]

Figure H.3 Relationship between surcharge and channel-full flows - triangular channels

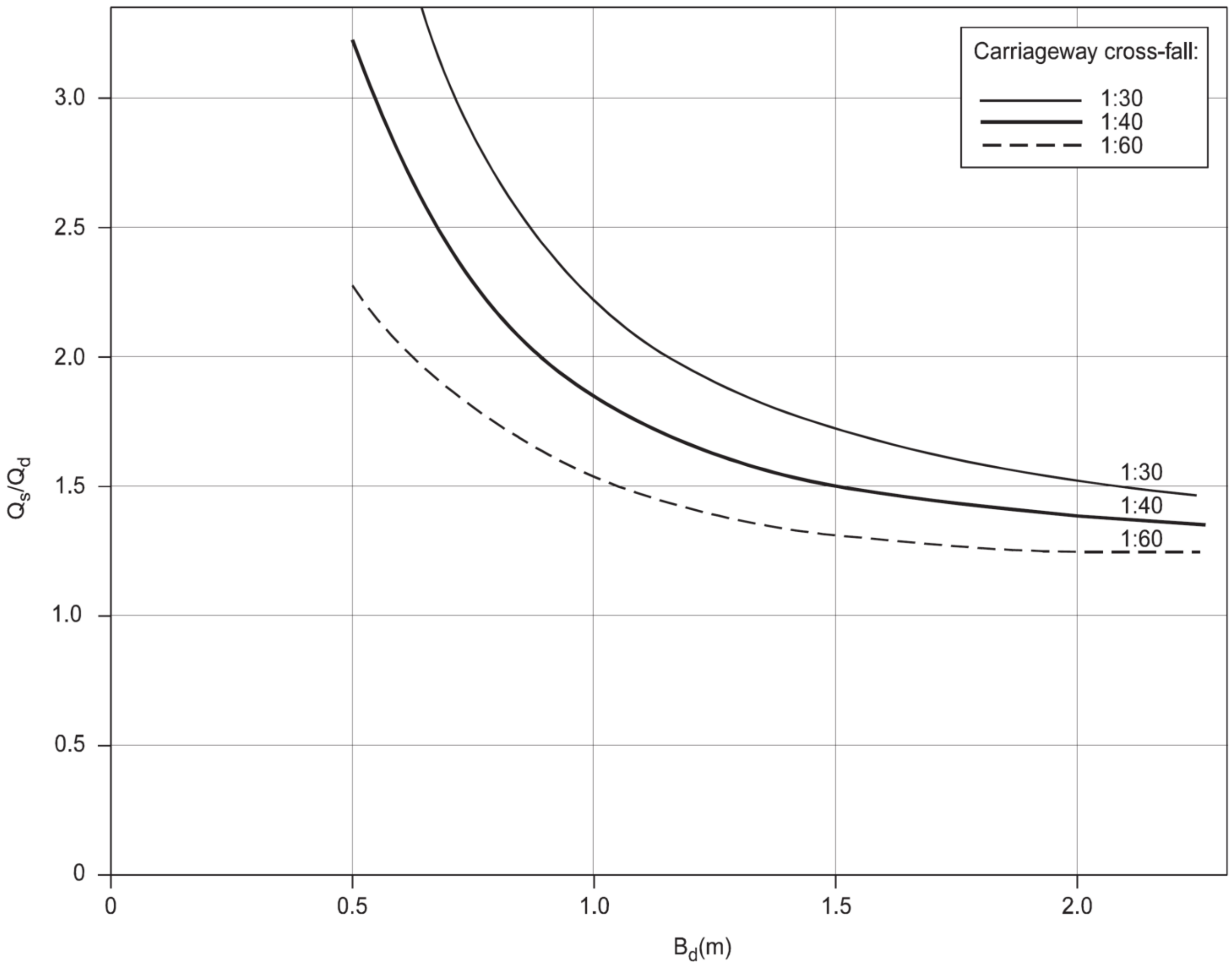


Figure H.4 Relationship between surcharged and channel-full flows - trapezoidal channels

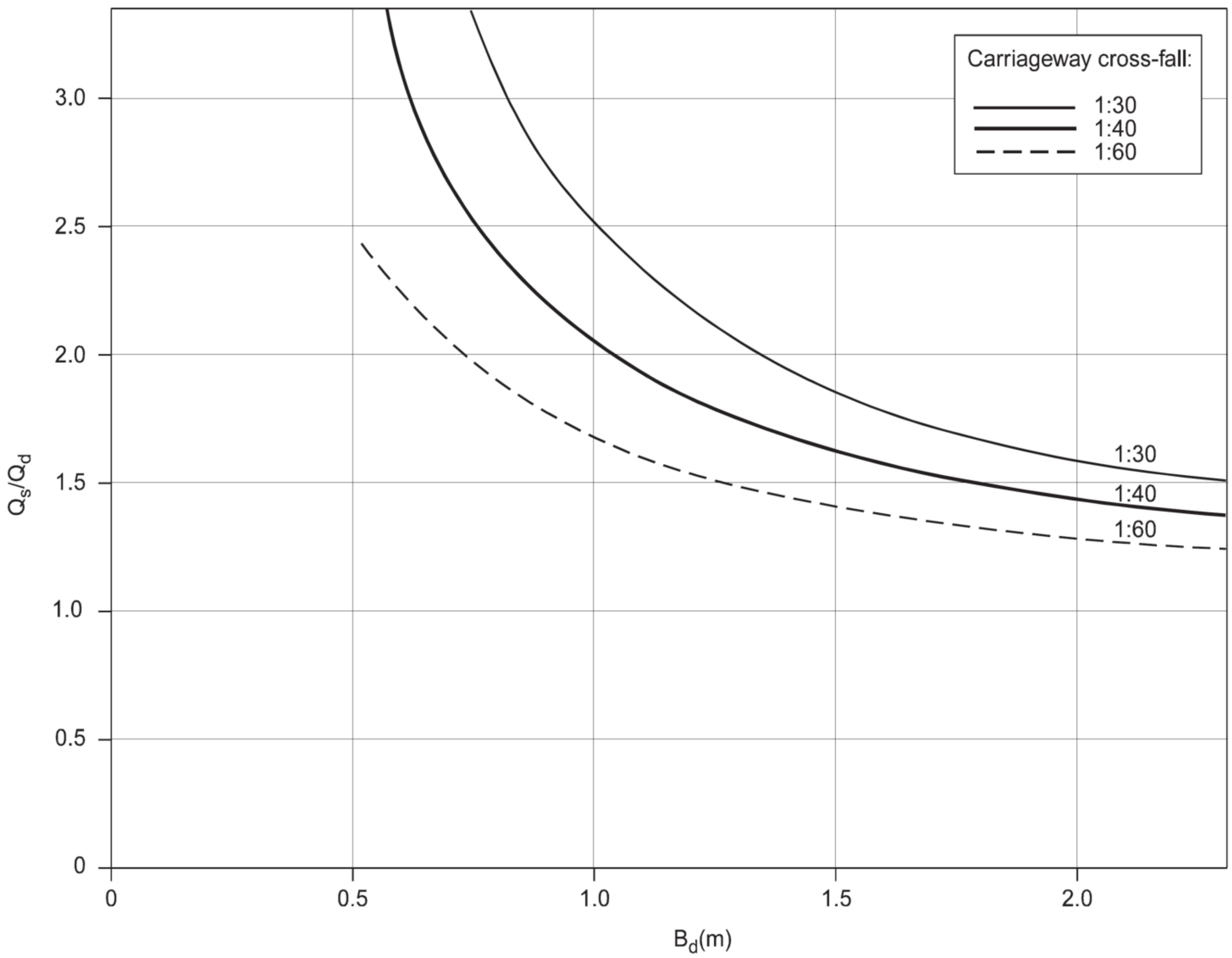


Figure H.5 Triangular channel in-line outlet

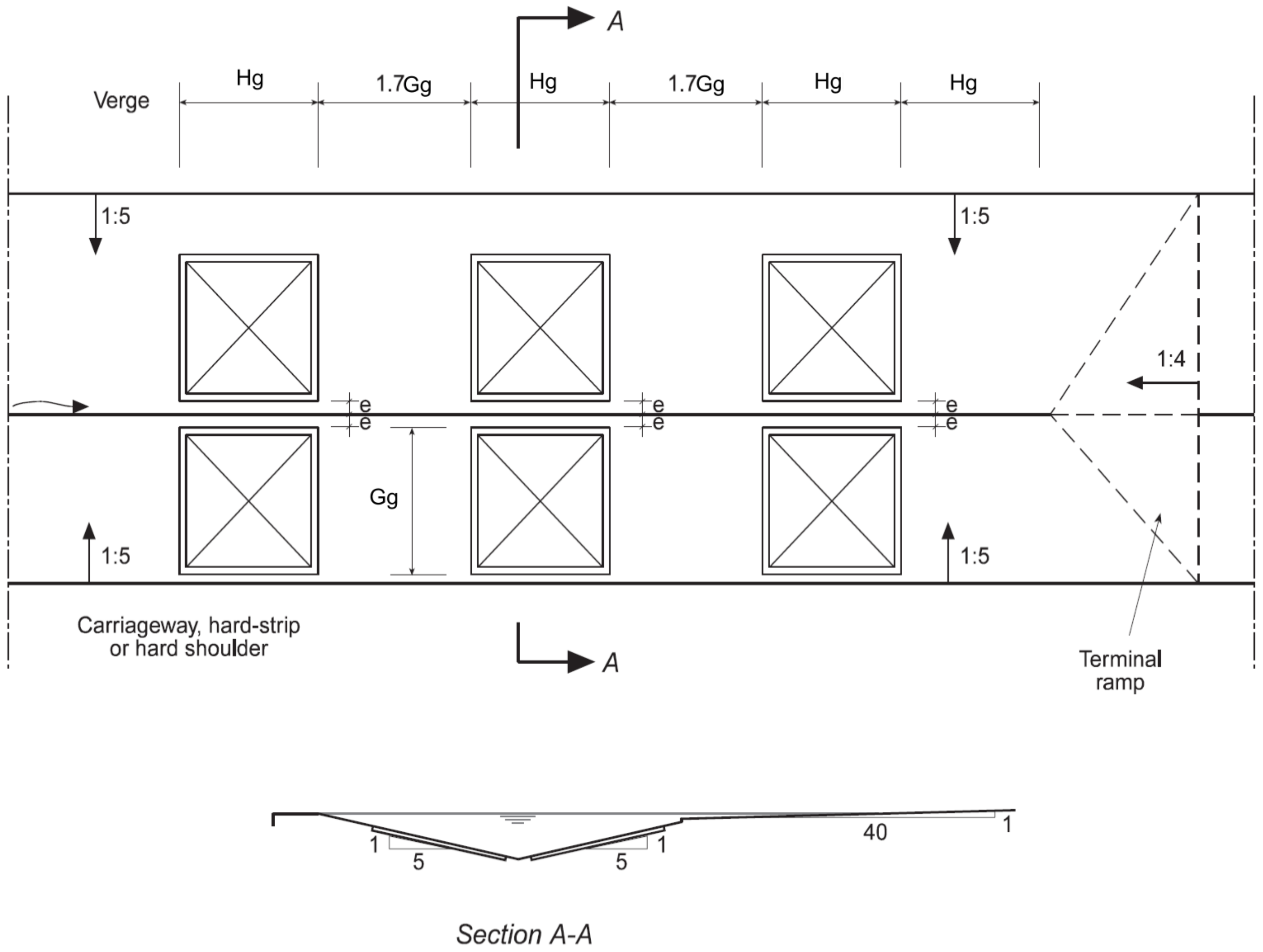


Figure H.6 Triangular channel off-line outlet

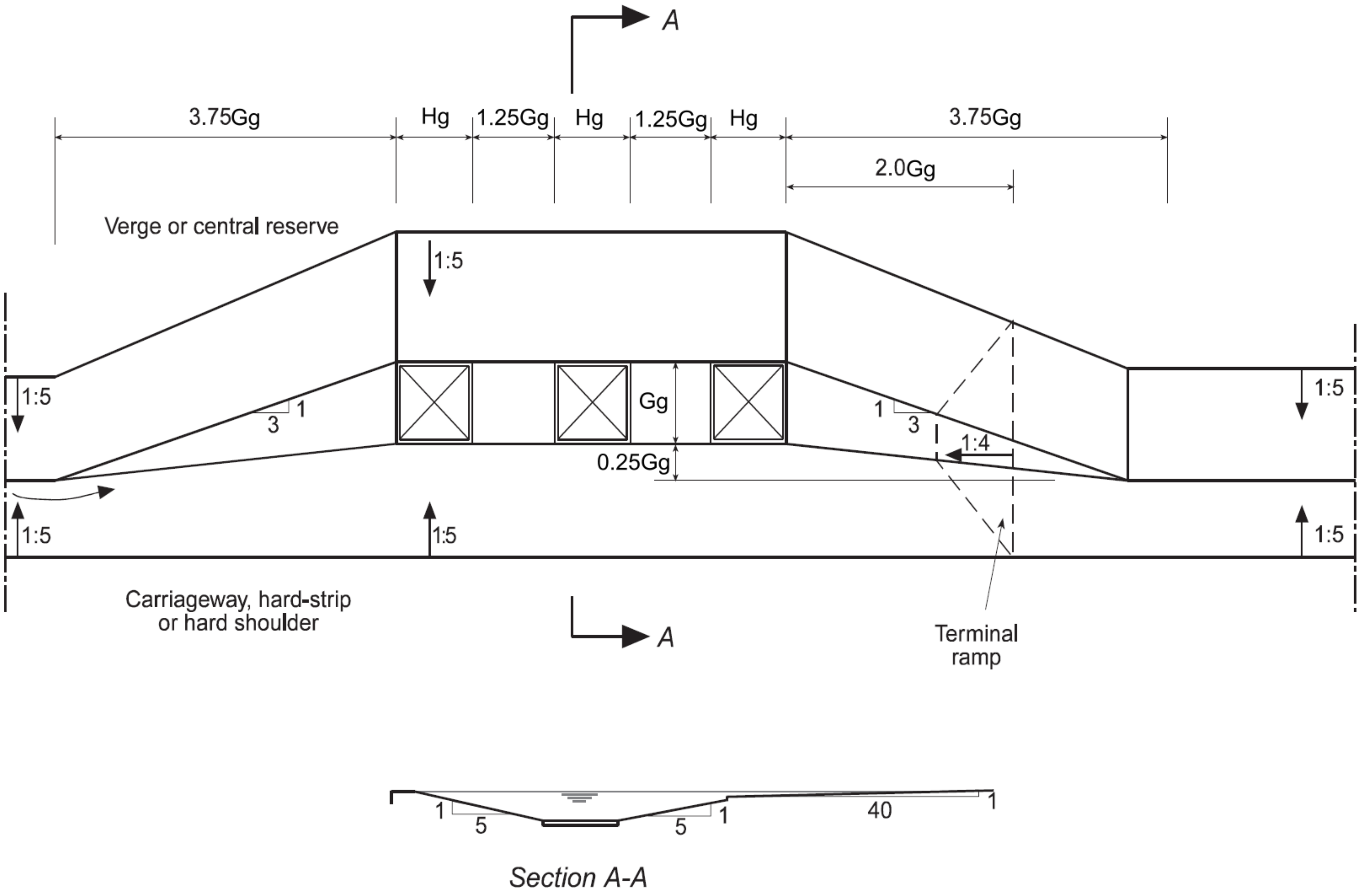


Figure H.7 Trapezoidal channel with cross-falls of 1:4.5 - in-line outlet

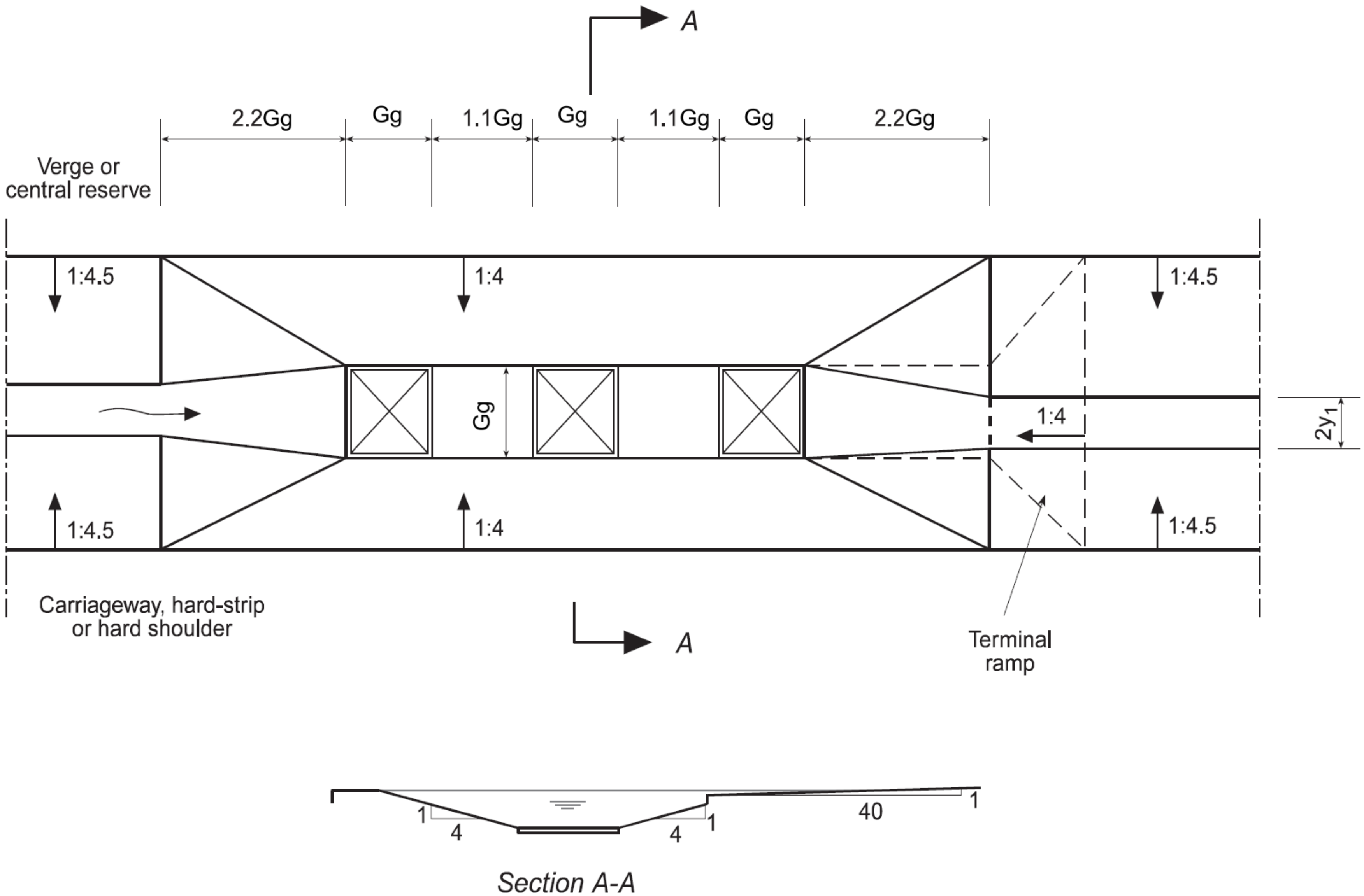


Figure H.8 Trapezoidal channel with cross-falls of 1:4.5 - off-line outlet

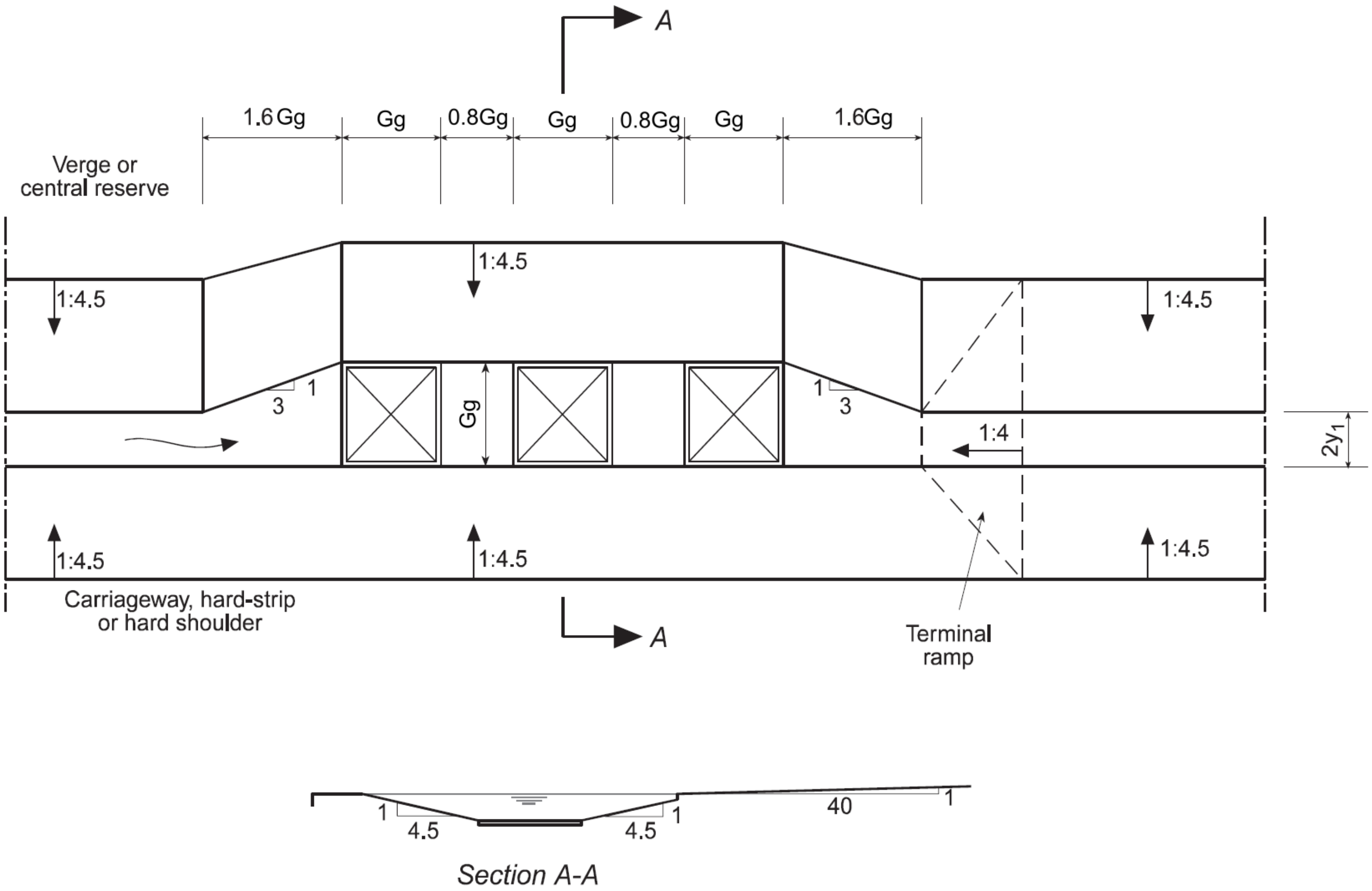


Figure H.9 Trapezoidal channel with cross-falls of 1:5 - in-line outlet

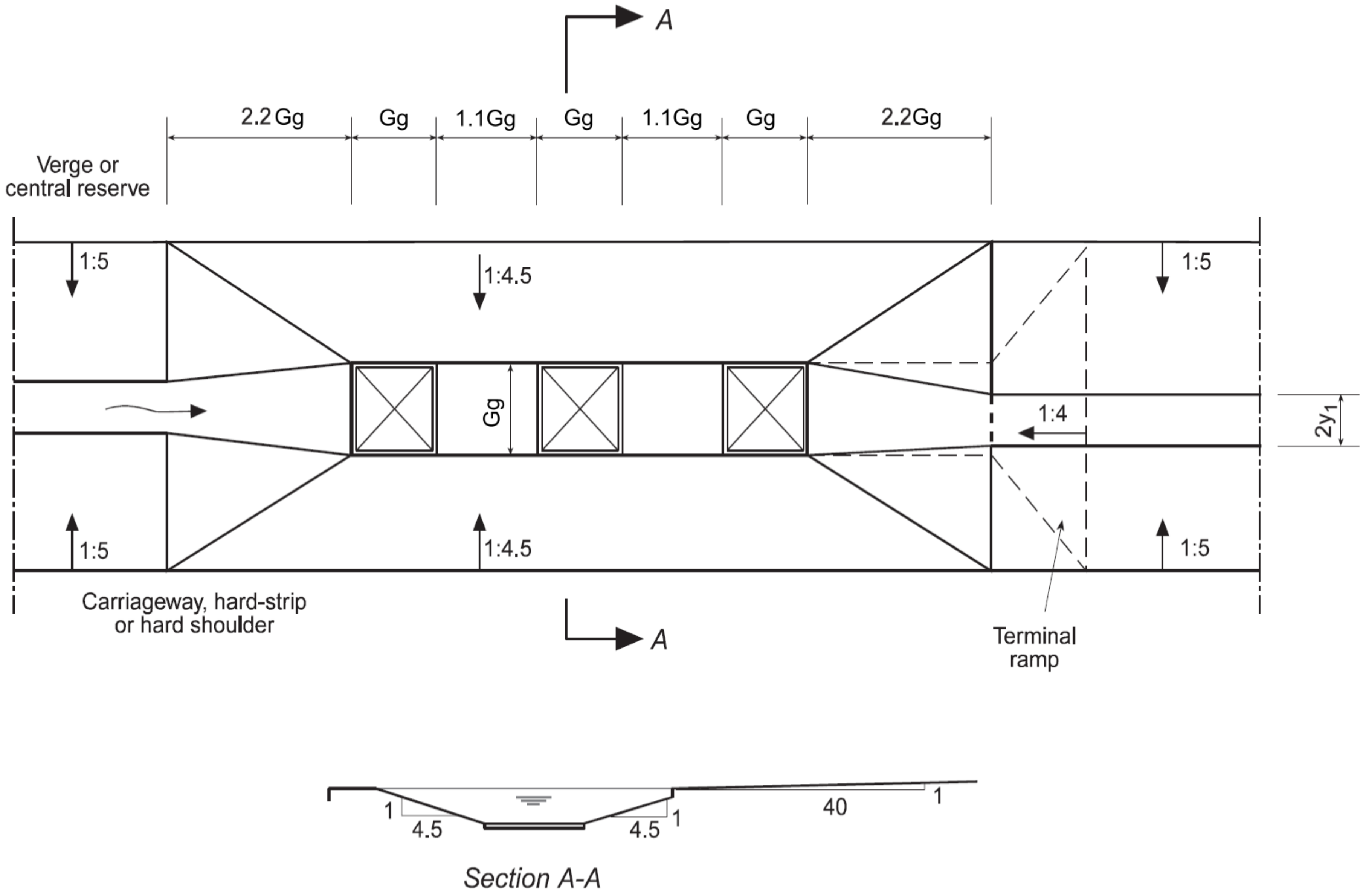


Figure H.10 Trapezoidal channel with cross-falls of 1:5 - off-line outlet

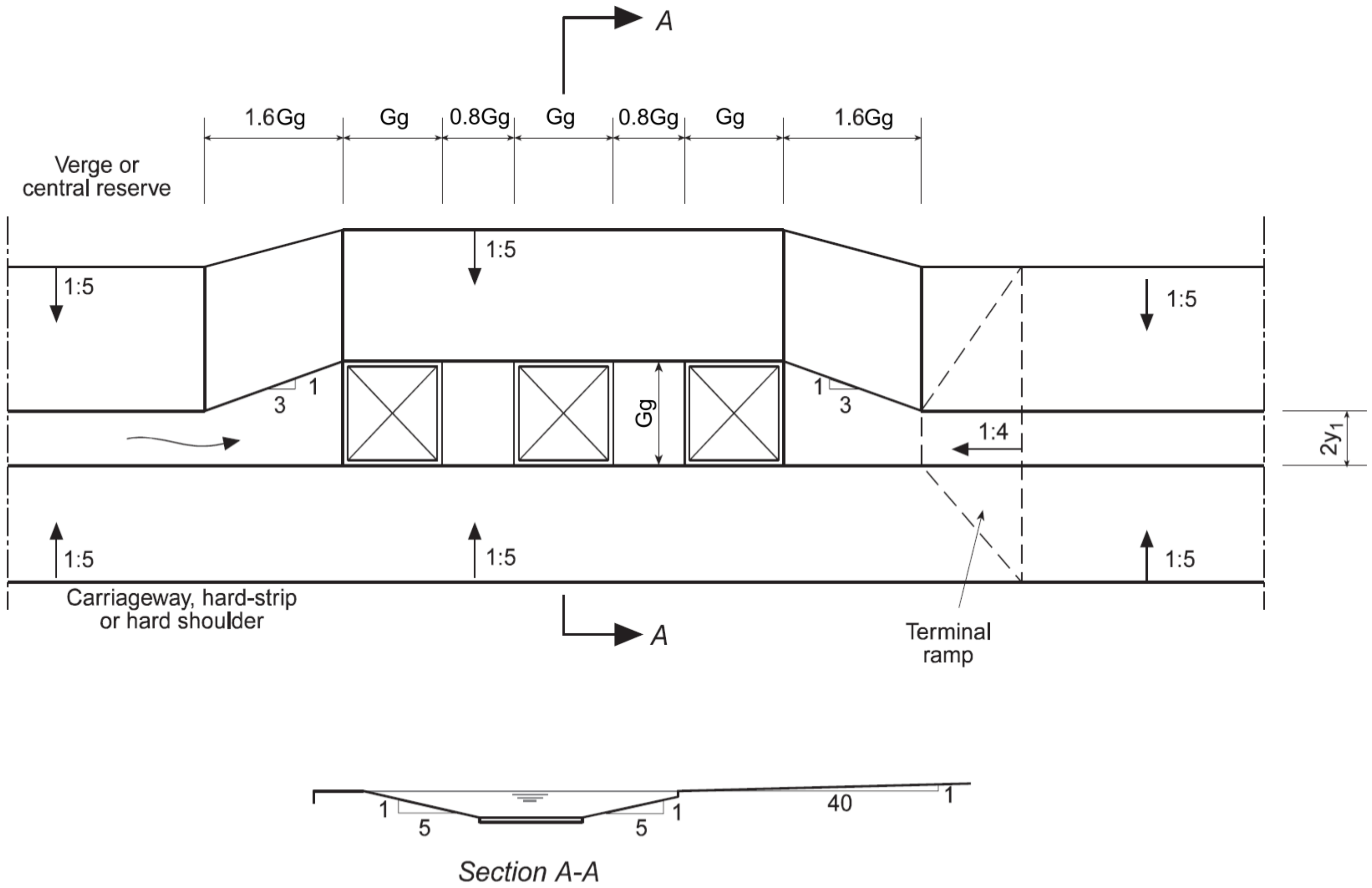


Figure H.11 Design curves: triangular channel - in-line outlet channel full

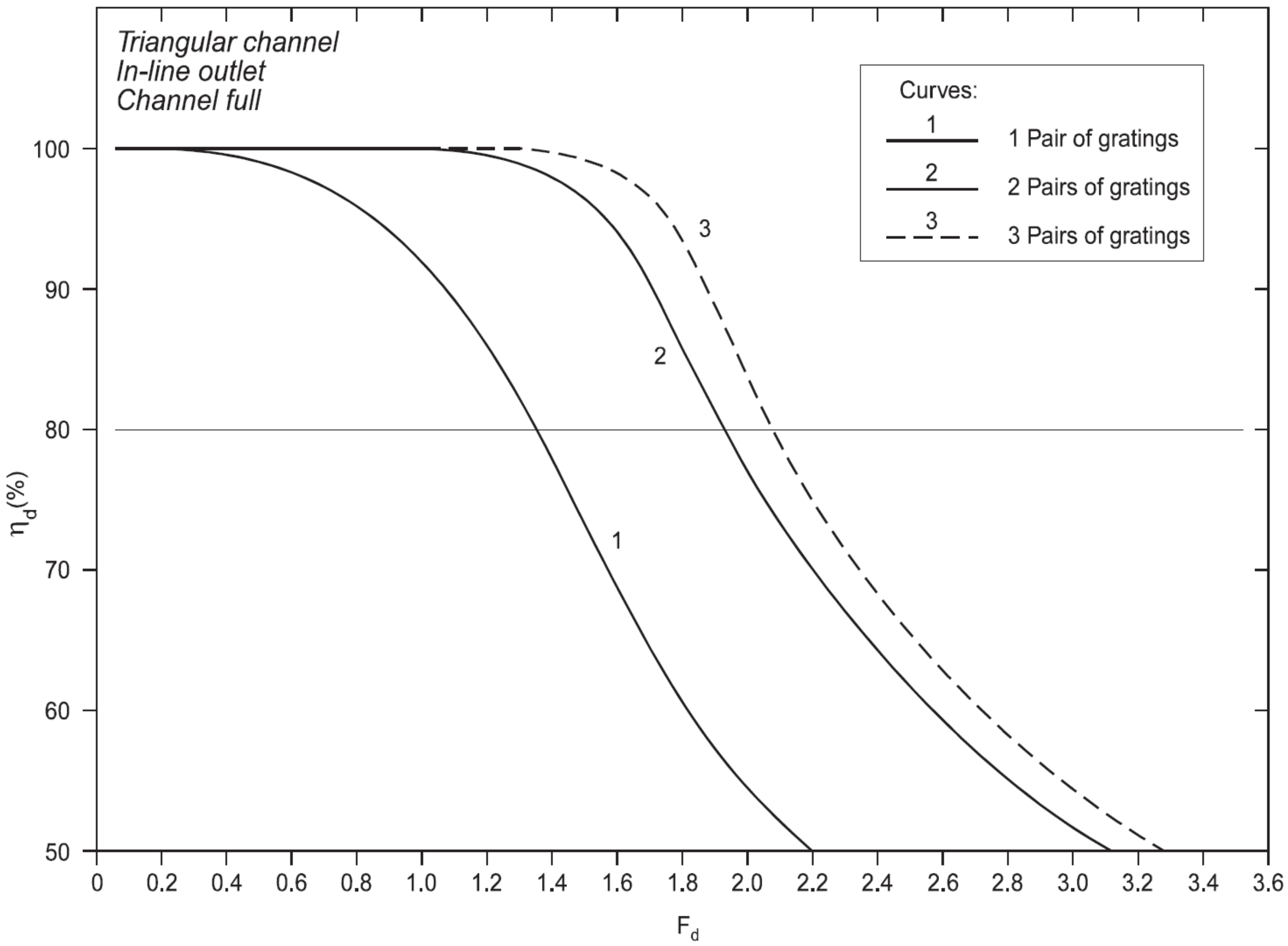


Figure H.12 Design curves: triangular channel - in-line outlet surcharged channel

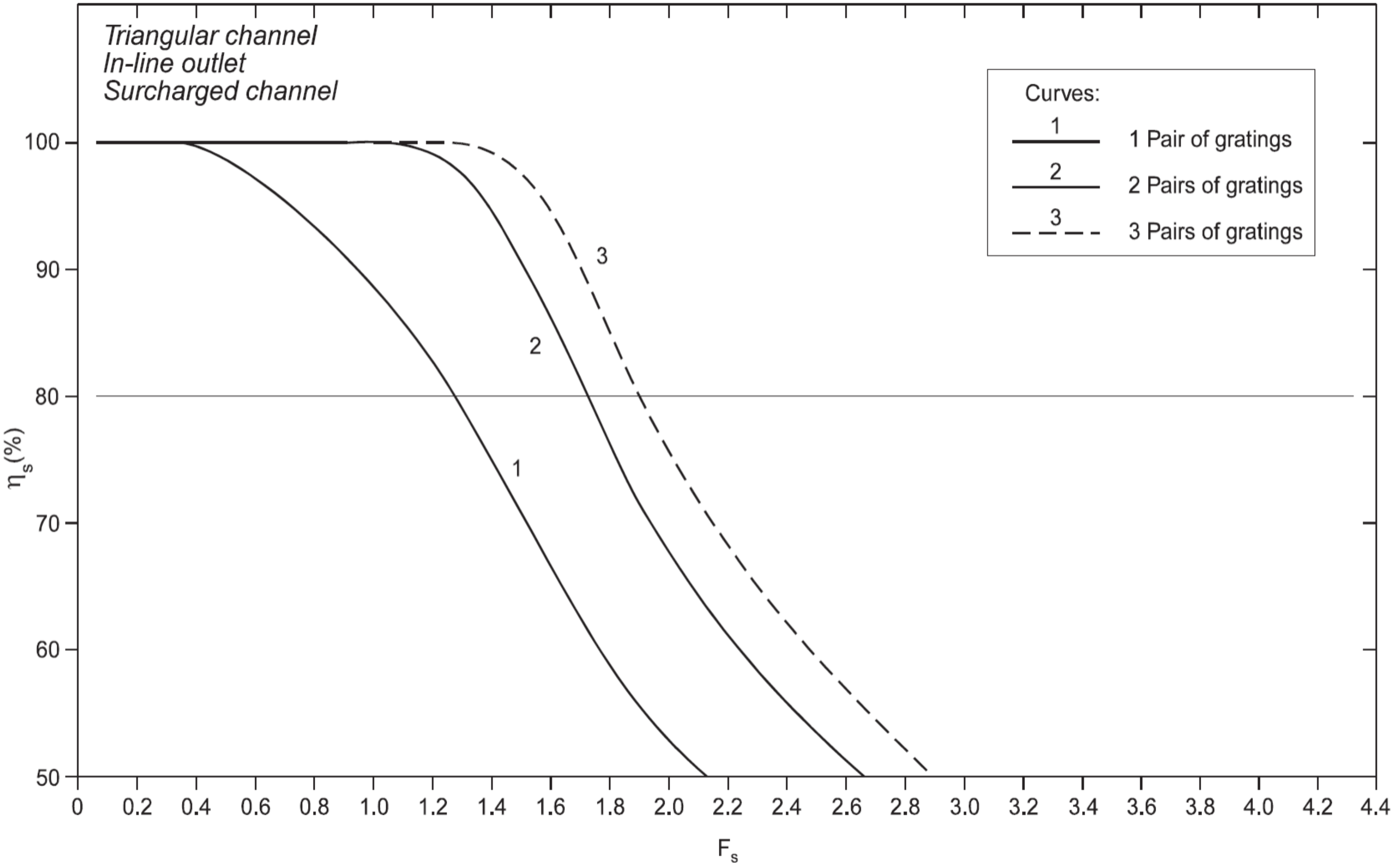


Figure H.13 Design curves: triangular channel - off-line outlet channel full

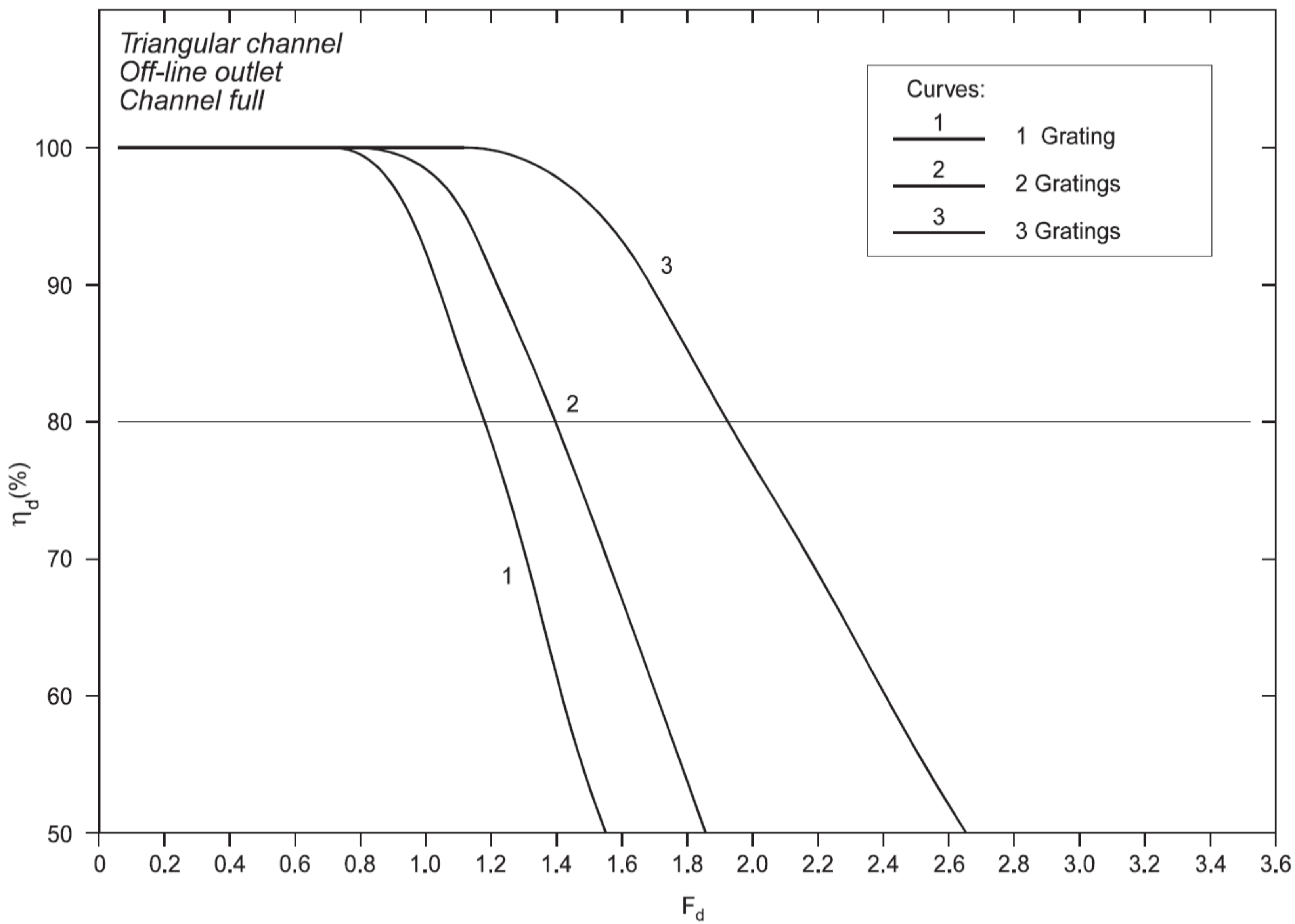


Figure H.14 Design curves: triangular channel - off-line outlet surcharged channel

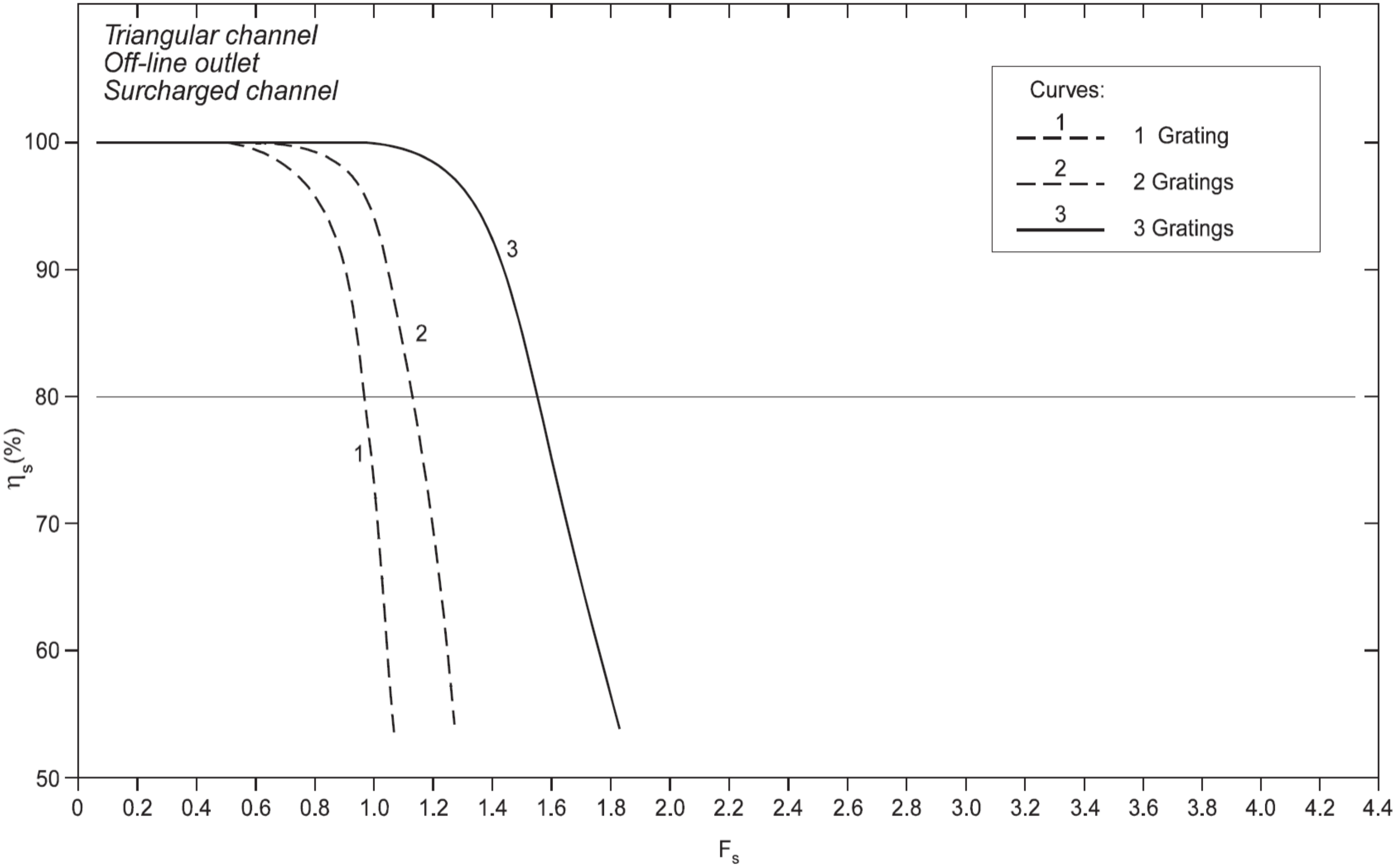


Figure H.15 Design curves: trapezoidal channel with cross-falls of 1:4.5 - in-line outlet channel full

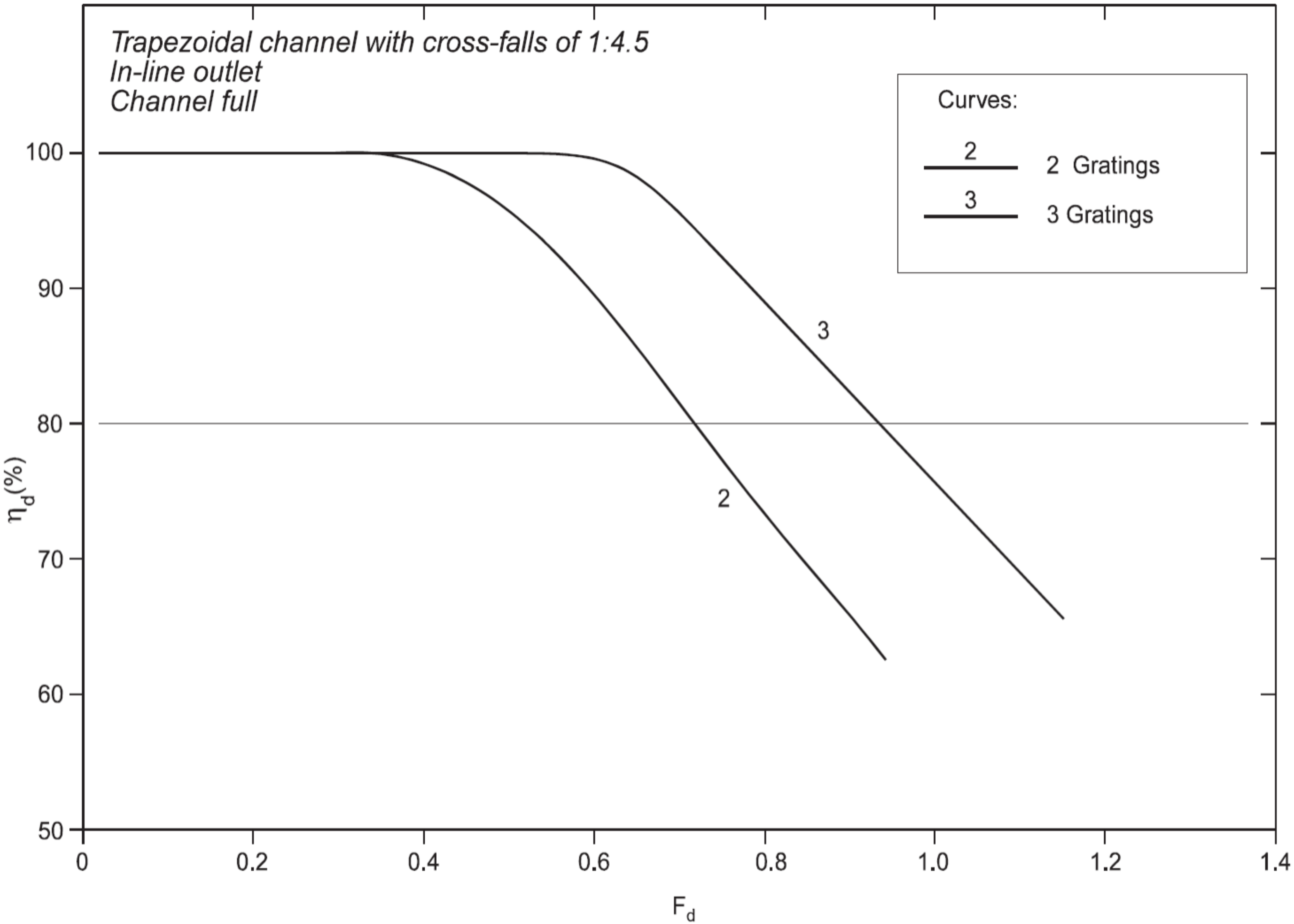


Figure H.16 Design curves: trapezoidal channel with cross-falls of 1:4.5 - in-line outlet surcharged channel

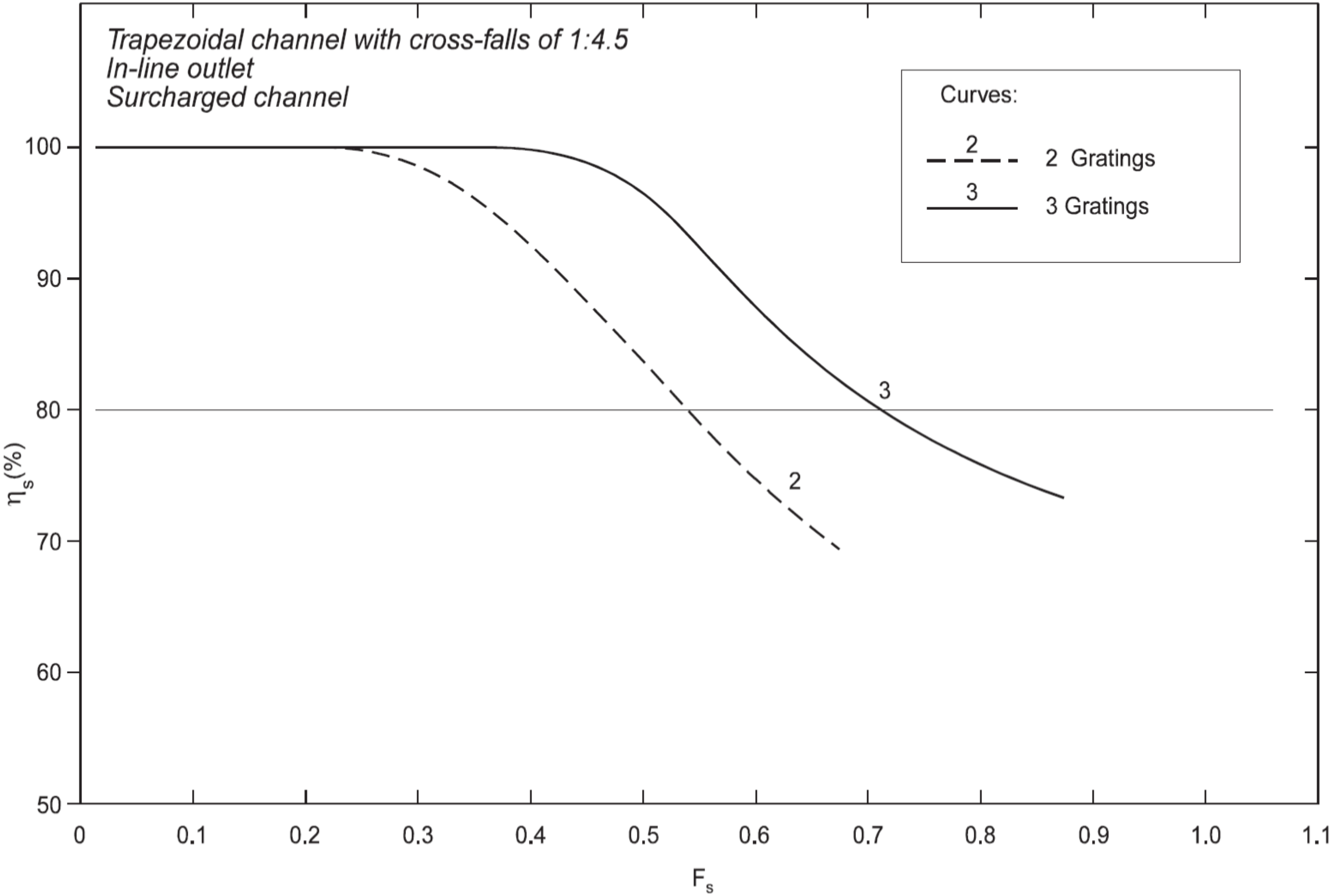


Figure H.17 Design curves: trapezoidal channel with cross-falls of 1:4.5 - off-line outlet channel full

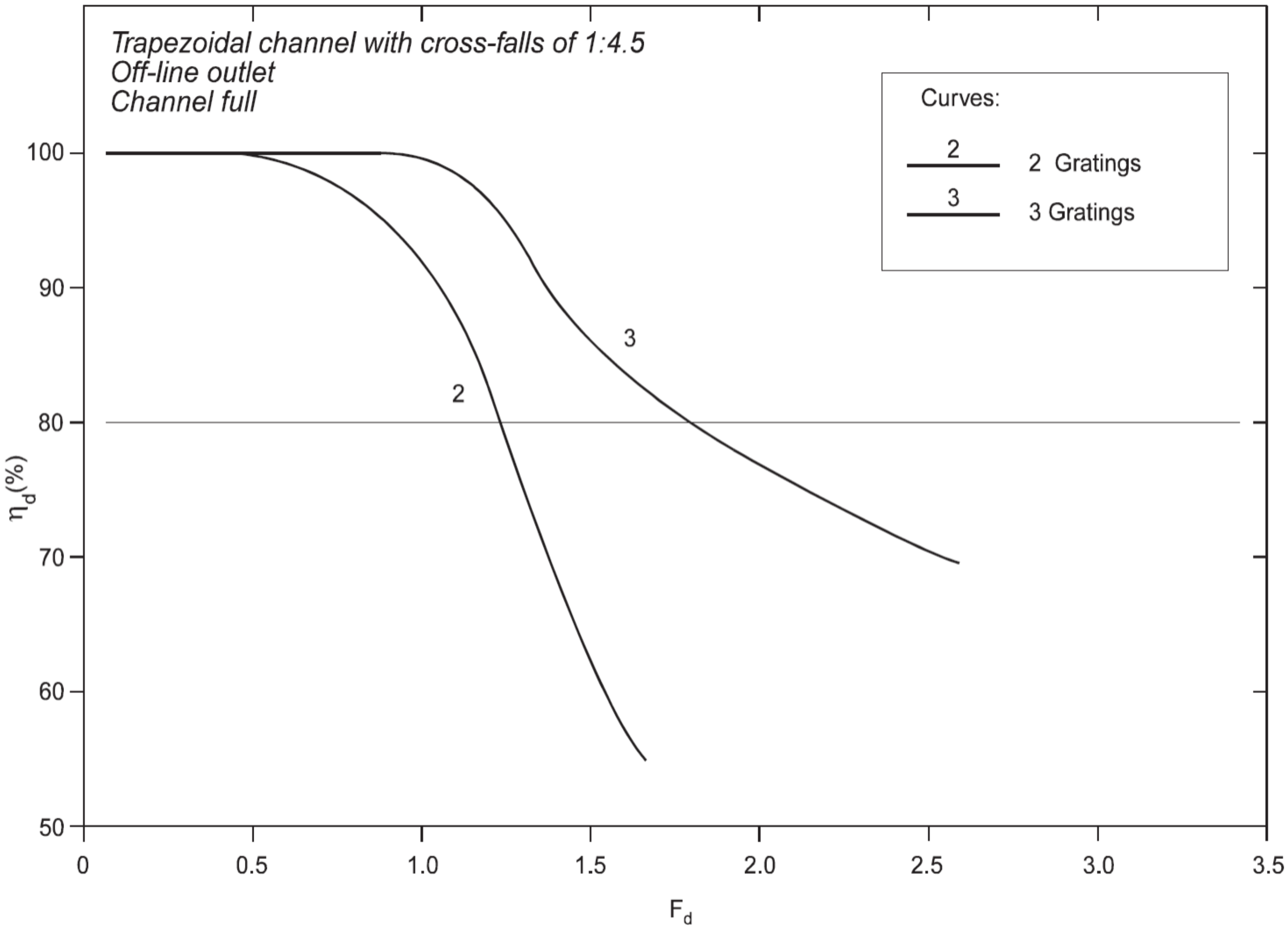


Figure H.18 Design curves: trapezoidal channel with cross-falls of 1:4.5 - off-line outlet surcharged channel

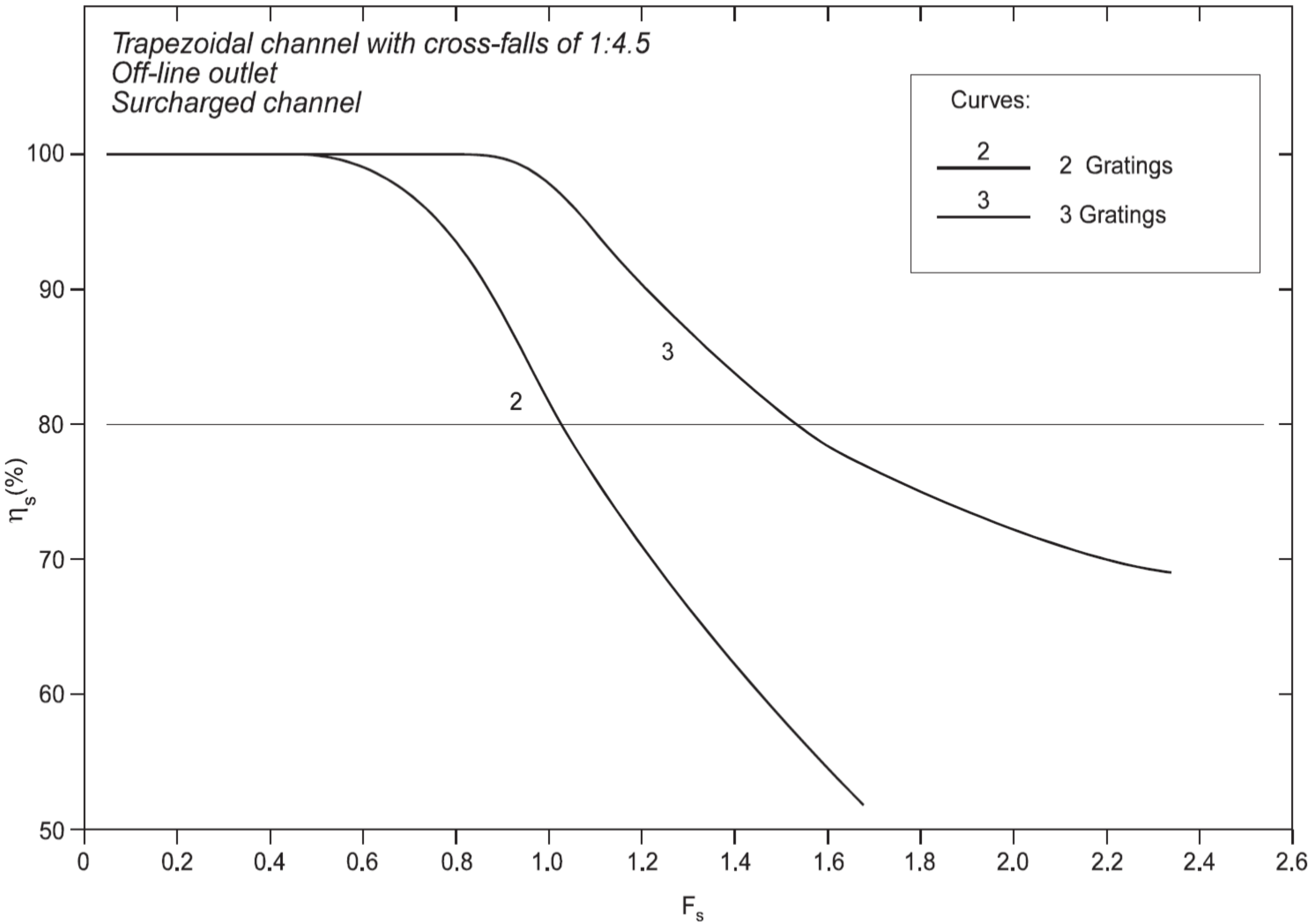


Figure H.19 Design curves: trapezoidal channel with cross-falls of 1:4.5 - in-line outlet channel full

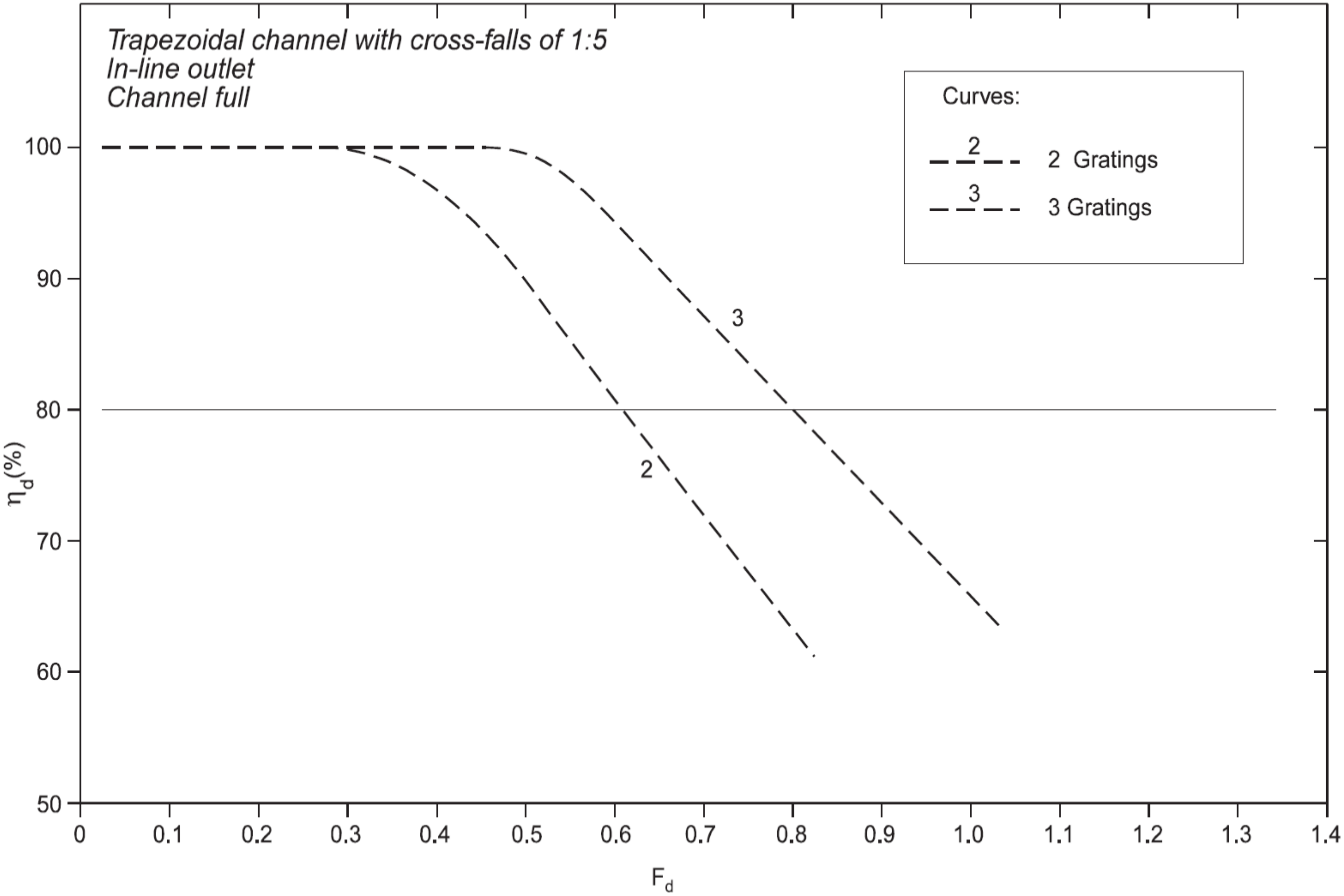


Figure H.20 Design curves: trapezoidal channel with cross-falls of 1:5 - in-line outlet surcharged channel

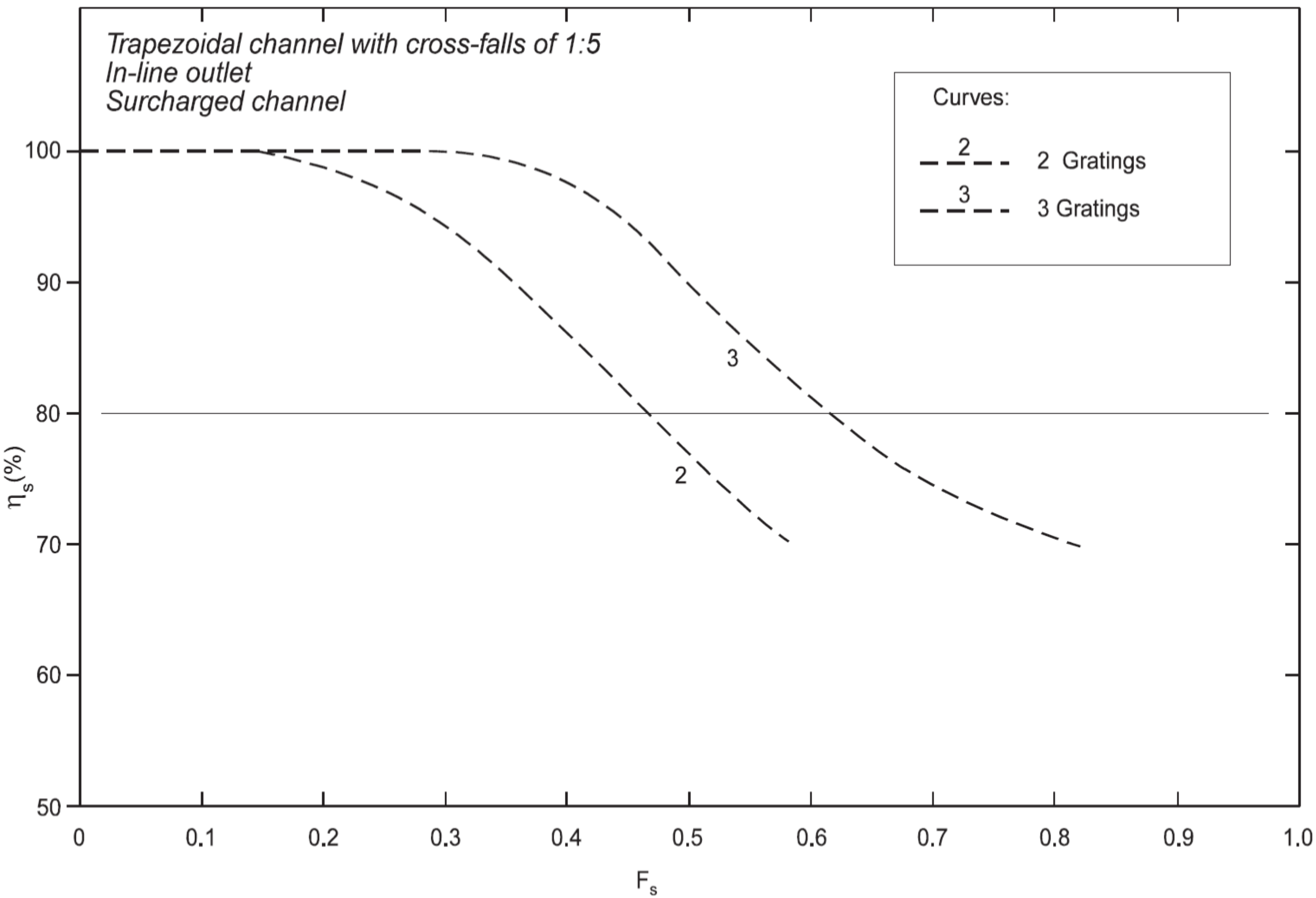


Figure H.21 Design curves: trapezoidal channel with cross-falls of 1:5 - off-line outlet channel full

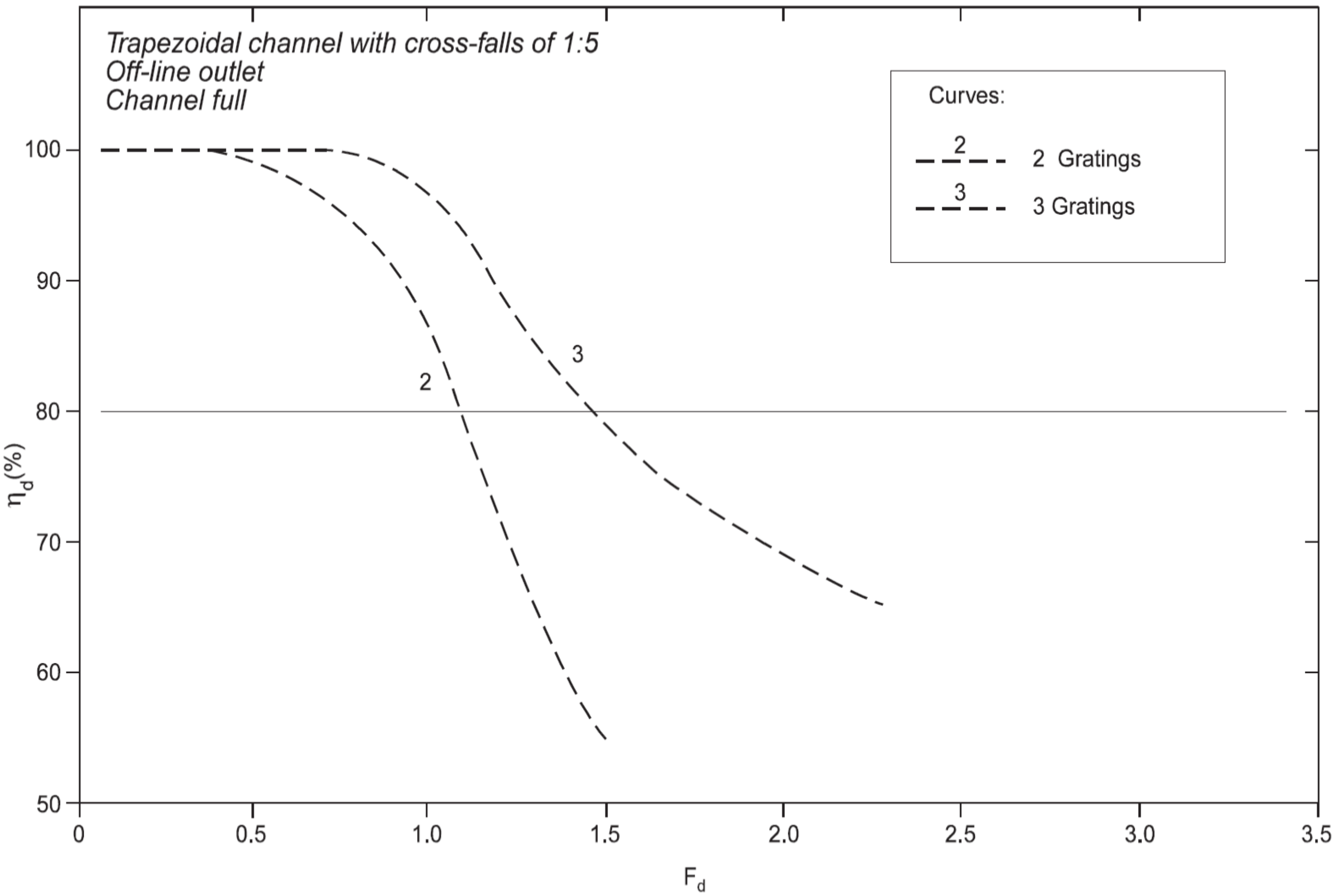


Figure H.22 Design curves: trapezoidal channel with cross-falls of 1:5 - off-line outlet surcharged channel

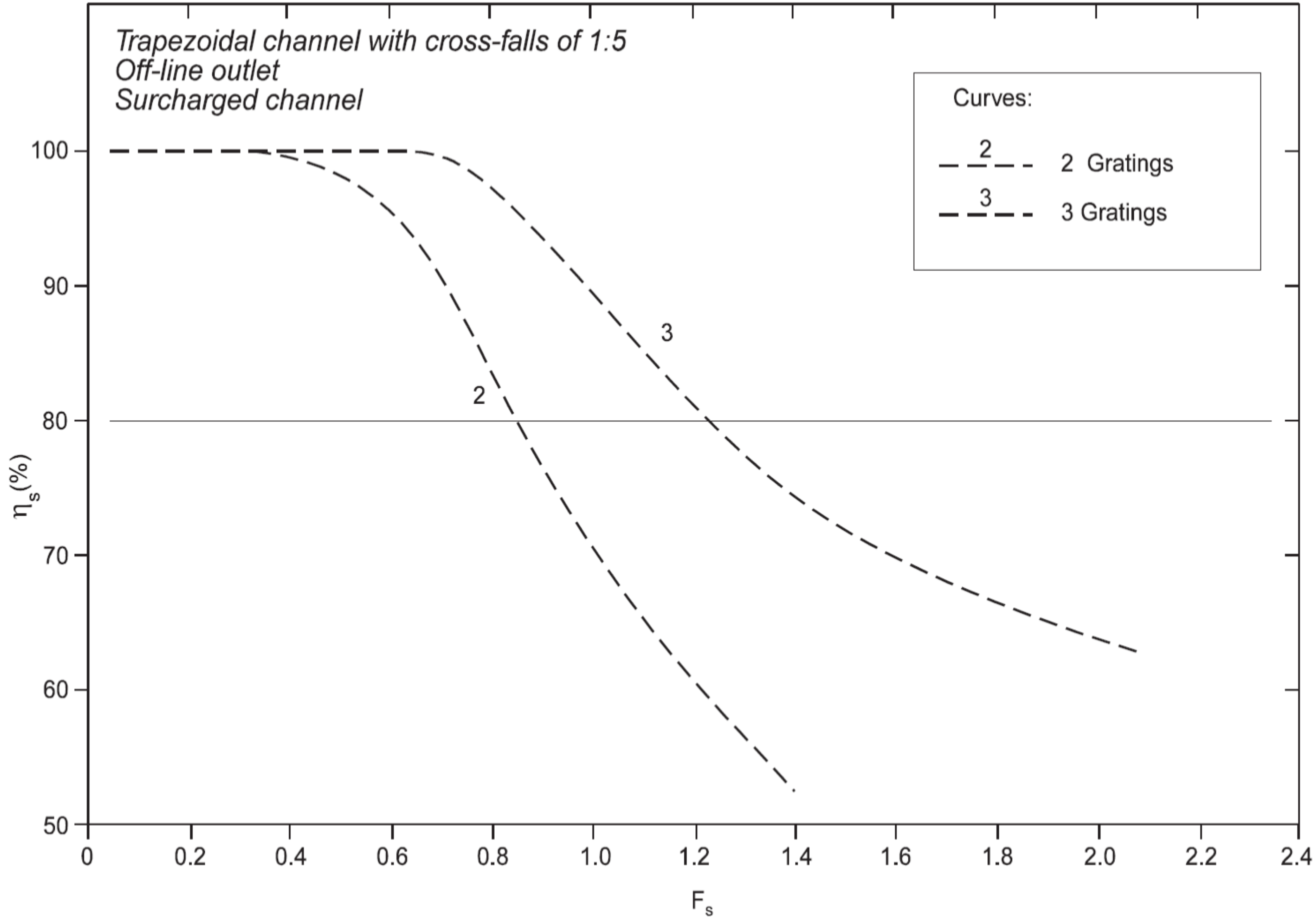


Figure H.23 Isometric view of weir outlet indicating possible location of safety fence

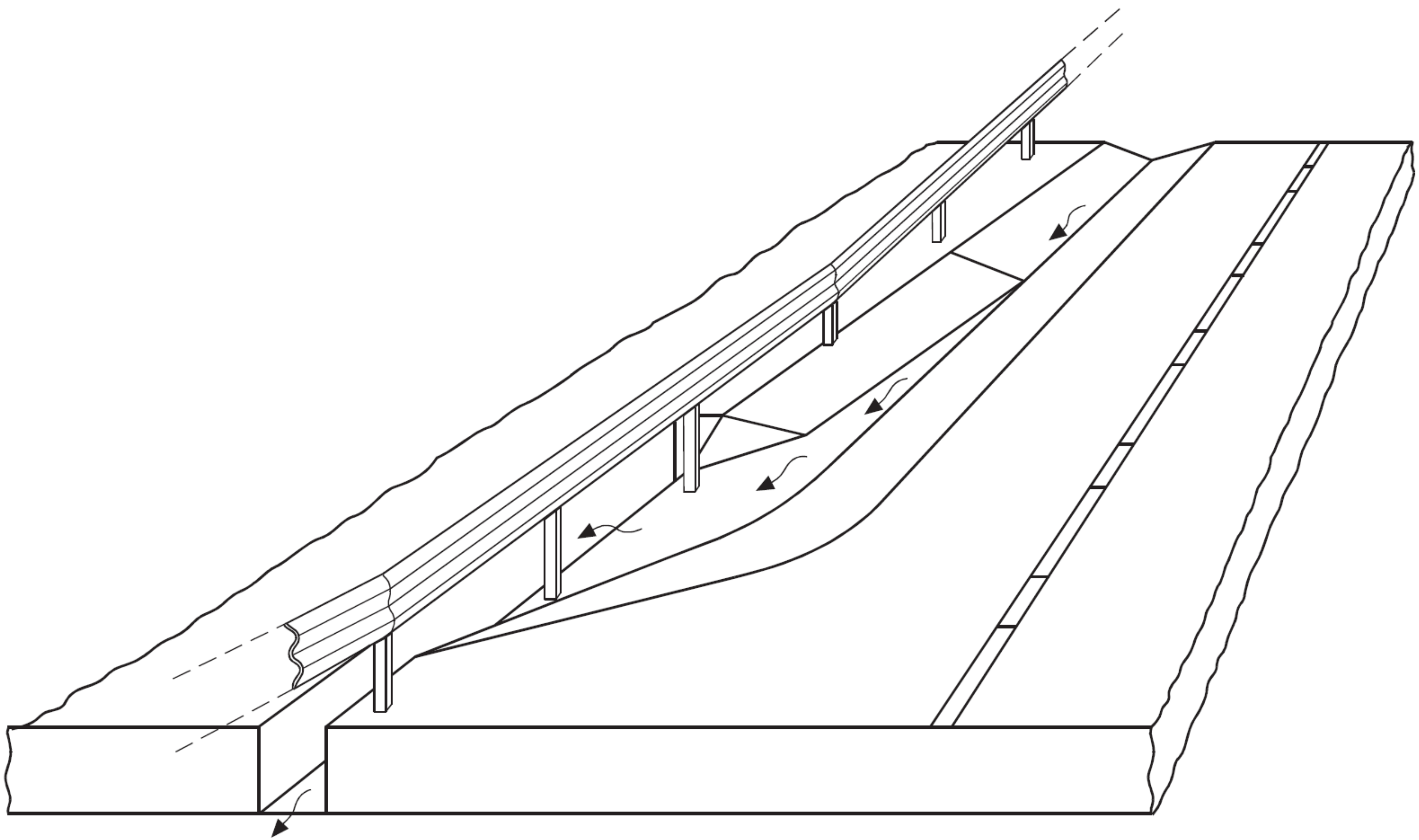
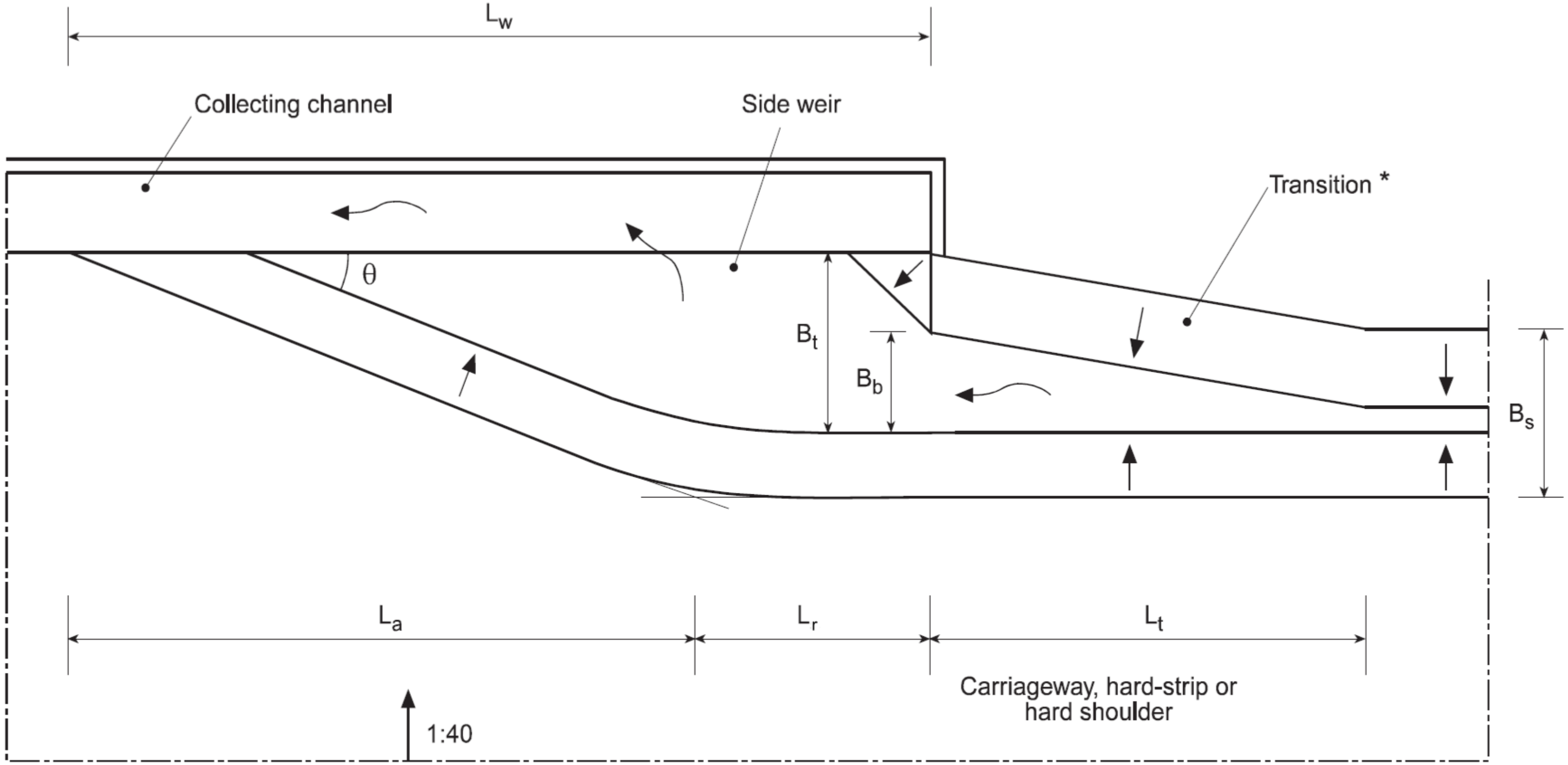


Figure H.24 Diagrammatic layout of weir outlet and upstream transition



* See Figure H.23 for example of transition in triangular channel

Plan view

Figure H.25 Variations of geometry of weir outlet with flow conditions

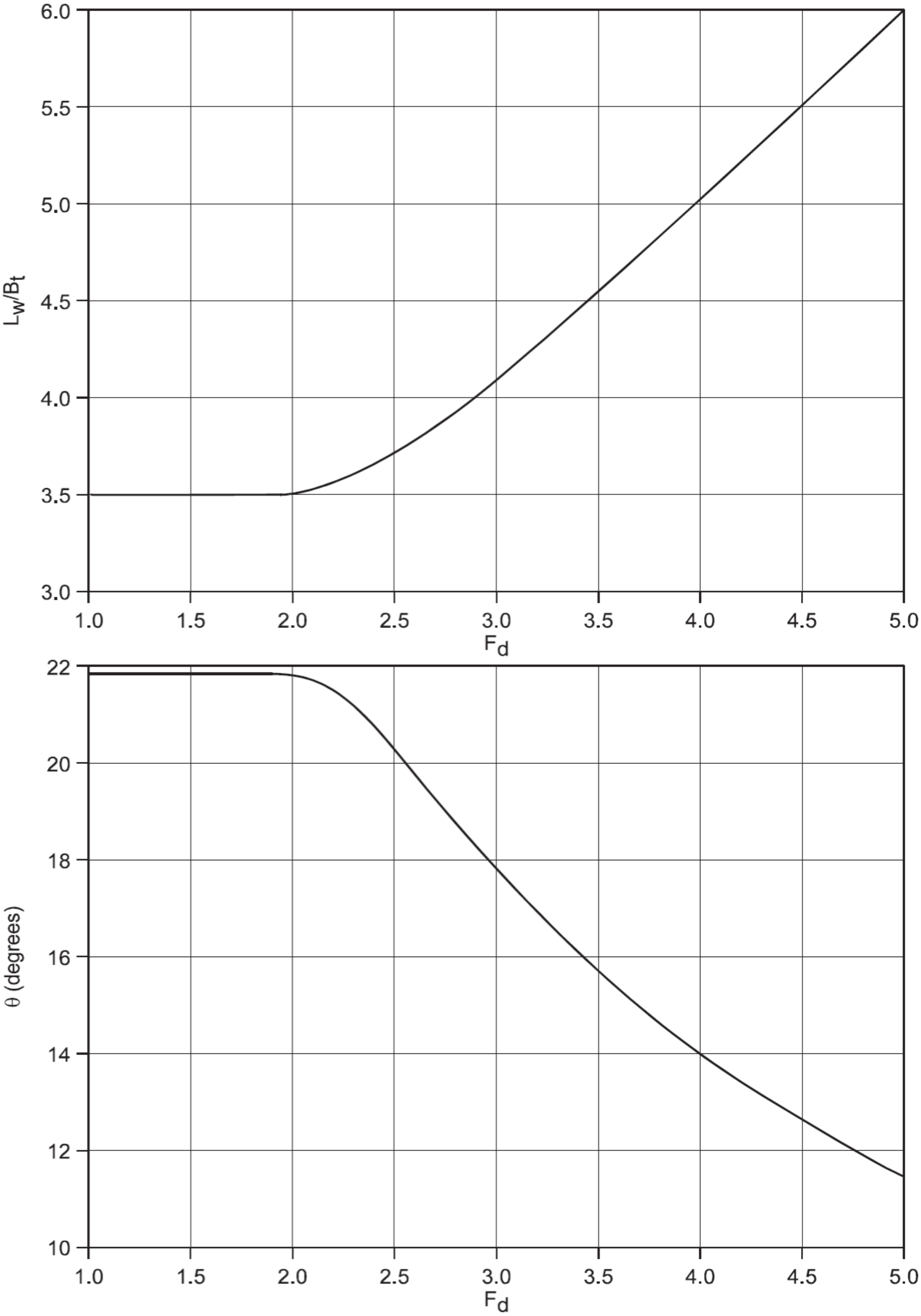


Figure H.26 Flow chart for design of weir outlets in triangular channels

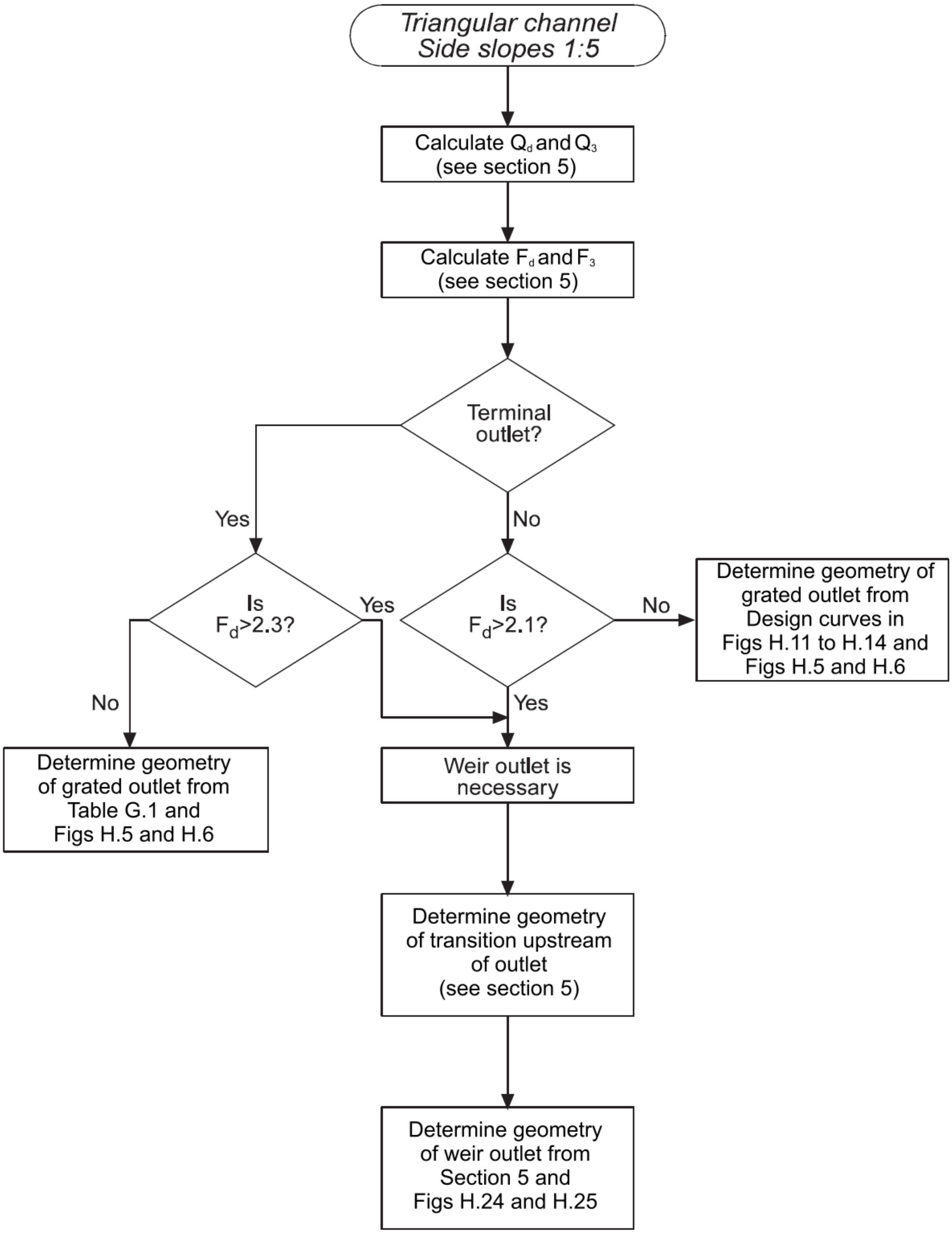


Figure H.27 Flow chart for design of weir outlets in trapezoidal channels with cross-falls of 1:4.5

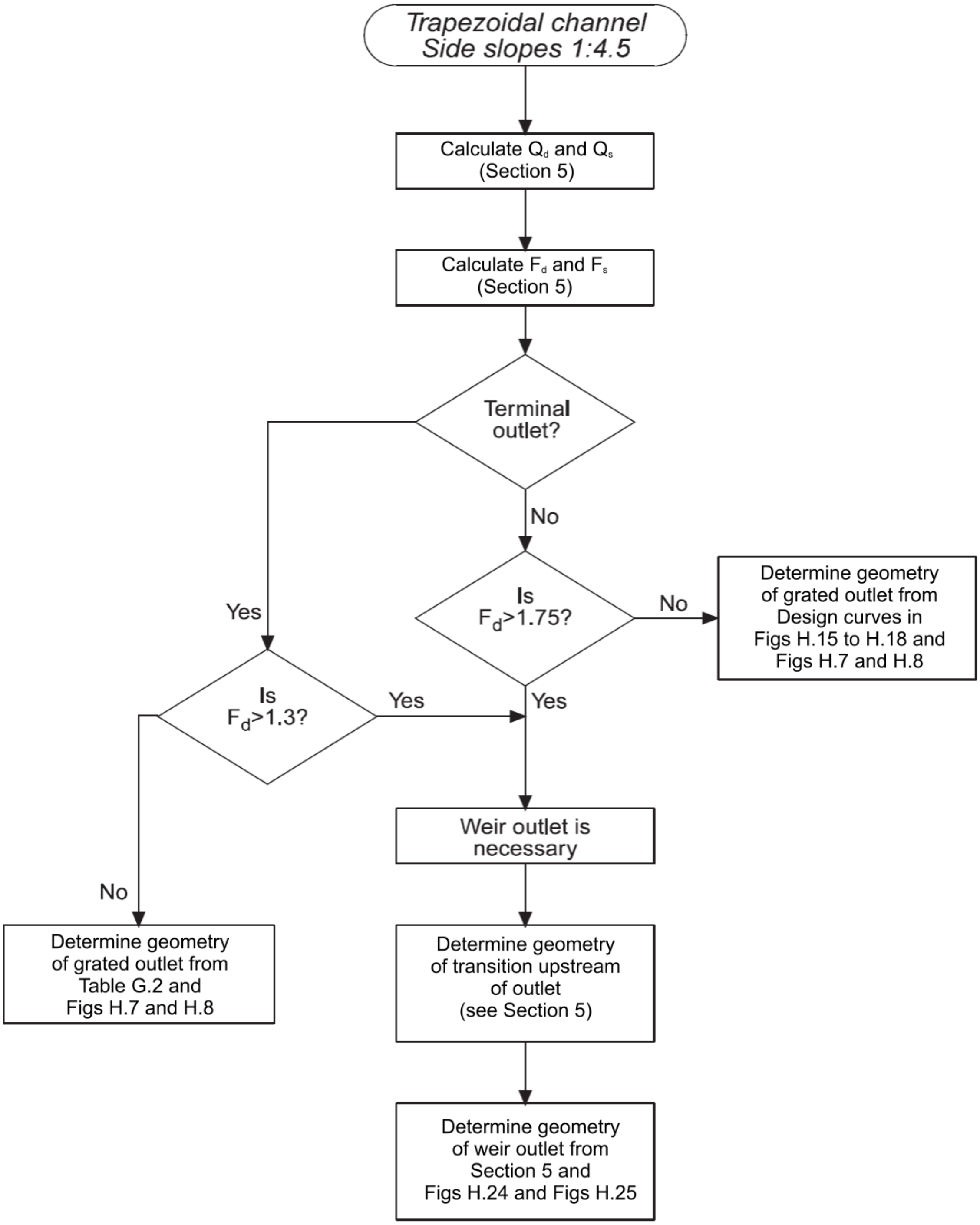
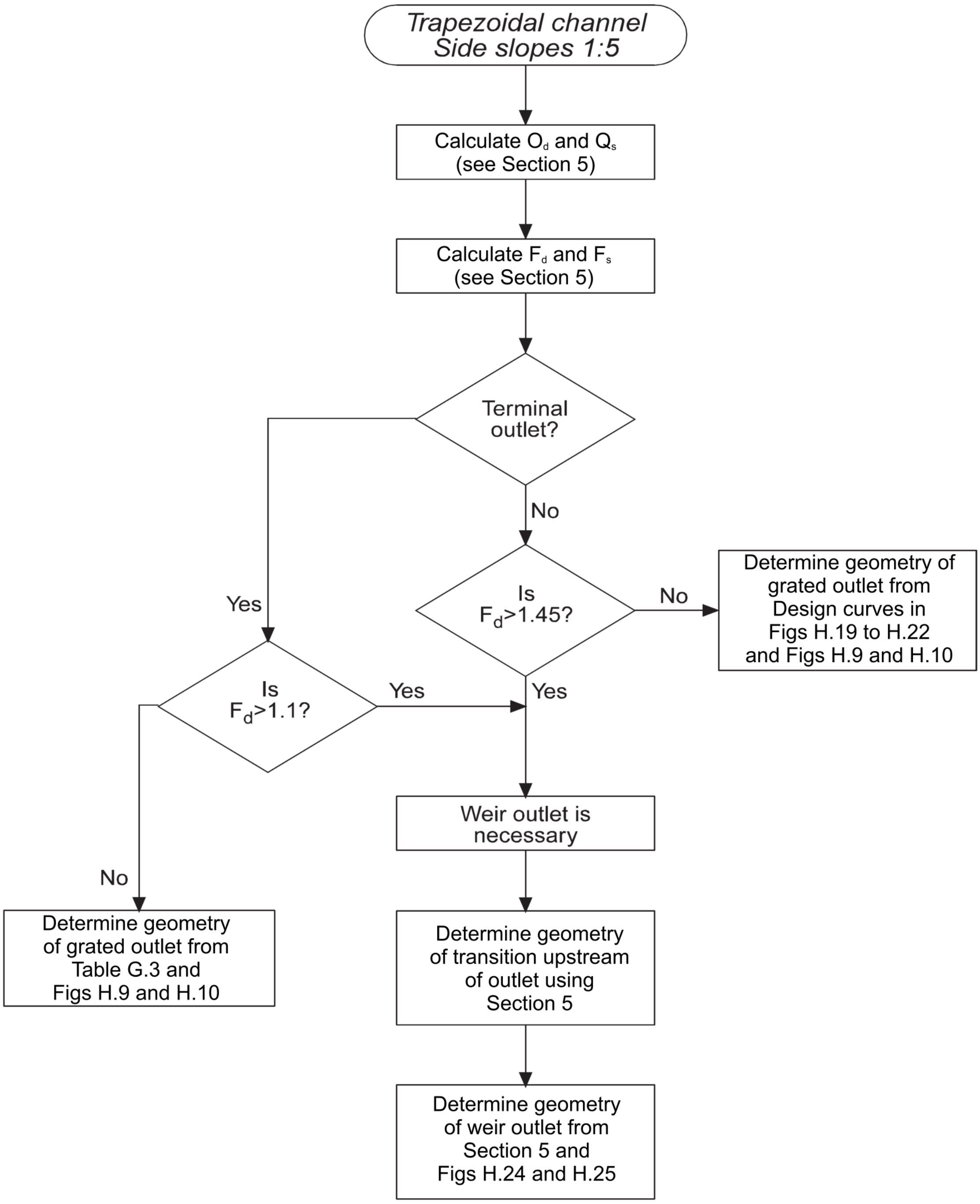


Figure H.28 Flow chart for design of weir outlets in trapezoidal channels with cross-falls of 1:5



Appendix I. Examples of collection chambers

Figure I.1 Example of collecting chamber for in-line outlet in trapezoidal channel

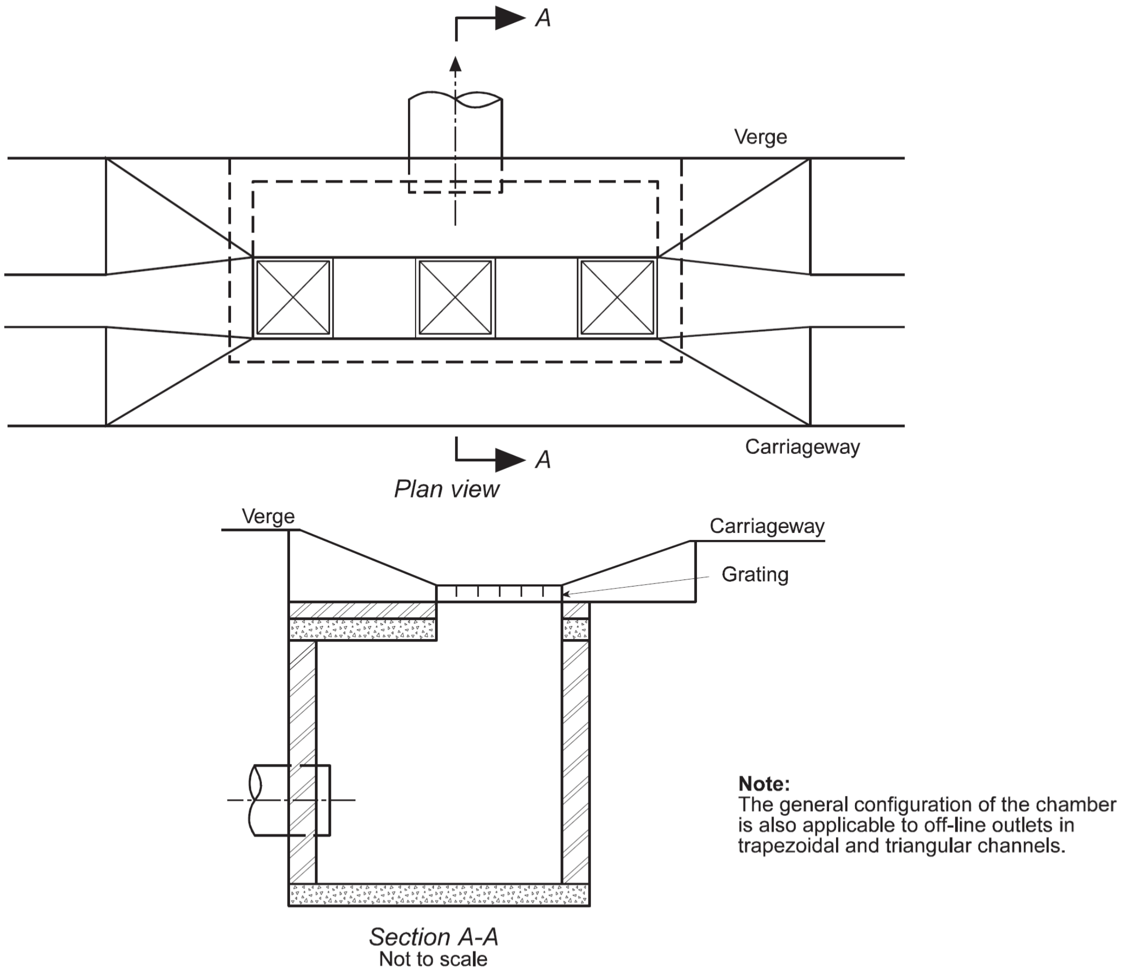
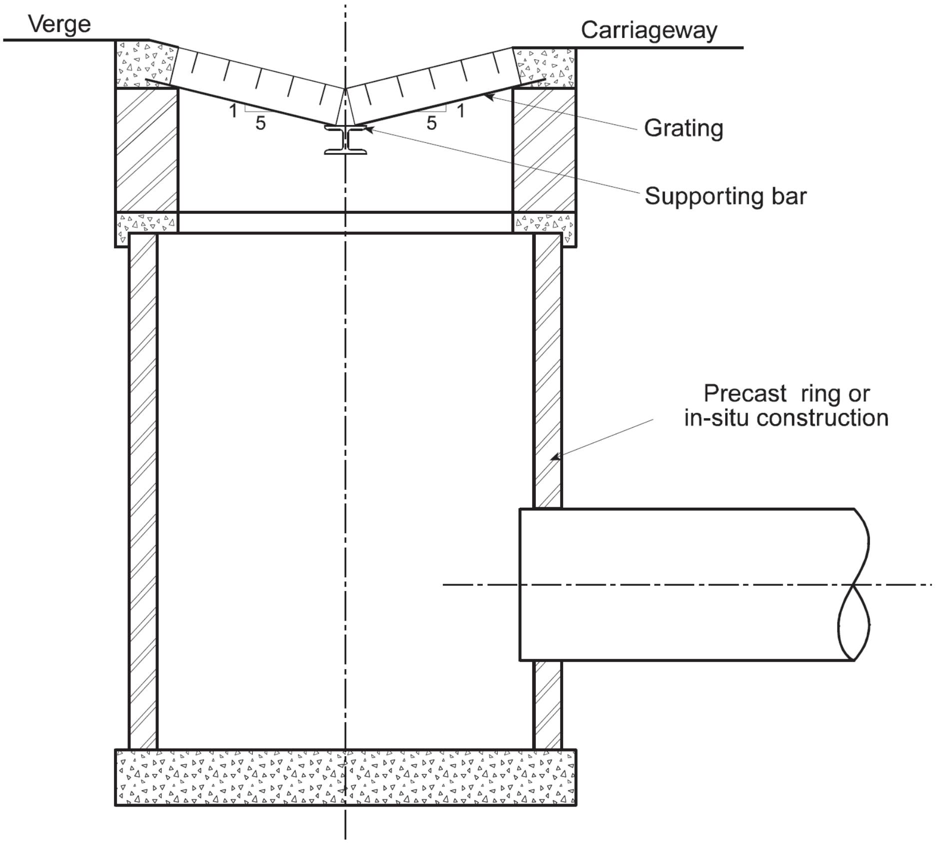
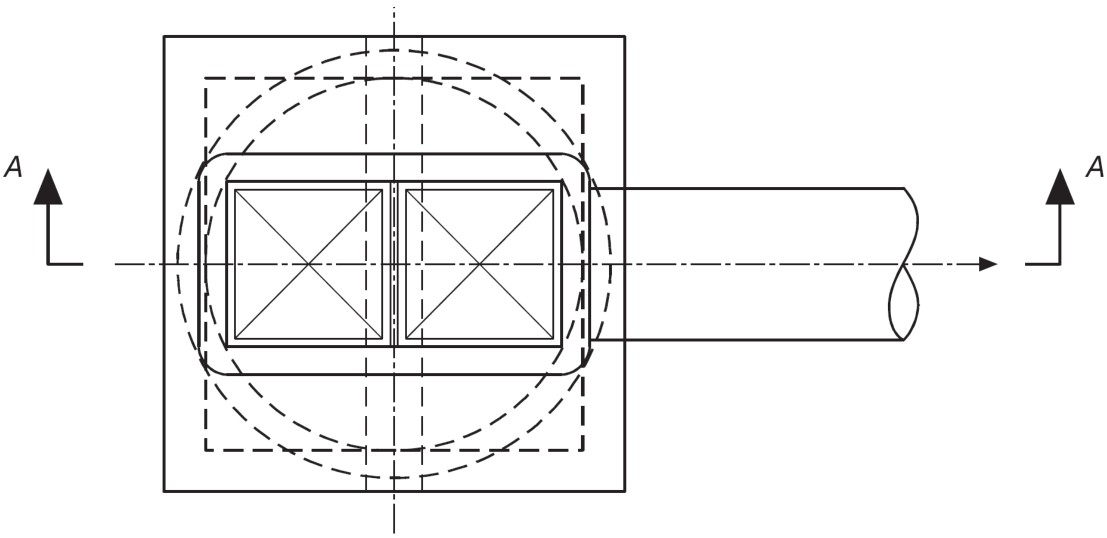


Figure I.2 Example of collecting chamber for in-line outlet in triangular channel



Section A-A



Plan view

Figure I.3 Example of terminal outlet - plan view (dimensions in mm)

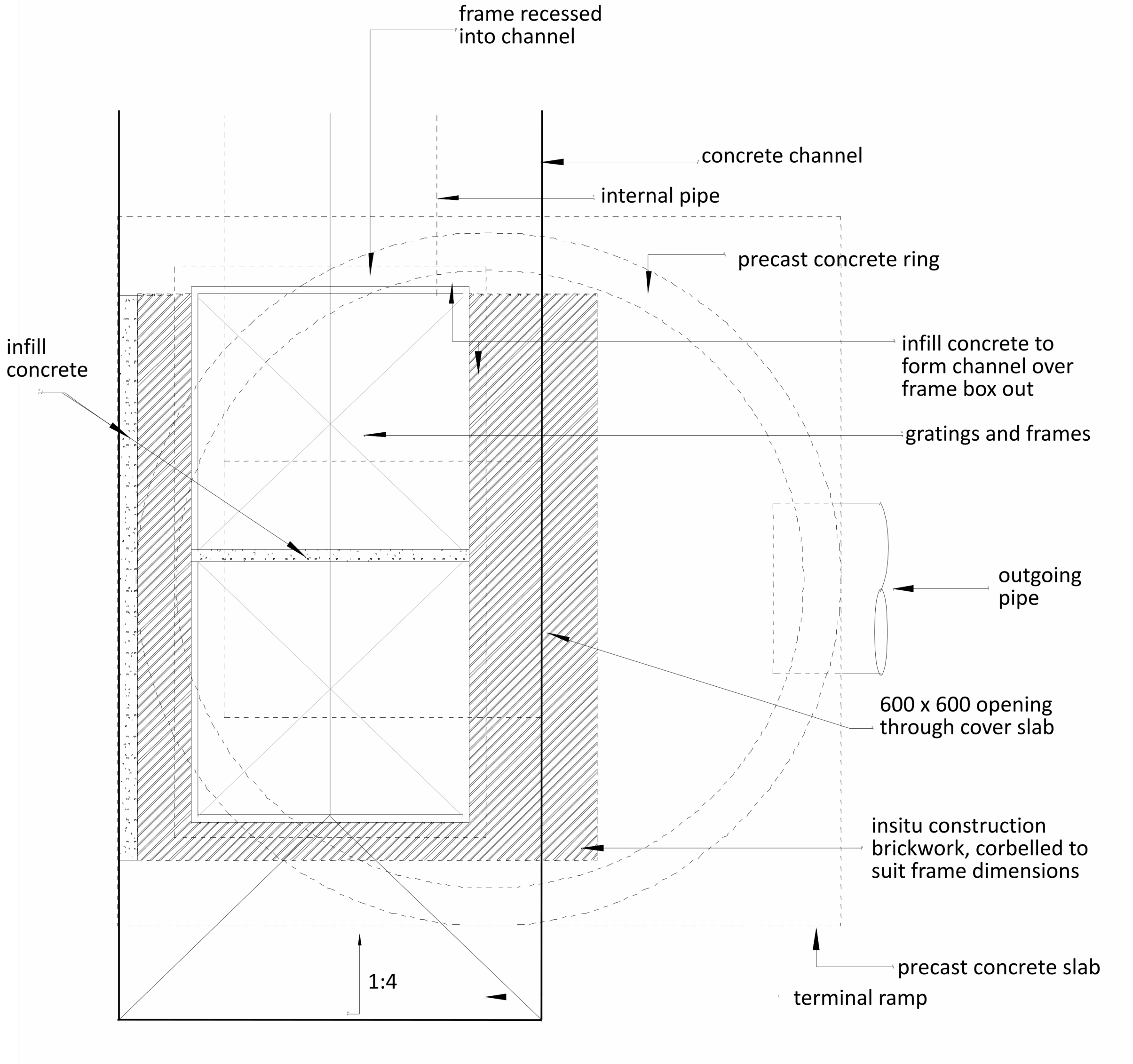


Figure I.4 Example of combined channel and pipe terminal outlet - longitudinal cross section (dimensions in mm)

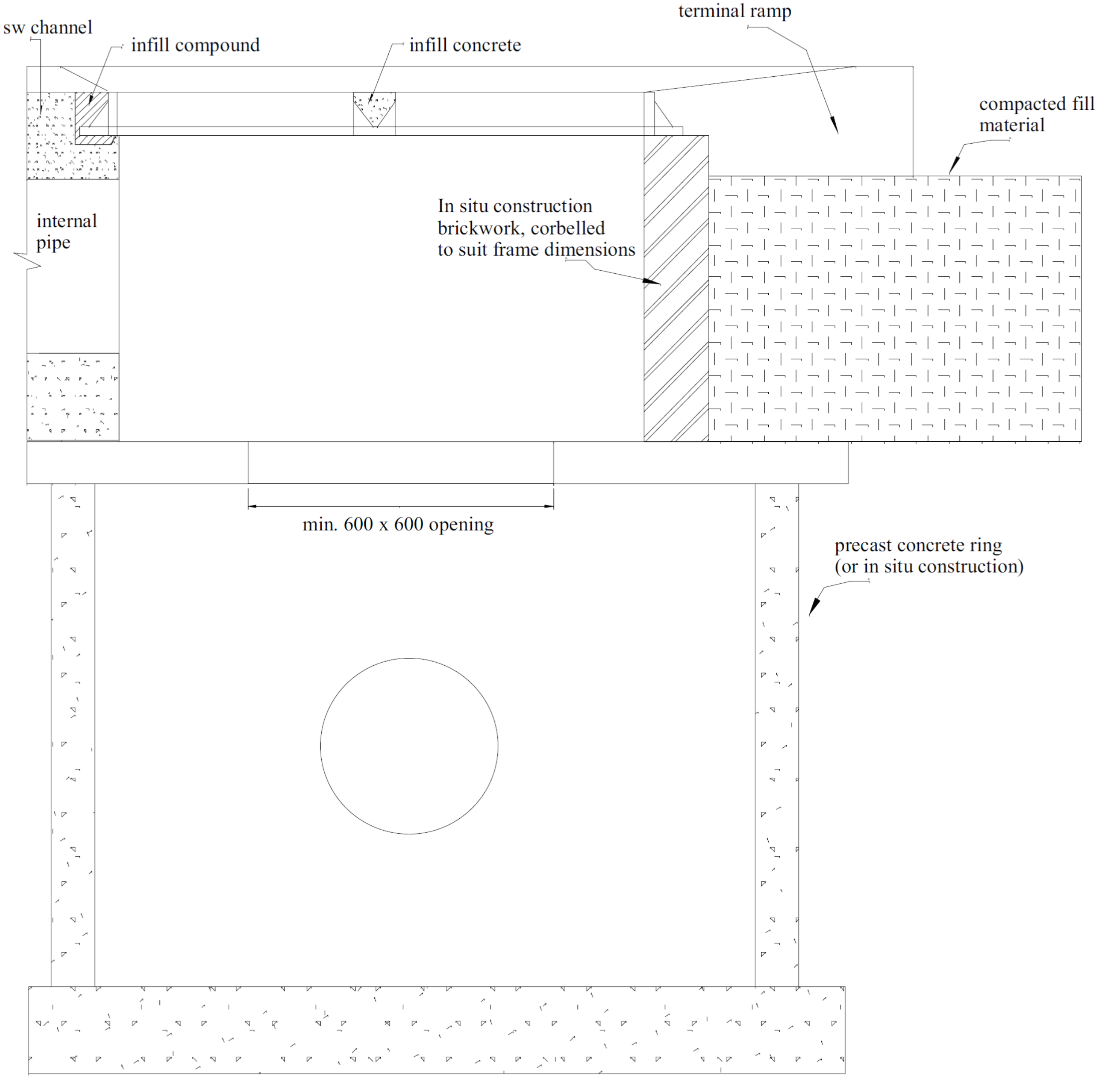
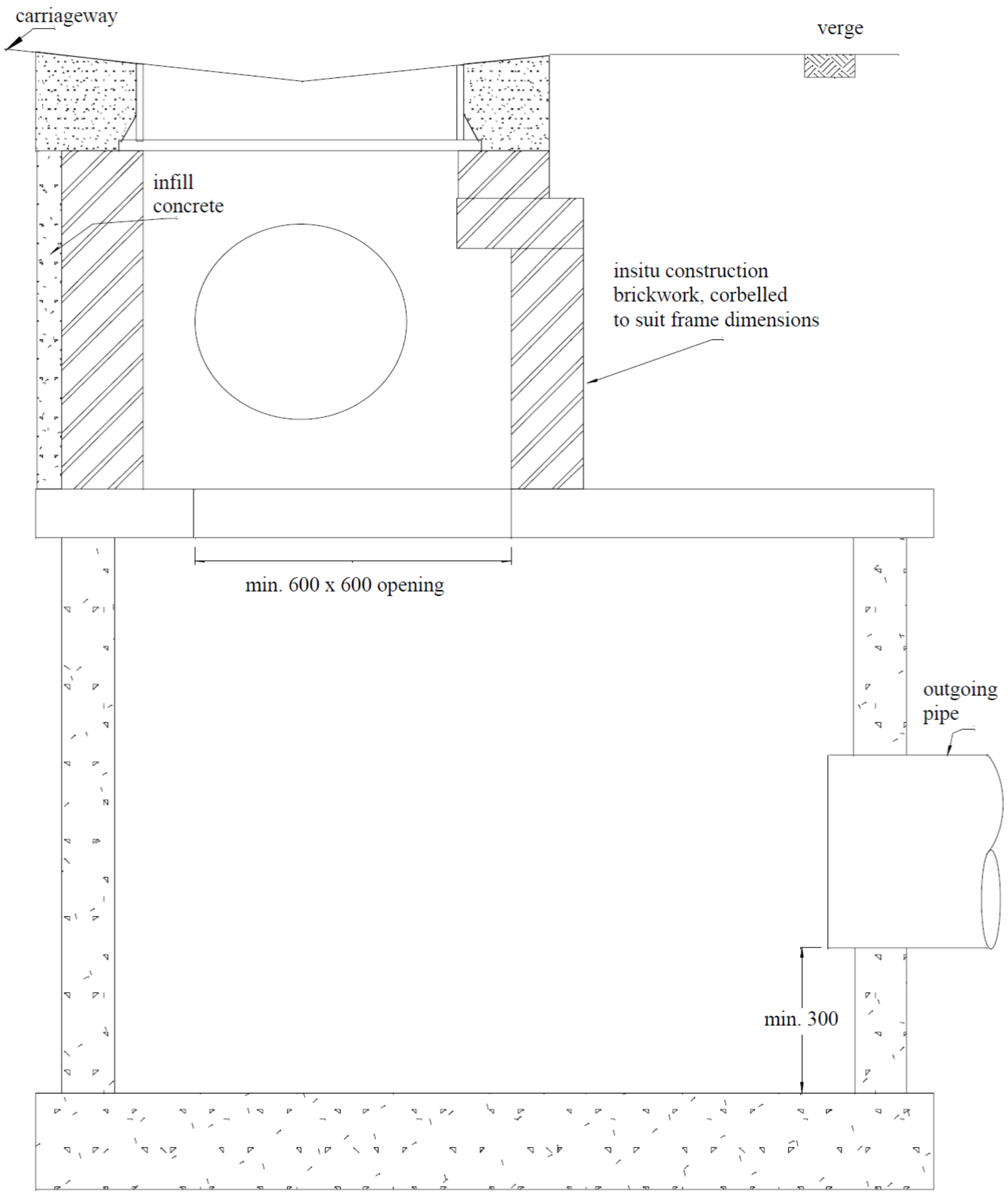


Figure I.5 Example of combined channel and pipe terminal outlet - transverse cross section (dimensions in mm)



Appendix J. Grass type selection

J1 Suitable grass types

No standard verge mix is specified in MCHW Series 0500 [Ref 11.N]

When selecting the most appropriate grass types for surface water channels the main issues to be considered are:

1) suitability of grasses for different climatic areas;
2) ease of establishment;
3) salt tolerance;
4) susceptibility to pollution from exhaust emissions and runoff from road surfaces;
5) tolerance of the wetter conditions that may prevail in drainage channels;
6) growth rates;
7) erosion control; and,
8) recovery rates from damage.

J1.1 Regional variation in climate

A wide range of cool season grasses is potentially available within grassed drainage channels in the UK. The climatic range is probably not great enough to justify differences in seed mixtures for different parts of the country, but grasses that predominate after establishment can be influenced by both climate and soil type.

J1.2 Grass establishment

The advantages and disadvantages of various techniques for establishing grass within the channel (seeding, hydro-seeding and turfing) are set out in:

Table J.1 Advantages and disadvantages of different establishment methods

Method	Advantages	Disadvantages
Seeding	Control over grass seed used; Low cost; Seed generally remains dormant if there are hot dry spells after sowing but can establish when suitable weather conditions return.	Potential loss of seed if heavy rainfall occurs during establishment; Greater risk of erosion.
Hydro-seeding	Control over grass seed used; Less risk of seed loss if heavy rain occurs during establishment; Less risk of erosion.	More expensive than conventional seeding.
Turfing	Instant grass cover.; Less risk of erosion.	High initial cost; High labour requirement/cost for laying; Cost of mowing; Vulnerable to drying out if hot, dry spell occurs after laying; Unless specifically grown for grassed drainage channels, may not have the grass species required.

Where grassed channels are to be established from seed, it is important that the seed germinates quickly and that the grass cover develops rapidly. Roadside verges are unlikely to receive irrigation to help establishment therefore the requirement is for grass types that can develop quickly.

The speed of grass establishment varies according to the species. The establishment rates for common UK turf grasses accoirding to Turfgrass Manual [Ref 19.I] are shown in Table J.2.

Table J.2 Establishment rates for common turf grasses

Species	Speed of establishment (5 = best)
Perennial ryegrass	5
Timothy	4
Crested dogstail	4
Strong creeping red fescue	4
Rough stalked meadow grass	4
Slender creeping red fescue	3-4
Chewings fescue	3
Annual meadow grass	3
Sheep's hard fescue	2
Bents	2
Smooth stalked meadow grass	1

J1.3 Salt tolerance

The use of salt for deicing requires the consideration of salt tolerance. An indication of salt tolerance of the main turf grasses is given by Table J.3.

Table J.3 Salt tolerance of turf grasses

Moderately tolerant	Moderately susceptible	Susceptible
Slender creeping red fescue cv Dawson; Tall fescue; Perennial ryegrass.	Annual ryegrass; Chewings fescue; Creeping bent; Strong creeping red fescue; Hard fescue; Rough stalked meadow grass.	Annual meadow grass; Browntop bent; Smooth stalked meadow grass.

None of the grasses has a high salt tolerance, in contrast to some warm-season species, but the most tolerant are slender creeping fescue, tall fescue and perennial ryegrass according to Adams & Gibbs 1993 [Ref 13.I].

J1.4 Pollution susceptibility

Grass is more resistant to phytotoxic effects of lead and other heavy metals than most other plants although very high concentrations can affect growth.

Some species such as strong creeping red fescue are known to have a greater resistance to heavy metals.

Raising the soil pH by liming improves plant health but has a detrimental effect on the plants absorption of toxic micronutrients and heavy metals.

J1.5 Tolerance to wetter conditions of drainage channels

Grassed channels can probably be wetter than grass verges on comparable soil types. This may cause changes in the balance of grass species over time, favouring grasses such as timothy, perennial ryegrass and annual meadow grass that are more tolerant of wet conditions. It is quite probable that these grasses may eventually become more dominant in the lower lying central section of the grassed channel, whereas the drier upper slope may retain grasses better adapted to the drier conditions, such as fescues.

J1.6 Growth rate

Road side verges are low maintenance areas and consequently it is desirable that any grasses used are slow growing so that mowing frequency is minimised and the volume of cuttings reduced.

Growth rates can be modified by fertility and soil moisture content. Guidance on growth rates is given by Turfgrass Manual [Ref 19.I] and Table J.4.

Table J.4 Growth rates for turf grasses

Species	Low growth rate (5=lowest rate)
Perennial ryegrass	1-2
Strong creeping red fescue	1-2
Timothy	1-2
Slender creeping red fescue	2-3
Smooth stalked meadow grass	2-4
Crested dogstail	3
Chewings fescue	3
Sheep's hard fescue	3
Rough stalked meadow grass	3
Bents	3-4
Annual meadow grass	3-5

J1.7 Damage recovery

The most likely cause of physical damage to the grassed channel is from vehicle over-run. The amount of damage that occurs can be dependent on the weight of the vehicle and the interaction between the soil moisture content and soil strength.

In severe cases extra topsoil and re-levelling may be required to repair deeper ruts.

The inclusion of a biodegradable matting can assist in the reinforcement of the grassed channel as the sward becomes established.

Recovery rates for different grasses from Turfgrass Manual [Ref 19.I] are given by Table J.5.

Table J.5 Recovery rates for turf grasses

Species	Recuperation (5=best)
Perennial ryegrass	5
Annual meadow grass	5
Timothy	3-4
Smooth stalked meadow grass	3-4
Slender creeping red fescue	3
Chewings fescue	3
Strong creeping red fescue	2-3
Bents	2-3
Sheep's hard fescue	2
Crested dogstail	1
Rough stalked meadow grass	1

J1.8 Indicative grass seed mix

Both perennial ryegrass dominated mixtures and fescues dominated mixtures are particularly suitable for grassed channels. The following list is an example of a resilient and slow growing mix, but is by no means the only mix suitable:

1) 20% Perennial ryegrass;
2) 10% Highland bent;
3) 20% Chewings fescue;
4) 40% Slender creeping red fescue; and,
5) 10% Smooth stalked meadow grass.

Appendix K. Maintenance of surface water channels

K1 Grassed surface water channels

K1.1 Frequency of grass cutting

A mowing regime should be developed for grassed surface water channels to maintain a grass length less than 75 mm. It is anticipated that the grass should be mown three times during the late spring and summer.

The profile of grassed surface water channels should be capable of being mowed using the same equipment that is used to maintain the verge.

K1.2 Weed control

Invasion of the grassed channel by weeds and native grass species is inevitable since mowing alone cannot prevent this. Low broad leaved weeds can cause the local grass to die back, however due to the relatively short drainage path to the watercourse, any risks associated with use of herbicides should be assessed.

K1.3 Removal of litter and detritus

The presence of litter and debris can cause the underlying grass to die with the consequential result of bare patches that may become prone to erosion. The use of grassed channels may not be appropriate on sections of road subject to very high traffic densities and the consequent frequent periods of slow moving and stationary traffic.

K1.4 Repair of vehicular damage

Vehicle over-run can result in rutting of the grass surface, especially if the channel is wet, or recently constructed.

While damp, ridges in the grass sward can be readily tamped down; wheel ruts may necessitate lifting the turf and placing an additional fine tilth of topsoil before recompacting the turf.

K1.5 Patching

Where the grass has died or is severely damaged, the affected area should be removed, the topsoil level reinstated and a section of appropriate turf inserted. The replacement turf should be watered regularly until it becomes established in the channel.

K1.6 Grassed surface reinforcement

Where a grass reinforcement system has been incorporated into the grassed channel construction, these areas should be identified within the drainage data management system (CD 535 [Ref 6.I] and the Overseeing Organisation's drainage requirements). This is essential to ensure mechanical grass cutting does not result in damage to the any reinforcement mats that have been installed.

K2 Combined surface water channel and pipe systems

K2.1 General

Channels should be regularly cleaned by sweeping in accordance with requirements set out in the relevant maintenance and management contracts.

Gully gratings should be cleaned regularly to ensure that they do not become blocked. There will normally be no necessity to remove the grating from the frame.

Jetting of internal pipes should be in accordance with MCHW Series 0500 [Ref 11.N].

The frequency of cleaning of catchpits in chambers of terminal outlets should not need to be greater than that for catchpits in systems with conventional concrete channels.

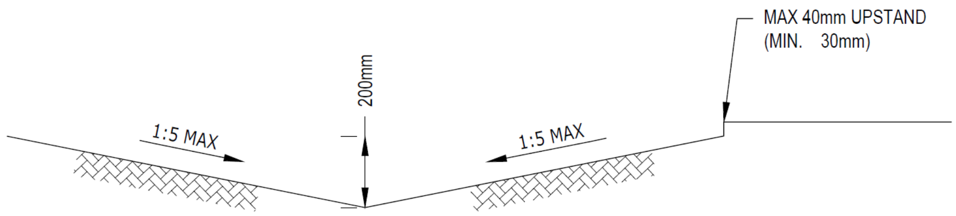
K2.2 Removal and replacement

In the event that a section of combined surface channel and pipe system has to be removed and subsequently replaced, the following procedure is suggested:

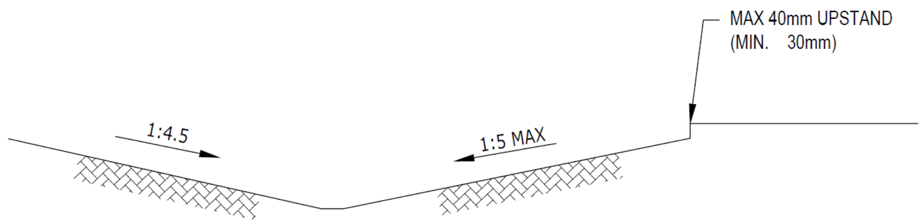
1) the section to be removed should be cut by sawing through both the channel and the pipe to the full depth of the block;
2) if the reinforcement can be left in place then the concrete should be broken out to expose it;
3) if the reinforcement needs to be removed, care should be taken to ensure that it is not cut during the sawing process. After removal of the concrete, the reinforcement can then be cut so as to leave sufficient exposed steel to comply with the splicing recommendations of the mesh manufacturer;
4) replacement mesh should be spliced to the exposed existing steel mesh in accordance with the recommendations of the manufacturer;
5) the exposed ends of the channel should be drilled and dowelled in accordance with CD 227 [Ref 2.N]. The steel dowels should be to grade 460 of BS 4449 [Ref 15.I] and have a length Ld = 600 mm if the dowels are of 16 mm diameter, or Ld = 500 mm if they are of 20 mm diameter. The embedded length of the dowels should be Ld /2;
6) ideally the tie bars should be at 600 mm centres with at least two dowels in each face. The minimum cover should be 40 mm;
7) a section of plastic pipe with an internal diameter similar to that of the pipe void, but not more than 25 mm smaller, should be cut to length and butted against each end of the channel section;
8) any gap between the pipe and the adjacent concrete mass should be packed with compressible filler and trimmed to minimise intrusion into the pipe void;
9) the ends of the plastic pipe should be temporarily strutted off the dowels to hold the pipe in place;
10) reinforced concrete should be placed and vibrocompacted around the steel mesh with care being taken not to dislodge the pipe. The concrete should then be brought up the sides and over the top of the pipe, working from the centre outwards. The struts should be removed as the concreting progresses;
11) to minimise the risk of flotation, a tied stopper may be inserted into the pipe void at a downstream access point and the pipe void filled with water as the concreting progresses. There is a potential risk of water escaping and washing cement from the concrete, thereby allowing concrete to enter the resulting gap around the pipe - this should be assessed and mitigation developed accordingly;
12) the surface channel should be provided with a steel trowel finish and have a cross-sectional profile similar to that of the original;
13) 5 mm deep saw cuts should be made across the width of the surface channel at the interfaces between the new and existing sections of concrete and the cuts filled with a waterproof sealant.

Appendix L. Grassed surface water channel profiles

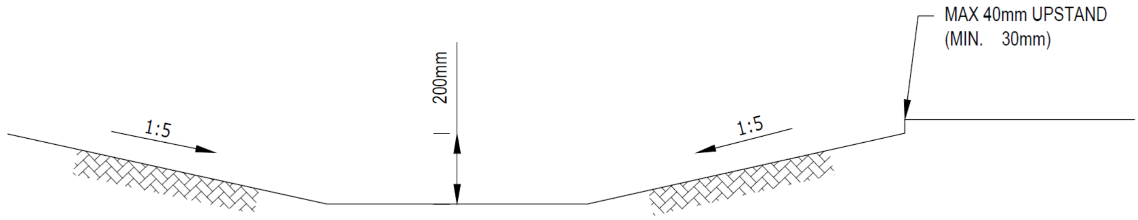
Figure L.1 Schematic channel profiles



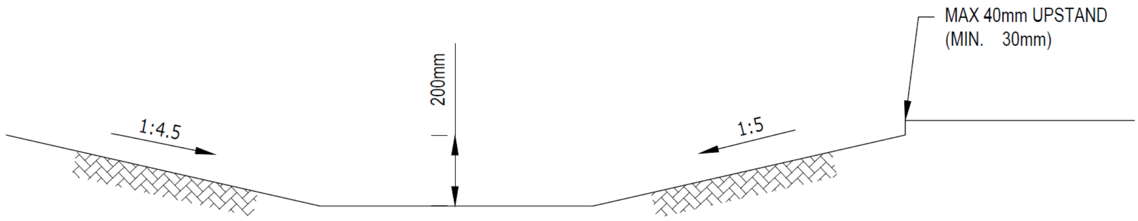
A. SYMMETRICAL TRIANGULAR



B. ASYMMETRICAL TRIANGULAR



C. SYMMETRICAL TRAPEZOIDAL



D. ASYMMETRICAL TRAPEZOIDAL

Appendix M. Construction aspects

M1 Combined channel and pipe systems

M1.1 General

For combined systems constructed using slipforming techniques, many potential combinations of channel size and pipe size are possible. Slipform shields are expensive to manufacture but can potentially be used many times over. It is therefore recommended that designers and specifiers of combined drainage systems (and also of conventional surface water channels) should co-operate with slip-orm contractors to limit the number of different designs required and thereby maximise the possibility of reuse. Three sizes of triangular channel and three sizes of pipe would cover a wide range of applications. Possible choices would be:

Top width of channel B (m):

1) 0.90;
2) 1.20;
3) 1.50.

Pipe diameter D (m)

1) 0.30;
2) 0.40;
3) 0.50.

If intermediate outlets of the in-line type are used, the channel should be sufficiently wide to accommodate two gratings and their frames with a minimum thickness of concrete surround of 100 mm. For 500 mm-wide gratings, the minimum channel width will be about 1.35 m. The required width may be reduced if inclined gratings in a single-piece frame are produced for this type of application.

In combined systems, the flow enters the pipe at discrete points along a drainage length so it is not necessary to provide a pipe under the most upstream length of channel. However, in practice, it may be simpler to construct the entire length of a system with an internal pipe so as to allow use of the same slipforming technique throughout (or minimise the number of different prefabricated units required). Where an unused section of pipe enters an outlet chamber, the end of the pipe should be blanked off so that incoming flow is directed smoothly into the downstream section of pipe.

The introduction of reinforcement into the slipformed concrete channel can be readily accomplished by the use of prefabricated steel mesh. The mesh should be cut into strips such that the transverse bar spacing is less than or equal to the longitudinal bar spacing. The mesh should be blocked off the blinding material to give a minimum cover to the steel of 40 mm. To eliminate the risk of the slipforming shield catching on the transverse bars, the mesh should be laid so that the transverse bars are beneath the longitudinal bars.

Splicing of the mesh sheets should be carried out in accordance with the manufacturer's recommendations.

The pipe void may be formed by a flexible tube passed through the shield and anchored prior to inflation. As the shield moves forwards, concrete is fed in behind. It is important that the inflatable tube does not snag on the mesh or ties.

M1.2 Contraction and expansion joints

Contraction cracks can be dealt with in the same way as for solid surface water channels. This involves forming narrow slots about 25 mm deep at suitable intervals across the top surface of the channel and filling the slots with a mastic sealant. Contraction cracks may spread downwards through the full depth of the channel block. However, the amount of leakage from the internal pipe through the hairline cracks is likely to be small, with the cracks gradually becoming blocked by fine silt carried by the drainage flows. Any minor leakage from contraction cracks will be prevented from reaching the pavement construction by the subsurface drainage system.

Where possible, any necessary expansion joints should be formed at intermediate outlets or terminal outfalls. If an expansion joint is necessary part way along a drainage length, a short length of plastic tube should be inserted and sealed to the sections of internal pipe either side of the joint in order to prevent leakage into the joint.

M1.3 Inspection

It is recommended that a CCTV inspection of the internal pipe, in accordance with CS 551 [Ref 5.N], be undertaken to ensure that the circular profile of the void is maintained over the length of the channel. Deformations in excess of 10% of the nominal bore of the pipe will not be acceptable.

M1.4 Sub-surface drainage

The construction sequence for a combined system will normally involve construction of the channel and pipe prior to placement of sub-base material and any capping material. Hence any water draining from the carriageway construction may become trapped against the pavement side of the channel. Since any subsurface drainage should be protected from this runoff, additional temporary drainage will be necessary. It may be possible to make use of the excavation for the temporary drain in the construction of the permanent subsurface drainage.

The Types 5 and 6 fin drain may be affixed to the pavement side of the channel, or Types 8 and 9 narrow filter drain may be installed in the excavation. Damage may occur during the pavement construction, in particular during the rolling of the sub-base material. It is therefore recommended that the subsurface drainage should not be installed until placement of the sub-base is complete.

M2 Grassed surface water channels

M2.1 Verge ancillaries

A large number of ancillary structures can be positioned adjacent to the carriageway and will require accommodation within, or close to, the grassed channel and to which access will be required. These structures can include fixed sign and variable message sign structures, gantries, lighting and CCTV columns, motorway communications cabinets and roadside emergency telephones.

M2.2 Ducted cables

Ducts for motorway communications cables are located in the verge. The location for the ducts is shown on drawings HCD MCX 0810 MCHW HCD NMCS [Ref 11.I].

Ducts run both parallel to and perpendicular to the carriageway and require the construction of chambers at changes in direction. It is essential that chambers are remote from the grassed channel as ducts are a means of introducing surface water into the pavement construction. It is also essential that the grassed channels do not run off surface water onto the chamber tops allowing the introduction of surface water into the duct network. The arrangement of chambers and motorway communications cabinets are shown on drawings HCD MCX 0812 (MCHW HCD NMCS [Ref 11.I]). The depth of ducts is shown on drawings HCD MCX 0814 (MCHW HCD NMCS [Ref 11.I]).

M2.3 Directly buried cables

Trenches in the verge for directly buried motorway communications cables are shown on drawing HCD MCX 0140 (MCHW HCD NMCS [Ref 11.I]).

M2.4 Detector loops

Detector loops in the carriageway surface and loop joint chambers in the verge result in very shallow cables being present at the carriageway edge. The designer is expected to be aware of the potential conflict between these cables and the grassed channel. Detector loops are generally installed at 500-m intervals. Further information can be found in TD 131 [Ref 14.I] and HCD G9 (MCHW HCD Series G [Ref 15.N]).

M2.5 Signage

Signs are generally remote from the pavement edge and are protected by safety barriers. The designer ensures that no signs encroach into the channel.

Marker posts may encroach into the grassed channel and care is to be taken to ensure that their installation will not result in any impermeable membrane being punctured.

M2.6 Lighting columns

Lighting columns are to be remote from the pavement edge, however where lighting columns are proposed, the designer is to ensure that any waterproof membrane used is brought around the structure and that the columns themselves are protected from channel flows.

M2.7 Safety barriers

Barriers may encroach into the grassed channel and any impermeable membrane is to be positioned around the posts.

The presence of barriers may adversely affect the maintenance (mowing) of the grass and hence the suitability of grassed channels where long sections of barriers are proposed.

M2.8 Grassed channel construction

It is recommended that a fin drain is installed at the edge of pavement to intercept infiltration through the grassed channel before it reaches the pavement construction and similarly intercept flows from beneath the pavement. The recommended fin drain is either a Type 5 or Type 6 (see HCD F18 and F19 MCHW HCD Series F [Ref 14.N]) with a double cuspated core.

During construction of the channels, temporary measures may be necessary to prevent surface runoff from the pavement, or verge, washing away the topsoil or surcharging the fin drain.

To reduce the risk of topsoil becoming saturated due to heavy rain, subsoil (where imported) and topsoil placement commences at the highest of the point of the channel and works downstream.

The subsoil is to be well compacted, if possible in layers approximately 100 mm thick and up to 50 mm of topsoil spread and compacted on top. An allowance is made for the thickness of turf, if used, when defining the final level of the topsoil. Note that subsoil and topsoil, when placed in landscaped areas are not normally compacted, however, in order to minimise the risk of damage caused by vehicles running into the channel, the soils are compacted in this instance.

Where turf is used, this is to be placed immediately after compaction of the topsoil to minimise the risk of soil fines being washed away by surface runoff. Turfing offers advantages over hydroseeding in that it will give a much greater level of initial protection to the topsoil and hydroseeding is very dependent on the quality of the seed mixture and the fibre reinforcement.

The grassed channel should be operational at the end of the road construction stage. To avoid long establishment times in winter months as well as the inclement weather of the hotter and colder months, grassed channel construction should preferably be undertaken in early Spring or early Autumn.

M2.9 Use in combination with a French drain

The typical filter (French) drain will be between 600 mm and 1000 mm wide and located against the pavement edge. Where it is proposed to remediate a problem such as stone scatter, by applying a topsoiled surfacing, it may be practical to incorporate a grassed channel in the surfacing. A detail for a grass surface to filter drains is shown in B15 MCHW HCD Series B [Ref 13.N] and in F2 Type L and Type M (MCHW HCD Series F [Ref 14.N]).

To be viable, there needs to be an additional width of verge behind the French drain that can be included in the construction of the grassed channel.

As a surfacing to existing filter (French) drains, sufficient stone filter medium and depth of adjacent verge material is removed to permit the formation of the 200-mm channel and sufficient depth of topsoil. A geotextile can be positioned over the filter material to prevent topsoil (and subsoil) from contaminating the drain, but still permitting water to soak through.

It is beneficial for the geotextile properties to comprise:

1) porosity – not be impermeable but should have permeability no greater than the compacted subsoils (channel needs to retain moisture to be able to support the grass);
2) woven or non-woven durable material and be clog resistant (not proof since the aim is to maintain channel flow on the surface);
3) tensile strength: – have adequate tear and puncture resistance to permit compaction of the channel subsoil and topsoil above it and be resistant to vehicle over run damage.

The topsoil (and subsoil) should be very well compacted.

M2.10 Vehicle pull-off location

Access to communications apparatus and similar equipment may necessitate vehicles being deliberately driven on to the grassed channel, particularly where there is only a one-metre hardstrip. In these circumstances it can be appropriate to locally reinforce the grassed channel to minimise damage in case the channel surface be softened by water flowing in the channel. Appropriate grass reinforcement systems include installing a reinforcing mat within the topsoil and grass roots, or proprietary grass surface reinforcement products.

M2.11 Field access

Where grassed channels are proposed for use on all-purpose roads, the presence of field access crossings should be considered. In these instances, the grassed channel should terminate at the crossing and recommence on the downstream side. A terminal outfall chamber and carrier drain will be required. The ends of the grassed channel should be sufficiently remote from the crossing that there is no risk of over-running by farm vehicles as they turn.