VOLUME 4 GEOTECHNICS AND DRAINAGE
SECTION 2 DRAINAGE

PART 6

HA 113/05

COMBINED CHANNEL AND PIPE SYSTEM FOR SURFACE WATER DRAINAGE

SUMMARY

This Advice Note gives guidance on the hydraulic and structural design of combined channel and pipe systems for highway drainage. The type of system considered consists of a surface water channel and an internal pipe formed within the base of the unit that is able to carry additional flow.

INSTRUCTIONS FOR USE

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THE DEPARTMENT FOR REGIONAL DEVELOPMENT
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Combined Channel and Pipe System for Surface Water Drainage

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1. INTRODUCTION

General

1.1 This Advice Note gives guidance on the hydraulic and structural design of combined channel and pipe systems for highway drainage. The type of system considered consists of a surface water channel and an internal pipe formed within the base of the unit that is able to carry additional flow. The system is particularly suited to in situ construction in concrete using slip-forming techniques. However, the hydraulic design procedures provided are generally applicable and are not limited to a particular method of construction. Although the advice should be fully taken into account in the design of new schemes (see 1.6), this Advice Note contains no mandatory requirements.

1.2 The function of the surface channel in the combined system is to collect and convey rainwater run-off from the road surface. At suitable points along the channel, water is discharged into an integral pipe formed in the lower part of the channel unit. Use of a combined system can remove the need for a separate carrier pipe in the verge and enables flow to be carried longer distances between outfalls to ditches or natural watercourses. By combining the surface drainage system into a single unit at the edge of the pavement, more space can be made available in the verge for other services.

1.3 This Advice Note should be read in conjunction with the following documents in DMRB 4.2:

- HD 33: Surface and Sub-Surface Drainage Systems for Highways
- HA 37: Hydraulic Design of Road-Edge Surface Water Channels
- HA 78: Design of Outfalls for Surface Water Channels
- HA 83: Safety Aspects of Road Edge Drainage Features. Further details are given in TRL Report 422 (Ref 3)
- HA 105: Sumpless Gullies.

1.4 The use of surface water channels should take account of advice on safety given in HA 83.

Scope

1.5 The principles outlined in this Advice Note apply to all schemes of Overseeing Organisations for Trunk Roads including motorways. They may also be applied generally to other new highway schemes and by other highway authorities for use during the preparation, design and construction of their own comparable schemes. Combined channel and pipe drainage systems may be installed during major maintenance works or as a retro-fit.

Implementation

1.6 This Advice Note should be used forthwith for all schemes currently being prepared provided that, in the opinion of the Overseeing Organisation, this would not result in significant additional expense or delay progress. (In Northern Ireland, this Advice Note will be applicable to those roads designated by the Overseeing Organisation.) Design Organisations should confirm its application to particular schemes with the Overseeing Organisation.

2. SAFETY ASPECTS

2.1 When considering the use of a combined drainage system having a surface channel and internal pipe, safety aspects relating to its location should be taken into account in accordance with the guidelines given in HA 83 (DMRB 4.2).

2.2 Systems with triangular or trapezoidal channels will usually be sited adjacent to the hardstrip or hardshoulder or at the edge of the carriageway and in front of the safety barrier, where one is provided. Layout details are given in the ‘A’ Series of the Highway Construction Details (HCD) (MCHW 3). In these locations, the maximum design depth of flow in the channel should be limited to 150mm. In verges and central reserves, the side slopes of the channel should not normally be steeper than 1:5 (vertical : horizontal) for triangular channels and 1:4.5 for trapezoidal channels. In very exceptional cases, side slopes of 1:4 are allowable for both types of channel.

2.3 Combined systems with rectangular channels, or triangular channels of depth greater than 150mm, should be used only when safety barriers are provided between the channel and the carriageway. Systems of this type will normally only be justified when safety barriers are warranted by other considerations. In addition, such systems should not be located in the zone behind the safety barrier into which the barrier might reasonably be expected to deflect on vehicle impact (because of the risk of the vehicle overturning due to it being too low relative to the safety barrier). Shallower channels of the types described in 2.1 may be located in this deflection zone, or be crossed by the safety barrier (usually at a narrow angle), provided that the combined layout complies with the requirements of other relevant parts of the DMRB (Ref 1, note that Volume 1, Section 0 contains a contents list and index).

Further advice on such layouts should be sought from the Overseeing Organisation.

2.4 Co-ordination of the layout of safety barriers and channels of combined drainage systems must be arranged at an early stage in design and not left to compromise at later stages. Where safety barriers are not immediately deemed necessary, sufficient space should be provided in the verge or central reserve to allow for their possible installation. The combined layout must comply with the requirements of TD 19, Safety Fences and Barriers (DMRB 2.2), TD 32 Wire Rope Safety Fence (DMRB 2.2.3) and the HCD (MCHW 3) in terms of set-back and clearance dimensions and the mounting height of the safety barrier.

2.5 The constraints on channel geometry given in this document also apply to the outlet arrangements used to discharge flow from the channel to the internal pipe of the combined system. For outlets and channel terminations, slopes exceeding 1:4 should not be used on any faces, particularly those orthogonal to the direction of traffic, unless such faces are behind a safety barrier.

2.6 If installed adjacent to the hardstrip or hardshoulder and not protected by a safety barrier, combined drainage systems with internal pipes should be capable of withstanding the required loading when tested in accordance with the procedures specified in HA Clause 517 of the Specification for Highway Works (SHW) (MCHW 1) and European Standard BS EN 1433 (Ref 4).

2.7 Gully gratings used in a combined system to discharge water from the surface channel to the internal pipe (or to an outfall) should meet the geometrical and structural requirements of BS EN 124 (Ref 5) and BS 7903 (Ref 6) and be of the appropriate load class (see Chapter 4).

3. DESCRIPTION OF COMBINED SYSTEM

General

3.1 The drainage system described in this Advice Note consists of a surface channel and an internal pipe that are constructed as a single unit and installed at the pavement edge to collect and convey rainfall run-off from the road surface. The cross-sectional geometry of a typical combined system is shown in Figure 1. Recommendations on appropriate methods of sub-surface drainage that can be used in conjunction with a combined system are given in Chapter 9.

3.2 The combined system is particularly suited to concrete construction using slip-forming techniques. The recommendations on maximum pipe size and minimum cover given in Chapter 4 relate specifically to slip-formed or cast in situ concrete systems. It may be possible to prefabricate hydraulically equivalent channel and pipe units, but any such system will need to meet the loading requirements in Chapter 4 and be approved for use by the Overseeing Organisation.

Recommended Configuration

3.3 The recommended configuration of a combined channel and pipe system has the following principal features:

(1) Surface water channel to be unslotted (as distinct from channels with continuous or regularly spaced slots along the invert).

(2) Flow to be discharged from the channel to the internal pipe at discrete points along a drainage length (see Figure 2).

(3) Flow to be discharged to the internal pipe via outlets consisting of gully gratings in the base of the channel, with water dropping through the gratings into shallow benched chambers constructed on the line of the pipe (see Chapter 8 for details of chambers).

(4) The internal pipe to be unlined and formed as a cylindrical void below the invert of the channel. With slip-form construction, the void may be produced by an inflated flexible tube positioned at the appropriate height above the base of the channel unit and with the face of the shield modified so that the tube is able to pass through it. After the concrete has achieved a sufficient strength, the tube can be deflated and removed from the void.

(5) Slip-formed combined systems to be constructed using a minimum of class C28/35 air entrained concrete either unreinforced or with steel mesh reinforcement in the base. (Addition of reinforcement increases the maximum allowable size of pipe, see Chapter 4.)

3.4 The recommended configuration has the following advantages:

(1) The combined flow capacity of the channel and pipe can be significantly larger than the capacity of a conventional surface water channel of the same overall width (see Chapters 6 and 7).

(2) Alternatively, a given flow capacity can be achieved with a channel of smaller overall width, which can be of benefit if space in the verge is limited (for example, in road-widening schemes).

(3) Use of an unslotted channel simplifies construction, increases the structural strength of the unit, avoids maintenance problems associated with the clogging of slots, and facilitates the use of pressure jetting for cleaning of the internal pipe.

(4) Use of an unslotted channel and discrete entry points to the internal pipe allows a higher flow capacity than an equivalent system with a slotted channel (see item (3) in 5.3).

3.5 A combined system will generally have a greater overall depth than a conventional surface water channel and therefore requires a modified sub-surface drainage system for removing seepage flows from the pavement construction (see Chapter 9). Due to its greater depth, the combined system requires more concrete than a conventional system, although the increase will be partly offset by the volume of the void forming the pipe. Due to its higher flow capacity, a combined system may reduce or eliminate the need for a separate carrier pipe, with consequent savings in materials and construction costs.

Surface Channel

3.6 The channel functions in the same way as a conventional road-edge surface water channel (see HD 33 and HA 37, DMRB 4.2, for guidance on selection and design). The limiting dimensions and cross-sectional shape of the channel are determined by considerations of vehicle safety as described in Chapter 2.

Internal Pipe

3.7 The hydraulic characteristics of the internal pipe in a combined system are similar to those of a conventional carrier pipe in which flow enters the pipe at manholes spaced at intervals along its length.

3.8 The larger the size of pipe that can be used in a combined system, the longer the length of road that can be drained without the need for an outfall.

Intermediate Outlets and Terminal Outfalls

3.9 At the point where the design rate of run-off from a length of road reaches the flow capacity of the channel, it is necessary to discharge the water from the channel into the internal pipe via an intermediate outlet. The outlet consists of one or more gully gratings installed in the invert of the channel; beneath the gratings, a shallow benched chamber is constructed on the line of the pipe. Information on the design of intermediate outlets is given in Chapter 8.

3.10 At the point where the design rate of run-off from the road reaches the total capacity of the combined system, the flow from the pipe and the flow from the most downstream section of channel need to be discharged into a terminal outfall chamber. From this chamber the water can then be conveyed to a watercourse or toe ditch, or discharged into a separate carrier pipe. Information on the design of terminal outfall chambers is given in Chapter 8.

Outlets in Steep Roads

3.11 In steep sections of road with longitudinal gradients exceeding about 1:50, gully gratings may not be able to collect a sufficiently large proportion of the high-velocity flow in the surface channel. Alternative designs of outlet, such as the weir outlet described in HA 78 (DMRB 4.2), can be used in these situations. However, the features that increase the hydraulic efficiency of these designs may also present a potential hazard to vehicles so they will usually need to be protected by a safety barrier. Further details are given in 8.14 to 8.16.

4. STRUCTURAL AND DIMENSIONAL REQUIREMENTS

4.1 Combined channel and pipe systems shall meet the loading and safety requirements specified by the Overseeing Organisation. Loading requirements should be based on the loading classes given in BS EN 124 (Ref 5), with testing carried out in accordance with the procedures specified in HA Clause 517 of the SHW (MCHW 1) and European Standard EN 1433 (Ref 4).

4.2 Surface channels at the edge of the pavement are normally either triangular or trapezoidal in cross-section. Rectangular channels may also be used provided they are protected from traffic by a safety barrier (see Chapter 2). The limiting dimensions for surface channels are as follows:

- Maximum channel depth:
  $Y_C = 150$mm.
- Maximum side slopes for triangular channels: 1:5 (vertical : horizontal).
- Maximum side slopes for trapezoidal channels: 1:4.5.
- At outlets, maximum side slopes of 1:4 are permitted locally in both triangular and trapezoidal channels.

4.3 The limiting dimensions are given in 4.4 to 4.6 for combined systems of concrete construction having a triangular surface channel and the type of cross-sectional profile shown in Figure 1. The dimensions corresponding to a loading class of D400 in BS EN 124 (Ref 4) were established from structural tests (see HR Wallingford and TRL, Ref 7). Combined systems that meet the appropriate geometric limits may be deemed to satisfy the corresponding loading requirement without further structural tests. For loading class C250 the maximum pipe size is limited to 300mm diameter if unreinforced concrete is used. If diameters larger than 300mm are required, reinforcement may be necessary and guidance in this regard should be sought from the Overseeing Organisation. If it is wished to use an alternative cross-sectional profile or construction material, approval must be sought from the Overseeing Organisation in advance and structural testing of the system carried out in accordance with HA Clause 517 of the SHW (MCHW 1) to demonstrate its ability to meet the specified loading requirement.

4.4 **Unreinforced C28/35 Mass Concrete**

The combined channel and pipe sections should be constructed from nominal C28/35 concrete to BS EN 206 (Ref 8) and air entrained to BS 5931 (Ref 9). All aggregate should be partially crushed or crushed in accordance with Clause 1103 of the SHW (MCHW 1).

The limiting dimensions for combined channel and pipe sections of this type are:

C250 and D400 loading class:

Maximum pipe size: D_{max} = 300mm
Minimum vertical cover: $U_{min} = D_{max}/2$
Minimum horizontal cover: $H_{min} = D_{max}/2$

4.5 **C28/35 Concrete with Light Mesh Reinforcement**

The combined channel and pipe sections should be constructed from nominal C28/35 concrete to BS EN 206 (Ref 8) and air entrained to BS 5931 (Ref 9). All aggregate should be partially crushed or crushed in accordance with Clause 1103 of the SHW (MCHW 1).

For the purposes of this Advice Note, 'light mesh reinforcement' is defined as a welded mesh formed of mild steel bars with a maximum spacing between bars of 200mm. It is to 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. The minimum area of steel perpendicular to the longitudinal centreline of the pipe should be 385mm^2 per metre run of pipe. The ends of the bars may be left flat and the concrete cover to the steel should not be less than 40mm.

The limiting dimensions for combined channel and pipe sections of this type are:

D400 loading class:

Maximum pipe size: D_{max} = 400mm
Minimum vertical cover: $U_{min} = D_{max}/2$
Minimum horizontal cover: $H_{min} = D_{max}/2$

4.6 C28/35 Concrete with Heavier Mesh Reinforcement

The combined pipe and channel sections should be constructed from nominal C28/35 concrete to BS EN 206 (Ref 8) and air entrained to BS 5931 (Ref 9). All aggregate should be partially crushed or crushed in accordance with Clause 1103 of the SHW (MCHW 1).

For the purposes of this Advice Note, 'heavier mesh reinforcement' is defined as a welded mesh formed of mild steel bars. It is to 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. The maximum spacing between the bars is to be 100mm for the bars placed perpendicular to the line of the pipe, and 200mm for those placed parallel to the line of the pipe. The minimum area of steel perpendicular to the longitudinal centreline of the pipe should be 1100mm^2 per metre run of pipe. The ends of the bars may be left flat and the concrete cover to the steel should not be less than 40mm.

The limiting dimensions for combined channel and pipe sections of this type are:

D400 loading class:

Maximum pipe size:	D_{max}	=	500mm
Minimum vertical cover:	U_{min}	=	$D_{max}/2$
Minimum horizontal cover:	H_{min}	=	$D_{max}/2$

5. HYDRAULIC DESIGN PRINCIPLES

5.1 The methods given in Chapters 6 and 7 for determining the drainage capacities of the channel and internal pipe of a combined system are based on the same principles as those used in HA 37 (DMRB 4.2) for conventional surface water channels. An outline description of the principles is given in this Advice Note but, for more detailed information on individual topics, reference should be made to May et al (Ref 7) and HA 37 (DMRB 4.2).

5.2 One of the key features of a combined system is that the longitudinal gradients of the channel and the internal pipe will normally be the same as the longitudinal gradient of the pavement being drained. Any increase in flow capacity that might be gained by constructing the pipe at a steeper gradient relative to the surface of the road would be small and outweighed by the increased cost and difficulty of construction. It is therefore assumed in this Advice Note that the road, the surface channel and the internal pipe all have common values of longitudinal gradient.

5.3 Subject to the limitations on maximum pipe size given in Chapter 4, the designer of a combined system can consider the flow capacities of the channel and pipe separately and has considerable freedom to vary their relative sizes. The following outline design procedure illustrates the case of a section of road of constant longitudinal gradient (see Figure 2).

(1) Assume a suitable size and cross-sectional geometry for the surface channel and use the method given in Chapter 6 to find the length of road, L_C (in m), that can be drained by the channel before it reaches its design capacity. This length, L_C, determines the maximum allowable distance between the upstream end of the system and the first outlet and also the spacings between subsequent outlets.

(2) Assume a suitable diameter of internal pipe and use the method in Chapter 7 to find the length of road, L_P (in m), that can be drained by the pipe before it reaches its maximum flow capacity.

(3) If no additional flow is discharged into the pipe from the surface, the internal pipe can be continued downstream of the drainage length, L_P. Therefore, as shown in Figure 2, the terminal outfall of the combined system can be located a distance of up to one channel length, L_C, downstream (provided the flow from the pipe and the flow from the last section of surface channel are able to discharge separately into the terminal outfall chamber). Therefore, the maximum total length, L_T, that can be drained by the type of combined system considered in this Advice Note is given by $L_T = L_P + L_C$. [Note that an equivalent combined system with a slotted channel would only be able to drain a total length of $L_T = L_P$].

(4) The values of L_C, L_P and L_T can be used to determine the number and location of outlets required along a road drained by a section of combined channel and pipe system. Suitable options are described in 7.15 to 7.17. In practice, the layout of a system may also be affected by local features and possible requirements to standardise outlet spacings within a scheme.

(5) As an example, if the maximum lengths that can be drained by the channel and the pipe are respectively L_C = 110m and L_P = 420m, one option would be to use four intermediate outlets and one terminal outfall. The spacings between adjacent outlets would be L_A = 105m and the total length of road that could be drained by the system (from the upstream end to the terminal outfall) would be 525m. The last intermediate outlet would be located at a distance of 420m from the upstream end, which matches the maximum drainage capacity of the pipe.

5.4 The key factors that determine the drainage capacity of a combined system are the:

- longitudinal gradient of the road, S (vertical fall per unit distance along the road, in m per m);
- effective width, W_E (in m), of the catchment drained by the combined system, taking account if appropriate of any run-off from cuttings (see Chapter 12 and Annex C of HA 37, DMRB 4.2);
- size, shape and cross-sectional area of the surface channel;
- diameter, D (in m), of the internal pipe;

- hydraulic roughness values of the channel and the pipe;
- statistical rainfall characteristics at the site, i.e. the relationship between the rainfall intensity, the duration of the design storm and its frequency of occurrence;
- variation of rainfall intensity with time during the design storm.

The effects of these various factors can be taken into account using a method based on kinematic wave theory. This method provides information about the variation of flow conditions with time during a storm and enables the duration of storm that produces the worst flow conditions to be determined. More details about the kinematic wave theory are given in HR Wallingford Report DE 30 (Ref 10), TRRL Contractor Report 8 (Ref 11) and May (Ref 12).

5.5 The flow capacity of a channel or pipe can be determined from the Manning resistance equation which has the form:

$$Q = \frac{A\, R^{2/3}\, S^{1/2}}{n} \qquad (1)$$

where Q is the flow rate (in m^3/s), A is the cross-sectional area of flow (in m^2), and n is the Manning roughness coefficient of the channel or pipe. The hydraulic radius, R (in m), of the flow is given by:

$$R = \frac{A}{P} \qquad (2)$$

where P is the wetted perimeter of the channel or pipe (in m).

5.6 Rainfall statistics for short-duration storms in the UK can be approximated by the following equation:

$$I_o = 3.27\ (N - 0.4)^{0.223}\ \frac{(T - 0.4)^{0.565}}{T}\ (2\text{min}\ M5) \qquad (3)$$

where I_O is the mean rainfall intensity (mm/h) occurring in a storm of duration T (minutes) with a return period of N (years), such that a storm of this intensity will occur on average once every N years. The quantity $2minM5$ is the depth of rainfall (in mm) occurring in a storm at the specified geographical location during a period of T = 2 minutes with a return period of N = 5 years. The variation of $2minM5$ with location in the UK is shown in Figure 3. Details of the basis for Equation (3) are given in Annex A of HA 37 (DMRB 4.2).

5.7 The rainfall intensity in a storm is not usually constant but varies with time. The design equations given in Chapters 6 and 7 for the drainage capacities of channels and pipes assume that the intensity varies in accordance with what is termed the 50% summer profile, as defined in Volume 2 of the Flood Estimation Handbook (Ref 13). With this profile, the peak intensity at the mid-point of the storm is approximately 3.9 times the mean intensity, I_O, averaged over the total duration of the storm.

6. DRAINAGE CAPACITY OF CHANNEL

Drainage Length

6.1 In a combined system, the surface channel is divided into separate drainage lengths by the intermediate outlets and terminal outfall. For a given size of channel, the maximum allowable distance between adjacent outlets will vary with the longitudinal gradient of the road and the effective width of the catchment being drained. The outlets may not therefore be equally spaced. Alternatively, it is possible to use a standardised spacing equal to the length of road that the channel can drain in the most critical section of the combined system.

6.2 For an individual section of surface channel, the drainage length, L_C (in m), is defined as the maximum length of road that can be drained by the channel under design conditions without the flow exceeding the allowable water depth in the channel. At the downstream end of the drainage length, the flow needs to be discharged from the channel either to the internal pipe of the combined system via an intermediate outlet, or to a watercourse or other drainage system via a terminal outfall (see Chapter 8).

6.3 In addition to the physical properties of the road and the channel, the value of L_C depends upon the rainfall characteristics at the site and the selected value of return period for the design storm. Based on the hydraulic principles described in Chapter 5, the following equation can be used to determine values of drainage length for triangular surface channels of symmetrical cross-section:

$$L_C = 1.56 \times 10^6 \frac{(B_C Y_C)^{2.29}}{\left(B_C^2 + 4Y_C^2\right)^{1/3}} \frac{S^{1/2}}{n_C} \frac{(N - 0.4)^{-0.362}}{[W_E\,(2\min M5)]^{1.62}} \quad (4)$$

where:

- Y_C is the design depth of flow in the triangular channel (in m) - see 2.2 and Figure 1.
- B_C is the corresponding surface width of flow (in m).
- S is the longitudinal gradient of the channel (in m per m).
- n_C is the Manning roughness coefficient of the channel.
- W_E is the effective width of the catchment drained by the channel (in m) - see 5.4.
- N is the return period of the design storm (in years).
- $2minM5$ is a value of rainfall depth (in mm) characteristic of the geographical location of the site - see 5.6 and Figure 3.

Equivalent formulae for the drainage capacities of other cross-sectional shapes of channel (asymmetric triangular, trapezoidal, rectangular and dished) are given in Chapter 5 of HA 37 (Ref 1).

Maximum Flow Capacity

6.4 The maximum flow capacity, Q_C (in m^3/s), of a surface channel when it is just flowing full at its design depth of flow, Y_C, can be determined from the Manning resistance equation (1). For the particular case of a triangular channel of symmetrical cross-section, the equation has the form:

$$Q_C = 0.315 \frac{(B_C Y_C)^{5/3}}{\left(B_C^2 + 4Y_C^2\right)^{1/3}} \frac{S^{1/2}}{n_C} \quad (5)$$

Longitudinal Gradient

6.5 If the longitudinal gradient of the road and the surface channel varies along the drainage distance, L_C, the value of S in Equations (4) and (5) should be replaced by the effective value of longitudinal gradient, S_E. This can be estimated approximately from:

$$S_E = \frac{\Delta Z}{L_C} \quad (6)$$

where ΔZ (in m) is the difference in invert level of the channel between the upstream and downstream ends of the drainage length, L_C. If the variation in longitudinal gradient is considerable, a more accurate estimate of S_E may be obtained from Equation (15) in Chapter 7. In either case, an iterative procedure may be necessary to determine S_E if the longitudinal profile of the road has been determined in advance of the hydraulic design.

Hydraulic Resistance of Channel

6.6 Recommended values of the effective Manning roughness coefficient for surface water channels are given in Table 1. The values for black top may be applicable when determining surcharged flows on adjacent sections of flexible pavement (see the calculation method referred to in 6.12), and may also be appropriate if overlays are applied to existing concrete channels as part of resurfacing work.

Channel Type	Condition	n_C
Concrete	Average	0.013
Concrete	Poor	0.016
Black top	Average	0.017
Black top	Poor	0.021

Table 1 Values of Manning Roughness for Surface Channels

6.7 Factors that influence the effective value of n_C are the surface finish of the channel, irregularities at joints, energy losses caused by the flow entering the channel from the road, and the presence of sediment or debris deposited in the channel.

Storm Return Period

6.8 Recommendations on the selection of design storm return periods for highway drainage systems are given in Chapter 6 of HD 33 (DMRB 4.2). Surface channels should be designed so that flows produced by storms with return periods of $N = 1$ year are contained within the cross-section of the channel (i.e. the design depth, Y_C, in Equation (4) is not exceeded).

Surcharging of Channel

6.9 Limited surcharging of surface channels is permissible during rarer storms. In verges, the maximum width of flow on the road surface during storms with return periods of $N = 5$ years should not exceed 1.5m in the case of hard shoulders and 1.0 m in the case of hard strips. In central reserves, storms with return periods of $N = 5$ years must not cause encroachment of flow on to the carriageway.

6.10 The following simplified method may be used to calculate the length of road that a surface channel can drain to an outlet when the channel is flowing in a surcharged condition:

- First use Equation (4) to calculate the maximum length of road, L_C (in m), that can be drained by the channel when just flowing full at the design flow depth, Y_C, for storms having a return period of $N = 1$ year.
- Depending on the allowable width of flow, B_S on the adjacent hard strip or hardshoulder (see 6.9), use either Figure 4 or 5 to determine the appropriate value of the drainage length factor, ϕ.
- The maximum length of road, L_S (in m), that the channel can drain to an outlet in the surcharged condition for storms having a return period of $N = 5$ years is given by:

$$L_S = \phi\, L_C \qquad (7)$$

This simplified method assumes that the channel has a symmetrical triangular profile and provides estimates of L_S that will tend to err on the conservative side.

6.11 The maximum flow capacity of the channel, Q_S (in m^3/s), under surcharged conditions can be estimated from:

$$Q_S = 1.575\, \phi\, Q_C \qquad (8)$$

where the value of Q_C is the design capacity of the channel obtained from Equation (5).

6.12 A more accurate but more complex method of estimating the maximum length of road, L_S, that can be drained by a surcharged channel is given in Chapter 13 of HA 37 (DMRB 4.2).

Flow By-passing at Intermediate Outlets

6.13 The value of drainage length, L_C, given by Equation (4) assumes that no water is entering the channel at the upstream end of the drainage length. This may not necessarily be the case because making an intermediate outlet large enough to collect 100% of the approaching flow may not result in the most economic overall solution, particularly in steeper channels. Guidelines in HA 78 (DMRB 4.2) allow the use of collection efficiencies between 100% and 80% for intermediate outlets in surface water channels.

6.14 The following allowance for flow by-passing is recommended in Chapter 14 of HA 37 (DMRB 4.2). Consider first the section of channel immediately upstream of the section being designed. Let the length of this upstream section be L_U (in m), and the collection efficiency of its intermediate outlet be η (defined as the ratio between the flow rate collected by the outlet and the flow rate approaching it). Allowable values of efficiency are in the range η = 1.0 to 0.8. For the section of channel being designed, calculate from Equation (4) the maximum length of road, L_C (in m), that could be drained if there were no flow bypassing the upstream intermediate outlet. Taking account of the actual bypassing, the maximum length of road, L_{CB} (in m), that the channel can drain is estimated from:

$$L_{CB} = L_C - \frac{1}{2}(1-\eta)\,L_U \tag{9}$$

If it is decided to adopt an equal spacing between intermediate outlets so that $L_{CB} = L_U$, Equation (9) can be simplified to:

$$L_{CB} = \frac{2\,L_C}{(3-\eta)} \tag{10}$$

6.15 Similar considerations apply for surcharged conditions. If surcharged flow causes by-passing at an upstream outlet, the maximum length of road, L_{SB} (in m), that can be drained by the channel may be calculated from either Equation (9) or (10) with L_{CB} replaced by L_{SB}, and L_C replaced by the value of L_S determined from 6.10 or 6.12.

Spacing of Outlets

6.16 The maximum allowable spacing, L_A (in m), between adjacent outlets (or between the upstream end of a combined system and the first outlet) is determined by the following criteria:

(1) No flow by-passing at upstream outlet:
$L_A \leq L_C$ and $L_A \leq L_S$.

(2) With flow by-passing at upstream outlet:
$L_A \leq L_{CB}$ and $L_A \leq L_{SB}$.

7. DRAINAGE CAPACITY OF INTERNAL PIPE

Drainage Length

7.1 The drainage length, L_P (in m), is defined as the maximum length of road that can be drained by a section of pipe under design conditions without the flow exceeding the allowable depth of water in the pipe. At the downstream end of the drainage length, the flow needs to be discharged from the pipe to an outfall. In addition to the physical properties of the road and the pipe, the value of L_P depends upon the rainfall characteristics at the site and the selected value of return period for the design storm. Values of drainage length for internal pipes of combined systems can be determined from the following equation:

$$L_P = 8.0\times10^6 \frac{R^{2/3}S^{1/2}}{n_P}(N-0.4)^{-0.362} \times \left[\frac{A}{W_E(2\min M5)}\right]^{1.62} \quad (11)$$

where R (in m) is the hydraulic radius of the flow in the pipe (see Equation (2)), A (in m^2) is the corresponding cross-sectional area of flow, n_P is the Manning roughness coefficient of the pipe, and the other quantities are as defined in 6.1. This equation is based on the hydraulic principles and assumptions described in Chapter 5 and so is fully consistent with the equivalent result for triangular surface channels given by Equation (4).

7.2 Since the depth of the pipe below the invert of the surface channel will normally be small, the amount of additional flow capacity that can be obtained by surcharging the pipe will also be small and should not be relied upon for design purposes. It is therefore recommended that the internal pipe should be sized so that it is able to cater for flows produced by storms with return periods of $N = 5$ years when just flowing full at its downstream end (where the flow rate is largest). On this basis, Equation (11) can be rearranged as follows to provide a direct relationship between the diameter of the internal pipe, D (in m), and the maximum length of road that can be drained:

$$L_P = 1.24\times10^6 \frac{S^{1/2}}{n_P}\frac{D^{3.91}}{[W_E(2\min M5)]^{1.62}} \quad (12)$$

7.3 If the pipe is designed to just flow full for storms with a return period of 5 years, it can be shown from Equation (11) that the maximum flow depths produced by storms with a return period of $N = 1$ year will not exceed about 60% of the pipe diameter.

Maximum Flow Capacity

7.4 The maximum flow capacity, Q_P (in m^3/s), of the internal pipe can be determined from the Manning resistance equation (1). For the particular case of a pipe just flowing full at its downstream end, the equation has the form:

$$Q_P = 0.312\frac{D^{8/3}S^{1/2}}{n_P} \quad (13)$$

The corresponding formula for the flow velocity, V_P (in m/s), in the pipe at its downstream end is:

$$V_P = 0.397\frac{D^{2/3}S^{1/2}}{n_P} \quad (14)$$

Longitudinal Gradient

7.5 Depending upon its size, the internal pipe of a combined system may have the capacity to drain a considerable length of road. Situations may therefore arise in which there is a significant variation in longitudinal gradient along the length of the pipe. In these cases, it is recommended to replace the value of S in Equations (11) and (12) by the effective value of longitudinal gradient, S_E. This is found by determining values of the local gradient, S_j, of the road at eleven equally-spaced points (j = 1 to 11) between the upstream and downstream ends of the drainage length being considered. The value of effective gradient is calculated from:

$$S_E = 400\left[S_1^{-0.5} + S_{11}^{-0.5} + 2\sum_{j=2}^{j=10}S_j^{-0.5}\right]^{-2} \quad (15)$$

An iterative procedure may be necessary to determine S_E if the longitudinal profile of the road has been determined in advance of the hydraulic design.

7.6 If the longitudinal gradient is locally zero at the upstream end of the pipe (j = 1), the zero value of S_1 should be replaced in Equation (15) by the modified value $S_1' = S_2 / 9$. Similarly, if the gradient is locally zero at the downstream end, the zero value of S_{11} should be replaced by the modified value $S_{11}' = S_{10} / 9$.

7.7 The hydraulic design method is not valid if a drainage length has intermediate crest or sag points. In such cases, the drainage length should be divided into separate sub-lengths and the pipe in each sub-length sized separately. At intermediate sag points, the flow in the internal pipe should be discharged via an outfall to a watercourse, toe ditch or separate carrier pipe.

Hydraulic Resistance of Pipes

7.8 Recommended values of the effective Manning roughness coefficient for smooth-bore pipes formed in concrete by the slip-forming process are given in Table 2.

Condition	n_P
Average	0.014
Poor	0.016

Table 2 Values of Manning Roughness for Internal Pipe

7.9 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 HR Wallingford and Barr, Ref 14) but with an additional allowance of Δn = 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 = 1.5mm and a depth of sediment deposit in the invert equal to 5% of the pipe diameter.

7.10 If the internal pipe is formed by a process other than slip-forming, appropriate values of n_P 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.

Self-cleansing Conditions

7.11 Run-off from roads can contain significant amounts of silt, sediment and debris. If flow velocities in pipes are not high enough, the larger and heavier sediment particles may form bed deposits that can significantly reduce the flow capacity of the pipes.

7.12 In the types of combined system considered in this Advice Note, the diameter of the pipe will usually be kept constant along a drainage length in order to simplify the construction process (see 7.18 to 7.20 for information on alternative tapered pipe systems). For cases of constant pipe diameter, it will usually be impossible to prevent sediment deposition occurring in the upstream sections of pipe where the flow rates are relatively low. However, due to the reserve capacity of the pipe, significant deposition may be able to occur at the upstream end without causing surcharging problems at road level.

7.13 In terms of the overall performance of a combined system, it is more important to ensure that deposition will not occur in the pipes at the downstream end where the flow rate is greatest and it is necessary to prevent surcharging of the pipe. The value of minimum velocity, V_{min} (in m/s), required to prevent deposition depends on the diameter of the pipe, the depth of flow, and the concentration and size of sediment entering the system. Based on guidance on sediment problems in pipes given in CIRIA Report 141 (Ref 15) and HA 105 (DMRB 4.2), it is recommended that combined systems should be designed so that the flow velocity, V_P, given by Equation (14) at the downstream end of a drainage length should not be less than the appropriate value in Table 3. Values of V_{min} for intermediate pipe sizes may be obtained by interpolation.

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

Table 3 Minimum pipe-full velocities for self-cleansing flows

Total Drainage Length

7.14 The maximum total length of road, L_T (in m), that can be drained by a section of combined channel and pipe system is given by:

$$L_T = L_P + L_A \tag{16}$$

where the drainage length, L_P, for the pipe is obtained from Equation (11) or (12), and the maximum allowable spacing, L_A, between the last intermediate outlet and the terminal outfall is determined from 6.16.

7.15 The number and positions of outlets along a combined system can be varied as appropriate provided that the calculated maximum values of L_P, L_A and L_T (see also 5.3) are not exceeded. Two possible options for determining suitable layouts for systems are described in 7.16 and 7.17.

7.16 This option is most appropriate for lengths of road of constant longitudinal gradient. In this case, construction considerations may favour the use of equal spacings between adjacent outlets, with the last intermediate outlet being located at a distance L_P from the upstream end of the system. This option requires one terminal outfall and N_I intermediate outlets, where the value of N_I is given by:

$$N_I = 1 + \text{INTEGER}\left(\frac{L_P}{L_C}\right) \tag{17}$$

where the INTEGER function rounds down the ratio L_P/L_C to the nearest whole number. The actual spacing, L'_A, between adjacent outlets is given by:

$$L'_A = \frac{L_P}{N_I} \tag{18}$$

which will be smaller than the maximum allowable value of L_A. However, the pipe will be used to its maximum capacity. The total length of road drained by this section of combined channel is:

$$L'_T = L_P + L'_A \tag{19}$$

A terminal outfall is required at this downstream point to discharge all the flow from the combined system to a watercourse, toe ditch or separate carrier pipe.

7.17 The second option may be more appropriate for lengths of road having a varying longitudinal gradient. In this case, the following procedure can be applied.

(1) Starting from the upstream end of the system, use the local value of longitudinal gradient to calculate the maximum allowable length of road, L_A, that can be drained by the surface channel. Locate the first intermediate outlet at this point.

(2) Proceed downstream, locating an intermediate outlet at each point at which the maximum drainage capacity of the channel is reached.

(3) Add together the individual values of L_C to find the cumulative drainage length, L_{cum}, measured from the upstream end of the system. The total length of road, L'_T, that can be drained by this section of combined system is equal to the first value of L_{cum} that exceeds the maximum drainage length, L_P, of the internal pipe.

(4) Locate a terminal outfall at this downstream point to discharge all the flow from the combined system to a watercourse, toe ditch or separate carrier pipe.

Tapered Pipe Systems

7.18 The diameter of the internal pipe does not need to be kept constant along the length of a combined system. Use of a smaller diameter in the upstream part of a system increases the velocity of flow and can therefore help to prevent sediment deposition. However, this advantage may be outweighed by the added complexity and cost of constructing a system with more than one size of internal pipe. As explained in 7.12, a degree of siltation can be accepted in an oversized pipe without surcharging problems occurring at road level.

7.19 If the diameter of the internal pipe is varied along the length of the system, the point at which it is necessary to increase from one pipe size to another can be found using Equation (12).

7.20 Any change in pipe size should coincide with the position of an intermediate outlet. The invert of the outgoing pipe should not be higher than the invert of the incoming pipe. Where possible the soffits of the two pipes should be set at the same level. This will require the vertical cover for the upstream pipe to be greater than the minimum value given in Chapter 4.

8. INTERMEDIATE OUTLETS AND TERMINAL OUTFALLS

Intermediate Outlets

8.1 Intermediate outlets in combined channel and pipe systems consist of two components:

(1) *gully gratings*, installed in the base of the channel, that discharge the flow from the surface water channel; and

(2) *shallow chambers* that enable flow from the surface channel to enter the internal pipe.

8.2 The hydraulic design of the gully gratings (type, spacing, number) is described in HA 78 (DMRB 4.2). The following alternative geometries for intermediate outlets, presented in HA 78 (DMRB 4.2), are generally suitable for the combined channel and pipe system:

(1) *In-line outlet*, where the water is essentially collected symmetrically either side of the channel invert (see Figures B5, B7 and B9 of HA 78, DMRB 4.2); or

(2) *Off-line outlet*, where the channel is widened away from the carriageway and the outlet is offset from the centreline of the channel (see Figures B6, B8 and B10 of HA 78, DMRB 4.2).

For triangular channels the in-line design is generally more efficient than the off-line design, but reasons for choosing between them will mainly depend on constructional aspects (see 8.4). Other factors being equal, in-line outlets are preferable to off-line outlets because they can allow use of a narrower verge.

8.3 Recommended designs for the outlet chamber that transfers flow from the surface channel to the internal pipe were established through experimental testing and analysis (Escarameia and May, Ref 16; Escarameia et al, Ref 17) and are based on the following principles:

(1) The plan shape of the chamber is determined by the layout of the gratings forming the upper part of the outlet.

(2) The depth of the chamber is determined by the invert level of the internal pipe (as well as by construction requirements, see Chapter 10) and therefore will usually be shallow.

(3) The flow in the chamber should be contained within benching to minimise energy losses.

8.4 Schematic diagrams of the chambers for intermediate off-line and in-line outlets are illustrated in Figure 6 and 7. These Figures give cross-sectional layouts and should be consulted in conjunction with Figures B5 and B6 of HA 78 (DMRB 4.2).

8.5 The off-line arrangement (see Figure 6) will normally involve the construction of chambers with walls formed using either brickwork, precast concrete sections or an internal liner, and with a partial cover slab to support one edge of the grating.

8.6 The chamber for the in-line arrangement (see Figure 7) can be formed by removing some of the concrete immediately after slip-forming so that the internal shape of the chamber can be boxed out. A metal beam can be inserted to support inclined gratings where the channel is of sufficient width (see 10.1). Heavier mesh reinforcement (as defined in 4.6) should be used in the base of the channel unit.

8.7 In order to minimise energy losses at the chambers, it is desirable to construct the benching up to the soffit level of the incoming pipe so as to fully contain the flow within the U-shaped benched channel. The vertical space available between the benching and the underside of the cover slab of the chamber may be limited, particularly for smaller sizes of internal pipe. In these cases the level of the benching may be lowered, but the depth of the U-shaped benched channel should not be less than 75% of the diameter of the incoming pipe. It is recommended to construct the benching with a minimum transverse slope of 1:10 to help direct the flow from the gratings towards the benched channel.

Terminal Outfalls

8.8 Terminal outfalls from combined channel and pipe systems consist of two components:

(1) *gully gratings*, installed in the base of the channel, that discharge the flow from the surface water channel; and

(2) *outfall chambers* with catchpits that also receive flow from the internal pipe, and convey the combined flow to a suitable watercourse, toe ditch or separate carrier pipe.

8.9 When not protected by a safety barrier, the upper surface of the terminal outfall must terminate with a smooth transition, without abrupt changes in level or width (following the recommendations in 3.16 of HA 78, DMRB 4.2). The flow collection efficiency provided by terminal outfall gratings will need to be higher than for intermediate outlets, and should be close to 100%. The recommended hydraulic design procedure is described in 4.18 and 4.19 of HA 78 (DMRB 4.2).

8.10 The plan shape of the chamber will be determined by the layout of the gratings forming the terminal outfall. The invert level of the outgoing pipe from the chamber should be governed by the following two criteria:

(1) The invert level should be set at a minimum of 300mm above the bottom of the chamber to provide an adequate volume for sediment retention.

(2) The invert level should be such that the water level in the chamber does not rise high enough to prevent flow discharging freely from the surface channel into the chamber.

8.11 In order to meet criterion (2) in 8.10, it is recommended that the water level in the chamber should be at least 150mm below the underside of the gratings when the chamber is receiving flow from the channel under surcharged conditions. The height Z (in m) of the water surface in the chamber above the invert of the outgoing pipe can be estimated from the equation:

$$Z = \frac{D}{2} + 0.23\frac{Q_T^2}{D^4} \qquad (20)$$

where D is the diameter of the outgoing pipe (in m) and Q_T is the total design flow rate (in m^3/s) given by:

$$Q_T = Q_P + Q_S \qquad (21)$$

where Q_P is the flow rate from the internal pipe given by Equation (13), and Q_S is the flow rate from the most downstream section of surface channel when operating under surcharged conditions (see 6.10 to 6.12 and Equation (8)).

8.12 The gradient and diameter of the outgoing pipe from the chamber should be determined from a suitable resistance equation or flow tables (such as HR Wallingford and Barr, Ref 14) assuming that the pipe is just running full at the design flow rate, Q_T, given by Equation (21).

8.13 An example of a suitable layout for a terminal outfall chamber is given in Figures 8a to 8c.

Steep Roads

8.14 On steep roads (typically with gradients of S > 1:50), the flow collection efficiency of gully gratings may be insufficient due to the effect of high water velocities in the surface channel. In these cases, HA 78 (DMRB 4.2) recommends the use of weir outlets (see Figures B23 and B24 in HA 78). With the weir outlet, the surface channel is locally widened on the verge side so that the flow can discharge smoothly over a longitudinal weir into an external sidespill channel. A safety barrier must be installed locally to prevent the wheels of vehicles dropping into the sidespill channel.

8.15 In the case of an intermediate chamber with a weir outlet, flow from the sidespill 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. A screen should be installed at the exit from the sidespill channel to prevent coarse debris being washed into the chamber.

Access for cleaning the chamber may be provided either by a removable manhole cover, or by a gully grating installed in the invert of the surface channel (as described in 8.4 to 8.6). The latter arrangement will provide some reserve flow collection capacity but this should not be taken into account when sizing the weir outlet.

The chamber should be benched internally so as to minimise energy losses between the straight-through flow carried by the internal pipe of the combined system and the side flow entering from the sidespill channel. Suitable layout details for shallow junction chambers are given in Figure F5 of the HCD (MCHW 3).

8.16 In the case of a terminal outfall, the flow in the internal pipe and the flow from the most downstream weir outlet can be discharged separately into a common chamber, from which the combined flow can be conveyed to a suitable watercourse, toe ditch or separate carrier pipe. See relevant sections of 8.8 to 8.13.

9. SUB-SURFACE DRAINAGE

General

9.1 Combined surface water channel and pipe systems will usually be significantly deeper than solid triangular surface water channels, and so will be founded at a lower level of the pavement construction. Consequently, the base of a combined unit will usually be at a similar level to the base of the adjacent pavement. Therefore, the type of sub-surface drainage appropriate for solid channels (see F21 of the HCD, MCHW 3) will not be suitable for use with combined systems.

Drainage System

9.2 Since the channel of a combined system will form an effective barrier to the horizontal movement of moisture at the pavement edge, the sub-surface drain must be located between the pavement construction and the channel. This is a change from the drainage philosophy for solid surface water channels in which the sub-surface drain is located at the extreme edge of the carriageway, where it is more readily accessible.

9.3 The recommended layout of sub-surface drainage system for combined channel and pipe systems is shown in Figure 9. Fin drains of Types 5, 6, 8 or 9 (see the HCD, MCHW 3) are suitable for use with this layout. However, it should be noted that the Type 10 filter drain (see F21 of the HCD, MCHW 3) used in conjunction with solid surface water channels is not suitable for use with combined systems.

9.4 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 sub-surface drainage must be protected from this run-off, 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 sub-surface drainage.

9.5 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 sub-surface drainage should not be installed until placement of the sub-base is complete.

9.6 The location of the sub-surface drainage will render it inaccessible for maintenance and therefore it is essential that the diameter of the carrier pipe is sized to accommodate some build-up of sediment during the life of the system.

10. CONSTRUCTION ASPECTS

10.1 For combined systems constructed using slip-forming techniques, many potential combinations of channel size and pipe size are possible. Slip-form 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-form contractors to limit the number of different designs required and thereby maximise the possibility of re-use. 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)

0.90
1.20
1.50

Pipe diameter *D* (m)

0.30
0.40
0.50

If intermediate outlets of the in-line type are used (see 8.4 and Figure 7), the channel needs to be sufficiently wide to accommodate two gratings and their frames with a minimum thickness of concrete surround of 100mm. For 500mm wide gratings, the minimum channel width will be about 1.35m. The required width may be reduced if inclined gratings in a single-piece frame are produced for this type of application.

10.2 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 (see Figure 2). 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 slip-forming 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.

10.3 If required, the diameter of the internal pipe can be varied with distance along the length of a combined system. The hydraulic factors to be taken into account are described in 7.18 to 7.20.

10.4 The introduction of reinforcement into the slip-formed 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 40mm. To eliminate the risk of the slip-forming shield catching on the transverse bars, the mesh should be laid so that the transverse bars are beneath the longitudinal bars.

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

10.6 The pipe void is 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.

Contraction and Expansion Joints

10.7 Contraction cracks can be dealt with in the same way as for solid surface water channels. This involves forming narrow slots about 25mm 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 sub-surface drainage system (see Chapter 9 and Figure 9).

10.8 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.

Inspection

10.9 It is recommended that a CCTV inspection of the internal pipe (see Specification for Specialist Activities, MCHW 5.9.2) 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.

11. MAINTENANCE ASPECTS

11.1 Channels should be regularly cleaned by sweeping in accordance with requirements set out in the Trunk Road Maintenance Manual (TRMM).

11.2 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.

11.3 Jetting of internal pipes shall be in accordance with Clause 521 of the SWH (MCHW 1).

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

11.5 In the rare 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) Even if the reinforcement needs to be removed, care must 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 HD 32 Maintenance of Concrete Roads (DMRB 7.4). The steel dowels should be to grade 460 of BS 4449 (Ref 19) and have a length L_d = 600mm if the dowels are of 16mm diameter, or L_d = 500mm if they are of 20mm diameter. The embedded length of the dowels should be L_d /2.

(6) Ideally the tie bars should be at 600mm centres with at least two dowels in each face. The minimum cover should be 40mm.

(7) A section of plastic pipe with an internal diameter similar to that of the pipe void, but not more than 25mm 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) C35 concrete complying with the requirements given in 4.4 should be placed and vibro-compacted 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) In order 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. Care must be taken since there is a significant risk of water escaping and washing cement from the concrete, thereby allowing concrete to enter the resulting gap around the pipe.

(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) 5mm 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.

12. WORKED EXAMPLE

12.1 It is required to determine the spacing between the intermediate outlets and terminal outfall 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 9.3m (including two 1.0m 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 will not receive run-off from any adjacent pervious areas.

12.2 The combined system will be slip-formed in C28/35 mass concrete with light mesh to meet a D400 loading requirement (see 4.5). The principal features of the system are as follows.

Surface water channel

- Symmetrical triangular channel with cross-falls of 1:5 (vertical : horizontal)
- Design flow depth: Y_C = 0.120 m
- Corresponding flow width: B_C = 1.20m
- Average roughness condition: from Table 1 (concrete), Manning roughness coefficient n_C = 0.013.

Internal pipe

- Diameter D = 0.400m
- Average roughness condition: from Table 2, Manning roughness coefficient n_P = 0.014.

Overall cross-sectional shape

- The surface channel is to be designed to allow a maximum width of surcharging of 1.0m on the adjacent hardstrip (see 6.9). 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 25mm above the level at the edge of the hardstrip (see HA 37, DMRB 4.2). 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_C + 0.125m = 1.325m.
- To meet the structural requirements in 4.4, a minimum concrete cover equal to half the pipe diameter needs to be provided. Therefore, the minimum depth of the concrete block is 0.12m + 0.20m + 0.40m + 0.20m = 0.92m (measured from the edge of the hardstrip).

Reinforcement

- The size of light mesh reinforcement required is determined from 4.5. The transverse bars of the mesh need to provide a minimum steel area of 385mm^2 per metre run of pipe. This can be provided, for example, by 7mm diameter transverse bars located at 100mm centres.

12.3 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:

$$W_E = 9.30 + 1.325 = 10.625 \text{ m}$$

12.4 The characteristic rainfall depth for the Norwich area is found from Figure 3 to be:

2*min M5* = 4.0mm

12.5 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 must be contained within the surface water channel with the flow depth not exceeding Y_C = 0.120m. Substituting the above values in Equation (4), it is found that the maximum drainage length is:

$$L_C = 307 \text{ m}$$

12.6 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 HA 78 (DMRB 4.2), 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 (10) to be:

$$L_{CB} = 292 \text{ m}$$

12.7 It is also necessary to check that the width of surcharging on the hardstrip will not exceed 1.0m during storms having a return period of N = 5 years. This can be done using the simplified calculation procedure given in 6.10. For a design flow depth in the channel of Y_C = 0.120m and a road cross-fall of 1:40, Figure 4 shows that the drainage length factor for surcharged conditions has a value of ϕ = 1.08. From Equation (7), the maximum possible length of road that can be drained under surcharged conditions is therefore:

$$L_S = 1.08 \times 307 = 332\,\text{m}$$

If the flow collection efficiency of the intermediate outlet under surcharged conditions is η = 0.85, it is found from 6.15 that the maximum spacing between intermediate outlets taking account of by-passing is:

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

12.8 The maximum allowable spacing, L_A, between intermediate outlets is the smaller of the two values L_{CB} and L_{SB} (see 6.16, item 2), which is:

$$L_A = 292\,\text{m}$$

12.9 The next step is to determine the length of road that can be drained by the internal pipe. As explained in 7.2, it is recommended that the pipe should be designed to flow just full for storms with a return period of N = 5 years. Using Equation (12) and the data given in 12.2 to 12.4, it is found that maximum possible length of road that can be drained by the 0.40m diameter pipe is:

$$L_P = 507\,\text{m}$$

The flow velocity at the downstream end of the pipe is obtained from Equation (14) and has the value:

$$V_P = 1.38\,\text{m/s}$$

This will produce satisfactory self-cleansing conditions since it exceeds the minimum velocity of V_{min} = 0.89m/s recommended in Table 3 for a pipe of 0.40m diameter.

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

$$L_T = L_P + L_A = 507 + 292 = 799\,\text{m}$$

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:

$$L'_P = 500\,\text{m and } L'_A = 250\,\text{m}$$

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

$$L'_T = 750\,\text{m}$$

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

12.11 The dimensions and layouts of the intermediate outfalls and the terminal outfall are determined using the recommendations in Chapter 8. Flow from the terminal outfall may be discharged to a watercourse or toe ditch, or to a separate carrier pipe in the verge or central reserve.

12.12 The maximum design flow rate discharged from the terminal outfall 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 (13):

$$Q_P = 0.173\,\text{m}^3/\text{s}$$

and from Equations (8) and (5):

$$Q_S = 0.127\,\text{m}^3/\text{s}$$

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

$$Q_T = 0.300\,\text{m}^3/\text{s}.$$

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14. ENQUIRIES

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ANNEX A LIST OF SYMBOLS

		Units
A	Cross-sectional area of flow in channel or pipe	m^2
B	Surface width of flow in channel or pipe	m
B_S	Allowable width of flow on hard strip or hardshoulder adjacent to channel during surcharged conditions	m
D	Internal diameter of pipe	m
H	Horizontal cover around pipe	m
I_O	Mean rainfall intensity	mm/h
k_S	Hydraulic roughness in Colebrook-White resistance equation	mm
L_A	Maximum allowable spacing between adjacent outlets in channel	m
L_C	Drainage length of channel, i.e. maximum length of road that can be drained by a section of surface channel at design depth of flow	m
L_{CB}	Value of L_C allowing for flow by-passing at upstream outlet	m
L_{cum}	Cumulative length of road drained by sections of surface channel, measured from upstream end of combined system	m
L_d	Length of dowel rod	mm
L_P	Maximum length of road that can be drained by a section of internal pipe	m
L_S	Maximum length of road that can be drained by a section of surface channel under surcharged conditions	m
L_{SB}	Value of L_S allowing for flow by-passing at upstream outlet	m
L_T	Total length of road that can be drained by a section of combined system	m
L_U	Drainage length of section of combined system immediately upstream of the drainage length being designed	m
N	Return period of storm	years
N_I	Number of intermediate outlets in combined system	-
n	Manning roughness coefficient of channel or pipe	-
Q	Flow rate in channel or pipe	m^3/s
Q_S	Flow capacity of channel in surcharged condition	m^3/s
Q_T	Total flow rate discharged from a section of combined system	m^3/s

P	Wetted perimeter of channel or pipe	m
R	Hydraulic radius of flow (= A/P)	m
S	Longitudinal gradient of road, channel or pipe (vertical fall per unit distance along road, channel or pipe)	m/m
S_E	Effective value of S for road, channel or pipe of non-uniform gradient	m/m
T	Duration of storm	minutes
U	Vertical cover around pipe	m
V	Velocity of flow	m/s
V_{min}	Minimum pipe-full velocity for self-cleansing flow	m/s
W_E	Effective width of catchment drained by combined system	m
Y_C	Design depth of flow in surface channel (from invert)	m
Z	Height of water surface in outfall chamber above invert level of outgoing pipe	m
ΔZ	Difference in invert level of channel between upstream and downstream ends of drainage length	m
η	Collection efficiency of outlet (= flow rate collected by outlet/flow rate in channel approaching outlet)	-
ϕ	Surcharge factor (ratio between drainage length for surcharged channel and drainage length for channel just flowing full)	-
$2minM5$	Rainfall depth occurring in 2 minutes with return period of 5 years	mm

Subscripts

B	value taking account of flow by-passing
C	value for channel
j	integer variable
min	minimum value
max	maximum value
P	value for pipe
S	value for surcharged conditions
$'$	actual value

ANNEX B FIGURES

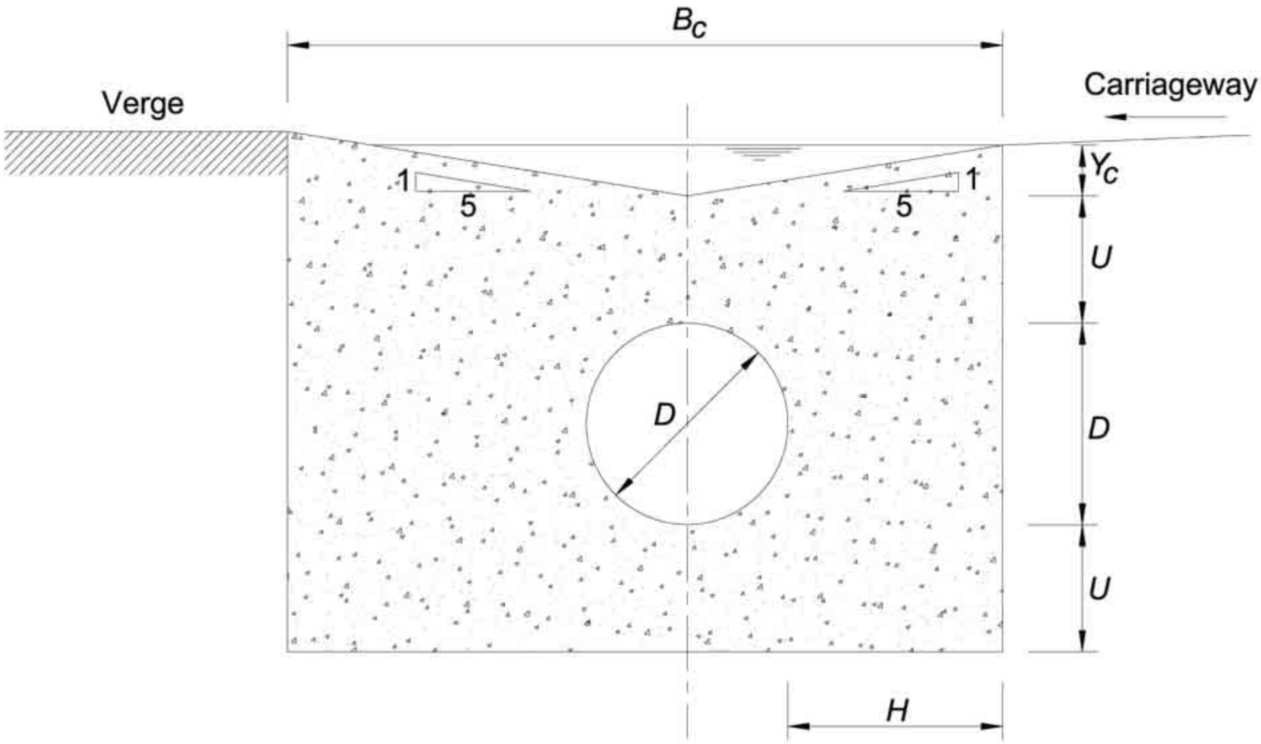

Figure 1 Typical Cross-section of Combined Surface Channel and Pipe System

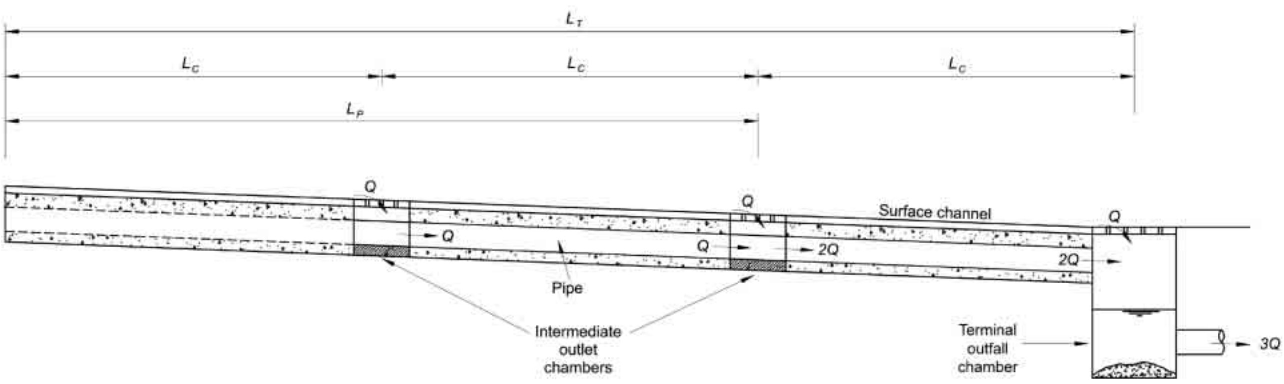

Figure 2 Longitudinal Profile of Combined Surface Channel and Pipe System

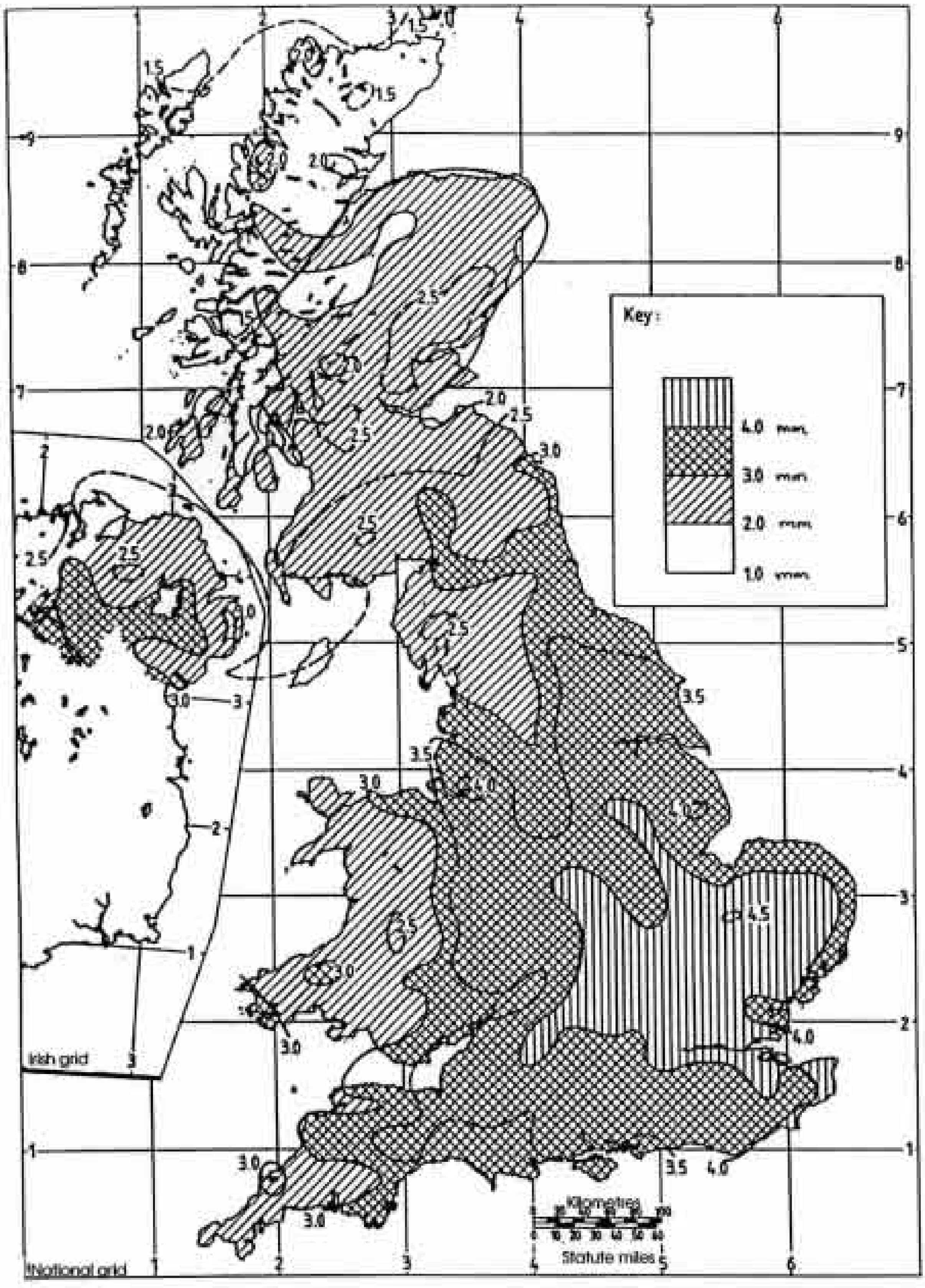

Figure 3 Values of 2*minM*5 Rainfall Depth for UK
(Reproduced from BS 6367:1983 by permission of British Standards Institution)

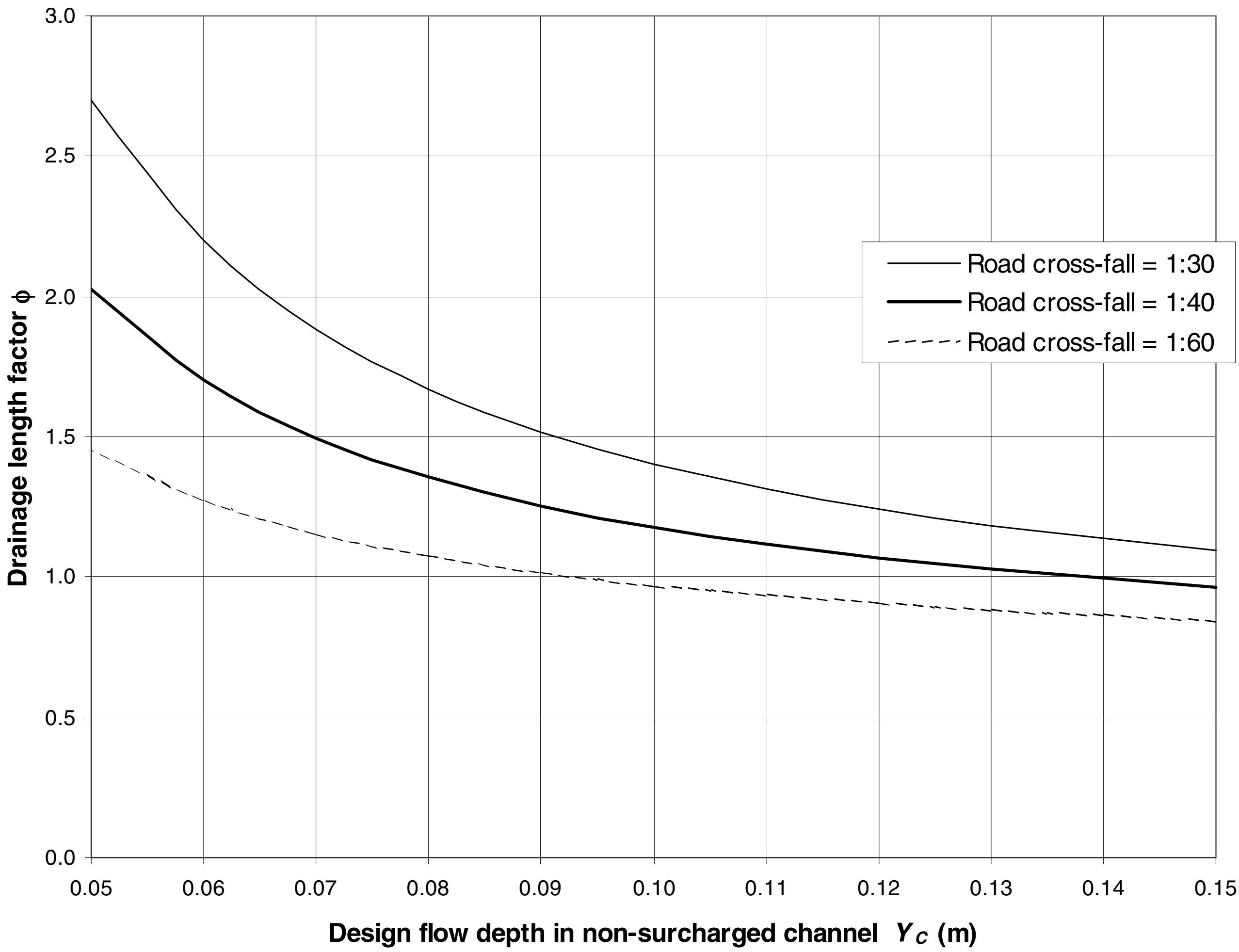

Figure 4 Drainage Length Factor φ for Triangular Channels with Surcharged Width of B_S = 1.0m

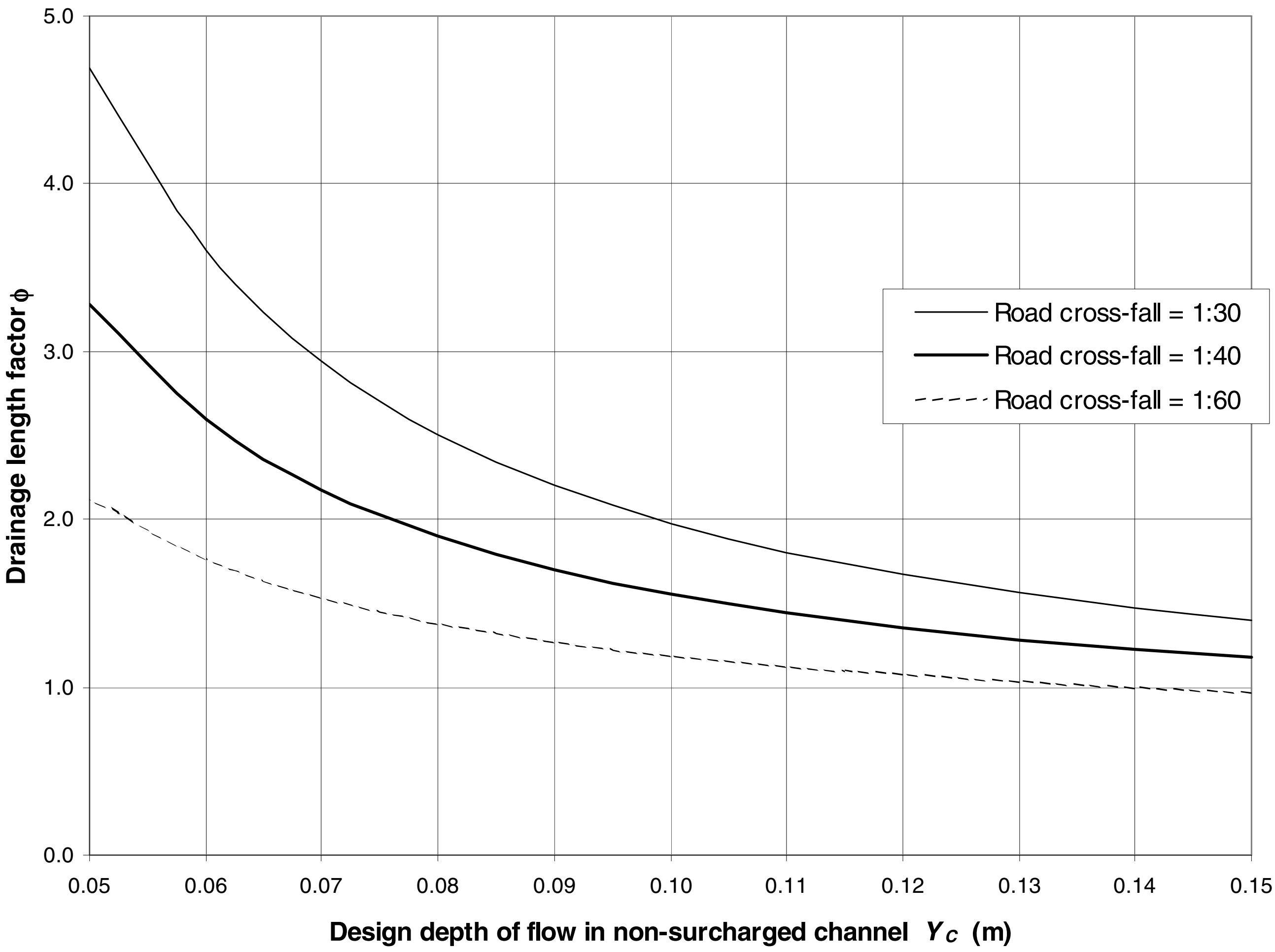

Figure 5 Drainage Length Factor ϕ for Triangular Channels with Surcharged Width of B_S = 1.5m

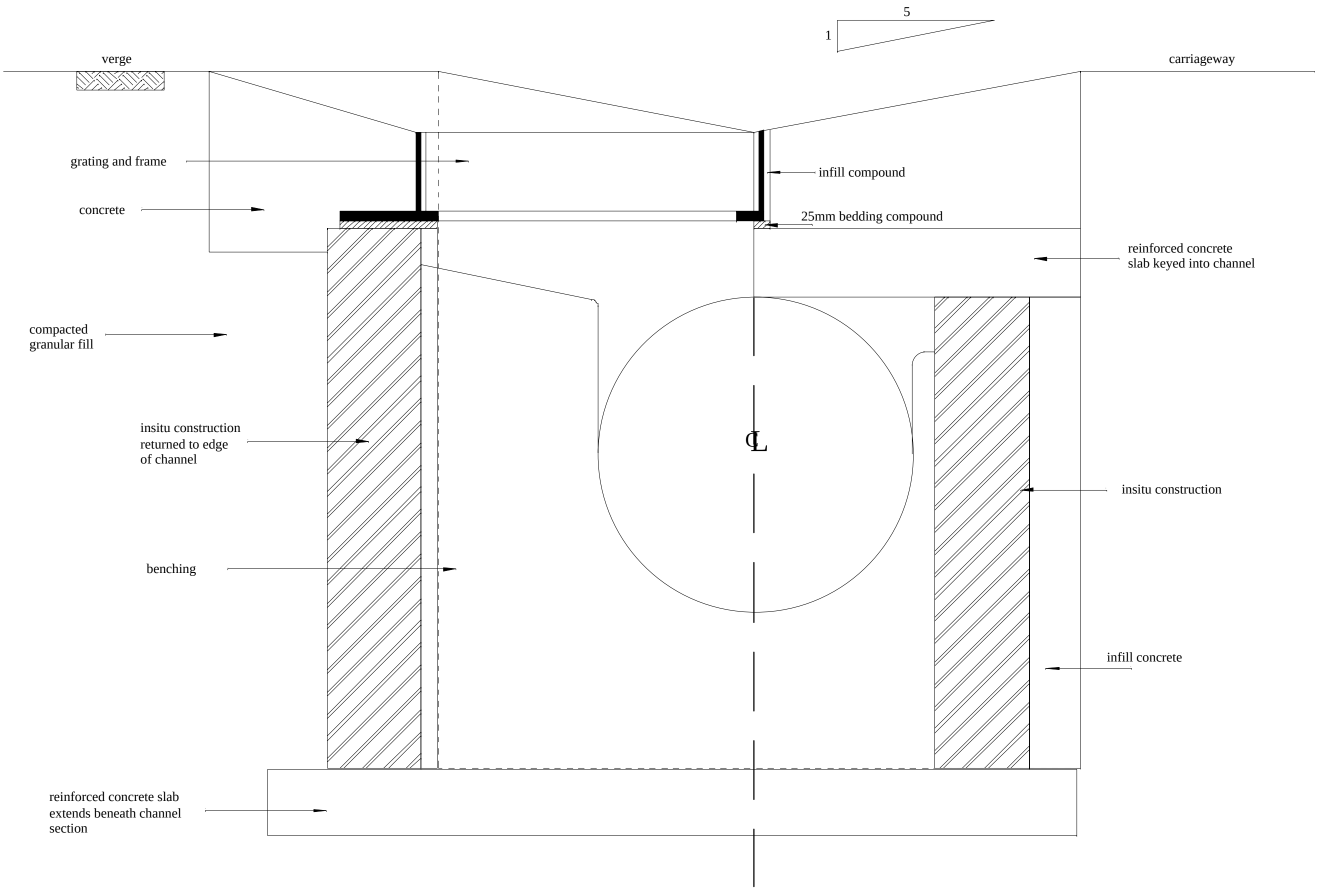

Figure 6 Example of Intermediate Outlet with Off-line Grating

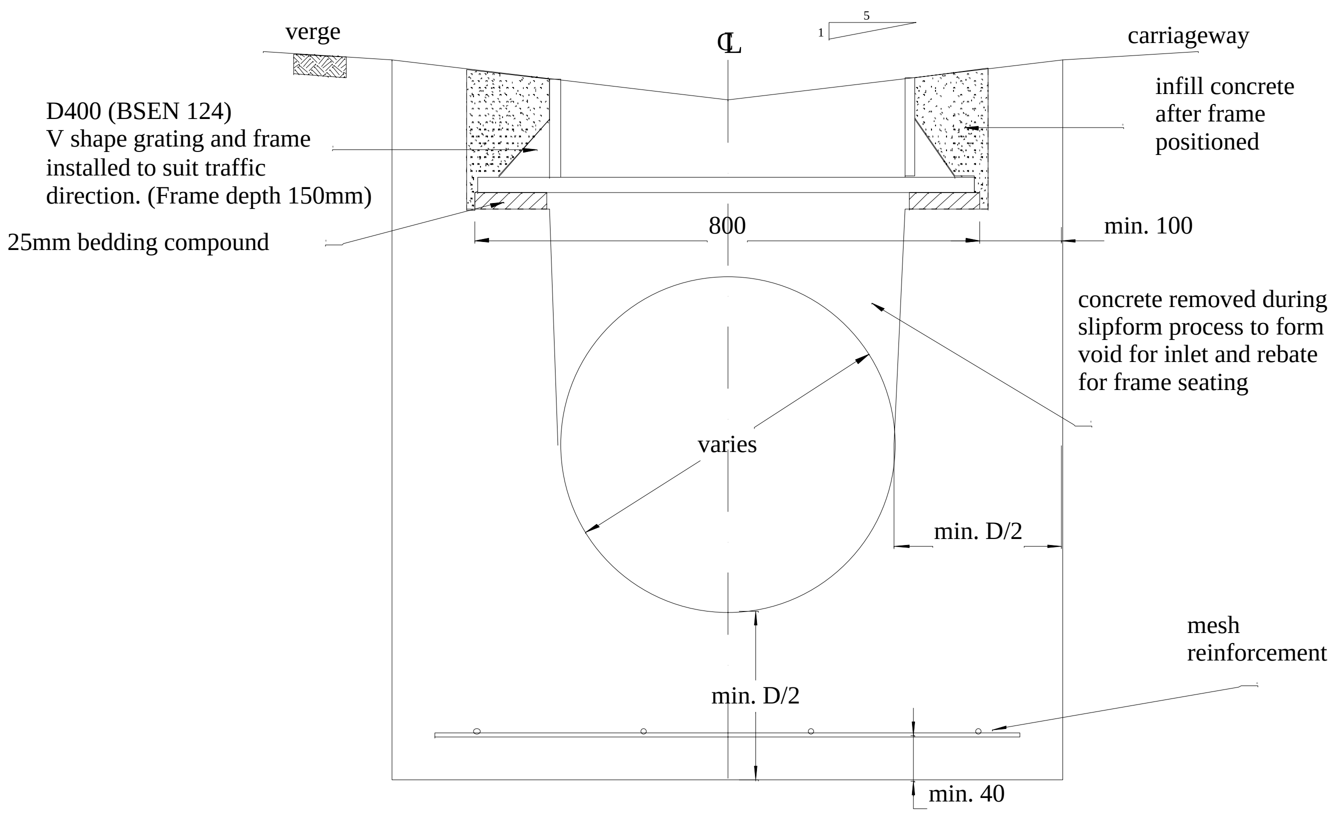

Figure 7 Example of Intermediate Outlet with In-line Grating

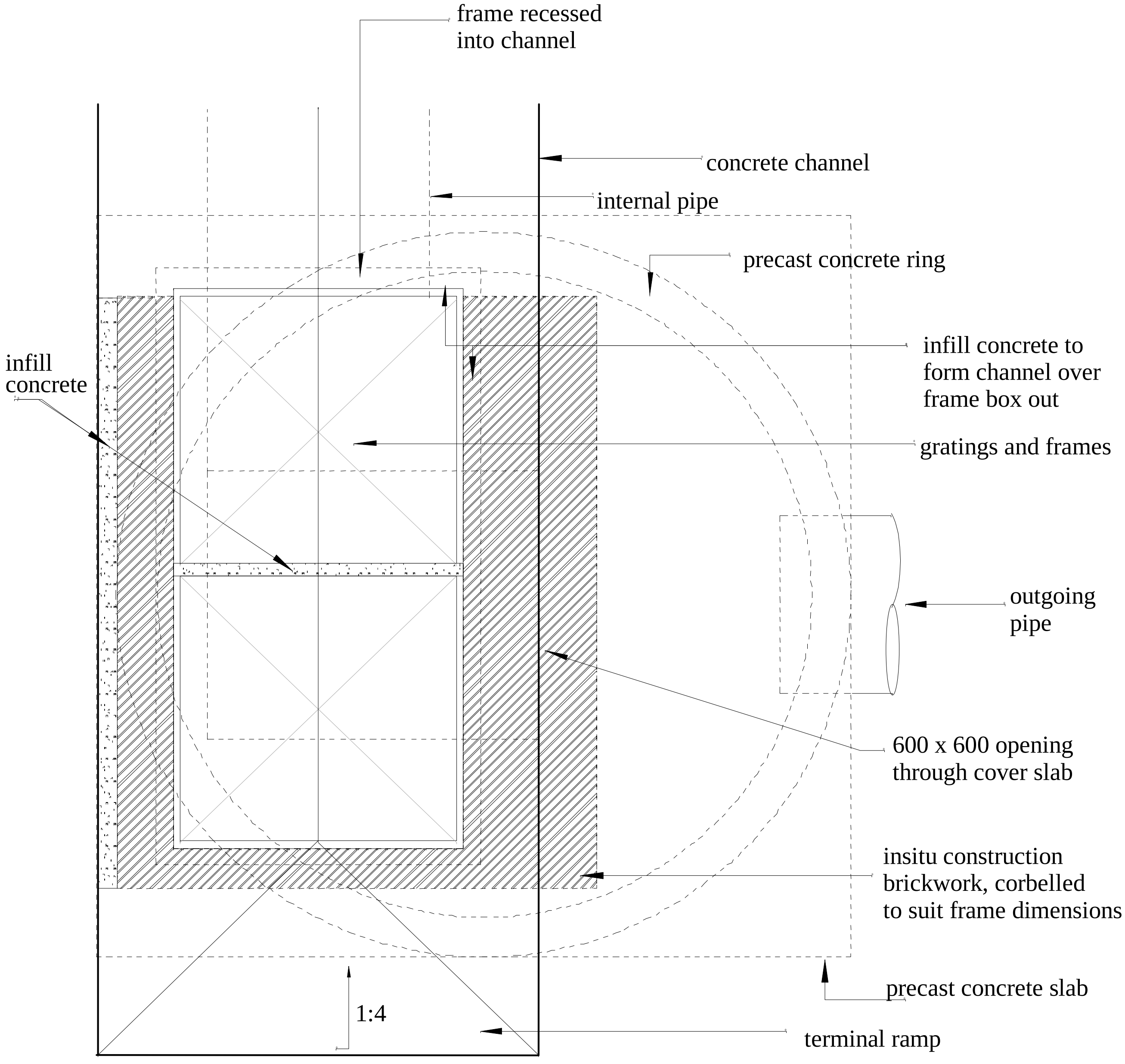

Figure 8a Example of Terminal Outfall - Plan View

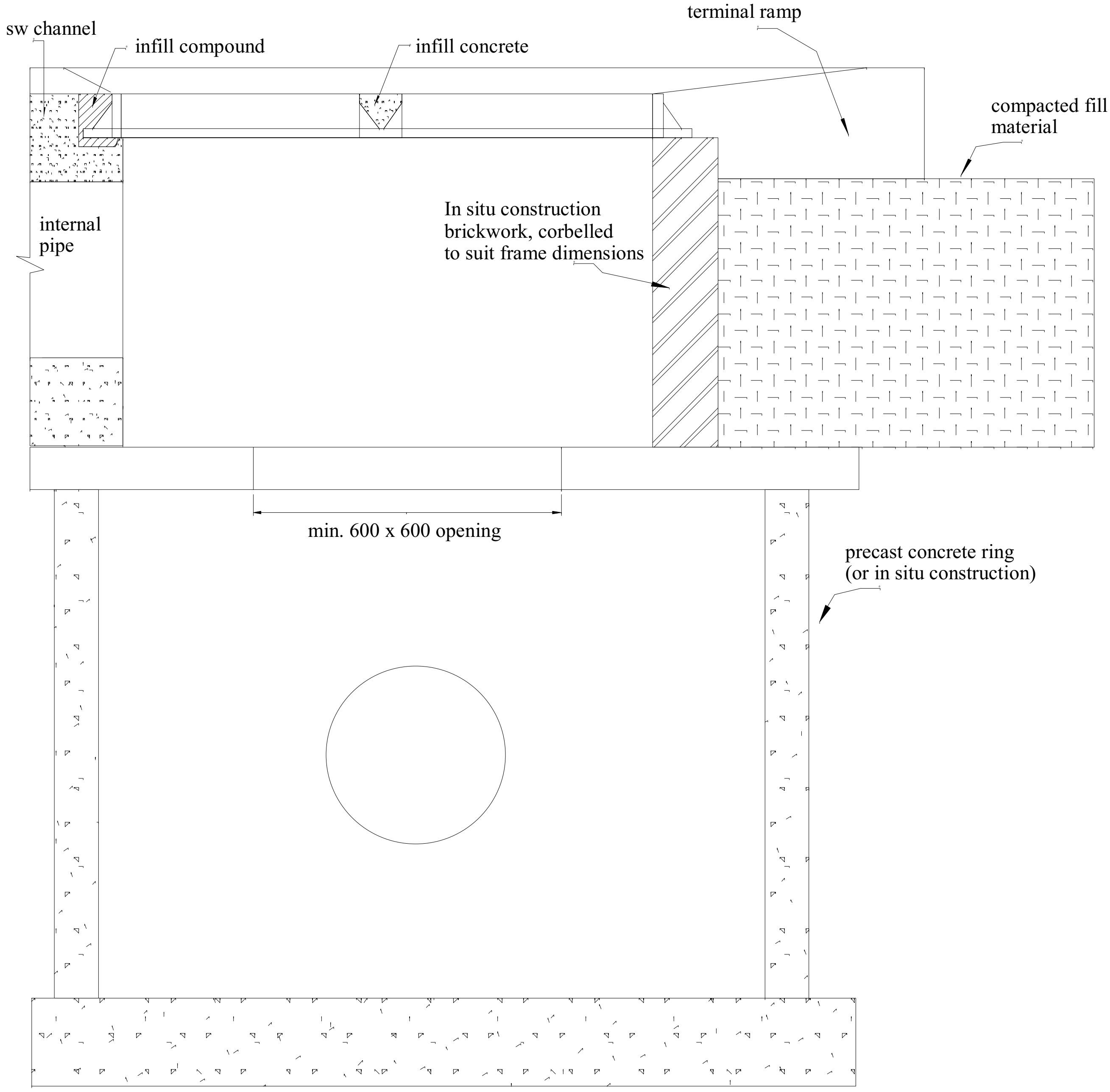

Figure 8b Example of Terminal Outfall - Longitudinal Cross-section

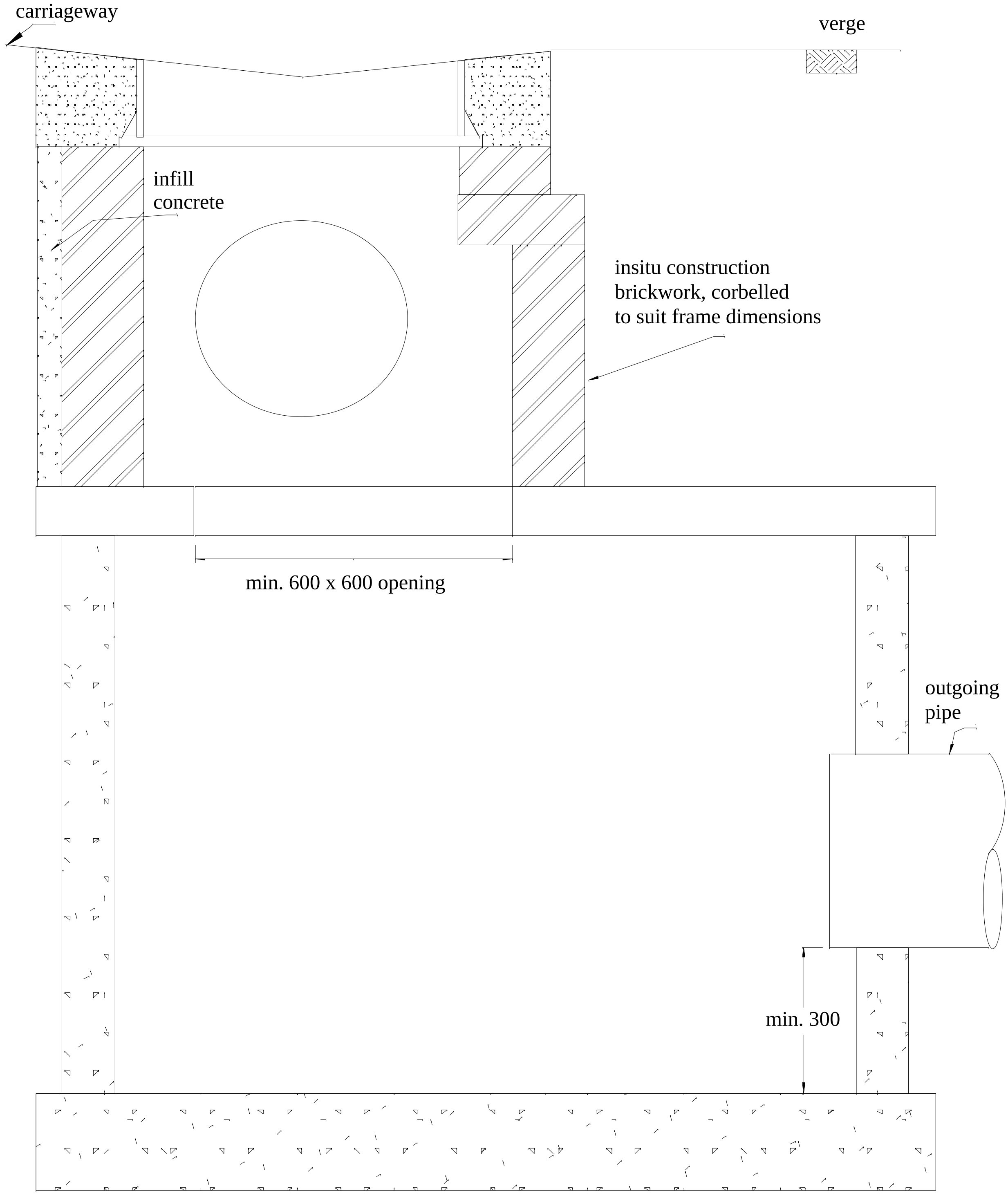

Figure 8c Example of Terminal Outfall - Transverse Cross-section

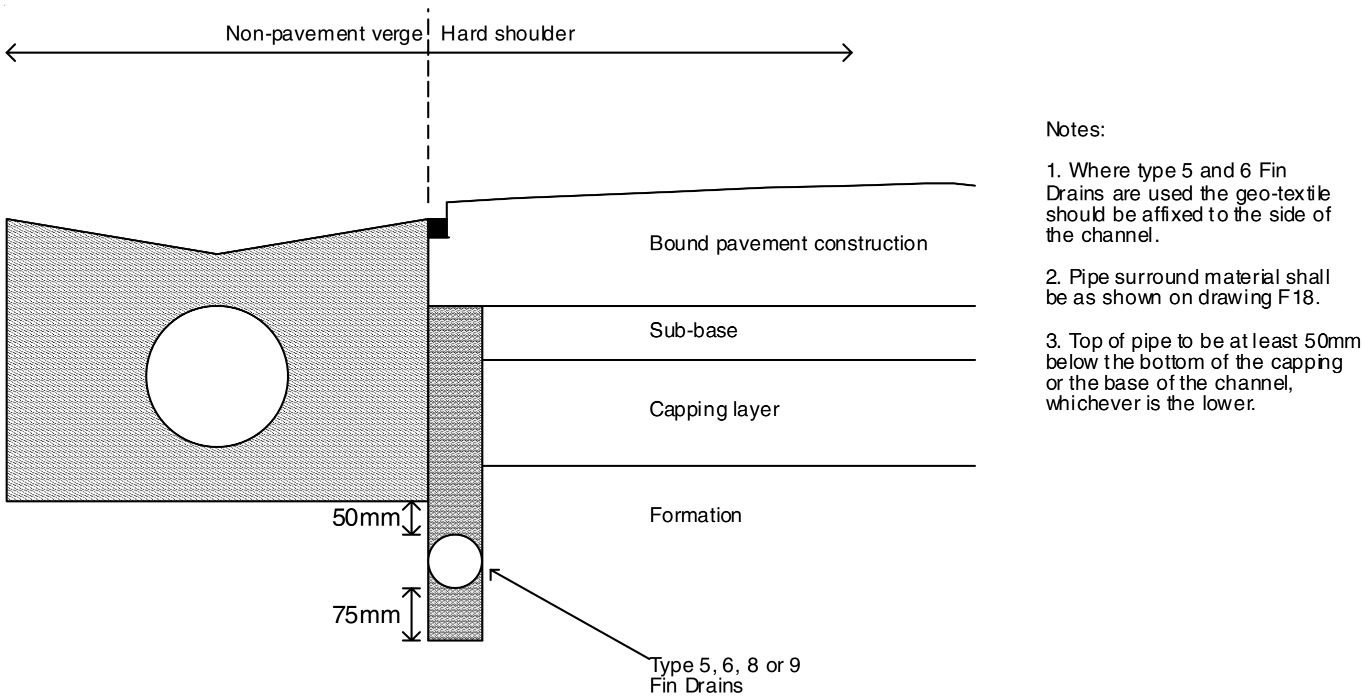

Figure 9 Sub-surface Drainage for Combined System