26 OPEN DRAINS

26.1 INTRODUCTION

This chapter provides guidelines for the design of open drainage system, grassed swales and lined drains. These facilities, along with stormwater inlets and pipe drains, are components of the minor drainage system designed to collect minor flood flows from roads, properties, and open space, and convey them to the major drainage system.

It should be noted that grassed swales referred to in this chapter are intended for runoffconveyance as distinct from swales for water quality improvement. Water quality swales are discussed in Chapter 31. Fully lined drains are not encouraged anymore in local practice. Developers and designers shall seek approval from the Local Authority if such needs arise. Much of procedures and experience that deals with this system have been established in Malaysian practices since late 1970s.

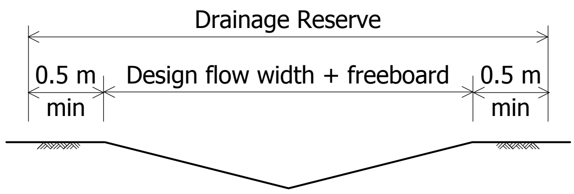
Where land reserves are available use open-grassed drains otherwise use pipe, especially in highly built up zones.

26.1.1 Design Storm

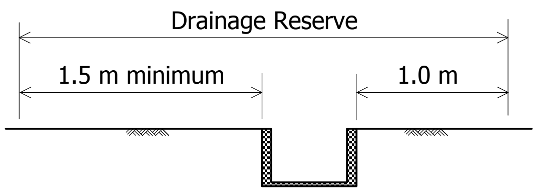
Open drains shall be designed to cater for flows up to and including the minor system design ARI specified in Table 4.1 (see Chapter 4) for the type of development.

26.1.2 Drainage Reserves

Most open drains will be located within a road reserve and therefore do not require a separate drainage reserve to allow access for maintenance. Drains located outside of road reserves, such as in public walkways and open space areas, should be provided with a drainage reserve in accordancewith Figure 26.1.



(a) Grassed Swale



(b) Lined Open Drain

Figure 26.1 Reserve Width for Open Drain

26.2 GRASSED SWALES

26.2.1 Location

A grassed swale, depression, or minor formalised overland flow path is generally located within parkland, open space areas, along pedestrian ways, and along roadways with limited access to adjacent properties.

Grassed swales should not be provided in urban street verges with adjacent standard density residential and commercial properties where on-street parking is permitted.

26.2.2 Alignment

Standardised alignments for grassed swales are provided to limit the negotiations needed when other services are involved.

(a) Roadway Reserves

In new development areas, the edge of a grassed swale should generally be located 0.5 m from the road reserve or property boundary. In existing areas, this alignment may be varied depending on the alignment and depth of existing underground services within the road verge. The designer should consult the Local Authority for appropriate alignments in existing areas.

Swales may also be located within road median strips, provided the median is of sufficient width to contain the swale plus a 1.0 m berm on either side. The swale should be centrally located within the median

(b) Privately Owned Lots

Municipal grassed swales shall not be located within privately owned properties. If swales are to be provided at the side or rear of private properties, they shall be placed within a separate drainage reserve of minimum dimensions in accordance with Figure 26.1(a).

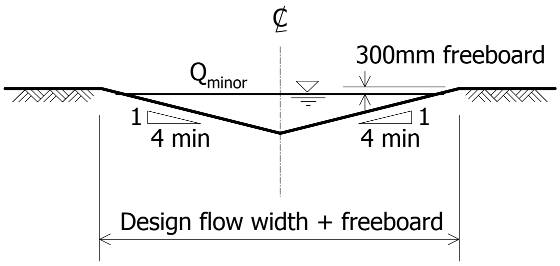
(c) Public Open Space

The location of swales within public land such as open space should generally conform to natural drainage paths wherever practical. The designer should consult with the Local Authority for appropriate alignments with due consideration for public safety.

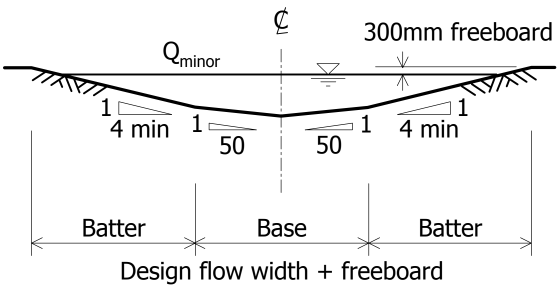
26.2.3 Geometry

The preferred shapes for grassed swales are shown in Figure 26.2. The flow depth shall not exceed 0.9 m.

A 'vee' shaped section will generally be sufficient for most applications, however, a trapezoidal section may be used for additional capacity or to limit the depth of the swale.



(a) 'Vee' Shaped



(b) Trapezoidal Shaped

Figure 26.2 Recommended Grassed Swale Cross-Sections

26.2.4 Freeboard

The depth of a grassed swale shall include a minimum freeboard of 50 mm above the design storm water level in the swale.

26.2.5 Velocities and Grades

The average flow velocity in a grassed swale shall not exceed 2 m/s. If this is not practical, an underground pipeline, lined open drain, or grass reinforcement system should be provided.

26.2.6 Grassing

The grass species chosen for lining of grassed swales must be sturdy, drought resistant, easy to establish, and able to spread and develop a strong turf layer after establishment. A thick root structure is necessary to control weed growth and erosion.

One or more of the following permanent grasses are recommended for permanent seed mixes:

- *Axonophus compressus* (Cow grass)
- *Vertiver grass*
- *Brachiaria sp.*
- *Cynodon dactylon* ((Bermuda grass)
- *Panicum virgatum* (Switch grass)

The quality of the grass seed used is important. Grass seed shall be fresh, recleaned grass seed of the latest crop available. Grass seed may range from 20% to 100% purity. Compensation for purity and germination shall be by furnishing sufficient additional seed to equal the specified pure live seed product.

General guidelines for establishing an effective grass lining are as follows:

- prepare a good, firm seed bed
- use a crop residue or a mulch to protect the swale and grass during establishment
- allow 3 months for grass to show an adequate stand
- select a simple grass mixture that best fits the conditions of the swale
- use good quality seed
- use grass origins and strains known to be adaptable to the site
- plant at the best date for the selected grass species
- use planting equipment and methods that give uniform distributions and proper placement of seed
- water grass as required to supplement rainfall until it is established
- fertilise according to the needs of the grass and the soils as shown by soil tests
- overseed or repair bare spots with sod chunks or mulch as necessary
- avoid driving vehicles on the swale or damaging the sod with tillage implements
- mow when grass can make good regrowth and restore food reserves in the roots

26.2.7 Dry Weather Flow Provision

For swales that will be subjected to dry weather flows, an underground pipe or surface invert should be provided in accordance with the requirements of Section 28.9.4.

26.2.8 Vehicular Crossings

As far as practical, the number of vehicular crossing points on swales should be kept to a minimum. Where crossing points are deemed necessary, they may be provided by any of the following methods:

- at-grade crossing
- box or pipe culvert
- bridge structure

At-grade crossings shall be constructed with a hard durable surface that will be stable under design flow conditions. The cross-section should be designed in accordance Standard Drawing SD F-42 to minimise the potential for ponding across the crossing caused by the buildup of the grassed surface over time on the low side of the crossing.

Culvert and bridge crossings should be sized with sufficient waterway area to minimise changes to the flow regime on both sides of the crossing and to minimise the potential for blockages. Restrictions caused be these types of crossings will cause sediment to deposit on the upstream side of the crossing, which may become a maintenance problem.

If entrance and exit velocities, particularly for culverts, are increased above the swale average velocity limit of 2 m/s, erosion protection measures will be required to prevent scouring of the swale (refer Chapter 29).

The level of culvert obverts and bridge soffits should be at least 50 mm above the design storm water level in the swale.

26.2.9 Maintenance

Periodical maintenance will be required to maintain the hydraulic capacity of a swale. Grass should be regularly mown and sediment, litter, and debris deposits removed, particularly at flow restrictions such as vehicular crossing points.

Bare patches and scoured areas must be repaired by removing dead grass, filling scour holes, and reseeding with a recommended permanent grass seed mix.

26.3 LINED DRAINS

26.3.1 Locations and Alignments

Standardised locations for lined drains are provided to limit the negotiations needed when other services are involved.

(a) Roadway Reserves

The outer edge of a lined drain should be located 0.5 m from the property boundary on the high side of road reserves to permit relatively short connections to service adjacent properties. Lined drains may also be located within road median strips.

The Local Authority should be consulted for standard alignments of public utility services within street verges.

Where there is significant advantage in placing a lined drain on an alignment reserved for another authority, it may be so placed provided that both the authority responsible for maintenance of the stormwater conveyance and the other authority concerned agree in writing to release the reservation.

Curved alignments are preferred on curved roadways. However, where there are significant advantages, e.g. culs-de-sac or narrow street verges, straight alignments may be acceptable.

(b) Privately Owned Lots

Municipal lined drains shall not be located within privately owned properties. Where lined drains are to be provided at the side or rear of private properties, they shall be placed within a separate drainage reserve in accordance with Figure 26.1(b).

(c) Public Open Space

The location of lined drains within public land such as open space shall be brought to the attention of the Local Authority for consideration. As a guide, unless directed otherwise, lined drains shall be located as close as practical to the nearest property boundary with due consideration for public safety.

26.3.2 Lining Materials

Lined drains shall be constructed from materials proven to be structurally sound and durable and have satisfactory jointing systems.

Lined open drains may be constructed with any of the following materials:

- plain concrete
- reinforced concrete
- stone pitching
- plastered brickwork
- precast masonry blocks

Alternative drain materials may be acceptable. Proposals for the use of other materials shall be referred to the Local Authority for consideration.

26.3.3 Geometry

The dimensions of lined open drains have been limited in the interests of public safety and to facilitate ease of maintenance. The minimum and maximum permissible cross-sectional dimensions are illustrated in Figure 26.3 and described as follows.

(a) Depth

The maximum depth for lined open drains shall be in accordance with Table 26.1.

Table 26.1 Recommended Maximum Depths

Cover Condition	Maximum Depth (m)
Without protective covering	0.5
With solid or grated cover	1.0

(b) Width

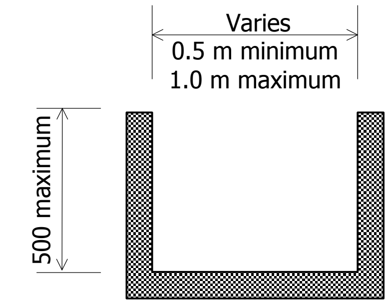
The width of lined open drains may vary between a minimum width of 0.5 m and a maximum width of 1.0 m.

(c) Side slope

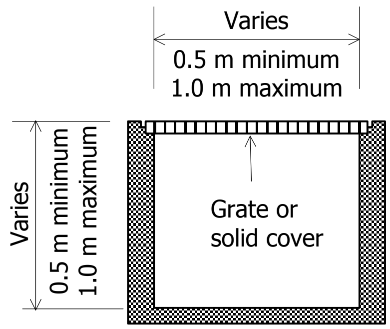
The recommended maximum side slopes for lined open drains are indicated in Table 26.2.

Table 26.2 Recommended Maximum Side Slopes

Drain Lining	Maximum Side Slope
Concrete, brickwork, and blockwork	Vertical
Stone pitching	1.5(H):1(V)
Grassed/Vegetated	2(H):1(V)



(a) Uncovered Open Drain



(b) Covered Open Drain

Figure 26.3 Dimension Limits for Open Lined Drains

26.3.4 Covers

Open drains in locations open to pedestrian access shall be covered if the depth of the drain exceeds 0.6 m. The type of drain cover used will depend on the expected live loadings and whether or not the drain is required to accept surface flow. The following types of drain covering are acceptable:

- precast reinforced concrete
- metal grates and solid plates

(a) Precast Reinforced Concrete Covers

Drains not subject to traffic loads or inflow of surface runoff may be covered using precast reinforced concrete covers. Covers should be sized such that the weight is limited to what can be easily lifted by 2 workmen to gain access for maintenance.

(b) Metal Grates and Solid Plates

Drains subject to vehicular traffic loads or inflow of surface runoff shall be covered using metal grates or solid plates. Metal covers shall be designed in accordance with the latest edition of relevant Malaysian Standard.

The type of drain cover shall be selected according to the following criteria:

- subject to traffic loadings Class C
- subject to traffic loadings Class D

Cast iron covers shall be 'GATIC', or equal.

(c) Cover Levels

Covers for lined open drains shall be set at the finished cover levels given in Table 26.3.

Table 26.3 Cover Levels

Location	Cover Level
Paved Areas	Flush with finished surface
Footpaths and street verges	Flush with finished surface
Elsewhere	100 mm above surface to allow for topsoiling and grassing

26.3.5 Freeboard

The depth of an open lined drain shall include a minimum freeboard of 50 mm above the design storm water level in the drain.

26.3.6 Velocities and Grades

To prevent sedimentation and vegetative growth, the minimum average flow velocity shall not be less than 0.6 m/s.

The maximum average flow velocity shall not exceed 4 m/s. For flow velocities in excess of 2 m/s, drains shall be provided with a 1.2 m high handrail fence, or covered with solid or grated covers for the entire length of the drain for public safety.

26.3.7 Vehicular Crossings

Driveway entrances to properties and other vehicular crossings shall be structurally designed for a 7 tonne wheel loading.

26.3.8 Concrete Works

(a) Concrete Lining Section Thickness

All concrete lining shall be designed to withstand the anticipated hydrodynamic and hydrostatic forces. The minimum thickness shall not be less than 100 mm.

(b) Concrete Joints

Concrete lined channels shall be constructed of either plain or reinforced concrete (depending on loading conditions) without transverse joints. Expansion/contraction joints shall be installed where new concrete lining is connected to a rigid structure or to existing concrete, which is not continuously reinforced. Longitudinal joints, where required, shall be constructed on the side walls at least 300 mm vertically above the drain invert.

Construction joints are required for all cold joints and where the lining thickness changes. Reinforcement, if required, shall be continuous through the joint.

All joints shall be designed to prevent differential movement.

(c) Concrete Finish

The surface of the concrete lining may be finished in any of the finishes listed in Design Chart 26.1. The designer should check with the Local Authority to determine which finishes are acceptable.

(d) Reinforcement Steel

Steel reinforcement shall have a minimum tensile strength f_y = 460 N/mm^2. Either deformed bars or wire mesh may be used depending on load requirements.

Reinforcing steel shall be placed at the centre of the section.

Provide additional steel as needed to meet retaining wall structural needs.

(e) Earthwork

The following areas shall be compacted to at least 95% of maximum density as determined by ASTM D698 (Standard Proctor):

- the top 150 mm of subgrade immediately beneath the drain bottom and side slopes
- the top 150 mm of earth surface within 1 m of the top edges of the drain
- all fill material

The subgrade under the drain must be of acceptable strength for the expected loadings, i.e. weight of concrete and water at maximum flow depth. The following may be used to strengthen or compensate for deficient subgrades:

- piling
- concrete blinding layer
- geotextiles

(f) Bedding

Provide 100 mm of granular bedding, equivalent in gradation to 20 mm concrete aggregate, under the drain bottom and side slopes.

26.3.9 Stone Pitching

(a) Stone

The stone used for pitching shall be hard, durable and dense, and not subject to deterioration upon exposure to air and water. Suitable stone is clean rough quarry stone, pit or river cobbles, or a mixture of any of these materials.

Individual pieces shall be approximately cubical or spherical. The maximum stone dimension shall be 250 mm with a minimum dimension between 100 and 150 mm.

(b) Cement Mortar

Cement mortar shall be 1 part ordinary Portland cement to 3 part fine aggregate by volume with sufficient water added to produce a suitable consistency for the intended purpose.

(c) Capping

The top of stone pitching shall be capped with cement mortar to produce an even surface to match the surrounding ground level and to provide seating for protective covers if required.

26.3.10 Bricks and Precast Blocks

Bricks shall be sound, hard, and shall comply with the requirements of Malaysian Standard 76. Precast blocks shall be constructed in accordance with the Manufacturer's specifications.

Cement mortar for brickwork and blockwork shall be the same as that specified for stone pitching.

All exposed brickwork surfaces shall be plastered with a 20 mm thickness of plaster consisting of 1 part masonry cement complying to Malaysian Standard 794 to 3 parts sand be volume.

26.3.11 Weep Holes

Appropriate numbers of weep holes shall be provided in the walls of all open drains relieve hydrostatic pressure.

26.3.12 Strut Beams

Precast or cast-in-situ struts shall be provided at the top of all stone pitched, brick, and unreinforced precast block drains that exceed 0.9 m in depth. Strut beams shall be spaced at intervals not exceeding 6 m.

Strut beams shall be 100 mm square in section and shall be reinforced with a single centrally located Y12 bar.

26.3.13 Maintenance

Lined open drains will require periodical maintenance to remove weed growth, sediment deposits, and debris and litter accumulation to maintain the designed hydraulic capacity of the drain.

Damaged linings or displaced joints or strut beams should be repaired as soon as practical to prevent further deterioration or failure of sections of the drain. Refer to Section 28.15 for recommendations for inspection.

26.4 COMPOSITE DRAINS

26.4.1 General

A combination of a grassed section and a lined drain may be provided in locations subject to dry-weather base flows which would otherwise damage the invert of a grassed swale, or in areas with highly erodible soils.

The lined drain section is provided at the drain invert to carry dry-weather base flows and minor flows up to a recommended limit of 50% of the 1 month ARI. The grassed section shall be sized to provide additional flow capacity up to and including the design storm ARI.

The composite drain components shall comply with the relevant design requirements specified for grassed swales and lined drains.

26.4.2 Geometry

The preferred shape for a composite drain is shown in Figure 26.5.

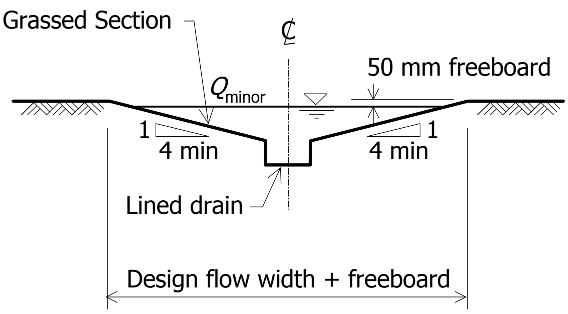


Figure 26.4 Recommended Composite Drain Cross-Section

26.5 CUT-OFF DRAINS

Cut off drains shall be provided to regulate hillslope runoff from public land adjacent to:

- road reserves
- property boundaries where the total uphill catchment is greater than 0.5 hectares

Cut off drains shall divert hillslope clear of privately owned properties and road reserves to discharge into the nearest natural watercourse, engineered waterway, or overland flow path. The design shall follow the natural land contours. Traversing of large natural gullies or major ridges is not desirable and will be permitted only when subject to special planning and design.

Cut off drains should be located such that the area between the drain and property boundaries which will contribute surface runoff is minimised as far as practicable (refer Figure 26.5).

Cut off drains form part of the urban edge zone, which may incorporate a number of diverse functions other than protection of development from surface runoff. The design of cut-off drains shall be considered in the context of any requirements for management of the edge zone including provisions for fire control, landscaping, and public access and recreation and multi-functional facilities should be provided wherever possible. The Local Authority shall be consulted regarding the functions and related requirements for the urban edge zone in the vicinity of a cut-off drain.

26.5.1 Drain Types

(a) Minor Drain

For small catchment areas, or in relatively flat terrain, it may be possible to utilise the access track as the cut-off drain to provide capacity for the design storm. Refer to Figure 26.5(a).

(b) Major Drain

A separate cut-off drain must be provided wherever the cross sectional area of a cambered track has insufficient capacity for the design storm. Refer to Figure 26.5(b).

26.5.2 Primary Outlets

Design flows shall normally be discharged to a designated overland flow path via an outlet pipe or a spillway chute. Discharge points with capacity for the design storm shall be provided at intervals not exceeding 600 m.

Where outlet pipes are provided, care shall be taken in the design to ensure that the entire design storm flow from the cut-off drain can be transferred to the outlet pipe. Inlet screening shall be provided to minimise the likelihood of blockage of the outlet from large debris.

Spillway chutes shall be stabilised to prevent scour. For supercritical flows, energy dissipation measures shall either be incorporated along the chute or provided at the point of discharge to the overland flow path (refer Chapter 29).

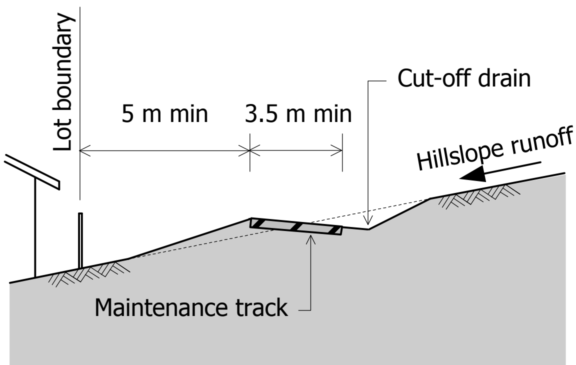
26.5.3 Relief Spillways

Subdivision layouts should be planned to minimise the potential for property damage resulting from possible overflows from cut-off drains.

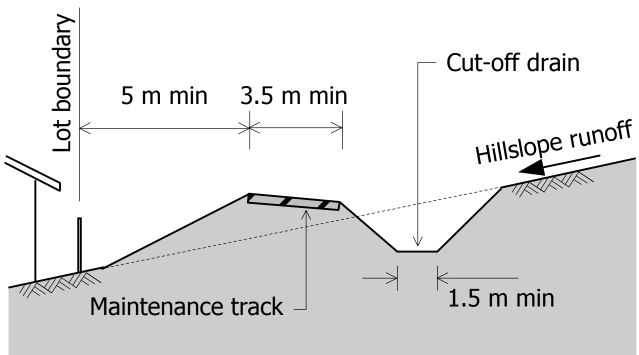
Relief spillways shall be provided at regular intervals to discharge flows in excess of the cut-off drain capacity or in the event of blockage of the drain or primary outlets.

Relief spillways shall be designed for a minimum capacity of 50 years ARI, and shall discharge to designated overland flow paths. Where overland flow paths are not available, the number of relief spillwaysshall be increased to avoid concentration of discharge and so minimise potential property damage.

Relief spillways shall be stabilised to prevent scour and provided with adequate energy dissipation measures for supercritical flow.



(a) Minor Drain



(b) Major Drain

Figure 26.5 Typical Cut-off Drain Cross Sections

26.5.4 Grades

(a) Longitudinal

(i) Minimum

Longitudinal grades shall not be less than 0.5% to minimise the likelihood of ponding and siltation within the drain.

(ii) Maximum

The maximum longitudinal grade shall be selected such that the average flow velocity in the drain does not exceed the following values under any operating conditions:

- 2 m/s for unlined drains
- 4 m/s for lined drains

(b) Side Slopes

The maximum side slopes of the cut-off drain and embankment shall be:

- slope in fill 2(H):1(V)
- slope in cut: earth 2(H):1(V)
  rock 0.25(H):1(V)

26.5.5 Access Requirements

Cut off drains shall be designed to allow for ease of maintenance, including ready access for maintenance machinery.

In general, cut-off drains shall be designed so that mechanical grass cutting equipment (i.e. motor mowers or tractor mounted mowers) can be used to control grass and weed growth. Maintenance of the drain cross section should be possible using conventional earthmoving equipment such as backhoes, front-end loaders, and trucks.

Where conditions do not permit ready access, cut-off drains shall be designed for minimum maintenance by providing such measures as concrete lining or stone pitching of the drain.

(a) Access Tracks

An all weather access track with a minimum width of 3.5 m shall be provided.

The access track shall be designed with the cross fall into the slope. The cross fall shall be within the following limits:

- 3% minimum
- 10% maximum

The preferred location for the track is on top of the drain embankment. However, in some instances it may be preferable to locate the track on the downstream side of the embankment.

Adequate scour protection shall be provided for the track. For longitudinal gradients exceeding 10%, the track should be surfaced with one of the following:

- two coat seal
- reinforced concrete
- unit paving
- bitumen stabilised decomposed granite gravel

Where access tracks have insufficient width to allow maintenance vehicles to pass, pull over bays shall be provided at a maximum spacing of 250 m.

(b) Access Points from Urban Area

Access from the urban road network via feeder roads, culs-de-sac, pedestrian ways, or floodways shall be provided at intervals not exceeding 500 m.

Access points shall have a minimum width of 3.5 m to allow unconstrained access for maintenance vehicles. Structures should not be allowed to impinge on the access.

Provision shall be made to prevent access to the cut-off drain by unauthorised vehicles.

Hard surfacing as specified in the previous section shall be provided for access points steeper than 10%.

(c) Crossing Points

Crossing points may be required to gain access to areas above a cut-off drain. The designer shall refer to the Local Authority for the requirement and location of crossing points.

The crossing point shall be provided with a hard surface to delineate the point as a crossing, provide scour protection, and prevent damage to the embankment and drain by vehicles.

Minor drain crossings may be provided at grade across the drain whilst major drain crossings should be utilise a culvert or bridge crossing. Adequate scour protection of the drain shall be provided on both sides of the culvert.

26.6 DESIGN PROCEDURE

26.6.1 Analysis

Open drains may be sized by Manning's formula (refer Chapter 12) using the roughness values provided in Design Chart 26.1. Composite roughness values for drains with more than one surface lining in the cross-section may be estimated using the procedure provided in Chapter 28, Section 28.8.3.

26.6.2 Procedure

Step 1: Estimate Manning's n of the lining material.

Step 2: Use Design Chart 26.2 or 26.4 to determine the flow depth, y , or use Design Chart 26.3 to determine the minimum base width for a trapezoidal shaped grassed swale. Estimate y from the charts or calculate manually.

Step 3: Check if y is within required limits for the open drain type. If not, adjust the drain dimensions and return to step 2.

Step 4: Calculate the average flow velocity from $V = Q/A$ and check that it is within the maximum and minimum velocity criteria for the open drain type. If not, adjust the drain dimensions and return to step 2.

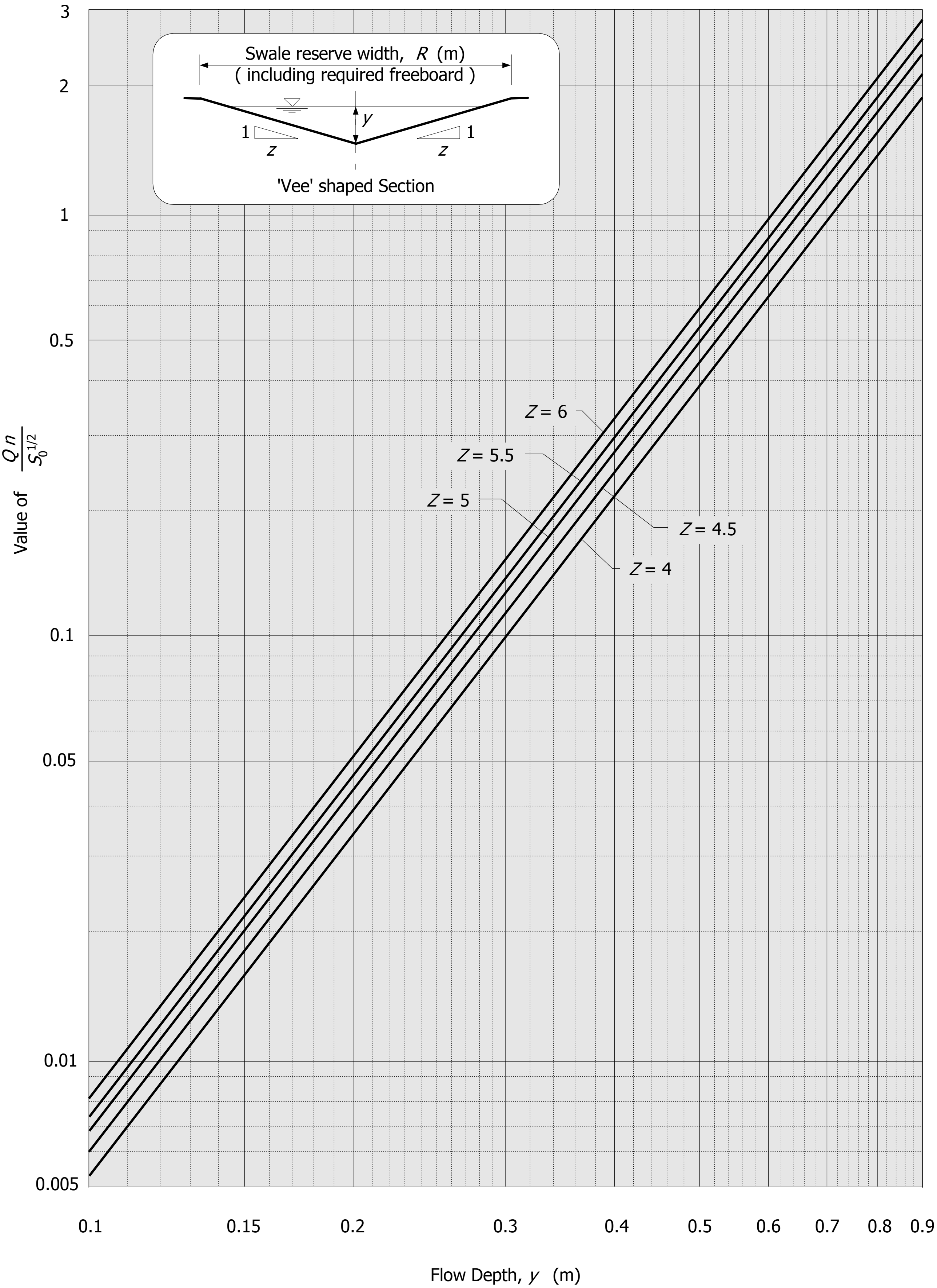
Step 5: Add required freeboard to y and calculate top width of drain for drains with sloping sides.

Step 6: If required, calculate width of drainage reserve.

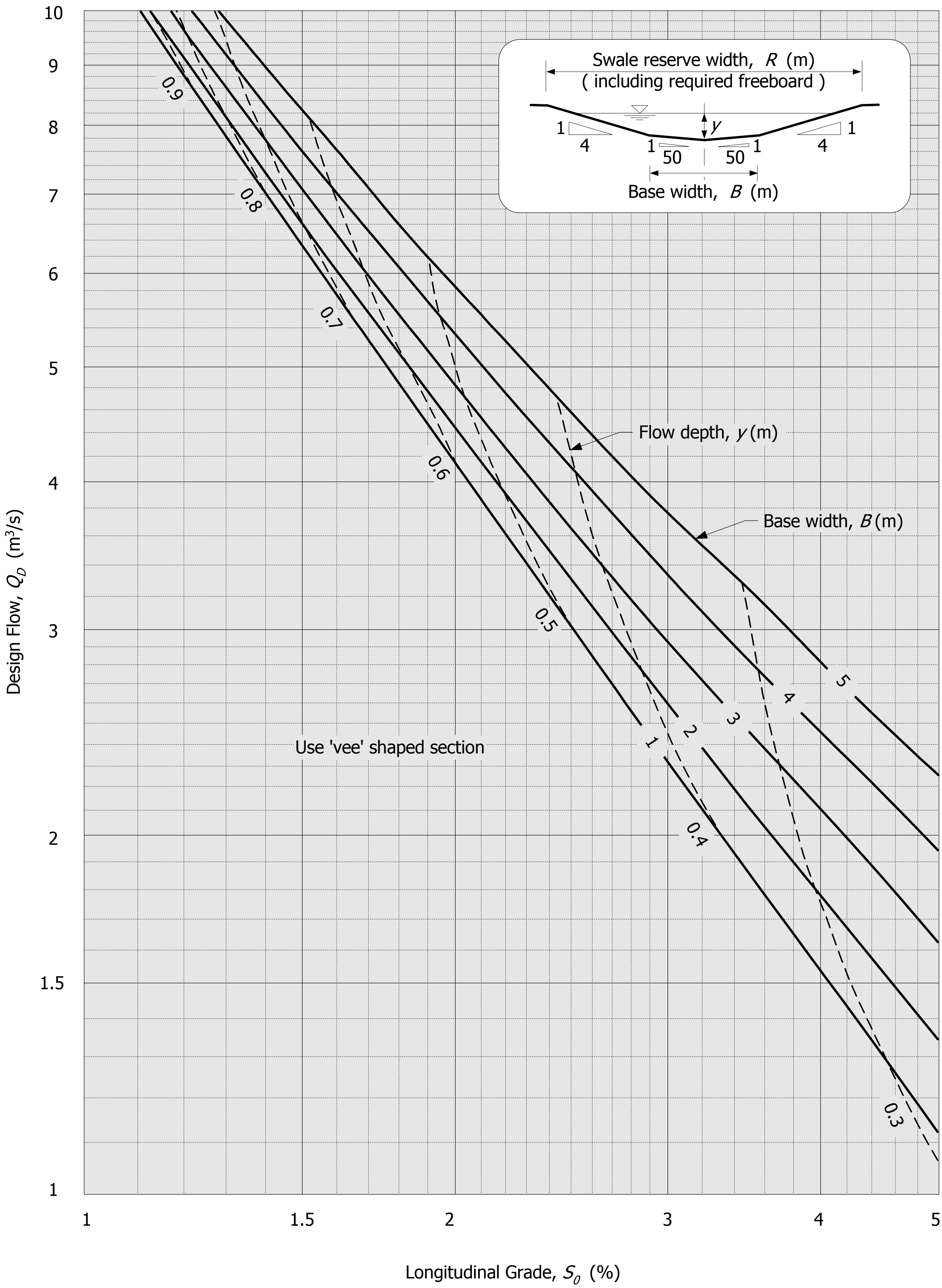
APPENDIX 26.A DESIGN CHARTS

Surface Cover or Finish	Suggested *n* values	
	Minimum	Maximum
Grassed Swales		
Short grass cover	0.030	0.035
Tall grass cover	0.035	0.050
Lined Drains		
Concrete		
Trowelled finish	0.011	0.015
Off form finish	0.013	0.018
Stone Pitching		
Dressed stone in mortar	0.015	0.017
Random stones in mortar or rubble masonry	0.020	0.035
Rock Riprap	0.025	0.030
Brickwork	0.012	0.018
Precast Masonry Blockwork	0.012	0.015

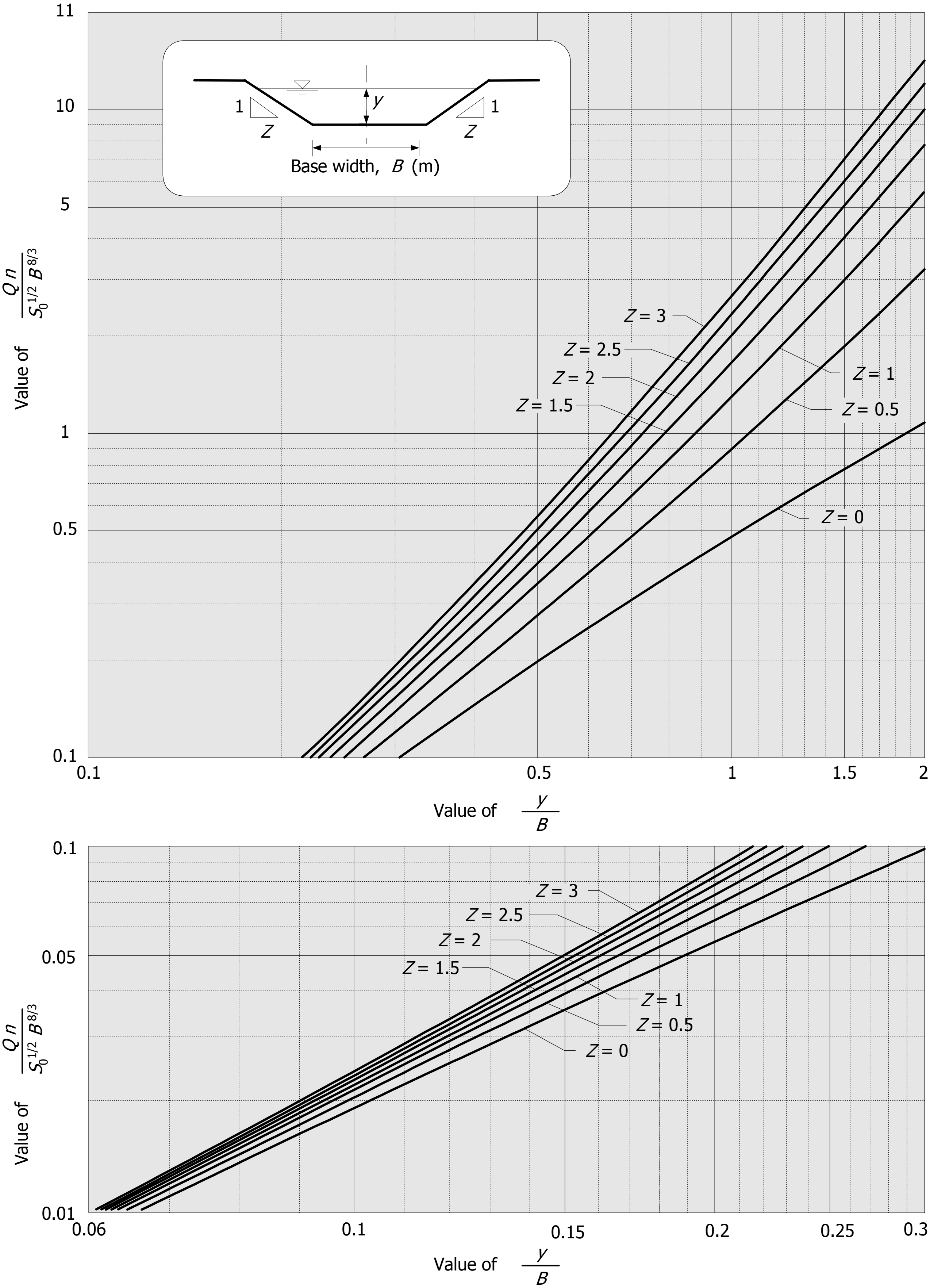
Design Chart 26.1 Suggested Values of Manning's Roughness Coefficient, *n*



Design Chart 26.2 Solution to Manning's Equation for 'Vee' Shaped Grassed Swale of Various Side Slope



Design Chart 26.3 Grassed Swale Base Width – Preliminary Estimate
(Manning's n = 0.035, Average Velocity = 2 m/s)



Design Chart 26.4 Solution to Manning's Equation for Lined Drains of Various Side Slopes

APPENDIX 26.B WORKED EXAMPLE

Problem:

Determine the size of a composite drain to convey a 2 year ARI minor system design flow from a proposed 5 hectare low density housing development in Kuala Lumpur. The post-development time of concentration t_c at the development outlet is estimated to be 10 minutes.

Solution:

Step (1) Determine design flows for the drain

The 2 year ARI rainfall intensity is estimated from Equation 13.3 since t_c is less than 30 minutes.

$$^2P_{10} = {}^2P_{30} - F\left({}^2P_{60} - {}^2P_{30}\right) = 50.18 - 1.28\,x\,(65.02 - 50.18) = 31.18 \text{ mm}$$

$$^2I_{10} = \frac{^2P_{10}}{d} = \frac{31.18}{\left(\frac{10}{60}\right)} = 187 \text{ mm/h}$$

$$^{0.083}I_{10} = 0.4 \text{ x } {}^2I_{10} = 75 \text{ mm/h}$$

Using the Rational Method, with a runoff coefficient C of 0.78 for 2 year ARI and 0.55 for 1 month ARI (Design Chart 14.3, category 5), the design flows are:

$$Q_2 = \frac{0.78\,x\,187\,x\,5}{360} = 2.03 \text{ m}^3\text{/s}$$

$$0.5\,Q_{0.083} = 0.5 \text{ x } \frac{0.55 \text{ x } 75 \text{ x } 5}{360} = 0.29 \text{ m}^3\text{/s}$$

Step (2) Calculate size of lined drain section

1. Manning's n for concrete = 0.013

2. The flow depth may be determined from Design Chart 26.4

Assuming the drain longitudinal slope is 0.5% and the drain width B is 0.6 m:

$$\frac{Q\,n}{S_o^{1/2}\,B^{8/3}} = \frac{0.29 \text{ x } 0.013}{\left(\frac{0.5}{100}\right)^{1/2} \text{ x } 0.6^{8/3}} = 0.21$$

From Design Chart 26.4 with $Z = 0$

$$\frac{y}{B} = 0.51 \qquad y = 0.51 \text{ x } 0.6 = 0.31 \text{ m}$$

Allowing a minimum freeboard of 50 mm, the drain dimensions are 0.6 m wide x 0.36 m deep, which is within the recommended limits given in Section 26.3.3.

3. Check flow velocity is less than upper limit of 2 m/s.

$$V = \frac{Q}{A} = \frac{0.29}{0.6\,x\,0.31} = 1.56 \text{ m/s} \qquad \text{OK}$$

Step (3) Calculate size of total drain section

To calculate the size of the total drain section, a composite Manning's *n* value for the concrete and grass sections needs to be estimated using Equation 28.1. As the flow depth in the total drain section is unknown, the sizing will involve a trial and error process.

Assuming an initial total flow depth of 1.0 m, trial and error calculations are summarised in the following table. Figure 26.B1 shows the flow segments used to calculate the composite Manning's roughness *n**.

y_t (m)	y_d (m)	y_t-y_d (m)	$A_{1\&3}$ (m^2)	$P_{1\&3}$ (m)	A_2 (m^2)	P_2 (m)	n^*	Q (m^3/s)	V (m/s)
1.00	0.36	0.64	1.638	2.639	0.600	1.320	0.029	6.70	1.73
0.75	0.36	0.39	0.608	1.608	0.450	1.320	0.024	2.48	1.49
0.70	0.36	0.34	0.462	1.402	0.420	1.320	0.023	1.96	1.45
0.71	0.36	0.35	0.482	1.432	0.424	1.320	0.023	2.03	1.46

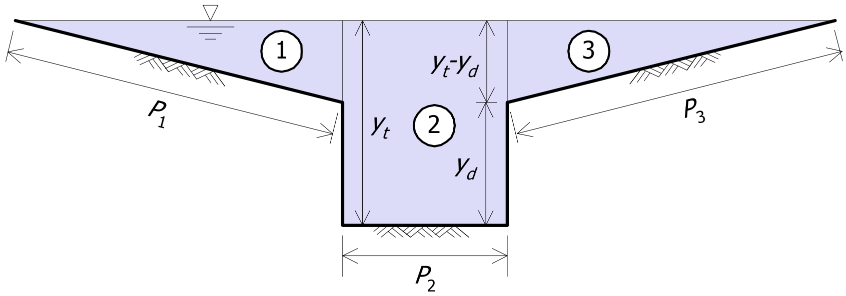


Figure 26.B1 Flow Segments for Calculating Composite Roughness

The total flow depth y_t is 0.71 m with an average flow velocity V of 1.46 m/s, which is less than the maximum allowable average velocity of 2 m/s.

Adding a minimum freeboard of 50 mm, the total drain depth is 0.76 m.

The minimum drainage reserve width is therefore 2 x [(0.76-0.36) x 4] + 0.6 = 3.8 m.

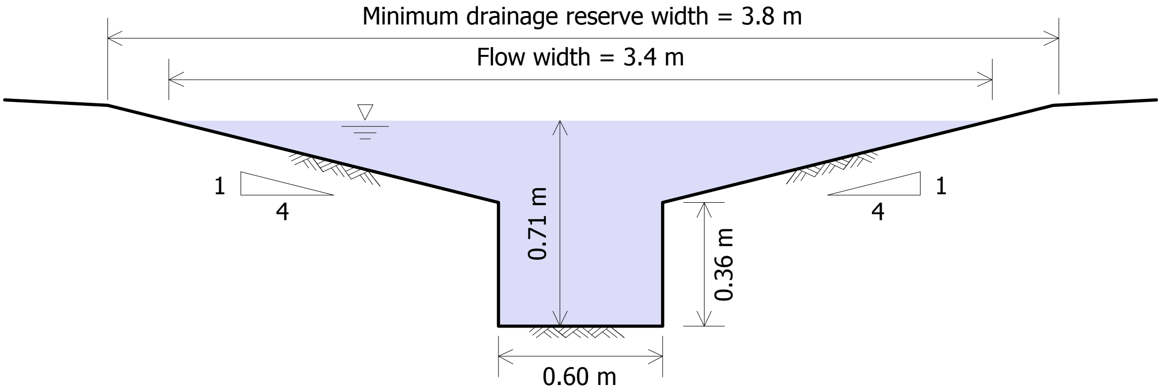


Figure 26.B2 Composite Drain Design Dimensions