# Guidelines for Road Drainage

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# Contents

# *Abstract*

The purpose of this document is to provide guidance for road authorities and other relevant bodies in respect of road drainage. It sets out the legal background in Ireland in relation to road drainage and summarises current practice throughout the country. It outlines some basic methods of drainage design and recommended drainage provisions for different situations. It also sets out general conclusions and good practice guidance. The document is not intended to be a comprehensive design manual for drainage for all new roads but concentrates on the design, rehabilitation and maintenance of drainage systems on regional and local roads. Some of the matters covered will also have applicability for national roads (particularly national secondary roads). The document suggests some basic methods and approaches for drainage design and references other documents for the design of major new schemes and where more rigorous drainage analysis is required.

# Acknowledgement

The Department of the Environment, Heritage and Local Government wishes to acknowledge the role of the Working Group involved in preparing and drafting this document. The members of the group are listed hereunder:

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# 1. Introduction

## 1.1 Aims of document

The purpose of this document is to provide guidance for road authorities and other relevant bodies in respect of road drainage. Chapter 2 sets out the legal background in relation to road drainage and Chapter 3 summarises current practice throughout the country. Chapter 4 outlines some basic methods of drainage design and recommended drainage provisions for different situations. Chapter 5 sets out general conclusions and good practice guidance. The document is not intended to be a comprehensive design manual for drainage for all new roads but concentrates on the design, rehabilitation and maintenance of drainage systems on regional and local roads. Some of the matters covered will also have applicability for national roads (particularly national secondary roads). The document suggests some basic methods and approaches for drainage design and references other documents for the design of major new schemes and where more rigorous drainage analysis is required.

## 1.2 Importance of drainage

It is essential that adequate provision is made for road drainage to ensure that a road pavement performs satisfactorily. The main functions of a road drainage system are:

- To prevent flooding of the road and ponding on the road surface
- To protect the bearing capacity of the pavement and the subgrade material
- To avoid the erosion of side slopes

The principal types of drainage systems are:

Open Drain
Piped (positive) Drain
French drain

The type of road drainage which is selected for a particular road will depend on such factors as to whether it is a rural or an urban road, or if it is in cut or fill and also on groundwater conditions.

Open drains are used to carry away surface water and can also pick up some subsoil water (depending on depth). Open drains facilitate the early visual detection of blockages but their use may be restricted by the lack of roadside space, safety considerations and the risk that they may be closed in by agricultural machinery.

A piped positive drain is normally associated with an urban situation and is used in conjunction with gullies and kerbs/footways. It may also be used in some rural embankment situations where it is deemed important that water from the road and hard shoulder should not be allowed to drain onto the embankment. A piped drainage system with gullies requires regular maintenance.

A french drain is the most commonly used system on newly constructed roads in rural areas. Open jointed pipes are laid in a trench which is backfilled with a porous material. French drains are a useful method of providing both surface water and subgrade drainage where space is limited.

# 2. *Legal Background*

## 2.1 Section 76 of the Roads Act, 1993

Section 76 of the 1993 Roads Act re-enacts in an updated and strengthened form the powers dealing with drainage of public roads and related matters which were previously contained in the Summary Jurisdiction (Ireland) Act, 1851 and the Local Government Act, 1925.

The 1993 Roads Act gives wide powers to road authorities to ensure adequate drainage of public roads. In particular, **section 76** allows a road authority to do the following:

- To construct and maintain drains in, on, under, through or to any land for the purpose of getting water off the road or keeping it off the road
- To use land for the temporary storage of materials
- To take immediate action in an emergency (in normal circumstances notice must be served on landowners)
- To ensure that any drain within 15 metres of the edge of a public road is not scoured, deepened, widened, filled or excavated without its consent (which may be subject to conditions)
- To seek remedial works where a landowner allows water, soil or other material to fall onto the public road from his/her land.

**Section 76** also sets out circumstances where a landowner is entitled to compensation and specifies legal avenues open to him/her where the landowner wishes to appeal a decision of the road authority. A road authority may not act indiscriminately and its actions must be governed by reasonableness and be directly related to the work specified in any notice.

Table 2.1 gives a summary of the 17 subsections contained in section 76 of the 1993 Roads Act.

**Table 2.1**

| Subsection Number | Description |
|---|---|
| 1 | Construct / Maintain drains & use land for temporary storage |
| 2 | Procedures for serving a notice |
| 3 | Emergency works |
| 4 | Compensation |
| 5 | Landowners' responsibilities |
| 6 | Notice to require landowner to do works |
| 7 | Landowners' right of appeal |
| 8 | Powers of District Court |
| 9 | District Court decision cannot be appealed except on a point of law |
| 10 | Effective date of any notice |
| 11 | An offence not to comply with a notice |
| 12 | Direct carrying out of works by Road Authority, if required |
| 13 | Immediate direct carrying out of works by Road Authority |
| 14 | Recovering of costs by Road Authority |
| 15 | Consent of Road Authority required for certain works within 15 metres of road edge |
| 16 | Advance & retrospective serving of notices |
| 17 | Definition of drain |

The following paragraphs set out in more detail the powers contained in the different subsections.

**Subsection 1** permits road authorities to construct or maintain drains to remove water from a public road or to prevent water from flowing onto one. Road authorities may use land for the temporary storage or preparation of road construction or maintenance materials such as gravel, earth etc.

**Subsection 2** obliges road authorities to give at least one month's notice to landowners before going onto any land to carry out drainage works or to temporarily prepare or store road construction materials. The landowner has a right to make objections or representations and these must be considered by the road authority. (Subsection 4 provides for compensation in respect of damage caused to land).

**Subsection 3** gives road authorities power to take action in an emergency such as a landslide, flooding, subsidence etc. where there is a serious hazard to road users or the road itself is being or will be seriously damaged. Wide powers are given to road authorities to prevent or reduce the hazard to road users or damage to the road. It is vital that road authorities be able to act quickly in emergencies without, if necessary, having to give advance notice. Compensation is payable in respect of any damage to land.

**Subsection 4** gives a right to compensation where the carrying out of drainage works, the preparation or storage of road construction materials or thc carrying out of emergency works has caused damage to land. A landowner will not be entitled to compensation in respect of pre-existing damage caused by water draining off a public road, but will be entitled to compensation for any additional damage caused by new works. There is a longstanding right from time immemorial to drain water off a public road.

**Subsection 5** requires landowners to take all reasonable steps to ensure that water is not prevented from draining off a public road into their land and to ensure that water, soil etc. does not escape from their land onto a public road.

**Subsection 6** enables a road authority to serve a written notice on a landowner or occupier requiring him / her to do specified works to ensure that water can drain from a public road onto his/her land or to prevent water, soil etc. from escaping from his/her land onto a public road.

**Subsection 7** gives a person on whom a notice has been served a right to appeal to the District Court against the notice within fourteen days.

A person may appeal on the grounds that he/she is not the owner or occupier of the land in question, he/she may claim that water is or was not prevented from draining off the road, that water, soil etc. is or was not falling onto the road, that the cost of carrying out the required action would be unreasonable or that sufficient time was not given in order to carry out the required action. The question as to what is “unreasonable expense” will have to be determined by the facts of each case.

Notice of an appeal must be given to the road authority and the road authority may plead its case in court.

**Subsection 8** provides that the District Court may, on appeal, affirm, reject or amend the notice issued by the road authority under subsection 6. It is the affirmed or amended notice that will have legal effect.

**Subsection 9** provides that the District Court in whose area the affected public road is located has jurisdiction to hear an appeal against a notice. Any appeal on a matter of fact from the decision of the District Court is precluded. The right of appeal to the High Court on a point of law is not of course denied.

**Subsection 10** states that notice under subsection 6 will not have effect until fourteen days after its service or until the date which the District Court specifies on determination of an appeal. If the Court does not specify a date, the order will come into effect on the date of the Court’s decision.

**Subsection 11** makes it an offence not to comply with a notice under this section. A person guilty of such an offence is liable, on summary conviction under Section 81 of the 1993 Roads Act, to a fine of up to 1,270 or to imprisonment of up to six months, or both. The road authority may prosecute the offence itself.

**Subsection 12** empowers the road authority to carry out the action specified in a notice issued under subsection 6 in a case where the person on whom the notice was served has failed to comply with it. The road authority is also being given the power to carry out reasonable additional remedial works as it sees fit.

This does not give a road authority power to act indiscriminately and its actions must be governed by reasonableness and be directly related to the work specified in any notice.

**Subsection 13** gives a road authority the right to take urgent action where there is an immediate and serious hazard to road users or actual or expected serious damage to the road arising from water being prevented from draining off a public road or from water, soil etc. falling onto a public road. This power can he exercised whether or not a notice has been issued under subsection 6.

**Subsection 14** gives the road authority discretion to recover its costs from the landowner where it takes urgent action under subsection 13 or where it carries out the works specified in a notice under subsection 6, the landowner having failed to do so.

**Subsection 15** prohibits scouring, deepening, widening or filling in drains or excavating new drains within 15 metres of the nearest edge of a public road unless the road authority has given its written consent. The doing of anything which would interfere with a bridge or any other structure (such as an embankment) which carries or supports a public road is also prohibited, unless the road authority gives its written permission.

The road authority may attach conditions, restrictions or requirements to a consent and it will be an offence not to comply.

A road authority may also prohibit certain activities referred to in this subsection where damage has, is being or will be caused to a public road. It is an offence not to comply and the cost of repairing or preventing the damage can be recovered from the person carrying out the activity which was prohibited or from the landowner, except where the local authority had previously given its consent to the activity.

**Subsection 16** makes provision for the service of notices on landowners. The local authority must serve a notice before it enters on land to carry out works under subsection 12. It must, if possible, give prior notice or alternatively the earliest possible notice once it has entered on land to carry out emergency or urgent works under subsections 3 or 13, or remedial works under subsection 15.

**Subsection 17** defines “drain” as ditch, channel, gutter, pipe, tunnel, culvert, soak pit, percolation area or trench for the purposes of this section.

## 2.2 Other procedures for obtaining consent to lay pipes under private land

Other procedures for obtaining consent to lay pipes under private land involve:

(a) acquisition of "way-leaves" in the traditional manner, either under the Public Health (Ireland) Act 1878 or using updated acquisition powers **under Section 213 of the Planning and Development Act, 2000 (preferred method)**

**or**

(b) exercising powers to place pipes in the ground in accordance with the simplified procedures provided for in section 182 of the Planning and Development Act 2000 (i.e., without acquiring "way-leaves").

### Way-leaves

General authority for sanitary authorities to lay water main and sewers through land is provided for in sections 18 and 64 of the Public Health (Ireland) Act 1878. Sections 202/203 of the Act also enable sanitary authorities to acquire land (by agreement or compulsory purchase).

In addition to the acquisition of land per se, the provisions of sections 202/203 have traditionally been applied in the water services sector to the acquisition of "easements" (usually known as "way-leaves") for the purpose of running pipes through land. Such interpretation arises from the inclusion of "easements" in the definition of land under section 2 of the 1878 Act.

Acquisition powers are now also provided for in section 213 of the Planning and Development Act 2000, which provides general authority for local authorities to acquire land, way-leaves or other rights over land or water for the purposes of any of their functions, either by agreement or compulsorily. Section 213(4) of the 2000 Act provides that, where required, CPO procedures would be applied in accordance with section 10 (as amended by section 86 of the Housing Act 1966) of the Local Government (No.2) Act 1960.

### Section 182 of the Planning and Development Act, 2000

Section 182 of the 2000 Act revolves around powers to lay pipes through land rather than the acquisition of way-leaves for this purpose. In addition to this simplified approach, the section also shifts the prerogative on to the local authority, in the face of refusal by a landowner or occupier to provide a definite response, to initiate proceedings to have the position of the landowner or occupier determined.

Under section 182 a local authority is authorised to lay pipes "including water pipes, sewers or drains" through any land, and to access them from time to time for maintenance and renewal. Such action is subject to the consent of the owner and occupier of the land. The local authority may also erect and maintain notices indicating the position of such pipes in any lands.

Section 182(4) provides that a consent "shall not be unreasonably withheld", and, at the initiative of the local authority where it considers that consent is being unreasonably withheld, enables it to appeal to An Bord Pleanála for a determination. If the Board subsequently determines that consent has been unreasonably witheld, it is deemed that the consent has been given, and the local authority is accordingly empowered to proceed with the works in accordance with the provisions of the section.

Compensation is payable in accordance with section 199 of the Act, which provides for restitution where it is shown that the value of an interest in the land is reduced or that a person has suffered damage by being disturbed in his or her enjoyment of the land. Detailed procedures on compensation are set out in Part XII, Chapter 1 of the Act.

### Distinction between section 182 and the acquisition of way-leaves

It should be noted that section 182 of the 2000 Act does not confer on a local authority any power to acquire a way-leave or land. Section 182 confers only the power to run a pipe and any ancillary apparatus through a stretch of land, and accordingly, its operation would not result in a burden being registered on the landowner's title.

Where a section 182 procedure is used, it is essential to avoid reference to acquisition of way-leaves in any related documentation or notification. Such a purpose is beyond the scope of the section, and such reference could undermine or invalidate any subsequent appeal taken by the authority.

## 2.3 Provision of a Culvert on a Watercourse

Section 50 of the Arterial Drainage Act, 1945 states that a local authority shall not construct any new bridge/culvert or alter, reconstruct, or restore any existing bridge/culvert over any watercourses without the consent of the Commissioners of Public Works. The Act states that watercourse includes rivers, streams, and other natural watercourses, and also canals, drains, and other artificial watercourses. Where consent is given by the Commissioners then the works should be carried out in accordance with any plans which have been approved of by the Commissioners. Where a local authority claims that the Commissioners have unreasonably refused the approval of plans for the construction of a new bridge or the alteration, reconstruction, or restoration of an existing bridge such claim shall be referred to the (now) Minister for the Environment, Heritage and Local Government. The Minister's decision shall be final.

The Office of Public Works (OPW) has produced a guidance document entitled: *Guide On Information To Accompany Applications For OPW Consent For Bridges And Culverts* [1]. This document sets out the OPW's assessment criteria for bridges and culverts. It is primarily concerned with bridges and culverts on rivers and streams which have associated catchment areas. In such cases, it recommends a minimum culvert diameter of 900mm to ensure accessibility for future maintenance and to reduce the risk of blockages. The OPW is also concerned with any effects that a bridge/culvert will have both upstream and downstream of its location. The OPW is not concerned with the detailed drainage design (longitudinal drainage, manhole details etc.) for a road scheme. However it must be consulted where a proposed road scheme will intercept a river or stream or canal and it sets out in its guidance document factors which must be assessed and taken into account.

Where a culvert is to be provided on a watercourse which supports or has the potential to support fish life then the relevant Fisheries Board should be consulted and appropriate measures incorporated into the scheme (see Fishery Guidelines for Local Authority Works [2] as published by the Department of the Marine and Natural Resources for further information)

# 3. Current Practice

In order to determine the maintenance practices and the types of drainage systems in use throughout the country a questionnaire was sent out to the major road authorities. Completed replies were received from 23 authorities and these replies came from both urban and rural road authorities. The results were collated and are set out in Figures 3.1 and 3.2 and in Table 3.1.

The survey indicated that existing road drainage systems use a mix of open drains, pipes and french drains depending on road circumstances. The maintenance of these systems is variable and in general most counties indicate reservations about the adequacy of current maintenance arrangements. The separate forms of drainage systems in common use are considered briefly in this review of current practice.

## 3.1 Open Drains

Open drains are the most common form of road drainage on rural national and non-national roads. Maintenance practice from the data available indicates various levels of attention to the open drain system. Opening of drainage inlets and/or total removal of road margin, to ensure rapid removal of road surface water, appears to be common practice. However, frequency of inlet opening is perceived to be inadequate in many circumstances. Open drains have the advantage of being easily inspected for blockages and are also effective at draining the road subgrade provided the drain flows to an adequate outfall. Open drains are generally, but not always, within the road limits. In circumstances where open drains are on private property the Authority's powers under the Roads Act should be exercised to ensure that drainage is not interfered with. The review suggests that drains outside the road limits may not be receiving adequate attention.

## 3.2 French Drains

French drains are used extensively on sections of the national network and to a limited extent on non-national roads. The drains generally include pipe work in conjunction with stone media. Maintenance levels are low and this may affect the long term performance. In most instances maintenance is carried out as problems manifest themselves, with few counties having an annual maintenance programme.

## 3.3 Piped Drainage

Piped drainage systems are essential in urban areas and are also used in rural areas where space is limited. Piped systems can be sealed or open-jointed. The normal practice is to use sealed systems in urban areas and open-jointed systems in rural areas. Piped systems with gullies require regular maintenance and while in many instances these systems are cleaned annually the data received suggests that the frequency of maintenance is generally considered inadequate

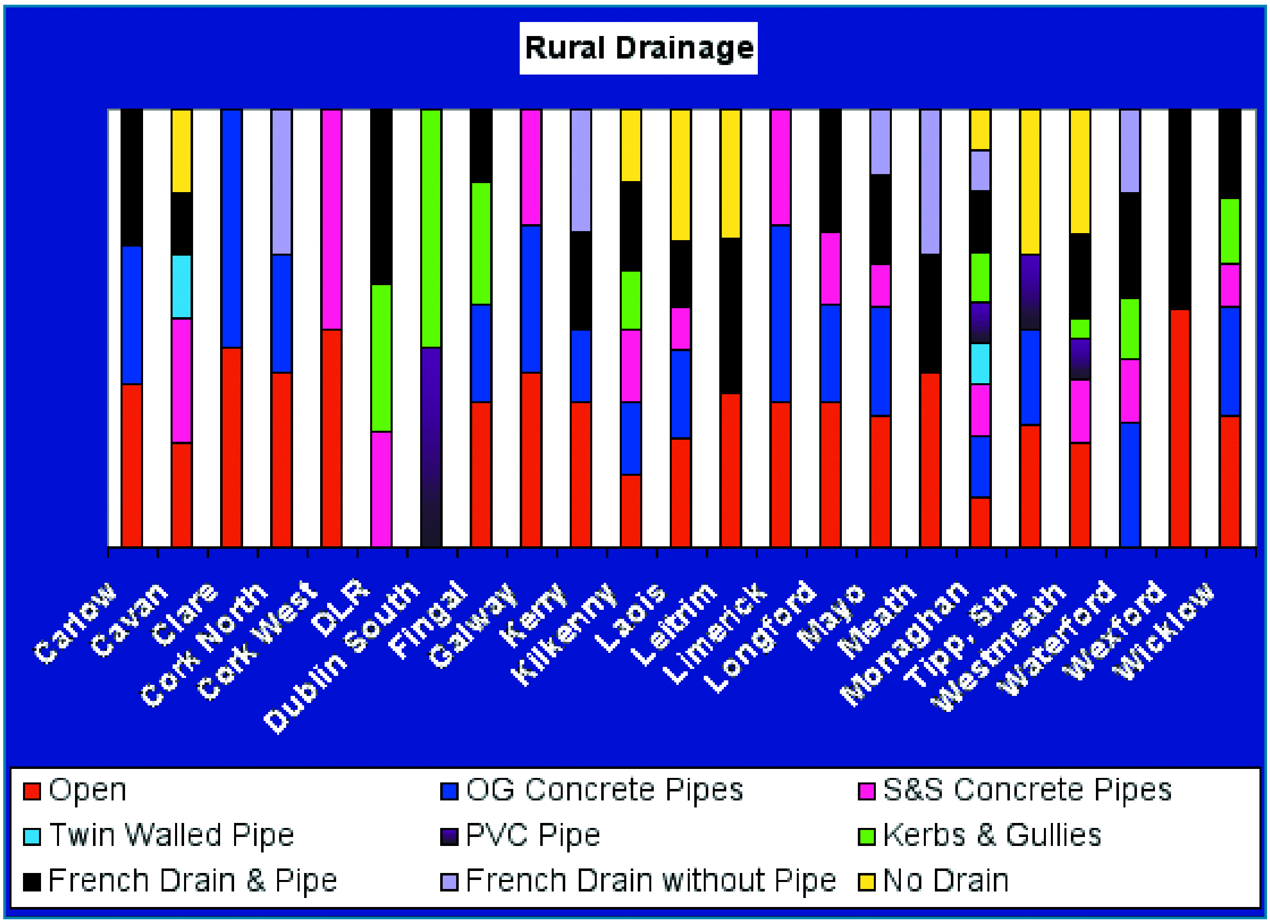



**Fig: 3.1 Rural Drainage Systems**

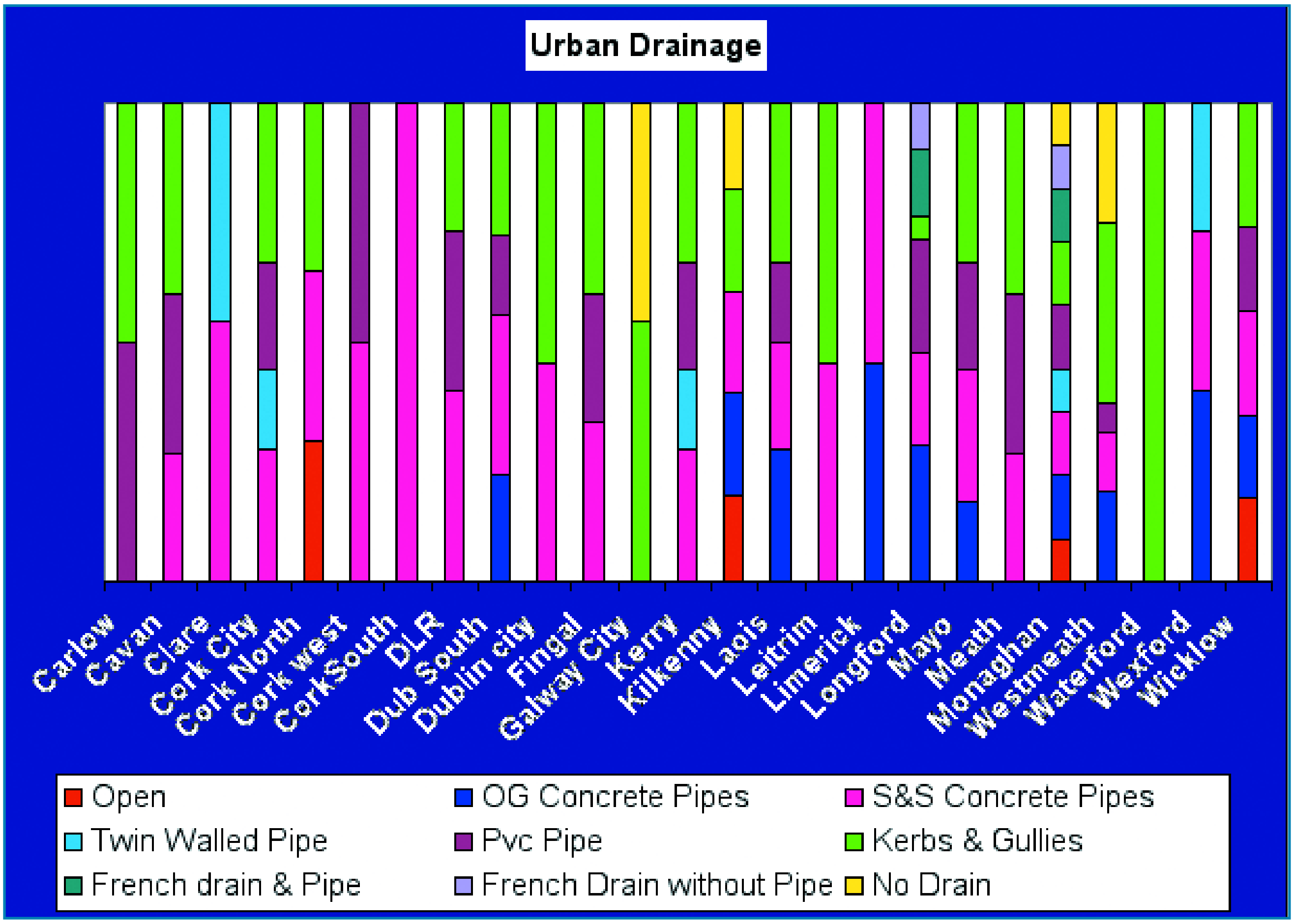



**Fig: 3.2 Urban Drainage Systems**

**Table 3.1 Types of Maintenance Systems**

| | Open Drain | Inlet/ watercuts | Piped Drains | Gullies | Culverts | French Drain |
|---|---|---|---|---|---|---|
| Carlow | JCB | JCB | JCB | suction | | |
| Cavan | Ditchmaster | | rodding | suction | | |
| Clare | JCB | JCB | rodding | man / Suc | | |
| Cork City | | Visual Insp | Jet / rodding | Man / Suc clean | Occ. Insp. | |
| Cork Nth | JCB | JCB | JCB | Man / JCB / Suc | Man / JCB | JCB |
| Cork West | JCB | JCB | Jet / Rod | Suction | Manpower | |
| Cork South | Manpower | | Contract | Direct Lab | Contract | |
| DLR | JCB | JCB | HPC | HPC | Manpower | Special machine |
| Dublin City | | | HPC | Suction cleaner | | |
| Dublin South | JCB | JCB | | HPC | | Replace Material |
| Fingal | JCB | JCB | HPC | Man / Suc. Clean | Manpower | JCB |
| Galway | JCB | JCB | rodding | Suction | | |
| Galway City | | JCB | HPC | Man / Suc.Clean | | |
| Kerry | JCB | JCB | rodding | Suction | rodding | JCB |
| Kilkenny | JCB | JCB | HPC | HPC | HPC | HPC |
| Laois | JCB | JCB | Jetter / rod | Suction | Manpower | |
| Leitrim | JCB | JCB | rodding | Suction | rodding | weedkiller |
| Limerick | JCB | JCB | HPC | Suction sweep | | |
| Longford | JCB | JCB | Suc / H.P | Suc / H.P | | |
| Mayo | JCB | JCB | HPC | Man / suc.sweep | Manpower | H.P Rod |
| Meath | JCB | JCB | Jetter | Manpower | Jetter | Manpower |
| Monaghan | JCB | Manpower | HPC | Suction cleaner | Man / JCB | HPC |
| Tipp Sth | JCB | JCB | | Manual | Man / JCB | |
| Waterford | JCB | JCB | HPC | man / suction | Manpower | Manpower |
| Westmeath | JCB | JCB | HPC | Man / Suc.sweep | Man / JCB | HPC |
| Wexford | JCB | JCB | HPC | Suction cleaner | manual | |
| Wicklow | JCB | JCB | HPC | Man / Suc clean | Man / HPC | JCB |

**HPC - High Pressure Cleaner**
**Suc - Suction sweeper**
**Man - Manual**
**Occ. Insp - occasional inspection**

The use of twin-walled pipes is growing with most counties appearing to favour the use of these pipes for ease of handling.

Piped systems require gullies and inspection chambers. The type of chambers used varies, with some counties using mainly precast units and other counties preferring to use block chambers. In general the adequacy of gully cleaning schedules is felt to be unsatisfactory.

Some examples of good and bad practice are shown in Photo Nos. 3.1 to 3.4

**Photo 3.1 Gully is too far from kerb**

**Photo 3.2 Poor Maintenance – Grating is barely visible**

**Photo 3.3 Side entry gully – facilitates cyclists**

**Photo 3.4 Lockable Gully (should use for new installations)**

## 3.4 Culverts

Road culverts would appear, from the data collected, to be neglected to a large extent with a very poor maintenance regime. Sometimes this can result in the collapse of a culvert.

## 3.5 Plant and Equipment

Open drainage systems and water inlets are almost exclusively maintained using manual labour and also using 180º rubber wheeled hydraulic excavators (e.g. a JCB - see Photo no. 3.5). Specialised equipment such as the 'ditchmaster' (see Photo no.3.6) is used in only one county. The "ditchmaster" is a purpose built machine which is used for cleaning open drains. The survey indicates that 360º rubber wheeled hydraulic excavators ("rubber ducks" – see Photo 3.7) are used infrequently.

Piped drainage systems and gullies are cleaned using a combination of suction, jetting and rodding. Gullies are also cleaned manually.

The maintenance of culverts is carried out using a combination of manpower and 180º rubber wheeled hydraulic excavators. In some instances this work has been contracted out.

French-drain maintenance includes annual weed control in some counties, use of 180º rubber wheeled hydraulic excavators and specialised equipment including rodding and jetting. Practice is very varied throughout the country.

## 3.6 Conclusion

Drainage maintenance practice based on the data received is variable. The general response suggests a dissatisfaction with the adequacy of maintenance. In almost all cases there is no specific allocation for road drainage. Drainage is included in the general road budget and consequently does not have the priority which would be desirable for a well maintained system.

**Photo 3.5 180 degree rubber wheeled hydraulic excavator**

**Photo 3.6 “Ditchmaster”**

**Photo 3.7 360 degree rubber wheeled hydraulic excavator**

# 4. *Design of Road Drainage Systems*

## 4.1 Effect of Drainage Requirements on Road Geometry

Drainage is a basic consideration in the establishment of road geometry and in general this means that:

(a) crossfalls should be a minimum of 2.5% on carriageways, with increased crossfalls of up to 5.0% on hard shoulders draining to filter drains;

(b) longitudinal gradients should not be less than 0.5% on kerbed roads;

(c) flat areas should be avoided and consideration of surface water drainage is particularly important at rollovers, roundabouts and junctions;

(d) outfall levels must be achievable;

(e) the spacing of road gullies should be sufficient to remove surface water whilst achieving an acceptable width of channel flow. One gully for every 200sq. m of paved surface is generally found to be satisfactory, however, reference should be made to U.K. Highways Agency Advice Note HA 102/00 for more detailed information on the spacing of road gullies.

DMRB Standard HD 33/96 (as amended by NRA Addendum to HD33/96) contains guidance to minimise problems in shedding water from carriageways and outlines the minimum standards of road geometry which the drainage designer would generally expect.

## 4.2 Types of Drainage Systems

Various types of drainage systems are available and the main types are briefly described as follows:

### Kerbs and Gullies

Road surface drainage by kerbs and gullies is commonly used in urban areas and in rural embankment conditions. Surface water flows over the pavement to a kerb at the edge of the road and is collected in gullies which are connected to longitudinal carrier drains set within the road verge. The carrier drain may be a sealed pipe for the collection of surface water only (separate system), or a perforated or open jointed pipe may be used in order to convey both surface water and subsoil water to the outfall (combined system). The gully can be located at the edge of the road pavement, or can be inset into the verge as indicated in photo 4.1. Alternatively a side entry gully can be used as shown in photo 4.2.

### Combined Kerb and Drainage Block (see Photo 4.3)

These are precast concrete units either in one piece or comprised of a top and bottom section. A continuous closed internal channel section is formed when contiguous blocks are laid. The part of the unit projecting above the road surface looks like a wide kerb and contains a preformed hole on its front face which admits water into the internal cavity. These units are especially useful where kerbs are necessary at locations with little or no longitudinal gradient. They can also be useful where there are a number of public utility services in the road verge, particularly in urban areas.

**Photo 4.1 Kerbs & Gully (inset into verge)**

**Photo 4.2 Side Entry Gully**

**Photo 4.3 Combined Kerb and Drainage Block**

**Photo 4.4 Linear Drainage Channel**

### Linear Drainage Channels (see Photo no. 4.4)

Linear drainage channels can be precast or formed in situ. They are set flush with the surface and contain a drainage conduit beneath the surface into which the surface water enters through slots or gratings. When used on shallow gradients they are prone to maintenance difficulties.

### Surface Water Channels (see Photo no. 4.5)

Surface water channels are normally of rounded or triangular concrete section, either slip-formed, cast or precast and set at the edge of the road pavement and flush with the road surface. Significant benefits can include ease of maintenance and the fact that long lengths can be constructed quickly and relatively inexpensively. Channel outlets can be located at appreciable spacings and possibly coincident with existing watercourses. However, roads with flat longitudinal gradients may necessitate discharge of channels fairly frequently into outfalls or parallel longitudinal carrier pipes in order to minimise the size of the channels.

Photo 4.5 Surface Water Channel

Photo 4.6 French Drain

**Combined Surface and Ground Water Filter Drains (French Drains) - see Photo no. 4.6**

Open jointed, porous or perforated pipes are laid in a trench which is backfilled with a porous media. These trenches are situated in verges adjacent to the low edge of the road pavement. Surface water runs off the carriageway and enters the top surface of the trench, passing through the filter material and into the pipe at the base of the trench. Pavement and capping layers must be contiguous with the side of the trench so that any water within these layers is also collected by the drain. The subsurface water drains through the porous media in the trench and into the open joints or perforated top surface of the pipe. The grading of the filter material is important and must be specified correctly to prevent silting-up of the drain. The filter drain may be enclosed by a geotextile sock to further limit the silting-up of the drain.

### Over-the-Edge Drainage (see photo no. 4.7)

This method of drainage is applicable to embankment conditions where the embankment is constructed of free draining material. It is not appropriate on embankments constructed of silty or clayey, moisture susceptible soils.

### Open Drains (see Photo no. 4.8)

Open drains are used to drain surface water and to act as interceptors for seepage water, including sub-soil water. The use of open drains may be restricted for reasons of safety and of maintenance. They are often used, however, at the bottom of embankments and as intercepting channels at the tops of cuttings. Open drains should be located a suitable distance from the edge of the road pavement to ensure that water does not seep back into the road foundation.

A lot of rural roads are drained by “inlets” (see Photo no. 4.9) which comprise shallow channels excavated across verges to allow drainage from road edges to roadside open drains. Inlets require regular maintenance as they are prone to rapid build up of silt and blockage by debris or vegetation growth. An inlet can be formed with a concrete base to reduce maintenance and improve serviceability.

**Photo 4.7 Over the Edge Drainage**

**Photo 4.8   Open Drain**

**Photo 4.9  Inlet (with concrete base to reduce maintenance)**

Table 4.1 sets out appropriate usages of the alternative drainage methods in respect of urban roads, major rural roads and minor rural roads.

Table 4.2 is a selection chart for Urban situations and Table 4.3 is a selection chart for Rural situations. Both charts make reference to various detailed drawings which illustrate different drainage systems as set out in Drawings 1 to 9.

**Table 4.1 Applications of different Drainage Systems**

| Road Type | Kerbs & Gullies | Combined Kerb & Drainage Blocks | Linear Drainage Channels | Surface Water Channels | Combined Surface and Ground Water Filter Drains | Over the Edge Drains | Open Drains |
|---|---|---|---|---|---|---|---|
| URBAN ROADS | General usage | Congested public utility services<br><br>Shallow outfalls<br><br>Flat longitudinal gradients | Car park areas<br><br>Adjacent to vertical concrete safety barrier<br><br>Nosing of interchanges | Not generally applicable | Applicable where ground water problems exist. | Not generally applicable | Not generally applicable |
| MAJOR RURAL ROADS | Footways within road verge e.g. lay bys<br><br>Roundabouts | Flat longitudinal gradients where footways are within road verge<br><br>Roundabouts | Adjacent to vertical concrete safety barrier<br><br>Nosing of interchanges | High speed roads especially on embankments | In verges in cuttings<br><br>Edge strengthening / widening | In verges on embankments | General usage<br><br>Cut-off drains |
| MINOR RURAL ROADS | Not generally applicable | Not generally applicable | Not generally applicable | Not generally applicable<br><br>Edge strengthening / widening | In verges in cuttings | In verges on embankments | General usage |

**URBAN APPLICATION**
**Kerbs (with gullies) Required**

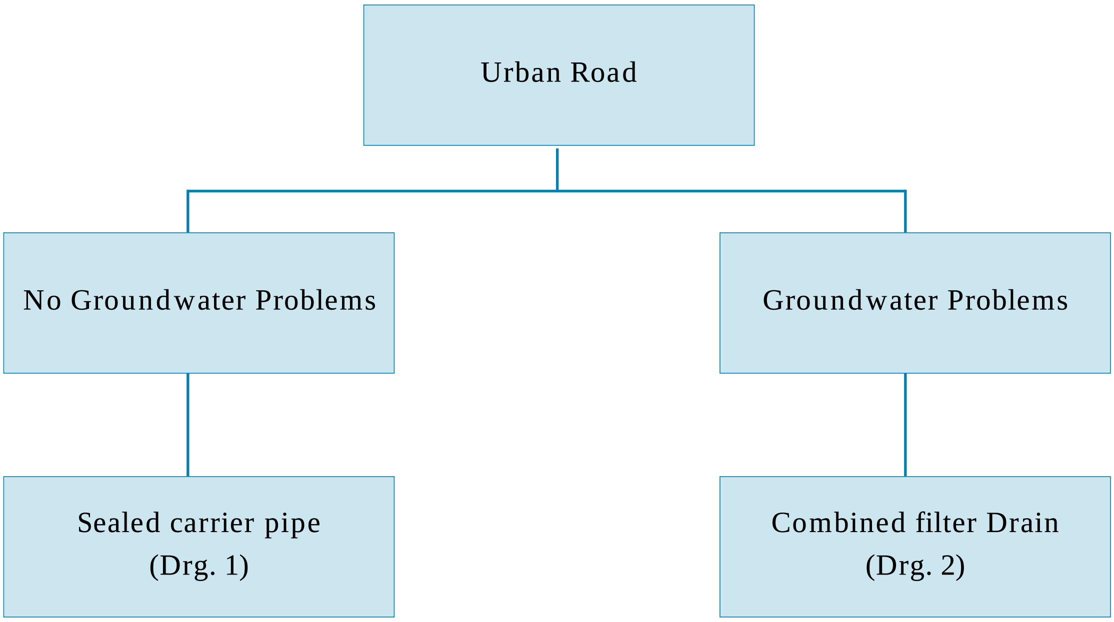
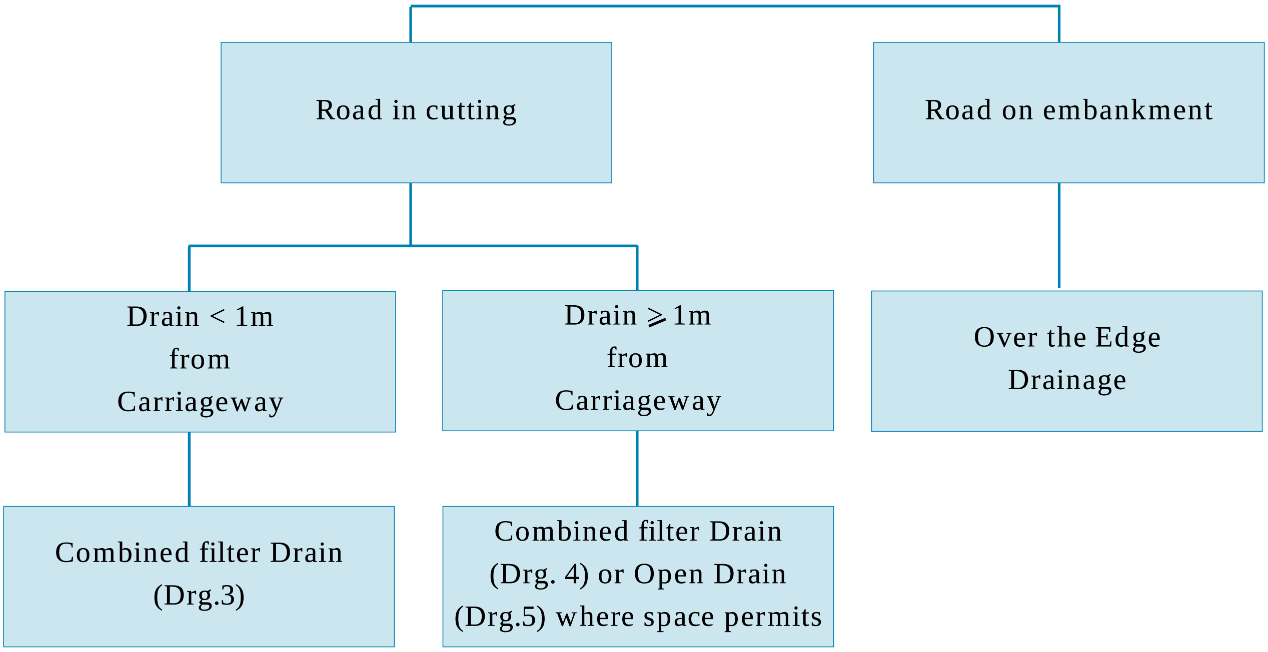



**Table 4.2 Recommended Design Selection for Urban Road Drainage**

**RURAL APPLICATION**




Note: 1. For road widening, where the drain is under the new carriageway, refer to Drawings 6(a) and 6(b).

2. Where a Feotextile membrane is being installed refer to Drawing 7.

**Table 4.3 Recommended Design Section for Rural Road Drainage**

## 4.3 Design of Surface Water Drainage

The quantity of water to be drained will depend on a number of variables, i.e. the intensity, duration and frequency of the rainfall, together with the size and type of the area contributing the run-off. The shorter the duration of a storm, the higher the intensity of the rainfall, as a general rule. Design is normally based on the rainfall intensity of short intense storms occurring during summer, which usually overload the drainage system more than the steady but less intense rainfall which occurs during the winter. The latter may be important, however, where the unpaved area drained is much greater than the paved area.

As a simplified ‘rule of thumb’ where a drain serves only a paved road surface, a 225mm diameter pipe will be sufficient up to a length of 200 m in most cases.

Where pipe sizes up to but not exceeding 600mm diameter are envisaged the ‘Rational’ (or Lloyd Davies) method may be used to determine the peak run-off. An advantage of this method is that it does not require computer application and it remains a valid procedure for design sizing of small pipe drainage systems. The basic principles of the Rational method are set out below, however, it is recommended that the second edition of Road Note 35 (1976) [3] should be referred to for a more detailed explanation of this procedure.

The TRRL unit hydrograph method is also described in Road Note 35 and gives more accurate results than the Rational method, but requires computer application. The Wallingford Procedure was published in 1981 and comprises a number of methods which incorporate research undertaken since publication of the earlier Road Note 35. Where possible, the Wallingford Hydrograph Method and Wallingford Simulation Method should be used for new major road schemes as they are considerable more accurate that the Rational or TRRL methods, leading to more economical designs. A number of commercial programs based upon the Wallingford Procedure are available and suitable for road drainage design.

The intensity of rainfall can be determined from rainfall records (Rational method) or by assuming values found to be adequate from experience (empirical approach).

The Rational approach to rainfall intensity is applicable where sufficient data in the form of rainfall records, giving frequencies and intensities of storms over a period of at least fifty years are available for a particular location. This approach is beyond the scope of these guidelines and for further details reference should be made to Road Note 35.

An empirical approach to rainfall intensity [4] is based on the premise that for the drainage of paved areas it is sufficiently accurate to take the following value for rainfall intensity:

(i) where the time of concentration is less than 10 minutes, assume a rainfall intensity (r ) = 38mm/hr

(ii) where the time of concentration is greater than 10 minutes, assume a rainfall intensity (r ) = 25mm/hr

The time of concentration ($t_c$) is obtained by adding together the time of entry ($t_e$) and the time of flow ($t_f$) for a particular length of pipe. In this country a time of entry of 3 minutes would appear adequate for rural roads with piped French drains. The time of flow will depend on the velocity of flow and this in turn depends on the size, gradient and roughness of the pipe. Having estimated a suitable pipe size the hydraulic flow chart (Fig B.2) in Appendix B can be used to find the velocity of flow. This chart uses the Colebrook-White formula for velocity of flow (recommended by TRRL) and assumes a roughness coefficient of 0.3mm, which is a typical value for a concrete pipe. The time of flow (length of time to travel in the pipe length under consideration) is calculated from full pipe velocity.

To determine the quantity of run-off to be disposed of, the simplified Rational formula is used.

$$Q = \frac{(A_p \times r)}{360}$$

Where Q = quantity of run-off (cu. metres/sec)

$A_p$ = impermeable area to be drained (hectares)

(1 hectare = 10,000 sq. m)

r = rainfall intensity (mm/hr)

The following parameters are recommended:

- the surface area contributing to the flow in the pipe should be taken to be 100% of the paved surfaces directly connected to the drainage system, such as road carriageways, paved shoulders and footpaths;
- in cuttings 70% of the plan area of the cutting slope is deemed to contribute to the flow in the pipe (departure from Road Note 35);
- the run-off from unpaved areas other than cuttings, e.g. flat grass verge and adjacent fields, is taken as zero;
- when a small stream is allowed to enter a piped drainage system, it will of course be necessary to take the resulting flow into account.

Having calculated the quantity of run-off, the size of the pipe required can be determined from the hydraulic flow chart (Fig. B.2) in Appendix B (for pipes with a roughness factor of 0.3mm). If the size of the pipe so determined is similar to that assumed when calculating the time of flow, no further calculation is required. If it differs from that originally assumed, the procedure of calculating the time of flow and the time of concentration, and determining the related intensity of rainfall, is repeated for the next largest size of pipe. Normally, it is unnecessary to go through more than two series of calculations.

A detailed example of the procedure for the design of surface water drainage for a rural road, similar in principle to that given in Road Note 35, is given in Appendix B.

## 4.4 Design of Subsurface Water Drainage

The main purpose of sub-surface drains is to control the level of groundwater and to remove any water which may permeate through the road pavement layers in both cut and fill situations. The main factors giving rise to the need for sub-surface drains are:

(i) entry of surface water through porous or defective surfacings on the carriageway and hard shoulder;

(ii) changes in the level of the water table under the road;

(iii) seepage of water under the road from adjoining higher ground;

(iv) seasonal transfer of moisture between the verge and the subgrade.

As a first step to analysing the various factors which may govern the need for sub-surface drainage in an area, a site survey should be carried out. Data from the initial site investigation for the route selection, if available, may be sufficient. The experience and knowledge of an engineer familiar with the site, together with some visual observations, will be sufficient in many cases.

The survey should:

- classify the soil type and note the thickness of strata;
- note the average water table level and any variations;
- note the catchment area, natural drainage of adjoining lands, springs, existing ditches and land drains.

It is desirable to determine water-table levels and seepage characteristics between late winter and early spring, when the water table is at its highest level and the sub-soil is at its wettest. Having carried out the investigation, the necessity for sub-surface drains on the site can be determined.

It is extremely difficult to estimate the quantity of sub-soil water to be drained because of the variability that is likely to occur in the strata through which the drains operate. The quantity of water flowing from springs and land drains can, however, be measured fairly easily. Normally, the volume of flow of sub-soil water is of an extremely small order, except where it originates from springs and land drains. Where a combined surface and sub-surface drainage system is used, the design size of the pipe to cater for surface water run-off will be sufficient for sub-soil water, other than flow from springs or land drains. Where a separate system is used it is usual to install a 100 mm diameter pipe for sub-soil drainage.

## 4.5 Disposal of Drained Water

### Outfalls

The preferred method for the disposal of drained water is via outfalls to existing ditches and watercourses. Discharge should always be in the direction of flow of the river or stream. Protection of the bed and edges of the watercourse at the point of entry (by means of rock armour, gabions, headwalls etc.) will help to prevent erosion by water discharging from the pipe during heavy storms.

The legal position in this country in relation to the discharge of water from public roads into adjoining lands is set out in Chapter 2 of this guideline document.

### Soakaways

In some locations difficulties can sometimes be experienced in finding a convenient outfall to which a roadway can be drained. In such circumstances it may be possible, if the subsoil conditions are appropriate, to dispose of run-off water to a soakaway. A soakaway provides an arrangement whereby surface water is removed by allowing it to soak into the soil. It consists of a pit into which the water is allowed to drain and through whose sides and floor the water may percolate to the surrounding ground. Some means of supporting the sides of the soakaway are necessary and this may consist of a porous lining of open-bonded concrete blockwork, or alternatively, the pit may be filled with hardcore.

The ability of a soakaway to perform satisfactorily depends on its size and the nature of the soil in which it is built. Soakaways should only be used in free-draining granular soils such as gravel or sand. If the water table is near the surface of the ground, or if the soil is relatively impervious (e.g. clay), the soakaway will not function. In ground with low permeability, it is necessary to provide storage capacity to retain the flows during prolonged or heavy rainfall. Where any doubt exists as to the suitability of the ground it will be necessary to obtain permeability figures by test. BRE Digest 365 [5] describes a simple test for the measurement of rate of percolation into the ground which is then used to determine the size of the soakaway for the area to be drained. This Digest also describes design and construction procedures for soakaways and gives some design examples.

Some road authorities are unwilling to accept soakaways as a means of draining the public roadway and for large paved areas they are not an attractive option. It is recommended that all efforts should be made to dispose of surface water to the nearest watercourse rather than to use soakaways.

## 4.6 Culverts

In the construction of new roads it is frequently necessary to culvert existing watercourses passing across the line of the roadway. The most common materials used for new culverts include concrete pipes, concrete box sections, and corrugated steel pipes and arches. Materials used for older culverts include brick, masonry and cast iron.

To calculate the optimum dimensions of culverts it is necessary to be able to estimate peak run-offs, usually without the help of any previous stream recordings. A simple method of estimating flood flows from natural catchments was developed by the Transport and Road Research Laboratory in the U.K. and is described in their Laboratory Report LR 565 [6].

Determining the hydraulic characteristics of a culvert can be complex because of the large number of flow conditions that can occur. The lack of an accepted standard design procedure has resulted in cases of over-design, which raises costs, under design, which can cause flooding, and poor detailing. The Construction Industry Research and Information Association (CIRIA) have produced Report 168 “Culvert Design Manual” [7] in 1997 which gives clear and concise guidelines for the hydraulic design of culverts. The report is intended for use by engineers who do not have specialist knowledge of hydraulics and provides an overall design process for new culverts, and information that can be used to analyse and assess existing culverts.

For guidance on the structural design of culverts the following DMRB standards (and associated NRA Addenda) should be referred to:

Concrete pipes > 900mm diameter
– BD 82/00 Design of Buried Rigid Pipes

Concrete box culverts

– BD 31/01 The Design of Buried Concrete Box and Portal Frame Structures

Corrugated steel pipes/arches

– BD 12/01 Design of Corrugated Steel Buried Structures

## 4.7 Materials and Testing

Various types of materials are referred to in this document and in particular in Drawing Nos. 1 to 9. Such references (e.g. Clause 804 sub-base material, Clause 503 bedding material etc.) refer to the National Road Authority's Manual of Contract Documents for Road Works, Volume 1 (entitled Specification for Road Works). Associated laying, compaction, testing and other requirements for such materials are also referenced in the National Road Authority's Specification for Road Works.

# 5. Recommendations

Road Authorities should periodically review the adequacy of road drainage systems under 2 headings:

1. Maintenance of existing road drainage systems

2. Improvement works which are required to bring the road drainage system up to an acceptable standard

Deficiencies in road drainage should be identified and ranked in order of priority as part of the normal maintenance programme. Where remedial treatments to road pavements are being carried out any deficiencies in road drainage must be addressed prior to or in conjunction with the pavement improvement works.

Where there is adequate space between fences open drains are the preferred option. In places where space is limited and there are safety considerations piped drains should be provided. In situations where traffic will (or is likely to) travel over a piped drain a load bearing pipe must be used.

Road authorities should consider providing a specific budget on an annual basis for both drainage maintenance works, drainage improvement works and for the maintenance/repair of culverts and bridges.

Road authorities should also aim to employ drainage inspectors who would monitor and report on required drainage maintenance works.

## 5.1 Maintenance issues

### Open drains

- Need to maintain existing inlets. The concreting/piping of inlets can help to reduce maintenance

- Check if additional inlets are required

- Need to clean out open drains by using manpower/ machine/ suitable chemical spray. Where feasible, mechanical plant/equipment should be used to expedite the cleaning out of inlets

### Piped drains

- A programme for cleaning out of road gullies is essential
- Checking that pipelines are clear
- In the case of french drains the need to ensure that the filter material is operating satisfactorily
- Where french drains are adjacent to major roads the top 300 mm of filter media usually requires replacing after 10 years and the maintenance programme for such drains should reflect this

### Entrances

- Ensure that an adequate pipe size (as specified by the road authority) is provided at all new entrances.
- Ensure that all pipes laid at entrances are functioning properly
- Ensure that surface water does not discharge onto the public road
- Construct a suitable interface at the boundary of the road pavement/ hard shoulder and the driveway entrance (e.g. see Drawing No. 9)

## 5.2 Drainage Improvement works

- The first requirement when examining any road drainage system is the identification and examination of the adequacy of the outfall. The effects of any pattern of flooding in respect of an outfall must be given careful consideration.
- **All pipes should be laid to line and level. The use of a laser can assist in achieving appropriate standards.**

- The installation of screens on the upstream side of culverts should only be considered where a watercourse does not support or have the potential to support fish life. Where screens are installed then regular inspections and maintenance must be carried out.

- Road drainage systems should be designed in accordance with chapter 4 of this document. The minimum pipe diameter which should be used for longitudinal drains is 225 mm.

- A transverse pipe should generally have a minimum diameter of 600 mm. Where a transverse pipe caters for a stream with a catchment area then the minimum pipe size should be at least 900 mm and the carrying capacity of the pipe/culvert must be based on the catchment design.

- Section 4.2 and in particular Tables 4.1, 4.2 and 4.3 set out the different drainage systems which are appropriate for different situations and Drawing Nos. 1 to 9 give technical details of such systems

- Lockable gullies should be used in all new works

- Side entry gullies can be useful where cyclists are being catered for and road width or cycle track width is limited. Where gullies with gratings are used on roads they should be as close as possible to the kerb line or edge of road (Photo 3.1 shows an example of a poorly positioned gully).

- The slots in the gully grating should be transverse to, rather than parallel to the direction of traffic unless the gully is inset into the verge as shown in Photo 4.1.

# References


1. Guide On Information To Accompany Applications For OPW Consent For Bridges And Culverts as published by the Office of Public Works, Ireland

2. Fishery Guidelines for Local Authority Works as published by the Department of the Marine and Natural Resources

3. Transport and Road Research Laboratory Road Note 35, 2nd Edition, A Guide for Engineers to the Design of Storm Sewer Systems, HMSO, 1976.

4. Plant, J.E. The Drainage of Rural Roads, An Foras Forbatha Report RC. 50, 1971.

5. Building Research Establishment Digest 365, Soakaway Design, BRE 1991.

6. Young, C.P. and Prudhoe, J., Transport and Road Research Laboratory Report LR 565, The Estimation of Flood Flows from Natural Catchments, 1973.

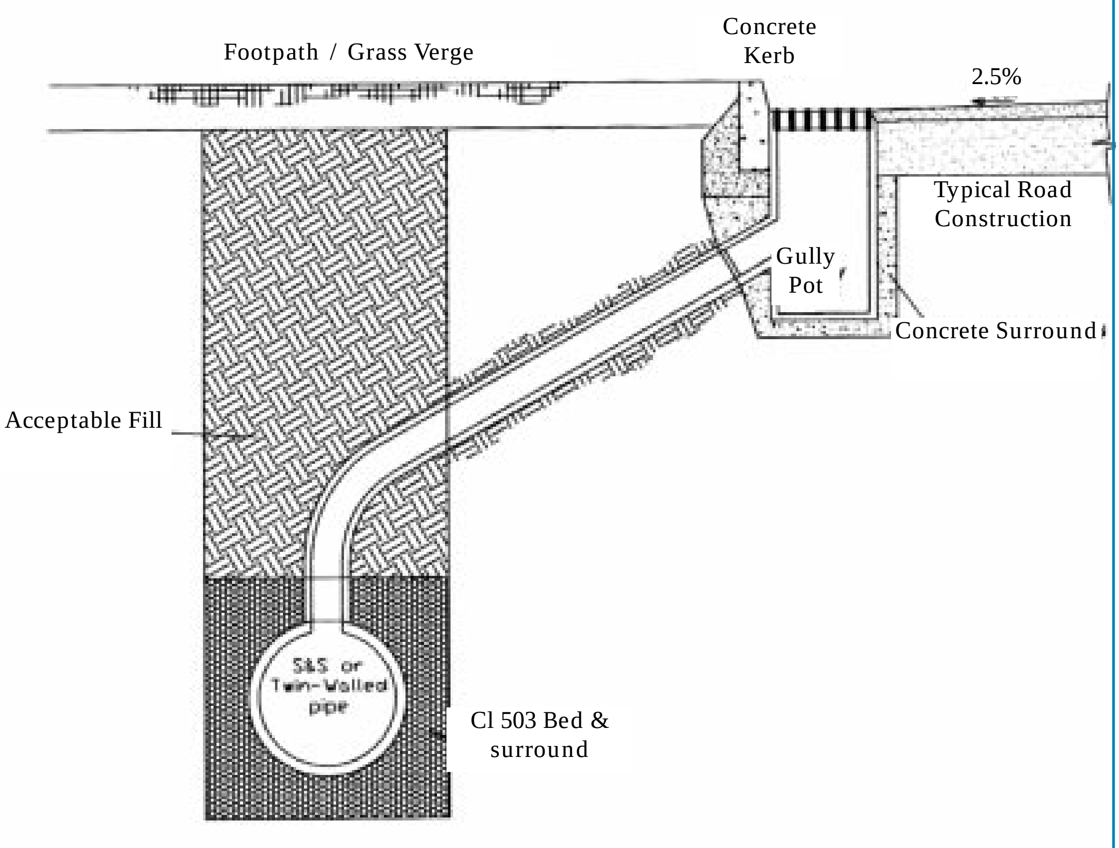
7. Construction Industry Research and Information Association Report 168, Culvert Design Guide, CIRIA 1997.

# *Appendix A - Drawings*

## Schedule of Drawings

| Drawing No. | Drawing Title |
|---|---|
| 1 | Kerbs with Gullies - Sealed System |
| 2 | Kerbs with Gullies – Combined Filter Drain |
| 3 | Drainage System located $< 1$m from road edge |
| 4 | Drainage System located $\geqslant 1$m from road edge |
| 5 | Open Drain |
| 6(a) | Road Widening with pipe cover $\geqslant 1$m |
| 6(b) | Road Widening with pipe cover $< 1$m |
| 7 | French Drain with Geo-Textile Membrane |
| 8 | Recommended Trench Widths and Dimensions for Surface Water Drains |
| 9 | Road Edge Detail at Entrances |

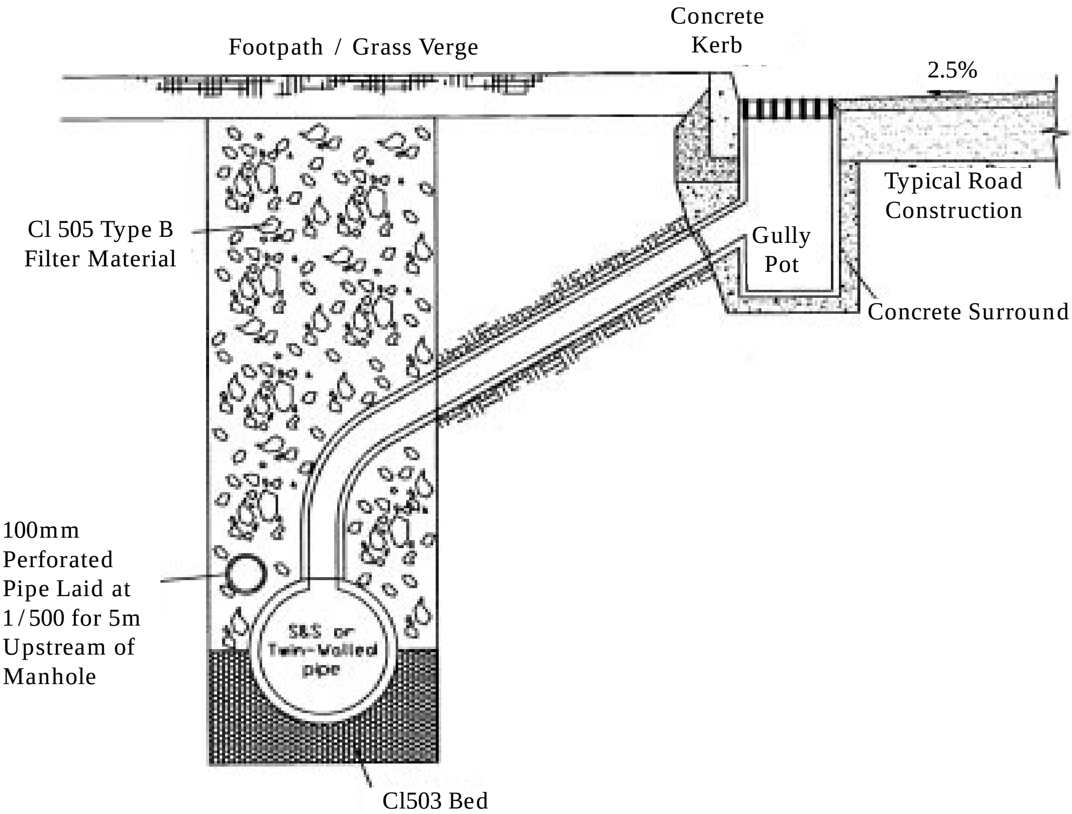
| Kerbs with Gullies - Sealed System | Drawing No. 1 |
|---|---|




Notes:

1. Where the trench for the drain is within 1m of the carraigeway edge, then Cl 804 should be used as backfill

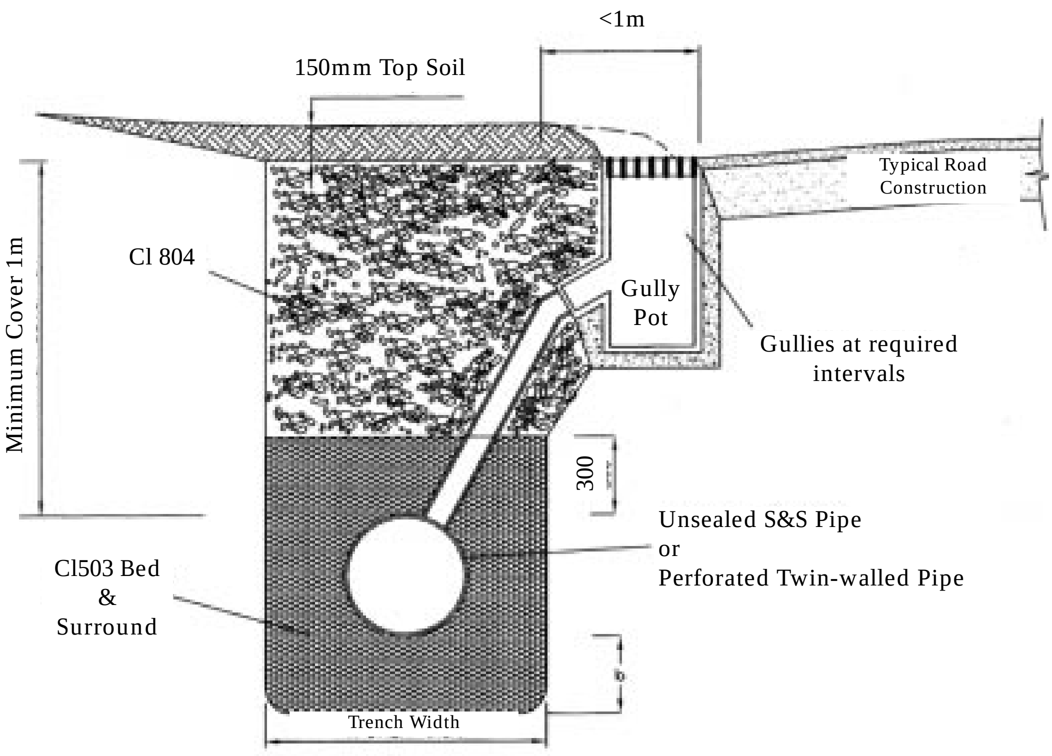
| Kerbs with Gullies - Combined Filter Drain | Drawing No. 2 |
| --- | --- |




Notes:

1. An alternative pipe system using a semi-perforated pipe, in lieu of sealed carrier pipe, may be used

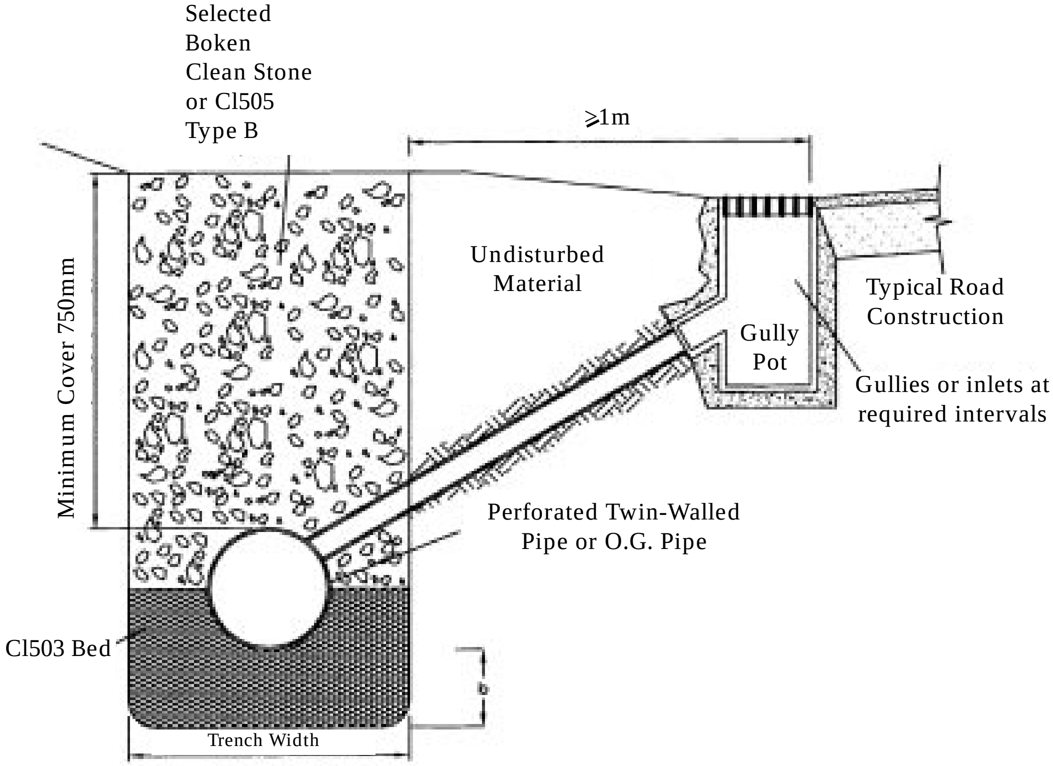
| Drainage System Located <1m from road edge | Drawing No. 3 |
| --- | --- |




Notes:

1. Gullies located at intervals of 200 sq.m road area
2. Concrete apron of 300mm Depth to be provided at all Entrances

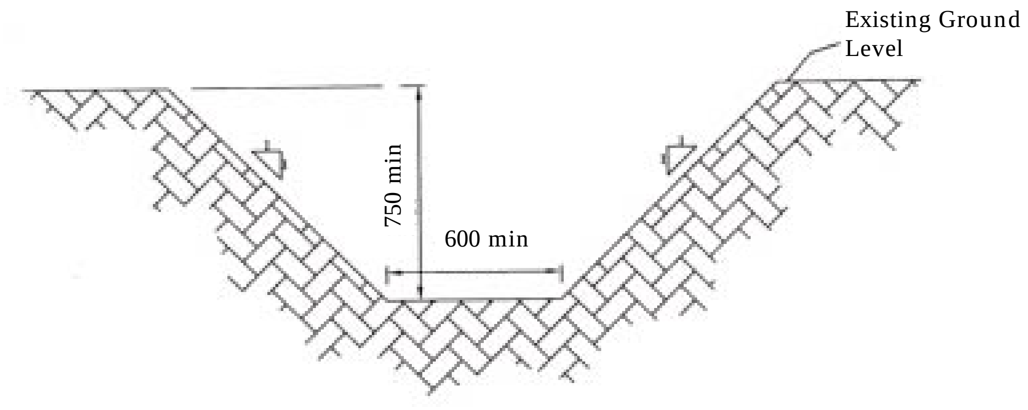
| Drainage System Located ≥1m from road edge | Drawing No. 4 |
|---|---|




Notes:

1. Gullies located at intervals of 200 sq.m road area or inlets every 40m.
2. Concrete apron of 300mm Depth to be provided at all Entrances.
3. Refer to Figure 7 where geo-textile membrane is required.

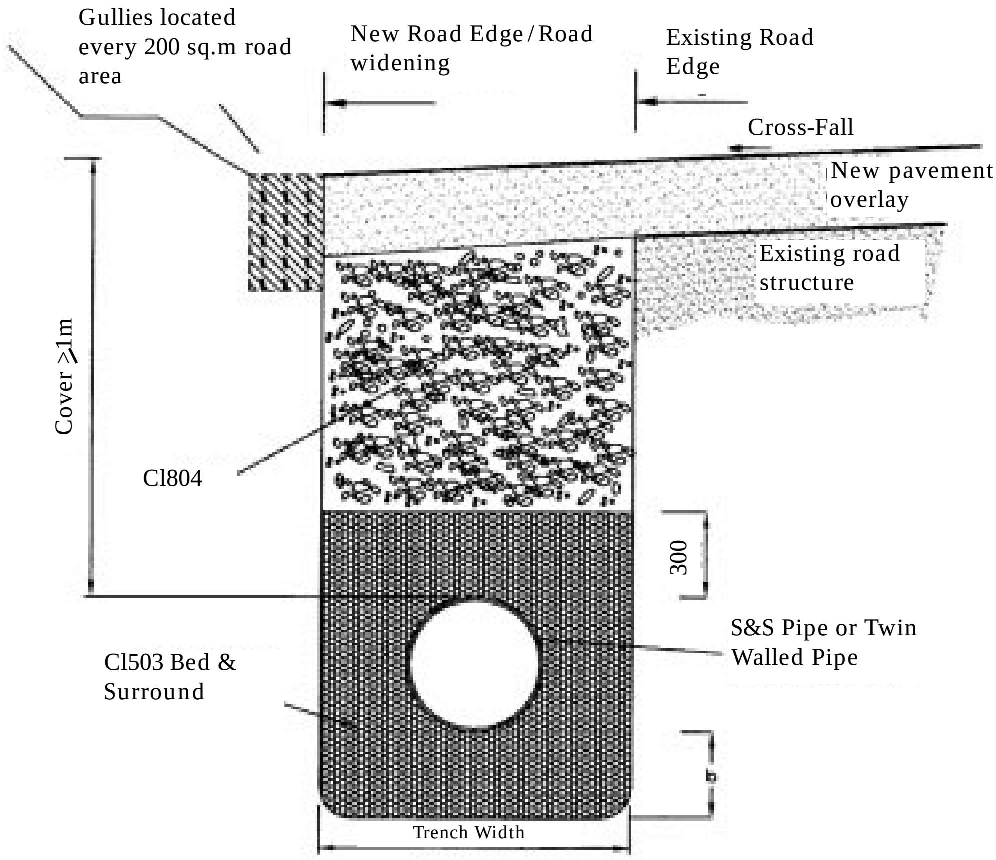
| Open Drain | Drawing No. 5 |
| --- | --- |




Notes:

1. Inlets every 30m.

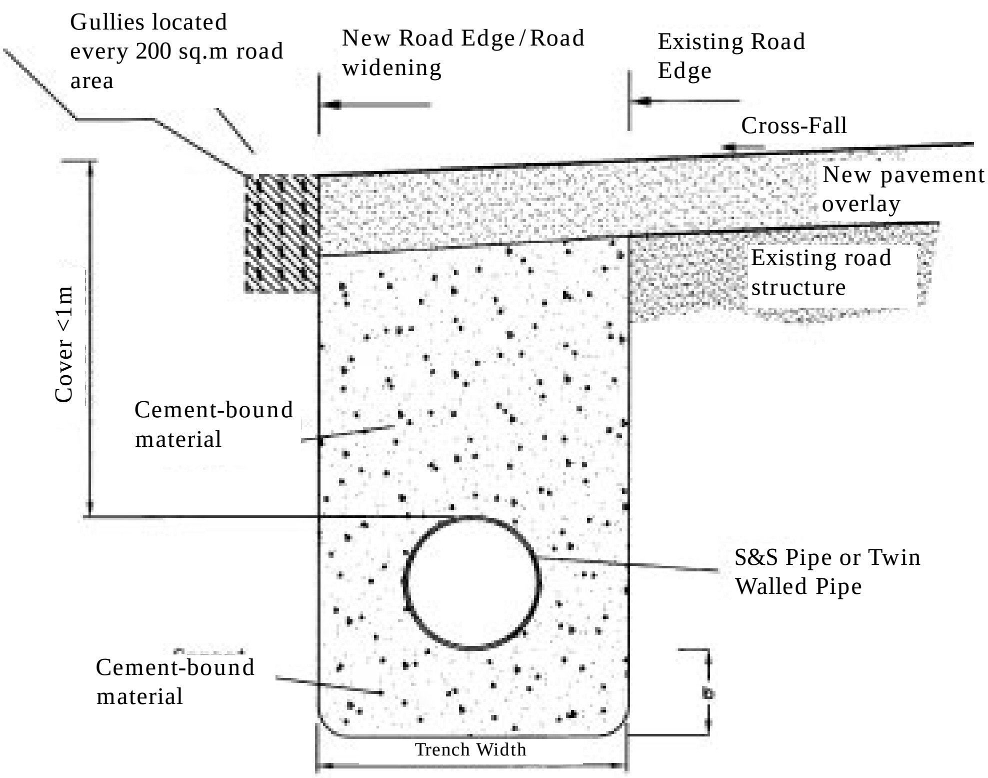
| Road Widening with pipe cover ⩾1m | Drawing No. 6(a) |
| --- | --- |




Notes:

1. If groundwater problems exist, an unsealed S&S pipe or Semi-perforated twin-walled pipe should be used

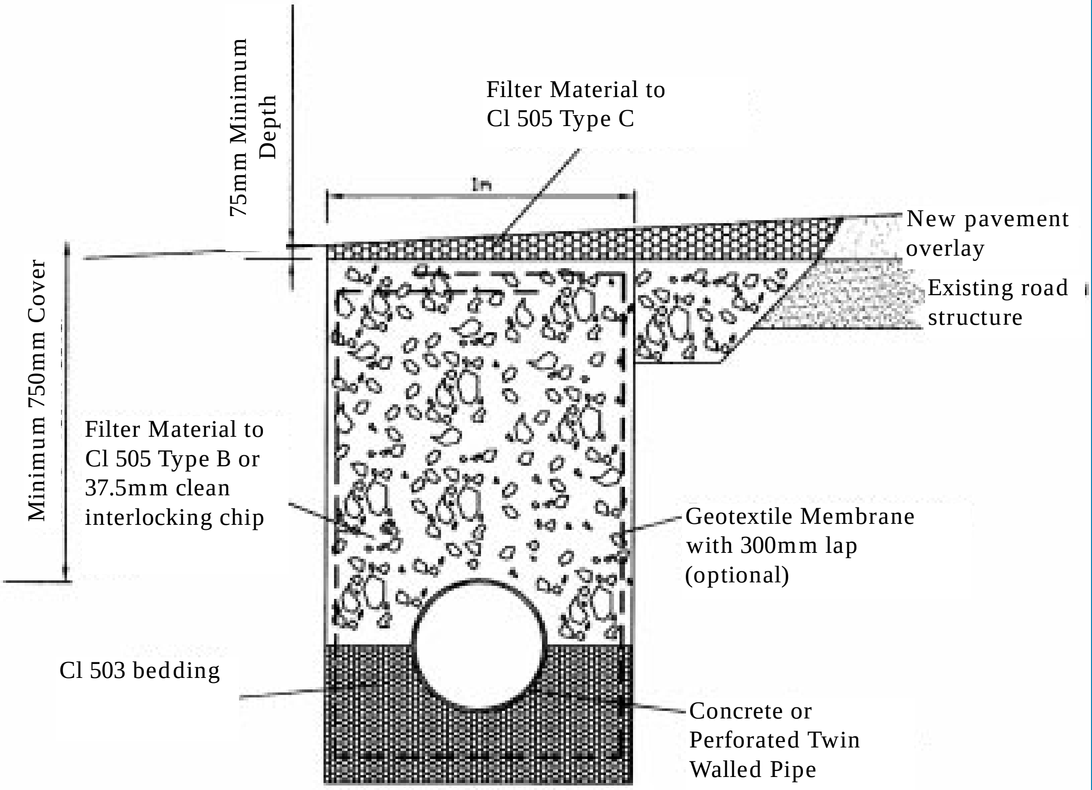
| Road Widening with pipe cover <1m | Drawing No. 6(b) |
|---|---|




Notes:

1. If groundwater problems exist, bed & surround the pipe with Cl503 up to 150mm above the pipe, and use on unsealed S&S or Semi-perforated Twin-Walled Pipe, then backfill the trench with Cement Bound Material.

| French Drain with Geo-Textile Membrane | Drawing No. 7 |
| --- | --- |

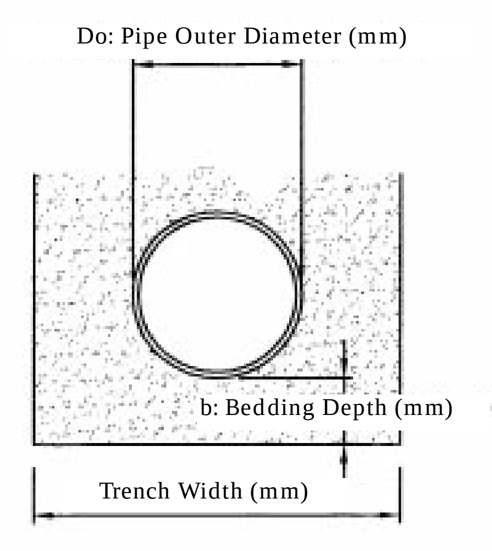



Notes:

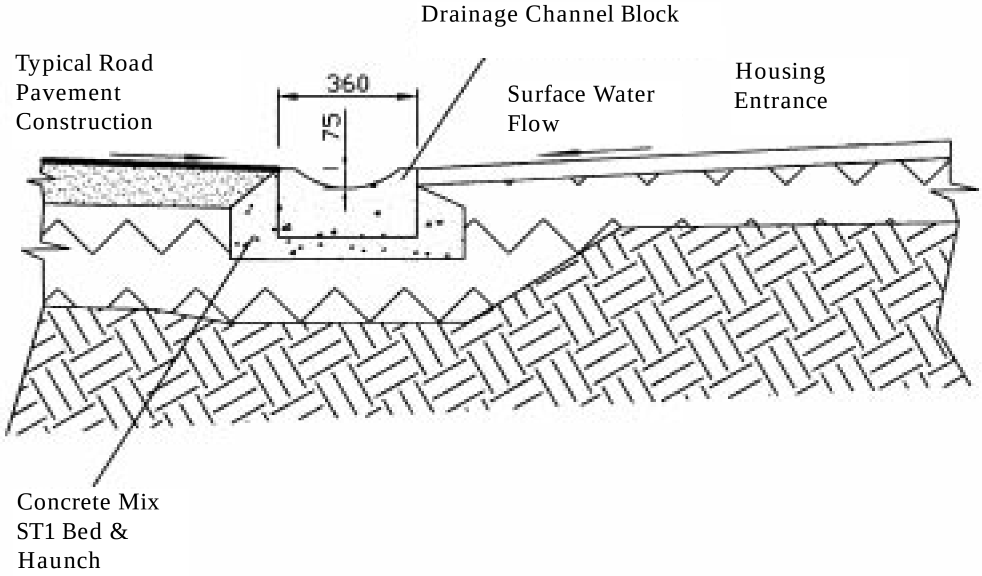
1. Perforated Pipes are to be laid with slots or perforations facing upwards.
2. Geotextile membrane may be omitted on non-national roads.
3. On narrow rural roads without shoulders, a load bearing pipe should be used where the drain is within 1m of the road edge.

| Recommended Trench widths and dimensions for surface water drains | Drawing No. 8 |
|---|---|

| TRENCH WIDTHS AND DIMENSIONS FOR SURFACE WATER DRAINS | | | |
|---|---|---|---|
| PIPE DIA. MM | Do | b | TRENCH WIDTH |
| 225 | 300 | 120 | 750 |
| 300 | 400 | 120 | 850 |
| 375 | 480 | 150 | 950 |
| 450 | 560 | 150 | 1000 |
| 525 | 650 | 150 | 1100 |
| 600 | 735 | 150 | 1200 |
| 675 | 850 | 200 | 1350 |
| 750 | 910 | 200 | 1450 |
| 900 | 1080 | 200 | 1650 |



| Road Edge Detail At Entrances | Drawing No. 9 |
|---|---|



# *Appendix B - Worked Example*

## CALCULATION OF PIPE SIZES REQUIRED TO CATER FOR RUN-OFF FROM A TYPICAL LENGTH OF ROAD

A layout of a typical length of road is shown in Figure B.1. The road runs on a low embankment at a gradient of 2% and then enters a cutting where the gradient slackens to 1% and finally to 0.5%. The road width is 8.0m, which includes a carriageway width of 7.0m and two hard strips of 0.5m. In this example a concrete pipe with a roughness factor of 0.3mm is assumed. Where a different type of pipe is to be used the pipe manufacturer should be consulted with regard to an appropriate roughness factor.

The following procedure can be followed for designs based on the empirical approach to rainfall intensity:

1. Divide the pipeline into 100m lengths (assumed distance between manholes). Give each length a classification number starting with the highest point in the pipeline, 1.1, 1.2, 1.3, 1.4, 1.5 etc. as shown in Figure B.1.

2. Draw up a table with fourteen columns as shown in Table B.1.

3. Fill in columns 1, 2, 3 & 4 for length 1.1.

4. Enter the smallest pipe size normally used at the top of column 14 (a 225mm pipe has been assumed in this example as this document recommends that it is adopted as the minimum size to avoid silting up of the pipe, however, a 150mm pipe would be adequate to deal with the calculated flow).

5. Knowing the size of the pipe and the gradient, calculate the velocity of flow from the hydraulic flow chart attached (Fig. B.2 for pipes with a roughness factor Ks = 0.3mm), and enter in column 5. For simplicity the velocity of flow in the pipe is assumed to be the velocity corresponding to pipe flowing full conditions.

6. Calculate the time of flow and enter in column 6. The time of entry (assumed to be 3 minutes) is added to the time of flow, to give the time of concentration in column 7.

7. The intensity of rainfall entered in column 8 is:

   (i) when the time of concentration is less than 10 minutes - 38mm / hr.
   (ii) when the time of concentration is greater than 10 minutes - 25mm / hr.

8. Calculate the areas drained by length 1.1. Enter the paved area in column 9; the paved area contributing consists of half the carriageway plus the hard strip / shoulder (unless the carriageway is superelevated). Where the road runs in a cutting, enter the plan areas of cutting slope in column 10 (assume 70% impermeability). Enter the total of column 9 and 10 in column 11. Enter the cumulative total area in column 12.

9. Calculate the rate of flow of run-off by multiplying the cumulative area (column 12) by the intensity of rainfall (column 8) and enter in column 13.

10. Check whether the pipe size assumed (225mm diameter in this case) is capable of carrying the computed rate of flow by referring to the attached hydraulic flow chart. If it is not able to do so, select the next largest size of pipe, and recalculate columns 5, 6, 7, 8 and 13.

11. Analyse the length 1.2 in the same manner. The time of concentration for 1.2 will be the time of flow along 1.1 plus the time of flow along 1.2 plus the time of entry (3 minutes). The cumulative area for 1.2 is the impermeable area draining into 1.1 plus the impermeable area draining into 1.2.

12. Analyse length 1.3, 1.4, 1.5 etc. in a similar manner.

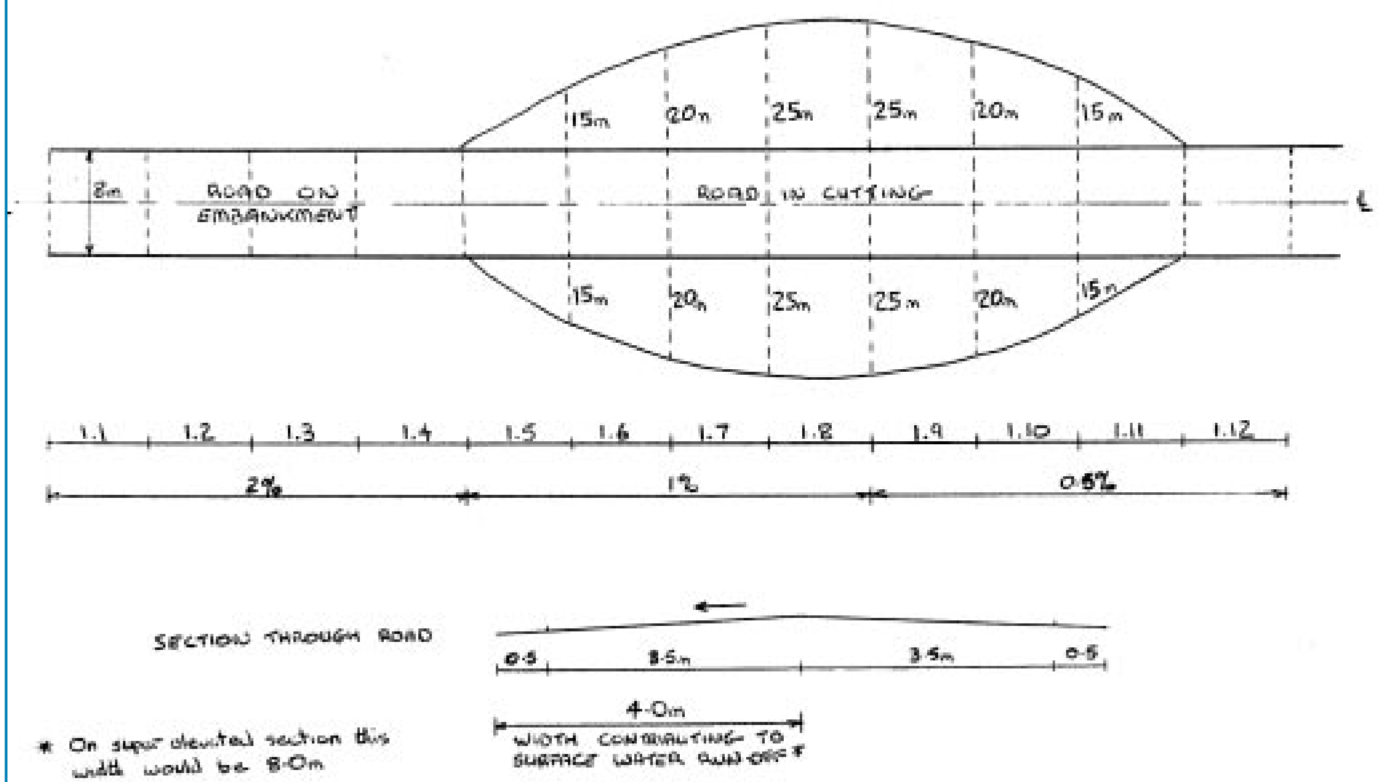
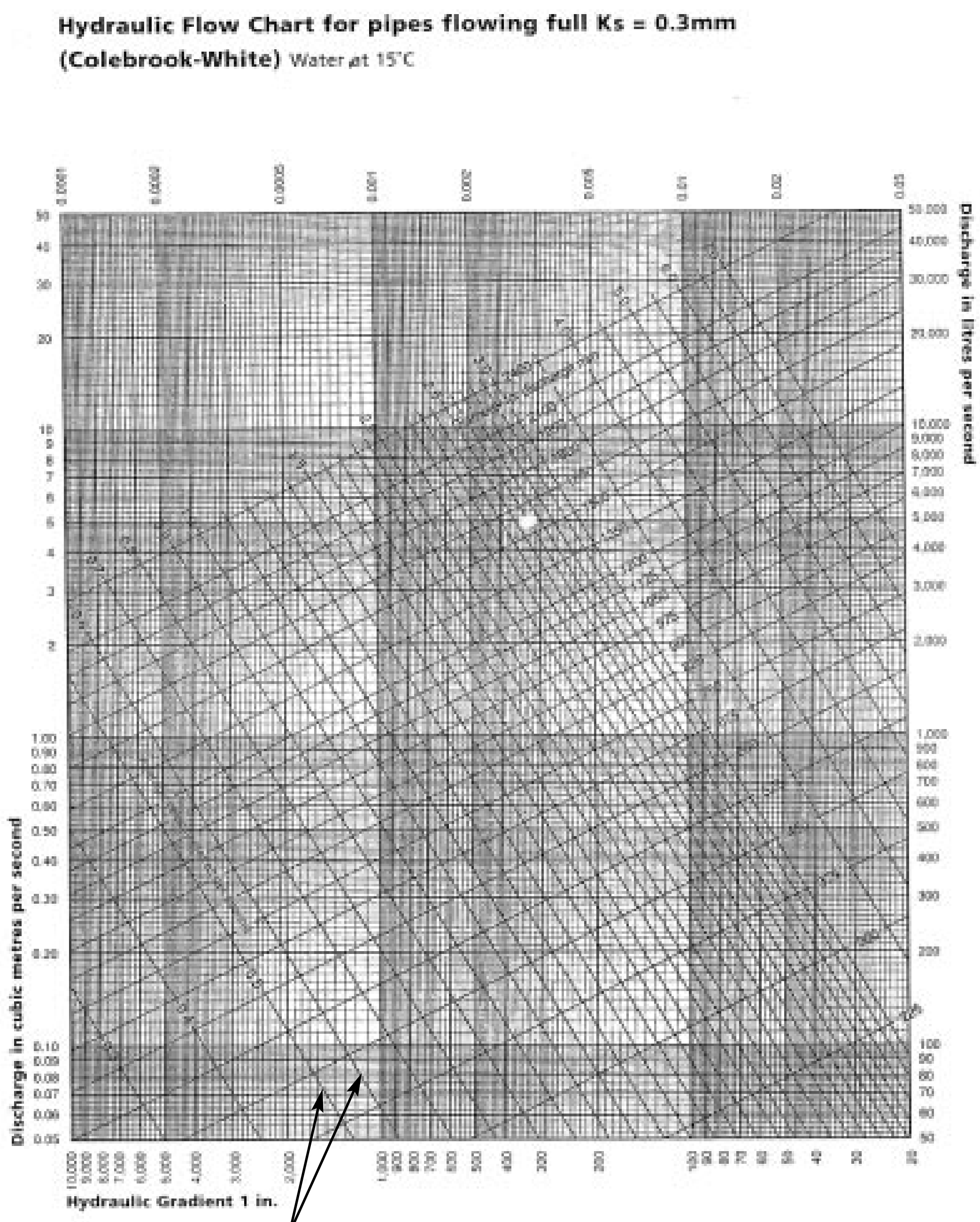



FIGURE B.1 - PLAN OF TYPICAL ROAD FOR WHICH SIZES OF PIPES FOR SURFACE WATER DRAINS ARE TO BE COMPUTED

Table B. 1 Design Sheet Empirical Approach

Roughness factor Ks = 0.3mm

| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Length No. | Difference in Level (m) | Length (m) | Gradient % | Velocity (m / sec) | Time of Flow (mins) | Time of Concentration (mins) | Rainfall Inensity (mm / hr) | Impermeable Area ($m^2$) | | | | Rate of Flow ($m^3$ / sec) | Pipe Dia. (mm) |
| | | | | | | | | Paved (100%) | Cuttings (70%) | Total | Cumulative | | |
| 1.1 | 2.0 | 100 | 2 | 2.05 | 0.81 | 3.81 | 38.0 | 400 | - | 400 | 400 | 0.004 | 225 |
| 1.2 | 2.0 | 100 | 2 | 2.05 | 0.81 | 4.62 | 38.0 | 400 | - | 400 | 800 | 0.008 | 225 |
| 1.3 | 2.0 | 100 | 2 | 2.05 | 0.81 | 5.43 | 38.0 | 400 | - | 400 | 1200 | 0.013 | 225 |
| 1.4 | 2.0 | 100 | 2 | 2.05 | 0.81 | 6.24 | 38.0 | 400 | - | 400 | 1600 | 0.017 | 225 |
| 1.5 | 1.0 | 100 | 1 | 1.45 | 1.15 | 7.39 | 38.0 | 400 | 525 | 925 | 2525 | 0.027 | 225 |
| 1.6 | 1.0 | 100 | 1 | 1.45 | 1.15 | 8.54 | 38.0 | 400 | 1255 | 1625 | 4150 | 0.044 | 225 |
| 1.7 | 1.0 | 100 | 1 | 1.70 | 0.98 | 9.52 | 38.0 | 400 | 1575 | 1975 | 6125 | 0.065 | 300 |
| 1.8 | 1.0 | 100 | 1 | 1.70 | 0.98 | 10.5 | 25.0 | 400 | 1750 | 2150 | 8275 | 0.057 | 300 |
| 1.9 | 0.5 | 100 | 0.5 | 1.20 | 1.39 | 11.89 | 25.0 | 400 | 1575 | 1975 | 10250 | 0.071 | 300 |
| 1.10 | 0.5 | 100 | 0.5 | 1.37 | 1.22 | 13.11 | 25.0 | 400 | 1255 | 1625 | 11875 | 0.083 | 375 |
| 1.11 | 0.5 | 100 | 0.5 | 1.37 | 1.22 | 14.33 | 25.0 | 400 | 525 | 925 | 12800 | 0.089 | 375 |
| 1.12 | 0.5 | 100 | 0.5 | 1.37 | 1.22 | 15.55 | 25.0 | 400 | - | 400 | 13200 | 0.092 | 375 |




Average velocity in metres per second

Figure B. 2