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Singhadurbar, Kathmandu

Road Safety Note 2

DESIGNING SAFER SIDE DRAINS

Updated

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ROAD SAFETY NOTE 2

DESIGNING SAFER SIDE DRAINS

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List of Abbreviations

CBS	:	Central Bureau of Statistics
DoR	:	Department of Roads
FHWA	:	Federal Highway Administration
GIS	:	Geographic Information System
GoN	:	Government of Nepal
HEC-HMS	:	Hydrologic Engineering Center’s Hydrologic Modeling System
HEC-RAS	:	Hydrologic Engineering Center’s River Analysis System
IDF	:	Intensity - Duration – Frequency
MoPIT	:	Ministry of Physical Infrastructure and Transport
MPH	:	Miles per Hours
NH	:	National Highway
RTU	:	Research and Training Unit
SWAT	:	Soil and Water Assessment Tool

1 INTRODUCTION

1.1 Background

Runoff that accumulates or flows onto the road surface poses a potential hazard to road users and must be promptly and efficiently removed. The road's geometry, including pavement crossfall and longitudinal grade, guides the flow of surface runoff, directing it towards the carriageway's edge for collection. In areas without kerbs, open channels are utilized for collection and drainage of surface runoff. Conversely, on kerbed roads, drainage inlets are used to capture the run-off, and convey it to the underground network for ultimate disposal.

Improving the safety of drains on roads is essential to prevent crashes and enhance overall road safety. Drainage systems that remove storm water run-off from streets and highways are an integral feature of a safe system. Removing water effectively from the streets, highways, sidewalks ensure safety of motorists, bicyclists, drivers and pedestrians. Water that remains on the roadway surface can contribute to vehicle hydroplaning. In winter, standing water can freeze and cause skidding.

In designing side drain, the primary objective is to properly accommodate surface runoff along the highway right-of-way through the application of sound hydraulic principles. However, a second, important goal is that of incorporating safety into the design of drainage appurtenances. The best design would be the one which would efficiently accommodate drainage and be traversable by an out-of-control vehicle without rollover or abrupt change in speed.

According to "Guide for Local Street and Highway Maintenance Personnel" by FHWA maintaining roadway drainage is important for safety and for ensuring the long life of the roadway by:

- Preventing erosion of the roadway.
- Preventing saturation of the subbase.
- Preventing damage to roadway structures.

1.2 Impact of Improper Drainage on Traffic Safety

The safe design and maintenance of drainage features, such as travel way and shoulder surfaces, side slopes, drop inlets, pipe ends, ditches, headwalls, safety grates, culverts, gutters, ensures that the storm water is drained properly without any safety hazards. The safety hazards due to improper drainage on pavement surface, side slopes are described below:

- **Hydroplaning:** The thin layer of water on the travel surface can initiate motor vehicle hydroplaning at speeds as low as 55 kmph (35 mph). When a vehicle tire rides on top of this thin layer of water, the vehicle cannot be steered or stopped easily. A vehicle that is hydroplaning behaves similarly to a vehicle on ice.
- **Infringing on the other lane:** Ponding or standing water in the travel way may also cause some drivers, bicyclists, or pedestrians to divert from their desired path. Cyclists and drivers of motor vehicles may decide to avoid going through the water by infringing on the other lane, putting other drivers and themselves in danger. The manhole covers not in flush with the pavement surface also pose high risks.
- **Braking efficiency:** The braking efficiency of the vehicles reduce highly when water is not drained off the pavement. Water ponding at junctions can be particularly dangerous since it may take longer for cars to stop. In sections of the travel way where run-off drains directly onto the shoulders (where there are no curb and/or gutters), water may collect along the edge of the travel way. Water on a portion of roadway can result in drivers losing control of their motor vehicle, particularly when braking in an emergency.
- **Deterioration of pavement:** Intense storm runoff can cause erosion and damage to road surfaces, creating hazards such as potholes and road subsidence. These road defects can pose risks to vehicles and may contribute to crashes.

1.3 Planning

During the planning phase, it is essential to develop a comprehensive drainage plan that encompasses all external drainage areas, considering both present and future land use conditions. The drainage system should be designed to accommodate both minor, routine flows within the drainage system, and major flows during extreme flood events. During extreme flood events, the maximum acceptable depth of surface flooding or, at the very least, identifying the potential for flooding.

The drainage design for the road should provide for:

- Cross drainage -Taking storm water to flow across the road by culverts, scuppers, etc.
- Road surface drainage -Draining the storm water falling on the roadway by ditches, chutes, etc.
- Sub-surface draining -The drains should not hinder in sub-surface draining but should help draining the sub- surface Water.
- Erosion control -Protecting the roadway and adjoining properties from erosion by ditches, intercepting channels, slope lining, riprap, etc.

Careful planning of alignment and other features will help in achieving better side drains. In flat and easy terrain, side drains are usually designed for draining water from road formation only whereas in hilly terrain they have to provide for water coming from adjacent watershed area and provide for erosion control.

Where space permits the drains and its outlets should be constructed away from the road edge. This not only provides space for future expansion but also provide recovery space for straying vehicles. Usually scouring problems are more acute near the outlets that can not only be hazardous to the road but also to the traffic.

Final disposals should only be at stable dry watercourses or running streams and not at any other location. If water is disposed at other places, it can destabilize the area causing severe environmental damage.

Surveying the outlet gully to estimate if it can safety contain the increased discharge, and if it requires, strengthening is essential.

1.4 Recognizing Drainage Problems

Recognizing potentially dangerous circumstances as soon as feasible is crucial. While some of these variables might have been around for a while, others might have just emerged because of a storm or other change in the weather. There are multiple methods to identify the sites of drainage issues:

- Citizen complaints: Every day drivers are the first to identify problems on the roadways. A phone number should be included that is clearly visible to the public so that they may report issues and complaints. Also, a proper website can be created to report incidents by the public.
- Local police: Local police can play a role in recognizing and addressing drainage problems within their jurisdiction. While their primary focus is on law enforcement, they often act as first responders and liaisons to other agencies during emergencies. Regular patrols by police officers can help identify visible signs of drainage issues, such as standing water, flooding, or erosion along roadways.
- Crash data: A periodic review of crash data can reveal some locations where drainage deficiencies may be a contributing factor. Locations that experience a higher-than-average number of wet weather crashes may have deteriorated pavement surfaces. Also, look for crashes with fixed objects, which could include drainage structures that need to be removed or protected by a barrier.
- GIS Mapping: Use Geographic Information System (GIS) mapping to analyze topography, land use, and existing drainage infrastructure. Identify areas with low-lying terrain, high impervious surfaces, or inadequate drainage systems.
- Stormwater Drainage Network Evaluation: Evaluate the existing storm water drainage network to identify potential bottlenecks or areas with insufficient capacity. Inspect storm water drains, culverts, and other infrastructure for blockages or damage.
- Remote Sensing Technology: Utilize remote sensing technologies, such as satellite imagery and aerial surveys, to identify patterns of water accumulation or areas prone to flooding. Remote sensing can provide a broader perspective on the landscape.
- Field reviews: Potentially hazardous drainage features are best identified through field reviews. Drainage features may be reviewed alone or in a combined safety review. An excellent time to review a road or section of highway is when there is other highway work being planned. For example, if a section of road is scheduled for an overlay, the section may be reviewed to determine if there are any safety improvements that can be included. Including drainage improvements on other projects will often reduce the cost of the work and the inconvenience to the public.

2 DESIGN DISCHARGE

2.1 Design Flood and Its Frequency

The first step in designing facilities is to estimate the quantity of water that is to be drained. Drainage facilities should have sufficient capacity to carry off safely not only peak runoffs, which occur frequently, say several times a year, but also larger runoffs, occurring less frequently. For a major highway linking major economic centers, where disruption of traffic, caused by damage or washout of culverts, may not be acceptable, a peak runoff that recurs every 25 years needs to be considered. In contrast, for a rural highway where some minor traffic disturbances can be tolerated, a peak runoff that recurs every 10 years is sufficient. The recommended return periods for calculating design discharge as per NRS (2070) is given in Table 2-1.

However, where serious damage would result from erosion caused by the inadequate capacity of drainage facilities, the less frequent peak runoffs would have to be used. It is not practicable to design for a maximum probable flood to cater for the worst possible flood, as the capital costs increase rapidly with the increment of the peak runoff. In order to economize the construction costs, frequency of flood is selected for longer or shorter return periods, depending upon the importance of the structure.

The design flood is a flood corresponding to the selected return period. It is not economical to over design. It should be kept in mind that the flooding of tile road for short period after a big storm is acceptable where it is unlikely to damage the road by such event.

Table 2-1 Return periods for calculating design discharges

Road Class	I and II	III	IV
Return Period in years	50	33	25

(Source: NRS 2070)

2.2 Method of Runoff Prediction

2.2.1 Rational Method

Rational formula is applied to estimate the peak runoff, which is given by Eqn. (2.1),

$$Q = \frac{C I_c A}{360} \tag{2.1}$$

This method is applicable to small catchments (1 to 2 sq. km) only.

Where,

Q: Peak runoff in m3/sec

I_c: Critical intensity in mm/hr. - corresponding to time of concentration of catchment.

A: Catchment area in hectares, and

C: Dimension less constant, the runoff coefficient (from Table 2-2).

The peak runoff frequency is assumed identical to the rainfall intensity frequency.

Critical intensity (I_c): The critical intensity for a catchment is that maximum intensity which can occur in a time interval equal to the concentration time (T_c) of the catchment during the severest storm (in the region) of a given frequency. Since each catchment has its own concentration time, it will have its own critical intensity.

Critical Intensity of Rainfall can be obtained using Eqn. (2.2),

$$I_c = \frac{P(T+1)}{T(T_c+1)} \tag{2.2}$$

Where,

I_c: Critical intensity of rainfall corresponding to time of concentration in mm per hour.

P: Precipitation of a storm in mm

T: Duration of storm in hours, and

T_c: Time of concentration in hrs.

The time of concentration (T_c) is given by the formula of Eqn. (2.3) from IRC SP 13-2004 Cl 4.7;

$$T_c = \left(0.87 \times \frac{L^3}{H}\right)^{0.385} \tag{2.3}$$

Where,

T_c: Concentration time duration of a storm corresponding to tile maximum rate of runoff in hrs.,

L: Length of watercourse from the farthest point in the catchment to the outlet in km,

H: Height difference between the farthest point and the outlet, m.

L, H can be calculated from the survey plans of the catchment area.

Table 2-2 Maximum values of runoff coefficient 'C' for various soil covers

Soil Cover	"C"
Steep, bare rock, also city pavements	0.90
Rocks steep, wooded	0.80
Plateau, lightly covered	0.70
Clayey soils, stiff and bare	0.60
Clayey soils, lightly covered	0.50
Loam, lightly, cultivated or covered	0.40
Loam, Predominately cultivated	0.30
Sandy soil, light growth	0.20
Sandy soil, covered, heavy bush	0.10

(Source: Road Safety Note 2 DoR, 1996)

2.2.2 Other Methods for Discharge Calculation

In case of existing road or where the data is not available, approximate flow can be calculated by various other means. Few of these are as follows:

i. **Information from the locals:** Talking with the local people or even personnel who have been working on the road for longer period can provide information on which we can base a rough estimate of flow.

ii. **Observation:** Personally, going out on the field during heavy rains and observing can be of help. The size of rain cut ditches, catchment area and present drainage outlets also help in approximating the flow.

iii. **Remote sensing and GIS:** Satellite imagery and GIS (Geographic Information System) data can be used to estimate land cover, slope, and other factors that influence flow.

iv. **Expert judgment:** In the absence of quantitative data, experienced hydrologists or engineers may use their judgment to make qualitative estimates based on local knowledge and observations.

v. **Hydrologic models:** Hydrologic models, such as the Soil and Water Assessment Tool (SWAT) or Hydrologic Engineering Center's Hydrologic Modeling System (HEC-HMS), Hydrologic Engineering Center's River Analysis System (HEC-RAS) can simulate hydrological processes and provide estimates of flow. These models may require various inputs, such as precipitation, land use, soil types, and topography.

2.3 Capacity of Drains

Flow in open channels is classified as steady and unsteady. Unsteady flow occurs when the quantity of water, cross sections of flow, and the slope of the carrying channels are changing. However, for simplicity of hydraulic calculations, flows in road drainage channels are treated as if occurring under steady conditions.

a) Uniform Flow

Uniform flow will take place when the cross section, roughness, and slope of the channel remain constant over the stretch under consideration. The errors involved in assuming uniform flow in drainage channels is relatively small compared to errors in establishing design peak flows, hence drainage channels with constant cross section, roughness, and slope are often designed as, uniform flow channels.

The most widely, used equation for uniform flow is the following Manning's equation (Eqn. 2.4):

$$v = \frac{1}{n} R^{\frac{2}{3}} S^{\frac{1}{2}} \tag{2.4}$$

Where,

v: Velocity, m/sec,

n: Rugosity coefficient (see Table 2-3)

R: Hydraulic radius, m, (A/P)

A: Wetted cross-sectional area of flow

P: Wetted perimeter, m and

S: Slope of the channel

The safe velocities of the different materials are given in Table 2-4. After finding velocity from the above equation, the discharge of the channel can be calculated by using Eqn. (2.5):

$$Q = AV \tag{2.5}$$

Where,

Q: Flows, m^3 /sec,

A: Cross sectional area of flow, m^2 and

v: Velocity of flow, m/sec

Table 2-3 Manning, roughness coefficient

Type	'n'
Closed conduits	
Concrete pipe	0.011 - 0.018
Corrugated metal pipe	0.024
Cast iron pipe	0.013
Brick	0.014 - 0.017
Cement rubble masonry with natural floor	0.019 - 0.023
Open Channels	
Earthen, clean, recently completed	0.016 - 0.018
Earthen with short grass and weeds	0.022 - 0.027
Gravely soil, clean, uniform	0.022 - 0.025
Earthen fairly uniform sides, clean cobble bottom	0.030 - 0.040
Concrete formed no finish	0.013 - 0.017
Concrete bottom, dressed stone sides	0.015 - 0.017
Cement rubble masonry	0.030 - 0.025
Brick	0.014 - 0.017
Mountain stream, no vegetation in channel, steep banks, trees and brush along bank submerged at high stage	
Bottom of gravel, cobbles, few boulders	0.04-0.05
Bottom of cobbles, with large boulders	0.05-0.07

(Source: Road Safety Note 2 DoR, 1996)

Table 2-4 Typical safe velocities for different materials

Bed Material	Safe velocity (m/s)
Loose clay or line sand	up to 0.5
Coarse sand	0.5- 1.0
Fine sandy or stiff clay	1.0- 1.5
Coarse gravel, rocky soil	1.5 -2.5
Boulders, rock	2.5 - 5.0

(Source: Road Safety Note 2 DoR, 1996)

b) Non - Uniform or Varied Flow

Varied steady flow occurs when quantity of water remains constant, but the depth of the flow velocity, or cross section changes from section to section. The relation, which is also called equation of continuity (Eqn. 2.6), of all cross section will be:

$$Q = A_1 V_1 = A_2 V_2 = A_n V_n \quad (2.6)$$

The cross-sectional area should be sufficient for effective drainage from carriageway and the adjacent area. Though we do not want eroding velocity, adequate longitudinal slope should be provided so that water does not accumulate and percolate to the subgrade. However, ditches do not need to be watertight and indeed, it is better if they are not watertight on the side nearest the carriageway. Even in areas of tropical rainfall they will be dry for much longer then they are wet. If the side of the ditch is porous, evaporation takes place rapidly and dries out not only water which has percolated sideways from the ditch into the subgrade but also any which has percolated vertically into the subgrade from cracks in the surface of the pavement.

2.4 Steps in Discharge Calculation

Simplified steps for the design of longitudinal drains of a road to drain off the surface water are as follows:

i. The frequency of return period such as 10 years, 25 years etc. is decided based on finances available and desired margin of safety, for the design of the drainage system.
ii. The values of coefficients of runoff C1, C2, C3 etc. from drainage areas A1, A2, A3 etc. are found and weighted average value of C is computed.
iii. Time of concentration 'T_c' is calculated from the formula mentioned above.

iv. From the rain fall Intensity - Duration –Frequency (IDF) curves the rainfall intensity I_c is found in mm/sec corresponding to the duration T and frequency of return period or calculated by the formula mentioned in this document.

v. The total area of drainage A_d is found in units of hectares

vi. The runoff quantity Q is computed as $\frac{CIA_d}{360}$

vii. The cross-sectional area of flow of the drain is calculated as Q/V, where V is the allowable speed of flow in the drain.

viii. The required depth of flow in the drain is calculated for a convenient bottom width and side slope of the drain. The actual depth of the open channel drain may be increased slightly to give a free board. The hydraulic mean radius of flow R is determined.

ix. The required longitudinal slope S of the drain is calculated using Manning's formula adopting suitable value of roughness coefficient n.

x. If the slope required is higher or lower, the velocity assumed is accordingly lowered or increased.

3 BASIC GUIDE

3.1 Basic Guidelines for Surface Drainage in Rural areas

Following are some basic guidelines for effective surface drainage to maintain road integrity and safety in rural environments.

a. Water should be drained from the road surface with adequate camber of both the carriageway and the shoulder.
b. Road side drains should be provided in all cut sections to remove water in the longitudinal direction.
c. Toe-of-slope road side drains should be constructed in low fill (<0.8m filling height) sections to convey water away to water courses
d. Intercepting or catch water drains should be placed on back of the top of cut slopes to intercept surface water. Distance of these drains from the edge of the cutting should not be less than 5m.
e. Flumes should provided to carry collected water down deep cuts or high fill slopes.
f. Drains should be provided with minimum 0.5% longitudinal grade.
g. Trapezoidal shape of drains is preferred.
h. For calculating design discharge on roadside drains, the return periods mention in Table 2-1 should be taken.
i. Outlets from the side drains should be provided at no more than 500m intervals.

3.2 Basic Guidelines for Surface drainage on Hill Roads:

Frequency of drain outlets on hill roads should be as high as possible as:

i. The drain section would be smaller and hence more forgiving to tile traffic and pedestrians,
ii. Long side drains (in excess of 100 in. without outlets) in high rainfall area creates massive damage if they become blocked by debris and landslide,
iii. The risk of damage to the outlets and the drain itself is reduced as discharge will be less. Lower volume of discharge means smaller drain section and, though more in numbers, simpler and smaller culverts are adequate and hence would be cheaper.
iv. Final disposals should be at stable dry watercourses or running streams.
v. In hill roads where rainfall is heavy, it is recommended that culverts or other suitable type of cross drainage be provided every 60 - 100 m with proper disposals.

Care should be taken at the time of construction to oversee the correct slope and the invert level of cross drains.

vi. In hilly road, side drains on valley side should be avoided as far as possible; provided only in exceptional cases and by properly managing the discharge from the outlet.

vii. In hilly road, the valley side slope without drains should be stable enough to drain any flow coming onto it due to rain. It just needs to be ensured that water is not collected and discharged at one point of the slope but should be drained all along the side of the road. When it is allowed to discharge through one point, it can severely damage the slope.

3.3 Kerbed Drainage

Kerbing, also known as curbing, refers to the raised edge along the sides of a road or pavement. The use of kerbing along urban roads serves multiple purpose, including:

i. to delineate the edges of carriageways,

ii. to separate carriageways from areas used by other modes of transport, such as pedestrians,

iii. to separate carriageways from areas to be put to other uses, such as landscaping,

iv. to support the edge of the base course of pavement.

Proper utilization of roadway cross slope is crucial to ensure effective channeling of surface run off on the road surface toward the kerbing. This runoff is then collected in the gutter and safely conveyed to final discharge point. In the absence of kerbed drainage system in urban area, runoff water redirects to downstream following the longitudinal gradient of the road, until it reaches lowest point where ponding may occur. Ponding of runoff and encroaching into other areas used by traffic poses a risk to road users. Inlet pits are one component of the overall urban drainage network, which also includes junction pits and piped conduits. The inlets capture the run-off from the road surface and convey it to the underground piped network for disposal.

3.3.1 Types of Inlet

Drainage inlets can be side entry or top entry, e.g. grated gully pits. Side entry inlets are located behind the kerb with an opening in the kerb face for capturing run-off. Grated, or top entry, inlets are located within the flow path of stormwater run-off, are therefore hydraulically more efficient. The decision to use one style of inlet over another is dependent on many factors, including location of existing drainage infrastructure, presence of underground services, road geometry, the safety of road users (including cyclists and pedestrians) and jurisdictional preferences.

Side entry inlets are vertical openings in the kerb covered by a top slab. Due to their relatively large openings they are less prone to blockage and are therefore suited to areas of anticipated debris build-up such as within sag vertical curves. They have traditionally been considered more ‘cycle-friendly’ than grated gullies.

Grated, or top entry inlets consist of an opening in the gutter covered by a grate. These inlets require transverse bars where there is bicycle traffic. For other roads where cyclists are prohibited, parallel bars, which are less prone to blockage and perform with greater hydraulic efficiency, may be used

Combination of side entry inlets consisting of a side entry pit and grated gully inlet, cast into the same structure may be used.

For situations where flat crossfalls make capture of flows with conventional structures difficult, a more practical solution is to utilize continuous capture inlets such as slotted kerb drain or grated trench drain (Figure 3-1).

Figure 3-1 Slotted kerb drain and grated trench drain

3.3.2 Inlet Location

In general, drainage inlets should be provided/considered at the following locations:

- In the low points of all sags. Capacity can be increased by providing reserve inlet within 10 m.
- Locate pits immediately upstream of a potential pedestrian crossing to permit pedestrian access.
- Immediately upstream of superelevation, median openings, any bridge abutment etc.
- At intersections, place pits where long/oversize vehicles cannot traverse them when turning to minimize potential for damage.
- Maximum pit spacing to facilitate inspection and cleaning of pits should be 200 m for pipes greater than 1800 mm diameter, otherwise 120 m maximum pit spacing.
- Maximum clear opening of 90 mm is required where it is necessary to exclude the entry of the torso of a child.
- The placement of kerbed drainage inlets for the collection of road surface run-off is dependent largely on acceptable limits for the spread of the run-off into the carriageway.
- For major roads, 50 years return period of rain fall is to be considered for discharge calculation.
- The placement of kerbed drainage inlets for the collection of road surface run-off is dependent largely on acceptable limits for the spread of the run-off into the carriageway.
- Roadway flow shall be limited with particular reference to floor levels of adjacent buildings, pedestrian and vehicle safety.
- The rational method for discharge calculation and Mannings equations for the flow width can be applied as in other drainage design.

3.4 Underground Piped Networks

On kerbed roads, drainage inlets are employed to capture runoff and convey it to the underground network for ultimate disposal. Underground piped network comprises various components, including drainage inlets, drainage pits (comprising access chambers or manholes and inlet pits), underground conduits or pipes, and discharge points.

3.4.1 Design Considerations

This section offers designers guidance for designing underground drainage networks responsible for conveying surface runoff collected from the road surface to the designated point of disposal or discharge (e.g., existing network, drainage basin, waterway). The network encompasses inlet pits, junction pits, and interconnecting conduits or pipes. It is important to note that while other materials and conduit shapes may be applicable in specific situations, this guide predominantly acknowledges the prevalent use of pipe conduits. Therefore, the guide commonly refers to the underground infrastructure as 'piped' networks.

i. It is desirable to locate access chambers outside of wheel paths to minimize damage to the drainage infrastructure and the vehicles.
ii. The location of existing drainage infrastructure can also provide an indication as to where new inlets might best be placed.
iii. Access chambers and pipes are subjected to a variety of loadings that must be taken into consideration.
iv. Access chambers should not be placed within pedestrian crossings as the inherent level difference between pit cover and the adjacent road surface can create a hazard for those with disabilities and in particular the elderly or sight impaired persons.
v. Access chambers within shoulders frequented by cyclists should have their lids set flush with the adjacent sealed surfaces.
vi. The maximum spacing for access chambers can be 100 m to 200 m for pipes.
vii. The minimum cover over any pipe, irrespective of location, class and bedding, should be 300 mm.
viii. From the pit locations, mark out the contributing sub-catchments.
ix. From the discharge in the pipe and Mannings equation, calculate size of the pipe.
x. Drainage facilities should be designed and constructed recognizing that periodic inspection and repair will be required, and should provide safety to maintenance personnel as well as road users.

3.5 Open Drains and Channels

Open channels may be constructed to achieve one of three main functions:

i. To capture and convey run-off originating from the road formation.

ii. To capture and convey overland flows before they reach the road formation, including catch drains at the top of cut batters to prevent scour.
iii. To capture and convey flows beneath the road formation, including flows from the outlets of culverts or other drainage infrastructure.

3.5.1 Types as Per Use

As per use, open drains and channels can be classified as:

a) Side Drain

Side drains collect and divert water away from the road surface, preventing potential damage and ensuring the stability and functionality of the road.

b) Median Drain

Median drains collect run-off from the roadway pavement and median and direct the flow to the pavement drainage system. The median drains shall be provided with desirable safe slopes of one in 10 or flatter for recovery of the errant vehicles.

c) Catch Drain

Catch drains intercept the surface water at the top of cut batters in order to prevent rilling, erosion or scouring of the batter slope. This type of drain is usually about 0.3 m deep. Alternatively, catch drains placed at the bottom of fill slopes intercept water from adjacent properties as well as convey road drainage to an outlet.

3.5.2 Recommendation for Safety

Surface drainage control is the aim of roadside channels. Usually, these are constructed as open-channel ditches that are carved out of the surrounding landscape. Because roadside canals with steep sides are more hydraulically efficient, they are typically chosen. Factors related to right-of-way, building, maintenance, and soil stability may limit the steepness of the slope.

The effect of different slope combinations on cars pulling off the road must be taken into account in roadside design. Regardless of channel design, the impacts of travelling across roadside waterways that are less than 4 to 8 feet wide are comparable for different slope combinations. Greater vehicle recovery distance and greater flexibility in selecting back slopes for safe traversal are made possible by flatter fore slopes (Figure 3-2).

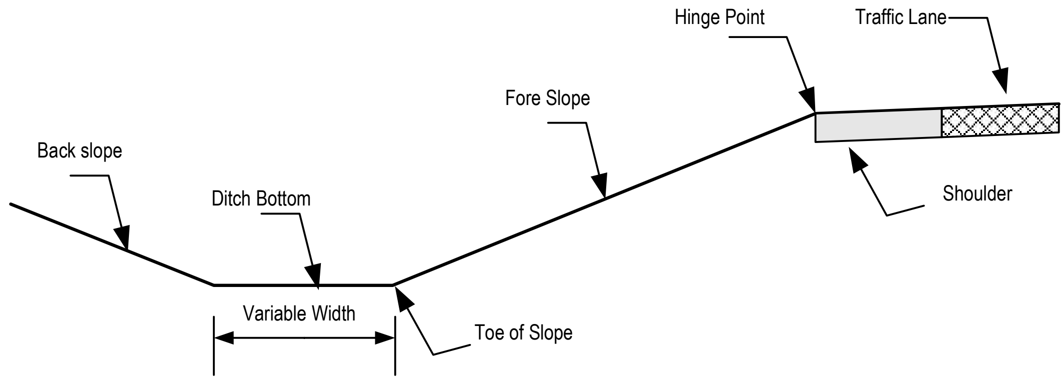

Figure 3-2 Parts of open drain

(Source: Taylor, 2023)

Reducing crash severity at intersections is a major concern for designers. Potential design solutions include: flatter slopes between the shoulder edge and ditch bottom; longer lateral offset from the roadway; and enclosed drainage facilities.

i) Top of slope (hinge point): It contributes to loss of steering control. Vehicles may become airborne at this point. Rounding of the top of slope may increase general roadside safety.

ii) Fore slope: It provides area for recovery maneuver or speed reduction prior to impact.

Steeper than 1V:4H	-Not desirable, limits choices of back slopes
1V:3H or steeper	-For locations where flatter slopes cannot be used, may require roadside barriers

iii) Back slopes:

1V:3H or flatter	-Typically used, accommodates maintenance equipment
Steeper than 1V:3H	- Needs evaluation for soil stability and crash impacts
Steeper than 1V:2H	- Retaining walls may be required
1V:2H or flatter	-May be determined by soil characteristics

iv) Toe of Slope: It is the intersection of fore slope with level ground or back slope. It is usually within clear zone and impacted by vehicle.

3.5.3 Typical Drains in Nepal

i) Earthen Drains

This is simply a trench or dish shaped drain dug up as per required shape and size along the side of a road and hence is the cheapest. Due to its low safe velocity and high risk of being eroded, it is not preferable in hilly roads or in areas with excessive flows. It can however be used in rural roads with low traffic and limited budget.

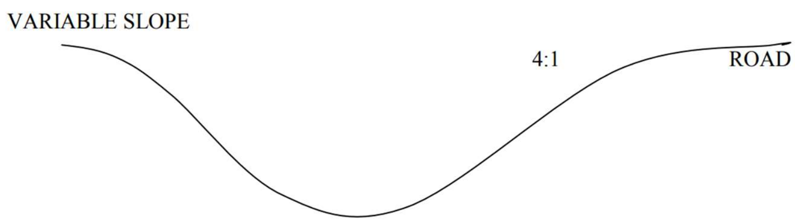

Figure 3-3 Earthen drain

In Terai area where there is enough space and the flow velocity, very low earthen drains could be effectively used. Check dams, mid rip raps can effectively solve the problem of scouring.

Earthen ditches can erode over time. The ruts and deposits of silt and debris can change the shape of the ditch, resulting in sections that are no longer traversable or forgiving. Furthermore, non-traversable ditches can be created by maintenance tasks like ditch cleaning.

Additionally, side slopes near the road path may erode, especially if ditches fill with silt. The moderately traversable steeper side slopes (1V:3H and 1V:4H) become dangerous when they form erosion channels that might cause a tire to snag or trip.

ii) Masonry Drain

Stone or brick lining cement mortar is a compromise between high-cost linings and cheaper dry-stone linings. It is versatile as any shape or size can be constructed easily. Drains with masonry linings if constructed properly with proper quality control, it can withstand vehicle-induced loads. Maintenance is also low and it can be covered with slabs when necessary. However, strict supervision for quality control is needed. Table 3-1 shows the type of lining required based on the type of soil at site and the longitudinal slopes.

Table 3-1 Type of lining of side drains

Type of lining	Longitudinal slopes,%	
	Sandy Soil	Clayey Soil
No lining required	<1	<2
Grass turfing	1~3	2~3
Stone Rip Rap,masonry,concrete	3~5	3~5
Stepping	>5	>5

(Source: NRS 2070)

- **Dish type -** This is usually used for low flow condition, though where space permits it can be used to drain larger volumes. Due to its shape (Figure 3-4), it is more forgiving to traffic and can also be used by pedestrians.
- **Channel type -** Trench drains lined or unlined of trapezoidal (Figure 3-5) and U - type shapes are used where space is limited. It can also be covered for safety and to reduce blockage from falling rock and soil.

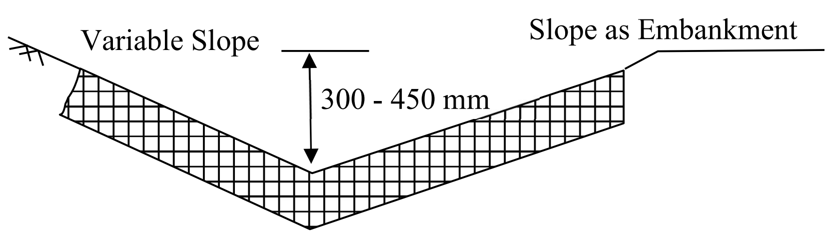

Figure 3-4 Masonry Drain (Dish Type)

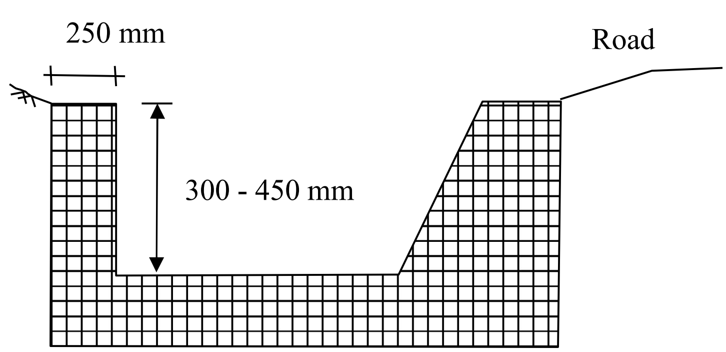

Figure 3-5 Masonry Drain (Channel Type)

iii) Precast Concrete Drains

Precast concrete, metal and synthetic conduits are usually used for sub-surface draining. However, they can be used for short stretches where traffic has to run over them often or in sections through villages and towns. These are the safest drain with respect to safety to the traffic. These are usually covered trench type and are most forgiving to the traffic Structurally, this is by far the soundest type of drain and requires minimum maintenance.

- **Dish type** - Precast concrete of required shape are cast and placed to form dish shaped or tick type drains (Figure 3-6).
- **Channel type** - These are usually covered trench type and are most forgiving to the traffic (Figure 3-7).

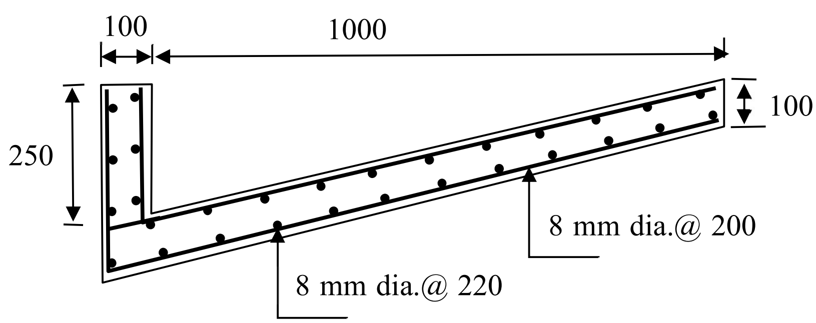

Figure 3-6 Pre-cast concrete drain (Dish type)

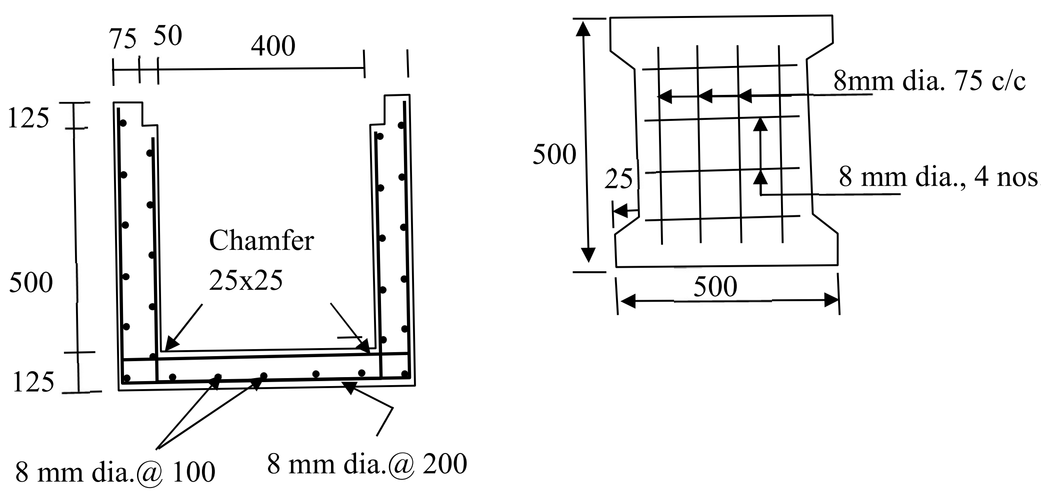

Figure 3-7 Pre-cast concrete drain (Channel type)

Quality control of pre-cast concrete drain is easier as they can be cast centrally. It is preferred as it cause minimum disturbance to the road traffic. Its high safe flow velocity and low coefficient of rugosity allows smaller section than from other types of lining for the same flow. It can be covered type where space is limited so that traffic and pedestrians can pass over it when necessary. Alternate type of channel type drain is to have cast-in-situ base with brick walls, cast-in capping and precast cover slab, which would be cheaper than the above type.

iv) Buried Drains

Along with cement masonry and precast concrete drains, we can have fabricated closed conduits for draining (Figure 3-8). Its high cost and difficulty in keeping clear of debris are the main constraints against using it as side drains. So, it is usually used for sub surface drainage. We could however use it for short stretches only where space is limited for closed drain and traffic requires to flow over the drain for prolonged period and in places where there is restriction of space or when road formation is in cutting and construction of deep open drain is undesirable.

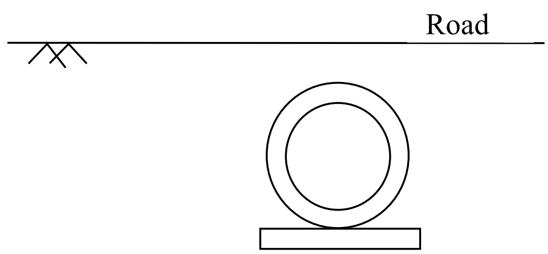

Figure 3-8 Buried drains

3.5.4 Factors to be Considered while Selecting Channel Type

In selecting the type of channel to be adopted, consideration should be given to:

- Capacity: The channel should have adequate capacity for the design flow.
- Erosion: Erosion control is a necessary part of good drainage design. Scour may occur unless the channel is protected where velocities exceed those likely to cause erosion to the material forming the channel.
- Maintenance: Maintenance methods should be considered so that the type of channel section adopted will be suitable for the methods and equipment that will be used for maintenance.

3.5.5 Design Consideration

The following aspects should be considered/established before the design of the channel commences:

- Avoid vertical drop to minimize safety concerns and erosion control problems.
- On high-speed carriageways, kerbs or steep batter slopes should be avoided for safety reasons.
- Median drains are usually flat bottomed and 2.0 m to 2.5 m wide at the bottom to accommodate maintenance machinery. For very wide medians, it is desirable from a road safety perspective to have batter slopes of about 1:10 (to cater for trucks) and grated pits and underground pipes.
- Using Manning's equation, determine the depth and velocity of flow based on a known discharge/flow rate in a stream.
- Channel velocity: Velocities need to be considered for their potential for scouring the channel.
- Channel slope: The minimum channel slope should not be less than 0.25% for a hard-lined channel and not be less than 0.5% for vegetated and bare-earth channels.
- Channel side slopes: Slopes should be based on the stability of the material. Typically, this will be in the range one in one to one in four.
- Maintenance: Safe access for maintenance equipment should be considered in addition to the ease of maintenance operations based on the cross-section shape.
- Freeboard: The freeboard to be adopted for open channels is the greater of (i) 300 mm, ii) 20% of the flow depth, and iii) velocity head. Where flooding of adjacent land and buildings does not represent a risk, the 300 mm requirement can be reduced to 150 mm.
- Trapezoidal channels are more common. The most efficient trapezoidal shape is the half-hexagon.
- A suitable grass species should be quick to establish, self-repairing, able to survive short durations of inundation, able to withstand proposed design velocities, and native to the area.
- Grassed channel velocity should not fall below 0.5 m/s. To function well, grassed channels normally have longitudinal slopes of 0.2% to 0.6%.
- The thickness of the riprap should be not less than 1.5 times the largest diameter of rock for riprap and rock filled channel.
- To reduce the velocity, a flatter slope than that existing may be adopted by introducing drop structures or meanders.

- The use of channel drops, waterfalls or scour checks may permit flatter channel slopes to be employed. For safety reasons, it is generally desirable to use several low-head drops rather than fewer higher drops.
- Baffle chutes provide a satisfactory method of dissipating the energy of flow in a channel where the slope is steep.

3.6 Camber Drainage

Two-way camber at straight section and one-way cross slope at super elevated section is provided for drainage of surface water towards the edge from pavement. Generally, shoulder cross slope is 0.5% more than pavement surface.

In multiple lane road with divided carriageway, depressed median with lined saucer drain can be provided, which can function as drainage.

In multiple lane road with divided carriage way by raised median, one-way cross slope is uneconomical and lead to large volume of water flowing toward the edge. The disposal of the water through central median drain is recommended.

In urban road with kerb at the edge, two-way camber at straight section and one-way cross slope at super elevated section is provided to direct water to the road edge. The water thus collected at the edge is disposed through the outlet provided at kerb.

4 MAINTENANCE

4.1 Correcting Unsafe Drainage Features

Drainage features should be built with safety in mind when they are next to or on a roadway where there is a possibility that a car, bike, or pedestrian could run over or into them. The corrective measures that can be performed to lessen the impact of a drainage issues that pose a safety risk once identified are covered in this section.

4.2 Correcting the Effects of Erosion on Roadway Side Slopes

- Side slopes, whether cut or fill embankments, and ditch sides, are usually constructed with slopes ranging from 1V:3H to 1V: 6H (or 1V:8H in relatively flat areas). Steeper slopes pose greater safety risks to motor vehicles traveling across or down them. These steeper slopes are also more challenging to maintain.
- Side slopes of 1V:4H or flatter are commonly accepted as safe side slopes. These slopes are traversable and recoverable. Such slopes allow drivers of errant vehicles to steer, brake, and recover from a run-off-the-road mistake.
- Side slopes between 1V:3H and 1V:4H offer marginal safety for vehicles. These slopes are called traversable, but non-recoverable and vehicles will travel beyond the bottom of the slope; therefore, a recovery area should be provided at the bottom of the embankment.
- All slope surfaces should be smooth, free of fixed objects, and free of snagging features, such as headwalls. Vehicles descending slopes are difficult to control and may collide, roll over or drop into a feature such as a pipe end, which can cause the vehicle to halt abruptly, become unstable and roll over, or strike the back of the slope.

4.3 Correcting the Effects of Erosion on Culvert and Pipe Ends

Pipes and culverts may have headwalls or specialized pipe end sections. Headwalls tend to channel water around their edges and can cause erosion gullies to develop.

Pipe and culvert ends should be inspected regularly, especially following significant storms or annually. It is essential to clear any debris that may obstruct water flow and to repair eroded areas by reestablishing them with appropriate soil/aggregate mixtures followed by reseeding.

4.4 Correcting the Effects of Erosion on Ditches

Both earth and lined ditches require maintenance to remove debris and prevent erosion that can create roadside hazards and/or reduce the effectiveness of the drainage system. It is important to restore eroded earth ditches and shoulders to their original safety profiles during repairs.

Earth roadside ditches that erode frequently and require regrading once or more times a year should be considered as candidates for paving or another lining solution that eliminates erosion and reduces the speed of the run-off.

Roadside ditches, along with the other drainage features such as drop inlets, should be checked annually and after major storms to ensure they are not clogged with debris or eroded.

4.5 Maintaining Good Drainage at Intersections and Access Points

Access points, such as road intersections, driveways, pedestrian and bicycle crossings are important areas where drainage features should be reviewed and, improved as needed. The intersection or the crosswalks should be at a relatively higher grade than the legs of the intersection such that water drains rapidly from the intersection.

4.5.1 Design Stage

- Proper cross drainage structure/causeway to pass water under/over the road should be designed.
- Wheel guard in the form of parapet wall should be placed to prevent vehicle toppling.
- Hazard marker should be installed at the side of parapet wall to caution running traffic.
- Guard post should be provided before and after cross drainage structure where embankment height exceeds 1.5m.

4.5.2 Post Construction Stage

- Placement, condition of cross drainage structure should be checked.
- Placement, condition of parapet wall, hazard marker, guard post should be checked.
- Shoulder dropping, rain cuts should be checked.

4.6 Safety Considerations

Drainage pit inlets can present an important safety issue that designers must consider. Considerable debate exists regarding the recommended maximum clear opening for kerb inlets to provide safety for small children. Even though past history has shown the likelihood to be low, the consequences of a child being swept down a flooded kerb and into a stormwater inlet can be extreme. It should be noted that a maximum clear opening shall not be more than 88 mm (based on test procedures in AS 4685.1/2004) to prevent the entry of a child. This precaution is particularly critical in parks, schools and childcare centers. Consideration should be given to the use of grilles across the drainage pit opening as an additional preventive measure. Also, the grate designs shall be such that it prevents bicycle tires from getting trapped.

Safety barriers must be installed near deep drainage ditches or catch pits to prevent vehicles from veering off the road. Also, it should be ensured that all drainage structures, including barriers, are clearly visible to drivers, especially at night or in poor weather conditions. Reflective materials or paint shall be used for better visibility.

Culverts and bridges should be adequately sized to handle extreme weather events without creating bottlenecks. Frequent inspections, particularly after severe weather, should be conducted to check for damage or blockages. Slopes should be designed such that the drainage ditches are traversable by vehicles that have accidentally left the road, thereby minimizing the risk of rollovers.

Public education campaigns should emphasize the importance of not littering, as debris can clog drainage systems and lead to road hazards.

4.7 Field Inspection Check Lists

FIELD INSPECTION CHECK LIST
(CHECK FOR THE FOLLOWING CONDITIONS)

1. *Rutting or shoving of pavement surface.*
2. *Discontinuity of surface level between the pavement and shoulder (shoulder drop-off).*
3. *Accumulation of earth or debris on shoulder.*
4. *Existence of erosion channels on ditch side slopes.*
5. *Silt or debris accumulation in ditch.*
6. *Headwalls and drainage structures that are not flush with the ground.*
7. *Damage to drainage structures, such as crushed culverts.*
8. *Grates with wide openings parallel to the roadway that can trap bicyclists.*
9. *Drains blocked by soil and debris.*
10. *Side slopes that have steepened due to erosion.*
11. *Erosion around all roadside structures such as headwalls, sign posts, and guardrail posts.*
12. *Drainage structures within clear zone that are not traversable or protected by suitable barrier system.*

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