His Majesty's Government of Nepal

Road Safety Notes 2

Design Safe Side Drains

Design Branch, Department of Roads

Ministry of Works and Transport

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ROAD SAFETY NOTES

Road Safety Notes are produced by tile Traffic Engineering and Safety Unit of Department of Roads as a means of increasing road safety awareness amongst highway engineers and others. Some of the Notes provide information on aspects of the road accident situation Nepal, whilst others give detailed technical advice on highway safety measures. The Traffic Engineering and Safety Unit was set up in Balsakh 2052 to provide a road safety and traffic engineering service, and is based in the Design Branch of the Department of Roads at Babarmahal, Kathmandu. The Unit Head (telephone/fax 262843, e-mail: tesu@dor.mos.com.np) will be pleased to receive comments and suggestions which will help improve the Road Safety Notes.

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Summary

Side drains are in integral part of roads and are an essential means of preventing structural damage to the road. From general observation it is apparent that their design and construction is not given enough thought in Nepal, resulting in problems. They are sized by ad hoc selection of standard drawings without any calculations, resulting in expensive, oversized, unsafe drains.

Design of drainage ditches is not an easy task. We need drains that are large enough to effectively cater for large discharge but deep drains can be unforgiving to pedestrians and vehicles that stray into them. Gentle side slopes and shallow depths are safer to the traffic but drains need to be deep enough to drain sub grade water. It is evident that while opting for a most suitable drain compromises have to be made.

Careful planning is needed to achieve the most appropriate and safe section of side drains for different terrain. Drainage design should take care of cross drainage, road surface drainage, erosion control and Sub surface drainage.

The design of drains should be such that any vehicle falling in it should remain upright, be as little damaged as, possible and recovered easily.

Earthen drains with gentle side slope (1:4) are effective in flat terrain. Dish type drains are more forgiving than channel sections. Channel drains should ideally be no more than 300 mm. deep (Absolute maximum of 450 mm). Deeper Channel drains should be covered. Shallow “V”, Dish type, Tick drains or covered drains can function as footpath if necessary and also provide extra width where roads are narrow.

Drains should also be easily maintainable by keeping at least 400 mm. wide flat bottom for easy cleaning and providing self cleansing velocities.

Discharge calculation should be done to attain effective drain section and to avoid unnecessarily large sections which are hazardous to traffic.
Final disposals should always be at stable water courses.

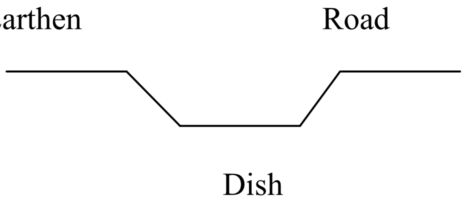
This document provides a guide for choosing and designing the most cost-effective and safe drain for any situation.

Overview

While designing we should go for the most suitable option. It should effectively drain tile Surface water, be easily maintainable, economic in cost, safe for traffic and other road Users.

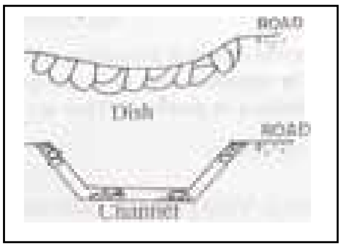
Main types of drains are given below

- Earthen



This is used in flat terrain where space is available and is usually of dish or shallow 'V' shaped.

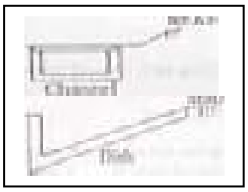
- Masonry drains



iii) Dish - This is usually used for low flow condition, though where space permits it can be used to drain larger volumes. Due to its shape it is more forgiving to traffic and can also be used by pedestrians

iv) Channel - Trench drains lined or unlined of trapezoidal 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.

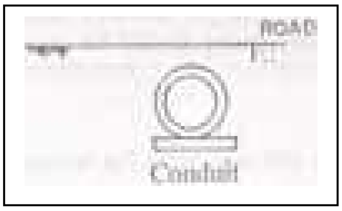
- Pre - cast Concrete drains-



i) Dish - Pre cast concrete of requited shape are cast and placed to form dish shaped or tick type drains.

ii) Channel - These are usually covered trench type and are most forgiving to the traffic

- Buried drains



Pre- cast concrete, metal and synthetic conduits are usually used for sub-surface draining, however they call be used for short stretches where traffic has to run over them often or in sections through villages and towns. These are tile safest drain with respect to safety to the traffic. These are usually covered trench type and are most forgiving to the traffic

Planning

The drainage design for the road should provide for:

- Cross drainage -Taking tile storm water flow across, the road by culverts, scuppers, etc.

- Road surface drainage -Draining the storm water falling oil (lie roadway by ditches, chutes, etc.
- Erosion control -Protecting the roadway and adjoining properties from erosion by ditches, intercepting channels, slope lining, riprap, etc.
- Sub-surface draining -The drains should not hinder in sub-surface draining but should help draining tile sub- surface Water.

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 load 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 which can not only be hazardous to tile road but also to tile traffic.

Final disposals should only be at stable dry water courses 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 also essential.

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

- The drain section would be smaller and hence more forgiving to tile traffic and pedestrians.
- 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.
- Comparatively lower How reduces the risk of damage to the outlets and the drain itself. Lower volume of discharge means smaller drain section and, though more in numbers, simpler and smaller culverts are adequate and hence would also be cheaper.
- Final disposals should be at stable dry water courses or running streams.

In hill roads where rainfall is heavy, it is recommended that culverts or other suitable type of cross drainage is provided every 60 - 100 m with proper disposals.

Appropriate camber in both the cross section of road and shoulder is required for tile drain to function properly. Nepal Road Standards should be followed for appropriate camber.

Drain should not be above the road surface if they are to function. Care should be taken at the time of construction to oversee the correct slope and the invert level to ensure this.

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

In hilly road the valley side slope is in existence before the road was built and hence without drains it should be stable enough to drain any flow coming oil to 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. Therefore drains on valley side would only shift tile aggravation to a new location without solving the problem at the first site. If it is unavoidable, down the discharge should be properly trained down to tile end point of the Outlets.

Variation in the cross section is another aspect which is often ignored. Smaller drain at the starting Point gradually increased towards the outlet not only reduces the cost but also enhances safety due to smaller drain size. The outlet of the drain should be dropped as far as possible from file road side so that the larger section drain is further away from the road.

Design Aspects

(A) Discharge Calculation

Designs of side drains and culverts based oil guesswork, do save-time and effort in the design, Process, but usually create problems that subsequently involve more time, effort and resources. Simple calculation will in most instances show that a smaller drain is adequate to effectively drain off the road and adjacent area.

Design Flood and Its Frequency

The first step in clesigimig facilities is to estimate the quantity of water likely 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 he tolerated, a peak runoff that recurs every 10 years is sufficient. 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 oil 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 of time after a big storm is acceptable where it is unlikely to damage the road by such event.

Method of Runoff Prediction

Rational formula

This method is applicable to small catchments (1 to 2 sq. km) only the peak runoff is given by

$$Q = CIcA/360$$

Where,

Q = Peak runoff in m3/sec

Ic = 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 (see Table 1).

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

The Critical intensity of rainfall Ic is determined as follows:

$$Ic = \frac{P(T+1)}{T(Tc+1)}$$

Where,

Ic = 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

Tc = Time of concentration in hrs.

The time of concentration (tc) is given by the formula below (The IRC, 1986) ;

tc [0.8 . 7 L3] 0385

H

Where ,

tc Concentration time duration of a storm corresponding to tile maximum rate of runoff (in hrs),

L Length of the watercourse from the farthest point ill the catchment to the outlet (in km), and

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

Table 1 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

In case of existing load and where data is unavailable we call approximate the flow by various other means. Few of these are tabulated below

i. Information from the locals.

Talking with the local people or even personnel who have been working on the road for longer period call provide information oil which we call base a rough estimate of flow.

ii. Observation

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

iii. Other Points

- Some small catchments may be flashy and grossly overload at discrete points
- Some chains are overloaded for irrigation purposes
- Changes in land use may increase run-off

Steps in Discharge Calculation

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

i. The frequency of return period such as 10),ears, 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 life weighted value of C is computed.

iii. Time of concentration 'tc' is calculated = (0.87 1, /if)0.385

iv. From tile rain fall Intensity - duration - frequency curves the rainfall intensity Ic is found in mm/sec. corresponding to duration T and frequency of return period or calculated by the formula $Ic = \frac{P(T+1)}{T\,(tc+1)}$

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

vi. The runoff quantity Q is computed $= \frac{C\,I\,Ad}{360}$

vii. The cross sectional area of flow A of the drain is calculated = 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 is required is higher or lower than the velocity assumed is accordingly lowered or increased.

xi. Once the tentative section has been obtained than changes can be made as per requirements as shown in the example in the appendix “A”.

(B) 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.

Steady flow can either be uniform or non-uniform (varied).

a) Uniform Flow

Uniform flow will take place when tile 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 me 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 tile following Manning Equation :

V = I R 2/3 S 1/2
n

Where,

V	-	Velocity, m/sec,
n	-	Rugosity coefficient (see Table 2)
R	-	hydraulic radius, m, (A/P)
A	-	Wetted cross sectional area of flow, in 2
P	-	Wetted perimeter, m and
S	-	Slope of the channel m/m.

After finding velocity from the above equation, tile discharge of the channel call be established by:

Q = AV

Where,

Q	-	Flows, m3 /sec,
A	-	Cross sectional area of flow, m2 and
V	-	Velocity of flow, m/sec.

Table 2 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

Table 3 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

b) Non - Uniform or varied flow

Varied steady flow occurs when tile quantity of' water remains constant, but the depth of the flow velocity, or cross section changes from section to section. The relation of all cross section will be:

Q = A1 V1 = A2 V2 = An, Vn,

The above equation is called Equation of Continuity.

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 water tight and, indeed, it is better if they are not water tight 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.

C) Safety Aspects -

a) Vehicles

Design of drains should be such that any vehicle which falls into them should:

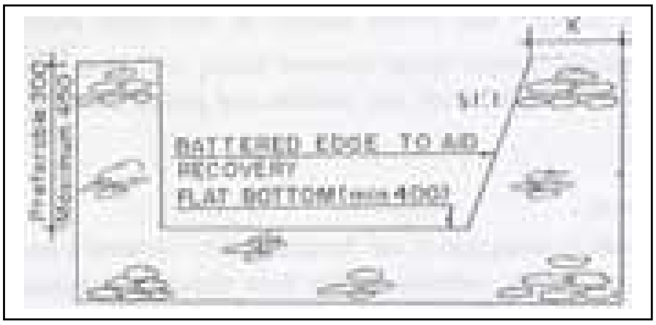
- remain upright (over turning or partial overturning can crush the passenger compartment, causing serious injury to the occupants.)
- be as little damaged as possible.
- be capable of being easily recovered.

Earthen Drains -

Slopes on the side of the drain nearest the road should not be more than 4:1 and preferably shallower if feasible, as this will make it possible for drivers of out-of-control vehicles to bring them to a stop without serious damage or injury.

Channel drains-

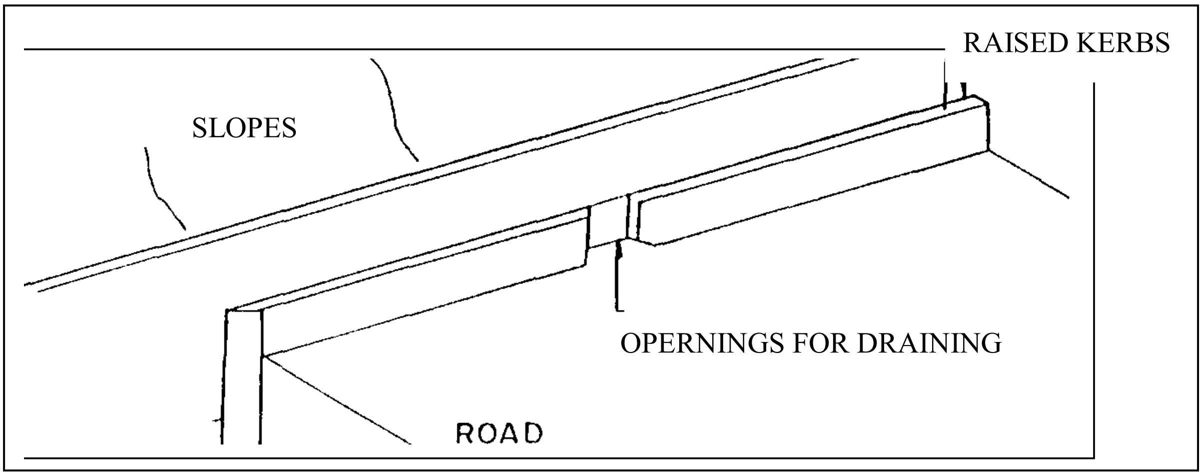
Usually drain depth below 300 min is forgiving to traffic, the absolute maximum for uncovered drain should be 450 mm. Larger depths can be avoided by either increasing the width where possible or even using half the section (up to the crest) of the paved road for limited duration to let as drain but care is needed to prevent any rut or erosion. Maximizing the width and minimizing the depth should always be the priority; however it should be deep enough to allow draining of pavement underlayers. Drain depth can be designed between these limits. Bottom of the drains must be flat to help vehicle stay upright.



Example of Safe Channel Drain

Masonry lined drains should be strong enough to withstand the loads exerted by vehicles crossing each other and traveling very near or even over the wall of the drain. There is a tendency to erect side walls in uncoursed random rubble and the sides of the walls facing the fill side is not properly constructed as they are finally covered up. This needs to be dissuaded as it can cause accidents when vehicles stray close to the drains, and the wall collapses due lo inadequate bearing strength.

Raising the roadside wall of the drain as a low kerb (see illustration below) can help vehicles from falling into it. However openings should be spaced at maximum one meter to avoid developing of puddles due to uneven micro topography of the road surface.



Example of Raised Kerb Channel Drain

Dish Drains -

As this is usually shallow and with mild side slopes it is more forgiving to traffic and any straying vehicles can recover to come back on the road.

Covered & Closed Drains –

These drains are wholly safe to the traffic if the cover stab is built strong enough to take the weight of the traffic. Size and weight of slab should be practicable for future maintenance i.e., slat) weighing around 50 Kgs. that can be lifted by two labours is practical.

b) Pedestrians

Where no footpath exists for pedestrian use tile shape or design of the drain should be such that it could be used by pedestrians. Shallow 'V', dish or covered type drain can function as footpath.

Drains on roads through villages and towns should be dish type, or covered or closed drains. In narrow road where space is limited cither covered drain, or if flow is low, dish drain is preferable, so that it call be used by both tile vehicle and pedestrians when necessary for safety.

(D) Maintenance Aspects -

- Drain dimension should be such that it call he both easily cleaned and requires minimal labour to keel) it clean i.e, tile velocity of the flow should be self cleansing, refer to Table no. 3.
- Proper design of' catch pits and treatment of slopes along tile drain ill hilly roads is required so that minimum amount of debris comes into the drain.
- Provision of check dams and rip rap oil sides at various stretches of drain in Terai road may be necessary to prevent scouring.

The lining of the drain should be strong enough, and the velocity of flow low enough so that there is very little wear.

These drains should also have a velocity that is between eroding and self cleansing to prevent excessive erosion and percolation into subgrade.

Drystone lining is a step up from earthen drain. The side & invert of the drain is lined with drystone. Though cheaper than masonry or other types of linings, due to high cost of maintenance, lack of structural, strength and excessive percolation of water into subgrande it is not preferred in heavy traffic highways. It can be used ill rural or side roads, or even temporarily in important roads.

Pre-cast concrete drains are more durable but the initial cost is very high. Masonry drains with proper quality control would be a better option.

Drains need to be kept clean for proper functioning. Open drains are easier to clean than closed ones but it' properly designed i.e. have sufficient longitudinal slope to induce self cleaning velocity, have catch pits, and are covered efficiently to prevent debris from entering the drain, closed ones ire equally maintainable. In areas where there are rockfalls and landslides covering the drains will prevent blockage.

The flat bottom dimension of a channel drain should be at least 400 mm to allow for cleaning with shovels.

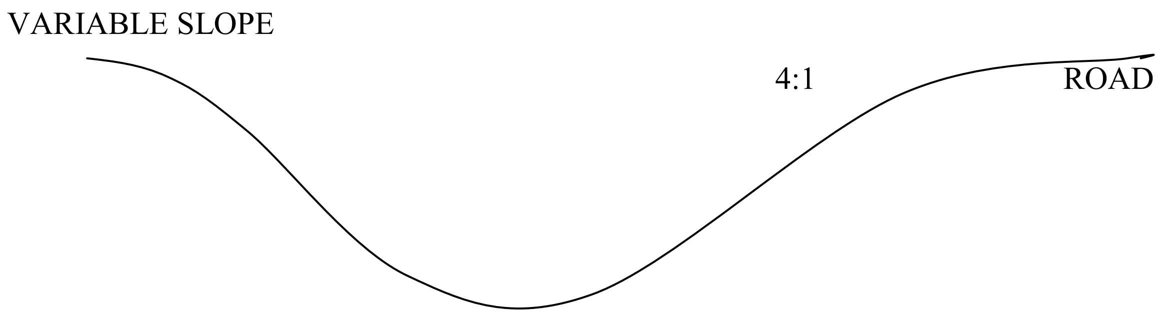
Recommended Drain Types -

The detail design showing, tile calculation of drain size is illustrated ill Appendix ‘A’. The dimension of, side walls, base, thickness of slab etc. is site specific and should he determined by the designers themselves.

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 tile cheapest. Due to its low safe velocity and high risk of being eroded it is not preferable in hilly, loads or in areas with excessive flows. It can however used in rural roads with low traffic and limited budget.

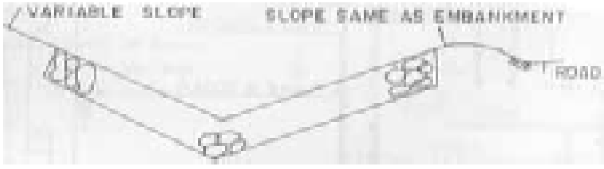
In Terai area where there is enough space and the flow velocity very low earthen drains could be effectively used. Check dams mid Rip Raps can effectively solve the problem of scouring.



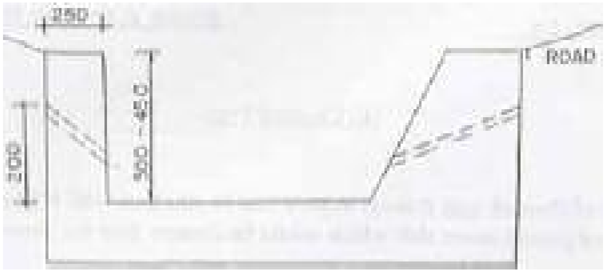
Example of Earthen drain

Masonry lining

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. 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. Few types are illustrated below.



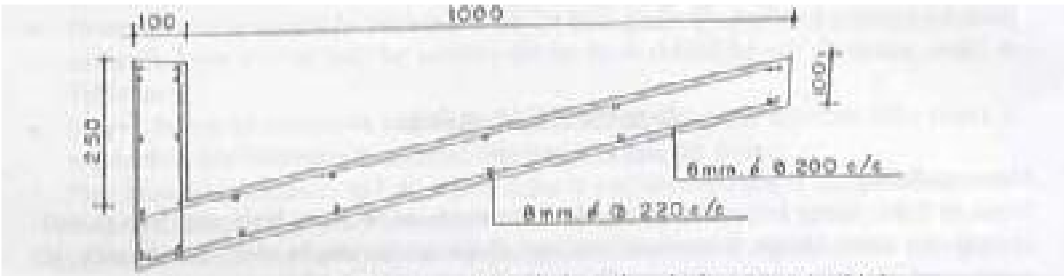
(i) Example of Dish Type



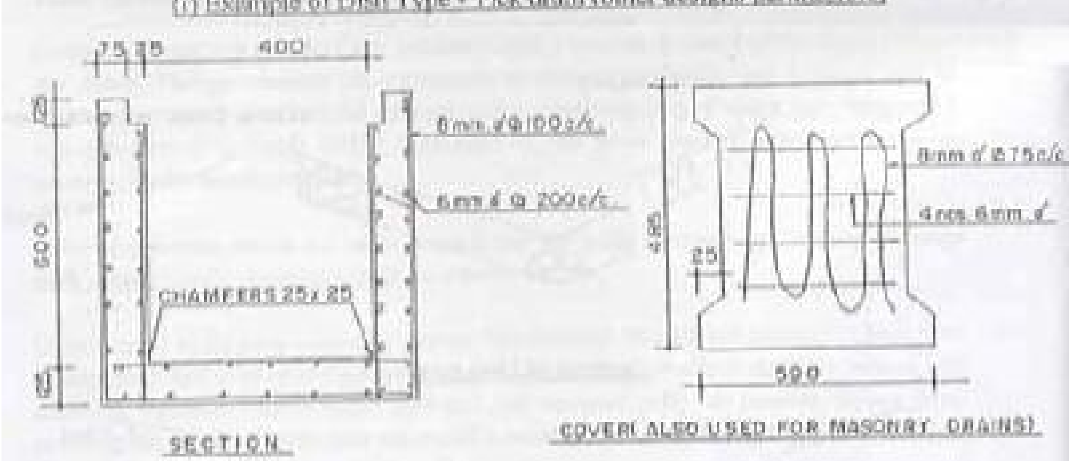
(ii) Example of Channel Type

Precast concrete drains

Structurally, this is by far the soundest type of drain and requires minimum maintenance. Quality control is easier as they can be cast centrally. It's placing 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 fining for the same flow. It can be covered type where space is limited so that traffic and pedestrians can pass over it when necessary. Typical sections are shown below.



(i) Example of Dish Type - Tick drain (other designs permissible)



(ii) Channel Type

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.

Buried drains

Along with cement masonry and precast concrete drains we can also have fabricated closed conduits for draining. It's high cost and difficulty in keeping it clear of debris is the main constrains against using it as side drains. It is usually used for sub surface drainage. We could however use it for short stretches where space is limited for closed drain and traffic requires to flow over the drain for prolonged period of time.

In places where there is restriction of space or when road formation is in cutting construction of' deep open drain may be undesirable. In such cases we can also use drainage trenches as shown below.

Appendix 'A'

Example of Typical Drain Section Design -

Drain length between cross drainage	=	100 meters (Assumed
Rainfall	=	125 mm/ 24 hrs (Assumed) This call be determined by referring Climatological records of Nepal for any particular region.
Watershed Area 'A'	=	4 Hectares (Assumed) It is usually less for this length
'C'	=	0.5 (From Table 1, assuming Clayey-soil with light cover
Time of Concentration 'tc'	=	(0.87xl-. 3 / 11) 0.385

'L' = Length of the watercourse from the farthest point in the catchment to the outlet, in km,
'H' = Height difference between the farthest point and the outlet, m,

	=	(0.87 x 1.13 /60) 0.315
	=	0.22 lirs
Critical Intensity of Rainfall IC	=	P (T+ 1) T(tC+1)

Where,

IC	=	Critical intensity of rainfall corresponding to time of concentration in mm/hour.
P	=	Precipitation of a storm in mm, 125mm
T	=	Duration of storm in hours, 24 hrs
Tc	=	Time of concentration in hrs, 0.22 hrs

Therefore "IC " = 125 (24+1) / 24 (0.22+1)

= 106.73

Discharge 'Q' = C Ic-A / 360

= 0.6 m3 /see,

Let 'V' = 4 m/sec, which is safe for masonry lined drain

Then Area of drain 'A' = 0.6 /4

= 0. 15 m 2

If the section is shown.

Then 0.15 = 0.4 d + 2d 2

Therefore d = 0.2 m

Hydraulic Radius R = Wetted cross sectional area flow, m2 'A' / Wetted Perimeter, m, 'P'

= 0.2 x 0.4 + 1/2 x 0.2 x 4 x 0.2 / 0.2 + 0.4 + (0.2 2 + 0.82)1/2

= 0.112

Required slope of drain 'S' = (Vn / R2/3)2

= (4 x 0.03/0.1122/3)2

= 27%

As the road gradient is 8% this slope is not feasible, therefore let tile flow velocity be 2.5 m/sec

Then, 'A' = 0.6 / 2.5

= 0.24m2

If the cross section is as shown below

then, 'A' = 0.4d + 1.5d2

d = 0.29m

R = 0.15

Required slope S = (2.5 x 0.03 /'0.152/3)2

= 7% which is feasible as the road gradient is 8%

Once we get this tentative section we can change it to some extent to suit our condition.
Let us assume that the slope of the drain is to be the same as that of the road gradient - 8%, and the sections as shown below -

Option - 1

Then ‘V’ = 1 R2/3 S1/2

I ((0.3xO.4 + 0.50.30.8) / (0.3+0.4+ (0.83 + 0.32) 1/2)) 2/3x 0.081/2

0. 03

= 2.7 m/sec Which is safe

Discharge 'Q' = 0.24 x 2.7

= 0.65 m3 Which is more than required, hence safe.

Option - II

'Then ‘V’ = 1 R2/3 S 1/21/2 4501

n

= 1 ((0.45xO.3+0.5xO.45xO.45)/(0.45A-0.3+(2xO.452)1/2))2/3 X0.081/2

0.03

= 2.9 m/sec which is safe

Discharge 'Q' = 0.29 x 0.24

= 0.69 m3 Which is more than required, hence safe.

Good example of safe, efficient drain design on Dharan- Dhankuta roads.

This drain through Gajuri village should have been covered for pedestrian and vehicle safety

Deep Triangular – shaped drains like this are hazardous.

Vehicle straying into side like that shown above tend to overturn causing severe damage.

Steep side of this earthen “V” drain may have caused the vehicle to overturn.