



Surface Water Drainage Channels

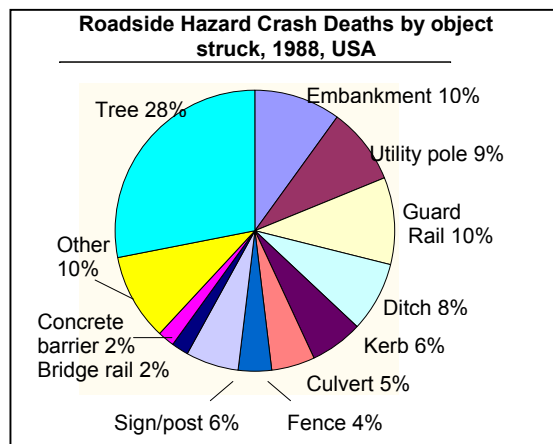
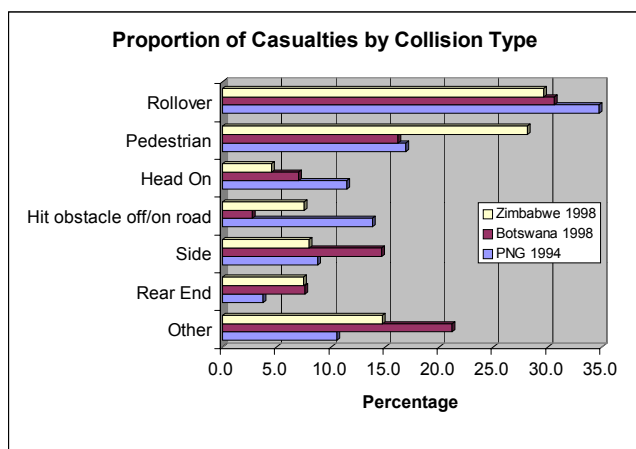


The Problem:

Many engineers consider good drainage to be the most important design consideration for a road, both to minimise road maintenance costs and maximise the time the road is operational. The lack of good drainage can lead to the ingress of water into the road structure leading to structural damage and costly repairs, whilst surface water can form a road safety hazard, especially on high speed roads when it can result in aquaplaning.

In rural locations, the drainage often consists of an open ditch parallel to the road carriageway with culverts at regular intervals to disperse the run-off to local watercourses. The fundamental problem, purely from a road safety point of view, is that these drainage structures in themselves can present a considerable hazard to errant vehicles leaving the carriageway, with a high probability that such vehicles will rollover. They also tend to reduce the effective carriageway width as many drivers like to keep their vehicle well away from the edge.

An analysis of data using TRL's Microcomputer Accident Analysis Package (MAAP) shows that for Zimbabwe, Botswana and Papua New Guinea, rollover accidents cause the largest group of casualties. A Canadian study showed that 22% of all run-off-the-road (ROR) rollover accidents involved hitting a ditch or embankment and in the USA a FHWA study determined that 55% of ROR rollover accidents result in injury and 1-3% in a fatality. A very high proportion of these are on rural roads.



Recommendations for Good Design:

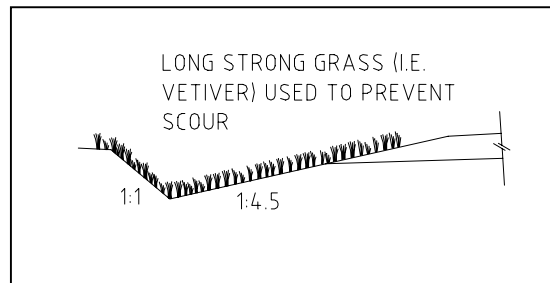
Research into these problems has led to guidance for producing safer drainage structures and other improvements for hazardous locations. Good design should incorporate where possible the following recommendations:

- The **side slopes** of the drain nearest to the road running surface should be shallow, preferably flatter than 1:4.5.
- The **drain depth** should be minimised, but ideally less than 150mm in depth to prevent the vehicle from over-turning. Deeper drains should be accompanied with flatter slopes.
- The drain and other obstacles should be located as far from the carriageway edge as is feasible and acceptable, but preferably a minimum of 4 metres, to provide an **obstacle-free zone** adjacent to the running surface.
- Visual, audible and other physical **deterrents**, such as safety barriers, should be used to warn drivers of hazardous locations (eg steep slopes or drains close to carriageway) and to prevent vehicles straying from the carriageway.

Range of designs available:

Engineers have developed a number of solutions to the general problem of road drainage. The differences in design are often forced by changes in geology and terrain, although some designs are not always economically justifiable for low traffic volumes. **It is apparent that certain designs are inherently safer than others whilst still fulfilling an engineering function.** An understanding of the critical elements of drainage design can result in a much safer and cost effective solution.

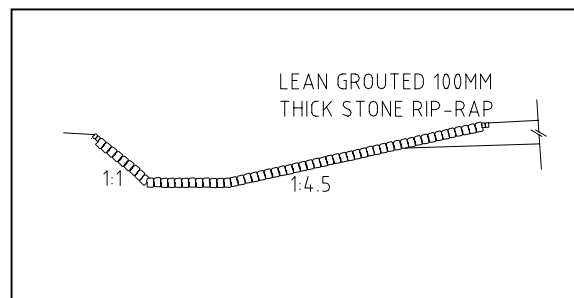
Conventional Vee-shaped drain



Cost 🚫🚫
Safety ★★

Vee-shaped drains are often used as a low-cost alternative to the more hydro-dynamic trapezoidal drains. There are many variations of the traditional shape with 'J' and 'Y' drains incorporating a lip on the roadside edge. The vee-shape is ideally suited to flat environments where there is plenty of room to incorporate a shallow roadside slope at low cost. It is also preferable to provide a slight slope on the vergeside edge to aid the vehicle in regaining the road carriageway.

Trapezoidal Drain



Cost 🚫🚫🚫
Safety ★★

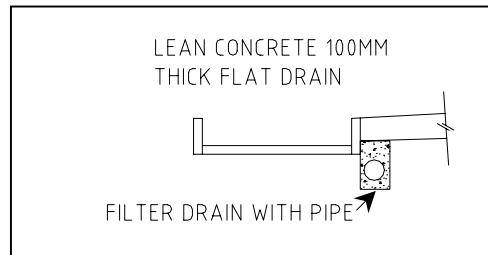
The trapezoidal drain has better hydro-dynamics than the vee-shaped drain but is still easy to form using a grader and digger. The drain can be protected from scour by the addition of gravel, grass or rip-rap. The trapezoidal drain is ideally suited to flat environments in high rainfall areas or alongside roads running through large rainfall catchment areas. Errant vehicles leaving the carriageway may be able to regain control if the side slope is no steeper than 1:4.5 gradient.

SAFETY CONSIDERATIONS OF DRAINS

- Drain depth should preferably be limited to 150mm if no safety fence or barrier kerb is provided between the road and ditch
- Drainage capacity can be improved by increasing the number and frequency of turnouts.
- In flat environments, the drain can be constructed further from the carriageway at very little extra cost. (See photo opposite)
- The side slope nearest the road should have a maximum gradient of 4.5:1 and preferably flatter
- Riprap aids the traction of the tyres of errant vehicles



Flat-Bottomed Drain



Cost 🏷️ 🏷️ 🏷️

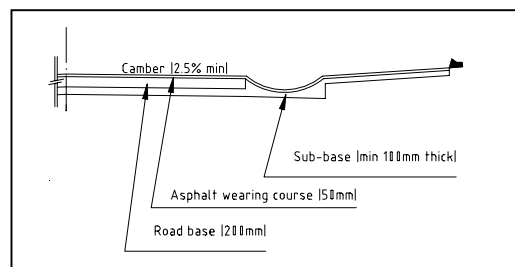
Safety ★ ★ ★

The flat-bottomed drain has good hydro-dynamics. The hydraulic capacity can be improved by widening the drain or deepening the soffit, although the depth should preferably not exceed 150mm. This type of drain is ideal for flat environments, cuttings or hilly terrain where space is restricted. The vertical edge to the drain may prevent errant vehicles from being able to regain control but, providing the depth is below 150mm, the risk of rollover accidents is negligible.

SAFETY CONSIDERATIONS

- The drain depth should preferably not exceed 150mm to prevent over-turning of vehicles.
- The drain should be located as far away from the road as possible
- The hydraulic capacity can be improved by increasing the number of cut-outs rather than increasing the drain depth.

Parabolic Dish Drain



Cost 🏷️ 🏷️

Safety ★ ★ ★ ★ ★

The parabolic dish drain has good hydro-dynamics but a low capacity. The capacity can be improved by deepening the parabola or by increasing the number of turn-outs. This style of drain is ideal for low rainfall situations or routes with a high number of roadside properties or accesses. A deeper drain can be constructed further away from the road to collect rainfall run-off from outlying land if required.

SAFETY CONSIDERATIONS

- The drain can be used to segregate the footpath / parking area from the main running surface.
- The parabolic arc should not exceed 20° or a gradient of 4.5:1
- A drain further from the road can be used to collect rainfall run-off from the outlying land.
- Turn-outs at frequent intervals will increase the drain capacity.

Covered Drains:

Whilst covered drains are usually associated with urban areas, situations do arise in the rural environment where a covered drain can offer an affordable alternative to an open drain. In Nepal covered drains have been used to prevent the drain becoming clogged by rock and debris falling from the cliff face. The lip on the drain lid is designed to prevent rocks and other debris from rolling onto the road, but it can also act as a deterrent to vehicle tyres leaving the road carriageway, and can even help as bend delineation by reflecting headlights. Additionally the lip can be sited to prevent vehicles from accidentally driving over the slabs, therefore the drain cover can be designed to lower load bearing standards at lower cost providing a cost effective alternative for rural environments. They must also be light enough to be lifted by 2 men for clearing when necessary.



French drains can provide a cheap innovative alternative to covered drains. This type of structure is commonly used in slope stabilisation but it can provide a scour free alternative for longitudinal drainage for the highway. French drains consist of a trench that is filled in with stone or other porous materials. In the UK, successful trials have been conducted using shredded rubber tyres with the top layer coated in bitumen in longitudinal drains for rural highways. If available the fill material should be wrapped in a geomembrane to prevent clogging by fine particles of soil.

Innovative Designs:

In Malawi, the construction of certain roads has utilised earth excavated from the side of the route alignment to construct the road embankment. This naturally lowered the water table in the vicinity of the road and by constructing gradual shoulders, at a maximum gradient of 1:4, provided a safe environment for vehicles to recover if they should accidentally leave the carriageway. These are commonly called 'scraper ditches'. This type of approach, sometimes referred to as a scraper ditch design, can lead to a cost and safety effective alternative to more conventional designs.



Driver Awareness:

Where it is not possible to alter the drain design to provide a safe zone for errant vehicles, signing and better delineation can help warn approaching vehicles that there is no recovery zone adjacent to the carriageway.



Signing: Signs fall into two categories; those that advise the driver of what the danger is and those that advise the driver of the actions he should take. On sections of road with a continuous hazard, the signs should be repeated at regular intervals dictated by the design speed.

Delineation: Improving a driver's perception of the forward road environment can also help address a crash problem. Edge delineation using white or yellow lines has been found to be an effective means of guiding a driver past a hazard. Typically, edge lines are 100mm wide, but research has shown increased benefits from providing a 200mm wide edge line (Pak-Poy and Kneebone Pty Ltd, 1988). More advanced road markings such as those laid using vibro-plastic combine a visual and aural warning to drivers straying from the road carriageway.



Crash Amelioration: An alternative solution to signing is to provide a physical barrier in front of the drain or steep slope to prevent cars leaving the carriageway. In Tanzania, vehicles are prevented from veering from the carriageway by a barrier kerb located in front of the drain. This provides a low-cost deterrent. Gaps are built into the structure to allow dirt and debris to be washed off the road.



Cost effective solutions

Very little research into the accident effects of alternative drainage ditch design is available largely because accident databases simply do not contain the information that is required to reveal the causative factors in rollover accidents. Safety recommendations have therefore developed from a small sample of studies. One study conducted by Zegeer et al (1987), provided guidance on the typical accident reduction rates that can be expected from flattening side slopes. From this, a cost benefit analysis showed that it is feasible to design side slopes at a minimum ratio of 4.5:1.

Reduction in Accidents					
Sideslope Ratio in After Condition					
Before	3:1	4:1	5:1	6:1	7:1 or flatter
2:1	2%	10%	15%	21%	27%
3:1	-	8%	14%	19%	26%

However, although it could be argued that revision of the relevant geometric standard to more forgiving designs should be a high priority, it is often not considered to be a feasible option. It is therefore important to consider alternative forms of prevention or amelioration of the accident severity once the vehicle has left the road running surface. The following table provides guidance on the typical reductions in injury accident numbers that can be expected for different types of countermeasure and estimates the potential first year rate of return (FYRR) based on average construction costs calculated from a sample of seven developing countries and an assumed average injury accident cost of £5,000 and an existing accident rate of 1 injury accident/km.

Measure	Do-nothing scenario	Additional cost from Do-nothing scenario £ / km length	% reduction in accident numbers	FYRR
White lines	-	£550	0-14%	0-127%
Warning signs	-	£800 (based on 4 signs at each of 2 hazards)	27%	168%
4:1 drain or embankment slope	2:1 drain or embankment slope	£1,200*	7-10%	29-42%
Steel safety barrier	-	£20,000	20%	5%
4m clear zone	-	£2,000* (based on clearing land and constructing an embankment)	29%	73%

* Based on a 1m embankment height

Cost and safety efficient design of longitudinal drains depends on balancing the capacity of the drain with the number and frequency of turnouts provided. The drain capacity is a function of the drain shape and size. Once the capacity has been estimated the frequency of turnouts can be calculated. Cost and safety efficient design should balance the design that provides the shallowest and flattest side slopes at a reasonable cost. The number of turnouts will vary the design shape and the final cost. Some basic design information needed to determine these parameters is provided below.

To determine the appropriate drainage design the engineer needs to estimate the design runoff and the velocity of flow and using this information estimate the size of drain and number of turnouts. The design runoff is most commonly calculated using the Rational Method formula. This is suitable for catchment areas up to 5km² (and sometimes 25km²) but the method makes no allowance for storage of rainfall on the slopes following a storm, and therefore tends to be very conservative and lead to overdesign. A number of alternative methods exist but are not presented here and in practice the engineer is advised to try a few and verify the results through field investigations.

Soil and Land Use	Runoff Coefficients, C		
	Average slope		
	Mild (0-4%)	Medium (4-10%)	Steep (10%+)
Rocky, heavy clay	0.60	0.75	0.85
Intense cultivation, loamy/ clay soils	0.50	0.60	0.70
Grass cover, medium soils	0.40	0.50	0.60
Dense vegetation, forest	0.05	0.15	0.25

The Rational Method

$$Q = 0.278CIA \text{ for } T \geq T_c$$

Q – peak run-off discharge (m³/s)

C – runoff coefficient (runoff/total rain)

I – mean rainfall intensity (mm/h) for a duration T_c and a return period P

A – drainage area (km²)

T_c – time of concentration (mins),

Where:

$$T_c = 0.01947L^{0.77} S^{-0.385}$$

L – maximum length of path of travel of water (m)

S – slope of catchment = H/L (m/m)

The mean intensity of rainfall is difficult to calculate. The current UK standard (HA37/97) adopts a rainfall depth occurring in 2 minutes with a return period of 5 years (2minM5) as the norm. More typically in developing countries a return period of 10 years is used. However, the final decision should be made following an evaluation of the cost and safety implications of the design return period being exceeded.

Once the engineer has estimated the amount of rainfall entering the catchment area, the capacity of the different drain designs needs to be determined to allow the designer to choose the best option. Most commonly, the Mannings formula is used. Although this assumes steady state conditions and a uniform flow, it provides a reasonable estimate for calculating the water velocity (scour) in the ditch. The final flow velocity should be kept below the safe flow velocity, V_{safe} .

Roughness coefficient, n			
Flood plains:	Good	Average	Poor
Grass or low crops	0.030	0.040	0.050
Brush	0.050	0.075	0.100
Trees	0.075	0.100	0.150

Manning's Formula

$$V = \frac{R^{\frac{2}{3}} S^{\frac{1}{2}}}{n} \leq V_{safe}$$

Where:

V – velocity (m/s)

R – hydraulic radius = A/P

n – roughness coefficient

S – average longitudinal gradient of ditch (m/m)

Material	Safe Flow Velocities, V_{safe}		
	Bare	Medium grass cover	Very good grass cover
Very light silty sand	0.3	0.75	1.5
Light loose sand	0.5	0.9	1.5
Coarse sand	0.75	1.25	1.7
Sandy soil	0.75	1.5	2.0
Firm clay loam	1	1.7	2.3
Stiff clay/stiff gravelly soil	1.5	1.8	2.0
Coarse gravel	1.5	1.8	Unlikely to grass over
Shale, handpan, soft rock, etc	1.8	Unlikely	Unlikely to grass over
Hard cemented conglomerates	2.5	Unlikely	Unlikely to grass over

References

Kirk S (1997). *Technical review of road accident countermeasures and engineering design features. A comparative study of their relative effectiveness at reducing and preventing accidents.* TRL Unpublished Project Report PR/OSC/125/97. Transport Research Laboratory, Crowthorne.

Pak-Poy and Kneebone Pty Ltd (1988). *Road Safety Benefits from rural improvements,* Transport and communications. Federal Office of Road Safety Report CR71. Australia: Federal Office of Road Safety.

Robinson B J (1996). *Assessment of vehicle handling safety when driving into roadside water drainage channels.* TRL Report TRL230. Transport Research Laboratory, Crowthorne.

Walker C D (1999). *Safety aspects of road edge drainage features.* TRL Report TRL422. Transport Research Laboratory, Crowthorne.

Viner J G (1995) *Rollovers on sideslopes and ditches.* Accident Analysis and Prevention, Vol 27, No 4, 483-491

Zegeer C V, Reinfurt D W, Hunter W W, Hummer J, Stewart R and Herf L (1987) *Accident effects of sideslope and other roadside features on two-lane roads.* Transportation Research record 1195.

CaSE Design:

The purpose of this project is to identify highway engineering designs that are inherently safe and that fulfil their engineering function at little or no extra cost to alternative designs. It is also concerned with the challenge of making low-cost engineering designs as safe as possible at minimum additional cost. If you have any suggestions for such designs or have comments on this CaSE Note, please contact Stephanie Kirk, Brian Hills or Chris Baguley at International Division, Transport Research Laboratory, Old Wokingham Road, Berkshire, UK RG45 6AU.

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Cost and Safety Efficient Design
for rural highways in Developing Countries

