LECTURE A10 - SAFETY DEVICES AND APPURTENANCES **PRESENTER : CD SCOTT**

1 INTRODUCTION

Every facet of the design of a road, particularly higher order roads, has the consideration of safety as one of the major criteria. Stringent standards of geometrics and construction lead to safer roads and the reduction of crashes. Good communication with the driver mainly through advisory and direction signage and surface markings will reduce dangerous, sudden, hesitant and erratic manoeuvres.

Crashes are multivariate in nature. The corner may be sharp and unexpected, the driver drunk/impatient/ incompetent/all-of-the-above or a vital bit may suddenly drop off his or her car. All three factors in combination will almost guarantee a crash. The legal profession refers to as the proximate cause of the crash. This could either be the main contributory factor or, alternatively, the last straw that broke the camel's back. While the crash was ultimately a combination of faults in all three elements of the driver, the vehicle and the road, it is essential that the designer should have a clear understanding of the weaknesses and characteristics of the last two elements because his primary concern is the first-mentioned, i.e. the road itself and the roadside.

The designer should adopt an attitude of compassion for the driver, for his shortcomings or poor judgment - an overtired or sleepy driver, an impatient of frustrated driver, one who suddenly becomes ill, or whose vehicle develops mechanical failure. There is also the case of the innocent driver who may have been forced off the road by a sideswipe or corrective manoeuvre or who used the roadside to avoid a crash. Any of these may be involved in a run-off the road crash, for which there should be a "forgiving highway". There is no excuse for a road design which compounds the problem. The forgiving road is one that does two things:

- it minimises the possibility of the driver making an error of judgement
- it minimises the consequences of an error of judgement

Designers must always be aware of the fact that good judgement comes with experience and that experience comes from bad judgement. He or she has to allow for the period of bad judgement in every driver's life.

Possibly the most important single rule in road design is consistency. Only by making every element conform to the driver's expectations and by avoiding abrupt changes in standards can a smooth-flowing, crash-free facility be produced. The basic function of any road system is to provide a safe and efficient means of transportation. Understanding how drivers perform is essential to providing quality transportation. A "user-friendly" highway is designed to be compatible with a driver's capabilities and limitations. The potential for problems arises as a result of an incompatibility created by inconsistent geometrics.

2 CRASHES RELATED TO ROAD CLASS AND LOCATION

2.1 Road Class

There is a distinct difference in the number, type and severity of crashes occurring on the various classes of roads. In-depth studies of crashes and the factors causing them has been undertaken in the United States of America. In South Africa, the reporting and recording of crash details has been of a lower standard in the past but, generally, local patterns follow those of the United States, with the exception that South Africa has between 5 and 10 times more crashes per vehicle or per veh-kms. The following is based on American publications.

Fatality rates on freeways are 1,5 per 100 million vehicle kilometres, whereas 2,93 deaths per 100 million vehicle kilometres occur on arterial routes. The rate increases on secondary rural roads.

Freeway crashes tend to be fatal by virtue of the speeds involved. The most usual freeway crash is the rear-ender caused by somebody braking sharply to avoid an object on the road. The cross-median crash is almost always fatal and this can usually be contained by selecting the width of median at about 9 m or more and filling the median up with shrubbery which operates as a sort of vegetable arrestor bed. Similar crashes occur on urban arterials although the lower speeds cause the consequences of these crashes to be less severe.

The crashes to watch out for on collectors normally occur at intersections. The sheer variety of crashes make these interesting and they are a study in themselves.

On residential streets, crashes between vehicles typically arise from someone emerging unexpectedly from a driveway. Speeds are very low and the damage is normally just restricted to the vehicles themselves. Cats and dogs are often hit by cars or the cars hit something else in their endeavours to miss the offending animal. Children are seldom hit by cars in spite of their being found on bicycles, skateboards, roller blades and constituting a fairly sizable unmotorised vehicle population.

2.2 Location

Crash rates in urban areas are higher for all classes of roads than in rural areas. However, the higher speeds associated with rural roads result in higher fatality rates.

Higher classes of urban roads with partial access control have higher speeds and correspondingly higher fatality rates, particularly pedestrian deaths because of the limited number of safe crossing points. Pedestrians are also not very inclined to move along a street to a safe crossing point but would rather just cross the road from wherever they happen to be and have been known to make it safely to the other side of the street but not always.

3 CRASHES RELATED TO GEOMETRIC ELEMENTS

3.1 Horizontal Alignment

Horizontal alignment features have a strong influence on crash experience. Records indicate that a rural road will have about 2,5 crashes per million vehicle kilometres on a curve of 200 m radius and only a rate of 1,0 for a 1 500 m radius. However the rate increases with the increase in curve frequency, which relates to driver expectancy. Similarly, relatively infrequent reductions in sight distance produce a higher incidence of crashes.

3.2 Vertical Alignment

There is a marked relationship between gradients and crash rates, largely due to speed differentials on upgrades and increased stopping distances on downgrades. Crash rates increase about threefold on grades of 6 % compared to 2 or 3 % gradients. Similarly, crash rates increase about twofold on crest and sag curves with the latter being slightly worse (probably because of the higher speeds).

3.3 Cross-Section

A marked decrease in crash rate for higher order roads with shoulders 2 m wide as opposed to those with minimal or no shoulders is observed.

Roadway width and individual lane widths are also critical safety factors. One study measured the decreases in crashes per million vehicle kilometres as shown in Table M3.2

3.4 Surface

Variables such as surface roughness, aggregate, drainage, gradients, cross-slopes and percentage time while road is wet all enter into the friction coefficient and skidding problem. In Britain it was found that, generally, the crash rate did not increase when roads were wet. However, the nature of crashes changed insofar those due to skidding doubled.

Table M3.1: RELATIONSHIP BETWEEN LANE WIDTH AND CRASH RATE	
Lane width (m)	**Crash rate (per 100 x 10^6 vehkm)**
2,74 (9')	**1,50**
3,04 (10')	**1,10**
3,35 (11')	**0,90**
3,65 (12')	**0,91**

Contrary to popular belief, drivers do not reduce their speed merely because the road is under water and the visibility, because of rain, is reduced. A recent American study found at one of their sites that speeds in fact increased under rainy conditions! Maybe everybody was just in a hurry to get home.

What all this amounts to is that the geometric designer should also be fairly knowledgeable about materials and be able to talk intelligently to the materials engineer about his needs in respect of skid resistance - particularly at intersections - effective drainage of the road surface and the like.

4 CRASHES DUE TO ROADSIDE AND ROADSIDE OBSTACLES

In the United States it has been found that 37 % of all fatalities are the result of single car crashes with fixed objects or as a result of leaving the roadway. Hitting fixed objects is one of the two major types of crash experienced. The only higher crash rate is that of rear end crashes.

4.1 Roadside Obstacles

Typical roadside obstructions which amount to a series of traps for the errant vehicle are:

- good sturdy trees
- steep slopes on which the vehicle will overturn
- ditches which the vehicle cannot traverse without severe deceleration (resulting in the front end digging in followed by the somersault)
- steep cut slopes in earth or rock resulting in unparalleled g-forces and/or the bounce
- exposed bridge parapet ends usually struck end-on resulting in the dead stop in all senses of the word
- drainage structures in the median or on the back slopes typically resulting in the vehicle rolling over
- median openings between bridges down which a vehicle can disappear in the best traditions of the Bermuda Triangle

- piers and gore areas
- light standards and signposts which formidably replace the original trees as a steel-trunked forest
- poorly designed or placed guardrails

This is not intended to be a comprehensive list as drivers are fairly imaginative in their search for different things to hit.

4.2 Roadside Safety

Research developments and some applications are showing progress in this area, but a much broader approach is needed, recognising that:

- vehicles WILL leave the roadway
- the optimal roadside design should allow the driver to recover control of his vehicle and redirect it to the roadway with little or no damage and with no crash with other vehicles
- the optimal design is not always feasible due to economic considerations.

To make the best of the real world with regard to roadside safety, the following priority of actions is recommended:

(a) eliminate the hazard

(b) relocate the hazard to a point where it is less likely to be struck

(c) use break-away devices to reduce the hazard

(d) use impact attenuation devices to reduce severity

(e) protect the driver through redirection of the errant vehicle

5 ROADSIDE DEVICES INTENDED FOR SAFETY

5.1 Improved Roadside Design

For major roads, the border areas should be kept as free from obstacles as possible and fill slopes for embankments should have a slope of 1:5 or flatter, thus eliminating the need for guardrails. Cut slopes should be sloped to 1:3 for the lower portion and the verge shaped so that efficient drainage can be achieved while still allowing an errant vehicle to traverse the ditch in safety. Steep cut section in rock should be faced in concrete which can be shaped to a "New Jersey" profile.

Recent research has, however, suggested that the New Jersey profile is not without its problems. The small wheels of the compact car do not roll all that well over the vertical 75 mm at the bottom of the profile. The car suffers a modest bounce with the nearside wheels then hitting the profile at a point roughly halfway up the profile. At this stage, the car has achieved a list of about 45 ^{0} to port or to starboard depending on the location of the barrier relative to the carriageway.

The wheels hitting the profile generate enough of a bounce to cause the car to capsize. Realising this problem, South Africa buries the New Jersey barrier by 75 mm into the road surface as shown in TRH 17. Cars are still caused to capsize by the New Jersey barrier but, hopefully, to a lesser extent. The current USA opinion is that the New Jersey profile should be replaced by a constant slope. What that slope should be is still the subject of research.

Where possible, the centre and shoulder piers of underpasses should be eliminated. Unfortunately, the cost implications of the clear span that this suggests renders the probability of being able to follow this course of action very low. The designer should, however, be aware of this possibility and use it if the occasion presents itself.

Openings between twin bridges can be eliminated by closing the area with structural decking. This removes the need for bridge rails and parapets in addition to covering the opening.

Open median drains with guardrail protection remain a hazard. The solution is to use grate-type inlets which permit the removal of the drainage structure and guardrails.

5.2 Sign Support and Light Poles

Highway signs and light poles, so necessary for proper traffic operations, can be very dangerous fixed obstacles. The "butterfly" gore sign can be mounted on a small break-away (frangible based, slip base etc) support. Overhead sign supports however are not well suited to the break-away post concept due to the danger of dropping a large sign bridge on the roadway. Such supports, if placed near the roadway, require guardrails to redirect the off-the-road vehicle away from the unyielding support.

Simply by virtue of their frequency, light poles constitute one of the greatest potential fixed-object hazards. Although these can be designed with break-away bases, these have had only limited success and lighting poles are normally located behind protective guardrails. This can be most effectively achieved by using central lighting in the median. In interchange areas, the use of high-mast lighting can virtually eliminate the hazard of light poles adjacent to the travelled way.

5.3 Guardrail Design

The Highway Research Board Special Report No. 81 on highway guardrails states that:

> *Every highway should be designed through judicious arrangement and balance of geometric features to preclude or minimise the need for guardrails or other protective devices.*

Guardrails are erected to protect errant vehicles from steep slopes or fixed objects. Many authorities tend to adopt the reverse approach by erecting guardrails to protect fixed objects, such as their signage, from moving traffic thus creating a hazard that need not have been there. A signpost that is well away from the shoulder is not necessarily a hazard, whereas the guardrail, mounted at the shoulder breakpoint to "protect" it, is. Longitudinal guardrail performs by redirection of errant vehicles away from the roadside hazard, providing constant and not excessively rapid deceleration. The vehicle should not be redirected onto or across the travelled lanes of the roadway.

The three basic types of barriers include

- rigid, of which the New Jersey barrier is the prime example
- semi-flexible, which basically includes the W-beam (blocked-out, strong post - basically Armco - arrangement)
- flexible, exemplified by the box-beam and the cable type (both of which are weak post arrangements)

Rigid barriers are used in situations where there is no room for deflection of the barrier on impact.

Flexible or semi-flexible guardrails are used where space along the roadside is sufficient to allow deflection of the rail on contact. The detail of mounting of guardrails is shown in Figure M3.1

Vital to the proper use of guardrail is the understanding that guardrail is as much an obstacle as it is a protective device. Guardrails ends are by far the most hazardous portions of the guardrail system. There are three basic end-treatments for guardrail: straight, ramped and flared, as shown in Figure M3.2.

Straight terminals sections are very vulnerable at the ends but have a low probability of being struck. If struck, they operate on the same lines as a chisel so that the phrase "terminal damage" takes on new meaning. They have been known to cause a car engine to end in the driver's lap as well as unplanned surgery on the occupants of the vehicle.

Ramped terminals prevent abrupt deceleration and impalement but may launch the vehicle causing rollovers with a more than 50 % probability that the rollover is back towards the road rather than down the slope.

Flared terminals also decrease the possibility of an end hit but they subject the vehicle to a larger angle of impact.

One of the problems that vehicles encounter is caused by the fact that flexible guardrails are intended to operate in tension rather than compression. This allows, thus, for relatively light weight guardrail sections as opposed to a good sturdy box girder type of construction. It follows that the approach end of the guardrail has to be well anchored usually by incorporating a short support spacing.

In the case of Armco guardrails, the normal support spacing is of the order of 3,8 m whereas, in the terminal area, the pole spacing is about 1,9 m. Recent research has indicated that flared terminals appear to be favourable in reducing the severity of crashes involving guardrail ends. In the flared W-Beam rail, the bent downward ground-anchored approach end and the free (rounded) and cable-anchored approach end have shown promising results under initial testing. The South African approach to end treatment is essentially of the genus belt-and-braces because the flared, buried terminal is the one of choice. The United States has, for many years, used the twisted and buried end treatment.

A recent development is the slotted guardrail end treatment. This treatment comprises a bull nose followed by standard guardrails that have had slots cut into them to allow the end section to crumple when struck. This promises to be a very interesting development because it actually departs from the basic principle of the guardrail acting in tension. The guardrail end serves as an impact attenuator and, in crumpling, is intended to reduce the g-forces operating on the vehicle and its occupants.

The Japanese have very recently developed a new guardrail profile. This stems from the fact that, as in the case of South Africa, more and more freight is being moved by road. Trucks, particularly with high loads, are inclined to tip over the guardrail and slid down the fill slope on their side spewing their load across the countryside. The Japanese now propose a Thrie-beam structure with a cargo supporting top rail. This is a far heavier structure than that normally used and crash testing shows that it works very well in containing the impact and keeping trucks on their wheels. In the case of lighter vehicles such as cars, it is likely that it will serve like a catapult, flicking the errant vehicle back into the traffic. This problem has yet to be evaluated and it is quite likely that the proud designers are still unaware of it.

Also important to proper design is the transition from guardrail (flexible barrier) to bridge parapet (rigid barrier).

5.4 Warrants for the Location of Guardrail

Traffic barrier warrants are described in terms of geometry and the location of roadside features and also crash experience.

1. Guardrail needs should be considered in conjunction with the basic road conditions of roadway sections on embankments, particularly high fills and/or those with steep slopes; divided roads with narrow medians carrying large volumes of traffic: and roadside hazards in the form of structures and appurtenances
2. The degree of need for the guardrail depends on the height of embankment, steepness of fill slope, width of shoulder or roadway, horizontal curvature, gradient or profile condition, roadside condition, climatic condition, type or classification of road, traffic characteristics (primarily volume and speed) and crash experience.
3. As stated above, a basic principle is that the road should be designed to preclude or minimise the use of guardrails. The final responsibility for the application of guardrails or other protective features should rest primarily with the geometric designer who determines and co-ordinates all road design features. Final checks and adjustment through field observation and operational experience should be part of the overall procedure.
4. Guardrails may generally be omitted on embankments with 1:4 or flatter side slopes unless other hazards are present
5. Sideslopes of 1:5 and preferably 1:6 should be used where feasible to further enhance roadside safety

6. Current practice indicates that, when roadside conditions are favourable, guardrails should be installed on major roads when the height of fill exceed 2,5 m, 3 m, 4 m, and 5 m in the conjunction with fill slopes of 1:1½, 1:2, 1:2½ and 1:3 respectively. For less favourable conditions, guardrails should be installed at lesser height of fill
7. On any one road or reasonable length of road, a constant width of shoulder and roadway is recommended, whether guardrail is used or not.
8. In rural areas, the face of the guardrail should be located not less than 300 mm and preferably 1 000 mm from the outer edge of shoulder; in urban areas the comparable dimensions are 300 mm and 450 mm.
9. Structural elements on the roadside, i.e. parapets, retaining walls, abutments etc, should be offset a uniform distance from the edge of the travelled way and in line with the guardrail.
10. Guardrail ending at or near parapets, abutments, piers etc should be anchored to these elements.
11. An isolated section of guardrail on embankments should not be less than 30 m long and preferably a minimum of 50 m in length.
12. Gaps between twin bridges at overpasses require properly designed guardrail protection.
13. Guardrail used in combination with a concrete kerb section must be located so that an errant vehicle cannot bounce over the rail.

A useful guide for consideration of the need for guardrails is as shown in Figure M3.1. The index as shown by the shaded envelope in the figure is the ratio between the consequences (usually cost) of a crash with and without guardrails installed.

5.5 Median Barriers

On high-speed high-volume major roads and freeways, median barriers are normally required when the median is less than 13 m wide.

Median-mounted lighting systems make good use of the median barriers. Light standards can be placed on top of, behind, or integrated with the median barrier, with some forms virtually eliminating the hazard of the poles. Sign supports on the median can be handled similarly where median barriers are used.

The main function of a median barrier is to prevent cross-median head-on crashes between vehicles travelling in opposite directions. The barriers also, as stated above, protect vehicles from obstacles within the median itself.

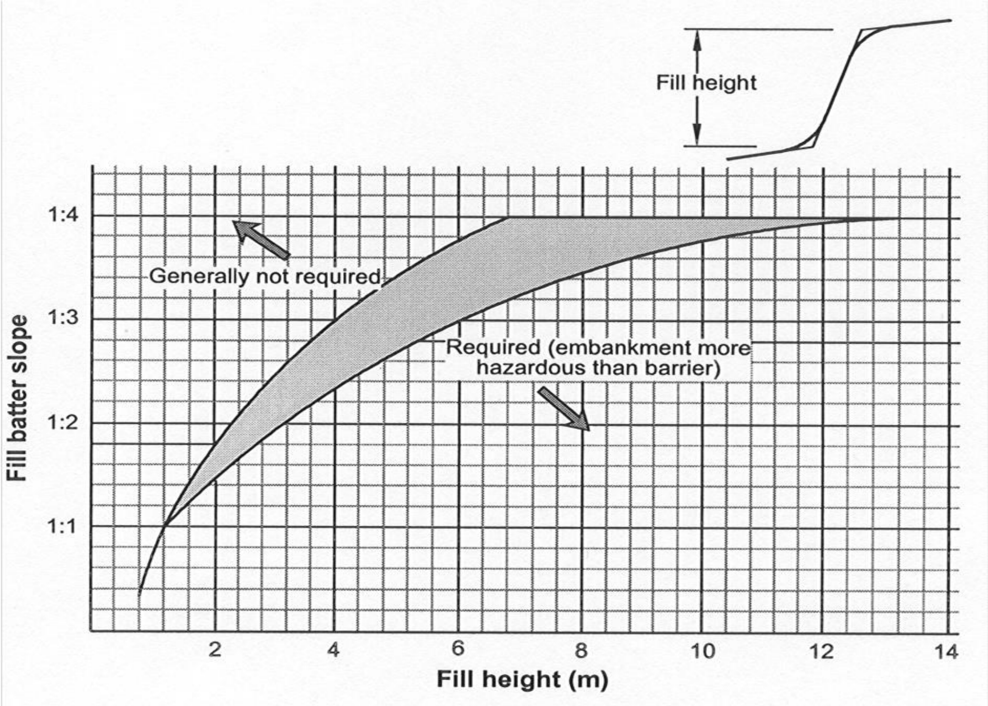

Figure M3.1: Warrant for guardrails

Continuous barriers are seldom provided on wider median rural highways, whereas in urban freeways, where reserve widths become a major consideration, the following general rule relating to the types of median barrier can be applied:

<u>Median width</u>	<u>Suggested barrier</u>
Up to 5,5 m	Rigid or semi-rigid*
5,5 to 9 m	Rigid, semi-rigid or flexible
9 m to 15 m	Semi-rigid or flexible

* *Semi-rigid system with dynamic deflection greater than one-half of median width not acceptable*

Continuous median barriers should be carried, where feasible, uniformly over bridges and through underpass structures. At overpasses with twin bridges, the median guardrail should be aligned to meet the structure parapets and be anchored to them. At underpasses with central piers, the median barrier should be continued through and connected to the pier or the barrier should be anchored to each end of the pier.

Light standards on narrow medians should be positioned within a median barrier with a clear space of not less than 600 mm between the beams.

Where the support for a large sign at a roadway exit must be located in the gore, protective treatment should be provided. A special guardrail assembly made up of a continuously curved section consisting of a double rail unit and closely spaced posts is recommended. The approach end of the assembly should be at least 10 m in front of the sign support.

The anticipated traffic volumes are a factor in deciding on the need for erecting median barriers. It is recommended that with medians widths of 3 m, 6 m, and 10 m, traffic volumes of 15 000, 30 000 and 45 000 ADT respectively justify the installation of barriers.

5.6 Impact Attenuation Devices or "Crash Cushions"

There are certain hazardous situations within the road environment that cannot be protected by continuous barriers and the installation of impact attenuation devices may be called for.

These devices control the deceleration of an impacting vehicle and thereby reduce the severity of the crash. In quality design, such devices should only be necessary in extreme cases.

Types of crash cushions that have been employed with success include:

- lengths of spiral steel in telescoping tube sections
- barrels (empty or sand-filled) bound together with steel strips
- water-filled plastic cells
- sand-filled frangible plastic barrels
- frangible vermiculite concrete with vertical voids
- large radius W-beam sections
- chain-link attenuators

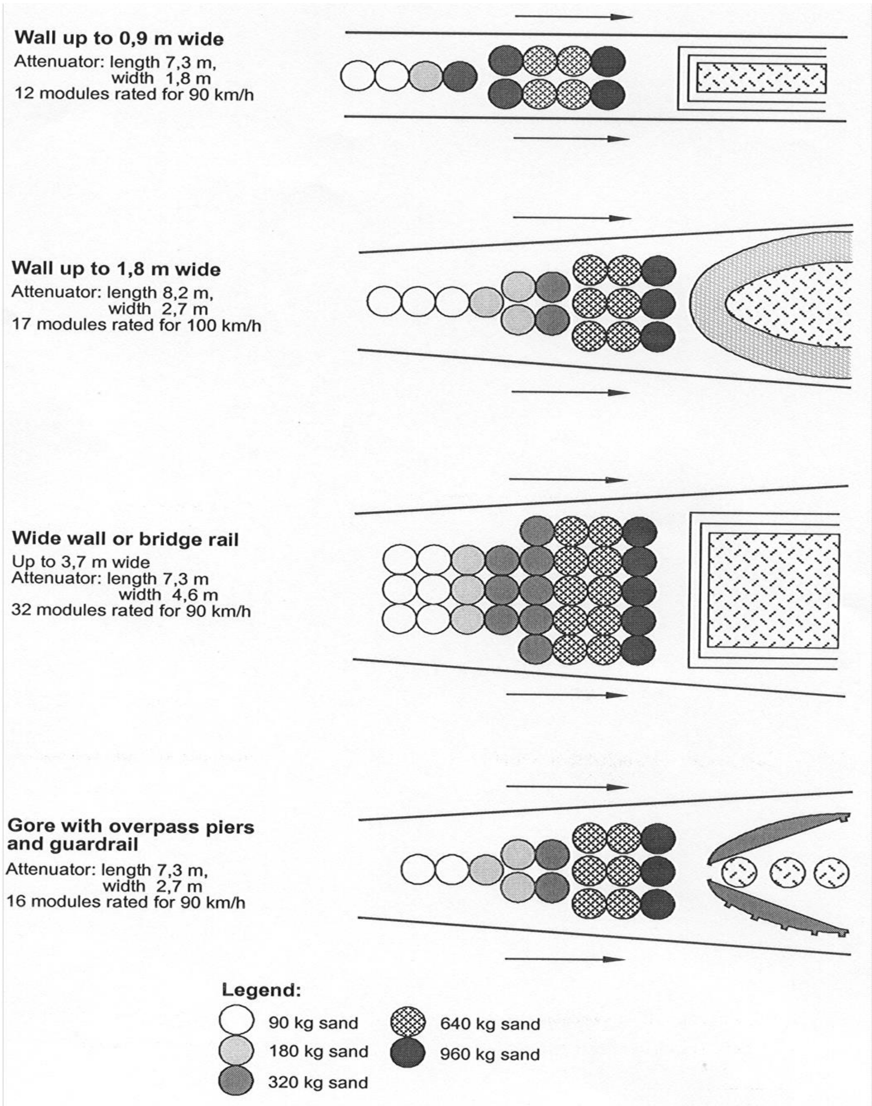

Figure M3.2: Typical impact attenuator layouts

5.7 Arrestor Beds

Arrestor beds are usually employed on long down hill sections where trucks, particularly when heavily or overloaded, are inclined to suffer overheated brakes, which then fail. The arrestor bed comprises an off ramp, which can be negotiated at speed and the bed itself, which is a long straight section of deep sand or gravel. The theory is that the truck sinks into the bed and the drag so created causes it to come to a safe halt. The theory works very well because trucks virtually bury themselves in a joyous explosion of sand and powerful winches or cranes have to be provided to extract the truck from the arrestor bed.

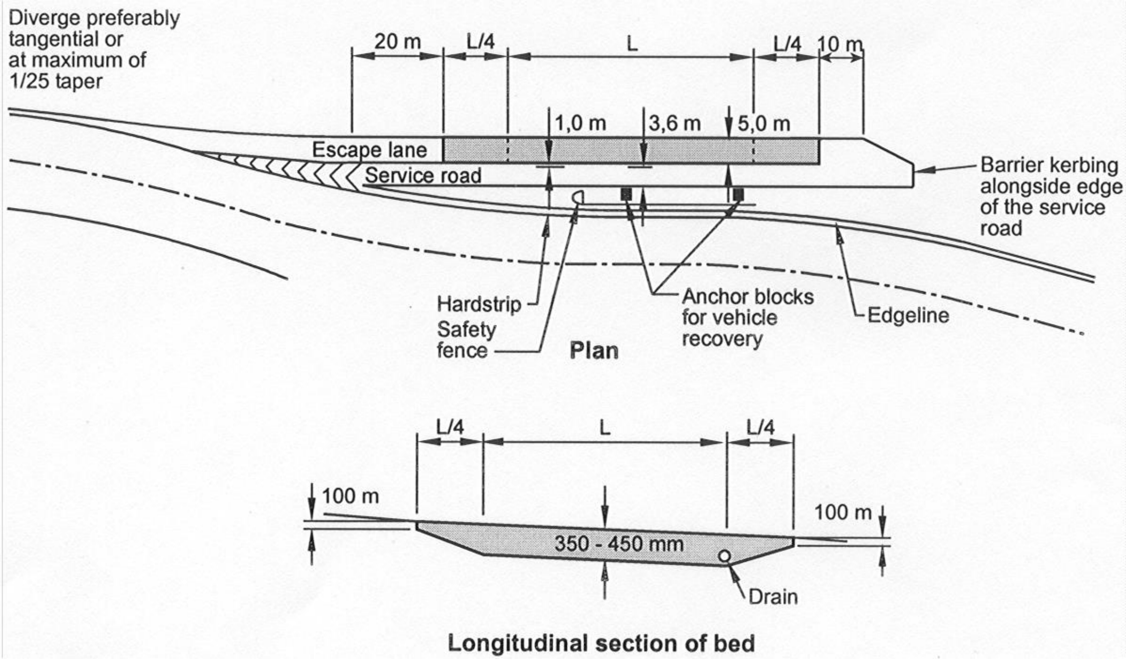

Figure M3.3: Typical layout of arrestor bed

5.8 Pavement Edge Protection

The edge of the paved roadway is subject to erosion both from stormwater flow and vehicular passage. The softer verges wear away, particularly on the inside of curves. The step or drop-off thus created is dangerous and may cause the motorist, leaving the road inadvertently, to lose control of his vehicle. This type of damage to the verge must therefore be regularly repaired. The use of surfaced shoulders will normally overcome the problem and short lengths of narrow surfaced shoulder beyond the painted edge line on the inside of the curve can provide suitable protection where continuous paved shoulders are not used.

5.9 Ditches and Drainage Structures

Ditches to carry storm water adjacent to the roadway are a necessary part of the road cross-section. Extensive research has been carried out to achieve a hydraulically efficient ditch cross-section that will enable an errant vehicle to traverse the ditch safely and, in particular, to avoid the vehicle's front bumper striking the ground. Nosing-in can cause the vehicle to somersault, which the average driver tends to find disconcerting. The profile of the ditch cross-section, when projected at reasonable angles of attack (according to Brafman-Bahar, of the order of 11^0) should yield a path such that the curvature would assure a margin of safety.

Some drainage structures are potentially dangerous. To provide safer roads:

1. Unnecessary drainage structures should be eliminated
2. Necessary structures should be located so that they create the least possible hazard.
3. Structures, which cannot be eliminated, should be designed to inflict minimum damage
4. Only when it is not possible to reduce the hazard sufficiently should guardrail protection be installed.
5. Generally, median inlets can be designed to be flush with the ground, including the use of grid inlets, although this increases the maintenance requirements
6. On roadsides, inlet and culvert openings should be located well away from the roadway to be beyond the hazard area.