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KERAJAAN MALAYSIA

DESIGN GUIDELINES FOR EMERGENCY ESCAPE RAMP

Ketua Pengarah Kerja Raya
Jabatan Kerja Raya Malaysia
Jalan Sultan Salahuddin
50582 Kuala Lumpur

NTJ 31/2015

DESIGN GUIDELINES FOR EMERGENCY ESCAPE RAMP

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DESIGN GUIDELINES FOR
EMERGENCY ESCAPE RAMP

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Cawangan Jalan
Jabatan Kerja Raya

FOREWORD

The purpose of publishing this Nota Teknik Jalan 31/2015, hereinafter called NTJ 31/2015 – Design Guidelines For Emergency Escape Ramp is to provide some basic requirements and design considerations for the implementation of emergency escape ramps. The application of this guideline is to improve the decision making process through applications of selected criteria.

The preparation of this document was carried out through some research and discussions by a Technical Committee which has been formally formed for the purpose. This Committee consisted of members with experiences in planning and design of roads and escape ramps. Feedbacks and comments received from stakeholders are carefully considered and incorporated into the document wherever appropriate. This document has been presented and approved in the *Mesyuarat Jawatankuasa Spesifikasi Piawai JKR bagi Kerja-Kerja Jalan Bil. 6/2014* on 9th December 2014.

For continuous improvement, this NTJ will be reviewed and updated from time to time to incorporate changes in policies and current design requirements. Following which it will be upgraded as part of the Arahan Teknik Jalan (ATJ) series of documents. In this respect, any comments and feedbacks regarding this document are welcome and should be forwarded to *Unit Standard & Spesifikasi, Bahagian Pembangunan Inovasi dan Standard, Pakar Kejuruteraan Jalan & Jambatan, Cawangan Jalan.*

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ABBREVIATIONS

LLM	Lembaga Lebuhraya Malaysia
MIROS	Malaysia Institute of Road Safety Research
EER	Emergency Escape Ramp
hv	heavy vehicle

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1 INTRODUCTION

1.1 General

Roads through rolling and mountainous terrain are sometimes designed under constrained circumstances due to various reasons including environmental and economic motives. Hence, adverse road geometric features are unintentionally constructed. Among such features is the design of substandard vertical profiles featuring long steep downgrade. Long downgrade alignments may be quite common, but some may present serious problems, especially to heavy laden commercial or transport vehicles.

The inability of drivers to control vehicle speeds on downgrades is not only hazardous, but it can also have costly consequences. Heavy commercial vehicles and long haul transport buses traveling on roads in rolling and mountainous terrain encounter the risk of losing control on these long steep downgrades. They may end up falling into ravines, crashing onto the faces of slope or populated built-up areas that are usually located at the bottom or valley areas.

Continuous use of vehicle braking by drivers may give rise to excessive heating of the brake system that will usually result in 'brake fading'. Brake fade is a term used to describe the partial or total loss of braking power used in a vehicle brake system. Brake fade occurs when the brake pad and the brake rotor no longer generate sufficient mutual friction to stop the vehicle at its preferred rate of deceleration and can happen on motorcycles, cars, buses and heavy commercial vehicles. The brake pad in any brake system is designed to work at certain operating temperatures. Being made of many different formulations, brake pads perform in very different ways under temperature. This certainly indicates the general quality of a brake pad and its fitness for application.

Runaway vehicles need special exit facilities to enable the vehicles to reduce its speed and regain control without causing serious casualties or affect other road users. These facilities, in the form of ramps, need to be properly located and adequately designed to ensure they can be used effectively. Adequate length of ramp and correct entry alignment, enhanced with sufficient alerting features, are some of the design elements of an emergency escape ramp including the use of suitable arrester bed material and containment features.

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1.2 Scope of this Guidelines

This guideline covers the design of emergency escape ramps and to some extent the construction aspect of the facilities. It is applicable to newly designed roads as well as for existing roads where conditions are favorable. Any provisions relating to the facility contained in other documents that are contradictory to this guideline are hereby deemed superseded.

This guideline is prepared based on well-established principles and best practices adopted by other countries but appropriately adapted to suit the local environmental conditions and harmonise with existing departmental guidelines.

1.3 Terms and Definitions

This section presents a list of terms commonly used in this document. Each term is defined in the context of the subject matter according to the civil engineering discipline.

a. Emergency escape ramps

   The ramp is an excavated trench filled with loose, round, smooth river rock. It is usually located on a curve of the downhill road.

b. Arrester
   A device that automatically arrests motion, by braking or stopping vehicles, which causes vehicles to come to a stop.

c. Arrester bed
   Long trenches filled with small ground gravel particles that are designed to stop runaway vehicles. The vehicle is stopped by drag and friction as the vehicle sinks into the gravel in the bed.

d. Sand pile
   A short length of a loose pile of sand.

e. Jack-knifing
   Jack-knifing means the folding of an articulated vehicle (such as one towing a trailer) such that it resembles the acute angle of a folding pocket knife. If a vehicle towing a trailer skids, the trailer can push from behind until it spins round and faces backwards.

f. Pull-off area
   A designated paved area beside a main road where vehicles can stop temporarily.

g. Rolling resistance
   A force resisting the motion between a vehiclere vehicles can stop temporarily.

h. Inertial resistance
   A force resisting movement of vehicle at rest or maintains a vehicle in motion unless the vehicle is acted on by some external force.

i. Gradient resistance
   A force needed to move the vehicle through a given vertical distance.

j. Air resistance
   A force that acts to retard the motion of vehicle.

k. Ramp length
   The length of the ramp mounted with special surfacing/bedding material to decelerate the motion of runaway vehicles. This is also known as the bed length.

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2 TYPES OF RAMPS

Escape ramps are constructed at certain roads to reduce speed of runaway vehicles by constructing them with certain geometric features, laying of tyre-gripping bed materials or/and fitted with special mechanical equipment. The common types of emergency escape ramps currently available throughout the world are as follows:

- ***Gravity escape ramp***
- ***Arrester bed ramp***
- ***Sand pile escape ramp***
- ***Mechanical-arrester escape ramp***

2.1 <u>Gravity Escape Ramp</u>

A gravity ramp has a paved or densely compacted aggregate surface, relying primarily on gravitational forces to slow and stop the runaway vehicles. Rolling resistance forces contribute little to assist in stopping the vehicle. Gravity ramps are usually long with steep downgrade and are usually constrained by topographic controls and costs. While a gravity ramp stops forward motion, the paved surface cannot prevent the vehicle from rolling back down the ramp grade and jack-knifing (without a positive capture mechanism). Therefore, the gravity ramp is the least desirable of the escape ramp types.

Picture 2.1: Gravity Escape Ramp (Longnan-Heyuan Expressway, China)

2.2 <u>Arrester Bed</u>

Arrester bed is a ramp constructed adjacent to the road, filled with gravel that provides rolling resistance to stop the runaway heavy vehicles. The length of the ramp depends on the mass and speed of the vehicle, the grade of the arrester bed, and the rolling resistance provided by the loose gravel bed. Depending on the terrain profile of the downhill segment, the ramp may be provided with any of the following grades:

2.2.1 Descending Grade Ramp

Descending grade ramps are constructed parallel and adjacent to the through lanes of the highway. They require the use of loose aggregate in an arrester bed to increase rolling resistance and therefore slow down the vehicle. The descending grade ramps can be rather lengthy because the gravitational effect is not acting to help reduce the speed of the vehicle.

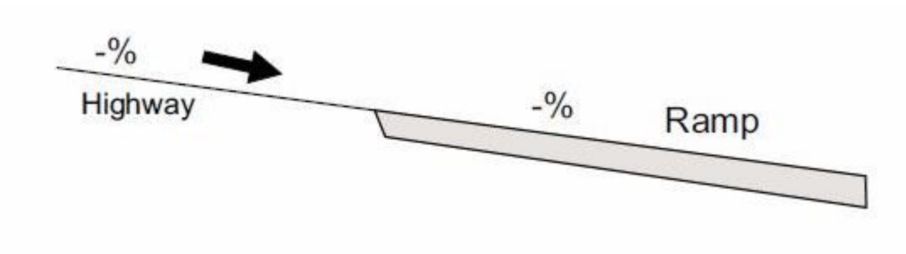


Figure 2.1: Descending Grade Ramp

2.2.2 Horizontal Grade Ramp

For the horizontal grade ramp, the effect of the force of gravity is zero and the increase in rolling resistance has to be supplied by an arrester bed composed of loose aggregate. This type of ramp will be longer than those using gravitational force acting to stop the vehicle.

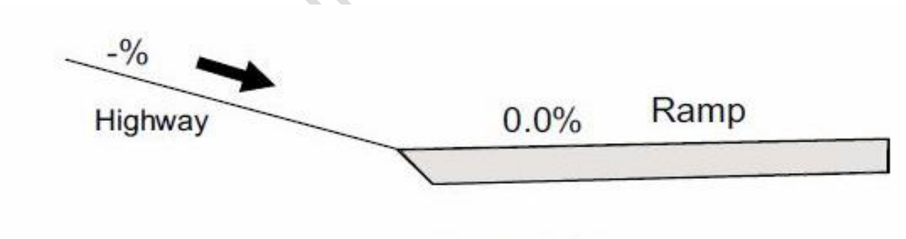
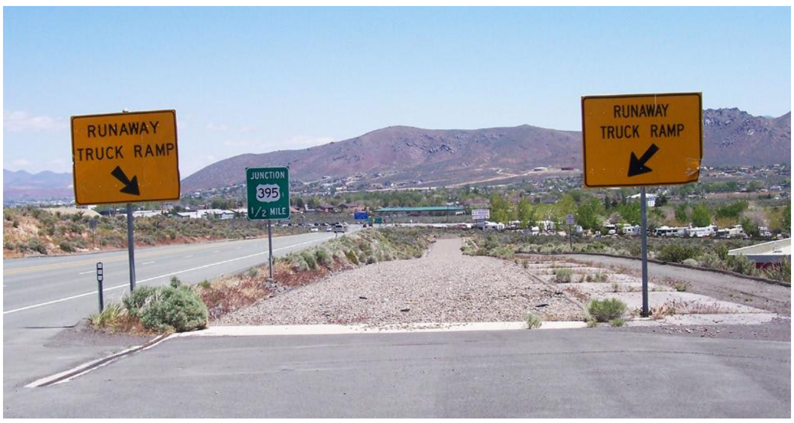


Figure 2.2: Horizontal Grade Ramp



Picture 2.2: Arrester Bed on Horizontal Grade (Nevada Truck Escape Ramp)

2.2.3 Ascending Grade Ramp

The ascending grade ramp uses both the arresting bed and the effect of gravity, in general reducing the length of ramp necessary to stop the vehicle. The loose material in the arrester bed increases the rolling resistance, as in the other types of ramps, while the force of gravity acts downgrade, opposite to the vehicle movement. The loose bedding material also serves to hold the vehicle in place on the ramp grade after it has come to a safe stop. Designs on an ascending grade ramp without an arresting bed are not encouraged as heavy vehicles may roll back and jack knife upon coming to rest.

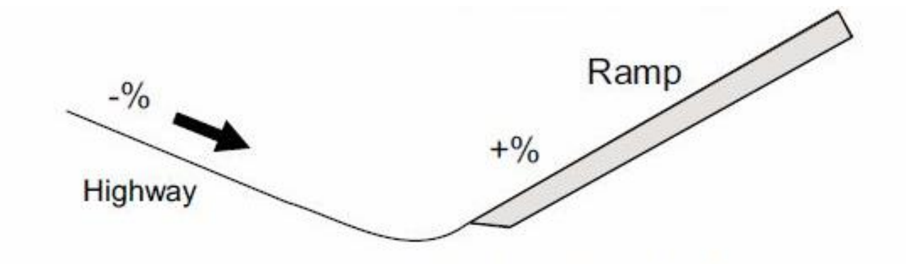


Figure 2.3: Ascending Grade Ramp

Picture 2.3: Arrester bed on ascending grade (Cameron Highlands)

2.3 Sand Pile Escape Ramp

The sand pile types are composed of loose, dry sand and are usually no more than 130 m in length on a horizontal slope. This length may vary subject to the influence of gravity which is dependent on the slope of the surface of the sand pile. The increase in rolling resistance to reduce overall lengths is supplied by the loose sand. Sand pile has several pertinent problems that may discourage its use. This type of ramp can cause excessive deceleration resulting with vehicles vaulting and/or overturning after contacting the sand pile. The sand layer can easily get compacted due to the effect of weather (water). Because of these characteristics, the sand pile is less desirable than the arrester bed. It may be suitable where space is limited and the compact dimensions of the sand pile are appropriate.

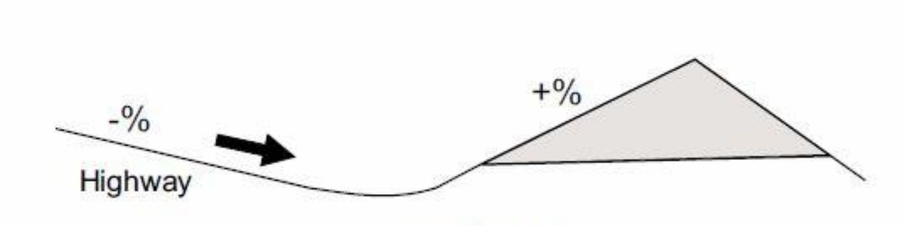


Figure 2.4: Sand Pile

Picture 2.4: Sand Pile (Genting Highlands)

2.4 Mechanical Arrester Escape Ramp

A mechanical arrester system consists of a series of mechanical energy-absorbing spools and stainless steel nets (sometimes known as dragnet) transversely spanning a paved ramp that engage and retard a runaway vehicle. This is a proprietary vehicle arrester system that has been designed specifically for the purpose.

It is a solution that can address safety need while minimising disruption to the existing surrounding conditions. Existing conditions usually include small installation sites located in a mixed-use, upscale neighborhood; topographical constraints; and, steep, winding grade terminated by a signalised intersection. Ramps of this type are typically shorter than gravity ramps and can have a downhill grade.

The stainless steel nets are connected to spooled-tape energy absorbers mounted in precast concrete barriers on either side of the ramp. As a vehicle enters the ramp and pulls the net, the spooled tape attaching the net to the side wall is pulled over a series of offset pins, bending the tape backwards beyond its strength point. This bending action is the principle mechanism for absorbing the kinetic energy of the runaway vehicle. The chambered spooled metal tape and offset pins make up the absorber, and with so few moving parts, the absorbers are virtually maintenance free. The size and number of nets in this type of escape ramp depend on the length and grade of the ramp, as well as the entry design speed and expected vehicle weight.

Picture 2.5: Mechanical Arrester Escape Ramp (U.S. 44 westbound in Avon Connecticut, USA)

However, the most widely used escape ramps are the ascending and horizontal grade arrester bed. Ramp installations of this type uses gradient resistance to advantage, supplementing the effects of the aggregate in the arrester bed and generally reducing the length of ramp needed to stop the vehicle. The loose material in the arresting bed increases the rolling resistance as in the other types of ramps, while the gradient resistance acts in a downward direction, opposite to the direction of vehicle movement. The loose bedding material also serves to hold the vehicle in place on the ramp grade after it has come to a safe stop.

Each of the ramp types is applicable to a particular situation where an emergency escape ramp is desirable and must be compatible with the location and topography. The most effective escape ramp is an ascending ramp with an arrester bed.

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3 DETERMINATION OF NEED

In resolving the problems of runaway vehicles while descending a long and steep downgrade, it is necessary that an evaluation is made of the existing features of the road. This guideline adopts a sequential based approach in the decision making process on the need of an escape ramp.

The purpose of this approach is to ensure that appropriate measures are taken before finally deciding to install an escape ramp. In the process, designers shall be required to undertake several important tasks. It is important that the recommendations from each of these tasks be implemented prior to selecting an escape ramp as the final solution. These tasks are described below in their chronological order of implementation.

3.1 Review Existing Signage

Initially, designer should review the existing signs available along the high risk area. This is to determine that all appropriate signs are adequate and properly placed. Curve and grade warning signs must be available together with suitable speed limit signs. Any deficiency in signage must be corrected prior to any further consideration. Examples of some of the appropriate signage are mentioned in Section 4.2.

If the above measures are implemented and prove to be ineffectual, then a roadside brake inspection area at the top of the grade is worth considering.

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3.2 Provide Brake Inspection Area

Pullover areas at the summit of a grade can be used for brake inspection areas or mandatory-stop areas to provide an opportunity for drivers to inspect their vehicles and check that the brakes are not overheated before beginning the descent. In addition, information about the grade ahead and the location of emergency escape ramps can be provided by installing appropriate signs. An elaborate design is not needed for these areas. A brake inspection area can be paved lane behind and separated from the shoulder or a widened shoulder where a heavy vehicle can stop. Warning signs should be placed to discourage casual stopping by the public. Brake inspection area is further discussed in Section 4.3.1.

If the provision of brake inspection area is not effective then the installation of an emergency escape ramp should then be considered.

3.3 Install Emergency Escape Ramps

There are many circumstances which may indicate the need for an escape ramp. The determinations of need can be based on accidents, geometric and heavy vehicles composition as detailed out below:

3.3.1 *Heavy Vehicles Accident Rates*

Accidents may sometimes be prevalent along long and steep downgrades. A primary indicator for the need of an emergency escape ramp is the rate of accidents involving runaway heavy vehicles. Details of this indicator are:

1. Presently high number of accidents (3 or more accidents in 3 years) occurring on ***a long and steep downgrade.***
2. ***Potential of high accident rate based on a design projection analysis.***
3. ***Existence of potentially serious consequence if heavy vehicles went out-of-control on a long, steep downgrade and crashing into school or active marketplace located at the bottom of the grade.***

Although it is not a critical factor, a secondary but yet relevant indicator is the relative number of heavy vehicles with excessively hot brakes. It is an indication of the potential risk of accident involving out-of-control heavy vehicles.

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3.3.2 *Geometric*

Where a new road is to be constructed, there is no operational experience upon which to base the need of an emergency escape ramp. Figure 3.1 provides some guidance on the determination of need for an emergency escape ramp on new roads. When the combination of percent and length of downgrade fall on or to the right of the curve, an emergency escape ramp should be considered as part of the initial construction. The curve is based on heavy vehicles arriving at the start of the downgrade with brakes at normal operating temperatures.

There is also a probability that heavy vehicles will arrive at the start of a downgrade with hot brakes from previous maneuver. In such case, even though the combination of percentage and length of downgrade falls to the left of the curve (Figure 3.1), consideration of an emergency escape ramp may sometimes be necessary. This is because there is a high possibility of mechanical failure due to the impending long length of steep downgrade.

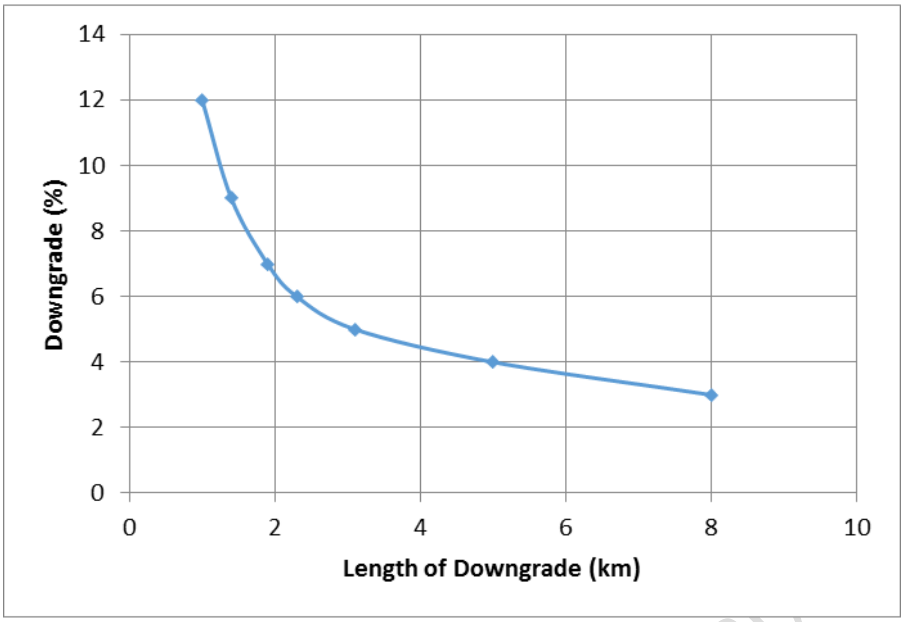

Figure 3.1: Emergency Escape Ramps on New Roads

3.3.3 Heavy Vehicles Composition

The downgrade movement of continuous flow of vehicles has long presented potentially dangerous conditions. The presence of a high volume of heavy vehicle travelling downhill may result in a congested and slow moving traffic. Heavy vehicles are forced to travel at low speeds with frequent braking. This may result in overheating and failure of the braking system which then increases the risk of drivers losing control of their vehicles.

Number of heavy vehicles as much as 200 vehicles per day travelling downhill at a grade 6% or more, though not sufficient to warrant for the installation of an escape ramp, should be a threshold figure for the authority to investigate and closely monitor the situation. However, together with medium range accident frequency occurring within the downgrade section, it should trigger the authority to take some drastic measures which may include the construction of the ramp.

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3.4 Banning of Selected Vehicles

Lastly, if none of the above measures prove to be effective in reducing heavy vehicles incidents, a final but highly controversial consideration would be banning certain types of heavy vehicles from using the route or the particular grade. However, this is a decision that should be decided by the authority with the consensus of the stakeholders.

4 DESIGN CONSIDERATION

Having finally decided that an emergency escape ramp is necessary for the road, the ensuing subject is the understanding of the important features relating to the construction of the ramp. This chapter and the following chapters shall focus on some of the important design elements of the emergency escape ramp including the related external features (i.e. downgrade section, approach alignment, etc.) that are very relevant for the proper construction of the facility. These design elements also determine the safety aspect of the scheme and ensure that it can be effectively used by the road users in case of emergency.

4.1 Location

The location of an emergency escape ramp, whether it is an arrester bed or gravity ramp, is controlled largely by terrain. In general, an escape ramp should only be considered on the lower half of the grade because this is where the need becomes most apparent to the driver of the vehicle and they would be compelled to use the ramp. An exception would be on long, sustained grades.

For both new and existing roads, engineering judgement is required to determine the appropriate location of the escape ramp. Relevant factors to be considered include:

1. location of previous accidents;
2. length of downgrade;
3. conditions at the bottom of the grade;
4. percentage of heavy vehicles;
5. horizontal alignment;
6. topography (i.e. effect on cost of earth works); and
7. toll plazas at the bottom of steep grades

Runaway-vehicle facilities should not be constructed where an out-of-control vehicle would need to cross the oncoming traffic.

On undivided roads, the escape ramp should be on the left side of the roadway. On divided roads, a heavy vehicle escape ramp should normally be on the left side of the one-way roadway. A right side escape ramp may be worth considering where there are three or more lanes in the downgrade direction. On such multilane facilities, the out-of-control heavy vehicles may be using the right or fast lane and could have easier access to right hand ramp, where space permits rather than try to thread their way through slower traffic to the left. Other factors to be considered are density of traffic in the left lane and which lanes the out-of-control heavy vehicles are using.

Escape ramps may be built at any practical location where the particular section of the road alignment is tangent to it. However, it should not be located on curves because it would create additional problems of control already faced by the driver. They should be in advance of horizontal curves that cannot be negotiated safely by an out-of-control vehicle. Escape ramps should exit to the left of the roadway. On divided multilane roads, where a right exit may appear to be the only practical

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condition, difficulties may be expected by the refusal of vehicles in the right lane to yield to out-of-control vehicles attempting to change lanes.

Although crashes involving runaway heavy vehicles can occur at various sites along a grade, locations having multiple escape ramps should be analysed in detail. Analysis of crash data pertinent to a prospective escape ramp site should include evaluation of the section of road immediately uphill, including the amount of curvature traversed and distance to and radius of the adjacent curve.

4.2 Road Signage and Marking

Road signage is an important traffic control tool to warn drivers of any impending danger ahead and should be clearly visible to users even for vehicles travelling on the fast lane. Warning can be given of the downgrades ahead so that the driver may stop and make the necessary checks of the vehicle before proceeding. Road signage is also important to inform the driver of the location of an escape ramp downhill. Signs that are likely to be required are those that:

- warn or advise of a steep descent
- provide advance notification of the facility
- indicate direction at the facility entrance
- advise heavy vehicles and bus drivers to use a low gear

Some information and warning signs can be installed along the roadway before the descent or at specially designated areas where drivers can safely pull off the road to check and cool the brakes before descending the hill. These signs can also be used to inform and educate the road users of the application and purpose of escape ramps.

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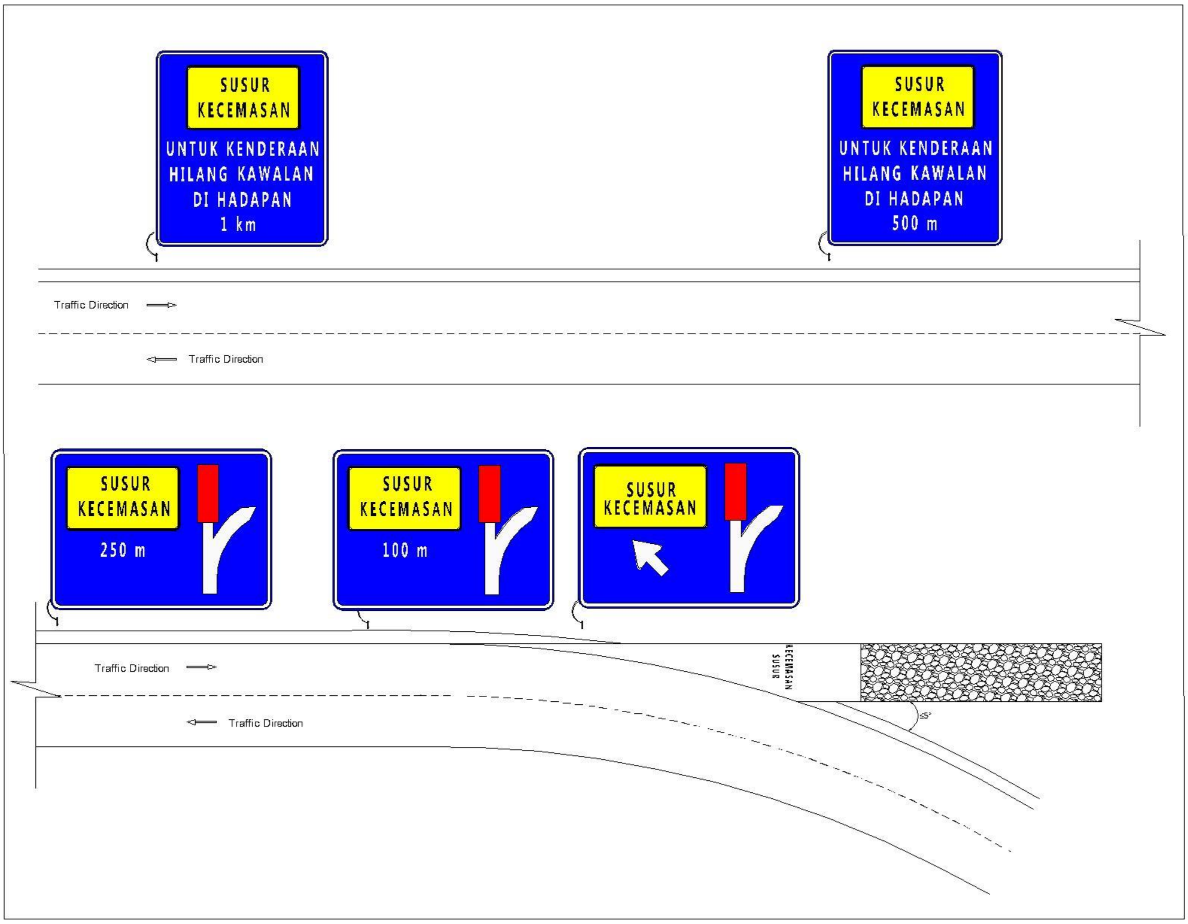

Figure 4.1: Traffic Signs and its arrangement

As the vehicle enters the downgrade section, the driver should be continuously informed with successive traffic signs indicating the distance to the escape ramp. These signs shall be presented in the form of words and/or symbol of the escape ramp. Figure 4.1 shows these signs located in their order of precedence as the driver approaches the escape ramp. The signs shall start from a maximum distance of 1 km before the ramp, followed with that at 500 m, 250 m, 100 m and finally at the entrance to the ramp itself. Certain signages should be used if the appropriate distance available is less than 1 km. The proposed dimensions of these signs are given in Appendix 2.

4.3 Supplemental Features

4.3.1 Brake Inspection and Rest Areas

A brake inspection or check area is an area set aside for heavy vehicles at the top of a steep descent, while a brake rest area is an area provided part way down (especially for multiple downgrades), or at the bottom of a descent. Drivers using these facilities should be able to begin a descent starting from a standstill or in low gear, which could make the difference between a controlled and an out-of-control descent. It is recommended that this facility be provided on routes that have long steep downgrades or multiple downgrades with volume of heavy vehicles of more than 100 vehicles per day. Possible locations of the facilities are shown in Figure 4.2 below.

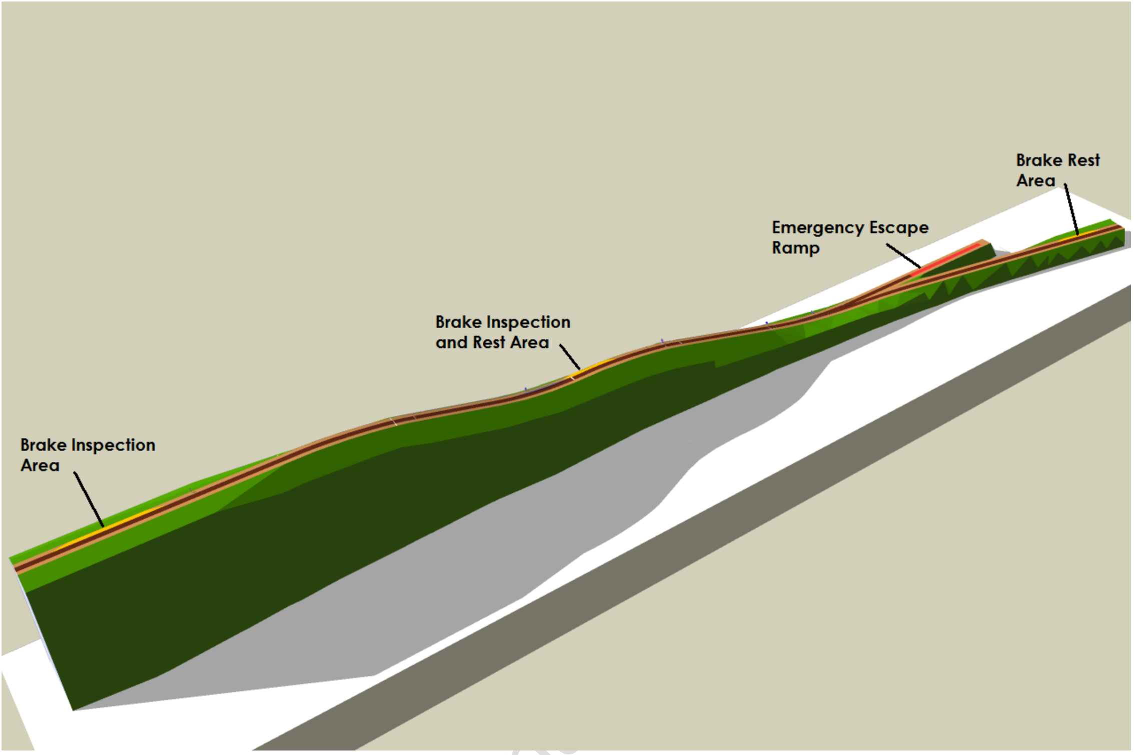

Figure 4.2: A 3D Model showing possible locations of various facilities

Turnouts or pull off areas at the summit of a grade can be used for brake inspection areas to provide an opportunity for a driver to inspect the condition of the vehicle and to ensure the brakes are not overheated before beginning the descent. The area can be a paved lane behind and separated from the shoulder or a widened shoulder where a heavy vehicle can stop. It must also be large enough to hold several heavy vehicles according to the predicted arrival rate, and should have good visibility together with acceleration and deceleration tapers.

Brake inspection areas also provide opportunity to display information about the grade ahead, escape ramps location and maximum safe descent speeds. Advance notice of the facility and special signs to discourage casual stop by the general public may be required.

4.3.2 *Variable Message Sign (VMS)*

In cases where the location of the escape ramp is not directly visible to descending vehicles, installation of variable message sign may be necessary. The purpose of the sign is to warn drivers of the status of occupancy of the downstream escape ramp. It can provide some protection for a vehicle already occupying the escape ramp or maintenance workers working in the ramp area. This variable message sign is especially important when the entrance to the escape ramp is hidden behind road curves. The sign should be located far upstream from the ramp entrance to warn descending vehicles if and when an escape ramp is occupied.

4.3.3 *Misuse of Escape Ramps*

An escape ramp can be misused by motorists changing drivers, seeking relief, checking their vehicle, pausing for a picnic, or many other reasons. If such a motorist becomes immobilised in the gravel bed, they stand a chance of being run over by an out-of-control heavy vehicle or forcing the heavy vehicle to bypass the escape ramp where it may possibly become involved in a severe accident.

In order to restrict a motorist from misusing a ramp, the ramp and the adjoining area should be reviewed for conditions that may induce misuse by motorists. Things to look for can include graded areas outside the escape ramp, absence of other areas for motorists to stop, inadequate signage, and an overcrowded upstream rest area. Treatment can include adequate warning signage, fencing, or landscaping to screen off the graded area. It is also important to ensure that the downgrade alignment is not hindered by any object or roadside activity and the entrance into the escape ramp must be kept clear at all times. A special Warning Notice sign should be provided and an example of the proposed sign is shown in Appendix 3.

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5 ESCAPE RAMP DESIGN

5.1 General

Out-of-control vehicles are the result of drivers unable to reduce the speed of their vehicles by braking and thus encounter limited control in steering or manoeuvring of the vehicles. The fast downhill movement also limits the degree of safe cornering without causing the vehicles to overturn. These characteristics of out-of-control vehicles are important in determining the location and design elements of the escape ramp.

Ramps should be located to intercept the greatest number of runaway vehicles, such as at the bottom of the grade and at intermediate points along the grade where an out-of-control vehicle could cause a catastrophic crash. Factors that should be considered in designing escape ramp include ramp alignment, grade, length, width and attenuation.

5.2 Approach to Ramp

An escape ramp should have an auxiliary lane to assist drivers as they approach and prepare to enter the ramp. This should give the out-of-control heavy vehicles a better chance of getting into the ramp area safely. Auxiliary lanes should be tapered with a length of at least 150 m long with a greater length to be evaluated on the basis of the number of traffic lanes and the volume of heavy vehicles as well as their speeds.

The main roadway surface should be extended to a point at or beyond the exit gore. This also provides preparation time for the driver before actual deceleration begins. The approach to the arrester bed should be squared off so that all wheels on an axle enter the bed simultaneously. Also the arrester bed should be offset laterally from the through lanes by a sufficient amount and start far enough so that loose bed material is not thrown into the travelled way when a heavy vehicle enters the bed.

Apart from signage installed along the downhill approach to the escape ramp, the auxiliary lane should also be marked as **"SUSUR KECEMASAN"** on the entrance pavement surface so as to provide further guidance on the entrance path into the ramp (see Appendix 3). Other warning signs may also be necessary to ensure that the marked area is kept clear at all times and lighting of the ramp entrance is worthy of consideration.

The arrester bed also should not be curved as any excessive steering manoeuvre could cause an articulated heavy vehicle to jackknife and overturn.

5.3 Ramp Alignment

The alignment of the escape ramp should be tangent or on very slight curvature to minimize the driver's difficulty in controlling the vehicle. A ramp should be on one continuous tangent. The connection between the approach roadway and the ramp

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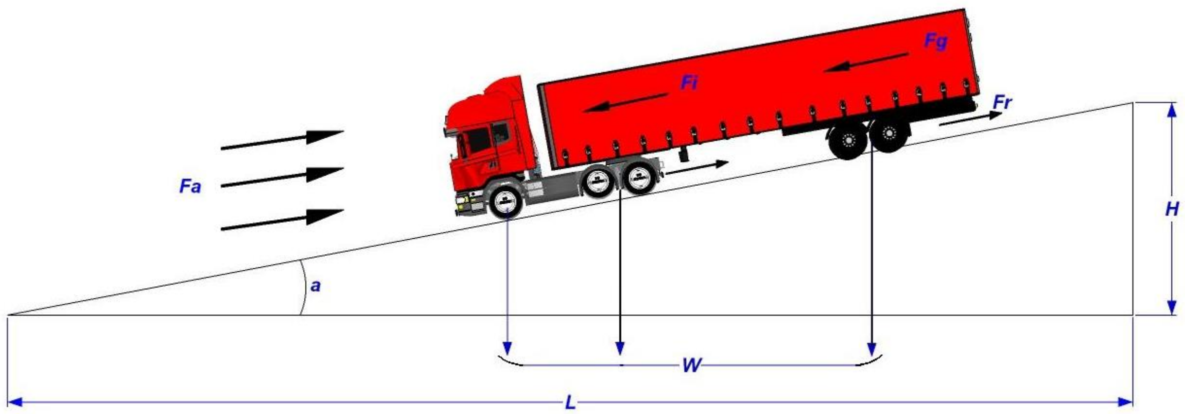
proper should be on as flat an angle as possible to accommodate a vehicle operating at the design speed of the ramp. The entrance to the ramp should be designed so that a vehicle travelling at high speed can enter easily and safely. Hence, the angle of departure of the ramp should be small, usually 5 degrees or less.

Driver of an out-of-control heavy vehicle is usually operating in or nearly in panic situation. For them to feel that the ramp can be negotiated safely they must be able to see, as much of the ramp as possible. Terrain condition affects the sight distance and may also influence the alignment design of the ramp. The alignment should be studied to ensure that no part of the escape ramp is hidden from the sight view of the approaching drivers. Grade sags or crests that obscure a portion of the ramp may affect an out-of-control driver's willingness to use the ramp without much hesitation.

5.4 Ramp Grades

In designing ramp grades, the forces that act on every vehicle such as the vehicle's speed and tractive resistance forces need to be considered. Engine and braking-resistance forces can be ignored in the design of escape ramps because the ramp should be designed for the worst case, in which the vehicle is out of gear and the brake system has failed. The tractive-resistance force contains four subclasses: inertial, aerodynamic, rolling and gradient. Inertial and negative gradient forces act to maintain motion of the vehicle, while rolling, positive gradient and air-resistance forces act to retard its motion. **Figure 5.1** below illustrates the action of the various resistance forces acting on a vehicle.



Fa = Air Resistance	*W = Gross Vehicle Mass (Weight)*
Fi = Inertial Resistance	*H = Height*
Fg = Gradient Resistance	*L = Length*
Fr = Rolling Resistance	*a = Slope Angle*

Figure 5.1: **Forces acting on a vehicle in motion**

Inertial resistance (Fi) can be described as a force that resists movement of a vehicle at rest or maintains a vehicle in motion, unless the vehicle is acted upon by some external force. Inertial resistance must be overcome to either increase or decrease the speed of a vehicle. Rolling resistance (Fr) and positive gradient resistance (Fg) are available to overcome the inertial resistance (Fi).

Rolling resistance is a general term used to describe the resistance to motion at the area of contact between a vehicle's tyres and the roadway surface and is only applicable when a vehicle is in motion. It is influenced by the type and displacement characteristics of the surfacing material of the roadway. The values shown in Table 5.1 for rolling resistance (expressed in kg/1000 kg of gross vehicle weight) obtained from various provide the best available estimate.

Gradient resistance resulted from gravity and is expressed as the force needed to move the vehicle through a given vertical distance. Depending on the grade of the ramp, gradient resistance can either provide a positive or negative resisting force on a moving vehicle. The amount of gradient resistance is influenced by the total weight of the vehicle and the magnitude of the grade. For each percent of grade, the gradient resistance is 10 kg/1000 kg gross vehicle weight whether the grade is positive or negative.

The remaining component of tractive resistance is the aerodynamic resistance (Fa), the force resulting from the retarding effect of air on the various surfaces of the vehicle. Air causes a significant resistance at speeds above 80 km/hr, but is negligible under 30 km/hr. The effect of aerodynamic resistance (Fa) has been neglected in determining the length of the arrester bed, thus providing a small additional margin of safety.

5.5 Ramp Length

To safely stop an out-of-control vehicle, the length of the ramp should be sufficient to dissipate the kinetic energy of the moving vehicle. When a vehicle rolls upgrade, it loses momentum and will eventually stop because of the effect of gravity. To determine the distance needed to bring the vehicle to a stop with consideration of the rolling resistance and gradient resistance, the following simplified equation may be used:

$$L = \frac{V_i^2 - V_f^2}{254\,(R + G)}$$

Where,

L = length travelled (m)
V_i = initial velocity (km/h)
V_f = final velocity (km/h). To determine the length of the ramp length this velocity equals to zero.
R = rolling resistance as a grade in percent from Table 5.1
G = grade in percent

For example, assume that topographic conditions at a site selected for an emergency escape ramp limit the ramp to an upgrade of 10 percent (G = +0.10). The arrester bed is to be constructed with loose gravel for an entering speed of 140 km/hr. Using Table 5.1, R is determined to be 0.10. The length of the arrester bed should be determined using the equation above. For this example, the length of the arrester bed is about 400 m.

When an arrester bed is constructed using more than one grade along its length, the speed loss occurring on each of the grades as the vehicle traverses the bed

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should be determined using the same equation above but expressed in a slightly different form:

$$V_f^2 = V_i^2 - 254\,L\,(R \pm G)$$

The final speed for one section of the ramp is a new entering speed for the next section of the ramp and the calculation repeated at each change in grade on the ramp until sufficient length is provided to reduce the speed of the out-of-control vehicle to zero.

5.6 Ramp Width

The width of the ramp should be adequate to accommodate more than one vehicle because it is not uncommon for two or more vehicles to have need of the escape ramp within a short time. A minimum width of 8 m may be all that is practical in most areas, though greater widths are preferred. Desirably, a width of 9 m to 12 m would more adequately accommodate two or more out-of-control vehicles at any one time.

5.7 Attenuation

Where an escape ramp is not being provided with sufficient length and grade to completely stop an out-of-control vehicle, it should be supplemented with an acceptable positive attenuation device. Likewise, if a full-length ramp is provided with full deceleration capability for the design speed, a “last-chance” attenuation device should also be considered when the consequences of leaving the end of the ramp are serious.

Any ramp-end treatment should be designed with care so that its advantages outweigh its disadvantages. The abrupt deceleration of an out-of-control vehicle may cause shifting of the load, shearing of the fifth wheel, or jack-knifing, all potentially harmful to the driver. However, the risk to others as the result of an out-of control vehicle overrunning the end of an escape ramp may be more important than the harm it does to the driver or damage to the cargo of the vehicles.

Mounts of bedding material between 0.6 m and 1.2 m high with 1V:1.5H slopes can be used at the end of ramps. Alternatively, it can be constructed with an array of crash cushions, wire rope or granular-filled barrel installed to prevent an out-of-control vehicle from leaving the end of the ramp.

Where hard surfaced gravity ramps are involved, a shallow gravel bed, sand barrel attenuator array or dragnet system may provide additional stopping capability as well as immobilising a brakeless vehicle that could roll backwards if not restrained.

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Picture 5.1: A Dragnet system replacing gravel bed arrester (Source: Road Talk - Ontario's Transportation Digest)

5.8 Side Barrier

On entering the escape ramp, there is also some possibility of the out-of-control vehicle making sudden swerve to the sides of the arrester bed and exit the bed onto the adjacent main carriageway or fall over the edge of the escape ramp embankment. Narrow ramp width will increase the risk of this happening.

To avoid such incidences, side barriers may be necessary to control and divert back the direction of movement of the vehicle. The barriers must be constructed with adequate strength to prevent penetration and to function effectively as required. A minimum standard of Test Level TL 4 barrier is recommended for this purpose.

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Picture 5.2: A Test Level (TL) 4 safety barrier installed on the sides of an EER (PLUS Jelapang Toll)

6 RAMP STRUCTURE

6.1 Layout for Escape Ramp

A typical layout for a gravel arrester bed escape ramp is shown in Figure 6.1.

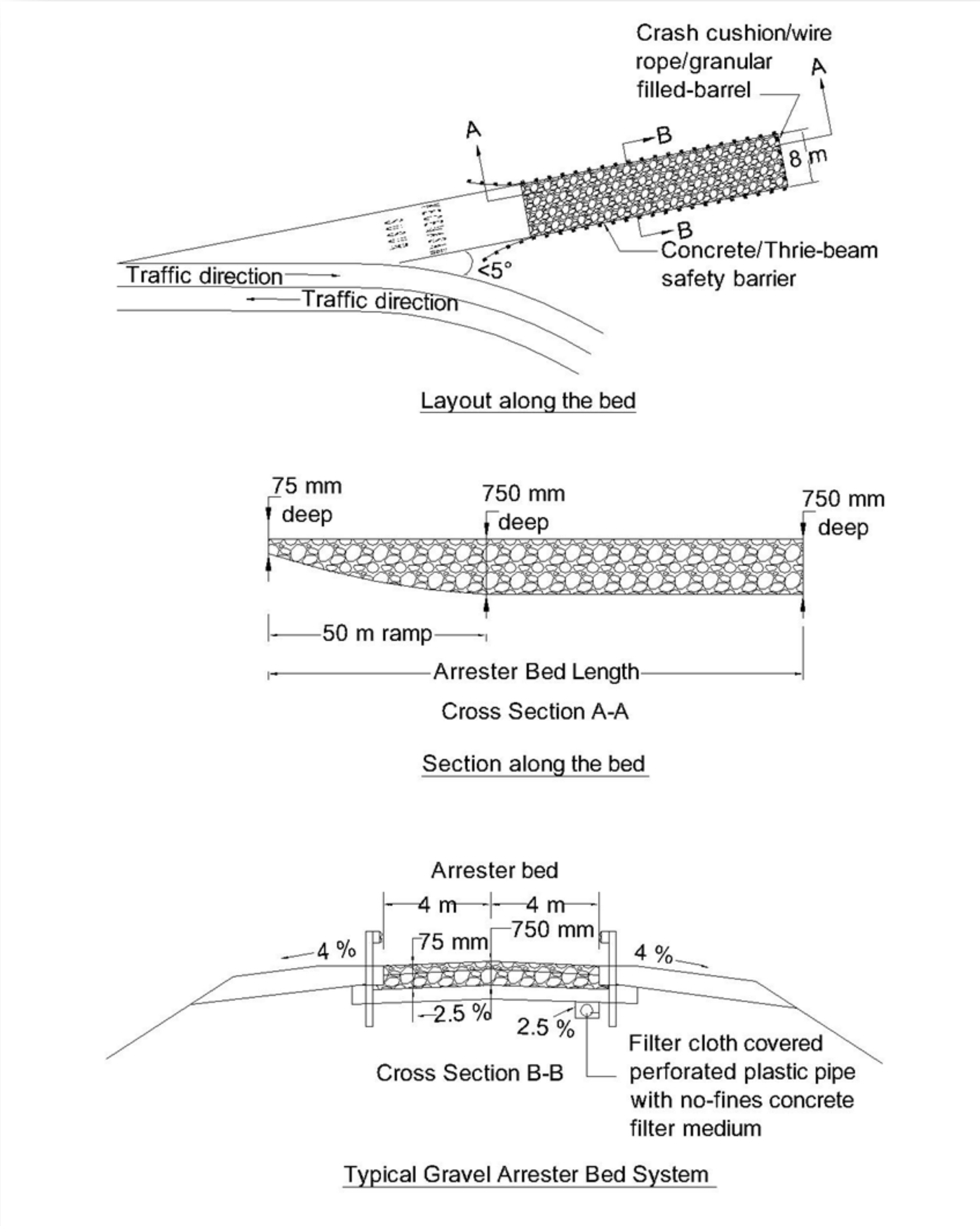

Figure 6.1: Typical Layout and Cross-Section of Escape Ramp

6.2 Arrester Bed Material

The bed material used in arrester bed should be clean, not easily compacted, and have a high coefficient of rolling resistance. In the design of arrester beds it is important to use rounded, uncrushed, predominantly single size gravel and as free from fines as possible. This quality of bedding material (i.e. river gravel) produces higher deceleration than the more angular crushed aggregate. This is because the vehicles sink deeper into a material with low shear strength. Angular gravel (i.e. crushed rock) tends to restrict wheel penetration and compact with time and usage. Table 6.1 gives the deceleration capability (rolling resistance) for various types of pavement surfacing and bedding materials.

Bed material, such as sand, has problems of drainage, compaction and contamination and should not be used unless alternative materials are unavailable. Beds using sand will require frequent de-compaction to ensure their continued effectiveness.

Surfacing/Bedding Material	Rolling Resistance (kg/1,000 kg GVW)	Equivalent Grade (%)
Portland cement concrete	10	1.0
Asphalt concrete	12	1.2
Gravel, compacted	15	1.5
Earth, sandy, loose	37	3.7
Crushed aggregate, loose	50	5.0
Gravel, loose	100	10.0
Sand	150	15.0
Pea Gravel	250	25.0

Table 6.1: Rolling Resistance of Roadway Surfacing/Bedding Materials
(Note: Rolling Resistance is also expressed as Equivalent Gradient; GVW – Gross Vehicle Weight)

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Picture 6.1: Example of Arrester Bed Material

The use of the appropriate bed material will maximise the percentage of voids in the material, thereby providing the optimum drainage and minimising interlocking and compaction. All of these conditions also maximise the retarding characteristics of the arrester bed. Durability of the bed material especially aggregate should also be evaluated. Los Angeles abrasion test (or equivalent) is one of the appropriate crush test and aggregate with a high crush test will not deteriorate easily and will therefore not produce fines.

If aggregate is used, a gradation with a top size of 40 mm is recommended. Material conforming to the AASHTO gradation no. 57 is effective if the fine-sized material is removed. The gradation should be as follows or close to it:

Sieve size	% Passing
Passing 37.5 (1 ½ inch) sieve	100
Passing 25.0 (1 inch) sieve	90-100
Passing 18.75 (¾ inch) sieve	0-10
Passing No. 4 sieve	0-2

Table 6.2: Grading of Bed Material
(Source: Dept. of Transport California, 1986)

Note the low allowable presence of fines. Fine material is one of the principle contaminants of arrester bed gravel. It can trap moisture and other materials that can cause the gravel to lock up and provide unyielding driving surface. The arrester bed must be designed to minimize and slow down the rate at which the gravel becomes contaminated.

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6.3 Bed Material Depth

The main arrester bed should be constructed with a minimum aggregate depth of 750 mm. Contamination of the bed material can reduce the effectiveness of the arrester bed due to the formation of a hard surface layer up to 300 mm thick at the bottom of the bed. The proposed minimum depth takes into account the effect of contamination.

As the vehicle enters the arrester bed, the wheels of the vehicle displace the surface, sinking into the bed material, thus increasing the rolling resistance. To assist in decelerating the vehicle smoothly, the depth of the initial 50 m length of the bed shall be tapered from a minimum of 75 mm at the entry point to the full depth of the granular bed material (i.e. 750 mm). The remaining length shall remain at a constant full depth throughout.

6.4 Drainage

It is essential that water entering an arrester bed be drained away as rapidly as possible. Effective means of draining the arrester bed should be provided to avoid contamination of the arrester bed material. This can be accomplished by grading the base to drain intercepting water prior to entering the bed using under-drain system with transverse outlets, or edge drains. Geotextiles can be used between the sub base and the bed materials to prevent infiltration of fine materials that may trap water.

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Picture 6.2: Drainage system on ascending grade ramp

7 DESIGN PROCESS

The previous few chapters should have enlightened the designers on the important elements of an escape ramp, including some relevant external features. The understanding of the subject matters is very necessary in undertaking the following tasks, which are the processes involved in the comprehensive design of an emergency escape ramp.

With the decision to construct an emergency escape ramp, the designer has to undertake the process of designing the details of the escape ramp. Designers shall be required to make reference to the relevant subjects discussed in the previous chapters during the design stage. Figure 7.1 below shows the steps involved in the design process.

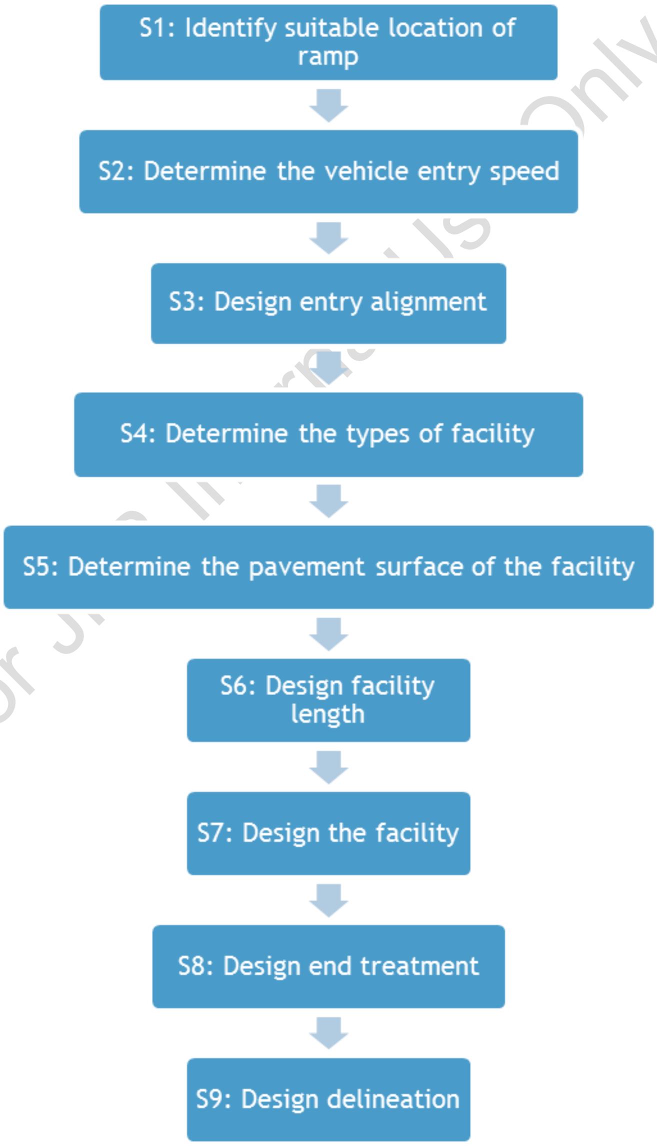

Figure 7.1: Design Process for Emergency Escape Ramp

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Brief description for each step shown in the design process are as follows:

Step S1 - Identify the suitable location of the ramp

The initial step in the design of the escape ramp is to determine the appropriate location for an emergency escape ramp.

Inspect the downgrade section of the road to identify any critical/substandard curves. Apart from evidence of previous accident on-site, accident records should also be used to help locate the exact location where frequent runoff accidents occur. Depending on the type of curve, the escape ramp should be provided at or before the substandard curves or accident prone locations.

For left turn curve, the ramp shall be constructed before the curve but in the case of a right turn curve, the ramp can be constructed before or at the curve. Whichever the case is, sufficient roadside area is necessary for construction of the escape ramp. Refer to Section 4.1 for further detail.

Step S2 - Determine Vehicle Entry Speed

The recommended design vehicle (e.g. SU or WB-15) should be determined as part of the design and should be used in determining the vehicle entry speed to the facility. Heavy runaway vehicles attain high speeds but speeds in excess of 130 km/h to 140 km/h will rarely, if ever, be attained. An escape ramp should therefore be designed for a minimum entering speed of 130 km/h, with a 140 km/h design speed being preferred. The selected speed and bed material to be used are important factors in computing the length of the ramp bed (see Steps 5 and 6).

Step S3 - Design Entry Alignment

This step involves the design of the approach to the ramp including the ramp alignment itself. The entry speed of a runaway vehicle is used for designing the approach and entry to safety ramps and arrester beds. The alignment of the escape ramp should be at a tangent or very slight curvature to reduce the likelihood of the driver experiencing vehicle control problems. The entrance to the ramp should be designed so that a vehicle travelling at high speed can enter easily and safely. This has also been discussed earlier and reference should be made to Sections 5.2 and 5.3 for further information.

Step S4 - Determine Type of Facility

The constraints posed by the terrain will largely determine the type of emergency escape ramp to be constructed. Several iterations of design may be necessary if a combination of several facility types proves to be necessary. Changes to the type of facility and bed type may be necessary to determine the best fit to the site constraints. Options for the appropriate type of facility are given in Chapter 2.

Step S5 - Determine Bed Material of Facility

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The Rolling Resistance of the bed material will have a significant influence on the length required for the containment facility. The selection of the appropriate bed material for the ramp is given in Section 6.2. The values shown in Table 6.1 are used for the calculation of the ramp bed length (see next step).

Step S6 - Design Facility Length

The length of a containment facility will vary depending on entry speed, grade, pavement material and the type of facility. The vehicle entry speed described in Step S2 is used as the initial speed for determining the length of an arrester bed. The length of an arrester bed can be calculated using the equation given in Section 5.5.

Step S7 - Design the Facility

This step involves the preparation of the layout and detail design of the facility. Several iterations with different combinations of facility types may be necessary. Apart from the design details presented earlier, the followings are some additional features in the design of the ramp that may need to be considered:

a. Safety ramp design features

The grade of the safety ramp will be largely determined by the terrain. Safety ramps need the steep-sided cut batters on both sides. When a runaway vehicle stops in an ascending grade ramp it will begin to roll back because the brakes are not functional. In this situation driver must jack-knife the vehicle against the sides of the ramp to prevent it rolling down the ramp.

b. Arrester bed design features

Arrester beds aim to provide deceleration similar to an emergency braking situation to avoid the risk of the truck cabin being crushed by a shifting load. Arrester beds can be constructed on up, level or downgrades depending on the topography at the site. Arrester beds on downgrades require additional length to bring out-of-control vehicles to rest.

An access area or service road on both sides of the arrester bed is not necessary in most cases but may be required where heavy vehicles on a particular route carry very heavy or difficult loads that require retrieval vehicles or cranes to work from both sides.

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Step S8 - Design End Treatment

The consequences of a vehicle passing through and out of the ramp or arrester bed should be considered. Crash cushions are designed for cars and have limited effectiveness for heavy vehicles. They should only be considered where they would act as cushioning devices before a rigid object such as a rock face. Some practices mentioned in Section 5.7 should be referred to and may be worthy of consideration.

Step S9 - Design Delineation

The existence and location of a containment facility must be made obvious by necessary signage to give the operator of an out-of-control vehicle time to react and decide to enter the facility. Standard signage should be provided and located in accordance with Figure 4.1 (refer Appendix 2 for details).

Adequate delineation should also be provided so that the entrance to a containment facility is not mistaken for the through carriageway and the entry path to the facility is clear by day and night. Installation of on-pavement signs and yellow box markings at the entrance to the escape ramp may also be necessary. Appendix 4 shows some dimensional details on the on-pavement sign marking.

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8 ESCAPE RAMP MAINTENANCE

All arrester beds and bedding materials require regular maintenance. Aggregate or any granular bedding material tends to compact over time. They can also get compacted with repeated traversals by machineries and vehicles. Thus, the bed material should be loosened up or scarified after each use of the ramp or every six (6) months, whichever comes first. Periodic maintenance should be able to retain the retarding characteristics of the bedding material and maintain free flowing drainage.

Arrester bed escape ramps require smoothing after every entry. An aggregate bed that contains humps and hollows can be very difficult to traverse and may unnecessarily damage the vehicles. Thus, it is essential that any bed material used shall be reshaped as soon as possible after a vehicle has been removed from the bed. Reshaping can be done using the right equipment to the full extent possible including scarifying the granular bed material.

Whenever the bedding material is scarified, it should be examined for contamination. If an excessive amount of fine material or other contaminants are noted, immediate provisions should be made to replace or reprocess the bedding material to its original specifications. Another indicator that the bedding material is becoming contaminated is when the vehicles using the ramp travel increasing distances along the ramp.

Maintenance of an arrester bed escape ramp requires suitable equipment. Hand tools are not acceptable. Proper power equipment assures that the ramp will be back in service in a minimum amount of time. Care must be taken to ensure that maintenance works will be minimally exposed to the chance of a runaway vehicle wanting to use the ramp.

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APPENDIX 1

SUMMARY DESIGN OF EMERGENCY ESCAPE RAMPS

Types	Gravity escape ramps Arrester bed Sand pile escape ramps Mechanical arrester escape ramps	
Ramp alignment	≤ 5°	
Approach to ramp	≥ 150 m	
Ramp grades		
Bedding material	Portland cement concrete Asphalt concrete Gravel, compacted Earth, sandy, loose Crushed aggregate, loose Gravel, loose	
Entering Speed (km/h)	130 - 140	$V_f^2 = V_i^2 - 254\,L\,(R \pm G)$
Ramp length	$L = \dfrac{V^2}{254\,(R - G)}$	
Ramp width	≥ 8 m	
Attenuation	Crash cushion Wire rope Granular-filled barrel	
Side barrier	≥ TL4	
Arrester bed material	40 mm is recommended	
Bed material depth	≥ 750 mm	

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APPENDIX 2

TYPES OF SIGNAGE


3085
150
150
300
1590
SUSUR
KECEMASAN
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900
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800
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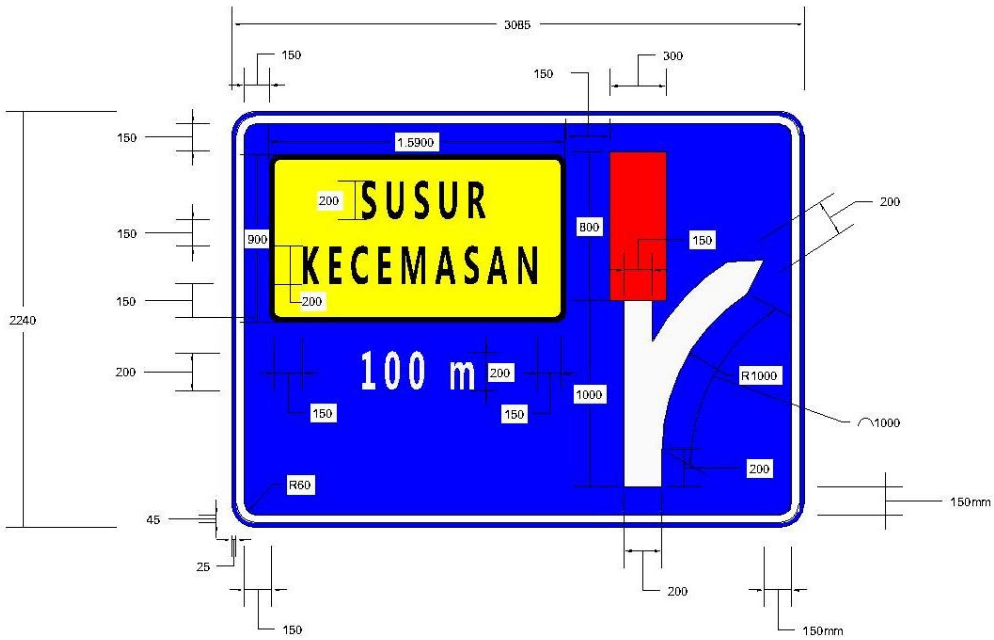
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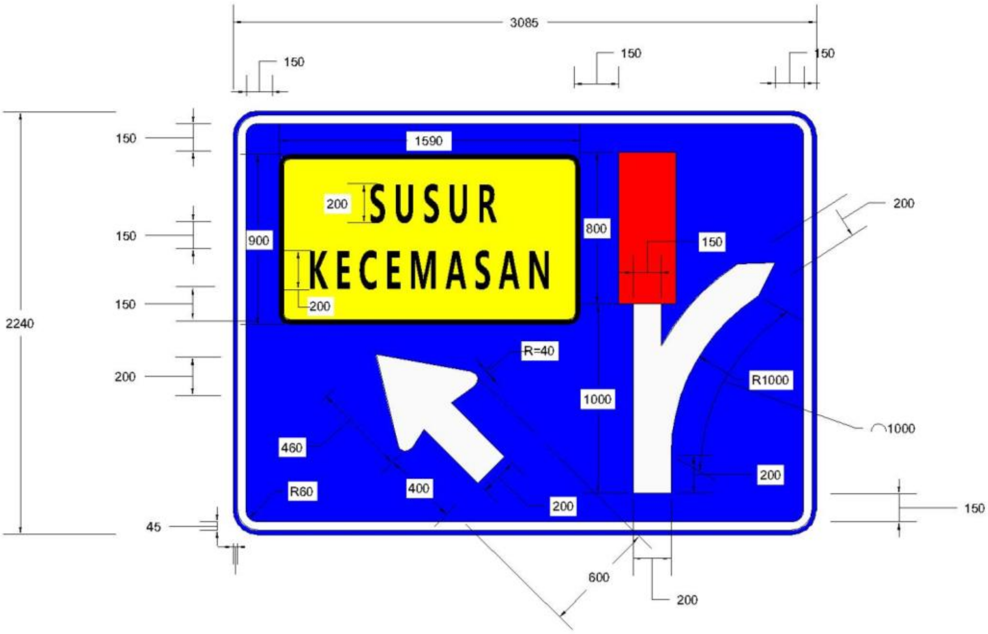

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APPENDIX 3

NOTICE REMINDER SIGN

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APPENDIX 4

ON-PAVEMENT SIGN MARKING