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Foreword

During the mid-year meeting of the Transportation Research Board's Committee on Roadside Safety Features (A2A04) in Reno, Nevada, July 2001, the Subcommittee on International Research Activities [A2A04(2)] met separately for a 1-day meeting. The meeting included several presentations by international experts in the field regarding standards for testing, evaluating, and locating roadside safety features. Contained within this E-Circular are several of the presentations selected by the subcommittee. These papers, presentations, slides, and standards should be of interest to the international community concerned with roadside safety features.

Contents

Update of U.S. Crash Test Procedures

HARRY W. TAYLOR
Federal Highway Administration

Click here to see Taylor's Powerpoint presentation.

Standards of Guard Fences

KAZUHIKO ANDO
Ministry of Land, Infrastructure, and Transport

In Japan, guard fences are installed in conformity with guard fence installation standards. As for the former standards of guard fences, a first edition had been notified in 1965 and has been revised twice (1967,1972). Recently, road traffic has tended to speed up, a consequence of the extension of expressways and sharp improvements in motor vehicle performance. These changes have been accompanied by a rise in the force of impacts nationwide. On the other hand, former standards of guard fences have stipulated structural details, the selection of types of guard fences to install has been limited, and little development has been undertaken to provide guard fences with structures or colors that contribute to the beautification of the road and its surroundings.

Considering the above conditions, Japanese standards of guard fences were revised in November 1998. Specifications of guard fences in the new standard had been prescribed by a former standard, but it is a most characteristic point in the 1998 version to prescribe performances of guard fences. In the new standards, there are two types of guard fences. Traffic barriers are for vehicle guidance after collision, and fences for pedestrians and cyclists protect pedestrians and cyclists from falling or crossing the road. The new standard includes the following characteristics:

1. Four functions of a traffic barrier are introduced in the standard, and a traffic barrier that confirmed performances by an experiment can be utilized. The four functions are
    - Preventing motor vehicles from deviating into off-road areas,
    - Preserving the safety of passengers,
    - Guiding motor vehicles, and
    - Preventing accidents caused by broken traffic barrier parts.
2. New classification of high-strength traffic barriers corresponding to high-speed collision of a large vehicle have been established(impact severity level: 160～650kJ).
3. The large-sized test vehicle has been raised to a 25-ton truck from the traditional 14-ton truck.
4. Traffic barriers should prevent damage to a third party on the road.
5. To evaluate the safety of passengers a moving average acceleration standard value of 10 m/s is used.

RECENT SOCIAL TRENDS CONCERNING GUARD FENCES

In Japan, guard fences are installed in conformity with the nationwide standards of guard fences, contributing greatly to the prevention of accidents caused by motor vehicles deviating into off-road areas. But traffic conditions in Japan have changed substantially since these standards were established. Road traffic has tended to speed up and vehicle size to increase, a consequence of the construction of expressways and sharp improvements in motor vehicle performance. These changes have been accompanied by a rise in the force of impacts to guard fences—a trend that is forecast to continue.

To provide an example of this increase in the size of motor vehicles, Figure 1 presents the increase in the number of 25-ton trucks in operation since their use was permitted by a 1993 revision of motor vehicle regulations.

Because Japanese guard fence installation standards have stipulated structural details, the selection of types of guard fences has been limited and little development has been undertaken to provide guard fences with structures or colors that contribute to the beautification of the road and its surroundings. As a consequence, the public has expressed a need for shapes that take advantage of the special features and the uniqueness of various regions, and city dwellers have demanded that guard fences installed in their areas have designs and colors that do not detract from the appearance of their streets.

Table 1 shows guard fence structures and design conditions that have been applied in the past.

THE NEW GUARD FENCE STANDARDS

For the above reasons, we revised the standard governing guard fences, establishing new categories of guard fences suited for larger/faster-moving motor vehicle traffic. And, in the future, it will be possible to install guard fences, regardless of their construction or materials, that have been verified by means of impact testing using actual motor vehicles.

An important feature of the new guard fence standards announced November 5 is that they permit the use of guard fences of various designs by providing for greater guard fence strength and by replacing structural stipulations with performance stipulations.

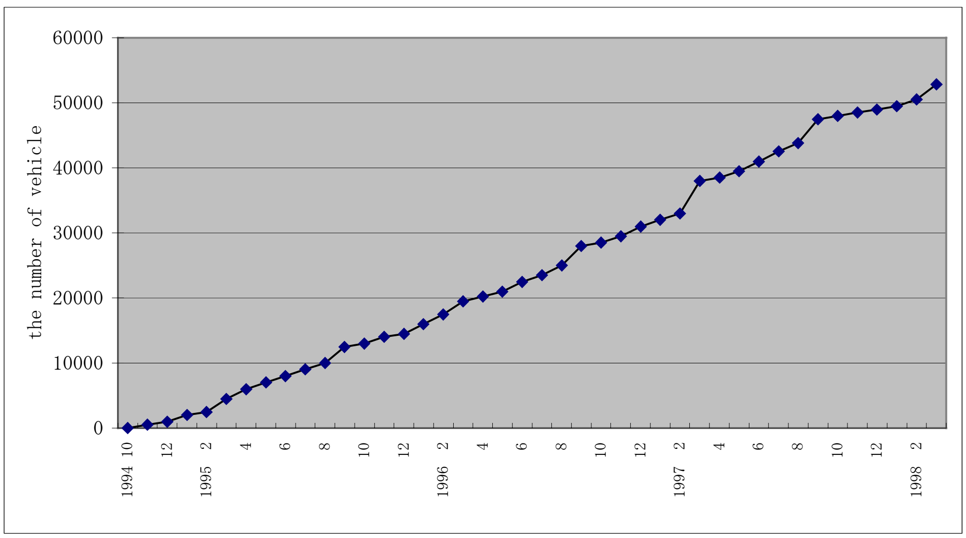
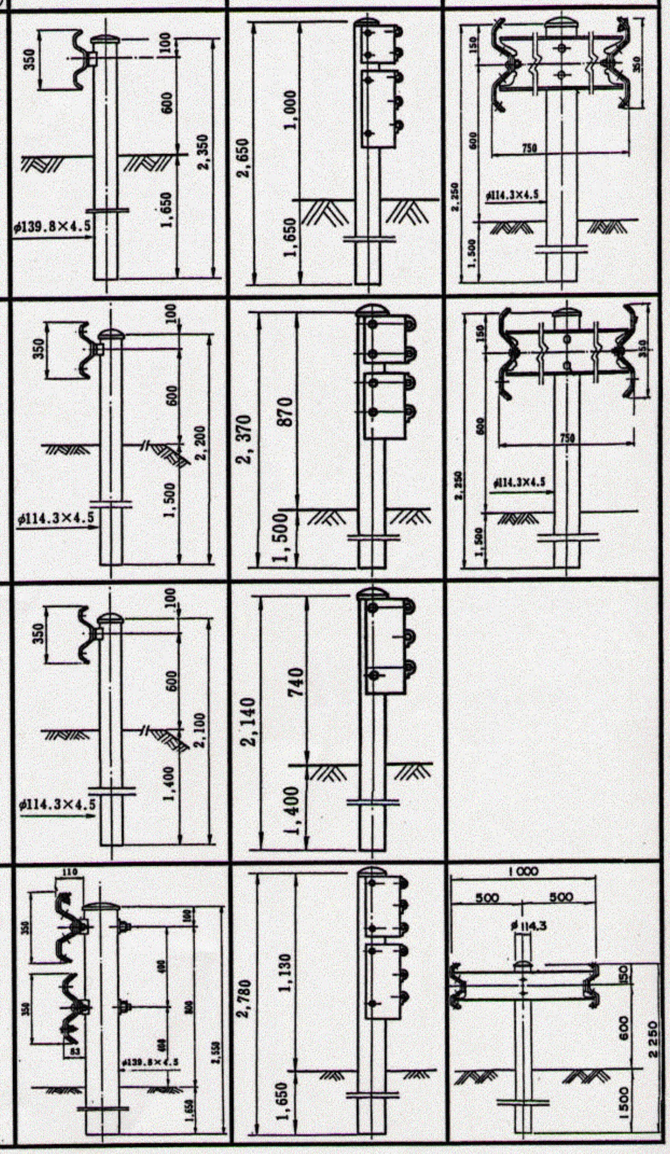


FIGURE 1 Increase in number of 25-ton trucks operating.

TABLE 1 Examples of Traffic Barrier Design Conditions and Typical Structures

Classification	Category	Impact Condition W [a] (ton)	Impact Condition V [b] (km/h)	Impact Condition θ [c] (deg)	Ex. of Structure of Barrier: Guardrail	Ex. of Structure of Barrier: Guardcable	Ex. of Structure of Barrier: Median Guardrail
Expressway National Highway	A	14	60	15			
National Highway Prefectural Road	B	14	40	15			
Other	C	14	35	15			
Grade Separation over the New Trunk Railway	S	14	80	15			

a) weight , b) Velocity , c) Angle



New guard fence standards are as follows:

1. Guard Fence Installation Standard from Director-General of Road Bureau, Ministry of Construction (MOC), November 5, 1998 (see Appendix).
2. Performance Evaluation Test Methods of Traffic Barriers from Director-General of Road Environment Division, Road Bureau, MOC, November 5, 1998.
3. Standard Specification of Traffic Barriers from Director-General of Road Environment

Division, Road Bureau, MOC, March 1999.

Classification of Guard Fences

Guard fences shall be classified as traffic barriers to protect motor vehicles and as fences to protect pedestrians and cyclists.

Traffic barriers are provided primarily to prevent a motor vehicle traveling in an incorrect course from deviating into an off-road area, into a lane used by oncoming traffic, or into a pedestrian sidewalk, to minimize injuries to its passengers and damage to the motor vehicle, and to return the motor vehicle to its correct course, and as a secondary function, to guide the line of sight of drivers.

Fences also prevent pedestrians and cyclists from falling or recklessly crossing streets.

Traffic Barriers
Installation Sections

Traffic barriers shall, in principle, be installed on sections or at locations that correspond to any of the following items in accordance with road and traffic conditions.

There are three installation sections (Figure 2).

1. Sections where traffic barriers shall be installed primarily to prevent personal injury to passengers of a motor vehicle caused by its deviation into the off-street area.
    - Sections at embankments, precipices, and retaining walls, and on bridges and viaducts.
    - Sections close to the sea, a lake, a river, a marsh, or a canal.
    - Sections of entrance to a bridge, viaduct, tunnel, etc., or adjacent to another road.
2. Sections where traffic barriers shall be installed primarily to prevent personal injuries to third parties caused by a motor vehicle deviating into the off-road area.
    - Sections of grade-separated crossing, sections close to a railway line or track or another road, etc.
    - Median of national expressways and motorways.
    - Median of sections where traffic moves at high speeds and roads with harsh gradient or alignment conditions.

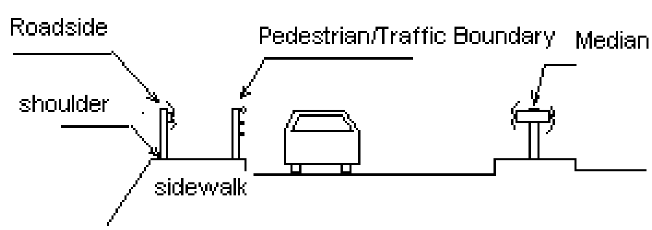


FIGURE 2 Installation location of traffic barriers.

3. Sections of a road where traffic barriers shall be installed on the boundaries between the traffic lane and sidewalks
   - Sections on roads where traffic moves at high speed and a barrier is needed to prevent serious accidents.

Choosing a Category Based on Strength and Installation Location

Traffic barriers are categorized according to the strength that will prevent breakage of the traffic barrier under the following degrees of impact severity (Table 2 and Figure 3).

- The existing category S has been broadened into sub-categories SS, SA, SB, and SC.
- Traffic barriers installed on medians and on boundaries with sidewalks are identified by the suffixes m and p respectively. (Am, Ap, etc.)

Required Performance

It is stipulated that all categories shall

1. Prevent motor vehicles from deviating into off-road areas;
2. Preserve the safety of passengers;
3. Guide motor vehicles; and
4. Prevent accidents caused by broken traffic barrier parts.

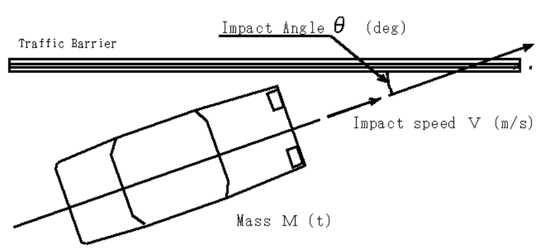
Road managers shall confirm their performance by means of impact tests.

Roadway Deviation Prevention (Strength and Deformation Properties) A traffic barrier must not break when impacted with the degree of impact stipulated for that traffic barrier category.

The maximum penetration by a motor vehicle impacting a flexible traffic barrier must be below a value stipulated for that category of traffic barrier (Table 3).

Table 2 Category of Traffic Barrier

Degree of Impact Severity (kJ)	650	420	280	160	130	60	45
Category	SS	SA	SB	SC	A	B	C



Impact Severity (kJ) = $(1/2) \cdot M \cdot (v \cdot \sin\theta)^2$

FIGURE 3 Impact severity.

TABLE 3 Maximum Penetration of a Flexible Traffic Barrier

Category	Columns Embedded in Ground	Columns Embedded in Concrete
Roadside	Max 1.1 m	Max 0.3 m
Median	Max 1.5 m (max 1.1 m)[a]	Max 0.5 m (max 0.3 m)[a]
Pedestrian/Traffic Boundary	Max 0.5 m	Max 0.3 m

[a] Values in parentheses are applied to category C and B.

TABLE 4 Impact Acceleration Evaluation Standard Value by Category

Category	Impact Speed	Acceleration Evaluation Standard Value
B, C	60 km/h	9-12G
A	100 km/h	15-18G
SC, SB, SA, SS	100 km/h	18-20G

Passenger Safety The impact acceleration (momentary value) applied to the body of a passenger in a motor vehicle impacting a traffic barrier must be lower than evaluation standard values by category of impact speed (Table 4).

Motor Vehicle Guidance After striking the traffic barrier, a motor vehicle must not overturn and its exit speed and exit angle must satisfy stipulated values.

Prevention of Accidents Caused by Broken Traffic Barrier Parts When a motor vehicle strikes a traffic barrier, its components will not be scattered very far.

Application of Categories

Road sections where traffic barriers are installed will be categorized as one of three sections: ordinary sections, sections where there is a danger of serious injuries occurring, and sections that cross or are close to high-speed railway lines according to the seriousness of the personal injuries that would be inflicted on third parties (secondary injuries) and of passenger injuries in the event that a vehicle entered an off-road area (Table 5).

Selection of Structure

When a traffic barrier is installed, it shall be installed so that it can fully function as a traffic barrier. The kind and type of traffic barrier shall be selected with full consideration given to road and traffic conditions.

Selection of the Kind and Type In principle, the traffic barrier selected shall be a flexible traffic barrier. But traffic barriers selected for installation on a structure such as a bridge or viaduct or on a narrow median where deformation of the traffic barrier cannot be permitted may, as necessary, be rigid traffic barriers.

Selection of Traffic Barrier Type The type of a traffic barrier shall be selected with full consideration given to performance, economic efficiency, maintenance, execution

TABLE 5 Application Sections and Categories

<table>
<tr><th>Road Category</th><th>Design Speed</th><th>Ordinary Section</th><th>Section Where There Is Danger of Serious Injuries</th><th>Section Crossing or Close to a High-Speed Railway Line, etc.</th></tr>
<tr><td>Expressways</td><td>80 km/h</td><td rowspan="2">A, Am (A)</td><td>SB, SBm</td><td>SS (S)</td></tr>
<tr><td>Motorways</td><td>60 km/h</td><td>SC, SCm</td><td>SA (A)</td></tr>
<tr><td rowspan="2">Other Roads</td><td>60 km/h</td><td>B, Bm, Bp (B)</td><td>A, Am Ap</td><td rowspan="2">SB, SBp (S)</td></tr>
<tr><td>50 km/h</td><td>C, Cm, Cp (C)</td><td>B, Bm, Bp</td></tr>
</table>

Note: Past application category standard shown in parentheses.

TABLE 6 Design Strength by Category

Category	Design Strength	Purpose
P	Vertical Load: min. 590 N/m(60kgf/m) Horizontal Load: min. 390 N/m(40kgf/m)	Prevention of falling Restraint of road crossing
SP	Vertical Load: min. 980 N/m(100kgf/m) Horizontal Load: min. 2,500 N/m(250kgf/m)	Prevention of falling

Notes: The load shall be assumed to act on the top of the fence. The bearing strength of the members of category P may be designed as the allowed limit.

conditions, median width, line of visual guidance, maintenance of visibility, anxiety-free driving, preserving attractive roadside scenery, and harmony with the environment. Table 6 and Figure 4 stipulate the types of traffic barriers.

Fences for Pedestrians/Cyclists
Installation Sections

Fences for pedestrians and cyclists shall be installed as necessary in accordance with road and traffic conditions in all road sections stipulated below.

1. Sections where a fences for pedestrians and cyclists shall be installed on the roadside or on the pedestrian/traffic boundary in order to prevent pedestrians from falling.
2. Sections where fences for pedestrians and cyclists shall be installed on pedestrian/traffic boundaries in order to restrain pedestrians from crossing the lanes of the road.
3. In low-speed sections of roads in large cities where simply dividing the sidewalk from the traffic lanes can be counted on to guarantee the safety of pedestrians on parts where it is considered to be particularly necessary.

Required Performance

1. Category P: Assumes a normal load. Guard fences used along pedestrian sidewalks and bicycle pathways are, in principle, category P.

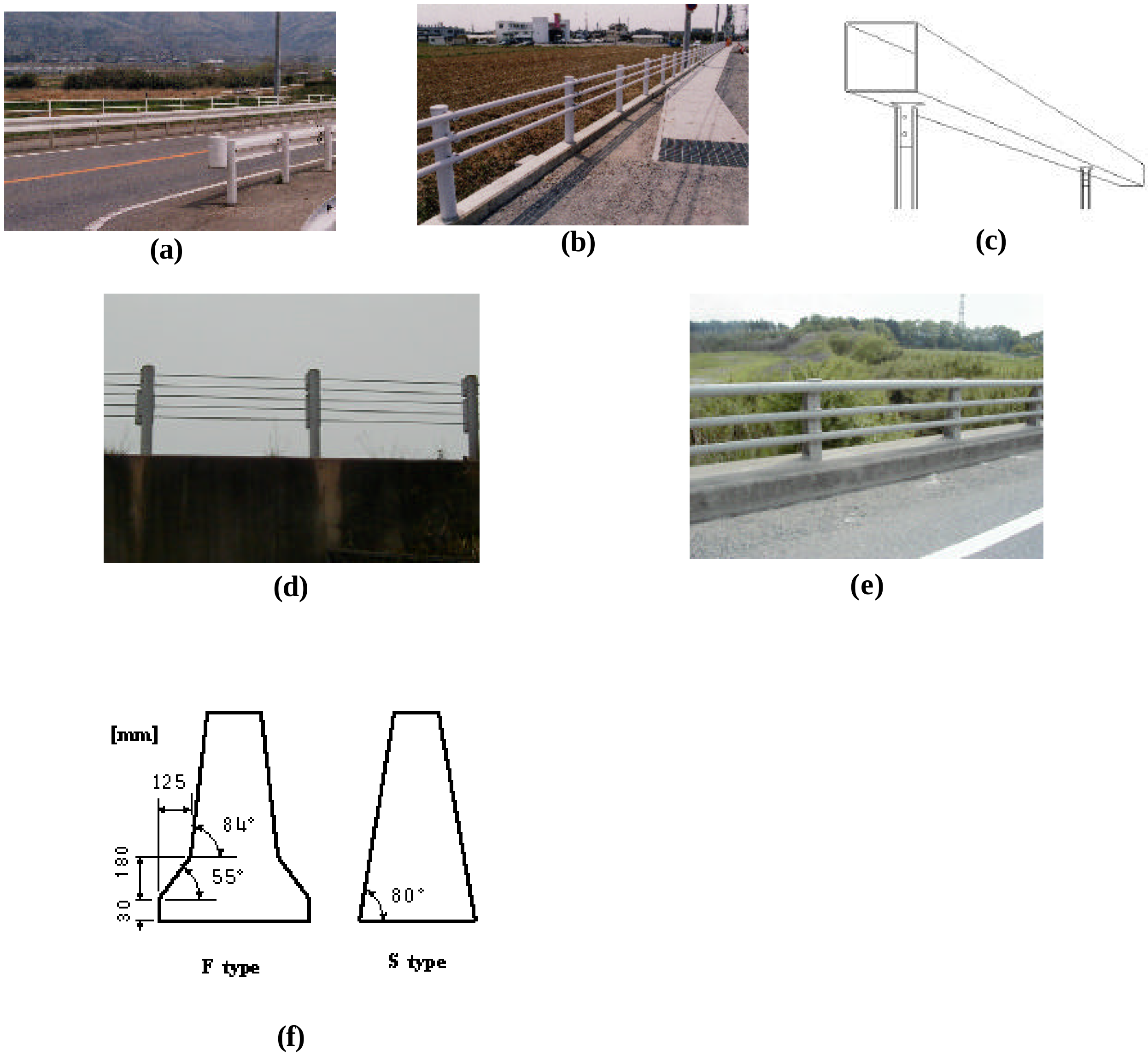


FIGURE 4 Types of traffic barriers: (a) guard rail; (b) guard pipe; (c) box beam; (d) cable-type traffic barrier; (e) bridge railing; (f) rigid traffic barrier.

2. Category SP: Assumes a group load. Fall prevention guard fences (handrails) installed on bridges and viaducts, fall prevention guard fences installed in sections where pedestrians stop walking.

Structure, Other

A fence for pedestrians and cyclists shall be typed with pedestrian safety in mind; typed in such a way that bolts or other projecting parts or member joints cannot harm pedestrians, etc. And the intervals between the cross-pieces of fences for pedestrians and cyclists installed to prevent falling shall be such that pedestrians, etc., cannot easily fall out between them.

Fences installed to prevent pedestrians from crossing a road shall be installed in cases where it is considered necessary after studying alternative methods such as the planting of a row of trees in order to improve the scenery.

APPENDIX

Guard Fence Installation Standard

Director-General, Road Bureau, Ministry of Construction, Japan
November 15, 1998

CHAPTER ONE—GENERAL PROVISIONS

Objective

This standard has been established to specify general technical criteria that guarantee that guard fences are correctly constructed and installed.

Definition of Traffic Barrier

In this standard, the word "guard fence" shall refer to a facility provided primarily to prevent a motor vehicle traveling in an incorrect course from deviating into an off-road area, into a lane used by oncoming traffic, or into a pedestrian sidewalk, to minimize injuries to its passengers and damage to the motor vehicle, and to return the motor vehicle to its correct course, and as secondary functions, to guide the line of sight of drivers and to prevent pedestrians and cyclists (hereinafter referred to as pedestrians) from falling or recklessly crossing streets.

Guard fences shall be classified as **traffic barriers** to protect motor vehicles and as **fences for pedestrians/cyclists** to protect pedestrians.

CHAPTER TWO—TRAFFIC BARRIERS

Installation Sections

Traffic barriers shall, in principle, be installed on sections or at locations (hereinafter referred to as sections) which correspond to any of the following items in accordance with road and traffic conditions.

1. Sections where traffic barriers shall be installed beside the road primarily to prevent personal injury to passengers of a motor vehicle caused by its deviation into the off-street area (including road shoulders, hereinafter referred to as off-street area).
    - Sections where it is considered necessary to do so because the off-street area is extremely dangerous: sections at embankments, precipices, and retaining walls, and on bridges and viaducts.
    - Sections where it is considered necessary to do so because the road is close to the sea, a lake, a river, a marsh, or a canal.
    - Sections where it is considered necessary to do so because of the relationship of the road with a structure adjacent to the entrance to a bridge, viaduct, tunnel, etc., or with another road.
2. Sections where traffic barriers shall be installed primarily to prevent personal injuries to

third parties (hereinafter referred to as secondary injuries) caused by a motor vehicle deviating into the off-road area.

- Sections where traffic barriers shall be installed beside the road primarily to prevent secondary injuries caused by a motor vehicle deviating into the off-road area.

3. Sections where a road either crosses a grade-separated crossing or is close to a railway line or track (excluding a streetcar track, hereinafter referred to as railway line) or another road, and where there is a danger of a motor vehicle deviating into the off-road area or entering the area of the railway line or the other road.

- Sections of a road with a median where traffic barriers shall be installed on the median primarily to prevent secondary injuries caused by a motor vehicle deviating into an oncoming lane.

4. National expressways and motorways.
5. Sections where traffic moves at high speed and where, because of harsh gradient or alignment conditions, it is considered to be particularly necessary to do so in order to prevent accidents caused by a motor vehicle deviating into an oncoming lane.

- Sections of a road where traffic barriers shall be installed on the boundaries (hereinafter referred to as pedestrian/traffic boundary) between the traffic lane and sidewalk, exclusive pedestrian road or bicycle paths (hereinafter referred to as pedestrian sidewalk) primarily to prevent secondary injuries caused by a motor vehicle entering a pedestrian sidewalk, etc. (including cases where a new sidewalk is created by installing a traffic barrier)

6. Sections on roads where traffic moves at high speed and where it is considered particularly necessary to do so in order to prevent serious accidents caused by a car driving into a home along the roadside.
7. Sections on roads where traffic moves at high speed and it is considered necessary to do so to protect pedestrians who are at high risk.

- Sections where traffic barriers are necessary for other reasons

8. Sections of roads where accidents occur frequently, or where there is a danger of accidents occurring frequently, and where it is believed that the installation of traffic barriers would be an effective measure.
9. Sections where it is considered necessary to do so because of the width or alignment of the road, or because of traffic conditions.
10. Sections where it is considered particularly necessary because of weather conditions.

Categories

Categorization

Traffic barriers shall be categorized as shown in Table 2-1 according to strength [scale of the degree of impact severity (IS) that will not break the traffic barrier when impacted by a motor vehicle] and installation location.

Performance

A traffic barrier shall provide the performance indicated by the following codes set for each category. In this case, impact condition A and impact condition B shall be conditions shown in Table 2-2.

TABLE 2-1 Design Strength by Category

Category	Design Strength	Purpose
P	Vertical Load: min. 590 N/m (60kgf/m) Horizontal Load: min. 390 N/m (40kgf/m)	Prevent falling Prevent road crossing
SP	Vertical Load: min. 980 N/m (100kgf/m) Horizontal Load: min. 2,500 N/m (250kgf/m)	Prevent falling

Notes: The load shall be assumed to act on the top of the fence. The bearing strength of the members of category P may be designed as the allowed limit.

TABLE 2-2 Impact Conditions

<table>
<tr><th colspan="3">Impact Condition</th></tr>
<tr><td>Impact Condition A</td><td colspan="2">Impact at the degree of IS for the categories in Table 2-1 by a large truck with a height of 1.4 m from the road surface to its center of gravity when fully loaded. Its impact angle at this time shall be 15 degrees.</td></tr>
<tr><td rowspan="3">Impact Condition B</td><td colspan="2">Impact by a passenger car weighing 1 ton. The impact speed shall be as indicated below with an angle of impact of 20 degrees.</td></tr>
<tr><th>Category</th><th>Impact Speed</th></tr>
<tr><td>C, Cm, Cp, B, Bm, Bp

A, Am, Ap, SC, SCm, SCp, SB, SBm, SBp, SA, Sam, SS, SSm</td><td>60 km/h

100 km/h</td></tr>
</table>

Motor Vehicle Road Deviation Prevention Function

Strength Performance A traffic barrier shall have strength sufficient to prevent it from breaking when subjected to an impact that conforms with impact condition A.

Deformation Performance When a flexible traffic barrier is subject to an impact that conforms with impact condition A, the maximum traffic barrier penetration distance of the motor vehicle shall satisfy the values in Table 2-3 according to the location where it is installed. Plastic deformation of the principal members of a rigid traffic barrier shall not occur.

Here, flexible traffic barrier and rigid traffic barrier shall refer to the following traffic barrier categories that are defined according to the traffic barrier design method.

1. Flexible traffic barrier: A traffic barrier designed by calculating the elasticity and plastic deformation of its principal members.
2. Rigid traffic barrier: A traffic barrier designed by calculating the deformation within the elastic boundary of its principal members.

TABLE 2-3 Maximum Penetration[a] of a Flexible Traffic Barrier by a Motor Vehicle

Category		Columns Embedded in the Ground	Columns Embedded in Concrete
Road Side	C, B, A, SC, SB, SA, SS	max. 1.1 m	max. 0.3 m
Median	Cm, Bm	max. 1.1 m	max. 0.3 m
	Am, SCm, SBm, SAm, SSm	max. 1.5 m	max. 0.5m
Pedestrian/Traffic Boundary	Cp, Bp, Ap, SCp, SBp	max. 0.5 m	max. 0.3 m

[a] The value of a distance that wheels go outside the road from the original position of the traffic barrier surface.

Safety of Passengers

When a traffic barrier is impacted by a motor vehicle under impact condition B, the acceleration applied to the motor vehicle shall satisfy the values in Table 2-4 according to the traffic barrier category and kind.

Guidance of Motor Vehicles

A traffic barrier shall satisfy the following conditions when it is impacted in conformity with either impact condition A or condition B.

1. The motor vehicle shall not overturn after impacting the traffic barrier.
2. The exit speed after impact with the traffic barrier shall be greater than 60% of the impact speed.
3. The exit angle after impact with the traffic barrier shall be less than 60% of the impact angle.

The exit speed and exit angle shall conform with Figure 2-1.

Constituent Member Scattering Prevention Performance

Parts of a traffic barrier shall not be scattered far when a motor vehicle impacts the traffic barrier under either impact condition A or impact condition B.

Structure and Materials

Traffic Barrier Height

The height from the road surface to the upper edge of a traffic barrier shall, in principle, be a minimum of 60 cm and a maximum of 100 cm.

In a case where the height of a traffic barrier must exceed 100 cm in order to satisfy the required performances, it shall be constructed so that it can protect the heads of the passengers in

TABLE 2-4 Acceleration of a Motor Vehicle

Category	Flexible Traffic Barrier		Rigid Traffic Barrier
	Columns Embedded in the Ground	Columns Embedded in Concrete	
C, Cm, Cp B, Bm, Bp	Less than $90m/s^2/10ms$	Less than $120m/s^2/10ms$	Less than $120m/s^2/10ms$
A, Am, Ap	Less than $150m/s^2/10ms$	Less than $180m/s^2/10ms$	Less than $180m/s^2/10ms$
SC, SCm, SCp SB, SBm, SBp SA, Sam SS, SSm	Less than $180m/s^2/10ms$	Less than $200m/s^2/10ms$	Less than $200m/s^2/10ms$

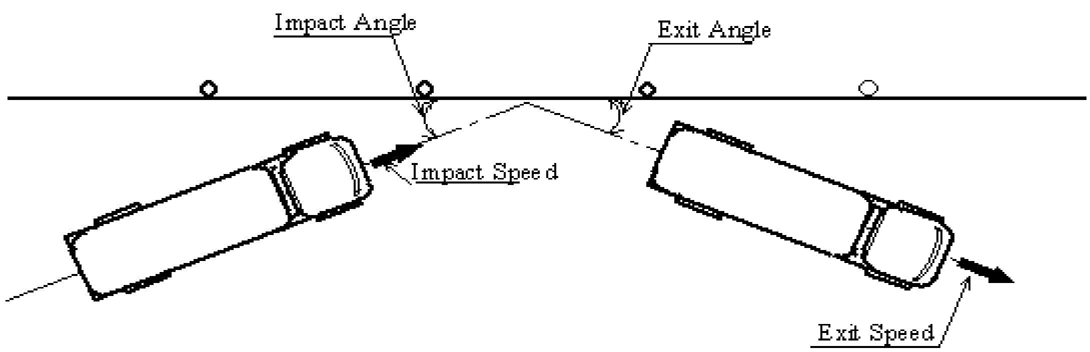


FIGURE 2-1 Exit speeds and exit angle.

the motor vehicle impacting the traffic barrier.

Type of a Traffic Barrier Installed on a Pedestrian/Traffic Boundary

A traffic barrier installed on a pedestrian/traffic boundary (categories Cp, Bp, Ap, SCp, and SBp) shall be typed with pedestrian safety in mind and typed in such a way that bolts or other projecting parts or member joints cannot harm pedestrians etc.

Materials

Materials used to construct a traffic barrier shall provide sufficient strength, be extremely durable, and be easy to maintain.

Rust Proofing and Corrosion Proofing

Metal used to make a traffic barrier shall be rust proofed or corrosion proofed using a method with effectiveness equal or superior to that stipulated by Japan Industrial Standards (JIS). Highly effective rust proofing and corrosion proofing shall be performed in cases of a traffic barrier that is to be installed at a location where, because the environment is particularly harsh, metal is susceptible to rusting and corrosion.

And if the metal treatments for rust and corrosion are not stipulated by JIS, the methods and the effectiveness of the methods of rust proofing and corrosion proofing suitable for the metal in questions shall be verified and the methods shall be applied.

Application of Traffic Barrier Categories

Installation Location

Traffic barriers that are installed on roadsides shall be traffic barriers for roadside (categories C, B, A, SC, SB, SA, and SS); those installed on medians shall be traffic barriers for median strips (Categories Cm, Bm, Am, SCm, SBm, SAm, and SSm), and those installed on pedestrian/traffic boundaries shall be traffic barriers for pedestrian/traffic boundary (categories Cp, Bp, Ap, SCp, SBp).

In a case in which a traffic barrier is to be installed on a median and either the facility is not wide enough or it would be difficult to install a traffic barrier for median on the median because there is a structure on the median, the traffic barrier for median strips may be replaced with a traffic barrier for roadside.

Application Sections

The category of traffic barrier that is installed shall, in principle, be one of the categories stipulated in Table 2-5 in accordance with the road classification, design speed, and the installation section.

Sections where there is a danger of serious damage refers to sections crossing or near urban railway lines and regional trunk railway lines, sections crossing or near expressways and motorways, sections where a traffic barrier is installed on a median where the traffic speed is

TABLE 2-5 Application of Traffic Barrier Categories

Road Classification	Design Speed	Ordinary Sections	Sections Where There Is a Danger of Serious Damage[a]	Sections Crossing or Close to a Sinkansen, etc.
Expressways Motorways	80 km/h≦	A,Am	SB,SBm	SS
	60km/h		SC,SCm	SA
Other Roads	60km/h≦	B,Bm,Bp	A,Am,Ap	SB,SBp
	≦50km/h	C,Cm,Cp	B,Bm,Bp*	

[a] Sections where there is a danger of serious damage.
* On roads with a design speed of 40 km/h or less, C, Cm, or Cp may be used.

particularly high and the traffic volume is heavy, where there is a danger of serious secondary damage or injury, and where roadside conditions seriously reduce the safety from injury of motor vehicle passengers.

In a section where, because of the traffic speed or road alignment conditions, the likelihood of impact with traffic barriers is extremely high, the traffic barrier installed may be one or more performance categories higher than that stipulated in Table 2-5.

Installation Methods

When a traffic barrier is installed, it shall be installed so that it can fully function as a traffic barrier by selecting a kind and type of traffic barrier with full consideration given to road and traffic conditions.

Selection of the Kind and Type

In principle, the traffic barrier selected shall be a flexible traffic barrier. But traffic barriers selected for installation on a structure such as a bridge or viaduct or on a narrow median where deformation of the traffic barrier cannot be permitted may, as necessary, be rigid traffic barriers.

Selection of Traffic Barrier Type

The type of traffic barrier shall be selected with full consideration given to performance, economic efficiency, maintenance, execution conditions, median width, line of visual guidance, maintenance of visibility, anxiety-free driving, preserving attractive roadside scenery, and harmony with the environment.

Table 2-6 stipulates the types of traffic barriers.

Handling Short Structure Sections In a case in which a structure such as a short bridge is located in an earthworks section, in principle, its type shall be identical to that of the traffic barrier in the rest of the section.

But this provision shall not apply in a case where the use of a traffic barrier with a different type is unavoidable.

Height When a traffic barrier is installed, it shall be installed so that the stipulated height from the installation data plane to the top of the traffic barrier to be installed is maintained.

Foundation In a case where a traffic barrier is installed in an earthworks section, it shall be installed based on a complete study of the form of the ground, soil conditions, etc., at that installation location, and when a traffic barrier is installed on a bridge, viaduct, or other structure, it shall be installed based on a complete study of the bearing strength of the structure.

Installation Length

A traffic barrier shall be long enough to prevent the traffic barrier from overturning or sliding. A flexible traffic barrier installed in any of the installation locations stipulated in Chapter 2 shall, in principle, extend 20 m beyond each end of the section.

TABLE 2-6 Types of Traffic Barriers

Kind	Type	Description of the Type
Flexible Traffic Barrier	Beam Traffic Barrier	
	Guard rail	Structure formed by columns supporting linked beams with wavy sections
	Guard pipe	Structure formed by columns supporting multiple linked pipes
	Box beam	Structure formed by columns supporting linked pipes with box-typed sections
	Cable Traffic Barrier	
	Guard cable	Structure formed by columns supporting ropes that apply initial tension
	Bridge Railing	Structure of traffic barriers installed on bridges, viaducts, or other structures; formed by columns supporting multiple linked beams either round or box-typed closed section.
Rigid Traffic Barrier	Concrete Traffic Barrier	Traffic barriers with either vertical or inclined front surfaces made of concrete that does not deform.

Width Allowance

Flexible traffic barriers installed on roadsides and on pedestrian/traffic boundaries shall, in principle, be installed to provide sufficient width from the front surface of the traffic barrier in the off-road direction to allow for the maximum penetration of a motor vehicle, and flexible traffic barriers installed on medians shall, in principle, be installed to provide sufficient width from the traffic barrier surface facing the oncoming traffic lane in the direction of the oncoming traffic lane to allow for the maximum penetration of a motor vehicle.

Continuous Installation

Traffic barriers installed within sections where road and traffic conditions are uniform shall, in principle, be connected.

Installation on a Median

When a traffic barrier is installed on a median, in principle, it shall be installed in the center of the median. But this shall not apply in a case in which it is not possible to provide the stipulated traffic barrier height because of the gradient of the median.

Design of Ends

Design of Ends A traffic barrier shall be installed with consideration given to the prevention of impact by motor vehicles on the end of the traffic barrier and to the improvement of the buffering performance of the end. Therefore, the end of a traffic barrier where motor vehicles enter the traffic barrier section shall, wherever possible, be designed so that it should be considered of using the off-set structure in the off-road area direction for example. And the ends of traffic barriers shall be installed with consideration given to their relationship with openings in medians, intersections with access roads, and other road structures. But in a case where it is unavoidable because of off-road conditions, the end of the traffic barrier should be installed at a location where there is little danger of a motor vehicle impacting the end of the traffic barrier or other appropriate measure shall be taken.

Transitions In principle, when differing categories, kinds, and types of traffic barriers are constructed side by side, the barrier surfaces provided to guide motor vehicles shall be connected.

Branches of Expressways Where a traffic barrier is constructed at the branch of an expressway, etc., visual guidance devices, lights indicating obstructions, and other attention attraction devices or additional buffering materials shall also be provided as necessary, fully accounting for the condition of the road and traffic in order to prevent collisions with the ends of the traffic barrier and to improve the buffering performance of the ends.

Guaranteeing Visibility at Merging Sections

Traffic barriers installed at merging sections or intersections of roads shall be installed in such a way that they do not obstruct the visibility of drivers in order that they can properly observe road and traffic conditions.

Snowy Regions

As necessary, traffic barriers installed in snowy regions shall be installed accounting for the snow load.

Color

The standard color of traffic barriers shall be white in order to guarantee that they can guide the line of sight of drivers. But in a case in which visual guidance can be provided by other means, this shall not apply and a color that contributes to the beautification of the road may be used.

CHAPTER THREE—FENCES FOR PEDESTRIANS/CYCLISTS

Installation Sections

Fences for pedestrians/cyclists shall be installed as necessary in accordance with road and traffic conditions in all road sections stipulated below.

1. Sections where a fences for pedestrians and cyclist shall be installed on the roadside or on the pedestrian/traffic boundary in order to prevent pedestrians from falling.
   - Dangerous off-road sections of sidewalks, bicycle paths, and exclusive pedestrian paths where it is deemed necessary to prevent pedestrians from falling.
2. Sections where fences for pedestrians and cyclists shall be installed on pedestrian/traffic boundaries in order to restrain pedestrians from crossing the traffic lanes of the road.
   - Sections where pedestrians are prohibited from crossing the road and where it is considered necessary to do so
   - Sections other than sections where there is a pedestrian crossing, and where it is considered particularly necessary to restrain pedestrians from crossing the road
   - In low-speed sections of roads in large cities where simply dividing the sidewalk from the traffic lanes can be counted on to guarantee the safety of pedestrians on parts where it is considered to be particularly necessary.

Fences installed to prevent pedestrians from crossing a road shall be installed in cases in which it is considered necessary after studying alternative methods such as the planting of a row of trees in order to improve the scenery.

Categories

Categorization

Fences for pedestrians and cyclists shall be categorized as shown below according to the design strength shown in Table 3-1.

Performance

Plastic deformation of a fence for pedestrians and cyclists shall not occur under the design load by category as stipulated in Table 3-1.

Structure and Materials

Height of Fences

The standard height of a fence installed to prevent pedestrians, etc., from falling shall be 110 cm from the road surface to the top edge of the fence. The standard height of a fence installed to

TABLE 3-1 Design Strength by Category

Category	Design Strength	Purpose
P	Vertical Load: min. 590 N/m (60kgf/m) Horizontal Load: min. 390 N/m (40kgf/m)	Prevent falling Restrain road crossing
SP	Vertical Load: min. 980 N/m (100kgf/m) Horizontal Load: min. 2,500 N/m (250kgf/m)	Prevent falling

Notes: The load shall be assumed to act on the top of the fence. The bearing strength of the members of category P may be designed as the allowed limit.

restrain pedestrians from crossing a road shall be between 70 and 80 cm from the road surface to the top edge of the traffic barrier.

Type

A fence for pedestrians and cyclists (categories P and SP) shall be typed with pedestrian safety in mind and typed in such a way that bolts or other projecting parts or member joints cannot harm pedestrians, etc. The intervals between the cross-pieces of fences for pedestrians and cyclists installed to prevent falling shall be such that pedestrians cannot easily fall between them.

Materials

Materials used to construct a fence for pedestrians/cyclists shall provide sufficient strength, be extremely durable, and be easy to maintain.

Rust Proofing and Corrosion Proofing

Rust proofing or corrosion proofing the metal used to make a fence for pedestrians and cyclists shall conform to the stipulations for rust proofing and corrosion proofing of traffic barriers.

A traffic barrier that satisfies the above specifications may also be used as a fence for pedestrians and cyclists.

Application of Categories

Fences for pedestrians and cyclists shall, in principle, be category P, and fences preventing pedestrians from falling in sections where pedestrians are expected to stop and gather and in sections of bridges and viaducts shall, assuming that a group load will be borne in such sections, be category SP.

Installation Method

When a fence for pedestrians and cyclists is installed, it shall be installed so that it can fully function as a fence with full consideration given to road and traffic conditions.

Height

When a fence for pedestrians/cyclists is installed, it shall be installed in order to provide the height from the road surface to the top of the fence that is stipulated for the fence.

Foundation

In a case in which a fence for pedestrians/cyclists is installed in an earthworks section, it shall be installed based on a complete study of the form of the ground, soil conditions, etc., at that installation location, and when a fence for pedestrians/cyclists is installed on a bridge, viaduct, or other structure, it shall be installed based on a complete study of the bearing strength of the structure.

Preventing Pedestrians, etc., from Falling Out Between Fences

Fences for pedestrians and cyclists of the same category installed to prevent falling shall, in principle, be connected.

When fences of differing categories must be installed side by side, the gaps between the different kinds of fences shall be designed carefully so that pedestrians cannot easily fall through the fences.

Guaranteeing Visibility at Merging Sections

Fences for pedestrians and cyclists installed at merging sections or intersections of roads shall be installed in such a way that they do not obstruct the visibility of drivers in order that they can properly observe road and traffic conditions.

Color

The color of a fence for pedestrians/cyclists shall contribute to the beautification of the road.

Snowy Regions

As necessary, fences for pedestrians/cyclists installed in snowy regions shall be installed accounting for the snow load.

CHAPTER FOUR—COMMON ITEMS

Execution

Execution

Guard fences shall be executed safety and reliably and with concern for their effects on traffic safety and on other structures.

Information Plates

Guard fences shall bear plates indicating the category, installation date, road manager's name, etc.

Maintenance

Inspections

As part of daily road patrols, periodic inspections shall be performed to observe the external appearance of guard fences to make sure they are in normal condition. Appropriately thorough visual inspections of rigid traffic barriers that do not suffer plastic deformation when struck by motor vehicles shall be performed to discover if repeated impacts by motor vehicles have reduced their strength.

Road inspections performed following heavy rainfall or an earthquake shall be accompanied by inspections of guard fences. When these inspections are carried out, careful attention shall be paid to the following points.

Flexible Traffic Barriers

1. Condition of connections between columns and horizontal members;
2. Settlement, inclination, or bending of the columns and condition of the column anchors;
3. Soiling of the traffic barriers and condition of their paint;
4. Deformation or breakage of guard rails, guard pipes, and the horizontal members of bridge use beam kind traffic barriers;
5. Damage to the beam joints and paddles of box beams; and
6. Deflection of cables.

Rigid Traffic Barriers

1. Cracking or chipping of their surfaces
2. State of road shoulders and slopes
3. State of drainage facilities

Maintenance

Repairs

When a guard fence cannot function as a guard fence because it has been deformed or damaged by an accident, disaster, etc., it shall be repaired promptly.

Cleaning

A guard fence that has become conspicuously dirty shall be cleaned.

Painting

When any of the paint has been scraped off a guard fence, or rusting has conspicuously peeled paint from a guard fence, it shall be repainted.

Record Keeping

In order that guard fence maintenance be performed correctly, a ledger recording the locations where guard fences are installed, their categories, installation dates, and codes indicating type and other necessary information shall be maintained. Records of guard fence damage, specifically the extent of damage, road conditions at the location of damage, and the cause of damage shall be prepared and maintained.

Snowy Regions

In snowy regions, snow removal work must be carefully planned to protect guard fences—facilities highly susceptible to damage by snow removal equipment.

Toward a Review of the Need for and Selection of Appropriate End Treatments in Permanent and Work Zone Situations

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The basic objective of a roadside barrier and the accompanying end treatment is to confine the movement of errant or out-of-control vehicles to the roadway area.

The problem of vehicles running off road and hitting roadside furniture was first recognized in the mid to late 1960s. This led to a proliferation of designs of roadside barriers and end treatments.

This presentation focuses primarily on selection of end treatments to barriers but also on protection of "spot" hazards such as bridge piers and gantry poles.

There are five alternative solutions to protecting roadside hazards. These are

1. Design the treatment to eliminate the hazard.
2. Make the hazard breakaway.
3. Use a barrier combined with a suitable economical end treatment to shield the hazard.
4. Use a crash cushion to shield the hazard.
5. Delineate the hazard if no other is available.

When it is necessary to adopt either of alternatives 3 or 4 it is important that the end treatment does not create a hazard in itself. In many cases alternative 3 could be more economical than alternative 4.

A proper end treatment has two functions. **First, for any non-rigid or semi-rigid barrier system, it must provide an anchor to allow the full tensile strength of the system to be developed during downstream angle impacts on the side of the barrier. Second, regardless of the barrier, it must be crashworthy during end-on impacts.** The end treatment must keep the vehicle stable, which means the vehicle will not roll, be speared, or vault. It must also keep the motorist away from the hard points created by rigid posts, concrete barriers, or the ends of semi-rigid barriers that if not protected will create high decelerations causing serious injuries or death during an impact. Therefore, every type and variation of end treatment must be thoroughly tested before it is used on the road.

Over the years a variety of end treatments have been used to eliminate the hard point at the ends of safety barriers. Some designs for flexible barriers used the same shapes and softened the ends by weakening the posts. One of the most popular solutions in the 1970s was to turn the end down to form a ramp. While this is arguably a safer alternative than blunt ends, tests and real-life impacts showed that the turned down end can be extremely dangerous as it can cause an impacting vehicle to become airborne or overturn or be directed onto the hazard that the barrier was intended to shield. Around the world, most highway authorities now recognize the inherent danger of a ramped end of a safety barrier, whether the barrier be rigid or flexible; and ramped or turned down ends are now generally prohibited, especially on higher speed roads.

TYPES OF END TREATMENTS

End treatments can be defined as being one of two basic types. These are an end terminal or a crash cushion.

An end terminal is described as a device designed to treat the end of a longitudinal barrier. The terminal may function by

- Decelerating a vehicle to a safe stop within a relatively short distance,
- Permitting controlled penetration of the vehicle behind the device,
- Containing and redirecting the vehicle, or
- A combination of the above.

A crash cushion is described as a device designed primarily to safely stop a vehicle within a relatively short distance. A crash cushion is either a

- Redirective system—designed to redirect the impacting vehicle that impacts at an angle on the side of the system, on the impact side of the system after the systems "point of redirection" or "point of redirective capacity." Angled impacts before this point will result in a vehicle trajectory behind the system.
- Non-redirective system—designed to capture the vehicle or allow the vehicle to have a trajectory behind the system from all impacts at an angle along the side of the system.

Whether the safety device is a terminal at the end of the longitudinal barrier or a crash cushion shielding a fixed object, such as a bridge pier or gantry pole, it is either a

- Non-gating system—designed to have redirective characteristics for angled impacts along the side of the system, starting near the front of the system. However, angled impacts at the front of the system still allow some vehicle trajectory behind the system.
- Gating system—designed to have redirective characteristics downstream of the "point of redirection" or "point of redirective capacity." Angled impacts along the side of the system before this point and angled impacts at the front of the system will allow vehicle trajectory behind the system.

Thus, all systems will have some vehicle trajectories behind the system and all redirective systems will have some post-impact vehicle trajectories on the impact side of the system. There are some sites where this characteristic is sufficiently important that the designer should only consider redirective and non-gating systems. However, since the actual differences between the system's trajectory characteristics are fairly minor and are affected most by the location of the point of impact within the system there is a fair amount of latitude in choosing the systems with the best overall characteristics to improve the safety of the highway system. Since redirective non-gating systems cost several times as much as non-redirective systems and approximately twice as much as redirective gating systems, choosing to treat more sites with the same expenditure could have a more profound effect on highway system safety than small differences in post-impact vehicle trajectory characteristics.

END TERMINALS

Most end terminals are gating systems. This means that when they are impacted at an angle on the end, or at a point upstream of the beginning of the length of need (the point where the barrier begins to be able to redirect), the systems are designed to break away, pivot, or hinge like a "gate," and allow the vehicle to pass through. The end terminal functions properly if the vehicle remains stable during and after the impact, and the motorist is kept away from the hard point in the safety barrier as well as the hazard the safety barrier was designed to protect.

Many of the gating guardrail end terminal designs are some form of breakaway system. The earlier end terminals were weakened through the use of weakened wood posts so the resulting impact was less violent for the motorist. Slip base steel posts with these earlier cable terminals were tried in the United States with unacceptable results. More recently, new terminals have been developed with steel posts with breakaway couplings that function very well and do not have the problems previously encountered.

The most popular non-proprietary end terminal was the breakaway cable terminal (BCT). This was a vast improvement on the lethal "fish tail" guardrail ends still seen on older installations on our roads. It is a full height, flared W-beam terminal with an integral cable anchorage. The BCT requires a 1.2-m parabolic offset, and satisfactory performance is very sensitive to this offset. The first two wooden posts are designed to break away when impacted head on, then the guardrail pivots and allows the vehicle to safely pass through and behind the barrier.

The BCT was installed in the United States and subsequently in Australia in large numbers throughout the 1970s. This system was introduced prior to the NCHRP 230 guidelines being used, and all initial tests on this system were conducted with cars ranging from 1000 to 2000 kg. When tested at 97 km/h (60 mph) head on with the 820-kg vehicle required by NCHRP 230 test #45, the BCT proved to be too stiff and caused the short-wheelbase small car to rotate. The smaller car was often speared during the impact because it did not produce enough kinetic energy to activate the breakaway mechanism. The FHWA noted this performance as being unacceptable, leading to it being banned in 1994 by the FHWA on high-speed, high-volume roads on the National Highway System. It has not been acceptable on new installations in New South Wales (NSW) for some years.

The basic BCT went through a series of modifications to accommodate the small-car, end-on impacts. The first modification resulted in the eccentric loader terminal (ELT). Although the ELT technically passed the NCHRP 230 tests, it was not widely accepted by the marketplace due to its appearance and complexity.

FHWA continued its effort to develop a crashworthy non-proprietary end treatment, and the modified eccentric loader terminal (MELT) was introduced in early 1991. Except for a simplified nose design, the MELT is identical to the ELT. In fact, the FHWA only required two of the four NCHRP 230 tests to be conducted on the MELT. They agreed to substitute the test results from the ELT for the other two MELT tests.

Initially the perceived market advantage of the MELT compared to some other end was cost. The disadvantage of the MELT was its limited performance capability due to its gating feature, lack of reusability, and need to flare the system. The FHWA subsequently abandoned its efforts to upgrade a modified MELT to meet NCHRP 350 requirements. Various organizations have now developed end treatments to meet NCHRP 350 requirements. Compared with the MELT some of these systems are hard to compete with from a cost/performance perspective.

The MELT continues to be acceptable in NSW with regard to the different composition of the vehicle fleet (almost no heavy 2000 kg pickup trucks, which is the test vehicle for NCHRP 350).

Although the basic BCT has been tested in the United States and found to be acceptable as a gating system when impacted by larger vehicles, the double BCT often used as an end terminal for double-faced guardrail in medians has never satisfactorily passed any tests. This type of terminal when tested in a head-on impact at 95 to 100 km/h has been shown to lift as the support legs broke away, with the vehicle underriding the double BCT with potentially disastrous consequences for the occupants. This is a clear example of an end terminal developed without any understanding of how a BCT is designed to operate. Here we have two gating systems, designed to deflect laterally when used as individual systems, working against each other in a horizontal plane when used in tandem, and deflecting in the only other available direction, that is upwards and very likely through the windscreen of the impacting vehicle. Unfortunately, all too many of these are present on today's roads.

CRASH CUSHIONS

A crash cushion is designed as a device designed primarily to safely stop a vehicle within a relatively short distance. A crash cushion is either a

- Redirective system—designed to contain and direct a vehicle impacting downstream from the nose of the cushion.
- Non-Redirective—designed to contain and capture a vehicle impacting downstream from the nose of the cushion.

Whether the safety device is a terminal at the end of the longitudinal barrier or a crash cushion shielding a fixed object, such as a bridge pier or gantry pole, it is either

- Non-gating—having redirective capabilities along its entire length, or
- Gating—designed to allow controlled penetration of a vehicle when impacted upstream of the beginning of the length of need.

The earliest models were based on expending water from water-filled tubes and subsequently using light-weight vermiculite concrete to accommodate cars in the range 1000 to 2000 kg. As well as having the ability to absorb energy in a head-on or near-head-on impact, the early models generally had lateral restraints so that they were non-gating and redirective.

A crash cushion has to be able to safely stop both the lightest and the heaviest vehicles in the vehicle fleet. In end-on impacts the deceleration characteristics are different for each of these two extremes in weight. In the case of the light vehicle much of the deceleration results from momentum transfer at the point of impact followed by further deceleration as the crash cushion collapses. For a heavy vehicle momentum transfer on impact is significantly lower; further deceleration occurs as the crash cushion is collapsed with a final instantaneous deceleration as the residual velocity is expended against the backup of the system.

PERFORMANCE STANDARDS FOR END TREATMENTS

In 1981 the NCHRP 230 extended the vehicle range from 820 to 2000 kg and defined standards for performance evaluation in terms of structural adequacy, occupant risk, and vehicle trajectory at 97 km/h (60 mph). Treatments were not permitted to spear, roll, pitch, or yaw the impacting vehicle. The vehicle had to stay upright. Water-filled tubes and vermiculite concrete were replaced by a honeycombed polyurethane substance with the trade name Hexfoam. Other friction-based devices were also introduced into the market.

Following is a summary of the requirements based on these three criteria.

1. Structural adequacy is generally the first factor to be evaluated, and the appurtenance should perform successfully according to the requirements presented in this program. Otherwise the appurtenance may present a more severe and unpredictable roadside hazard than the roadway without the appurtenance. Depending on its intended function, the appurtenance may satisfy structural adequacy by redirecting or stopping the vehicle or permitting the vehicle to break through the device.

   Detached elements, fragments, or other debris from the test article should not penetrate or show potential for penetrating the passenger compartment or present undue hazard to other traffic.
2. A first requirement for occupant risk evaluation is for the impacting vehicle to remain upright during and after the collision, although moderate roll, pitching, and yawing are acceptable.

   Occupant risk is then indicated by the projected forward and lateral reactions and dynamics of a hypothetical unrestrained front seat occupant who is propelled through the compartment space by vehicle collision accelerations, strikes the instrument panel, windshield, or side structure, and then subsequently is assumed to experience the remainder of the vehicle collision acceleration pulse by remaining in contact with the interior surface.
3. Vehicle trajectory hazard is a measure of the potential of after-collision trajectory of the vehicle to cause a subsequent multivehicle collision or subject vehicle occupants to undue hazard. After collision, the vehicle trajectory and final stopping position should intrude a minimum distance, if at all, into adjacent or opposing traffic lanes. In tests in which the vehicle is judged to be redirected into or stopped while in adjacent traffic lanes, the vehicle speed change during test article contact should be less than 24 km/h (15 mph) and the exit angle from the test article should be less than 60% of the impact angle. For certain classes of appurtenances, vehicle trajectory behind the test article is acceptable.

It should be noted that costs (i.e., installation, maintenance, damage repair, etc.), aesthetics, and other service requirements were not evaluated.

NCHRP 350 replaced NCHRP 230 in 1993 and maintained the basic performance evaluations in terms of structural adequacy, occupant risk, and vehicle trajectory. It was basically designed to accommodate high-center-of-gravity vans, pickup trucks, and heavy 4-wheel drive utility vehicles. The larger car (2000 kg) became a 2000-kg pickup truck.

NCHRP 350 defines various test levels one to six for different vehicle types, weights, and speeds in lieu of the one test speed 97 km/h defined by NCHRP 230. These test levels are

- TL1, TL2: Vehicles (820 to 2000 kg) light cars and pickup;
- TL3: Trucks at speeds of 50, 70, and 100 km/h;

- TL4: Single unit trucks (8000 kg) at 80 km/h;
- TL5: Tractor/van-type trailer (36 000 kg) at 80 km/h; and
- TL6: Tractor/tank trailer truck (36 000 kg) at 80 km/h.

TL1 to TL3 were designed to apply to end terminals and crash cushions as well as continuous barriers and became effective beginning in October 1998. TL4 to TL6 apply only to continuous barriers. Barriers capable of meeting these standards have to date been developed as far as TL4, and more recently to TL5 and TL6.

Obviously, the higher the test level, the higher the required performance of the product. General applications are as follows:

- TL1: Some work zones and local streets.
- TL2: Most work zones, collector roads, and sub-arterial roads.
- TL3: Most high-speed roads, arterial, or limited access; and in the United States, some work zones. (This level approximates the previous NCHRP 230 standards at 60 mph.)

Generally NCHRP 350 TL3 is more rigorous than NCHRP 230. Now with regard to the relative compositions of the U.S. and Australian vehicle fleets and the renewed trend toward smaller, more fuel-efficient vehicles following increasing oil prices, it could be that NCHRP 230 is more appropriate than NCHRP 350 TL3. In addition, some of the test impact angles are most unlikely to be attained on Australian roads.

NCHRP 350 combines terminals and crash cushions and divides them into one of three categories. A system can either be

- Redirective: Non-gating (8 tests required);
- Redirective: Gating (7 tests required); or
- Non-redirective: Gating (5 tests required).

Note that for each of the three categories, tests may be conducted for TL1 (50 km/h), TL2 (70 km/h), and TL3 (100 km/h).

By contrast NCHRP 230 required only four tests.

To date the only effective standards that could be applied in Australia have been NCHRP 230 and 350. European standards have been in the course of development over a number of years. Until recently European standards being proposed by individual members of the European Union have been contradictory and confusing. In 2000 a new European Draft Standard EN1317—Parts 1, 2 and 3 Covering Road Restraint Systems: Technology and General Criteria for the Test Methods; Performance Classes, Impact Test Acceptance Criteria, and Test Methods for Safety Barriers; and Performance Classes, Impact Test Acceptance Criteria and Test Methods for Crash Cushions, respectively—was approved.

The matrix of vehicle size and test speeds, being somewhat of a compromise of various European inputs, is more complicated than in NCHRP 350.

The test pattern is similar to those used in NCHRP 230 and 350 in terms of position and angle of hits. But the maximum test vehicle performance is for a 1500-kg vehicle (motor car) travelling at 110 km/h, with the kinetic energy to be absorbed being about 10% less than in NCHRP 350 TL3 and about 3% less than in NCHRP 230. In addition the maximum test angle for angular impacts is only 15 degrees in lieu of 20 degrees in NCHRP 350. This is more realistic for Australian roads.

Test speeds are 50, 80, 100, and 110 km/h for vehicles of 900, 1300, and 1500 kg. These reflect the smaller vehicle fleet in Europe, but, interestingly enough, the minimum-size vehicle is 900 kg compared with 820 kg under NCHRP 350. This is probably more realistic—despite vehicles getting smaller in external dimensions—they are not getting lighter. This presumably is due to additional safety, sound proofing, and electronic equipment being incorporated into small vehicles.

APPLICATIONS

End terminals and crash cushions can be employed to protect a barrier end, bridge pier, or gantry pole in permanent situations:

1. In narrow medians on two-lane, four-lane, or multilane roads,
2. On or near the edge of a wide median,
3. In or near the center of a wide median,
4. Adjoining the nearside shoulder of a two-lane or multilane road,
5. In the gore of an exit ramp, or
6. At a bifurcation within an interchange.

They can also be employed to protect barrier ends in work-zone areas.

The need to specify the appropriate functional type of end terminal or crash cushion for a particular application will depend on a number of factors. These include

1. The planned location of the device;
2. The need for redirective/non-redirective and gating/non-gating characteristics;
3. The design speed(s) and the posted speed limit(s) of the adjacent roadway(s) and hence the likely impact speed or practicable design impact speed;
4. The physical layout of the area, including space availability;
5. Relevant traffic volumes;
6. Capacity to absorb nuisance hits; and
7. Reusability, cost, and ease of restoration after impact.

When these factors are related to the type of location being reviewed, the following preliminary assessments can be made:

1. A non-gating, redirective device is almost always required in a narrow median. For two-lane roads the need for the device to pass all the angle tests at the angles specified in NCHRP 350 is questionable, particularly in the case of wrong-way impacts. This is because it is not possible to attain the speeds at the angles specified in NCHRP 350. The same may apply to four-lane roads with a narrow median barrier.
2. A device located on or near the edge of a wide median could be gating depending on the size and characteristics of the run-out area beyond the device. Possibly the barrier should be extended so that a more favorable run-out area can be obtained and thus allow a less expensive non-redirective/gating device to be used in lieu of a non-gating device. Note that all systems have some exposure to trajectories on the back side of the systems. Thus, it could be argued that

in some situations, it would actually be less hazardous to use non-redirective or redirective gating systems for overall lowest exposure to secondary impacts.

3. & 4. A similar approach can be adopted when the device is to be located in or near the center of a wide median and also when adjoining the nearside shoulder of a two-lane or multi-lane road. When cut and fill is involved, the alternative of extending the barrier to be anchored in the adjacent cut should be seriously considered. This treatment eliminates the dangers of an untreated end and greatly reduces the opportunity for vehicles to penetrate behind the ending, since nearly all exposure barrier is intended to redirect impacting vehicles. This treatment is most appropriate for rigid and semi-rigid barriers.

5. This refers to a situation in which the exit ramp leads to a lesser and probably lower speed surface arterial or subarterial. In many cases, when potential exposure to secondary impact is considered, a gating device should be specified in lieu of a non-gating device. Factors to be considered include:

- The relative volumes and speeds of the through road and exit ramp.
- The horizontal alignment, which would provide some indication of the likely angles of impact from the through carriage way and exit ramp.
- The vertical alignment and cross sections in the area of the device and along the run-out area if a gating device is selected.
- The presence of shoulders and/or breakdown lanes on the through carriage way and exit ramp and hence the lateral clearance between the device and the edges of the traveled way.

6. The same principles would apply at a bifurcation within an interchange but lateral clearance could be restricted, and hence a non-gating device may be required particularly at higher speeds.

SITE FACTORS: SUPPLEMENTARY NOTES

Hazard Width and Height The size of the hazard is an important factor when selecting an attenuator system. Wide hazards can be treated using a wide attenuator system or, in some cases, transitioned to a narrow attenuator system using guardrail. The amount of transitioning required can be a key factor when selecting an attenuator system. In bi-directional situations the effect on sight distance should be considered.

Hazard Proximity to Traffic The key issue is the distance from the edge of the traffic lane(s) to the hazard. It is a key factor when determining whether redirection and non-gating characteristics are needed to avoid secondary collisions. Hazard site width considers the overall width of the hazard area; for example, the size of the median or gore, etc.

Uni- or Bi-Directional Traffic Hazards can be exposed to traffic from one direction (uni-directional) or traffic coming from both directions (bi-directional). For example, an attenuator system on a median is typically exposed to traffic travelling on both sides of it, whereas an attenuator system on a shoulder is exposed to traffic travelling in one direction only.

Design Speed The design speed of the roadway is often not necessarily the posted speed limit. The roadway’s design speed should be matched to the attenuator system’s capacity to provide protection that matches the site’s requirements.

Available Longitudinal Space This site characteristic involves the space in front of the hazard, running lengthwise, parallel to the roadway. This factor will determine the maximum practicable length of the selected attenuator system. Factors that affect this space include the presence of items such as drain inlets, junction boxes, grading changes, etc.

Available Lateral Space This site characteristic evaluates the space available on both immediate sides of the hazard, the space between the roadway and the hazard, and the clear space on the side of the hazard opposite the roadway. This space should allow for a clear area between the roadway and the attenuator system, as well as behind the attenuator system, when required for proper system performance. Presence of drains and dropoffs should not be overlooked.

Grading Each attenuator system has specific grading requirements. These requirements vary from system to system and should be considered when making the final attenuator selection for a site.

Surface Conditions/Anchoring Options This factor involves the installation of the attenuator system. It includes consideration of the soil characteristics, sub-base strength and thickness, drainage, cross slopes and expansion joints, which all affect anchoring.

Traffic Volume This is an important factor in assessing likely impact frequency. The more traffic that passes by the hazard, the greater the chance of an impact occurring.

Available Maintenance Space This may play an important role by limiting the type of equipment available to refurbish or maintain the units. In addition, the more dangerous the site, the more critical it is that the attenuator system can be refurbished quickly to reduce the time crews are exposed to moving traffic at the site.

Likely Impact Frequency The higher the frequency of impacts, the more important it becomes to effectively shield the hazard. Easy, fast, and cost-effective refurbishment also becomes increasingly important as impact frequency increases.

Testing, Evaluation, and Application of Standards for Road Safety Devices in South Africa

IDA VAN SCHALKWYK
Rand Afrikaans University

In 1998 over 510,000 road traffic accidents were reported in South Africa. Almost 130,000 people were injured, and over 9,000 people lost their lives in these accidents. The estimated cost of these accidents in 1998 Rand amounted to R13.5-bn.

SOUTH AFRICAN ROAD SAFETY MANUAL

In May 1999 the final draft of the *South African Road Safety Manual* was completed. The manual consists of seven volumes. Volume 6 deals with roadside hazard management and covers basic aspects related to roadside safety and the use of roadside safety devices.

The government of South Africa accepted the *South African Road Safety Manual* as a best-practice guideline document for road safety engineering. It is not known to what extent the document is utilized by transportation professionals in South Africa. Some major road authorities have, however, incorporated the document in policies relating to road safety–related issues.

The first edition of the manual is yet to be published, and updating, particularly to certain sections of Volume 6, is urgently needed.

GENERAL ROADSIDE SAFETY–RELATED KNOWLEDGE OF TRANSPORTATION PROFESSIONALS

Up to 1995, knowledge on roadside safety–related issues was restricted to the use of typical drawings of barrier systems as contained in AASHTO's *A Policy on Geometric Design of Highways and Streets*. In 1997 the first road safety audit workshop was held in KwaZulu-Natal as part of the KwaZulu-Natal Provincial Road Safety Strategy. At this workshop, the first training with respect to roadside safety started. Since then, several transportation professionals received training on roadside safety as part of road safety audit workshops across the country. Awareness on roadside safety–related issues is improving and some road authorities are making a serious effort to improve current unsafe practices.

STANDARDS AND CRASH TESTING IN SOUTH AFRICA

South Africa does not have a crash test facility for roadside safety furniture. In terms of the current available funding, it is not likely that the country will have a facility in the near future. Limited funding forces professionals to utilize existing funding carefully so as to ensure a safer road environment. Research funding for roadside safety–related studies are also not available.

The *South African Road Safety Manual* provides best-practice information on standards for barrier systems and the document proposes the use of the NCHRP 350 standard for systems. Its use, however, is not contained in any regulation, and it depends entirely on the particular road authority to use whichever system it prefers. This is particularly worrying as systems that conform generally cost more. It is evident from the last few years that only regulation will ensure that only systems tested and conforming to a set standard will improve roadside safety with particular reference to barrier systems.

ROADSIDE SAFETY FEATURES IN SOUTH AFRICA

In many respects, South Africa is not performing well with respect to roadside safety. Several unsafe practices are still accepted and, in most cases, resistance to changes in existing accepted practice is generally experienced. Fear of litigation is also keeping road authorities from making definite (whether written or verbal) statements acknowledging the current unsafe conditions.

Guardrails, some without any blockouts, are generally utilized on South African roads. In most cases, ignorance about containment levels and the provision for deflection and protection of ends is evident. Generally speaking, accidents are still regarded as "caused by the driver," removing the responsibility of the road authority to provide a safe road environment or an as-safe-as-possible environment. Spoon-ends are accepted as safe, and efforts to change the existing practice are met with resistance due to the high costs associated with safe end-treatments for guardrail systems. Monitoring of maintenance activities to guardrails is also not evaluated to ensure that locations that are hit regularly are replaced by more cost-effective systems. Damage to guardrail systems is fixed, and, in most cases, it takes a considerable amount of time before it is done (up to 6 months). Guardrail systems are not checked regularly or even annually in terms of bolts, soil settlement, etc. Installation heights and utilization of guardrails in inappropriate locations are also issues of concern.

On some major highways, concrete barrier systems are utilized. The single-slope design has been utilized in some cases over the last few years, but, in general, the traditional New Jersey shape with the lower vertical kerb is still being constructed. Significant negative perceptions exist about concrete barrier systems and sales representatives for other barrier systems use these incorrect perceptions to sell their particular systems.

Some cable systems were installed on the road network. Recent interviews revealed that some systems conform to NCHRP 350 and others do not. Sales representatives of some systems that do not conform are claiming that the systems do conform, and installations reveal the use of incorrect anchoring systems and unsafe installations along short complex curves, among others.

The use of impact attenuation devices or crash cushions is limited and generally consists of sandbags or a bunch of old tires. It is not known whether the impact attenuation devices (a barrel system) utilized at some toll booths conforms to any particular standard or they were crash tested.

Roadside safety at road works is also of particular concern. Plastic water-filled barrier systems are utilized but none conforms to any standard. Systems are installed incorrectly and generally do not contain any water. In cases in which temporary concrete barrier systems are utilized, the individual segments are generally not connected and ends of systems are generally not protected.

An awareness program is currently being run through a road construction magazine with a wide readership, and we are convinced that this will add to the continued efforts to improve roadside safety on South African roads.

CONCLUSIONS

In general, the current status of roadside safety in South Africa is worrying. Progress is, however, being made—slowly but gradually. Existing roadside safety conditions are poor, and limited funding makes correction of these sites particularly difficult. Acceptance of a set standard such as NCHRP 350 is required to ensure that all new systems implemented are safe for road users.

National Standards—Korea

1 INTRODUCTION

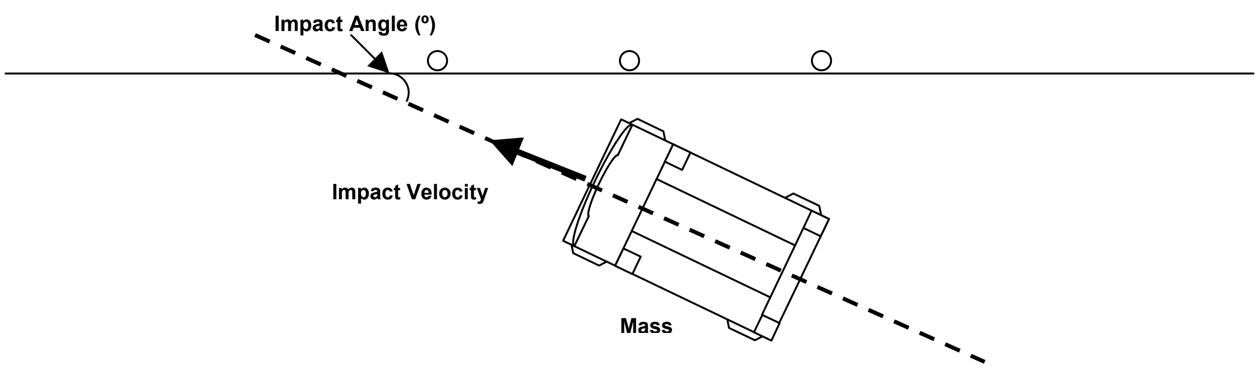
1.1 Scope

1.2 Terminology

2 GENERAL

2.1 Index of Severity

The performance of road safety facilities is tested by an index of severity (IS) through the full-scale impact test. The IS is the average force from kinematics from car collision (Figure 1).



$$IS = \tfrac{1}{2} \times m \times (V/3.6 \times \sin\theta)^2$$

where

m = Total vehicle mass (ton)
V = Impact speed (km/h)
θ = Impact angle (°)

FIGURE 1 Method for calculating degree of impact severity.

2.2 Test Conditions

2.2.1 Test Subjects

A single test subject is tested under each test condition.

2.2.2 Vehicle Specification Under Test Conditions (Table 1)

TABLE 1 Vehicle Specification Under Test Conditions

	Type of Vehicle	Mass (kg)	Type of Facilities	Evaluation Item
LC	Car 1	900	Crash Cushion	All
NC	Car 2	1,000	Barrier	Occupants' Safety
HC	Car 3	1,500	Crash Cushion	All
NT	Truck 1	14,000	Barrier	Intensity Capability
HT	Truck 2	25,000	Barrier	Intensity Capability
ST	Semi-trailer	36,000	Barrier	Intensity Capability

Consider using same size passenger car for both the crash cushion and barrier.

2.2.3 Impact Speed

Road design speed is classified into five categories (50, 60, 80, 100, and 120 km/h) depending on the class of the roads. We apply 80% of design speeds for the impact test of safety barriers, and apply the design speed for the test for IS and the impact test of crash cushions.

I am not sure I understand the difference in speed requirements between safety barriers and crash cushions. Requiring a 120 km/h crash cushion may be more than you need in most cases if you design for an unrestrained driver. U.S. crash cushions are designed for 100 km/h even though our design speeds are often 70 and above on our freeways. Our crash cushions work very well.

Maybe you could eliminate one of the lower speeds such as 60. I am not sure it gives you much of a graduation.

2.2.4 Impact Angle

Impact angles vary depending on test conditions. For safety barriers, the test angle for trucks is 15 degrees and the test angle for cars is 20 degrees.

I agree that the test angle for barriers should be a minimum of 20 degrees.

2.2.5 Soil

It is recommended that soil condition for road safety facilities meet the Ministry of Construction and Transportation's (MOCT's) standard specifications for materials for roadworks (MOCT 1996).

I am not familiar with the standard specification for soil, but the requirements may need to be stricter for lab tests for comparison purposes.

2.3 Impact Severity

2.3.1 Theoretical Head Impact Velocity (THIV)

2.3.2 Post-Impact Head Deceleration (PHD)

2.3.3 Acceleration Severity Index (ASI)

2.4 Tolerance on Impact Conditions (Table 2)

TABLE 2 Tolerances on Impact Conditions

Variables		Tolerances	
Impact/Exit Speed		Within 1% / ± 5km/h	
Impact & Exit Angles		± 0.5 degrees	
IS		Car: ± 5% Trucks and semi-trailers: more than standard IS	
Impact Point	Road Safety Facilities Vehicle	± 30cm ±0.05W	
Vehicle Acceleration Speed		Static	Within 1.5% of channel amplitude class
		Dynamic	Channel amplitude class: 400Hz, within 1.5% 400Hz < Channel amplitude class: 900Hz, within 2% 900Hz < 3000Hz, within 2.5%
Vehicle Trajectory		±30cm	
Vehicle Roll, Pitch, Yaw Ratio		±1% of vehicle size	
Dynamic Deformation of Road Safety Facilities		±5cm	

You may wish to revisit your tolerances. You may wish to consider just referring to a common standard such as SAE J211.

2.5 Test Report

1. Testing Laboratory
2. Report Number
3. Client
4. Test Items
5. Test Procedure
    - Test Type
    - Installation
    - Vehicle
6. Results
    - Test item
    - Vehicle

- Assessment of IS

7. General statements
8. Approval of report

2.6 Test Laboratory

The test area shall be generally flat, with a gradient not exceeding 2.5%. It shall have a level, hardened, paved surface and shall be clear of standing water, ice, or snow at the time of the test. It shall be of sufficient size to enable the test vehicle to be accelerated up to the required speed and controlled so that its approach to the safety barrier is stable.

To enable the vehicle exit characteristics to be evaluated, the paved area shall exceed 40 m in length beyond the expected break point and 15 m in front of the safety barrier line of vehicle contact with the safety barrier.

It is possible to choose the test sites depending on the impact test condition such as impact speed, total vehicle mass, and so on.

3 SAFETY BARRIERS

3.1 Performance Classes (Table 3)

TABLE 3 Performance Classes

Class	Road Types		Design Speed (km/h)	Roads	Standard IS (kJ)
C	General Roads	Low Speed	50	Collector Streets	60
B		Medium Speed	60	1-Lane Arterial Highways	90
		High Speed	80	4-Lane Arterial Highways	150
A		High Speed	80	4-Lane Arterial Highways	150
S1		Standard	100	Freeways	230
S2		Hazard		Freeways	420
S3		High Speed	120	Roads with High Design Speed	650
SS		Special	100	Roads with High Portion of Heavy Vehicles	600

3.2 Test Conditions (Tables 4 and 5)

TABLE 4 Test Matrices for Intensity Capability Test

<table>
<tr><th>Classes</th><th>Impact Speed (km/h)</th><th>Total Vehicle Mass (kg)</th><th>Impact Angle (degrees)</th></tr>
<tr><td>C</td><td>40</td><td rowspan="4">14,000</td><td rowspan="7">15</td></tr>
<tr><td>B</td><td>50</td></tr>
<tr><td>A</td><td>65</td></tr>
<tr><td>S1</td><td rowspan="2">80</td></tr>
<tr><td>S2</td><td rowspan="2">25,000</td></tr>
<tr><td>S3</td><td>100</td></tr>
<tr><td>SS</td><td>80</td><td>36,000</td></tr>
</table>

TABLE 5 Test Matrices for Occupants' Safety

<table>
<tr><th>Class</th><th>Impact Speed (km/h)</th><th>Total Vehicle Mass (kg)</th><th>Impact Angle (degrees)</th></tr>
<tr><td>C, B</td><td>60</td><td rowspan="4">1,000</td><td rowspan="4">15</td></tr>
<tr><td>A, S1, S2</td><td>100</td></tr>
<tr><td>S3</td><td>120</td></tr>
<tr><td>SS</td><td>100</td></tr>
</table>

Consider using 20 degrees as we have found that the use of 15 degrees is not discerning. This test needs to serve as a surrogate for curve impacts.

3.3 Performance Evaluation Criteria

3.3.1 Intensity Capability

After full-scale impact test, flexible safety barriers shall allow maximum 0.3 m deflection distance and rigid safety barriers shall not allow any kind of plastic deformation in main materials.

Consider not having a minimum deflection distance for barriers. If you want to place into deflection classes, consider using the CEN approach.

Consider placing warranting and application information such as maximum deflection into another document or other documents. This will not exclude other barriers such as cable that might fit a need you have.

3.3.2 Occupants' Safety (Table 6)

TABLE 6 Performance Evaluation Criteria for Occupants' Safety Criteria

Criteria	Units	Min	Max
THIV	M/s	9	12
	km/h	33	44
PHD	Gs	15	20

3.3.3 Post-Impact Vehicle Behavior (Figure 2)

Road safety barriers shall satisfy the following conditions in case of collision:

- The vehicle must not turn over upon impact against the safety barriers.
- The exit speed after collision shall not be less than 60% of the impact speed.
- The exit angle after collision shall not be greater than 60% of the impact angle.

The first may be overly restricted for heavy vehicles, although it may not be with the test conditions required. Some of the single unit vans are not all that stable. In some cases the latter two requirements may eliminate from consideration some well-performing barriers.

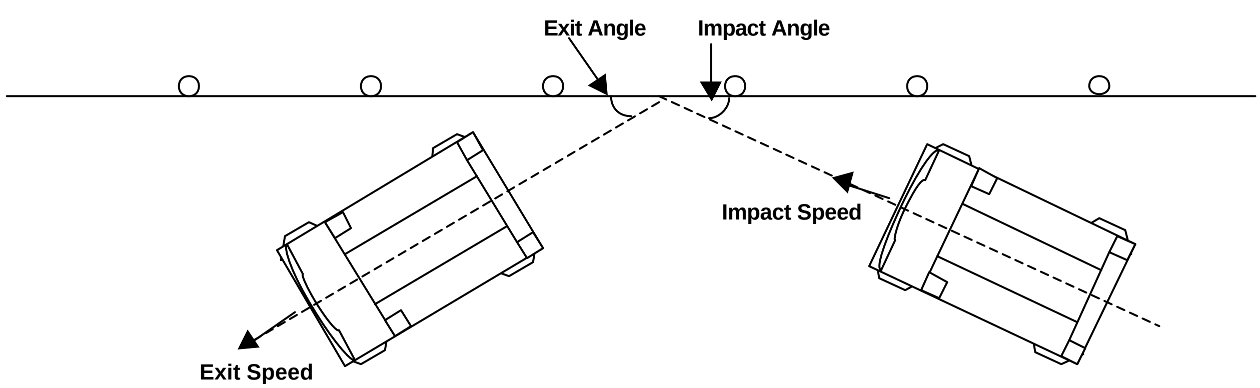


FIGURE 2 Exit speed and exit angle.

3.3.4 Prevention of Scattering of Constituent Components

Components of the traffic barrier shall not split off and scatter widely upon collision by a large vehicle or small vehicle.

3.4 Test methods

3.4.1 Test and loading conditions

Test shall comply with test conditions. Fixed ballast may be added if necessary.

3.4.2 Performance of Safety Barriers

- Prevention of deviation from road
  — Intensity capability: Damage of safety barriers
  — Deflection performance: Maximum deflection, plastic deformation of rigid safety barriers
- Occupants' safety: Acceleration of the center of gravity of the test vehicle
- Vehicle guidance performance: Vehicle trajectory, exit speed, exit angle
- Prevention of scattering of constituent components

3.4.3 Test Report (Figure 3)

The test report shall comply with the format given in Figure 4, and detailed test results are recorded in the test reports.

Photographic coverage shall be sufficient to clearly describe crash-cushion behavior and vehicle motion during and after impact. Photographic records from high-speed cameras are necessary for the complete record of the vehicle responses and safety barriers. High speed cameras shall be operated at a minimum of 200 frames per second. The need for additional cameras should be considered to cover areas of special interest.

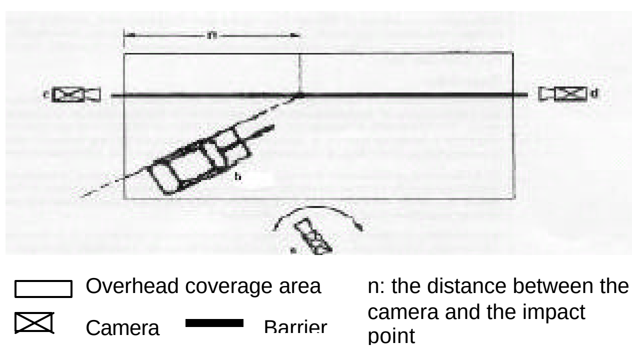


FIGURE 3 Layout of cameras for recording tests.

Test Results of Safety Barrier Crash Test							
							Report Date
Name of Safety Barrier					**Client**		
Type		Class			Installation Site		
Height	m	Materials					
		Length			Soil Condition		
Note							
Crash Test Results							
Test		Note			Test Serial No.		
1. Test Conditions							
Impact Test 1					Impact Test 2		
(Test Date:)					(Test Date:)		
Mass of Vehicle (t)	Impact Speed (km/h)	Impact Angle (degrees)	IS (kJ)	Height of Vehicle C.M (m)	Test Vehicle Mass (t)	Impact Speed (km/h)	Impact Angle (degrees)
Soil Condition				Foundation			
Specimen Length				Installation Method			
2. Test Results							
Impact Test Acceptance Criteria				Items		Test Results	
Intensity Capability	Safety Barrier Deformation			Damage Range			
	Test Vehicle Deformation			Deformation Range			
IS	PHD, THIV						
Test Vehicle Behaviour	Test Vehicle Behaviour						
	Exit Speed						
	Exit Angle						
Scattered Materials	Status						
Supplementary Notes							

FIGURE 4 Test reports for safety barriers.

How about terminals? One third of our barrier fatalities are caused by impacts with terminals.

4 CRASH CUSHION

4.1 Performance Classes (Table 7)

TABLE 7 Performance Classes

<table>
<tr><th>Classes</th><th colspan="3">Road Types</th><th>Design Speed</th><th>Roads</th></tr>
<tr><td>C</td><td rowspan="3">General Roads</td><td colspan="2">Low Speed</td><td>50</td><td>Roads</td></tr>
<tr><td>B</td><td rowspan="2">High Speed</td><td>Urban</td><td>80</td><td>Urban Arterial Highways (more than 4 lanes)</td></tr>
<tr><td>A</td><td>Rural</td><td>80</td><td>Rural Arterial Roads (more than 4 lanes)</td></tr>
<tr><td>S</td><td>Expressways</td><td colspan="2"></td><td>100</td><td>Freeways</td></tr>
</table>

4.2 Test Conditions (Table 8; Figure 5)

TABLE 8 Test Matrices for Crash Cushions

Class	Impact Velocity (km/h)	Total Vehicle Mass (kg)	Test
C	50	900	Test 1
		1,500	Test 2
B	80	900	Test 1
		900	Test 2
		1,500	Test 3
A	80	900	Test 1
		900	Test 2
		1,500	Test 3
		1,500	Test 4
		1,500	Test 5
S	100	900	Test 1
		1,500	Test 1
		900	Test 2
		1,500	Test 3
		1,500	Test 4
		1,500	Test 5

- Above criteria only apply for the redirective crash cushions
- Test 4 and Test 5 are excluded for non-redirective crash cushions
- In case vehicle is not able to approach Test 5 direction, Test 5 is also excluded.

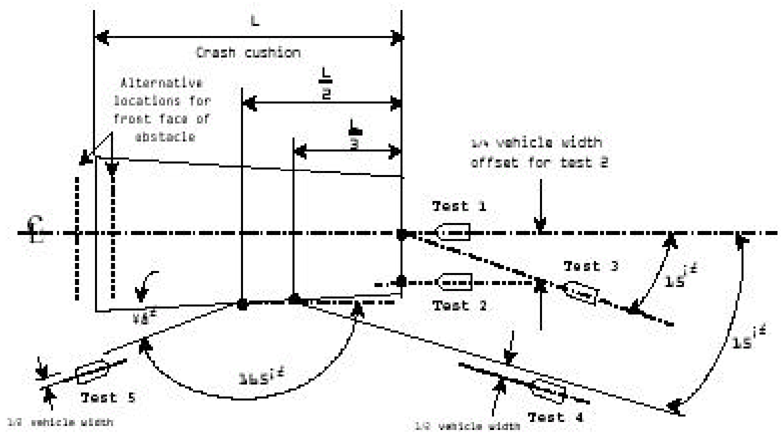


FIGURE 5 Vehicle approach paths for Tests 1 to 5.

4.3 Performance Evaluation Criteria

4.3.1 Occupants' Safety (Table 9)

TABLE 9 Performance Evaluation Criteria for Occupants' Safety

Criteria	Unit	
THIV	m/s	12 (44) (test 1,2,3)
	km/h	9 (33) (test 4,5)
PHD	Gs	20

4.3.2 Crash-Cushion Behavior (Figure 6; Table 10)

1. Elements of the crash cushion shall not penetrate the passenger compartment of the vehicle. Deformations of, or intrusions into, the passenger compartment that could cause serious injuries to the occupants are not permitted.
2. No major element of the crash cushion, having a solid mass greater than or equal to 2.0kg, shall become totally detached, unless this is required by the working of the crash cushion. No major element of the crash cushion shall impede the path of adjacent traffic. The final position of the detached element shall be considered to determine the displacement classification. The four classes D1 to D4 for the permanent lateral displacement of the crash cushion shall be as shown in Table 10 and Figure 6. The permanent lateral displacement shall be measured and recorded in the test report, which makes it possible for road authorities to choose the right facilities.

2 kg may be too restrictive. This and the CEN requirements may be too restrictive. If the crash is serious enough for the vehicle to be towed, any debris will be cleaned up. We have not experienced a problem with debris from crash-cushion impacts. .

3. In any test the crash cushion shall not intrude the broken line representing the front face of the obstacle in Figure 6.

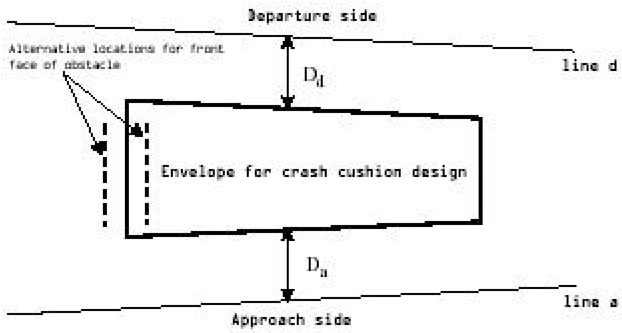


FIGURE 6 Crash cushion permanent deflection limits.

TABLE 10 Permanent Lateral Displacement Zones for Crash Cushions

Class	Displacement	
	Da (m)	Dd (m)
D1	0.5	0.5
D2	1.0	1.0
D3	2.0	2.0
D4	3.0	3.0

4.3.3 Post-Impact Vehicle Behavior (Figure 7)

The vehicle shall remain upright during and after collision although yawing and moderate rolling and pitching are acceptable.

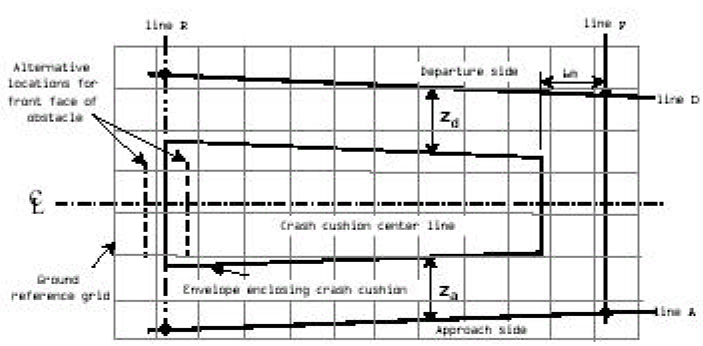


FIGURE 7 Exit box.

For different tests, the vehicle post-impact trajectory shall be restricted by the following criteria:

1. In any test the vehicle shall not intrude the broken line representing the front face of the obstacle.
2. In tests 1 to 5 the wheels of the vehicle shall not encroach the lines of the exit box specified in Table 11 unless the velocity of the vehicle center of gravity at the instant of encroachment is less than 10% of the prescribed impact speed.

TABLE 11 Exit Box Control Lines

Test	Exit Box Control Lines
1	F, A, D, R
2 to 4	F, A, D
5	A

3. The classes of crash cushions shall be ranked according to the distances Za and Zd given in Table 12 and shown in Figure 7. The classes of crash cushions shall be recorded in the test report, which makes it possible for road authorities to choose the right facilities.

TABLE 12 Redirection zone dimensions

Classes of Z	Za (m)	Zd (m)
Z1	4	4
Z2	6	6

4.3.4 Scattered Materials

The status of scattering of components of the traffic barrier following the vehicle impact test shall be confirmed. Descriptions, distances, weights, causes of scattering, impact on the surrounding, etc., shall be assessed. If components of the traffic barrier are scattered in pieces, then the quality, quantity, distance of scattering, and impact on users of nearby roads shall be examined.

4.4 Test Methods

4.4.1 Impact Test

The impact point shall be chosen to demonstrate the worst testing conditions of the crash cushion and shall include any sensitive feature of the design. The required impact point for Tests 1 to 5 shall be as defined in Figure 5.

The vehicle shall not be restrained by control of the steering or by any other means (e.g. braking, antilock brakes, blocking, or fixing) during impact and while the vehicle is in the redirection zone.

4.4.2 Measurement

The minimum vehicle instrumentation for recording linear acceleration and angular velocities shall consist of a set of at least two acceleration transducers aligned with the vehicle axis, plus one angular rate transducer to record yaw rate.

Three sensors should be mounted on a common block and placed as close to the vehicle's center of gravity as practical.

4.4.3 Procedures for recording test data

1. Pre-test
   - mass of the vehicle and location of the center of gravity of the vehicle in the test condition
   - interior and exterior photographs of the vehicle
   - photographs of the position and construction of the crash cushion
2. Test data
   - vehicle speed at impact
   - vehicle approach path
   - vehicle rebound speed, if required
   - linear accelerations and angular velocities
   - permanent deflection of the crash-cushion system, to be measured 10 to 15 minutes after impact
   - Photographic records from high-speed cine film cameras to give a complete record of the vehicle response and crash-cushion behavior (Figure 8)
   - Vehicle exit speed of center of gravity when first wheel encroaches any of the lines specified in Figure 7.
3. Post-test data
   - Damage to the crash cushion
   - Still photographs to aid reporting
   - Ambient temperature
4. Photographic coverage shall be sufficient to clearly describe crash-cushion behavior and vehicle motion during and after impact. Photographic records from high-speed cameras are necessary for the complete record of the vehicle responses and crash cushions. High-speed cameras shall be operated at a minimum of 200 frames per second. A minimum of two high-speed cameras and one normal-speed camera shall be located to record the performance of the crash cushion.

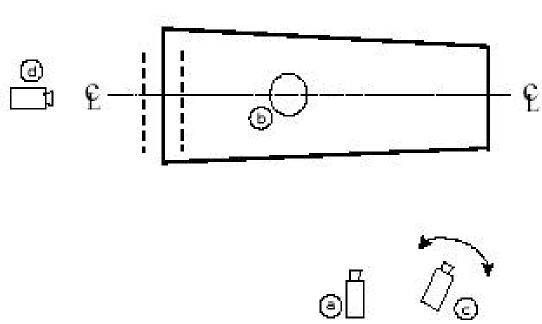


FIGURE 8 Layout of cameras for recording tests.

Status of Standards for Truck-Mounted Attenuators Outside of the United States

Michael Kempen
Impact Absorption Inc.

GENERAL OVERVIEW

Truck-mounted attenuators (TMAs) are an integral part of work-zone safety and overall road safety. These systems are primarily used in work zones of moderate and short duration.

These systems are, and have been, widely used in the United States for more than 20 years. Consequently, most, if not all, international standards for truck-mounted attenuators refer to, or directly use, the U.S. performance standards, NCHRP 230 and the current NCHRP 350. The one exception to this is the United Kingdom, which has three performance standards. Two of these are American, and one is uniquely English.

The current standard in the United States is NCHRP 350; however truck-mounted attenuators tested to either NCHRP 230 or NCHRP 350 are currently on U.S. roads. In the United States, as of October 1998, NCHRP 230 equipment could no longer be sold. NCHRP 230–approved TMAs sold prior to October of 1998 remain in use. NCHRP 230 systems must be replaced, when impacted, with NCHRP 350–approved TMAs.

A brief overview of the relevant tests in the current U.S. standard is as follows.

Test Level 2 (Basic)

- Test 2-50 — 820-kilo vehicle, 70 km/h, head-on impact, shadow vehicle positioned against an immovable wall to prevent forward roll of the shadow vehicle.
- Test 2-51 — 2000-kilo pickup truck, 70 km/h, head-on impact, shadow vehicle allowed to roll forward while restrained by transmission in second gear and with the parking brake in the on position.
- Test 2-52 — 2000-kilo pickup truck, 70 km/h, offset one-half the width of the impacting vehicle, shadow vehicle allowed to roll forward while restrained by transmission in second gear and with the parking brake in the on position.
- Test 2-53 — 2000-kilo pickup truck, 70 km/h, 10-degree angle impact at the centerline of the TMA, shadow vehicle allowed to roll forward while restrained by transmission in second gear and with the parking brake in the on position.

Test Level 3

- Test 3-50 — 820-kilo vehicle, 100 km/h, head-on impact, shadow vehicle positioned against an immovable wall to prevent forward roll of the shadow vehicle.
- Test 3-51 — 2000-kilo pickup truck, 100 km/h, head-on impact, shadow vehicle allowed to roll forward while restrained by transmission in second gear and with the parking brake in the on position.

- Test 3-52—2000-kilo pickup truck, 100 km/h, offset one-half the width of the impacting vehicle, shadow vehicle allowed to roll forward while restrained by transmission in second gear and with the parking brake in the on position.
- Test 3-53—2000-kilo pickup truck, 100 km/h, 10-degree angle impact at the centerline of the TMA. shadow vehicle allowed to roll forward while restrained by transmission in second gear and with the parking brake in the on position.

The above listed tests have a + or - 4% tolerance on impact speed and a tolerance of 1.5 degrees in angle of impact.

It is recommended in the U.S. standards that shadow vehicles weigh 9000 kilos plus or minus 5%.

This overview gives an idea of the testing criteria for truck-mounted attenuators. Passing or failing is determined by a number of factors of which the most relevant is a 20 *g* load on the occupants of the test vehicle and a ride down of a 12 millisecond average or less.

With these factors in mind, the following is an overview of standards on a country-by-country basis of those countries that use or acknowledge the use of TMAs as an effective safety tool.

SPECIFIC REVIEW OF STANDARDS BY REGION

Europe

Germany

- No recognized standard at this time.
- A number of systems in use but no significant desire to create a standard or specification at this time.
- When standards are developed, it is likely that the form, speed, and weight classes, etc., will be very similar to the performance criteria embodied within prEN 1317-3.
- Systems in use are mostly 70 km/h systems.

France

- No recognized standard at this time. There are discussions ongoing now.
- A number of systems are in use, but there is a significant desire to create a national standard or specification.
- When standards are developed, it is likely the form, speed, and weight classes, etc., will be very similar to the performance criteria embodied within prEN 1317-3.
- The exception to the prEN norms will most likely encompass speed, with a top speed class of 80 km/h.
- There is one TMA that has been tested in France. Renco has been tested at the LIER in Lyon, France.
- The French norm may encompass the following test criteria:
    - TC 1.2.80 - frontal impact, 1300-kilo vehicle, 80 km/h.

— TC 1.1.80 — Frontal impact, 900-kilo test vehicle, 80 km/h. (This test may well be optional.)
— TC 2.1.80 — Offset impact, 900-kilo vehicle, 80 km/h.
— France perceives a safety issue and will most probably address the issue over the next 12 to 24 months.
— CEN 226 is currently chaired by the French representative.

Italy

- No recognized standard at this time. There are discussions ongoing now.
- A small number of systems are in use. There is a significant desire to create a standard or specification.
- When standards are developed, it is likely the form, speed, and weight classes, etc., will be very similar to the performance criteria embodied within prEN 1317-3.
- There is concern in Italy about impacts in work zones with road construction vehicles, and I surmise that there will ultimately be a standard. There is no estimate as to when this may occur.
- At this time the CEN 226/WG-1 is chaired by the Italian representative of the CEN committee.

The Netherlands

- The Netherlands refers to NCHRP 230 and NCHRP 350 as the criteria for the use and sale of truck-mounted attenuators.
- The vast majority of TMAs sold in the Netherlands are test level 2 systems rated at 70 km/h.
- 8000-kilo weight for the shadow vehicle.

Portugal

- No national standard.
- Awaiting a CEN norm.
- Use NCHRP 230 or NCHRP 350 on a case by case basis.

Spain

- No national standard.
- Awaiting a CEN norm.
- A number of TMAs have been sold in Spain in the early 1990s using European Union monies.
- Use NCHRP 230 or NCHRP 350 on a case-by-case basis.

Belgium

- Belgium refers to NCHRP 230 and NCHRP 350 as the criteria for the use and sale of TMAs.

- The overwhelming majority of TMAs sold in Belgium are test level 2 systems rated at 70 km/h.
- Southern French-speaking regions use test level 3 systems
- Northern regions use test level 2 systems

The United Kingdom

- TMAs are referred to as LMCCs in the United Kingdom. (lorry-mounted crash cushions).
- The United Kingdom has a national performance standard for truck-mounted attenuators.
- NCHRP 230 or NCHRP 350 criteria are acceptable.
- The U.K. standard is similar to the U.S. standard.
- The exceptions are the speed classification, the weight of the test vehicle, the final resting place of the impacting vehicle and the weight of the shadow vehicle.
- LMCCs/TMAs are widely used in the United Kingdom and are specified.
- U.K. performance specification

U.K. Performance Specification: Lorry Mounted Crash Cushions

This performance standard specifies that LMCCs can be tested to the U.K. Specification Test Level 2 (TL2.UK) or to those of NCHRP 230 (TL2, TL3) or NCHRP 350 (TL2, TL3) as identified in the following tables. Additional tests may be undertaken, these are indicated as optional tests.

U.K. Test Matrices and Procedures

When subjected to the impact tests defined in Table A1(a), LMCCs intended for deployment by the U.K. Highways Agency shall meet the performance requirements described in Table A3. The testing procedures shall conform to those contained in NCHRP 230, Chapter 4 (amended where necessary to comply with Table A1(a) and Table A1(b).

TABLE 1 Test Matrix—U.K.

Test designation Car	TL2.UK /2-50
Test Inertial Mass	825 kg (e.g., Fiesta)
Impact Speed	80 km/h
Approach	Head on
Location of Impact	Center
Test Designation	TL2.UK /2-51
Test Inertial Mass	Car 1500 (e.g., Granada)
Impact Speed	80 km/h
Approach	Head on
Location of Impact	Center

TABLE 2 Condition of Block Vehicle—U.K. Tests

Block vehicle	
Test inertial mass	(kg) not less than 7500
Engine	Off
Parking brake	On
Transmission	Neutral

Alternatively, when subjected to the impact tests defined in Table A2(a) or A2(b), LMCCs intended for deployment by the U.K. Highways Agency shall meet the performance requirements described in Table A3, except that criterion "K" has been changed from "the vehicle's trajectory should not intrude" to "the vehicle's trajectory shall not intrude."

TABLE 3 Occupant Impact Velocity Limits (m/s)

Preferred	9
Maximum	12

TABLE 4 Occupant Ride Down Accelerations

Occupant Ride Down Acceleration Limits (*g*)	
Preferred	15
Maximum	20

TABLE 5 Further Evaluation Factors

THIV
PHD
OCDI (Per prEN 1317 - 3)

Scandinavia

Sweden

- NCHRP 350 Test Level 3, Tests 3-50, 3-51 and offset test 3-52 (100 km/h).
- NCHRP 230 Test Level 3, Tests 50, 51 and 54 (96 km/h).
- Minimum width of the cushion or impact plate > 1.75 m.
- Shadow vehicle weight—not specified.
- NCHRP 230 testing will not be accepted after 2003.

Norway, Denmark, and Finland

- Generally these Scandinavian countries rely on research and standards developed in Sweden.
- Optional tests not required at this time; however, each country may ultimately require Test 3-52, offset testing.
- No shadow vehicle weight specified.
- Norway is using TMAs now, and they use Test Level 3 systems, which are approved to "international standards."
- Denmark is using TMAs now, and they use Test Level 3 systems, which are approved to "international standards."
- Finland will begin using TMAs either in late 2001 or early 2002. Shadow vehicle weight will not be specified. Finland is considering two options for their standard.
- The difference in the options is whether to include Test 3-52 or not to include Test 3-52. Cost is the general parameter for this consideration.

Australasia

Australia

- National standards (ANZS 3845); however, this standard is largely ignored.
- Strong state standards (New South Wales, Victoria, and Queensland).
- NCHRP 350 Test Level 2 and 3.
- No NCHRP 350 optional tests are required.

Malaysia and Singapore

- National standards, Malaysia.
    - Malaysia uses NCHRP 350.
    - No optional tests required.
- National standards, Singapore.
    - Singapore uses NCHRP 230, as written in their last tender specifications.
    - Shadow vehicle weight is specified at 7500 kilograms
    - Height restrictions in the raised position

New Zealand

- New Zealand Standard ANZS 3845-M-23 (amendment dated 1999).
- NCHRP 350 Test Level 2 or 3, Test Level 3 mandatory on 6/02.
- No optional tests required.

THE FUTURE—A GENERAL OVERVIEW OF WHERE WE ARE GOING

Europe will move to greater use of TMAs over the next 2 to 4 years. Growth will be moderate and use will remain on a country-by-country basis pending a CEN (European-wide) norm and a possible CEN specification. It is more likely in the short run that there will not be a European wide norm.

CEN will develop a standard over the next 2 to 4 years. It will reflect values in existing standards, which include, prEN 1317-3., NCHRP 230 and NCHRP 350. There will be debate on speed and weight classes similar to the debate over prEN 1317-3.

Scandinavia and the United Kingdom will continue to expand the use of TMAs at a more rapid rate than the other members of the European Union. Sweden has over 187 systems on their roads at the writing of this paper, and the United Kingdom has well over 200 systems on their roads.

Denmark, Finland, and Norway will also expand their use of TMAs at a more rapid rate.

Overall, Europe and Scandinavia, when viewed as a whole, will have steady, moderate growth over the next 2 to 4 years. Growth will quicken with a CEN norm.

Australasia will also expand TMA use. New Zealand is already using TL-2 systems and will move to TL-3 systems within 2 years.

Australia will also continue to use small numbers of TL-2 systems along with TL-3 systems in Singapore. Malaysia is uncertain.

The expansion of standards for truck-mounted attenuators will save lives in work zones, worldwide.

Currently there are six systems available worldwide at the TL-3 level. They are:

1. RENCO—RAM 100 (optional testing under consideration)
2. Traffix—Scorpion 100 (optional testing performed)
3. Trinity—MPS 350 (optional testing under consideration)
4. EAS—Safe Stop (optional testing performed)
5. Impact—Multihit 100 (optional testing scheduled)
6. U-MAD 100 (one optional test performed and one optional test scheduled)

Currently there are four TL-2 systems available worldwide. They are:

1. Renco—Rengard 70.
2. EAS—Alpha 70.
3. Trinity—Hexcel 70.
4. Traffix—Scorpion 70.

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