

Vehicle restraint systems —

Part 6: Crashworthy roadside features — Impact attenuators

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Foreword

This part of PD 6634 has been prepared by Subcommittee B/509/1. The other parts in the series are:

- *Part 1: Fundamentals — Database;*
- *Part 2: Fundamentals of highway restraint systems;*
- *Part 3: Development of vehicle highway barriers in the United Kingdom;*
- *Part 4: Development of bridge parapets in the United Kingdom;*
- *Part 5: Development of barrier transitions and terminals.*

Over the last 30 years the Department of the Environment, Transport and the Regions (DETR), the Transport Research Laboratory (TRL), the British Standards Institution (BSI) and other organizations have been involved in research, testing, design and the preparation of specifications and standards for vehicle restraint systems such as safety fences, barriers and bridge parapets. Much of this work has been published in the form of Transport Research Laboratory reports, drawings, specifications and standards.

Over recent years, particularly since the introduction of quality assurance schemes for both the manufacture of components and the erection of safety fences and parapets, the need for additional advice, guidance and background information has been highlighted. In 1988 the then Department of Transport (DTp) and BSI agreed to the preparation of a comprehensive British Standard or reference manual on vehicle restraint systems.

A steering group of representatives from BSI, DTp and TRL was formed to supervise the project and the following terms of reference were formulated.

“To prepare the draft of a comprehensive document on safety fences, barriers and bridge parapets covering research and development, design, specification, manufacture, installation, repair and maintenance.”

It was decided to split the reference manual into several parts and the following groups were formed:

- Working Group 1 — Part 1 dealing with the fundamentals of safety fences, barriers, parapets and transitions;
- Working Group 2 — Part 2 dealing with the specification and layout of safety fences and barriers;
- Working Group 3 — Part 3 dealing with the installation, inspection and repair of safety fences;
- Working Group 4 — Part 4 dealing with the installation, inspection and repair of safety barriers;
- Working Group 5 — Part 5 dealing with all aspects of bridge parapets.

Of these proposed parts PD 6634 forms part 1 and BS 7669-3 forms part 3. Work on the other parts has been suspended.

This publication does not purport to include all necessary provisions of a contract. Users are responsible for its correct application.

This Published Document is not to be regarded as a British Standard.

Summary of pages

This document comprises a front cover, an inside front cover, pages i and ii, pages 1 to 21 and a back cover.

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Introduction

The purpose of a roadside impact attenuator is to reduce the severity of vehicle impact with a fixed object into a less severe collision. Typical examples are where crash cushions are placed to protect vehicles from direct contact with rigid roadside features such as bridge piers, ends of roadside safety barriers and toll booths. In many cases the installation of a crash cushion to protect against collision with every roadside hazard is both cumbersome and prohibitively expensive.

Accordingly, where direct contact can be made with roadside features such as lighting columns, telegraph poles or road-sign poles, the severity of impact can be reduced by the inclusion of a yielding slip joint in the shaft of the pole or column.

The installation of a crash cushion or other impact attenuator may not reduce the total number of accidents but, if it is well designed, it should reduce the risk of injury to vehicle occupants; it is a passive safety device.

Impact attenuators decelerate a vehicle both by absorbing energy and by transferring energy to another medium. For example, a crash cushion may be designed to predominantly absorb energy, transfer energy or use a combination of both qualities. An example of the first type would be a design whereby the energy of a colliding vehicle is absorbed by plastic deformation (non-elastic) of the metal structure of the cushion. In an example of the second case, the vehicle's energy may be transferred to sand or water in drum containers; the energy is absorbed by projection of the contents of the containers. A vehicle run-off trap or arrester bed located on a steep hill for the emergency stopping of vehicles with brake failure, is a typical example of an energy transfer attenuator (Laker, 1971 [1]). A metal crash cushion of substantial mass may decelerate a vehicle by transferring energy from the car into acceleration of this mass, as well as by absorbing energy through plastic deformation of the metal (AASHTO, 1989 [2] Macdonald, 1989 [3]).

To protect civil engineering teams on highways, energy absorbing crash cushions may be fitted to the rear of shadow vehicles to give protection to staff in those situations where traffic may erroneously enter the work zone. The lorry or truck mounted crash cushion (LMCC) is located in a position where staff can work in the protective shadow of the vehicle (TD 49/97, 1997 [4]).

Slip joints inserted into utility poles reduce the severity of impact that can occur during impact into an unmodified pole; in this case, little energy absorption takes place. A good design should permit the vehicle to run on while also ensuring that driver control of the vehicle is not lost; the vehicle is brought to rest by braking. However, because little energy is absorbed both the vehicle and the detached pole can be a hazard if other vehicles or pedestrians are close by; the roadside siting of such devices should take this into account.

There are locations where earth mounds on roadsides, primarily used as noise barriers, have some potential to restrain errant vehicles. The attachment of a horizontal barrier rail to these mounds, although not primarily energy absorbers, can reduce the severity of impact that has been shown to occur when a vehicle is brought abruptly to rest by digging in or penetrating the unprotected earth mound.

1 Scope

This part of PD 6634 describes impact attenuators, including ground-based crash cushions, lorry mounted crash cushions, vehicle arrester aggregate beds, rose bush arrester beds, bull nose small radius safety fences and earth acoustic mounds. It also examines the effects of impacts into utility poles such as street lighting columns, road signs and telegraph poles.

2 Roadside and lorry mounted crash cushions

2.1 Basic concepts of roadside crash cushions

In the situation where a driver of an errant vehicle is unable to avoid collision by application of the brakes or by steering control, then on contact with a crash cushion the vehicle needs to be brought to rest with the minimum risk of injury to the occupants.

There is no simple relationship between the deceleration of a vehicle and an unrestrained occupant. Even in the case where seat belts are worn, the deceleration of the wearer may take a different pattern from that of the vehicle; however, once the occupant has come into contact with the interior he may experience decelerations similar to the vehicle. Initially, injury may be caused by the occupant making primary contact with the interior of the passenger compartment; following this, deceleration forces acting on the body organs can cause injury as the occupant follows the deceleration pattern of the vehicle. If, during an accident, the person is ejected from the car, contact with the road and surrounds are likely to be a prime cause of injury. It is reasonable to presume that vehicles undergoing low levels of deceleration are less likely to cause injury to occupants.

The wearing of seatbelts can reduce injuries caused by occupant contact with the interior of the vehicle, and so crash cushions could be designed for relatively high levels of deceleration given that seat belts are used. However, high vehicle decelerations in the longitudinal direction may cause considerable deformation of the passenger compartment, with penetration of the engine into the compartment a real hazardous possibility.

The rate at which vehicles can be brought to rest or decelerated are subject to the equations of motion as follows:

$$V^2 = U^2 - 2aD \tag{1}$$
where

- V = final speed in metres per second (m/s)
($V = 0$ in this simple analysis);
- U = initial speed in metres per second (m/s);
- a = deceleration in metres per second squared (m/s²);
- D = stopping distance in metres (m).

NOTE Values of “a” in units of “g” = $a/9.806\ 7\ \text{m/s}^2$.
The information in Table 1 is taken from the European Standard prEN 1317-3 and shows the required impact tests to meet a range of crash cushion performance classes.

Table 1 — Crash cushion impact tests
(prEN 1317-3)

Approach path	Vehicle mass kg	Speed km/h
Head-on centre	900	50
	900	80
	900	100
	1 300	80
	1 300	100
	1 500	110
Head-on ¼ vehicle offset	900	80
	900	100
On the nose at 15°	1 300	80
	1 300	100
	1 500	110
Side impact at 15°	1 300	50
	1 300	80
	1 300	100
	1 500	110
Side impact at 165°	1 300	80
	1 300	100
	1 500	110

Figure 1 shows the mean deceleration levels derived from equation (1), in values of “g” for given stopping distances D , from speeds of 110 km/h, 80 km/h and 50 km/h.

For example, it is possible to achieve a deceleration level of 1.0 g in a suitably designed aggregate arrester bed. Figure 1 shows that at this deceleration level a 50 km/h vehicle can be brought to rest in a distance of about 10 m. However, a 110 km/h vehicle would need to be decelerated at a level of about 5.0 g; to achieve this magnitude of deceleration a degree of resistive force considerably higher than that possible in an aggregate arrester bed is required. Plastic deformation of a metal structure or energy transfer in a sand-bin type crash cushion can produce this level of force.

Consequently, for end-on impact conditions the first constraint on the design of a cushion is that a prescribed minimum length of cushion is necessary to uniformly decelerate a vehicle of given speed to rest (see Figure 1).

In practical cases, some crash cushions do not generate uniform deceleration. They are designed to accommodate small car impacts by having a softer nose than the subsequent stiffer length.

In simple designs, the calculated average deceleration will approximate to the mean uniform deceleration, as defined by equation (1), although short peak decelerations may arise through complex interaction of the vehicle and the cushion. Simple analysis does not permit their derivation; full scale instrumented tests are necessary to determine peak values.

In the preceding considerations, the crush distance of the vehicle has not been taken into account. This distance will usually be fairly small in comparison with the length of a typical cushion; its exclusion provides a conservative estimate for the performance of the cushion. Nevertheless, for cushions of short length the crush distance of the car can considerably reduce the deceleration levels.

So far in this discussion the mass of the vehicle has not been a factor in the design of a crash cushion. The above discourse has demonstrated that a crash cushion designer needs firstly to consider impact speed and the mean level of vehicle deceleration, which itself is a function of the stopping distance or effective length of the cushion.

After due consideration of the likely maximum impact speed and the space available for its installation, the effective resistive force necessary to decelerate the vehicle in this available space needs to be determined. This force is a function of the mass of the vehicle; it is defined by the following equation:

$$P = Ma \tag{2}$$

where

- P = resistive force in newtons (N);
- M = mass of vehicle in kilograms (kg);
- a = deceleration in metres per second squared (m/s²).

Figure 2 shows the resistive force required to decelerate vehicles of mass 1 500 kg, 1 300 kg and 900 kg for given levels of deceleration in units of “g”. For example a 1 500 kg car requires a resistive force of about 300 kN to decelerate it at 20 g; about half this value is required for a 900 kg car.

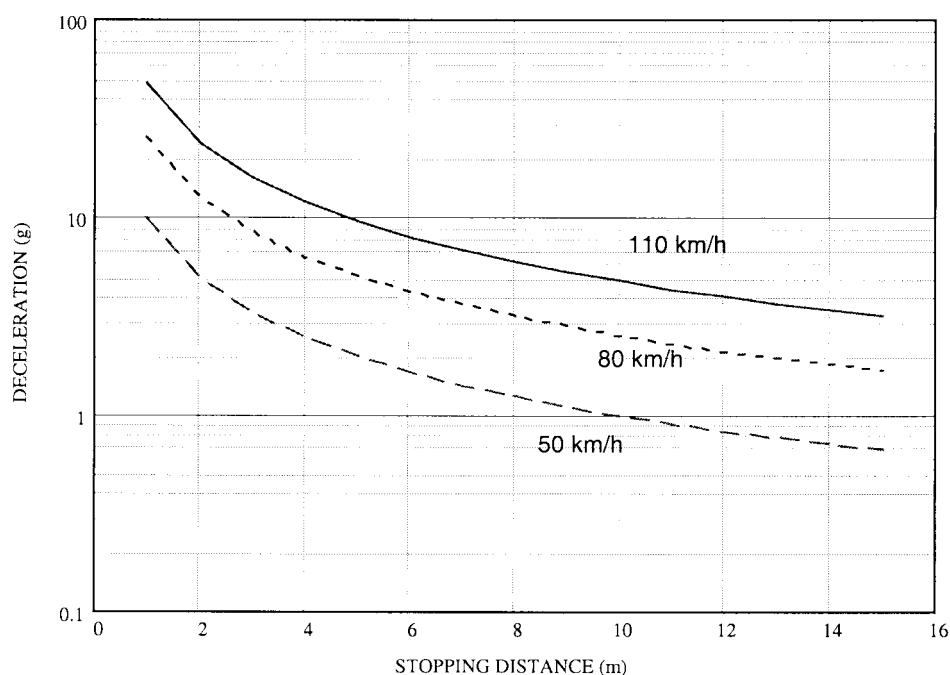


Figure 1 — Deceleration for given stopping distances

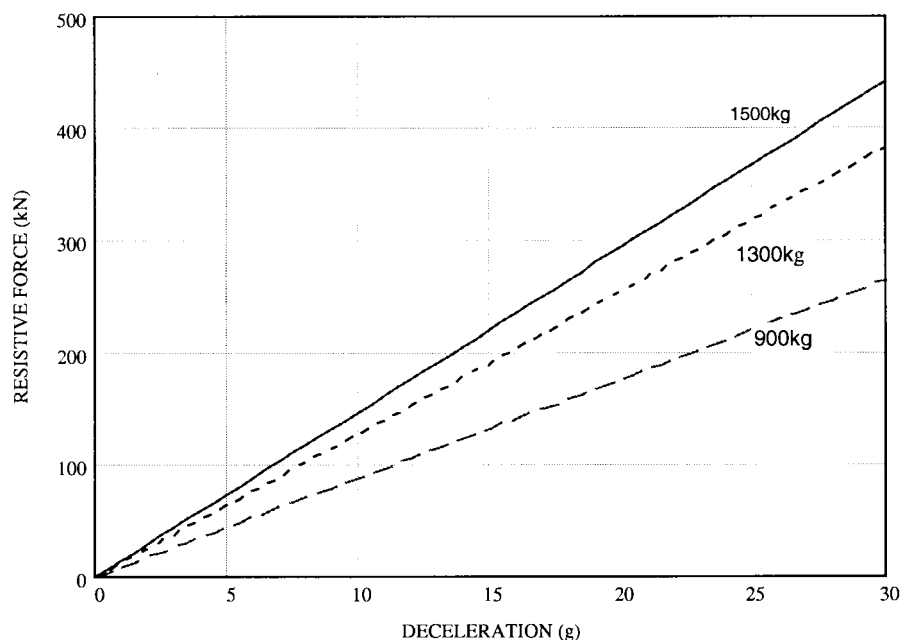


Figure 2 — Resistive force to decelerate vehicles of given mass

For an end-on impact into a crash cushion at zero degrees, the cushion generates a resistive force on the front of the car just above bumper height (see Figure 3). To minimize the risk of injury to the occupants it is necessary that the passenger compartment is not substantially deformed or intruded by displacement of the engine. TRL impact

tests with cars into a concrete block have shown that an engine is likely to be displaced at vehicle deceleration levels of 20 g to 30 g; intrusion into the passenger compartment is not likely below a deceleration level of about 25 g (Neilson et al, 1968 [5]).

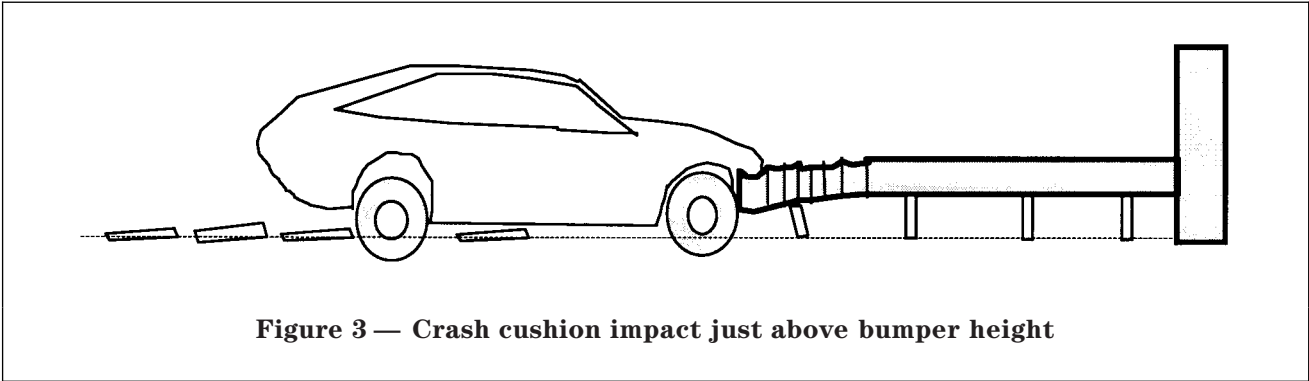


Figure 3 — Crash cushion impact just above bumper height

Hence the second constraint on a crash cushion design is that the resistive force generated during vehicle contact should not excessively deform or cause intrusion into the passenger compartment. From these elementary considerations of vehicle integrity and a knowledge of the roadside space available in which to install a crash cushion, it is possible to make practical approximations for their length and crush strength.

For example, given that the prime feature is that the passenger compartment should not be intruded by the engine, a conservative mean deceleration of 12 g requires a crash cushion to have the following characteristics as derived from equations (1) and (2) and shown in Table 1.

Practical crash cushions can exhibit non-linear crush characteristics, consequently deceleration/time patterns and peak levels need to be recorded during full scale tests.

Table 2 shows that to bring vehicles of different mass to rest from speed requires different resistive characteristics of a crash cushion. While the stopping distances in Table 2 are theoretically sound, controlled crash tests and real life experience show that installed crash cushions should be somewhat longer because a practical cushion can be crushed only to a finite length.

Table 2 — Resistive force and stopping distance at 12 g deceleration

Vehicle mass	Speed	Resistive force	Stopping distance
kg	km/h	kN	m
900	50	106	0.76
	80	106	2.12
	110	106	4.16
1 300	50	152	0.76
	80	152	2.12
	110	152	4.16
1 500	50	177	0.76
	80	177	2.12
	110	177	4.16

Clearly, it is not acceptable to arrange for roadside cushions to protect cars of only one single mass. The resistive force of the cushion needs to be sufficient to decelerate the heaviest and fastest vehicle for which it is designed. This should be consistent with good impact performance for the smaller vehicles. Consequently, either a compromise should be reached in the crush strength of the cushion, or it should be designed to have a graded resistive crush strength; perhaps by providing a soft nose to accommodate the impact of the lighter vehicle.

To confirm that good impact performance is maintained for the lighter vehicles, it is necessary to include vehicles of different masses to form an impact test matrix. It is not sufficient to carry out tests with the heaviest vehicle and then scale down to determine the impact response characteristics of vehicles of lighter mass.

For development test purposes it seems reasonable to select vehicle masses that represent the heaviest and lightest ends of the vehicle population distribution to ensure that the crash cushion performs well under fairly extreme conditions. Three masses of vehicle have been included in the European Standard prEN 1317-3 to form the test matrix; these are 900 kg, 1 300 kg and 1 500 kg.

The maximum speed limit on UK roads is 70 mile/h (113 km/h). Many European countries have maxima close to this although in some cases there are no upper limits. From practical considerations of roadside space and cost of units, it is unreasonable to expect that crash cushion designs can perform as well for the heaviest and fastest impacts as for the more likely and consequently more frequent impacts of the more popular cars. Nevertheless, it is conceivable that even the heaviest and highest speed impact will be ameliorated by the cushion.

It is likely that uses for crash cushions will mostly be found in areas where the higher speed limit zones exist. Taking this into account it is proposed that cushions for these roads should be tested at 70 mile/h (110 km/h) and 50 mile/h (80 km/h). For dense urban areas, a single test at 30 mile/h (50 km/h) is included mainly to confirm good performance at low speed, after the more severe tests have proved successful.