

Vehicle restraint systems —

Part 4: Development of bridge parapets in the United Kingdom

ICS 93.080.30

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- Aluminium Federation
- Association of Consulting Engineers
- Association of County Councils
- Association of Safety Fencing Contractors
- British Cement Association
- British In-situ Concrete Paving Association
- British Precast Concrete Federation Ltd
- County Surveyors' Society
- Department of Transport (Highways Agency)
- Institution of Civil Engineers
- Motor Industry Research Association
- National Fencing Training Authority
- Railtrack
- Royal Society for the Prevention of Accidents
- Transport Research Laboratory
- UK Steel Association

This Published Document, having been prepared under the direction of the Sector Committee for Building and Civil Engineering, was published under the authority of the Standards Committee and comes into effect on 15 October 1999

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The following BSI reference relates to the work on this standard:
Committee reference B/509/1

ISBN 0 580 28228 7

Amendments issued since publication

Amd. No.	Date	Comments

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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 — Data base;*
- *Part 2: Fundamentals of highway restraint systems;*
- *Part 3: Development of vehicle highway barriers in the United Kingdom;*
- *Part 5: Development of barrier transitions and terminals;*
- *Part 6: Crashworthy roadside features — Impact attenuators.*

BSI Committee B/509/1, whose constitution is shown in this Published Document takes collective responsibility for its preparation under the authority of the Standards Committee. The committee wishes to acknowledge the personal contribution of Mr I B Laker.

Over the last 30 years the Department of the Environment, Transport and the Regions (DETR), the Transport Research Laboratory (TRL), 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 TRL 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 the 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

Rails or parapets have been installed on bridges, since their first inception, to act as protection for pedestrians making their way across. Large bridges needed substantial parapets to provide a sense of security and restraint for horse drawn vehicles. These bridges, mostly built or reconstructed in the 19th century, eventually had to provide passage for the growing numbers of private and commercial vehicles on the roads. The load capacity of the national stock of bridges became of prime concern. At present bridges have to cope with live loads generated by vehicles of gross weights approaching 48 t.

Little documented attention was paid to the vehicle impact capability of the installed bridge parapets until the drafting of DTp Technical Memorandum BE5 began in 1967. Accordingly, parapets can be classified into those built before the publication of Technical Memorandum BE5 and those which have been built since that date. Parapets built before then included a large number manufactured from masonry and brick, generally associated with masonry arch bridges. They relied mainly on their mass to keep the stresses on the mortar layers compressive under light to moderate impact loads. They could not be relied on to contain heavy vehicles travelling at speed; also, secondary hazards could arise from impact debris falling from the bridge. Inclusion of a reinforced concrete core cast integral with the horizontal deck slab later upgraded such designs.

Pre-1967 bridges, other than masonry arch types, had parapets manufactured from cast and wrought iron, steel, timber, masonry and in situ and precast concrete. It was predicted that the substructures of such bridges would not have sufficient capacity to withstand impact loads transmitted through modern designs of parapets, and so caution was needed in upgrading. The older bridges had little reserve in the way of dead load to permit strengthening of the existing structures. In addition, those parapets of lighter mass than the masonry constructions could be subject to penetration even from minor impacts.

1 Scope

This part of PD 6634 describes the development of bridge parapets in the United Kingdom as a result of theoretical models and impact testing. Bridge parapet designs are described for the containment of vehicles of mass from about 825 kg to 30 000 kg. Impact tests are described for the lighter vehicles at speeds up to 110 km/h (70 mile/h) and for heavy commercial vehicles (HCVs) at up to 80 km/h (50 mile/h).

2 DTp Technical Memorandum BE5

Improvements to the design of structures commensurate with adequate impact characteristics was central to the drafting of Technical Memorandum BE5. The first draft was produced in 1966; it underwent several revisions and amendments until the 4th Revision, 1st Amendment, was published in 1984. An important change was the agreement with the British Rail board on P6 high containment transverse loading criteria, and application criteria following on from a report to the Rail board on the need for this level of containment in 1974. In 1984 BSI took over the task of developing standards related to the design and testing of bridge parapets; the content of these publications is discussed later under separate headings related to the material from which the bridge parapets are constructed. Essentially this breaks down into parapets fabricated from metal, concrete, combined metal and concrete, masonry and wood. The standards are presently being developed under the heading of BS 6779; all the documentation is not yet complete.

Technical Memorandum BE5 formed the keystone in the development and testing of bridge parapets. It has also made a distinct contribution to the formulation of the various parts of BS 6779; consequently it is of relevance to refer to some of the main points in the document.

Table 1 gives a summary of the vehicle impact containment requirements of bridge parapets as listed in Technical Memorandum BE5 (1984)[1]. Parapet construction was permitted in metal, reinforced concrete, structural masonry or brick work, or in a combination of these materials. The designated heights of parapet classes ranged from 1 000 mm for vehicle and pedestrian parapets to 1 800 mm for bridges on bridleways.

Table 1 — BE5: vehicle containment requirements for bridge parapets

Group	Structure class	Containment level
P1	Bridges carrying motorways or major roads	Saloon car impact 1 500 kg at 113 km/h and 20°
P2	Bridges carrying other roads	Saloon car impact 1 500 kg at 80 km/h and 20°
P4	Footbridges	Static horizontal load 700 N/m to 1 400 N/m at top of parapet
P5	Bridges over railways	Saloon car impact 1 500 kg at 113 km/h and 20°
P6	Bridges at high risk areas	Heavy commercial vehicle 30 000 kg at 64 km/h and 20°

Material strengths for posts and longitudinal members, for given post spacings, were quoted for all metal parapets, other than the high containment P6 group.

Ultimate moments of resistance and ultimate shear resistance relative to the design of reinforced concrete parapets were given for P1 to P6 parapet groups.

The shape and form of all types of parapet materials were considered; for example, the cross-sectional profile shapes of concrete parapets were defined and the post and rail spacings were outlined for metal parapets. Infill on the face of an open design of parapet was required where it was necessary to prevent objects falling on a sensitive area below the bridge, such as a motorway or railway. Designs to prevent wilful climbing of a parapet were called for where pedestrians had access to a bridge.

To prevent direct impact between a vehicle and the end of a parapet, Technical Memorandum BE5 required provision of a safety barrier at the approaches to a bridge.

The criteria to be met for acceptance of an impact test as successful were listed in Technical Memorandum BE5 as follows.

- The vehicle shall be contained.
- No part of the parapet shall become detached.
- The transverse displacement shall not be more than 800 mm.
- There shall be no cracking of the concrete under a metal post base plate.
- No part of the vehicle shall be arrested abruptly by the impact with a post.
- The test vehicle shall not roll over.
- The car shall preferably be steered back to the line of the parapet, or it shall be redirected at not more than 12° to the line of the parapet.
- A test report shall be submitted for approval.

BSI is working towards completion of BS 6779 for vehicle containment parapets on highways. Meanwhile reference can be made to the Design Manual for Roads and Bridges (BD 52/93) [2]. The April 1993 issue of BD 52/93 supersedes Technical Memorandum BE5.

The main changes included in BD 52/93 are as follows.

- The implementation of BS 6779-1 for metal parapets.
- Clarification on the end-treatment of high containment (P6) parapets.
- The replacement of sloping front faces on parapets with near vertical faces.
- The acceptance of steel in the construction of high containment (P6) parapets.
- Revision of bridge deck loadings for high containment (P6) parapets.
- Special requirements as agreed with the railway inspectorate.

3 Developments of bridge parapets under BS 6779

3.1 General

Technical Memorandum BE5 laid down many of the basic requirements for the design of bridge parapets. BS 6779-1 has built on this document and this has led to the development of improved designs of bridge parapets fabricated in aluminium alloys and steel.

Table 2 gives the present vehicle impact containment requirement for bridge parapets according to BS 6779. European Standards (EN 1317-1 and -2) are being drafted for the impact performance of highway vehicle restraint systems; bridge parapets are included. The main effect of the implementation of the European Standard in the UK will be the addition of a test for a light car of mass 900 kg at an impact speed of 100 km/h and the inclusion of impact severity indices (see PD 6634-2:1999, clause 7).

Bridge parapets having a normal level of containment are intended to offer a reasonable level of prevention of vehicles breaching the parapet, consistent with a good compromise on safety considerations for vehicle occupants, for all but the most exceptional impact circumstances.

Parapets having a low level of containment are mainly restricted to use in 80 km/h (50 mile/h) speed zones. There are exceptions where their use is restricted to 50 km/h (30 mile/h) zones; this applies mainly to the application of metal parapets that contain vertical infill bars.

Table 2 — Vehicle containment requirements for bridge parapets (from BS 6779)

Containment level	Vehicle	Mass	Speed	Angle	Height of centre of gravity
		kg	km/h	degrees	mm
Low	Saloon car	1 500	80.0	20	600
Normal	Saloon car	1 500	113.0	20	600
High	HVC 4-axle	30 000	64.0	20	1 650
Additional EN 1317 test	Light weight car	900	100.0	20	500

The main design objectives for parapets under BS 6779 are:

- to provide specified levels of containment to limit penetration by errant vehicles;
- to protect highway users by safely redirecting an errant vehicle, with minimum deceleration force, on a path close to the line of the undeflected parapet;
- to reduce the risk of vehicles overturning.

3.2 Derivation of theoretical design forces

In designing parapets to meet the objectives listed in 3.1, a balance has to be found between the overall risk to road users, the level of containment, the ability of the main bridge structure to cope with the vehicle impact loads and the consequent overall actuarial economic costs.

A part of BS 6779 has been written in general terms to allow new types of parapets to be developed, and also to give clear and detailed design guidance based on the types of parapets presently in use in the UK.

It is not possible to depend on theoretical design alone because of the complex interactions between a vehicle and the deflection of the impacted parapet; consequently dynamic proving of a new design is part of the British Standard requirement although there are circumstances in which certain concessions can be made, particularly in the field of concrete parapets. The following paragraphs give a background to levels of containment and the theoretical impact forces imposed on parapets.

The mean lateral acceleration acting on a safety barrier or parapet is discussed in PD 6634-2:1999, 5.3. For convenience, the combined equation that describes the mean lateral force is repeated here as,

$$F(v) = \frac{M(v \sin \theta)^2}{2000(c \sin \theta + b(\cos \theta - 1) + z)} \quad (1)$$

where

- | | |
|-------------|--|
| $F(v)$ | is the impact force in kN; |
| M | is the mass of the vehicle in kg; |
| v | is the vehicle speed in km/h; |
| z | is the vehicle and parapet crush distance in m; |
| θ | is the angle between the car and the parapet on impact (20°); |
| b and c | are constants (see Figures 1 and 2). |

Figure 1 shows the variation in the lateral force experienced by a parapet for changes in the lateral speed component of an impacting vehicle. In general, the average value is derived from the moment of first contact, to the moment when the vehicle has become parallel to the line of the parapet; specifically it is the maximum lateral movement of the vehicle's centre of gravity measured from the point of first contact. Barrier deflection and vehicle crushing can take place during this period and this is indicated by the value of z . The moment at which the vehicle is parallel to the parapet might not be coincident with the maximum deflection, but for a first order approximation it is frequently taken to be so.

Figure 1 relates to a 1 500 kg saloon car impacting at an angle of 20° . For a parapet of normal containment level the impact speed is 70 mile/h (113 km/h).

Figure 1 shows the average lateral load on the parapet is about 60 kN. The lateral force F varies rapidly with speed; in effect the force is proportional to the square of the speed.

Figure 2 shows the advantages that can be gained by increasing the value of z . For example, BS 6779 permits a parapet deflection of 0.8 m. Assuming there is no crushing of the car, Figure 2 shows the lateral force F takes a value of 54.6 kN. However, if the car crushes the same distance, the value of z becomes 1.6 m and the lateral force reduces by about 35 % to 36 kN.

It is apparent that the degree of structural damage to a parapet may be minimized if energy can be absorbed over a useful crushing distance of the impact vehicle. In addition, smaller impact forces on the car are consistent with lower injury-producing forces being exerted on the vehicle occupants (see PD 6634-2:1999, clause 6).

3.3 Design load safety factors

3.3.1 General

The ultimate load that a structure such as a safety fence can withstand before complete collapse is discussed in PD 6634-3:1999, 2.2, in terms of plastic deformation where a metal under load is considered to be in state of perfect plasticity, capable of infinite strain. In parallel with this philosophy, in the case of the necessity for bridge parapets not to collapse completely for safety reasons, there is a need to determine a margin of safety against collapse. The margin of safety may be considered under the concepts of partial load factors and limit state design.

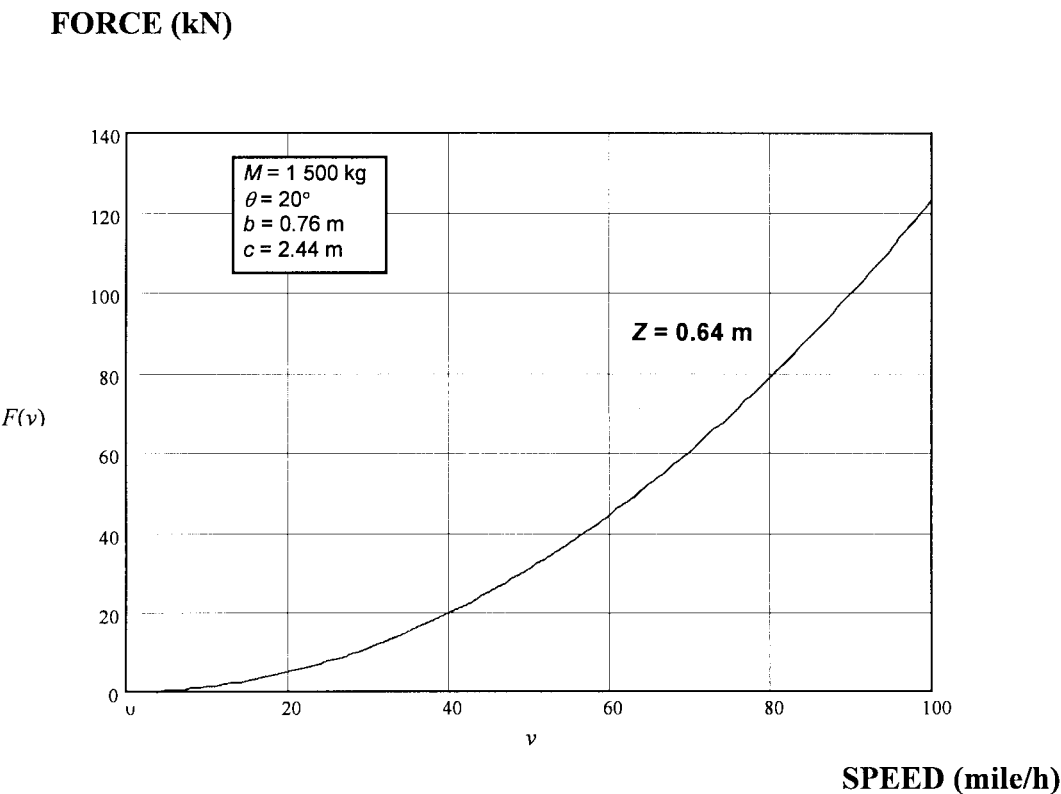


Figure 1 — Variation of impact force F with vehicle speed v

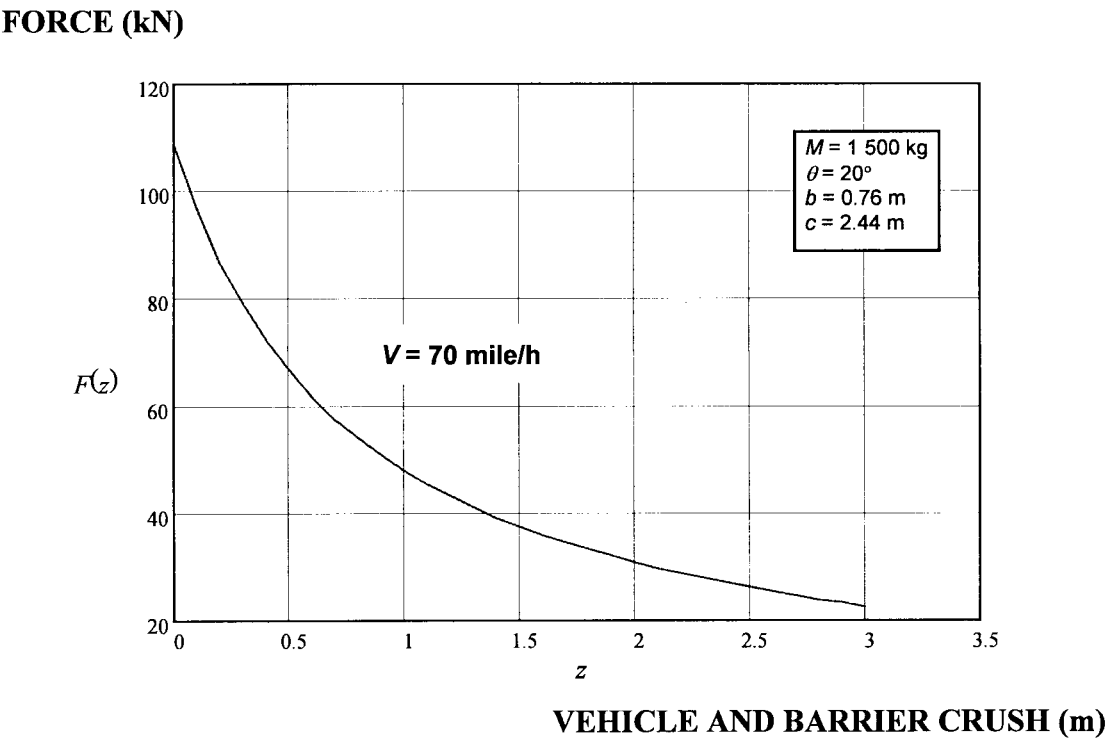


Figure 2 — Variation of lateral impact force F with vehicle and parapet crush distance z