Vehicle restraint systems —

Part 4: Development of bridge parapets in the United Kingdom

ICS 93.080.30

Committees responsible for this Published Document

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Association of Safety Fencing Contractors
British Cement Association
British In-situ Concrete Paving Association
British Precast Concrete Federation Ltd
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Institution of Civil Engineers
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Contents

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 kg	Speed km/h	Angle degrees	Height of centre of gravity 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,

$$F(v) = \frac{M(v\text{Sin }\theta)^2}{2\,000(c\text{Sin}\theta + b(\text{Cos}\theta - 1) + z)} \qquad (1)$$

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.

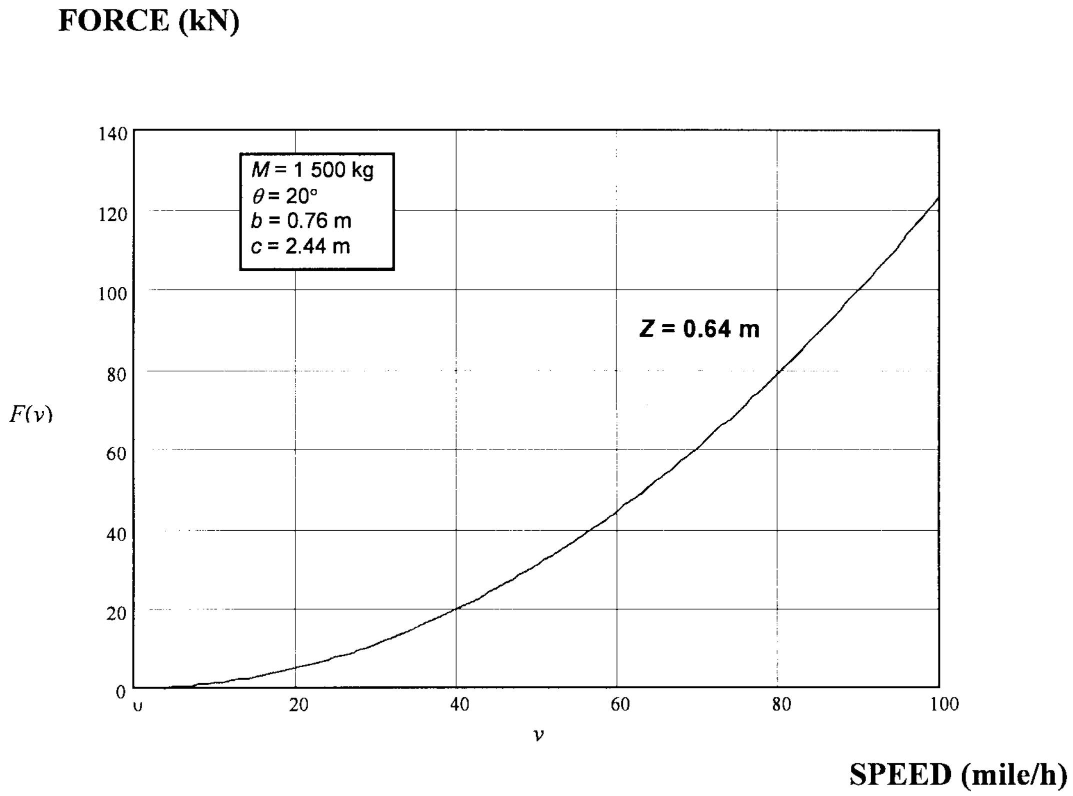

Figure 1 — Variation of impact force F with vehicle speed v

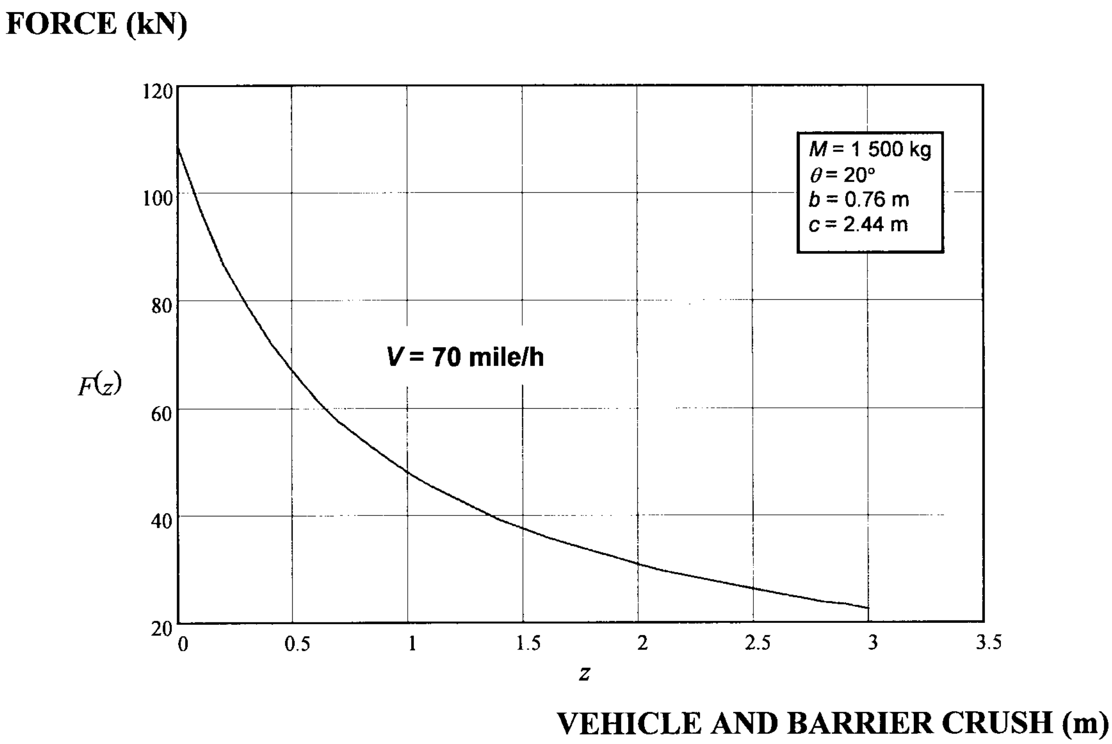

Figure 2 — Variation of lateral impact force F with vehicle and parapet crush distance z

3.3.2 ***Partial load factors***

Clearly a structure such as a bridge parapet must never experience complete collapse when in service. The safety margin allows for uncertainties including design inaccuracies, variations in material strengths, fabrication errors, foundation settlement, residual stresses and errors in the assumed loading. These uncertainties may never be quantified, but must be allowed for by global factors.

To overcome the uncertainties the concept of partial safety factors has been introduced. Factors are applied to the variety of probable loadings, by which the specified loads are multiplied, to arrive at an algebraically summated load, under which the structure is considered to be on the point of collapse at the level of the factored design load. So, there is no fixed value for an overall safety factor, since it will depend on the proportion of loadings from the several factored sources.

3.3.3 ***Limit state design***

The fundamental objectives of structural design are to provide a structure which is safe and serviceable in use and performs its intended function. Design procedures can produce an apparently satisfactory structure without necessarily predicting its exact behaviour under spontaneous stress. Design rules are not able to cover every situation which designers may encounter, and so judgement must be exercised in their interpretation and application.

By using limit state philosophy engineers have to consider two possible conditions of failure.

1) The serviceability limit state, when a structure suffers excessive deformation such as might be imposed by dead loads.

2) The ultimate limit state, when a structure has reached an unsafe condition for its intended purpose and catastrophic failure is about to take place.

Appropriate factors of safety need to be determined and in addition it should be appreciated that various parts of a structure are more sensitive than others to failure.

3.3.4 ***Bridge parapet factors of safety***

In accordance with the philosophies outlined in **3.3.2** and **3.3.3**, the anchorages, attachment systems and main bridge structure, including the plynth, must be designed to resist without damage all loads which the parapet is capable of transmitting, up to and including failure, in any mode that may be induced by vehicle impact. Removal and replacement of damaged parts should be readily achievable.

BS 6779-1, annex B, gives guidance on limit state design. The appropriate limit states for steel are given in BS 5400-3; and for aluminium alloys the reference document is BS 8118.

The design load Q^* should be determined from the nominal loads Q_k according to the relationship,

$$Q^* = \gamma_{fL} Q_k \quad (2)$$

where

γ_{fL} is the partial load factor (BS 6779-1).

The design load effects S^* can be obtained from the design loads Q^*, according to the relationship,

$$S^* = \gamma_{f3} Q^* \quad (3)$$

where

γ_{f3} is a factor that takes account of inaccurate assessments of effects of loading and unforeseen stress distributions in parapets.

The accurate determination of design load effects of vehicular impact by theoretical methods alone is not readily achievable and therefore dynamic testing is essential for parapet design. The value of γ_{f3} may be modified on the basis of these tests.

4 Development of metal bridge parapets

4.1 General

BS 6779-1 defines the requirements for the design of metal bridge parapets; it applies to both aluminium and steel fabrications. The key, full scale, impact tests that led to the drafting of BS 6779 and the subsequent endorsement of the document are highlighted in **4.2** and **4.3**.

4.2 Development of aluminium alloy parapets

In January 1967 the Ministry of Transport issued Technical Memorandum BE5 specifying design standards for highway bridge parapets. The memorandum was open to revision subject to further experience such as full scale impact testing.

The strength requirements for parapet posts and rails were given in terms of the products of the plastic moduli of their geometric sections and the minimum yield stresses of the materials used. For the posts, this was required to be not less than the moment induced by a specified transverse force, F, acting on any post according to the positions of the rails. The strength for the rails was required to be not less than $FL/6n$, where L is the post spacing and n is the number of rails.

Table 3 shows a list of tests (numbers 83 to 90) made during 1967 by TRL and the British Aluminium Company, on Membury Airfield, on a range of designs of aluminium alloy parapets. These included group P1 parapets for bridges carrying motorways, later designated as normal containment, and group P2 parapets for bridges carrying roads over motorways, later designated as low containment parapets. Impact conditions for P1 parapets were 113 km/h at 20° with a 1 500 kg car. For P2 parapets the impact speed was reduced to 80 km/h. Other conditions remained the same.

Table 3 — Vehicle impact tests on aluminium alloy parapets

Test No.	Date	Mass of vehicle kg	Speed km/h	Impact angle degrees	Parapet type	Height to top rail mm	Post spacing and cross-section mm	Intrusion length m	Maximum Deflection, m (side=0.3m)	PHD	THIV	Comment
83	12.9.67	1 360	74	20	BA (P2): low containment	900 2 rails	3 800 114 × 89	Breached	Breached	—	—	Infill dislodged
84	14.9.67	1 360	114	20	BA (P1): normal containment	900 3 rails	2 850 210 × 70 base	8.5	0.61	—	—	Two posts broke free
85	19.9.67	1 360	93.3	20	BA (P1): normal containment	900 3 rails	3 800 210 × 70 base	8.2	0.56	—	—	Successful Tapered posts
86	21.9.67	1 361	81.4	20	BA (P2): low containment	910 3 rails	3 800 114 × 89	9.1	1.14	—	—	High deflection
87	27.9.67	1 361	86.1	20	BA (P2): low containment	900 3 rails	3 800 210 × 70 base	6.9	0.61	—	—	Vehicle overturned Tapered posts
88	29.9.67	1 361	112.8	20	BA (P1): normal containment	900 3 rails	3 800 210 × 70 base	11.0	1.07	—	—	High deflection Tapered posts
89	18.10.67	5 140 Coach	72.9	20	BA (P1): normal containment	900 3 rails	2 850 210 × 70 base	21.0	1.60 front 2.39 rear			Parapet failed
90	26.10.67	1 361	111.0	23	BA (P1): normal containment	900 3 rails	2 850 steel 152 × 76 RSJ	6.9	0.1	—	—	Successful Steel posts
123	10.9.70	5 194 Coach	82.0	20	TRL (P1): frangible post	1 000 2-OBB[a]	3 660 210 × 70 base	27.0	1.60	—	—	Successful. Aluminium posts, steel rails
125	9.10.70	1 488	116.0	20	TRL (P1): frangible posts	1 000 2-OBB	3 660 210 × 70	11.0	0.15	—	—	Successful. Aluminium posts, steel rails
K0016	4.9.92	1 498	115.0	20	Alcan: (P1) Lindley: normal	1 000 3 rails	3 000 —	7.2	0.53	6.3	8.2	Passed BS 6779
K0916	28.10.92	1 503	113.8	20	Phoenix: (P1) Grundy: normal	965 3 rails	3 000 —	3.4	0.30	10.0	9.2	Passed BS 6779
K0019	4.12.92	1 495	112.2	20	Baco (P1): normal containment	945 3 rails	3 000 —	6.0	0.29	8.0	8.2	Passed BS 6779
L6006	13.4.93	1 499	79.6	20	Phoenix: low containment	1 002 3 rails	3 800 —	2.6	0.10	—	—	Passed BS 6779
L6012	20.10.93	1 495	114.7	20	Grundy: normal containment	990 3 rails	3 000 —	3.0	0.17	—	—	Passed BS 6779
M0049	7.9.94	1 495	115.9	20	Alcan: normal containment	1 000 3 rails	3 000 —	6.3	0.30	—	—	Passed BS 6779
M6032	21.7.94	1 499	113.9	20	Baco: normal containment	945 3 rails	3 000 —	6.1	0.50	—	—	Passed BS 6779
N0028	28.6.95	1 496	113.3	20	Lindley: normal containment	1 000 3 rails	3 000 —	7.1	0.44	—	—	Passed BS 6779

[a] OBB = open box beam.

At the time, Technical Memorandum BE5 was of an interim nature; the tests were made to establish the dynamic performance of the parapets in terms of vehicle containment and redirection and to determine an optimum post spacing consistent with post strength and overall parapet deflection (Jehu, Laker and Blamey:1967 [3]).

In six 1 500 kg car tests (numbers 83 to 88, Table 3), the posts within the impact zone fractured at their bases, so transferring loading to adjacent posts and, in consequence, reducing the severity of the impact.

For group P1 parapets it was found that with the post set at 2.85 m spacing and the static rail strength 1.6 times above the permitted Technical Memorandum BE5 minimum, the 3-rail parapet performed satisfactorily, although two posts were completely separated from the rails (test 84, Table 3). In later tests, the post to rail aluminium fixing bolts were replaced by stainless steel and proved acceptable.

Test 83 (Table 3) of a two horizontal rail, group P2, system with vertical infill bars, revealed deficiency in the design wherein the lower rail acted as a ramp to launch the vehicle upwards, whilst the vertical bars and their fixings were insufficient to transfer tensile loading between the two horizontal rails. This design was not pursued further for fabrication in aluminium alloy. The vertical infill was removed, a third rail added (test 86) and subsequently, stronger posts were used (test 87). Vehicle redirection was achieved with the vehicle exit path angles less than 9°, although the cars then veered across the road and one of which overturned.

A further test was made on the P1 parapet with a 5 t coach at 72.9 km/h (test 89); the parapet failed to contain the vehicle.

The concept of frangible aluminium posts that fractured in the impact zone to reduce impact severity was pursued in a later series of test (Jehu: 1972 [4]). Some details of this series are shown in Table 3 in test numbers 123 and 125. Steel open box beam (OBB) rails were mounted on frangible aluminium posts. A lower rubbing rail at a height of 0.61 m was added to prevent the car from contacting the stiff posts; the centre height to the top rail was 1.0 m.

The design was a natural development from tests run on the bridge railing manufactured by the British Aluminium Company. Tests at an impact angle of 20° with a 5 t coach at 82 km/h and with a 1 488 kg car at 116 k/h, were both successful. The impact loading transmitted to the bridge deck was no greater than that applied by the aluminium alloy group P1 parapet.

In April 1993 DTp issued document BD 52/93 [2] which superseded Technical Memorandum BE5. Included in BD 52/93 was the introduction of British Standard BS 6779-1, that dealt with the design of metal parapets. Several designs of group P1 and P2 parapets had been fabricated and installed by various manufacturers between the implementation of BE5 in 1967 and the introduction of BS 6779 in 1993. The groups P1 and P2 had been retitled under the headings of normal and low containments.

Table 3 lists some of the revalidation tests made between September 1992 and June 1995, on a range of proprietary aluminium bridge parapets, according to BS 6779 requirements.

In tests K0016, K0916, and K0019 acknowledgement was made to the European Standard EN 1317, whereby instrumentation was included in the tests to measure the impact severity criteria of theoretical head impact velocity (THIV) and post impact head deceleration (PHD) (see PD 6634-2:1999, **7.6**).

4.3 Development of steel parapets

4.3.1 *P1 (normal) and P2 (low) containment steel parapets*

Early development of steel bridge parapets began in 1962 by Stewart & Lloyds Ltd on Harringworth Aerodrome near Corby. A series of vehicle impact tests were made (see Table 4) on a horizontal 3-rail barrier system with alternative post spacings of 6 ft, 12 ft and 24 ft spans. Rail dimensions were 5 in × 2.125 in × 9g, RHS, and posts (two in number, welded together), were 5 in × 2.125 in × 7g, Grade 16, RHS. The design by Tubewrights of Liverpool, was for primary use on flyovers and bridges. Pre-war Morris cars, of 0.9 t in weight, were used as test vehicles, at a 45 mile/h impact speed, with an approach angle of 20°. The tests proved successful and it was noted that damage to the cars was most severe when impact was arranged to be near a post. A 2.6 t Fordson lorry test at 40 mile/h deflected the 24 ft span arrangement a distance of 1 ft; damage to the lorry was superficial. A 10 t lorry impacting at 90° and 20 mile/h demolished the parapet. At 15° and 22 mile/h the 10 t lorry was successfully redirected.

In 1975 BSC, sponsored by the Department of the Environment, successfully tested a P1 parapet fitted with a noise barrier. The 117 km/h, 1 500 kg car was redirected from a 20° impact, in a satisfactory manner. The noise barrier sheets remained attached to the parapet.

Stewart & Lloyds Ltd became incorporated into the British Steel Corporation and, in collaboration with Transport and Road Research Laboratory, there began in July 1968 a series of tests according to the requirements of Technical Memorandum BE5, on the development of P1 (normal containment) and P2 (low containment) bridge parapets (see Table 4).

Table 4 — Vehicle impact tests on steel parapets

Test No.	Date	Mass of vehicle kg	Mass of dummy kg	Speed km/h	Impact angle degrees	Barrier type	Height to top rail mm	Post spacing and cross-section mm	Intrusion length m	Maximum Deflection, m (side=0.3m)	PHD	THIV	Comment
Early P1 and P2 parapets to BE5													
93	8.7.68	1 550 Standard Ensign	—	60.2	20	P2 Vertical infill	1 000	3 000	5.5	0.41	—	—	Vehicle overturned Weld fractures
95	14.8.68	1 380 Morris Oxford	—	73.0	21.5	P2 Vertical infill	1 000	3 000	4.3	0.43	—	—	Vehicle overturned
102	19.6.99	1 490 Zephyr 4	—	98.9	19	P1 C&N hydraulic	1 000 full height	3 050	4.0	0.47	—	—	Successful at low speed
103	26.6.69	5 400 Coach	—	88.8	19	P1 C&N hydraulic	1 000 full height	3 050	8.5	0.7	—	—	Successful
104	3.7.69	1 470 Zephyr 4	—	111.0	18.5	P1 3-rail	1 000	3 660	4.1	0.52	—	—	Successful
105	17.7.69	1 470 Zephyr 4	—	82.6	19	P2 3-rail	1 000	3 660	4.0	0.34	—	—	Successful
108	17.6.69	4 920 Coach	—	92.8	17	P1 3-rail	1 000	3 660	10.5	1.1	—	—	Contained but vehicle overturned
P6 High containment parapet development													
D139	19.9.86	1 040 Talbot	75	112.0	20	P6 4-rail	1 500	2 000 203 × 03	4.0	Negligible	—	8.5	Successful
D140	1.10.86	1 000 Talbot	75	111.0	20	P6 4-rail +face panel	1 500	2 000 203 × 203	3.0	Negligible	—	10.5	Successful High THIV
D142	16.10.86	15 900 2-axle HCV	—	82.9	20	P6 4-rail	1 500	2 000 203 × 203	8.0	0.2	—	5.7	Successful
D144	6.11.86	30 700 4-axle HCV	—	66.6	20	P6 4-rail	1 500	2 000 203 × 203	10.0	0.2	—	5.4	Successful
D148	30.4.87	31 300 4-axle HCV	—	66.1	20	P6 4-rail + face panel	1 500	3 000 203 × 203	12.0	0.3	—	4.3	Successful Increased spacings
E173	17.2.88	32 100 4-axle HCV	—	65.3	20	P6 4-rail	1 500	3 000 203 × 203	13.5	0.4	—	3.6	Successful
P1 (low) and P2 (normal) containment (BS 6779)													
K0910	16.7.92	1 500 Rover	—	115.9	20	N. 3-rail BSC (P1)	1 000	3 660	6.0	0.41	13.0	7.9+	THIV at 0.25 m to be adjusted to 0.3 m
L0027	2.3.93	1 503 Rover	—	112.8	20	N. 3-rail BSC (P1)	1 000	3 660	5.5	0.25	12.4	8.4+	THIV at 0.25 m to be adjusted to 0.3 m
M0043	1.3.94	1 500 Rover	—	115.1	20	N. 3-rail V&G (P1)	1 000	3 660 100 × 100	3.2	0.42	10.4	7.6	Failed BS 6779 Post detached
M0052	13.10.94	1 498 Rover	—	114.6	20	N. 3-rail V&G (P1)	1 000	3 660 100 × 100	2.1	0.33	13.1	8.0	Passed BS 6779 Improved cleat
N0013	6.2.95	825 Fiesta	75	100.2	21	N. 3-rail V&G (P1)	1 000	3 660 100 × 100	2.5	0.6	15.9	9.5	Failed BS 6779 High:- Exit; THIV
N0029	27.9.95	1 499 Rover	—	81.4	20	Low (P2) Vertical Infill	100	3 660 90 × 90	4.4	0.05	2.6	7.6	Passed BS 6779 BSC parapet

Test 93 revealed a characteristic vehicle response from impact into a P2 containment level parapet, constructed from two horizontal rails with closely spaced vertical infill columns. The test vehicle struck the vertical infill at 60.2 km/h at 20°; as the impact load increased it was transmitted to the upper and lower rails which broke at the welded joints. The vehicle pushed a 1.7 m length of parapet about a post whose weld had fractured on three sides of the base. It then began to climb the parapet and after losing considerable forward speed it rolled away onto its side. This test was instrumental in restricting vertical infill parapets to 50 km/h (30 mile/h) speed zones.

In test 105, a 3-rail version of a P2 parapet fitted with anti-climbing mesh, was successfully tested at 82.6 km/h.

Test 104, where impact was directed at the rail to post connection, saw the successful development and testing of a P1, 3-rail parapet, at a speed and angle of 111.0 km/h, 20°, by a nominal 1 500 kg car (Blamey: 1972 [5]).

In Test 102, a parapet in which two horizontal rails were fixed to hinged posts restrained by hydraulic shock absorbers was subjected to impact by a 1 490 kg car at 20° and 98.9 km/h. The test was successful, although the impact speed was lower than the 113 km/h required for P1 parapets (Jehu and Taylor: 1972 [6]).

Impact with nominal 5 t coaches on containment level P1 parapets (test 103 and test 108) proved partly successful in that the vehicles were contained, but it was clear that higher containment parapets (P6) were necessary to withstand impact by public service vehicles and HCVs.

The work on the development of the P1 and P2 parapets, from a background of the Technical Memorandum BE5 requirements, led to the formulation of BS 6779-1. New and modified designs had evolved during this period and, accordingly, validation tests to BS 6779 were completed during the period between 1992 to 1995 (Table 4).

4.3.2 *A P6 (high) containment steel parapet*

Technical Memorandum BE5 (4th revision, 1982) advised that, group P6 high containment parapets should be constructed in reinforced concrete. Criteria for designs in other materials, such as metal and masonry, are not available at present.

In 1986 TRL, in association with DTp, commissioned civil engineering contractors, WS Atkins and Partners, to design a P6 steel parapet for installation at the Motor Industry Research Association proving ground, for full scale impact testing with vehicles of total mass up to 30 t (Laker: 1989 [7]). Figure 3 gives an outline sketch of the 4-rail high containment parapet installed at the proving ground, mounted on an elevated platform to represent a bridge deck.

Earlier tests with HCVs into high containment concrete bridge parapets showed that the parapet receives two dominant impact blows in approximately the same area. The first blow occurs on initial impact, the second is delivered by the rear of the vehicle as it yaws into the parapet; other subsidiary loading may occur as the vehicle makes contact between vehicle compressible components, such as the front bumper and the mudguards. It was considered possible that the first blow would cause such damage to the posts in the vicinity of the impact, that the second blow would need to be absorbed, by the rails alone in bending and tension.

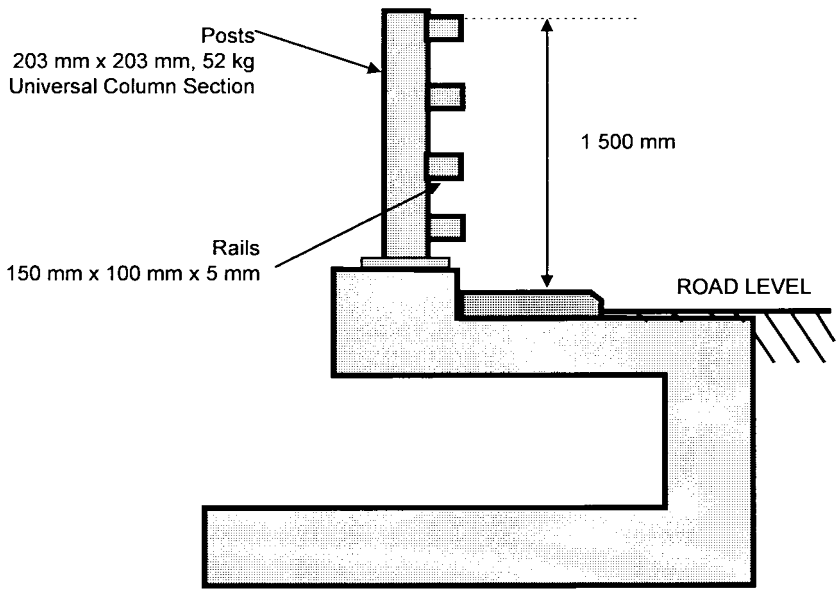

Figure 3 — High containment (P6) steel parapet arrangement for full scale impact tests — Parapet design concept

The use of frangible posts, which fracture at the base, was considered but there was an overriding problem in that the joints would not release under forces less than their design strength, and higher blows were liable to cause several posts to fracture and unzip the parapet. With these factors in mind, the frangible post concept was rejected in favour of a rigid design.

To protect the integrity of the bridge deck, the resistive moment of the post anchorages were designed to be 50 % higher than the ultimate bending resistance of the posts.

The design requirements for a high containment P6 parapet as given in Technical Memorandum BE5 are listed in Table 5; of singular interest to the design was that the maximum deflection should not exceed 0.8 m.

Table 5 — Design parameters for P6 parapet

Parapet parameters	Dimensions
Test length	30 m minimum
Parapet height	1.5 m
Number of rails	4
Plinth height	0.1 m
Cladding thickness	3 mm
Maximum deflection	0.8 m

The mean lateral force acting on a vehicle is given by equation (1) (see **3.2**). The equation predicts a force of 227 kN is necessary to redirect a 64 km/h HCV impacting at 20°, if the value of z is set at 0.8 m.

Alternatively, allowing for a margin of error within the design limits, a resistive force of 270 kN is generated for a given z value of 0.4 m.

Horizontal rails below a height of 0.3 m above the running surface are not regarded as load bearing members; their purpose is to protect a car's wheel from snagging on a post.

The lateral design load is assumed to be spread equally over the effective horizontal rails for the purposes of deriving the bending moment capacity of the posts. If only the top three rails are assumed to be effective then the derived bending moment of the posts is 25 % greater than that developed over four rails. A 203 mm × 203 mm, 60 kg universal column section (UCS) should support 310 kN over four rails, or 248 kN over three rails.

Static load tests showed the 60 kg UCS posts gave a 30 % higher value than the theoretical value; possibly this was due to section plastic deformation under high load. In recognition of this, a lighter post section, 203 mm × 203 mm, 52 kg, was selected. Its load capacity over four rails was 271 kN, and 217 kN over the top three rails. For an assumed similar excess of 30 %, the lateral capacities of the posts become 352 kN for over four rails, and 282 kN over three. At these values the 203 mm × 203 mm, 52 kg UCS posts are sufficiently strong to withstand the impact load of 270 kN derived from equation (1).

The post base plates anchored to the in situ concrete plinth with eight M30 bolts, were designed to transmit 1.5 times the capacity of the posts. This ensured impact damage was confined to the parapet and not to the bridge deck.

Given a deflection of 0.8 m, the top three rails are loaded to 76.6 kN per rail. Assuming two posts would be demolished, the tension in the rails, derived from a triangle of forces becomes 225 kN per rail with posts at 3 m centres. A 150 mm × 150 mm × 5 mm rectangular hollow section (RHS) met these requirements.

Tests D139 to D148 and E173 in Table 4 give details of impact tests at 20° with a nominal 1 000 kg car, 16 000 kg, 2-axle rigid HCV and a 30 000 kg, 4-axle rigid HCV. The car impact speeds were nominally 113 km/h; HCV speeds ranged from 65 km/h to 83 km/h. In tests D140 and D148, cladding 3 mm thick was riveted to the impact face of the parapet, to impede climbing and to prevent debris from falling below the bridge. All impact tests were successful in containing and redirecting the vehicles; although the severity of the car impact in test D140 was high, having a THIV value of 10.5 m/s.

This development work on the P6 steel bridge parapet led to the inclusion of the high containment level of parapet design given in BS 6779-1.

5 Development of concrete based bridge parapets

5.1 General

Technical Memorandum BE5 (1984) set down the strength requirements for reinforced concrete parapets constructed in situ or as precast sections. The cross-section could be either fully concrete or a concrete plinth capped by metal posts and rails. The plinth was considered as an effective longitudinal member, with respect to vehicle impact, provided its height was at least 700 mm above the adjoining road surface and that it could resist prescribed horizontal transverse forces.

Table 6 gives an abbreviated version of some of the early requirements called for in BE5. The prescribed strength parameters were fundamental to the early designs subjected to vehicle impact tests in the course of development of concrete parapets.

Full scale impact testing began at TRL in 1969 on parapets that had already been designed and installed on highways. As work progressed over the succeeding years the need became clear for some simplification of Technical Memorandum BE5 by reduction of the number of *groups* of parapets, from P1 through to P6, to a shorter range that comprised only of group P1 at the *normal level* category of containment, and group P6 at the *high level* of containment. At the *normal test level*, a candidate parapet needed to contain a 20°, 113 km/h impact by a 1 500 kg car; at the *high level*, the appropriate impact containment was with a 30 000 kg HCV at 64 km/h and 20° (see Table 1).

Table 6 — Early design requirements for concrete parapets in BE5 (later modified after full scale testing – see BS 6779)

Item	Design requirement	P1	P2	P6
(i)	Minimum ultimate moment of resistance at the base of the parapet: rebar at traffic face	25.0 kNm/m	12.5 kNm/m	125.0 kNm/m
(ii)	Minimum ultimate moment of resistance at the base of the parapet: rebar at outer face	12.5 kNm/m	6.25 kNm/m	62.5 kNm/m
(iii)	Minimum ultimate moment of resistance of anchorage at the base of precast panel	37.5 kNm/m	18.7 kNm/m	—
(iv)	Minimum ultimate transverse shear resistance at vertical joints	65.5 kN/m	2.5 kN/m	165 kN/m
(v)	Minimum ultimate horizontal transverse shear resistance	—	—	220 kN
(vi)	Minimum thickness of parapet	180 mm	150 mm	Top 250 mm Base 430 mm

The *low level* category of containment given in Table 2, used in the development of metal parapets where the impact speed was set at 80 km/h, was excluded; it was considered not to be relevant to parapets developed in reinforced concrete.

Further simplification was achieved by making a division between those types of parapet that were constructed completely of concrete, and those that were constructed in the form of a concrete plinth, topped by a metal post and rail system. Accordingly, these simplifications and divisions led to the drafting of BS 6779-2 and BS 6779-3. The design parameters listed in these two documents eventually replaced those given above in Table 6.

The construction and testing of normal containment (P1) and high containment (P6) concrete parapets, and the work that led to the publication of BS 6779-2 and -3, is considered in **5.2** to **5.4** from the time full scale impact tests were introduced in 1969. The range of development tests included complete concrete and combined parapets built in situ on site, together with those formed at the fabricator's depot in precast lengths suitable for transportation and fixing to a bridge deck.

5.2 Development of combined metal and concrete parapets

5.2.1 *Combined normal containment (P1) parapets*

A bridge parapet, designed by G. Maunsell and Partners to Technical Memorandum BE5 P1 requirements, was installed on an elevated section of the M40, London in the late 1960s. During the construction the opportunity arose to install a length of the same parapet at TRL for test purposes (Jehu and Laker: 1972 [8]). Figure 4 shows a cross-section of the combined concrete parapet with a plinth height of 0.87 m capped by a steel rail giving an overall height above the level of the road surface at 1.33 m. The impact face of the parapet is plain and nominally vertical.

In test number 111 (Table 7) the parapet was struck by a 1 485 kg saloon car at 111 km/h and 19°. During impact the car remained stable; there was no appreciable roll although there was a tendency for the rear axle to lift and the bonnet to dip. The deceleration transverse to the line of the parapet was recorded at 8.3*g*; the car was redirected on an exit path of 4.5°.

In test number 101 the impact face of the parapet was fitted with a 0.46 m deep energy absorber constructed from open box beam safety barrier section, mounted on hexagonal energy absorbing brackets (Jehu and Laker: 1972 [8]).

The transverse deceleration was 5.9*g*. The maximum permanent deflection of any bracket was a compression of 170 mm from its original depth of 300 mm. The introduction of an energy absorber on the front face reduced the transverse impact force by about 30 %.

The precast parapet shown in Figure 5, in use on the Midlands Link motorway viaduct, was designed before the publication of Technical Memorandum BE5. Test number B111 (Table 7) subjected it to impact according to group P1 standard by impact with a 1 502 kg car. Sixteen units, each 1.82 m long were removed from the Wigmore viaduct on the M6 and mounted on a newly constructed slab detailed to simulate as closely as possible to the actual bridge deck cantilever of the viaduct construction (Laker: 1988 [9]).

The car was contained by the parapet and redirected in a well controlled manner and left the parapet at an exit angle of about 9°. The M5-M6 parapet had met the full scale tests requirements of BE5.

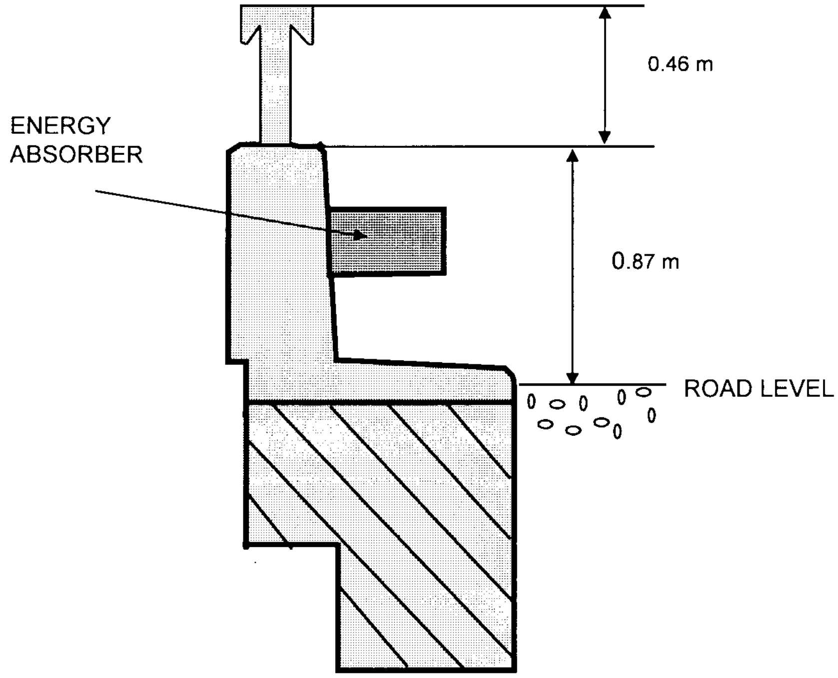

Figure 4 — Combined concrete parapet cross-section M40, London (based on BE5 in situ group P1)

A series of tests on shaped concrete barriers (Jehu and Pearson: 1976 [10]) had shown that, not withstanding a number of design changes to the cross-sectional sloped profiles, small cars at speed tended to ride up the face of the parapets and overturn with disastrous consequences. In consequence, the opportunity was taken, in test number B114, to impact the vertical face of the Midland Link parapet with a small 596 kg car at a speed of 112.6 km/h. Although the THIV value was high, at 9.8 m/s, the vehicle was successfully redirected without rollover. Further reporting is given in PD 6634-3:1998, **4.3** which describes how this small car test led to the development of the vertical face concrete barrier (VCB) which has now been introduced for use on high speed roads.

In a high energy impact to observe the possible containment limits of the M5-M6 parapet, test number B115 subjected the structure to impact by a nominal 16 t HCV at a speed of 81.9 km/h. The HCV was redirected but rolled onto its side during the final stages of the impact. The precast parapet sustained fractures in several places; two units required replacement although there was no breach of the parapet that required instant repairs to be set in place. The HCV test had demonstrated that the Midlands Link parapet was capable of withstanding an impact of energy level more than five times that generated in a P1 impact.

5.2.2 ***Combined high containment (P6) parapets***

The Transport and Road Research Laboratory in collaboration with DTp, contracted Scott Wilson and Kirkpatrick to design and construct a high containment combined metal and concrete parapet to conform with the requirements of Technical Memorandum BE5. The test parapet, 31.5 m in length, consisted of 15 precast reinforced concrete units (see Figure 6).

The capping rails, at an overall height of 1.5 m above the running surface, were constructed in aluminium and in steel. Separate full scale impact tests were made to examine the adequacy of each material for use in construction of high containment parapets.

Technical Memorandum BE5 stipulates that a high containment parapet must contain collision by a nominal 30 t HCV impact at a speed of 64 km/h and 20°.

In addition, in this series of tests, the parapet was subjected to impact by a 1 500 kg car to examine the response trajectory from a 113 km/h contact speed (G207, Table 7). The test met with the requirements of Technical Memorandum BE5 and it also fell within the requirements of BS 6779-1 with regard to limitations on the magnitude of the exit path angle. The impact was severe and a THIV value of 8.9 m/s was recorded; the limit set in EN 1317 for a small car is 9 m/s. The metal tubular rail was constructed in steel, but the vehicle made no contact during the impact and so a repeat test with an aluminium rail was unnecessary.

Table 7 — Vehicle impact tests on concrete parapets

Test No.	Date	Mass of vehicle kg	Mass of dummy kg	Speed km/h	Impact angle degrees	Barrier type and foundation	Barrier details	Height and section length mm	Contact length m	Maximum deflection, m PHD THIV (side=0.3m)	Comment
P1 Normal containment: In situ, combined with metal rail, Maunsel parapet, M40											
101	5.6.69	1 485 Zephyr	—	111.6	20	P1. Maunsel In situ	With energy brackets + rail	Lower 600 Top 1 330	4.0	0.3 — —	Met BE5. Lateral deceleration = 5.9 *g*
111	30.10.69	1 485 Zephyr	—	111.3	19	P1 Maunsel In situ	Vertical face, continuous	Base 870 Top 1 330	3.5	Nil — —	Met BE5. Lateral deceleration = 8.3 *g*
P1 Normal containment: Pre-cast, combined with metal rail, Midlands link parapet, M5-M6											
B111	28.2.85	1 502 Chrysler	—	114.7	20	P1 Midlands Link Precast	Vertical face unit length 1.8 m	Base 800 Top 1 140	5.0	Nil — —	Met BE5
B114	21.5.85	596 Mini	75	112.6	20	P1 Midlands Link Precast	Vertical face unit length 1.8 m	Base 800 Top 1 140	4.5	Nil — 9.8	Successful
B115	23.5.85	16 270 HCV	—	81.9	20	P1 Midlands Link Precast	Vertical face unit length 1.8 m	Base 800 Top 1 140	15.0	0.15 — 4.6	Contained but HCV overturned
P6 High containment: Cast in situ, no rail, designed to 1.75 times BE5 strength											
C118	22.8.85	610 Mini	75	112.0	20	P6 HC In situ	Sloped face Metal dowels	1 500 3 000	3.0	Nil — —	Violent. Overturned but contained
C119	3.9.85	16 300 HCV 2-axle rigid	—	77.9	20	P6 HC In situ	Sloped face Metal dowels	1 500 3 000	7.0	Nil — 4.4	Violent. Overturned but contained
C121	20.9.85	30 130 HCV 4-axle rigid	—	65.2	20	P6 HC In situ	Sloped face Metal dowels	1 500 3 000	8.0	Nil — 3.4	Successful
C124	10.12.85	30 650 HCV	—	86.2	20	P6 HC In situ	Sloped face Metal dowels	1 500 3 000	8.0	Nil — 4.3	Vehicle overturned but contained
P6 High containment: Precast, no rail, designed to BE5 strength											
E183	5.6.88	31 600 HCV 4-axle rigid	—	65.5	20	P6 HC Bolted to base	Vertical face Shear transfer	1 500 3 000	11.0	30.6 — 4.0	Met BE5
E185	22.6.88	31 300 HCV 4-axle rigid	—	65.5	20	P6 HC Bolted to base	Vertical face No shear panel	1 500 3 000	10.5	30 — 4.2	Met BE5
E186	14.7.88	31 600 HCV 4-axle rigid	—	65.5	20	P6 HC Bolted to base	Vertical face Shear transfer	1 500 2 100	8.0	21 — 4.8	Met BE5 Brick clad rear
E187	28.7.88	30 700 HCV 4-axle rigid	—	66.6	20	P6 HC Bolted to base	Vertical face No shear panel	1 500 2 100	10.5	31 — 4.3	Met BE5 Brick clad rear
J0011	20.11.91	29 960 HCV 4-axle rigid	—	64.7	20	P6 HC Bolted to base	Vertical face	1 500 3 000	11.0	15 — 5.7	
P6 High containment: Precast, combined with metal rail, designed to BE5 strength											
G207	15.8.89	1 454 Rover	75	115.0	19	P6 HC Bolted to base	Vertical face Shear transfer	Base 900 Top 1 500 2 100	4.0	Nil — 8.9	Met BE5 Tubular steel rail
G208	22.9.89	30 068 HCV 4-axle rigid	—	64.4	20	P6 HC Bolted to base	Vertical face Shear transfer	Base 900 Top 1 500 2 100	12.0	Nil — 2.7	Met BE5 Tubular steel rail
G209	4.10.89	30 700 HCV	—	65.3	20	P6 HC Bolted to base	Vertical face Shear transfer	Base 900 Top 1 500 2 100	12.0	50 — 4.2	Met BE5 Tubular aluminium rail

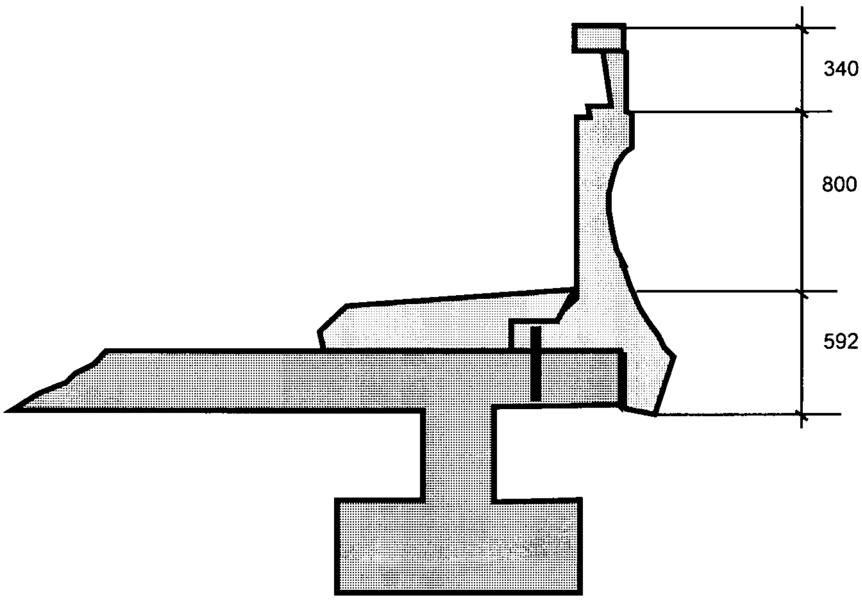

Figure 5 — Combined concrete parapet cross-section M5-M6 Midlands Link (precast construction)

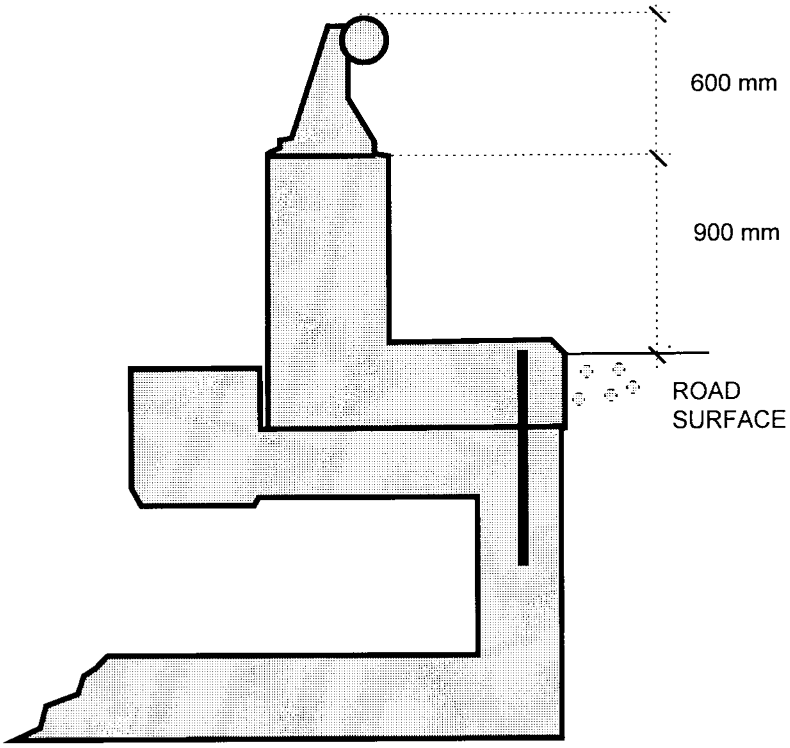

Figure 6 — Combined concrete parapet cross-section: high containment (P6) precast construction

In test G208 (Table 7), the high containment parapet with a steel rail was subjected to impact by a nominal 30 t HCV at 64.4 km/h. The tanker was contained and redirected in a stable manner; the test met Technical Memorandum BE5 requirements and complied with exit path criteria set out in BS 6779-1. The first axle of the 4-axle rigid chassis HCV became detached from its suspension and was pushed backwards under the second axle.

There was minimal deflection of the parapet during the impact. A section of concrete about 400 mm by 60 mm broke away from one of the precast units. Contact was made between the steel rail and the vehicle over a length of about 12 m. Repairs to the parapet included two units and 3 m of steel tubular rail.

Test G208 was repeated in test G209 with the steel rail replace by one constructed in aluminium. In an impact by a nominal 30 t 4-axle rigid chassis HCV, the tanker was contained and redirected in a stable manner from an approach speed of 65.3 km/h. Requirements of Technical Memorandum BE5 and BS 6779-1 were met.

Repairs to the parapet to bring it back into serviceable condition included two precast units, three aluminium posts and about 12 m of aluminium tubular bar.

The extent of the damage to the HCV was similar to that experienced in test G208 with the fitted steel rail. The front axle on the left hand side was pushed back a distance of about 1 m.

In summary, the series of private vehicle and HCV tests on the combined high containment combined metal and concrete parapets, fitted with steel or aluminium rails, had met the required conditions set out in Technical Memorandum BE5, and also had met the exit path requirements given in BS 6779-1 and EN 1317-2.

5.3 Development of concrete parapets

5.3.1 *An in situ high containment (P6) concrete parapet with a standard cross-section profile*

WS Atkins and Partners were commissioned by TRL in collaboration with DTp, to design and build, for test purposes, a reinforced in situ high containment (P6) bridge parapet, built on site to meet the design requirements given in Technical Memorandum BE5. The parapet would then be subjected to impact testing with vehicles ranging from a small car to a 30 t HCV. The purpose of the work was to validate the design parameters given in Technical Memorandum BE5 or to amend them as appropriate.

Technical Memorandum BE5 specifies the parapet capacity in terms of ultimate moments and shear forces per metre run; the distribution of the impact load is not considered.

The length of the parapet panels was not specified and so it appears that adequate containment can be achieved by considering specified moments and shears only. However, the length of a panel is of consequence when there is little load transfer across a vertical joint. The longer the panel, the greater the possible spread of impact load from the area of impact to the base of the parapet. In consequence, increased levels of containment could be achieved for longer lengths of panel, given the specified ultimate capacities listed in Technical Memorandum BE5. The values given in BE5 originated from an earlier report (Mander, Raikes and Marshall; November 1978 [11]) where an investigation, using grillage analysis, was made on panels of 1.5 m length.

The value for the design impact load was derived from the equation (1) (see **3.2**), based on a 30 t tanker impact at 64 km/h and 20°. A design load of 330 kN was derived, which is equivalent to a transverse deceleration of 1.1 *g*. Evidence from deceleration measurements in full scale impacts had revealed that peak impact forces could be as much as four times the average value; it should be recalled that equation (1) generates a value that approximates to the average. Consequently, the peak impact forces could be significantly in excess of a design based on equation (1).

Because of this range of uncertainties associated with dynamic impact testing and the need to obtain measured information from the test, it was decided to build the parapet of strength 1.75 times that required of Technical Memorandum BE5. Recording instrumentation was attached to the vehicles and the parapet to aid in the assessment of the design limits of the parapet if it remained intact after collision by a 30 t vehicle; complete collapse of an under-designed parapet would reveal little useful predictive information.

Figure 7 gives a cross-section of the shaped profile high containment P6 concrete bridge parapet set up for impact testing at the Motor Industry Research Association (MIRA) proving ground. Panel lengths were set at 3.0 m.

The knowledge that shaped profiles encouraged vehicles to ride up the impact face and overturn at high speeds emphasized the need to examine vehicle trajectory in test number C118, Table 7. There was no likelihood that the small vehicle would not be contained, but during contact, the vehicle rode up the face of the parapet and violently overturned before coming to rest.

In test number C119, a nominal 16 t HCV at 80 km/h, loaded with concrete blocks, was redirected and then rolled onto its side after extensive torsional deflection of the chassis induced by the lateral forces on the concrete blocks.

Stress in the parapet metal reinforcement bars approached the yield strength of the steel. Load transfer between panel joints was negligible. One panel needed in situ repair.

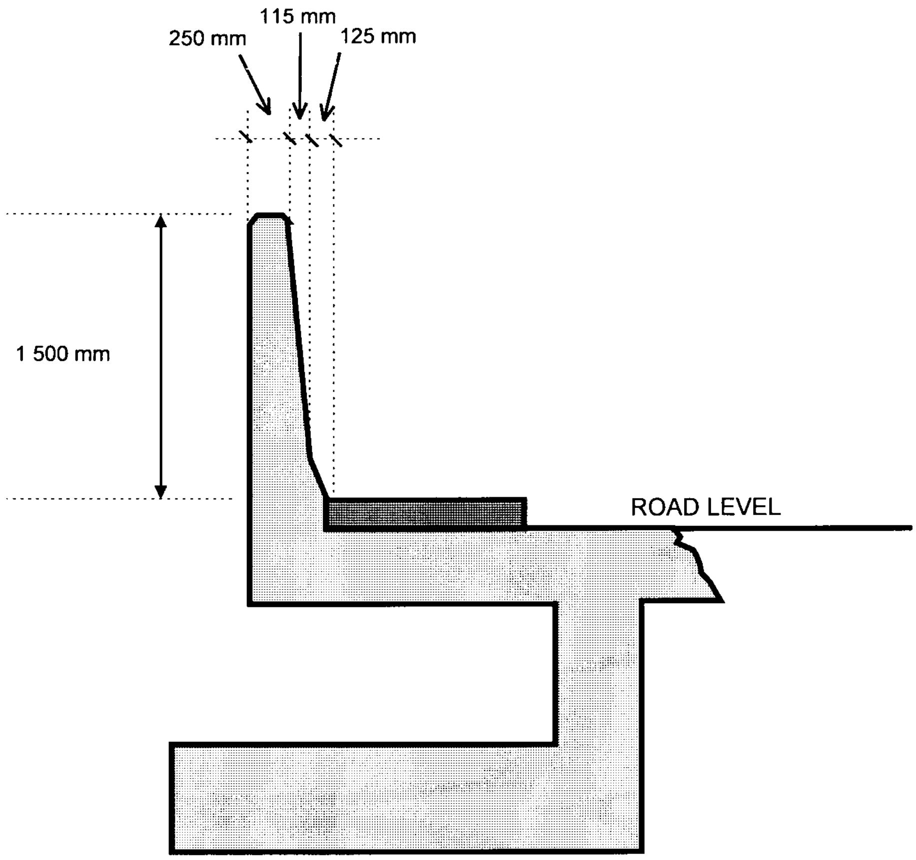

Figure 7 — Shaped concrete parapet cross-section: high containment (P6) in situ construction

Test number C121 at 65 km/h with a 30 t rigid, 4-axle HCV proved successful. Stress measurements of the metal reinforcement bars recorded a maximum value at 50 % of the specified yield characteristic of 460 N/mm^2. The parapet received only superficial damage from the impact. Very little load transfer was recorded between panels.

In the final test, C124, the impact speed of a 30 t HCV was increased to 86.2 km/h in an attempt to discover the ultimate strength of the parapet; the speed change is equivalent to an increase of 42 % in the impact energy compared with test C121.

The 30 t HCV impact was contained but the tanker rolled onto its side; it was airborne for about 10 m before pitching heavily on its front left hand corner. The second impact on the parapet by the rear of the vehicle, caused by rapid horizontal rotation from the primary impact to the front, was considerably more violent; the maximum recorded difference was about 5 times the first impact. The stress in the reinforcement was close to the yield stress although no repairs were required to the parapet. Little load transfer was recorded between the 3 m long panels.

The series of impact tests on the high containment P6 concrete in situ parapet confirmed that the design requirements set out in Technical Memorandum BE5 were broadly adequate for the containment of a 64 km/h impact by a 30 t, 4-axle rigid HCV at 20°. However, there were modifications required which included the following.

— The shaped cross-sectional profile was suitable for the response characteristics of a 30 t impact at 64 km/h. However, impact at 112 km/h by a small car with the shaped profile resulted in the vehicle violently overturning. Consequently Technical Memorandum BE5 should be amended to recommend a near vertical profile only should be used in concrete cross-sectional profiles; 5° from vertical would be acceptable.

— Although the tested parapet was designed to 1.75 times the strength requirements of Technical Memorandum BE5, it was predicted that a parapet designed to basic strength would have withstood impact by a 30 t HVC tanker at 64 km/h. Nevertheless, a 16 t HVC flat bed has different shaped characteristics from the tanker and it is possible that the 86 km/h test impact could have caused failure of the parapet had it been designed down to Technical Memorandum BE5 standards.

— The bending moment capacity should increase linearly from zero at the top of the parapet over its total height. For P6 containment the moment at a point H m from the top wall should be:

95H kNm/m for panels 3 m longer or greater;

95$H \times 3$ kNm/m for panels less than 3 m long.

— The shear capacity of 220 kN/m per metre run, given in Technical Memorandum BE5, is correct for the base of the wall. There was insufficient information to make further firm conclusions, however, for the 30 t tanker impact it was possible this could be reduced to 110 kN/m at the top of the wall; further testing would be needed to confirm this.

— Load transfer through metal dowels inserted vertically between parapet panels transferred little load between panels as measured by instrumentation in the base. It appears that dowels add little impact strength to the in situ parapet and could be left out of the design.

— Parapet height should remain at 1.5 m. Any reduction in height might cause the 30 t tanker to overtop the parapet.

— Forces to be considered in designing the bridge bearings and substructure should be based on the following nominal loads.

Transverse load:	Total shear applied to one 3 m panel = 660 kN.
Longitudinal load:	145 kN.
Vertical load:	175 kN. (Additional to the nominal live load given in BS 5400-2.)

5.3.2 ***A precast high containment (P6) concrete parapet with a near vertical cross-section profile***

Mander, Raikes and Marshall were commissioned in 1988 by TRL, in collaboration with DTp, to design and construct a P6 high containment precast bridge parapet for impact testing.

The purpose of the test programme was as follows:

— to verify the adequacy of the precast reinforced concrete parapet design requirements specified in Technical Memorandum BE5;

— to verify the precast reinforced parapet design requirements specified in draft BS 6779-2.

The following parameters were investigated:

— the effect of concrete panel lengths on overall performance of the parapet;

— the benefit of providing shear transfer keys between adjacent precast panel units;

— to assess the loads on the supporting structure;

— to examine the integrity under impact conditions of cladding the rear face with brick facing.

The candidate parapet installed at the MIRA proving ground for test purposes comprised 12 precast units making a total length of 30.6 m; six units were 3 m in length and six were 2.1 m. The height of the traffic face of the parapet above road level was 1.5 m (Figure 8).

The 2.1 m units were designed for a 330 kN load applied transversely at the top of the wall; the critical section for bending occurred at the base. On the basis of selection of the reinforcing bars at 20 mm, placed at 150 mm centres, the moment of resistance was 1.04 times that required.

The Technical Memorandum BE5 shear force requirement of 220 kN per metre run was just met at the 380 mm thick base of the wall; the shear force capacity at the top was 135 kN per metre run.

In the 3.0 m long units the same level of reinforcement per metre length of unit was retained as for the 2.1 m units. This gave a moment of resistance 1.48 times that required by Technical Memorandum BE5. It was possible that the 20 mm diameter bars could be reduced to 16 mm.

For test purposes, it was desirable to provide excess capacity to limit strain measurements to take place within the linear region; it also reduced the risk of catastrophic failure from which little useful information could have been gleaned.

The five configurations of parapets, listed below, were subjected to impact test by 30 t HCV, 4-axle, rigid chassis tankers at a nominal speed of 113 km/h at an angle of 20° (Table 7).

Test E183	3.0 m units with shear transfer.
Test E185	3.0 m units without shear transfer.
Test E186	2.1 m units with shear transfer; brick cladding on rear face.
Test E187	2.1 m units without shear transfer; brick cladding on rear face.
Test J0011	3.0 m units.

Summary results are as follows.

— All five tests were successful in meeting the impact performance requirements of Technical Memorandum BE5 and the exit path requirements of BS 6779-1. In all cases the vehicle was contained and redirected with damage level to the parapet repairable.

— The near vertical profile successfully redirected the 30 t tankers, from an impact speed of 64 km/h at 20°, in a stable manner.

— Technical Memorandum BE5 requirements are adequate for precast units where shear transfer is provided. The measured design force of 330 kN for 3 m units is about 68 % of that provided in the parapet construction of test E183 (330 kN × 1.48 = 488 kN). For 2.1 m units the design force of 250 kN is 73 % of that provided in test E186 (330 kN × 1.04 = 342 kN).

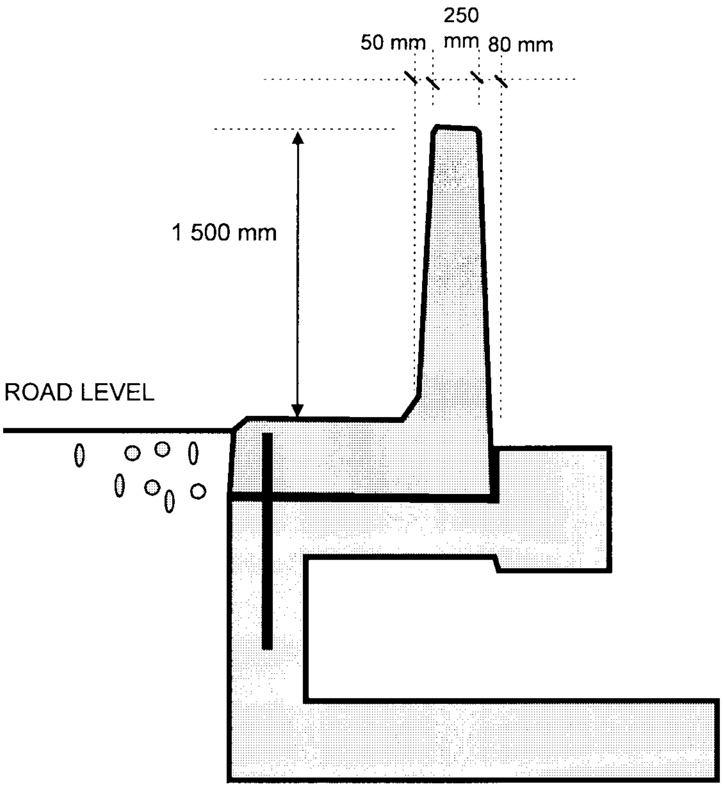

Figure 8 — Near vertical concrete parapet cross-section: high containment (P6) precast construction

— For units without shear transfer, the measured design force of 450 kN for 3 m panels is about 92 % of that observed in test E185 (488 kN). For 2.1 m panels the design force of 330 kN is about 96 % of that recorded in test E187 (342 kN).

— The retention of 220 kN shear force per metre run should be retained to resist localized high shear forces.

— For units where shear transfer is in place by stainless steel plates, there is no margin for reduction in the thickness of the parapet if the design strength of the shear joints is to be retained.

— With regard to the bridge structure, the results suggest the transverse load requirement at the top of the structure should be 660 kN.

— The brick cladding attached to the rear face of the parapet, in tests 186 and 187, remained in place. However, whilst the brick cladding secured by a proprietary facing system was not detached there was evidence that a slightly more severe blow could not be sustained by attached cladding and such construction is not permitted by BS 6779.

Closing remarks

As a result of the series of vehicle impact tests on high containment precast P6 concrete parapets, amendments to Technical Memorandum BE5 were recommended. However, the publication of these amendments was overtaken by their inclusion in a draft of BS 6779-2. Reference should be made to this document for full details of design.

It is of interest to note that partial load factors were introduced in the draft as follows.

Partial load factor γ_{fl} [equation (2)]was introduced to take account of uncertainties in the nominal load value as follows.

— There was only one vehicle test per parapet.

— Load values were derived from a limited number of strain gauge positions. Peak strains might not have been recorded.

— The amount of information on load transfer between panels is not substantial.

— Static loading tests were made on only one 3 m panel.

Factor γ_{f3} [equation (3)]was introduced to take account of inaccurate assessment of the effects of loading, unforeseen stress distribution in the structure and variations in dimensional accuracy during practical construction of the bridge parapet precast units.

6 Masonry parapets — Brick sandwich reinforced concrete parapets

In 1992, British Rail (BR) designed a high containment (P6) brick sandwich reinforced concrete parapet to meet the requirements of BS 6779-2. In collaboration with TRL, the parapet was built and then impact tested at the MIRA proving ground, by a 30 t, 4-axle, tanker at a speed of 64 km/h and approach angle of 20°.

The purpose of the test was to assess the performance of a brickwork sandwich parapet when subjected to the loading generated by vehicle impact under high level containment conditions. BS 6779-2, at the time, did not allow for the construction of the brick sandwich type parapet favoured by BR for compatibility with many of its structures. It was essential to determine that masonry facework structurally bonded and designed to act compositely with the reinforced concrete core would not become detached and become a hazard to passing trains. The British Standard could then be updated accordingly.

The parapet, shown diagrammatically in Figure 9, consists of a reinforced concrete core to which a brick masonry face is structurally bonded so that full composite action is developed. To monitor the stresses and strains in the wall, TRL fixed gauges to the steel bars, over the length of parapet within the impact zone. In addition, the Ceramic Research Association (CERAM) installed instrumentation to record the wall deflection and compressive stress in the outer face.

The 64 km/h, 30 t, test vehicle was successfully contained and redirected after impact with the parapet.

Several conclusions and recommendations were drawn from analysis of the parapet instrumentation. (See R. O'Rourke: 1993 [12] and BR 185-2-18 [13].)

— The parapet had adequate design strength.

— Negligible residual strain remained after impact, which implies the wall deflection was within the elastic range only.

— The wall was over reinforced; the ultimate moment of resistance of the brickwork was greater than the applied moment created by the impact, and was less than the corresponding steel moment of resistance.

— The neutral axis was within the outer brickwork; which therefore sustained all the compressive loading.

— Minimal damage was caused to the brickwork by the impact.

— The brickwork was found to be structurally significant; it experienced quite high stresses. If weaker material were used, the thickness of the concrete core would need to be increased.

— Parapets constructed of sandwich brick facing should be under reinforced to prevent explosive brickwork failure.

— The specification to which the wall was designed and tested is a reasonable basis on which to draft clauses for the British Standard on masonry faced reinforced concrete composite construction.

7 Timber parapets

Devon County Council (DCC), in 1991, commissioned Sarum Hardwood Structures Limited (SHS) to design, carry out structural analysis and construct a wooden bridge parapet based on drawings supplied by DCC.

The parapet (as shown in Figure 10) was constructed from the hardwood *Ekki lophira*, *Alata azobe*. TRADA Technology Ltd were engaged to make hardwood stress grading measurements including laboratory mechanical property tests. All of the tests gave properties that were in accordance with the published data for the species, after minor and normal variations in wood density were taken into account.

The parapet was erected for test purposes at the MIRA proving ground and subjected to vehicle impact according to the requirements set in BS 6779-1 for low containment parapets (P2). Impact conditions under this criteria are 80 km/h at 20° with a 1 500 kg car.

The test on 2 April 1992 was successful and the parapet satisfied BS-6779.

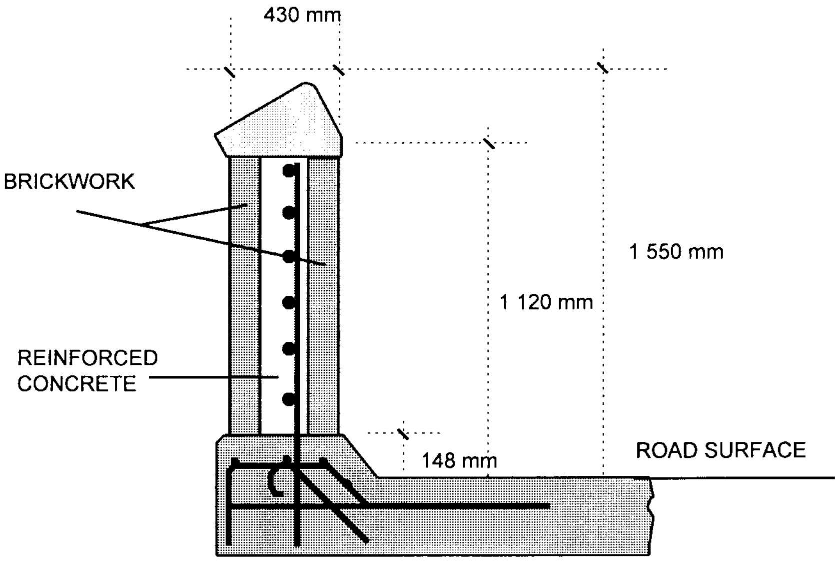

Figure 9 — Brick sandwich reinforced concrete parapet

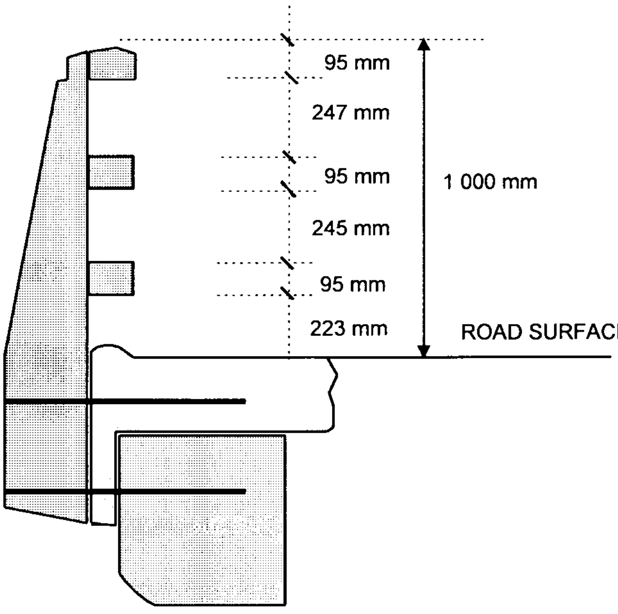

Figure 10 — Timber parapet prepared for Devon County Council

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