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Vehicle restraint systems —

Part 3: Development of vehicle highway barriers in the United Kingdom

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Committees responsible for this Published Document

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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 — Database;
- — Part 2: Fundamentals of highway restraint systems;
- — Part 4: Development of bridge parapets 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 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 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 36, an inside back cover and a back cover.

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Introduction

In general, the safety barriers developed in the UK can be separated into those types constructed on discrete footings, referred to as post and rail barriers, and those mounted on a continuous footing, which are mostly manufactured from concrete, although barriers constructed of soil and other materials have been employed. Post and rail barriers are usually manufactured in steel, but wood, concrete and plastics materials have been used.

A further subdivision of safety barriers is made with respect to their containment qualities, or impact performance, against vehicles of various weights, speeds and approach angles. The containment classes referred to in the European Standard EN 1317-2 are listed as low, normal, higher and very high containment levels, irrespective of their manner of construction.

This part of PD 6634 deals with the development in the UK of both post and rail barriers, and barriers of continuous footing, over the range from low to very high containment levels.

Bridge parapets are discussed in Part 4 of this standard.

1 Scope

This part of PD 6634 describes the development of vehicle highway safety barriers in the United Kingdom. The term "safety barrier" includes those barriers installed on highways using discrete post footings (post and rail types) as well as those on continuous ground footings (concrete or soil). Barrier designs are described for the containment of vehicles ranging in mass from about 825 kg to 38 000 kg. Controlled tests are described for private car impacts at speeds up to 110 km/h (70 mile/h) and commercial vehicle impacts at speeds up to 80 km/h (50 mile/h).

2 Post and rail barriers

2.1 Post strength

The concepts of weak post and strong post highway safety barriers are discussed in PD 6634-2, **6.2**.

The leading wheels or bodywork of vehicles impacting weak post barriers are expected to make direct contact with the barrier posts. The design strength of the post is such that they collapse on impact in the longitudinal direction of the barrier; wheel snagging is avoided and so the unstable condition of vehicle spinout is unlikely to occur.

With strong post barriers, vehicle contact with the posts is prevented by mounting the beams, or horizontal rails, on a blocking-out piece fixed between the posts and rails. If mounted in soil, the posts tend to rotate at a rotational centre below ground level. Strong posts mounted in non-yielding footings, on impact, are designed to bend at ground level in a direction normal to the line of the barrier.

2.2 Elastic and plastic deformation

Figures 1 and 2 represent the stress loading across the section of a rectangular metal bar undergoing bending about its neutral axis.

The bar is assumed to be rectangular, of width W, and depth H; it experiences its maximum stress, in compression and tension, at distances ± $h/2$ from the neutral axis. Figure 1 shows that under elastic loading the stress in the bar varies across its depth. In Figure 2 elastic loading is not considered, the beam experiences loading in the plastic region only, as indicated by the horizontal lines representing tension and compression.

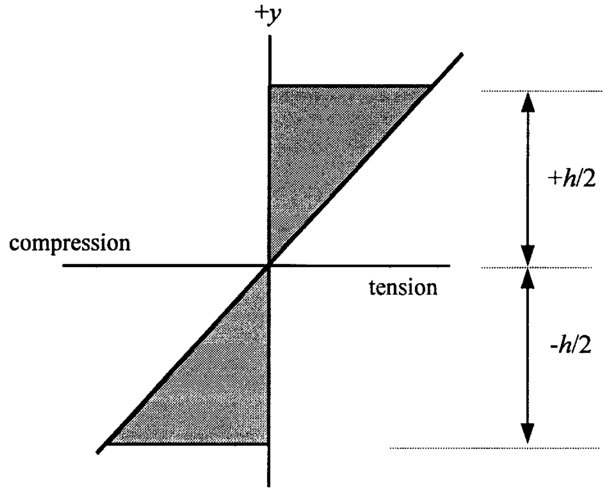


Figure 1 — Elastic deformation

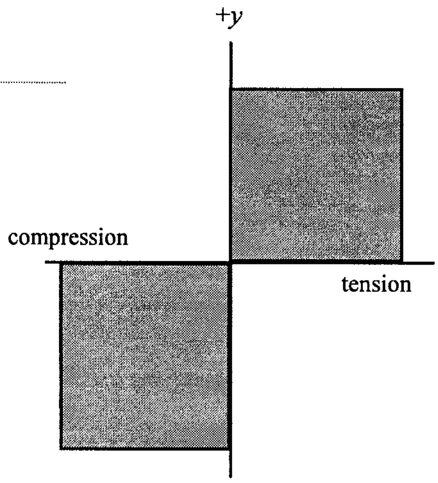


Figure 2 — Plastic deformation

The simple plastic theory is based on an idealized stress-strain relationship for structural steel. A linear, elastic, condition is assumed to exist up to the point-of-yield stress, σ_p; after this, the metal is presumed to be in a state of perfect plasticity, capable of infinite strain (see Figure 2).

The elastic and plastic moments of resistance to bending of a rectangular section are given by:

Elastic moment of resistance

$$M_e = \int_{-h/2}^{+h/2} \sigma_e \cdot w \cdot y \cdot dy \qquad (1)$$

where σ_e is the elastic stress and is a function of y as defined in equation (2):

$$\sigma_e = E \cdot y / \rho \qquad (2)$$

where

ρ	is the radius of curvature of stressed beam;
E	is Young's modulus;
σ_e	is the elastic stress;
M_e	is the elastic moment of resistance;
w	is the width of the section;
h	is the depth of the section.

Combining equations (1) and (2) gives:

$$M_e = \frac{E \cdot w}{\rho} \int_{-h/2}^{+h/2} y^2 \cdot dy \qquad (3)$$

Note that equation (3) represents the second moment of area (moment of inertia) of the material section, and reduces to:

$$M_e = \frac{w \cdot h^2 \cdot \sigma_e}{6} \qquad (4)$$

If,

$$Z_e = \frac{w \cdot h^2}{6}$$

where Z_e is the elastic modulus, then the elastic bending resistance M_e is:

$$M_e = \sigma_e \cdot Z_e \qquad (5)$$

Plastic moment of resistance

$$M_p = \int_{-h/2}^{+h/2} \sigma_p \cdot w \cdot y \cdot dy \qquad (6)$$

where M_p is the plastic moment of resistance, and σ_p is a constant representing the plastic yield stress; it can be placed outside the integral in equation (6) to give:

$$M_p = \sigma_p \cdot w \int_{-h/2}^{+h/2} y \cdot dy \qquad (7)$$

Note that equation (7) represents the first moment of area of the material section, and reduces to:

$$M_p = \frac{\sigma_p \cdot w \cdot h^2}{4} \qquad (8)$$

If,

$$Z_p = \frac{w \cdot h^2}{4}$$

where Z_p is the plastic modulus, then the plastic bending resistance, M_p is:

$$M_p = \sigma_p \cdot Z_p \qquad (9)$$

The ratio of the plastic to elastic moments of resistance, M_p/M_e, is known as the shape factor; for a rectangular section it is 1.5.

2.3 Plastic bending of Z-section safety barrier posts

Table 1 shows a list of types of safety barrier in use on UK highways. With the exception of the blocked out beam barrier (BOB), which employs rectangular section wooden posts, all the remaining barriers have posts with cross-sections formed in the shape of a letter Z (see BS 6579).

With reference to **2.2**, the plastic moments of resistance M_p, and plastic moduli Z_p, can be approximated as follows.

Plastic modulus about the longitudinal A-A axis

Figure 3 shows the approximate cross-section of a safety barrier Z-section post. In practise, the Z shape is formed by a sheet metal bending process, and so the angles of the Z tend to be more rounded than shown in the figure. The rounded shape limits bending fractures in the steel sheet.

Table 1 — Characteristics of safety barrier Z-section posts

Barrier type	**BS 6579 part no.**	**Beam centre height(s)** L mm	**Post cross-section (Figures 3 and 4)** mm	**Plastic section modulus** Z_p cm^3		**Plastic bending moment** M_p kN·m		**Yield force** F kN	
			$H \times W \times t$	A-A	B- B	A-A	B-B	A-A	B-B
TCB **(Z – post)**	1	610 ± 30	100 × 32 × 5 110 × 50 × 5	25.8 40.0	5.6 12.4	7.1 11.0	1.5 3.4	11.6 18.0	2.5 5.6
TCB (Offset brackets)	2[a]	610 ± 30	125 × 100 × 6	95.9	51.2	26.4	14.1	43.3	23.1
RHS (100 mm × 100 mm)	3	610 ± 30	100 × 32 × 5	25.8	5.6	7.1	1.5	11.6	2.5
RHS (200 mm × 100 mm)	4	610 ± 30	100 × 32 × 5	25.8	5.6	7.1	1.5	11.6	2.5
OBB (Single height)	5	610 ± 30	110 × 50 × 5	40.0	12.4	11.0	3.4	18.0	5.6
OBB (Double height)	6	610 ± 30 1 200 ± 30	125 × 90 × 6	87.9	42.4	24.2	11.7	39.6	19.1
UCB (BOB, wood)	7	610 ± 30	125 × 90 × 6 150 × 150 (wood)	87.9 —	42.4 —	24.2 —	11.7 —	39.6 —	19.1 —
WRSF (Wire rope)	—	585 ± 10 490 ± 10	100 × 32 × 6	30.2	6.4	8.3	1.8	14.22 17.0	3.0 3.6

NOTE 1 Yield stress: $\sigma_p = 275\ \text{N/mm}^2$.

NOTE 2 Theoretical plastic moduli and moments are derived from equations (13) and (14).

NOTE 3 $M_p = \sigma_p \cdot Z_p$.

NOTE 4 $F = M_p/L$.

[a] Not yet published.

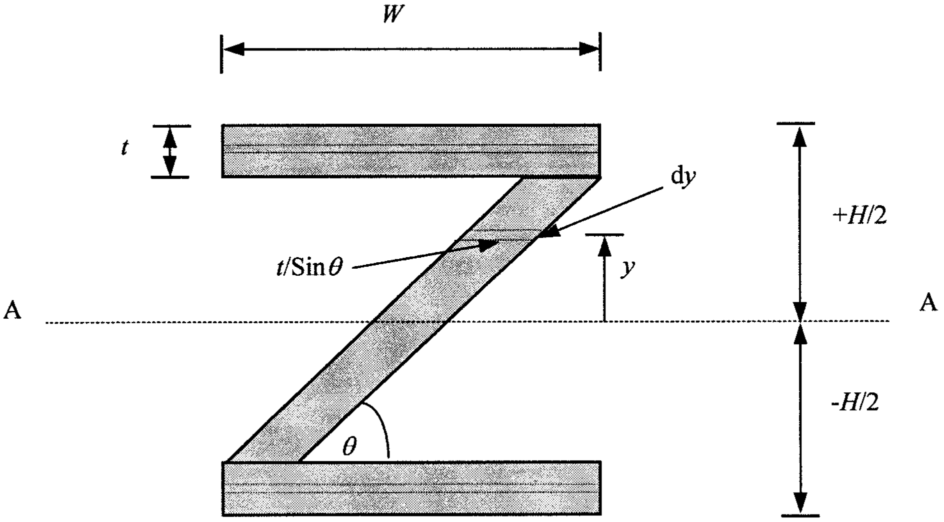


Figure 3 — Cross-section of Z-post on A-A axis

Comparison with equation (9) shows the plastic moment of resistance, $M_{p(A\text{-}A)}$, of a Z-section post about the A-A axis is given by the equation:

$$M_{p(A\text{-}A)} = \sigma_p \cdot Z_{p(A\text{-}A)} \tag{10}$$

The plastic modulus, $Z_{p(A\text{-}A)}$, about the A-A axis is given by the equation:

$$Z_{p(A\text{-}A)} = 2\int_{(H/2)-t}^{H/2} W \cdot y \cdot dy + 2\int_{0}^{(H/2)-t} \frac{t}{\sin\theta}\, y \cdot dy \tag{11}$$

NOTE The constant "2" allows for both arms of the Z-section to be included in equation (2).

From Figure (3);

$$\sin\theta = \frac{H}{\sqrt{W^2 + H^2}} \tag{12}$$

Integration of equation (11) gives:

$$Z_{p(A\text{-}A)} = W\left[y^2\right]_{(H/2)-t}^{H/2} + \frac{t}{\sin\theta}\left[y^2\right]^{(H/2)\text{-}t} \tag{13}$$

Therefore the Z-section plastic bending moment of resistance about the A-A axis is, from equations (10), (12) and (13)

$$M_{p(A\text{-}A)} = \sigma_p\left[W(H \cdot t - t^2) + \frac{t}{H}\sqrt{W^2 + H^2}\left(\frac{H}{2} - t\right)^2\right] \tag{14}$$

Plastic modulus about the transverse B-B axis

In a similar manner to that given above for the A-A axis, the plastic moment of resistance and plastic modulus about the B-B axis can be derived from Figure 4.

The Z-section post plastic bending moment of resistance about the B-B axis is:

$$M_{p(B\text{-}B)} = \sigma_p\left[\frac{t \cdot W^2}{2} + \frac{t}{4 \cdot W}(W - t)^2\sqrt{W^2 + H^2}\right] \tag{15}$$

Equations (14) and (15) do not take account of the rounded edges formed in the Z-post cross-section during the manufacturing process. Graphical methods of measuring the plastic modulus Z_p of actual posts, suggest that equation (14) gives a result about 5 % to 10 % higher, and equation (15) about 1 % to 3 % lower.

The effects on the plastic bending moments, M_p, of changes in the dimensions of the Z-post cross-sections, in terms of width W, height H, and metal thickness t, are shown in Figures 5 to 8. For comparative ranking purposes the yield stress, σ_p for steel, is fixed at 275 N/mm^2; although in manufacture, steels of other values are used to assist the production process.

Figure 5 shows that the lateral bending moment of the Z-section barrier post, about the A-A axis, can be significantly increased by changing the post cross-section, and less so by increasing the thickness of the post material. For example, the bending moment of an H = 75 mm (A-A) Z-section post (W = 32 mm) increases from about 4 kN·m to 6 kN·m for a change in metal thickness t from 4 mm to 7 mm, whereas the same change in moment can be achieved by increasing the height H from 75 mm to 100 mm.

For Figures 3 and 4, the cross-sectional area A_z, of a Z-post is given approximately by:

$$A_z = t\left[2W + \sqrt{(H - 2t)^2 + (W - t)^2}\right] \tag{16}$$

Table 2 gives the cross-sectional area of a commonly used Z-post of dimensions 100 mm × 30 mm × 5 mm; the table refers to it as the "base", shown in italic lettering. Its theoretical plastic bending moment of resistance $M_{p(A\text{-}A)}$ is 7.1 kN·m. Equations (14) and (15) and Figures 5 to 8 provide the opportunity to derive other dimensions of Z-sections that have the same plastic bending moment; the areas of some alternative sizes are also given in Table 2. It can be seen that the difference in cross-sectional areas, and accordingly, the difference in the mass of metal for the same length of post, varies from +24 % to −18 % about the base value.

Reference to Figures 5 and 6, which encompass much of Table 2, reveals that there is little change in the bending moment of resistance about the B-B axis which would detract from the performance of the weak post barrier system. If the mass of metal of a Z-post is assumed to be proportional to its cost, judicious choice of post cross-sectional dimensions could lead to economic benefits. Even so, it must be accepted that the Z-section shape, if not adequately supported, might collapse fairly early under load conditions. Consequently, economic benefits have to be weighed against the mechanical performance of the section, and also against the physical construction difficulties of manufacturing posts which are of considerable material thickness. Other exploratory analysis of optimum Z-post sizes can of course be made with the assistance of equations (14), (15) and (16).

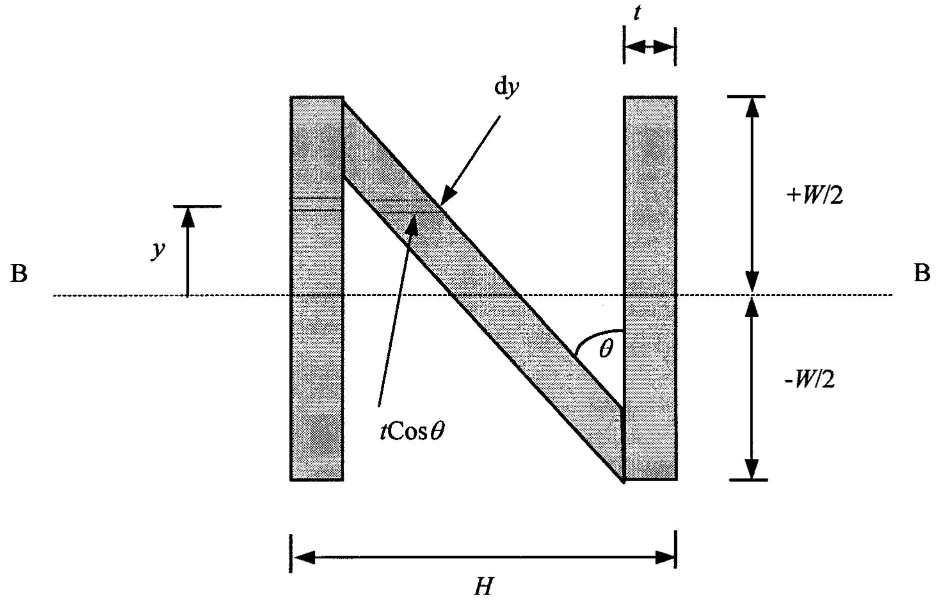


Figure 4 — Cross-section of Z-post on B-B axis

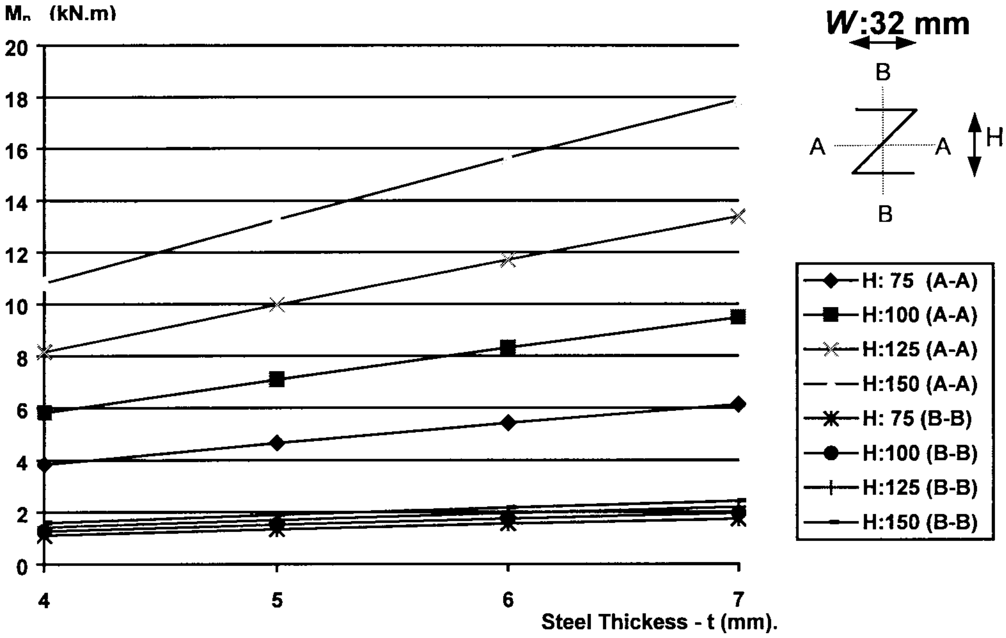


Figure 5 — Effect of H on plastic moment, M_p, for constant W = 50 mm

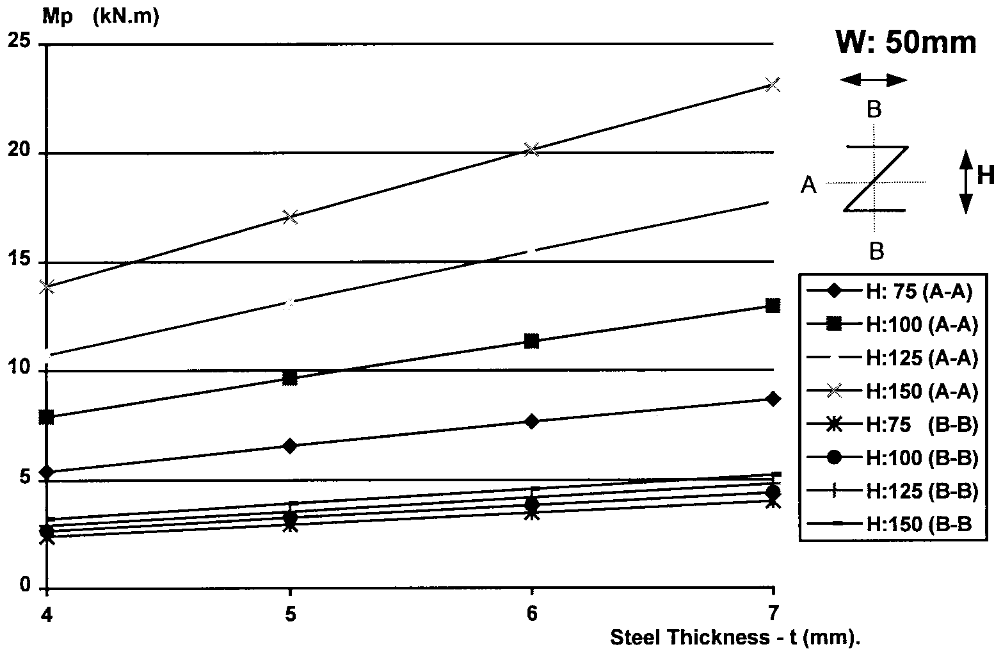


Figure 6 — Effect of H on plastic moment, M_p, for constant W = 75 mm

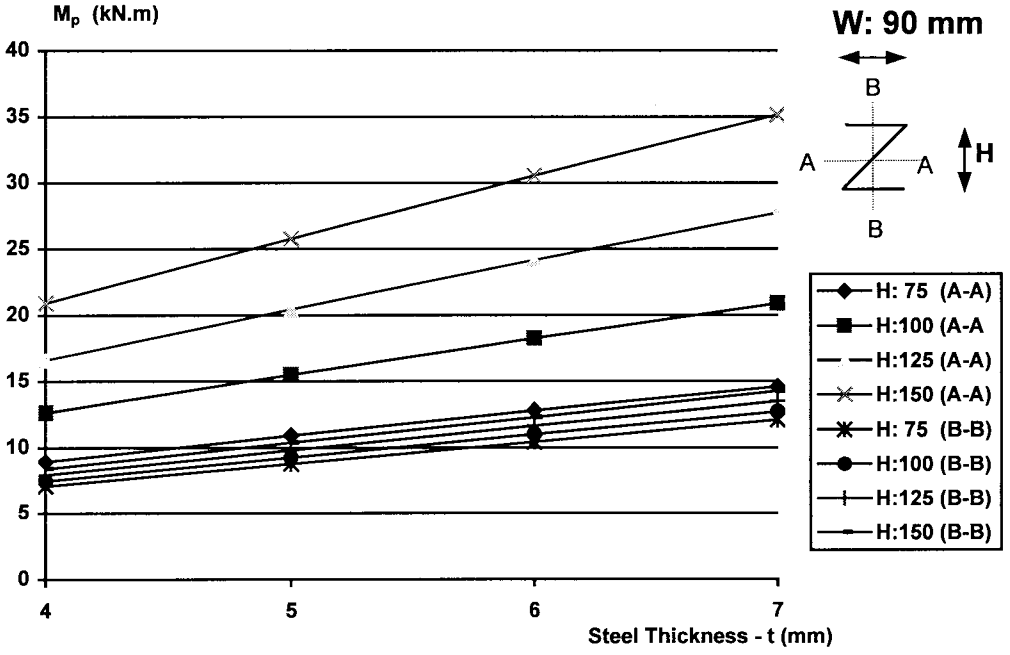


Figure 7 — Effect of H on plastic moment, M_p, for constant W = 90 mm

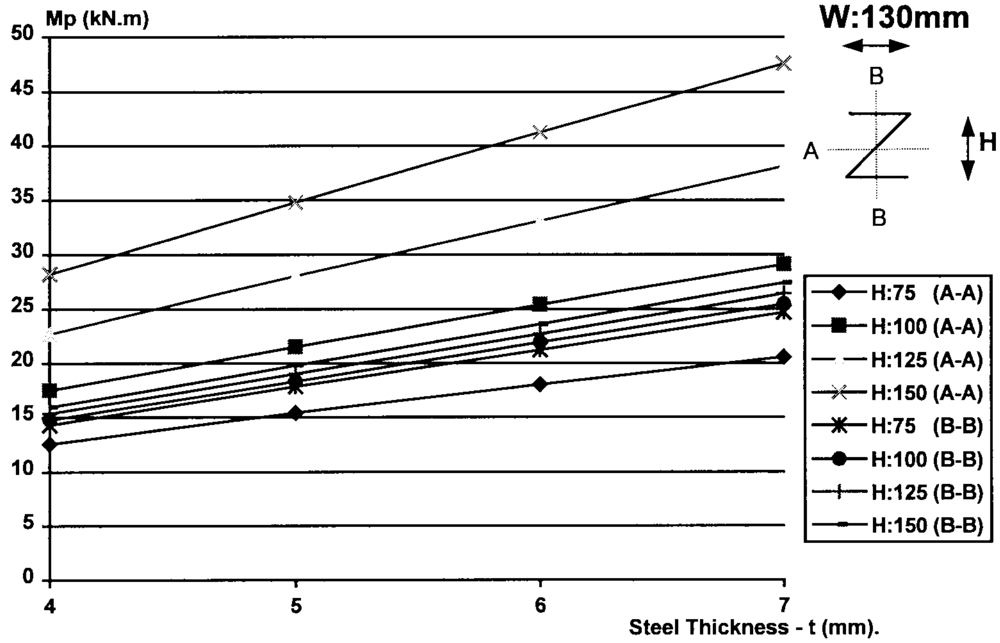


Figure 8 — Effect of *H* on plastic moment, M_p, for constant W = 130 mm

Table 2 — Cross-sectional area of Z-posts for similar bending moments

Height H	Metal gauge t	Width W	Bending moment $M_{p(A\text{-}A)}$	Area	% Increase in mass about Z-post
mm	mm	mm	kN·m	mm^2	(100 × 32 × 5) mm
75	5.5	50	7.1	978	+24 %
75	3.2	90	7.3	930	+18 %
100	***5.0***	***32***	***7.1***	***790***	***Base***
100	3.5	50	7.0	713	−10 %
125	3.5	32	7.2	648	−18 %

NOTE Bending moment for each section $M_{p(A\text{-}A)}$ = 7.1 kN·m (approximately).

2.4 Intermediate barrier post footing requirements

Intermediate barrier post footings are those installed over the normal length of need (LoN) for a safety barrier. The end treatment of a barrier, referred to as the terminal, requires substantially stronger footings to withstand tensile forces generated in the horizontal components (steel beams or wire ropes). End anchorages are discussed in **2.5**.

It is self evident that for any installed post which is subjected to its maximum bending moment, the quality of the footing need only be sufficient to develop that maximum. A stronger footing serves little purpose other than to increase the overall costs of the installation; a weaker footing would collapse or move in its mounting and so could not generate the maximum performance of the post.

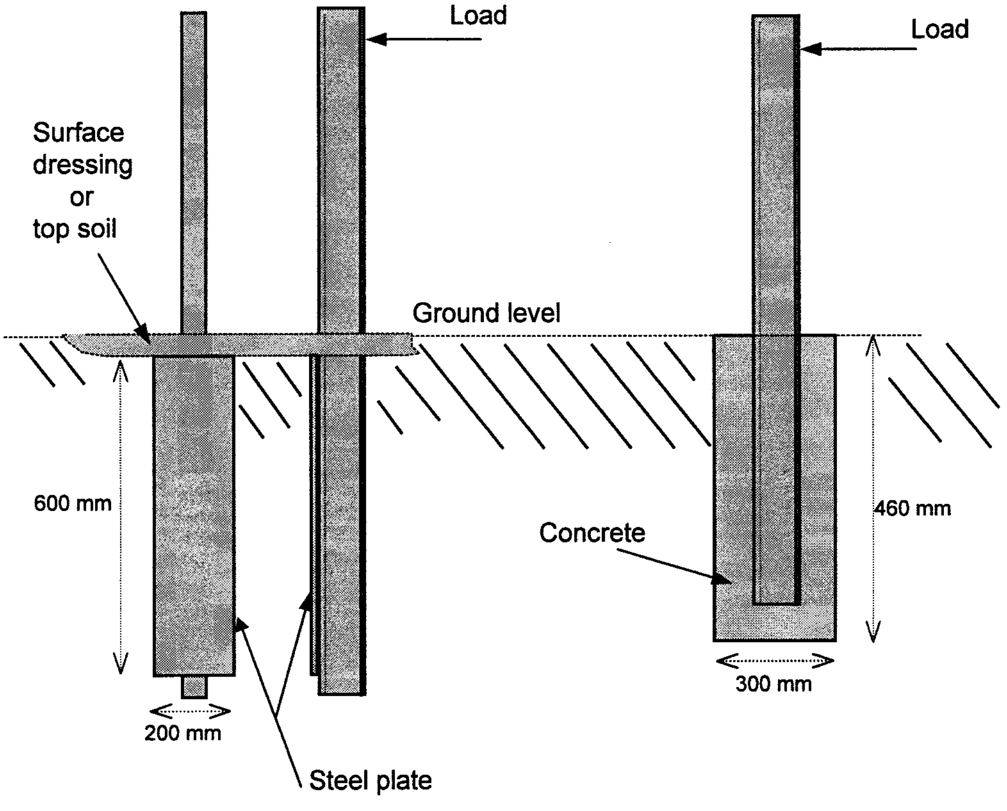
The exception applies to those types of safety barrier whose successful vehicle impact performance requires the posts to rotate in the soil. For UK type barriers, this requirement applies only to the BOB (see **3.2**) mounted on wooden posts (Table 1). Fortunately, as the use of the BOB type of fence is decreasing in the UK, the need for and difficulties in prescribing and maintaining specific soil characteristics to achieve full fence performance are encountered less frequently.

The performance of safety barrier post footings was investigated at TRL (see Laker: 1970 [1]). In particular, a common post size, of cross-section 100 mm × 32 mm × 5 mm, was subjected to a series of trials in which bending loads were applied to the post when mounted in various types of fixings.

Initially the 100 mm × 32 mm × 5 mm post, rigidly fixed in a bending machine, was subjected to tests by the engineering department of Cambridge University. The maximum bending moment was found to be 7.05 kN. This experimental value is very close to the theoretical value of 7.1 kN quoted in Table 2 for the plastic bending moment as derived from equation (14), and so supports the theoretical analysis.

For this particular set of on-site tests, the posts were mounted in brown clay with 50 mm of top soil; this was then removed and replaced by a single surface dressing. Horizontal loads were applied at a height of 760 mm above ground level for the two surface dressing conditions.

The arrangements for the two sets of trials are shown in Figure 9. The metal pressure plate, 600 mm × 200 mm × 6 mm, was welded to the section of the post driven below ground level to increase its overturning resistance in the soil. The concrete footing was cubical in shape and of size 460 mm × 300 mm × 300 mm.



a) driven post with pressure plate b) concrete footing

Figure 9 — Z-section post footings

Table 3 gives results of the trials. With the concrete footing, a bending moment in excess of the theoretical value was achieved. One explanation for this is the concrete around the base of the post could have offered some support that resisted the collapse of the Z-section shape.

Table 3 — Bending moments of Z-section post 100 mm × 32 mm × 5 mm

Trial no.	**Type of footing**	**Maximum bending moment** (kN·m)
1	Rigidly fixed in test machine (Bending moment at yield point)	7.05
2	Concrete — 460 mm × 300 mm × 300 mm	8.13
3	Brown clay with 50 mm of top soil, Pressure plate — 600 mm × 200 mm × 6 mm	6.78
4	Brown clay with single surface dressing, Pressure plate — 600 mm × 200 mm × 6 mm	6.45

Loading values plotted against post deflection showed that although the concrete footing exceeded the resistance offered by the pressure plate post, the concrete footing rotated in the soil and resistance quickly fell away after a measured deflection of 100 mm at the top of the post; whereas the pressure plate post maintained its resistance at a lower, but steady value, up to a deflection of about 400 mm.

The driven pressure plate posts were found to be a less costly method of installation than traditional concrete footings, although where site conditions are particularly poor, it remains necessary to specify adequate designs of concrete footings.

For sizes of Z-section posts other than 100 mm × 32 mm × 5 mm and where lower grade soil conditions prevail, pressure plates of larger dimensions are recommended as well as longer posts, driven deeper into the ground. Reference should be made to the Contract Documents, Specification for Highway Works (SHW) [2] and the Highway Construction Details (HCD) [3].

Over a period of time, experience from on-road vehicle accidents revealed that poor installation of concrete footings was reducing the effective impact performance of safety barriers. Further work was carried out by TRL wherein post footings were concreted into plastic cylinders that had been pre-positioned in augured holes in the soil (Macdonald: 1986 [4]). This technique ensured that where concrete footings were essential, consistent quality of installation could be achieved and the possibility of sub-standard footings avoided. An added advantage emerged from utilizing clearance sockets to receive the posts in their footings; accident repair was simplified by removing the damaged post manually and replacing it with a new one.

It is current practise, in civil engineering contracts for new barrier installations, to require site trials to be made with sample intermediate posts and footings to determine whether concrete or driven post may be used; the load/deflection values that must be met are set out in the Highway Construction Details (HCD) [3]. Test rigs are available for this purpose. (See SHW [2] and BS 7669-3.)

A method of non-destructive testing of existing barrier intermediate post foundations has been demonstrated by an on-site simple loading test (Macdonald, Laker: 1987 [5]). For a Z-post of cross-section 100 mm × 32 mm × 5 mm, the test required that a post should sustain a load of 6 kN applied in line with the B-B axis, at a height of 780 mm above ground level. Under this loading, the deflection at 600 mm above ground should not exceed 50 mm at loads less than 6 kN and this minimum load should be sustained over a deflection of 250 mm.

2.5 Safety barrier ground and full height anchors

The terminal of a safety barrier is considered to be the end-treatment that forms the anchorage of the horizontal rails in post and rail systems. The terminal's length usually lies outside the full barrier performance required over the length of need. The anchorage can be either at ground level or at full height. A full height anchor permits the termination of the horizontal rails at their operational height by attachment to a stiff metal frame.

The purpose of the anchorage is to permit tension to develop in the horizontal rails. The tension assists in limiting the amount of dynamic deflection of the barrier. Unlike the intermediate posts discussed in **2.4**, the steel end-post should not yield and enter the plastic region.

The maximum tensile loads that horizontal rails should sustain is high, irrespective of whether they are formed as a stiff beam or a flexible wire rope. Consequently, the end anchorages need to be able to resist the static loads imposed on first installation as well as the dynamic loads that arise from temperature variations and, of course, from vehicle impact loading.

For example, a single W-section rail yields at 330 kN and a single 19 mm diameter cable of wire rope can support tensile loads up to 200 kN. It is clear that ground anchors to withstand such loads to yield point would be of considerable size and cost. Consequently barrier design criteria have to consider the likely operational tensions that will develop during impact conditions and, with a margin of safety, design down accordingly to formulate an adequate barrier end-treatment.

There are no published requirements for testing end anchorages of safety barriers; contract documents for new installations should describe the installation and performance requirements for terminals.

3 Development of UK post and rail safety barriers

3.1 General

The development of current designs of post and rail highway safety barriers presently seen on UK highways began in the early 1960s at TRL. Work previously done in the USA in the mid 1950s had not reached an advanced stage with regard to acceptable vehicle impact response at high speeds.

The introduction of motorways in the UK road network, starting about that time, generated the need to investigate the increased potential for accidents involving vehicles leaving the motorway at high speed. In particular, the increased incidence of accidents involving vehicles crossing the central reservation of motorways gave cause to investigate the safe containment of these vehicles, in their own traffic lane, by the use of vehicle safety barriers.

The development of each barrier type is discussed in **3.2** to **3.6** in chronological order (although some of the barriers may have been under development concurrently).

3.2 The blocked out beam barrier (BOB) and the untensioned corrugated beam barrier (UCB)

Very early roadside safety barriers were little more than a rubbing rail for vehicles that inadvertently left the carriageway. A corrugated horizontal beam bolted directly on to wooden posts, or clamped to scaffold tubes, formed a rail to prevent vehicles from entering a dangerous area such as a steep embankment, or impacting a vulnerable part of a building.

The BOB was a modification of these early types and was devised for use as a median barrier on high speed roads. The main design change was the inclusion of 230 mm wooden blocks between the corrugated beam and the 150 mm × 150 mm oak posts. The blocks helped prevent the leading impact wheel from contacting the posts, so reducing the risk of vehicle spinout. Post spacings were 3.2 m and the double sided rails were mounted at a beam centre height of 535 mm.

Under full scale impact conditions, the overall length of the test section was 29 m and the posts were mounted in well compacted hoggin to a depth of 1.12 m. The spring rate of the posts, loaded at the centre of the posts, was about 440 N/mm.

Four manually driven tests at a nominal speed of 30 mile/h were carried out with 1 360 kg cars at impact angles of 5°, 10°, 15° and 20°. A fifth remote controlled test at 50 mile/h was made at 18 ° (Jehu: 1967 [6]).

On impact, the W-section beam was pushed back and the posts rotated in the soil. The vertical face of the beam, in effect, is held on a cantilever from the centre line of the posts by the blocking out piece, the depth of the W-section and half the thickness of the post. The rotation of the cantilever causes the beam height to rise. The maximum increase in height at the beam centre line occurs when the face of the W-beam is pushed back to the original position of the centre line of the undeflected posts. Assuming the point of rotation is about two-thirds below ground level, simple geometric analysis shows that the centre line of the beam rises about 75 mm. That is, the centre line rises from 535 mm (Figure 10) to about 610 mm.

The dynamic rise in beam height, under vehicle impact, reduces vehicle tendency to roll over the barrier, particularly for those vehicles whose centre of gravity is close to, or above the installed height of the barrier's W-beam centre line (PD 6634-2:1998, **5.4**). In all the tests the cars were safely contained and redirected. The exit angle at 18° for the 50 mile/h tests was about the same as the impact angle.

The BOB barrier was subsequently adopted in the construction of two 9 mile lengths of central reservation barrier on the M1 motorway in 1964, for experimental purposes. It was the first length installed on any UK motorway and was the subject of a cost/benefit analysis (see PD 6634-2:1998, clause **2**).

The development and testing of the BOB at TRL was the foundation work that led to the design and the decision to install, the many types of safety barrier and bridge parapets presently seen on the UK road network. The BOB remains in use, but it is limited to areas where vehicles are restricted to 50 mile/h.

Later, the BOB was modified to be mounted on steel posts. The wooden blocking out piece was replaced by a steel framed 200 mm × 300 mm offset bracket. The beam's centre height was adjusted to 610 mm, and posts could be mounted as soil driven Z-section posts, or surface mounted with a non-yielding footing (Figure 11).

On vehicle impact, the Z-section post on a non-yielding footing can bend at surface level, rather than below ground, which generates the greater dynamic lift to beam height, without loss of barrier performance, due to the installed beam centre height being some 75 mm higher than the BOB barrier.

The modified barrier, known as the untensioned corrugated beam barrier (UCB) was successfully tested on an installation mounted on 110 mm × 50 mm × 5 mm Z-section posts with an impact at 50 mile/h and 20°, with a 1 350 kg car containing a 75 kg instrumented dummy. The maximum dynamic deflection was 850 mm. The leading impact wheel was partly dislodged from its station. The test was repeated with the barrier mounted on the 125 mm × 90 mm × 6 mm Z-section posts quoted in Table 1 (HCD [3] and BS 6579-7). The vehicle was contained and redirected by the UCB, but the front wheel and suspension became completely detached from the test vehicle.

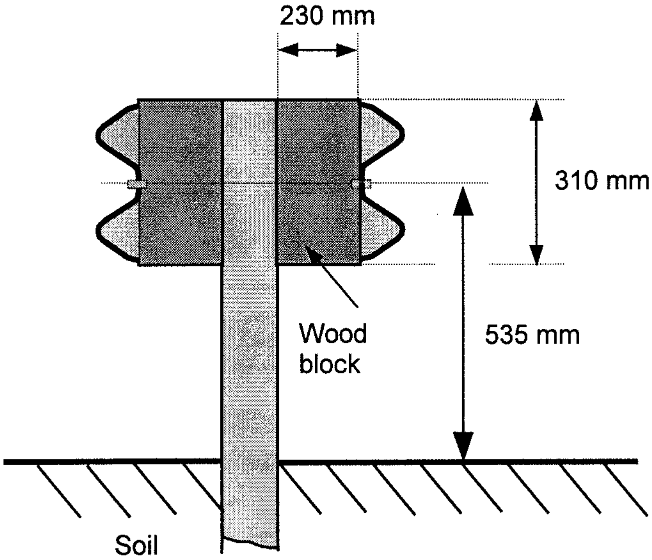


Figure 10 — Double sided BOB barrier on wooden posts (Soil mounted)

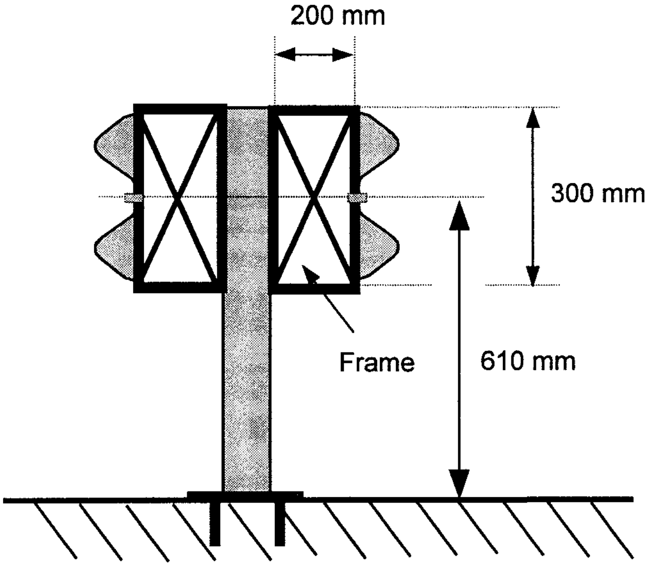


Figure 11 — Double sided UCB barrier on Z-posts (Surface mounted)

3.3 The wire rope safety fence (WRSF)

3.3.1 *General*

The blocked out beam barrier (BOB) and the untensioned corrugated beam barrier (UCB) had proved successful in the containment and redirection of a 50 mile/h saloon car impacting the barriers at an angle of 20°. With the growth of motorway construction in the UK it was clear that designs of safety barrier would be required that could safely restrain vehicle impact at higher speeds. The maximum speed of 70 mile/h permitted on motorways was initially the target design speed. However, test site facilities and vehicle remote control equipment, at the start of the development program in the early 1960s, were not sufficiently developed and, depending on the test vehicle mass, maximum speeds of only 60 mile/h to 65 mile/h were achievable.

The development of wire rope safety fences followed two stages. The first type of fence, some 1 140 mm in height, used relatively strong posts with either one or two cables clamped to the posts and faced with a chain link mesh (see Figure 12). (See Jehu, Laker: 1967 [7].) The second fence was a weak post system of height about 760 mm with two cables resting in a slot cut into the top of the posts, known as the wire rope slotted post barrier.

3.3.2 *The cable and chain link barrier*

Cable and chain link fences were the subject of vehicle impact testing in the USA in the late 1950s (Beaton, Field: 1960 [8]). Tests with a 8 800 kg, 60 mile/h car impacting at 30° proved successful but at low angle impacts, about 10°, the vehicle characteristically spunout and the fault was not remedied at that time.

To investigate the spinout problem, a factor likely to affect the lighter weight UK vehicle stock, several modifications to the cable and chain link barrier were subjected to a series of tests at TRL. Tests on paired ropes at single height, and on two ropes at two different heights (see Figure 12), were included in the matrix of tests.

Methods of attachment of the ropes to the posts varied from a thin metal 12 mm strap to 12 mm U-bolts. Post cross-sections were varied and ranged between 40 mm steel tubes to 75 mm × 38 mm and 70 mm × 25 mm I-section posts (Jehu and Laker: 1967 [7]).

As a result of this work, cable and chain link fences were found unsuitable for high speed impacts and so were not introduced on UK highways. However, the work revealed the need for the basic understanding of the mechanisms required in the design of weak post barrier systems.

Summary of section 3.3.2

Nine impact tests were made at TRL on various configurations of cable and chain link fences. The main factors arising were as follows.

— When cables at two heights are used (483 mm and 686 mm), the lower cables are stripped from the posts and might endanger a vehicle which runs over them.

— If a pair of cables at one height are used (610 mm), in low angle impacts (6° to 10°) the posts (1 140 mm) are not released from the cables, with the result that vehicles at high speeds and low angles can be overturned by the damaged fence.

— The chain link mesh is hazardous to vehicle response. The mesh bunches ahead of the vehicle and induces it to either spinout or ride up the fence and roll over.

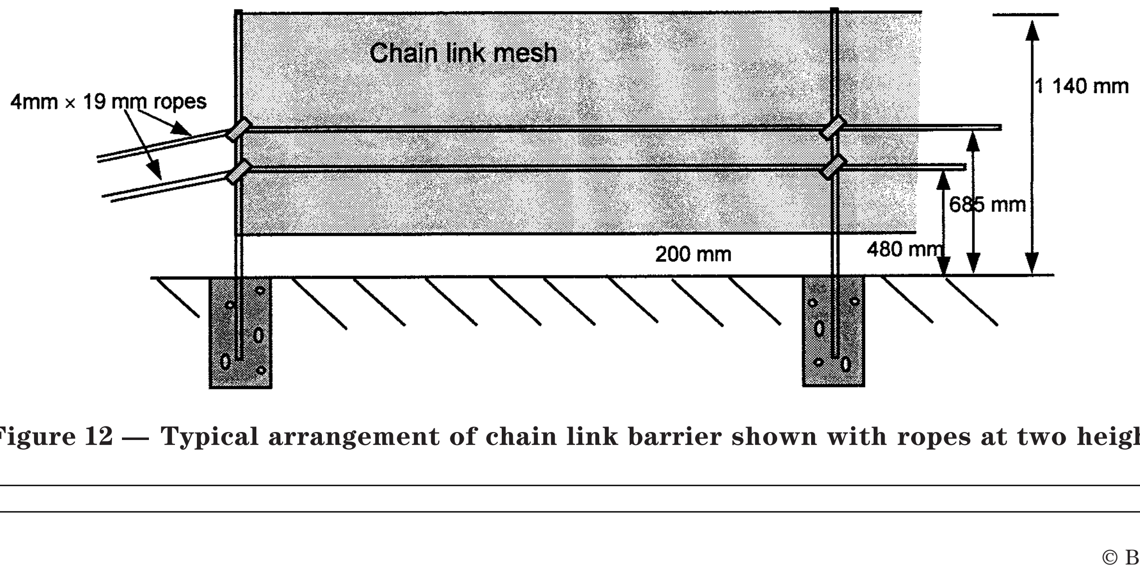


Figure 12 — Typical arrangement of chain link barrier shown with ropes at two heights

3.3.3 *The slotted post wire rope safety barrier*

The work on the cable and chain link barrier showed that for safe containment and redirection of an impacting car, the fixings of the cable to the post must be easily fractured to permit the posts to be run down without lowering the height of the cables to a level where they could entrap the leading impact wheel. Furthermore, facing of the fence with chain link mesh, or similar material, can bunch in front of the car and induce instability that results in spinout or overturning.

Twenty-eight tests were carried out on alternative designs of slotted post barrier. Most of them were made with 1 360 kg cars but in some tests lightweight 710 kg cars and commercial vehicles up to 3 700 kg were used. Vehicle speeds ranged from 17 mile/h to 67 mile/h at nominal impact angles from 6° to 20° (Jehu and Laker: 1967 [9]).

A further eight tests were carried out on a fence erected on the median strip of an unopened length of motorway, to determine the effect of rope tension, length between the rope anchorages and the effect of changing the post spacings.

In some tests the ropes were preconditioned to remove residual elasticity in the newly manufactured weave, by cyclical prestretching eight times to a load of about 80 kN.

A typical wire rope slotted post fence is shown in Figure 13.

Rope Tension

In one test the static tension in the ropes was set at 22.24 kN in the lower rope, and to 17.12 kN in the upper rope; the result was compared with a similar test where the tension in both ropes was set at the base level of 4.45 kN. The increased tension had little effect on the barrier deflection for a comparable impact. However, to ensure the ropes would not sag in hot weather the static tension was finalized at 13.34 kN. For the 19 mm diameter ropes used, a tension of 13.34 kN was reduced by 50 % at 38 °C and increased by 50 % at −18 °C. This range in temperature was considered to have little effect on the barrier performance.

The highest dynamic tension recorded in any single rope was 56 kN when struck by a 42 mile/h, 3 720 kg commercial vehicle at 18°. The ultimate strength of the cable was 174 kN.

Rope heights

Tests on the barrier with ropes at two heights, 635 mm and 760 mm, showed that only the upper rope was effective in redirecting commercial vehicles with high bumpers, but the lower rope was run over. For small vehicles it was concluded that the lower rope was effective but the upper rope, at a height of 760 mm, could slip over the bonnet. At that time, the difficult task of designing a two height rope barrier, which could accommodate all vehicles, was abandoned in favour of a single rope height that was effective for small cars and many commercial vehicles. The problem was solved by a later design of fence developed commercially in the UK, known as the Brifen wire rope safety fence (see **3.3.4**).

Rope lengths

Barrier lengths of 150 m, 305 m, 610 m and 1 500 m were installed on a motorway and impacted at speeds ranging from 50 mile/h to 60 mile/h. No correlation between installed length and barrier dynamic deflection was found in this series of tests. However the deflection of a 1 500 m fence reduced from 4.0 m to 2.7 m for a 610 m installation when each fence was similarly tested by a 62 mile/h, 1 360 kg car, at 20° angle of impact.

Intermediate rope anchorages.

A slotted post wire rope fence installed on a highway several miles in length requires a series of intermediate anchorages for the rope terminations; 610 m intervals is an optimum length. A ground anchorage arrangement was designed to permit a vehicle running through it to release the rope from its fixing and so avoid becoming entangled with the

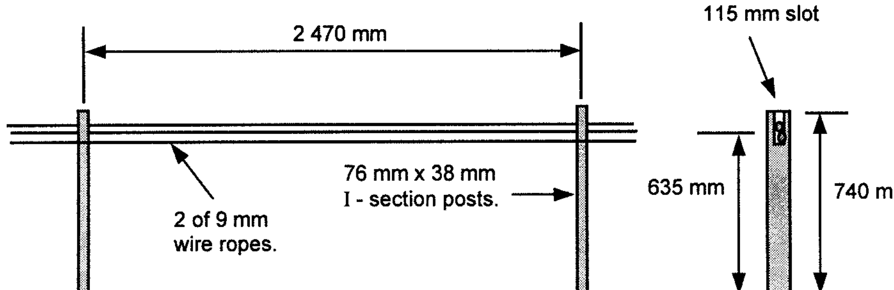


Figure 13 — Typical layout for a wire rope slotted post barrier

ramped rope end anchorage. Meanwhile, the vehicle was contained and redirected by a second, continuous rope, running at full height throughout the anchorage assembly. The connection for the ramped down rope consisted of a closed eye termination fixed to a spigot, facing into the barrier. In a test, the car struck the barrier in advance of the anchorage at 55 mile/h at 20°.

The closed eye was knocked off the spigot, the full height continuous rope redirected the vehicle and the rising rope of the next barrier section was run down, as intended, without detriment to the passage of the vehicle.

Post spacings

The effect of post spacing was examined by removing every other post to produce a fence with 4.9 m post centres. The maximum deflection for a 64 mile/h impact at 18° by a 1 360 kg car was 4.3 m; hence doubling the post spacing has about the same effect as doubling the distance between rope anchorages.

Weak post barriers

The series of tests on the slotted post wire rope barrier confirmed the concept that a weak post barrier, where the posts could easily be run down without causing spinout, was sound. Further barriers were developed using this principle and are discussed under the various types; e.g., TCB (see **3.4**), OBB (see **3.6**) and RHS (see **3.5**).

Summary of section 3.3.3

The following features relating to the impact performance of a single height slotted post wire rope safety fence emerged from the completed test programme.

— A means of ready detachment of ropes from the posts, irrespective of the angle and speed of impact, is obtained by supporting the ropes in vertical slots cut into the tops of the posts.

— A barrier with ropes at two heights, in which the lower rope is intended to deflect small vehicles and the upper rope is meant to contain larger vehicles, had the disadvantage that the upper rope is a serious hazard to small vehicles and the lower rope may be run down by large vehicles.

— Ropes arranged at a single height to deflect the small vehicle will also redirect the larger vehicle provided that they lodge in the soft bodywork above the front bumper. Where the ropes are well below the height of the centre of gravity of the large vehicle, the vehicle could overturn in a severe collision.

— The vehicle exit angles from the barrier are less than one-half of the impact angles.

— The setting of the single rope height is critical, consequently the surface beneath the fence needs to be hard and flat.

3.3.4 *The Brifen wire rope safety barrier*

Bridon plc, collaborated with TRL in the 1960s on the development of the wire rope slotted post safety barrier (see **3.3.3**). The development of the fence in the early years ceased with the proviso, on UK highways, that it should be installed on a hard flat running surface to overcome sensitivity to rope height. The fence was adopted by the Department of Transport (DTp) and proved successful in use, particularly in areas subject to heavy snow falls where the profile of the fence caused less snow drifting than some other types of barrier profiles.

The requirement that the fence should be mounted on a hardened running surface was an added cost that eventually resulted in it falling out of use.

Bridon plc, in 1986, decided to re-examine the single height rope design; the prime aim was to overcome the necessity and cost of the hard surface. A series of ten tests was made at the Motor Industry Research Association (MIRA).

In addition to the standard test with a 70 mile/h, 1 500 kg car impact at 20°, the DTp requested that the maximum deflection of the fence should be less than 2.0 m.

Also, the vehicle exit trajectory had to meet the box criteria of BS 7669-3, which states in part:

> "... if redirection takes place the vehicle shall be redirected so that no part of it crosses the line drawn parallel with and 2.13 m, plus the width of the vehicle, from the face of the barrier, within a distance of 10 m from the break point of vehicle contact with the barrier. The test vehicle shall neither turn on its side nor roll over .."

In anticipation of the coming requirements of European Standards for safety fences (EN 1317) a 750 kg Mini car test was also required at 70 mile/h at 20°.

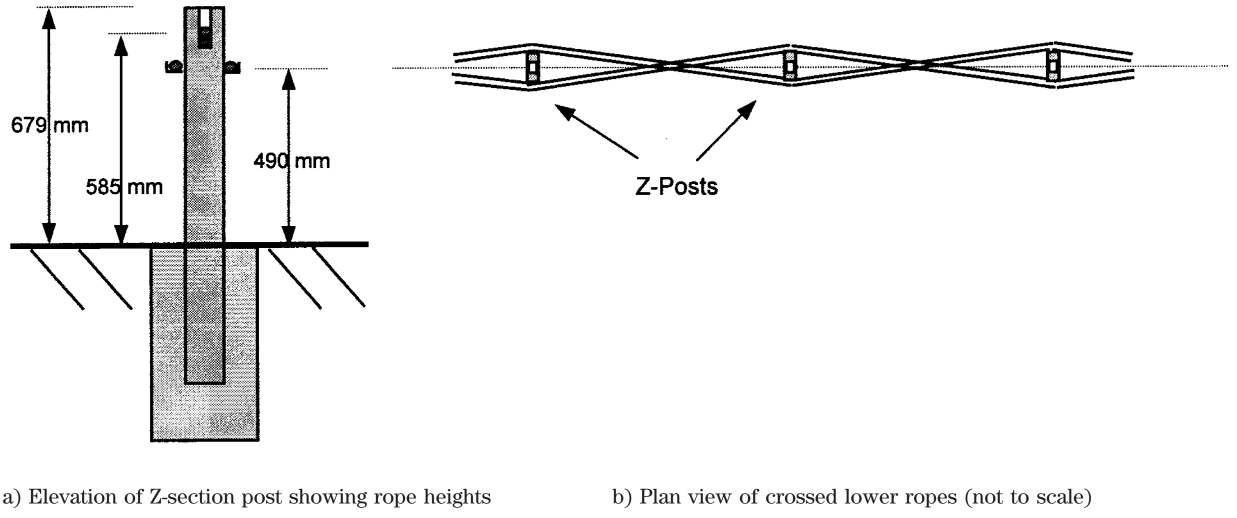
Weak posts and post spacings

Bridon considered that fence post spacings of 2.4 m would be needed to meet the 2.0 m maximum deflection requirement. It was foreseen that a stiffer fence would be necessary in an on-road situation where the fence was installed close to roadside features, such as lamp columns and gantry signs. To meet this situation, tests where made on a fence with spacings reduced from 2.4 m to 1.0 m (Laker and Naylor: 1993 [10]).

In the final design, the Brifen (see Figure 14), Z-section posts 100 mm × 32 mm were used, manufactured from 6 mm gauge steel of yield strength 335 kN/mm^2, set at post spacings of 3.2 m.

Rope configuration and tension

The essential difference between the Bridon two height cable fence and the early trials at TRL was the inter-weaving of the lower ropes between alternate posts, shown in Figure 14b).



a) Elevation of Z-section post showing rope heights

b) Plan view of crossed lower ropes (not to scale)

Figure 14 — Layout sketch of Brifen 4-rope safety fence

The effect of this was that posts ahead of the car, during the impact phase, were sufficiently clamped by the cross threading or weaving of the lower ropes, to prevent the lower rope on the remote impact side of the fence from being taken down by the preceding collapsing posts. In other words, the collapsing post near to the front of the car became released from all four ropes without dragging the cables running ahead of it to the ground. In effect, all four ropes were actively playing their part in containing the vehicle until they became detached from the posts.

Two 19 mm diameter wire ropes were placed in the upper slot at a height of 585 mm, and two further ropes were mounted in clips against the side of the posts at 490 mm [see Figure 14a)]. Impact tests showed that static rope tension between 13 kN and 27 kN had little effect on dynamic deflection of the fence.

This result is beneficial in service; the fence performance is not sensitive to variations in tension brought about by changes in ambient temperature. Static tension of 22 kN, set at 15 °C, is specified for the final design. Over a temperature range of −10 °C to 30 °C the rope tension ranges from 36 kN to 14 kN. Table 4 shows a series of development tests that led to the approval of the Brifen 4-rope barrier for use on UK roads. The target limit of 2.0 m dynamic deflection had been met under a standard impact test. Test number 731, with a medium sized car, was made in France; that test, together with the standard car test (E167), satisfied the requirements for the Brifen fence to be marketed and used in France. Tests numbers 7, 11, 12 and 25 were made in Sweden on the 4-rope and on a 3-rope system and they met the N2 containment requirements of the European Standard EN 1317. The EN 1317 Standard tests were repeated in the UK (N6014, N6015, N6016 and N6017) and successfully met the requirements of the Standard. The overall test length of fence installed was 101 m in Sweden and 106 m in the UK. The deflections for the 3-rope test were 1.40 m in Sweden and 1.73 m in the UK. For the 4-rope system the Swedish value was 1.30 m and the UK value was 1.77 m.

Although these deflections in themselves are not overtly different in the context of a 70 mile/h impact with a 1 500 kg car, the working widths, as assigned in EN 1317-2, fall into different categories. The Swedish tests place the 3-rope system in category W5 and the UK test places the 3-rope system in category W6. The 4-rope system is placed in category W4 in the Swedish test and in category W6 in the UK test. One interpretation of this result is that lower categories of working width might be commercially attractive for a proposed barrier installation contract where there is limited working width on site; accordingly it could be financially beneficial to test at the lowest possible limits of the tolerances given in EN 1317, to achieve the minimum value for barrier test deflection. The solution to the problem is not simple because the speed and angle tolerance set within the standard are already quite restrictive. A possible solution is either to weight the measured values of deflection according to the kinetic energy of the car, as derived from actual test data, or to widen the bands of the working widths required within the standard.

Table 4 — Table of tests on Brifen wire rope barrier (Brifen)

Test no.	Date	Inertial mass of vehicle kg	Inertial mass of dummy kg	Speed km/h	Impact angle degrees	Barrier type	Height to cable centre mm	Post spacing m and Z-section mm	Intrusion length m	Maximum deflection (m) PHD THIV[a] (side=0.3m)	Comment
E166	12.87	1 512	—	114.2	19.5	4-Cable weave	585 490	2.4 100 × 33 × 6	—	1.9 — —	Standard car
E167	2.88	1 480	—	112.0	19	4-Cable weave	585 490	2.4 100 × 32 × 6	—	1.7 — —	Standard car DTp approval
E190	12.88	753	—	115.8	19.0	4-Cable weave	585 490	2.4 100 × 32 × 6	—	1.2 — —	Small car DTp approval
J0903	8.91	1 510	75	115.8	19.0	4-Cable weave	585 490	1.0 100 × 32 × 6	—	1.2 — —	Standard car TD32/93 1.0 m spacings
J0904	8.91	744	—	113.4	19.0	4-Cable weave	585 490	1.0 100 × 32 × 6	—	0.86 — —	Small car TD32/93 1.0 m spacings
731	9.92	1 250	75	83	30.0	4-Cable weave	585 490	2.4 100 × 32 × 6	—	1.18 — —	Medium car French test
7	4.94	1 460	—	113.9	19.0	4-Cable weave	585 490	2.4 100 × 32 × 6	—	1.3 — —	Standard car Swedish test
11	4.94	1 450	—	112.8	19	4-Cable weave	585 490	3.2 100 × 32 × 6	—	1.3 — —	3.2 m spacing Swedish test
12	4.94	1 492	—	111.3	19	3-cable weave	585 490	3.2 100 × 32 × 6	—	1.4 — —	TB32 test 3-rope Sweden
25	4.94	875	—	103.5	19	3-cable weave	585 490	3.2 100 × 32 × 6	—	1.0 — —	TB11 test 3-rope Sweden
M6035	8.3.95	1 505	—	113.8	20	4-cable weave	585 490	3.2 100 × 32 × 6	18.0	1.5 — —	TB32 in front of 2 m wide ditch
N6014	17.6.95	909	75	119.5	20	4-cable weave	585 490	3.2 100 × 32 × 6	142	1.31 56 6.0	TB11 test 4-rope UK
N6015	17.6.95	1 499	—	114.3	20	4-cable weave	585 490	3.2 100 × 32 × 6	20.8	1.77 48 4.0	TB32 test 4-rope UK
N6016	19.6.95	903	75	113.9	20	3-cable weave	585 490	3.2 100 × 32 × 6	15.8	1.3 53 5.8	TB11 test 3-rope UK
N6017	19.6.95	1 505	—	115.1	20	3-cable weave	585 490	3.2 100 × 32 × 6	21.4	1.73 47 4.6	TB32 test 3-rope UK

[a] Definitions of PHD and THIV are given in PD 6634-2, **7.6**.

Summary of the development program referenced in section 3.3.4

— Development of the wire rope fence from a two rope to a four rope system, known as the Brifen fence, with post spacings at 2.4 m and 1.0 m, met the impact performance requirements of the UK, DTp. Tests to European Standard EN 1317-1 and -2, made in Sweden, were also successful. A further test, in France, met the requirements for installation of the Brifen fence on French highways.

— The maximum tension measured in any test was 22.6 kN; the breaking load of a single cable is 174 kN.

— The impact severity criterion THIV was measured at 4 m/s in the 1 500 kg car test against the safety fence with 2.4 m post spacings; the THIV value increased to 5.6 m/s against the 1.0 m fence. These values are within the maximum of 9 m/s required by EN 1317-1.

— The limit of a 2.0 m maximum dynamic deflection under standard impact conditions, required by the UK DTp, was met.

— Requirements for testing, manufacture and installation of the Brifen wire rope safety barrier are given in, TD32/89 [11], TD32/93 [12], SHW: Volumes 1 and 2 [13], BS 6579-12, BS 7669-3 and EN 1317-1 and -2.

3.4 The tensioned corrugated beam barrier (TCB)

3.4.1 *General*

The concept of the weak post barrier with tensioned cables was used in the development of the tensioned corrugated beam barrier (TCB). Tests on the blocked out beam (BOB) barrier had shown that its use should be restricted to highways with a statutory 50 mile/h speed limit. For higher speed impacts, the complication and cost of a second rail would be necessary to prevent the car's leading wheel striking the posts, if the risks of high impact levels and possible spinout were to be avoided.

It was also evident that a post and rail barrier, with a stiff steel beam attached directly to the face of the posts, required a mechanism whereby the posts could become easily detached from the rail and run down by the car as it progressed through the barrier impact zone.

In the same manner as the wire rope barrier, the terminals were ramped down to ground anchorages. The clearance slackness in the elongated holes in the W-section beams, used in fixing adjacent sections of beams, was jacked out before the lap bolts were tightened. The whole length of the installed barrier was finally tensioned to about 13 kN by inserting long bolts every 70 m, between sliding joints in overlapping rail sections. After tensioning, the lap bolts were firmly tightened.

Two methods of providing a detachable link between weak steel posts and the beam were investigated during the early 1960s (Jehu: 1967 [14], Jehu and Pearson: 1972 [15]).

3.4.2 *The TCB mounted on hollow tubes (circa 1965)*

In the first method, round steel tubes 350 mm long and 75 mm in diameter, with a centrally drilled bolt hole, were bolted to the rear face of the beams and the assembly was placed over the posts; the bolts half-way along the tubes rested on the top of the posts (Figure 15). Upon impact the bent posts slid out of the lower half of the tubes, while the beam remained at about its installed height through frictional contact with the car during containment and redirection. This method of post and rail separation performed satisfactorily on a 60 m length of barrier, but in severe impacts, on a 730 m length of fence, the rail stripped off the posts some way ahead of the vehicle, with the result that dynamic deflection of the barrier was excessive and long lengths of barrier were damaged.

Halving the post spacing from 3.2 m to 1.6 m overcame the defect, but this added considerably to the costs.

The overall height of the fence was fixed at about 760 mm with the centre height of the W-section beam at about 610 mm above ground level.

3.4.3 *The TCB fixed by shearbolts*

Early tests (circa 1966)

The second beam to post attachment investigated was by a small shear bolt which held the rail directly against the traffic face of the posts; on impact the shear joint fractured. Stiffer I-section posts with a cross-section of 75 mm × 38 mm were used, and the shear bolt size was found by experiment to be 8 mm diameter. This method of attachment was found to be superior to the tube method and it was also less expensive.

The beam centre height remained at 610 mm and the TCB shear bolt fence was subjected to a number of impact tests. A test on a 60 m length of barrier with a 1 360 kg, 66 mile/h car at 20° produced a maximum deflection of 91 mm with the post spacing at 3.2 m. A similar impact on a 730 m length of barrier with the same post spacing produced the same deflection. Halving the post spacing reduced barrier deflection to 76 mm but the exit angle increased from 4.5° to 10.5°.

The addition of a second rail, with metal cross bracing straps between beams and fixed at central points between posts, produced a double sided barrier suitable for use on the central reserve of a motorway (see Figure 16). A 71 mile/h test at 20° with a 1 360 kg car produced a barrier deflection of 685 mm. The car was deflected at a small angle and, on exit, returned to strike the barrier a second time.

Throughout this series of early tests, post footings of various types were investigated for fixing on structures such as bridges, driven into soil or mounted in concrete footings. It was clear that, if the post fixings or footings were sufficiently sound to develop the bending strength of the posts, the performance of the TCB barrier was independent of the variations in soil characteristics or post mountings.

Later tests (1988 to 1991)

Over the period of 20 years from the first development of the TCB it became necessary, through the changes in vehicle characteristics, requirements of UK and European Standards and the need to rationalize the manufacture and storage of barrier components, to carry out a series of confirmation tests on the TCB. The development of the Z-section post, discussed in **2.3**, which had been in use in the open box barrier since the 1970s, made the production of common barrier parts an economic benefit.

Resurfacing of one carriageway of a dual carriageway motorway temporarily effects the height of the safety barrier relative to the level of the road surface. For example a 75 mm overlay reduces the relative height at the resurfaced site by this amount and when the appropriate adjustment is made to the barrier level, the height relative to the unrepaired carriageway is in excess of the standard 610 mm to the centre of the beam.

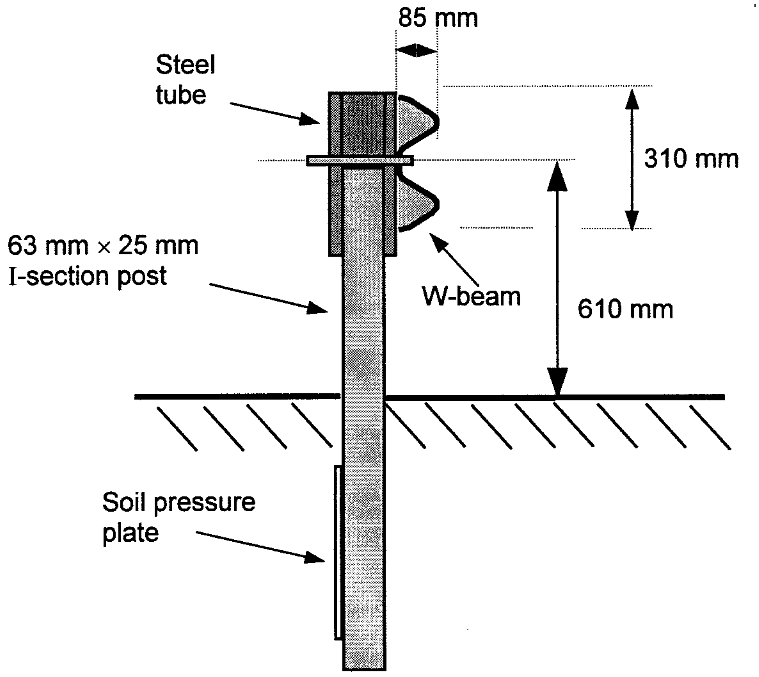


Figure 15 — Single sided TCB freely mounted on steel tubes

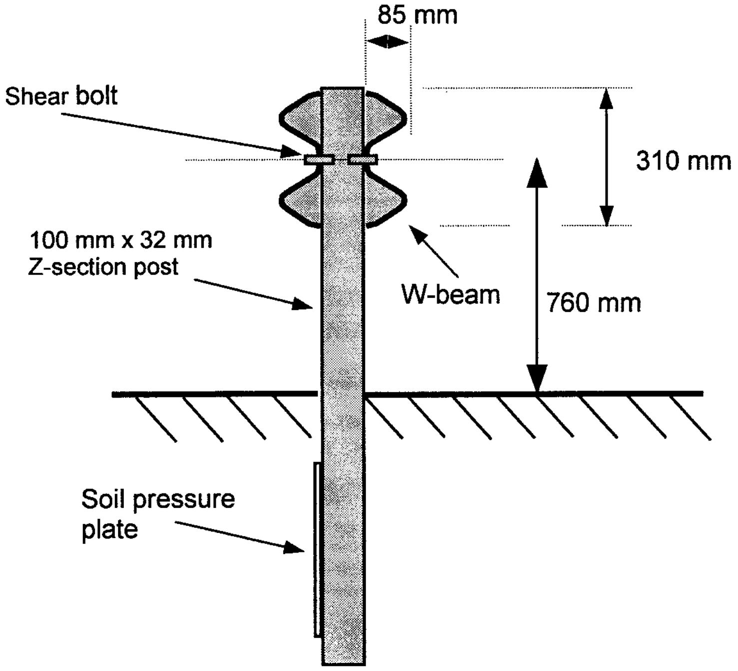


Figure 16 — Double sided TCB with shear bolts

Although this is to some extent a temporary condition that only exists during road repairs, the possible extent of the time lag between repairing opposing carriageway road surfaces led to the inclusion of a series of tests, within the revalidation program. Table 5 summarizes the series.

Within the permitted impact test tolerances, the standard test at 70 mile/h and 20° with a 1 500 kg car, into the single sided TCB barrier mounted at a central beam height of 610 mm above the surrounding surface, produced a dynamic deflection of 1.6 m (E176, Table 5). This same result was achieved when the 100 mm × 32 mm Z-section posts were replaced by 110 mm × 50 mm posts, normally used in the OBB barrier (F205, Table 5); the unexpected close similarity in the results could be accounted for by the fact that the recorded impact angle was 2° higher than in test E176; accordingly the impact energy was higher into the fence with the stronger posts. With halved post spacing the dynamic deflection reduced to 1.2 m, (E175, Table 5)

The double sided TCB produced a dynamic deflection of 1.3 m under a standard test, (J0006, Table 5); this reduced to 1.06 m when the distance between post centres was halved (J0005, Table 5).

In a number of tests to investigate vehicle impact response with beam heights above and below the standard level of 610 mm, the height was increased by 100 mm in D150, and reduced by 75 mm in D152. Whereas the high beam, as tested, was single sided to observe whether the car would drive under the more flexible barrier, the low height test was made with a double sided TCB to examine the likelihood of the vehicle rolling over the stiffer fence. Both tests proved successful, although the dynamic deflection for the high beam test was 2.1 m, that is 0.6 m more than the standard TCB barrier.

In addition, the double sided higher fence was tested by a 750 kg Mini car at a nominal speed of 70 mile/h at 20°, to reveal whether vehicle spinout could be induced in a small vehicle by direct wheel contact with posts permitted by the high beam fence. In the event, a dynamic deflection of 0.9 m was recorded and the car was safely redirected (D157, Table 5).

The TCB fence has been in continuous use on UK highways since the early 1970s and has proved successful in on-road vehicle impact experience. Safety barrier installers and maintenance teams have reported that in high ambient temperatures TCB rails, although tensioned as prescribed in instructions, can generate clearance gaps at the bolt tensioners spaced at 70 m intervals along the fence; this phenomenon is probably due to thermal expansion. The effect was examined in E174 wherein a gap of 25 mm slack was left at each tensioner in an installed test length of 115 m. A standard impact test showed that the recorded dynamic deflection at 1.87 m was 270 mm higher than the fully tensioned standard TCB fence; nevertheless the car was safely redirected.

3.4.4 *TCB and anti-glare screens*

A central reservation barrier forms a convenient structure on which to mount an anti-glare screen. For glare protection to include drivers of heavy vehicles, the overall height of the screen should be about 1.7 m. On motorways, a cut-off angle of 15° is sufficient for bends which have radii of curvature greater than 870 m. The mesh can be of plastic or metal. The mesh supports should be dropped into sockets welded to the cross bracing straps fitted to the double sided TCB. In this way the anti-glare screen is attached to the beams and not to the posts.

3.5 The tensioned rectangular hollow section barrier (RHS)

The British Steel Corporation (BSC), Tubes Division, in 1970, decided to use rectangular hollow section (RHS) steel beams, in the design of a vehicle safety barrier to meet the then growing requirement for the installation of barriers on UK highways.

To offer a wide field of application, to include a flexible as well as a more rigid barrier for use where roadside space was restricted, BSC successfully developed and dynamically tested two prototype designs.

The first uses 100 mm × 100 mm × 5 mm rectangular hollow section beams (RHS); and the second employs a larger cross-section at 200 mm × 100 mm × 5 mm; both are mounted on 100 mm × 32 mm × 5 mm, Z-section posts. Turn buckle tensioners are installed in the barrier length between end anchor blocks at maximum intervals of 70.5 m to eliminate slack, and so minimize the impact dynamic deflection. To pre-set the tension at installation, a tension measuring indicator is included in the line of the fence. (BS 6579-3 and -4. HCD; Vol. 3, Sect. 2 [3]).

The Z-section posts are connected to the rails by U-straps and shear bolts. The posts are spaced at 3.2 m. Concrete footings or soil mounted posts fitted with steel distribution plates can be used. The centre line of the horizontal beam is set at a height of 610 mm above the surrounding ground level (Figure 17).

The barrier is a weak post system. On impact the shear bolts fracture, the posts disconnect from the rails and are run down. During the period of the impact the horizontal beam maintains its operational height by frictional contact between the vehicle and the beam.

Table 6 presents some details of the series of development tests made by the BSC in 1971/74. The result of test number 6 (1972) led to the approval of the 100 mm × 100 mm × 5 mm RHS barrier for use on UK highways where it was mounted over a hardened surrounding surface. The requirement for the hardened surface prevented the possibility of the barrier being ridden down, or under run, on undulating surfaces such as on ill prepared verges or central medians.

Table 5 — Table of tests on tensioned corrugated beam barrier (TCB)

Test no.	Date	Inertial mass of vehicle kg	Inertial mass of dummy kg	Speed km/h	Impact angle degrees	Barrier type	Height to beam centre mm	Post spacing and cross-section mm	Intrusion length m	Maximum deflection m	THIV[a] (side = 0.3m) m/s	Comment
D150	8.5.87	1 442	75	113.4	20.0	Single sided	610 +100	3 200 100 × 32 × 5	19.2	2.1	4.7	High beam standard posts
D152	12.5.87	1 442	75	114.2	20	Double sided	610 −75	3 200 100 × 32 × 5	35.8	1.5	4.7	Low beam double sided
D157	23.7.87	750	75	115.3	20.0	Single sided	610 +100	3 200 100 × 32 × 5	12.8	0.9	6.5	High beam (Mini car)
E174	25.3.88	1 435	75	116.3	19.5	Single sided	610 +0	3 200 100 × 32 × 5	27.5	1.87	4.7	25 mm slack at adjuster
E175	6.4.88	1 435	75	116.0	20.0	Single sided	610 +0	1 600 100 × 32 × 5	15.2	1.2	5.9	Half post spacings
E176	19.4.88	1 465	75	113.8	19.0	Single sided	610 +0	3 200 100 × 32 × 6	20.5	1.6	4.3	Standard height
F205	16.3.89	1 498	0	114.8	21.0	Single sided	610 +0	3 200 110 × 50 × 5	20.5	1.6	—	OBB posts
J0005	5.9.91	1 445	75	113.9	20.0	Double sided	610 +0	1 600 100 × 32 × 5	9.6	1.06	6.1	Half post spacings
J0006	11.9.91	1 440	75	112.6	20.0	Double sided	610 +0	3 200 100 × 32 × 5	19.2	1.3	5.2	Standard double sided

[a] Definitions of PHD and THIV are given in PD 6634-2, **7.6**.

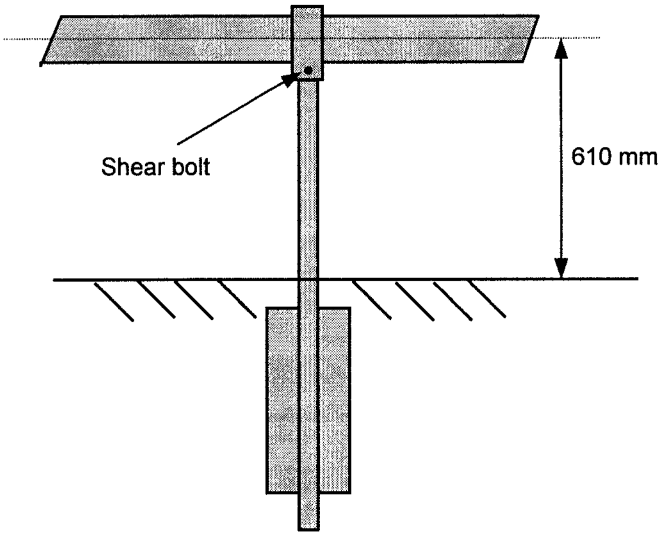


Figure 17 — Tensioned rectangular hollow section barrier (RHS)

The increased depth of face of the RHS, from 100 mm × 100 mm to 200 mm × 100 mm × 5 mm beam section, overcame the problem of uneven surfaces; the barrier was authorized for use on UK roads after completing test number 1 (23.4.74).

Although at the time the European Standard EN 1317 was not in force, further validation tests, supported by the Highways Agency, were made in 1995 according to containment level N2. This requires successful performance of a barrier when subjected to impact at 20° by a 100 km/h, 900 kg car, including a dummy, and by a 1 500 kg car at 113 km/h. Both the 100 mm × 100 mm × 5 mm and the 200 mm × 100 mm × 5 mm tensioned RHS barriers proved successful (tests N0015 to N0018, Table 6).

Table 6 — Table of tests on rectangular hollow section barrier (RHS)

Test no.	**Date**	**Inertial mass of vehicle** kg	**Inertial mass of dummy** kg	**Speed** km/h	**Impact angle** degrees	**Barrier type**	**Height to beam centre** mm	**Post spacing and cross-section** mm	**Intrusion length** m	**Maximum deflection,** m **PHD THIV**[a] (side=0.3m)	**Comment**
1	1971	1 360		60	20	100 × 100 × 5 Grade 43		3 200 100 × 32 × 5Z		0.48 — —	Test OK CE/73/47/1/A
2	1971	1 360		76	20	100 × 100 × 5 Grade 43		3 200 100 × 32 × 5Z		0.86 — —	Car contained
3	1971	1 360		113	20	100 × 100 × 5 Grade 43		3 200 100 × 32 × 5Z		1.52 — —	Car contained
4	1971	1 360		105	20	100 × 100 × 5 Grade 43		3 200 100 × 32 × 5Z		— — —	U-clips failed Car rode over rail
5	1971	1 360		97	20	100 × 100 × 5 new U-clips		3 200 100 × 32 × 5Z		1.07 — —	Car contained
6	1972	1 360		105	20	100 × 100 × 5 Grade 50 Tensioner		3 200 100 × 32 × 5Z		1.17 — —	Barrier approved for hard surfaces CE73/47/1/A
1	23.4.74	1 360		120	20	200 × 100 × 5 Grade 43 Tensioner	610	3 200 100 × 32 × 5Z	13.0	0.86 — —	Barrier approved for all surfaces CE73/121
N0015	13.2.95	833	75	100.4	19.5	200 × 100 × 5	610	3 200 100 × 32 × 5Z	9.3	0.8 49 6.0	N2 small car TB11 Euro test
N0016	16.2.95	1 502		113.3	21	200 × 100 × 5	610	3 200	13.8	1.38 71.6 6.7	N2 car test TB32 Euro test
N0017	23.2.95	825	75	100.9	20	100 × 100 × 5	610	3 200 100 × 32 × 5Z	13.0	0.82 48.1 5.2	N2 small car TB11 Euro test
N0018	27.2.95	1 505		114.5	20	100 × 100 × 5	610	3 200 100 × 32 × 5Z	117.2	1.58 53.0 4.7	N2 car test TB32 Euro test

[a] Definitions of PHD and THIV are given in PD 6634-2, **7.6**.

3.6 The open box beam safety barrier (OBB)

3.6.1 *Background to development of higher containment classes*

The open box beam (OBB) safety barrier was developed to provide vehicle containment, on high speed roads, in locations were there was insufficient width for fence deflection, to permit the use of more flexible fences such as the tensioned corrugated beam barrier. Vehicle containment levels had historically developed and eventually concentrated on the standard impact by a 113 km/h, 1 500 kg car at an angle of 20° to the line of the barrier with a supplementary impact at the same speed and angle by a 750 kg small car. Initially the small car test was introduced to monitor and observe safe redirection without spinout or rollover. The requirement for this type of test increased with the proposed harmonization of European Standards, in which a 900 kg small car test including a 75 kg dummy, is mandatory (PD 6634-2:1998, Table 1).

To complete this brief review of UK experience and requirements, test impact conditions for barriers used in some restricted speed zones can be reduced to 80 km/h for the 1 500 kg car impact at 20°; this is shown as class N1 (low) in Table 7.

The enhanced normal containment class does not appear in EN 1317. It relates to early work in the UK on the development of safety barriers of higher containment level than the normal class, in which a 5 000 kg single deck coach was used as the test vehicle (see BS 6579-1).

Analysis had shown that the inclusion of safety barriers on UK highways to contain heavy commercial vehicles (HCVs) was not an economic proposition for the installation of long lengths on motorways (PD 6634-2:1998, clause **2**). Nevertheless it had been noted that sensitive areas, near to bridge piers, lighting columns, gantry signs, buildings or embankments, should be considered for protection against higher energy collisions than the standard impact. The OBB barrier was specifically introduced to provide a post and rail barrier that could provide protection in such locations.

Taking into account the progressive development of impact test criteria in the UK and the European harmonization of barrier performance standards (EN 1317), Table 7 offers a provisional test matrix of vehicle impact containment classes that would meet UK requirements in the future, for both safety barriers and bridge parapets.

Table 7 — Provisional UK vehicle containment classes for safety barriers and bridge parapets

Containment class	Mass kg	Speed km/h	Impact angle degrees
N1 (low)	1 500	80	20
N2 (normal)	1 500 900	110 100	20 20
Enhanced N2 (normal)	5 000	65	20
Safety barriers H4b (very high)	38 000 900	65 100	20 20
Bridge parapets H4a (very high)	30 000 900	65 100	20 20

3.6.2 *Single height, single and double sided OBB*

Single height single sided OBB

Figure 18 shows a sketch of the single beam height, double sided version of the open box beam barrier (SHDS OBB). The provision of a shear bolt connecting the beams to the posts was carried over from the TCB safety barrier.

The single sided version (SHSS) was first tested in August 1969 and proved successful under impact by a 1 488 kg car at 102 km/h and 20° (Jehu and Pearson: 1972 [15]).

The maximum wheel penetration at 0.6 m was about two-thirds that of a single sided TCB barrier. A 5 035 kg coach, tested at 88 km/h at 19°, rolled over the single height barrier.

Revalidation tests in the Spring of 1988 with the standard 1 500 kg car at 117.1 km/h at 19° revealed a deflection of 1.05 m (E179, Table 8), compared with 1.6 m for the revalidated TCB barrier (E176, Table 5). That is, the single height single sided OBB barrier met the standard test; also the two-thirds penetration ratio was repeated and confirmed. The post spacing was reduced by one-half (E177, Table 8) and the dynamic penetration reduced to 0.6 m.

To investigate stability of a Mini car impact, the SHSS OBB barrier was raised 100 mm in height from 610 mm and impacted by a 114.9 km/h, 686 kg Mini car containing a 75 kg dummy (E180, Table 8). The vehicle was safely redirected after penetrating the barrier a distance of 0.63 m.

Single height double sided OBB

The single height double sided OBB barrier (SHDS OBB) was successfully tested in May 1988 (E181, Table 8). The penetration reduced from 1.05 m to 0.97 m compared with the single sided version. The beam height was then lowered by 75 mm to investigate the possibility of rollover. A re-test with a standard 1 500 kg car impact proved satisfactory for containment and redirection of the vehicle; the deflection was 0.80 m.

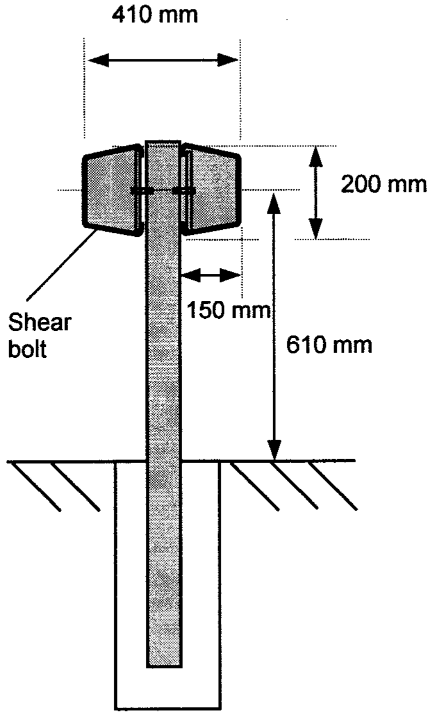


Figure 18 — Single height double sided OBB barrier

3.6.3 *Double height, double and single sided OBB*

Double height single sided OBB

With the failure of the single height OBB to contain the 5 000 kg coach, a second rail at a height of 1 020 mm was added to the single height fence to produce the double height single sided open box barrier (DHSS OBB); the concept of impact fracturing a shear bolt connecting the beams to the posts was retained.

A test in May 1970 with a 5 194 kg, 80 km/h coach impacting at 20° was successful (Jehu and Pearson: 1972 [15]). The coach was contained in a deflection distance of 1.0 m and redirected. However, with an increase in impact speed from 80 km/h to 90 km/h the coach was redirected, but overturned after it had left contact with the fence.

To date, no further tests have been carried out on the DHSS OBB barrier mounted on steel Z-section posts. Later, double height OBB beams were mounted on frangible aluminium posts and tested (Jehu: 1972 [16]); they are discussed in PD 6634-4, under the heading of bridge parapets.

Double height double sided OBB

Following the addition of a higher rail to the OBB barrier the barrier was further stiffened to a double height double sided barrier (DHDS OBB). The intention was to develop a high containment barrier for restricted use in highway locations where vulnerable buildings or roadside features such as bridge piers or gantries must be protected (Laker: 1986 [17]).

The DHDS OBB has been designed to use, so far as possible, components based on the single height OBB (a cross-section is shown in Figure 19). The fence consists of four parallel beams set on either side of the posts, at heights of 610 mm and 1 020 mm. These are supported by Z-section posts set 2.4 m apart, from which they are blocked out by lengths of Z-section material. The blocking out sections are attached to the posts by single shear bolts designed to fracture on vehicle impact. This allows the fence beams to remain at full height by frictional contact with the vehicle, while the posts are run down. Between posts, the beams are braced by cross structured frames to hold them in rectangular position.

The small and medium cars (A100, A103, Table 8), the 16 t HCV (A106), the 30 t HCV (A105), the 39 t articulated HCV (A22) and the 14 t passenger coach (A102) were all contained in the 15° impacts, although the 30 t HCV eventually overturned on the fence after leaving it at a small exit angle.

The limit of high containment of the DHSS OBB fence was investigated by increasing the impact angle to 25°. This is equivalent to increasing the impact energy due to the component of velocity normal to the barrier, by a factor of 2.7 times. The medium sized car (B112) experienced severe deceleration when the road wheel impacted the base of the posts. It was clear that a lower, or rubbing, rail was necessary to protect the car from direct contact with the posts.

The HCV 25° impact (B113) tested the fence beyond its limit.

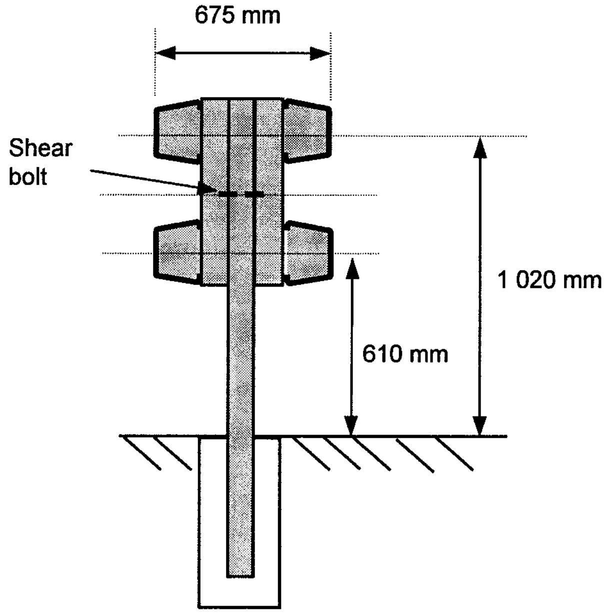


Figure 19 — Double height double sided OBB barrier

Table 8 — Table of tests on open box beam barrier (OBB)

Test no.	Date	Inertial mass of vehicle	Inertial mass of dummy	Speed	Impact angle	Barrier type	Height to centre	Post spacing m and cross-section	Intrusion length	Maximum deflection	THIV[a] (Side =0.3 m)	Comment
		kg	kg	km/h	degrees		mm	mm	m	m	m/s	
A21	1.11.83	16 460	—	83.0	15	DHDS	610 1 020	2.4 125 × 90 × 6	60.0	0.80	—	HCV-rigid 2-axle Load moved
A22	10.11.83	39 100	—	81.0	15	DHDS	610 1 020	2.4 125 × 90 × 6	42.0	1.75	—	HCV-artic. 5-axle
A100	17.4.84	780	—	116.5	5	DHDS	610 1 020	2.4 125 × 90 × 6	6.0	0.09	—	Mini car
A102	17.5.84	14 290	—	91.6	15	DHDS	610 1 020	2.4 125 × 90 × 6	17.0	1.14	—	Coach high-floor
A103	21.5.84	986	—	116.3	15	DHDS	610 1 020	2.4 125 × 90 × 6	5.0	0.25		Medium car
A105	10.7.84	30 750	—	82.5	15	DHDS	610 1 020	2.4 125 × 90 × 6	> 50.0	1.40	—	HCV rigid 4-axle Overturned
A106	19.9.84	16 300	—	81.8	15	DHDS	610 1 020	2.4 125 × 90 × 6	25.0	1.22	—	HCV-rigid 2-axle
B112	15.5.85	1 038	75	111.9	25	DHDS	610 1 020	2.4 125 × 90 × 6	13.0	0.40	7.7	Medium car Snagged, spinout
B113	17.5.85	16 700	—	80.3	25	DHDS	610 1 020	2.4 125 × 90 × 6	> 40	Breached fence	—	HCV-rigid 2-axle Overturned
B116	19.6.85	1 500	—	114.2	20	SHSS	610	2.4 110 × 50 × 5	13.0	0.98	—	Standard car Beam steel poor
B117	9.7.85	140 000	—	16.0	25	DHDS	610 1 020	2.4 125 × 90 × 6	21.0	1.30	—	VHCV-artic. 5-axle
C122	24.10.85	1 030	75	116.3	25	DHDS	400 1 020	2.4 125 × 90 × 6	18.0	0.30	7.7	Medium car, low rail, spinout
C123	15.11.85	1 442	75	118.7	25	THDS	300, 610 1 020	2.4 125 × 90 × 6	3.5	0.27	8.9	Standard car
C125	3.12.85	16 300	—	66.9	25	THDS	300, 610 1 020	2.4 125 × 90 × 60	—	1.16	2.8	HCV-rigid 2-axle Mounted fence
C127	24.4.86	1 461	75	117.8	20	SHSS on long bolts	610 Noise panel 2m	2.4 I-127 × 60	12.0	0.49	6.5	Standard test on energy brackets
C128	2.5.86	1 493	75	117.6	21	SHSS on long bolts	610 Noise panel 2m	2.4 I-152 × 76	10.0	0.41	6.8	Standard test on energy brackets
C129	9.5.86	1 011	75	115.8	20	SHSS on short bolts	610 Noise panel 2m	2.4 I-152 × 76	10.0	0.30	8.1	Medium car on energy brackets
E177	22.4.88	1 414	75	115.4	19	SHSS	610	1.24 110 × 50 × 5	12.0	0.60	6.3	Standard car test. ½ spacing
E179	6.5.88	1 452	75	117.1	19.5	SHSS	610	2.4 110 × 50 × 5	16.0	1.05	5.5	Standard car test

Table 8 — Table of tests on open box beam barrier (OBB) *(continued)*

Test no.	Date	Inertial mass of vehicle	Inertial mass of dummy	Speed	Impact angle	Barrier type	Height to centre	Post spacing m and cross-section	Intrusion length	Maximum deflection	THIV[a] (Side= 0.3 m)	Comment
		kg	kg	km/h	degrees		mm	mm	m	m	m/s	
E180	11.5.88	686	75	114.9	19.5	SHSS	610 + 100	2.4 110 × 50 × 5	10.0	0.63	6.9	Small car High beam
E181	19.5.88	1 433	75	115.8	20	SHDS	610	2.4 110 × 50 × 5	14.0	0.97	5.5	Standard test on double sided
E182	13.6.88	1 448	75	115.4	20	SHDS	610 - 75	2.4 110 × 50 × 5	20.0	0.80	6.6	Standard test on low beam
F201	2.12.88	1 435	75	116.3	19.5	DHDS	610 1 020	2.4 125 × 90 × 60	>15	0.30	7.5	Standard test on DHDS

[a] A definition of THIV is given in PD 6634-2, **7.6**.

3.6.4 *Triple height, double sided OBB*

The increase in impact angle from 15° to 25° had caused the 16 t, 25° impact to give the fence a higher energy blow than either the 39 t or the 30 t HCVs at 15°. A third open box rail was added at a height of 300 mm to the double height barrier to form the triple height double sided open box beam barrier (THDS OBB).

The THDS OBB fence was successful in containing and safely redirecting a 1 442 kg car, containing a 75 kg dummy, impacting at 118.7 km/h and 25° (C123); the rubbing rail had proved successful.

The 80.3 km/h, 25°, 16 t HCV test which failed on the DHDS OBB (B113) was repeated on the THDS barrier at the lower speed of 66.9 km/h (C125). At this speed the energy blow due to the lateral velocity component was 1.8 times higher than the 15° test at 81.8 km/h (A106). The 16 t vehicle was contained and redirected by the THDS OBB barrier although it overturned on the fence, but the vehicle eventually came to rest on the impact side of the fence. No impacts at 15° were made on the THDS OBB; it was judged likely to produce the same or better containment than the DHDS OBB.

4 Concrete safety barriers

4.1 General

The use of concrete to restrain vehicles from leaving the carriageway has been commonly used in the construction of bridge parapets for many decades. Its use in the manufacture of roadside longitudinal safety barriers, although prevalent in the USA and many European countries, had not been extensively employed in the UK when research on the subject began at TRL in the mid 1980s.

Concrete safety barriers are particularly useful where the space for barrier deflection is limited, where it is advantageous for the collision induced stresses to be distributed along the length of the foundation and where access for maintenance is restricted.

Controlled impact tests on bridge parapets in the late 1960s had shown that cars experience high levels of deceleration when redirected by concrete parapets. Methods of cushioning the blow were developed by fixing energy absorbing material to the parapet face (Jehu and Laker: 1972 [18]) and by shaping the profile to redirect the road wheels to steer away from the parapet. Unfortunately, shaped profiles tend to induce small vehicles to overturn, as demonstrated in controlled tests (Jehu and Pearson: 1977 [19]) and confirmed by on-road accidents both in Europe and the USA (Viner: 1984 [20]). For this reason concrete barriers with a shaped profile were limited to 80 km/h speed zones in the United Kingdom.

Later paragraphs discuss preliminary work on other profiles that led to the design of near-vertical face concrete barriers, whose performance under impact made them suitable for use on UK high speed roads (113 km/h), for the containment of both private and heavy commercial vehicles (HCVs).

4.2 The British concrete barrier (BCB)

The development of the next generation of safety barriers for containment of HCVs began with barriers manufactured in steel, and was quickly followed by pre-cast and slip formed concrete designs.

The British concrete barrier (BCB) was based on early work carried out at TRL on shaped concrete parapet profiles (Jehu and Pearson: 1977 [19]). A cross-section of the BCB is shown in Figure 20 and is detailed in BS 6579-8. The barrier tested consisted of pre-cast units, 3 m in length, fixed by six dowel pins per unit, onto a concrete foundation, flush with the road surface; alternative methods are given in BS 6579-8. The units were linked together by simple vertical tongued and grooved joints.

The BCB was subjected to a series of four impact tests during 1984/85 (Table 9). The nominal planned impact angle for all tests was 15°. The medium car test (B108) at a speed of 115 km/h and a Mini car test at 103 km/h (A108) were successful; so also was a HCV test with a 16.5 t, 2-axle vehicle at 80.9 km/h (A107). However, the BCB was breached by 38 t 84 km/h, 5-axle articulated test (B110). During the impact, virtually all the axles were stripped from the chassis.

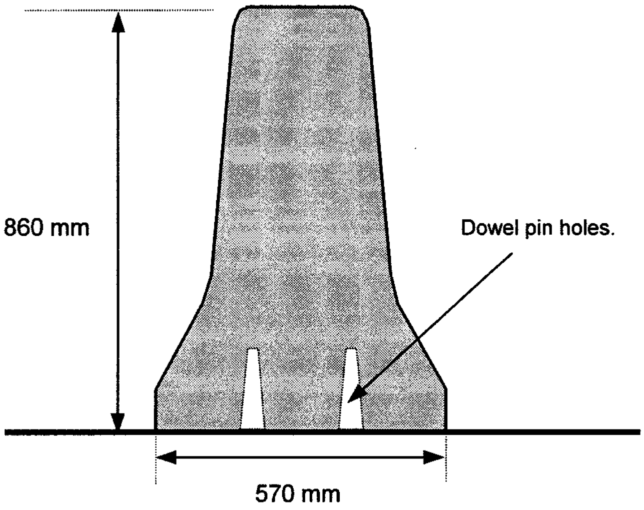


Figure 20 — The British concrete barrier (BCB) — Section

The tests had shown that a surface mounted BCB had considerable potential for containment of the 16 t rigid HCV, but its containment capacity was exceeded by a 38 t articulated HCV impact at about the same speed.

Although the Mini car did not overturn at the test speed of 103 km/h, the vehicle roll angle was prominent. The leading road wheel climbed up to three-quarters the height of the barrier.

Due to this tendency for small vehicles to ride up the sloping profile, the British concrete barrier is restricted to use in speed zones up to 80 km/h. In a commercial vehicle test, the BCB satisfactorily contained and redirected an 80 km/h, 16 t HCV impact at 15° although the roll angle, at about 31°, was high and there was considerable torsional flexing of the chassis (Laker: 1986 [17]; Laker: 1988 [21]; Gutteridge: 1994 [22]; Macdonald: 1992 [23]).

4.3 The near vertical concrete barrier (VCB)

The test on the BCB with a Mini car impact at 15° and 103 km/h had shown considerable roll in the vehicle response. In consequence the impact test was re-run at the higher speed of 112 km/h at an angle of 20°, into a high containment P6 prototype concrete parapet, which, although higher than the BCB at 1.5 m in overall height, had a sloped face at its base similar in profile to the BCB (C118, Table 9). The test resulted in the Mini car climbing high up the face of the parapet and then overturning. Figure 21 shows the car at 90° to the face of the parapet just before it completely rolled and pitched.

A bridge parapet designed by G Maunsel and Partners (UK), installed on the elevated sections of the M5 and M6 motorways, known as the Midlands Link Parapet, has a near vertical profile about 800 mm high, capped by a steel rail, giving an overall height to the parapet of about 1.33 m.

During a series of vehicle impact tests to establish that the Midlands Link parapet met UK standard requirements for the containment of a 1.5 t car, TRL took the opportunity to examine the response of a 650 kg Mini car impact at 113 km/h, along an approach path at 20° to the barrier face (B114, Table 9).

Although the impact was severe, as expected from collision with a rigid structure, the vehicle was successfully redirected in a stable condition along a departure path 5° to the line of the parapet. Figure 22 shows the steady level position of the Mini car whilst in contact with the vertical face of the Midlands Link parapet, in contrast to a Mini car response during impact with the shaped profile of the P6 parapet in Figure 21. The vehicle roll angle against the vertical face parapet was a maximum of 12° away from the barrier. In the case of the shaped profile the vehicle violently rolled over and pitched onto the bonnet during a series of overturns.

It was the observation of the steady impact response of the Mini car against the vertical face of the Midlands Link parapet in test B114 (Table 9), that led to the development of the near vertical concrete barrier (VCB).

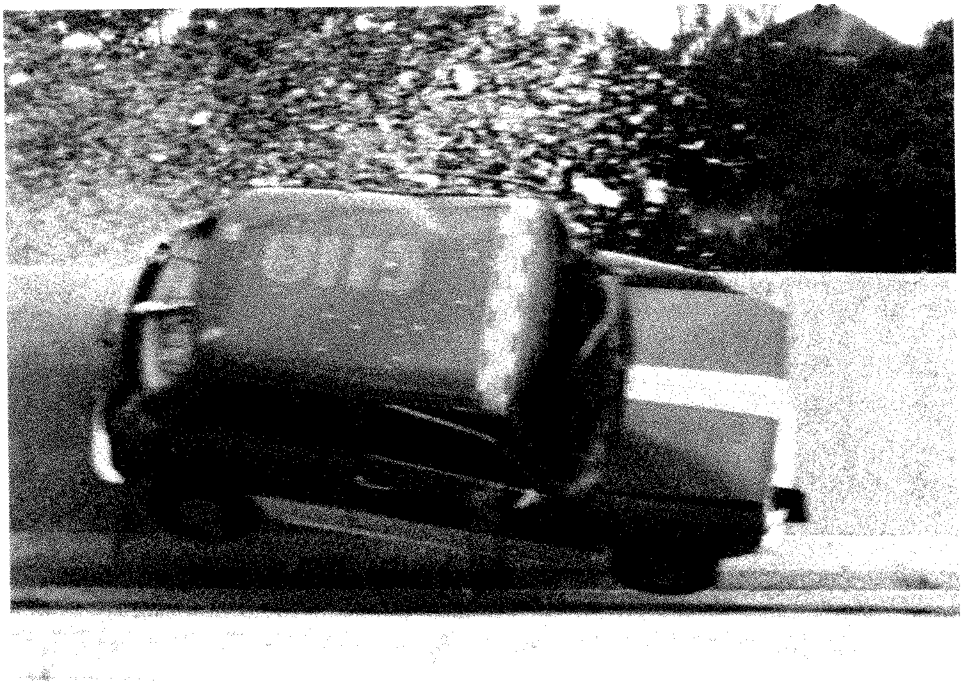


Figure 21 — Test C118 — P6 concrete parapet — Shaped profile

Table 9 — Table of tests on concrete barriers

Test no.	Date	Inertial mass of vehicle kg	Inertial mass of dummy kg	Speed km/h	Impact angle °	Barrier type and foundation	Shape and key joints	Height/ section length mm	Damage m	Maximum deflection, m	PHD	THIV[a] (side=0.3m)	Comment
A107	18.10.84	16 500 HCV 2-axle	—	80.9	14	BCB - dowels 6 × 25mm	Sloped face: T&G joint	806 3 000	18.0	50	—	—	Satisfactory
A108	14.11.84	639	75	102.5	15	BCB - dowels 6 × 25mm	Sloped face T&G joint	806 3 000	Small crack	Zero	—	7.1	Satisfactory
B108	8.1.85	986	75	114.7	15	BCB - dowels 6 × 25mm	Sloped face: T&G joint	806 3 000	Small crack	Zero	—	7.3	Satisfactory
B110	23.1.85	38 000 HCV artic	—	83.8	15	BCB - dowels 6 × 25mm	Sloped face: T&G joint	806 3 000	24.0	—	—	2.8	Barrier breached
B114	21.5.85	596	75	112.6	20	Midlands Link Parapet	Vertical face	Face: 800 Rail: +340	Minor	Zero	—	9,8	Satisfactory, but exceeded THIV
C118	22.8.85	610	75	112.0	20	P6 Concrete in-situ parapet	Sloped face	Face: 255 Tot: 1 500	Minor	Zero	—	9.4	Mini overturned; THIV exceeded
C137	15.7.86	602	75	115.4	20	VCB 210mm trench	Vertical face: T&G joint	790 3 000	Small cracks	Zero	—	10.0	Exceeded THIV values of 9.0 m/s
C138	23.7.86	1 431	75	113.4	20	VCB 210mm trench	Vertical face T&G joint	790 3 000	small cracks	Small	—	8.2	Satisfactory
D143	24.10.86	1 434	75	114.5	20	VCB: 3-bolts 210mm trench	Vertical face: scarf joint	790 3 000	Superficial	Small	—	8.0	Satisfactory
D145	18.11.86	15 900 HCV 2-axle	—	79.6	15	VCB: 3-bolts 210mm trench	Vertical face: scarf joint	790 3 000	6.00	Small	—	3.0	HCV rolled over barrier
D147	8.4.87	16 100 HCV 2-axle	—	79.2	15	VCB: 3-bolts 210mm trench	Vertical face: scarf joint	790 3 000	9.00	Small	—	2.6	Extra load fixing: HCV rolled over
F188	7.12.88	1 460	75	81.9	21	TBCB surface mounted	Sloped face: hinged joint	806 3 000	Chipped	0.65	—	6.9	Satisfactory, but high deflection
F203	2.2.89	1 433	75	82.7	20	TVCB: 2-bolts surface mounted	Vertical face: scarf joint	800 3 000	Cracks	0.15	—	3.7	Satisfactory
G210	23.11.89	16 500 HCV 2-axle	—	79.8	15	TVCB: 2-bolts surface mounted	Vertical face: scarf joint	800 3 000	15.0	0.9	—	2.7	Barrier breached wrong hand joint

Table 9 — Table of tests on concrete barriers *(continued)*

Test no.	**Date**	**Inertial mass of vehicle** kg	**Inertial mass of dummy** kg	**Speed** km/h	**Impact angle** °	**Barrier type and foundation**	**Shape and key joints**	**Height/ section length** mm	**Damage** m	**Maximum deflection,** m **PHD THIV**[a] (side=0.3m)	**Comment**
G211	11.7.90	16 200 HCV 2-axle	—	80.8	15	HVCB 250 mm trench	Vertical face: slip formed	1 200	Superficial	0.013 — 3.8	Satisfactory: 8 re/bar rods
G212	25.7.90	16 500 HCV 2-axle	—	81.9	15	HVCB 250 mm trench	Vertical face: slip formed	1 200	Superficial	0.04 — 3.8	HCV rolled onto its side: 12 rods
H213	19.12.90	16 600 HCV 2-axle	—	80.6	20	HVCB 250 mm trench	Vertical face: slip formed	1 200	Concrete dislodged	0.05 — 4.3	HCV rolled on barrier: 8 rods
H0002	27.6.91	21 500 HCV 4-axle	—	83.7	20	HVCB 250 mm trench	Vertical face: slip formed	1 200	Superficial	n/r — 4.9	Satisfactory: 12 re/bar rods
J0014		30 330 HCV 4-axle	—	63.0	20.5	HVCB: 250 mm trench	Vertical face: slip formed	1 200	Superficial	n/r — 3.3	Satisfactory: 12 re/bar rods
L0020	27.1.93	30 400 HCV 4-axle	—	64.4	20.5	THVCB: 3-bolts: 200 mm trench	Vertical face: scarf joint	1 200 3 000	Superficial	0.04 27.9 4.0	Satisfactory
L0026	16.3.93	30 100 HCV 4-axle	—	67.0	21	THVCB: 3-bolts: 200 mm trench	Vertical face: scarf joint	1 200 3 000	Barrier toppled	n/r 26.0 2.9	HCV overturned
M0041	20.1.94	1 505	75	113.5	20	TVCB: 2-bolts: surface mounted	Vertical face: scarf joint	800 3 000	Cracks	0.35 66.0 7.7	Satisfactory: 8.8 grade bolts
M0044	10.2.94	1 500	75	113.9	20	TVCB: 2-bolts: surface mounted	Vertical face: scarf joint	800 3 000	9.0	0.57 163.5 6.5	Satisfactory: 4.6 grade bolts
M0046	17.3.95	1 500	75	115.1 75	20	TVCB: 2-bolts: surface mounted	Vertical face: scarf joint	800 3 000	18.0	0.45 77.0 7.2	Satisfactory: shear links +8.8

[a] Definitions of PHD and THIV are given in PD 6634-2, **7.6**.

Figure 22 — Test B114 — Midlands link — Vertical profile

It is of some interest to note that the P6 parapet had a raised kerb, or walkway, 75 mm high by 600 mm in width, and the Midlands Link kerb had a kerb of 100 mm high by 1 130 mm in width, laid at the front of each parapet. Close examination of high speed ciné film revealed the kerbs had little effect on the roll attitude of either car. The travel of the wheel suspension system absorbed most of the kerb height as the cars crossed the walkway just before impacting the barrier at an angle of 20°. The roll angle on the vehicles at the moment the cars first touched the parapets was measured at 2.5° and 5° respectively. The inference is that kerbs, or walkways, of about 100 mm in height and 110 mm in width, set in front of a parapet or barrier, will not affect the barrier's impact performance for high speed impacts. There is bound to be a trade-off where the barrier is set some distance back from the level of the normal road running surface, where the amount of set back is sufficient for the vehicle suspension to recover its running height, before impact takes place.

In those cases the barrier is set at a height relative to its surrounding ground level, rather than to the approach level of the carriageway or normal running surface.

The VCB was subjected to a series of tests with cars and HCVs during 1986/87 (Table 9). The barrier cross-section is shown in Figure 23. Initially 3.0 m long pre-cast units were linked together by a tongue and grooved joint and embedded in a trench about 225 mm in depth. The first tests revealed unacceptable fracturing of the tongue and grooved joint and so it was redesigned in the form of a reinforced scarf joint (Figure 25) clamped together by three bolts per section, later reduced to two (BS 6579-9).

The Mini car (C137) and standard car test (C138 and C143) proved successful regarding containment and redirection of the vehicles. However, in the Mini car test the impact severity criterion, THIV, value was within the 9 m/s threshold for the then UK defined occupant box size of 0.6 m (front) by 0.2 m (side), but on increasing the side width to 0.3 m to conform with the European Standard EN 1317, the THIV value was exceeded (Table 9).

Impact tests with a 16 t, 2-axle, HCVs at nominal speeds of 80 km/h at 15° were not fully successful (D145, D147). Although the vehicles were contained and the barrier was not breached, the shift in the concrete block ballast loads caused the HCVs to partially roll over the barrier at the end of the test length.

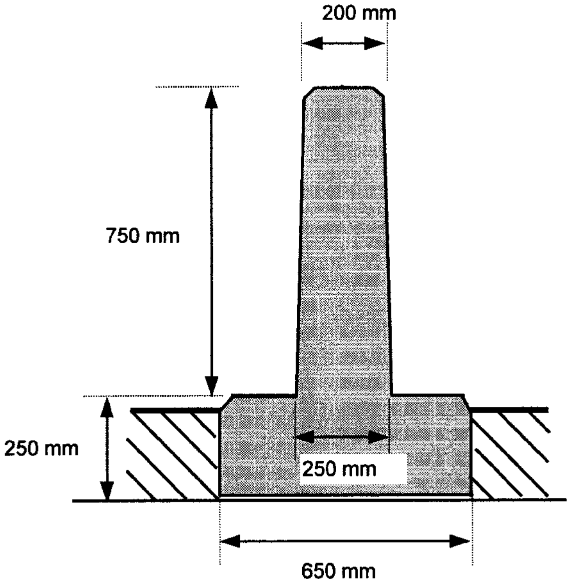


Figure 23 — The near vertical concrete barrier

4.4 The temporary BCB (TBCB) and temporary VCB (TVCB)

Temporary concrete safety barriers are intended to provide vehicle containment and redirection under impact, and also provide protection to operators working close to traffic lanes where vehicles speeds are limited to 80 km/h.

As a benefit of their simple ground surface mounting, the barriers are portable from site to site. The pre-cast units of 3.0 m in length are coupled, or hinged together, on a free standing surface and accordingly some lateral displacement is likely when struck by a vehicle at speed.

The pre-cast 3.0 m lengths of the temporary British concrete barrier [TBCB: Figure 24a)] are linked together by metal loops embedded in the ends of the units, locked together by steel pins to form a loose hinge. A test with a 1 500 kg car at 21° and 81.9 km/h, produced a barrier deflection of 0.65 m.

The result was not satisfactory: there was a pronounced tendency for the car to run up the face of the barrier and, in so doing, cause the unacceptably large deflection of 0.65 m within a short length of about two barrier units (F188, Table 9).

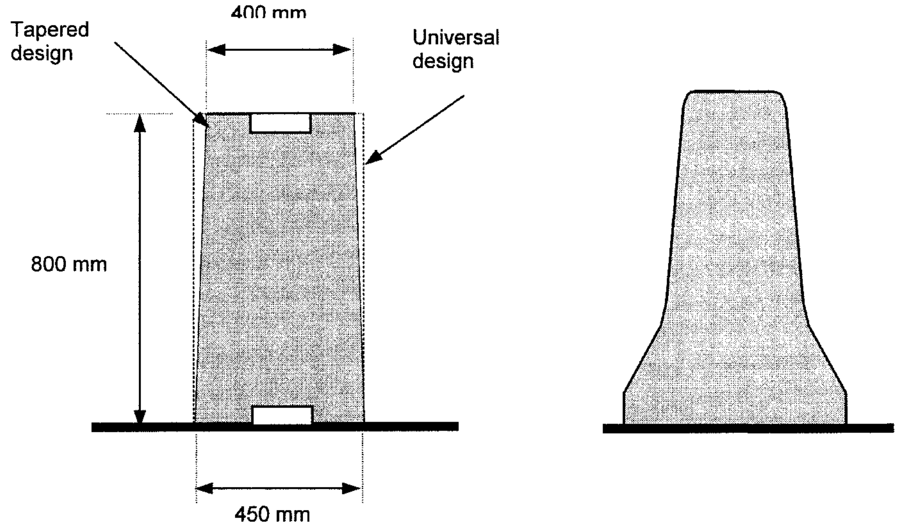
The near vertical concrete barrier was modified to form two free standing designs, shown in Figure 24b). Both are known as the temporary vertical concrete barrier (TVCB). The first design reproduced the near vertical, or tapered face of the VCB; the second design introduced a unit with an absolute vertical face.

The need for completely vertical barriers derives from the fact that the scarf joint between barrier units is sensitive to the direction of traffic flow (Figure 25). Vehicle contact during impact across the length of two units must cause the joint to close against the concrete faces and not to rely solely on the tensile strengths of the bolts. For example, if a TVCB barrier was subsequently moved bodily across the carriageway, the impact from traffic travelling in the opposite direction would tend to open the joint. However, if the barrier was inverted as well as being transversely moved across opposing traffic lanes, the appropriate impact conditions for the scarf joint would be correctly re-imposed. The absolute vertical face permits the barrier to be inverted without detriment to its performance.

The TVCB was successfully tested with a 1 500 kg car at a speed of 82.7 km/h at an angle of 20° (F203, Table 9). The barrier deflection reduced from 0.65 m for the hinged TBCB to 0.15 m for the bolted scarf joint TVCB. The tendency for the car to climb the face of the barrier was removed.

Three further tests (M0041, M0044 and M0046, Table 9) were made on the TVCB in accordance with the European EN 1317 Standard, with a 1 500 kg car at a nominal speed of 113 km/h at 20°. The principle of the scarf joint between pre-cast units was preserved and joint strengths were investigated by use of improved grades of bolt steel and added metal sheer links. All the tests proved successful: barrier deflections ranged from 0.35 m to 0.57 m.

The TVCB was tested by impact with a 16.5 t, 2-axle, HCV at a speed of 79.8 km/h and angle of 15° (G210, Table 9). The scarf joint was handed in the wrong direction for the traffic flow (Figure 25). This meant that the full force of the impact had to be taken by the tensile strength of the steel bolts. In the event the barrier was breached because the bolts were



24a) TBCB

24b) TVCB

Figure 24 — Temporary vertical concrete barriers (Vertical, tapered and shaped designs)

forced through their concrete sockets. No further tests were made on the TVCB with HCVs. The barrier was subsequently heightened to form a higher vertical concrete barrier.

4.5 The higher vertical concrete barrier (HVCB)

To improve the effectiveness of the VCB against impact by heavy commercial vehicles, the height of the barrier was increased by 400 mm to an overall height of 1 200 mm and was referred to as the higher vertical concrete barrier (HVCB). (See Figure 26.)

A slip forming process was used to construct the barrier in continuous lengths of reinforced concrete. In a series of five tests in 1990/91 the HVCB was constructed with two patterns of reinforcing bar and subjected to impact with commercial vehicles ranging in mass from 16.2 t to 30.3 t.

Impact speeds were set at a nominal value of 80 km/h, but the 30.3 t vehicle impact was made at the lower speed of 63 km/h; vehicle approach angles covered 15° and 20° impacts (G211, G212, H213, H0002 and J0014, Table 9).

Successful tests were completed with a 16.2 t vehicle at 80.8 km/h at 15° (G211) and with a 21.5 t, 4-axle, HCV at 83.7 km/h at 20° (H0002). The 30.3 t test at 63 km/h at 20.5° was also successful (J0014).

The successful completion of the HVCB tests led to its use in the widening of the M25 carriageway from a three lane to a four lane system. Low deflection values of the barrier were recorded over a range from 13 mm to 50 mm; its narrow profile permitted encroachment of carriageway rebuilding onto the central reservation with low risk of vehicles entering into the nearby opposing carriageway.

4.6 Temporary higher vertical concrete barrier (THVCB)

To achieve higher protection for staff working on roads where civil engineering projects were likely to take place over several months, and high volumes of traffic were anticipated, the containment capability of the TVCB (see **4.4**) was enhanced.

The barrier height above the road surface was increased from 800 mm to 1 200 mm. The simple surface mounting used for the installation of the TVCB was modified to accommodate a trench 200 mm deep. This barrier became the temporary higher vertical concrete barrier (THVCB). (See Figure 27.)

In test L0020 (Table 9), the trench was 700 mm wide and back filled each side of the base of the THVCB with compacted hot rolled asphalt. A clearance of a further 500 mm was given to the rear of the barrier base in test L0026, and back filled with a weak mix concrete.

Impact tests were made with nominal 30 t, 4-axle, HCVs at an impact angle of 20° and speed about 64 km/h.

Test L0020 was successful. Although the vehicle rolled heavily towards the THVCB the mounting base was sufficiently constructed to resist both the overturn of the vehicle and the toppling of the barrier. However, the looser base mounting in test L0026 permitted the barrier to move: and both the HCV and the barrier overturned.

The THVCB had successfully withstood a 30 t vehicle impact that has to be met under BS 7669-3 for approval of high containment bridge parapets on UK roads.

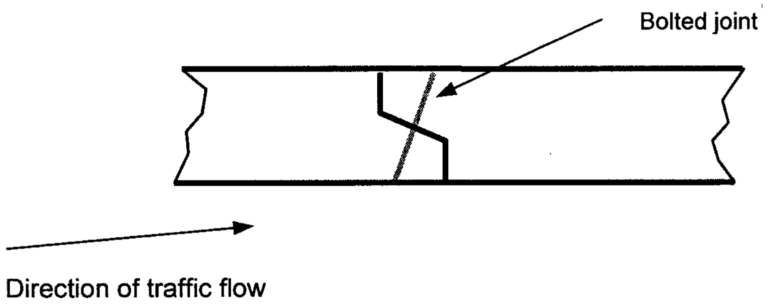


Figure 25 — Bolted scarf joint handed for traffic flow

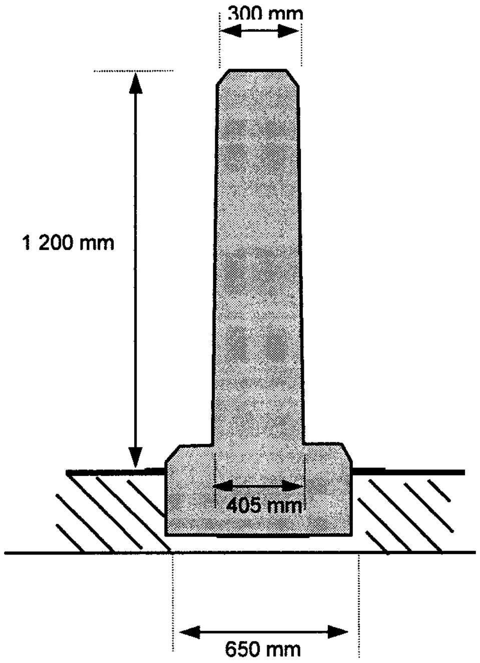


Figure 26 — The higher vertical concrete barrier

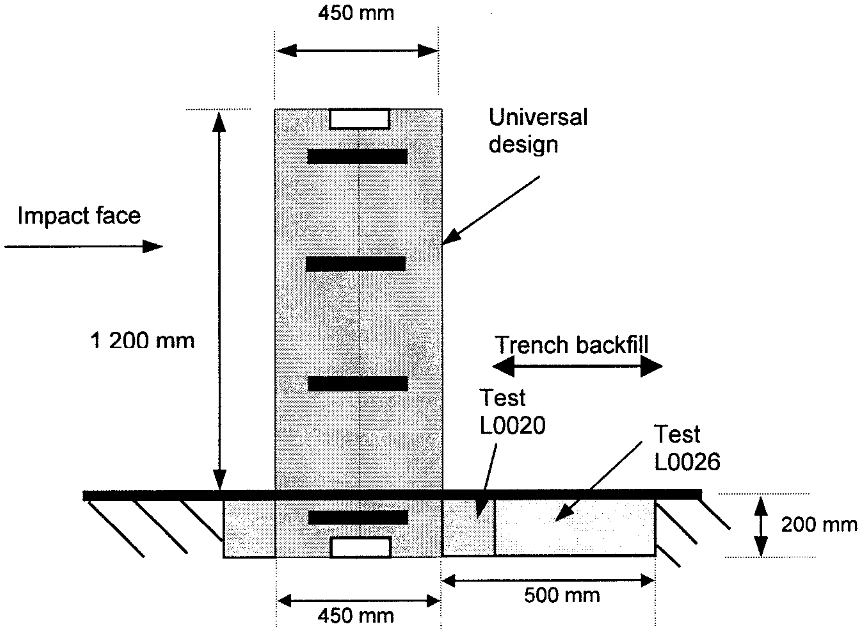


Figure 27 — The temporary higher vertical concrete barrier

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