

Vehicle restraint systems —

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

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Foreword

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

- Part 1: Fundamentals — Database;
- Part 2: Fundamentals of highway restraint systems;
- Part 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.

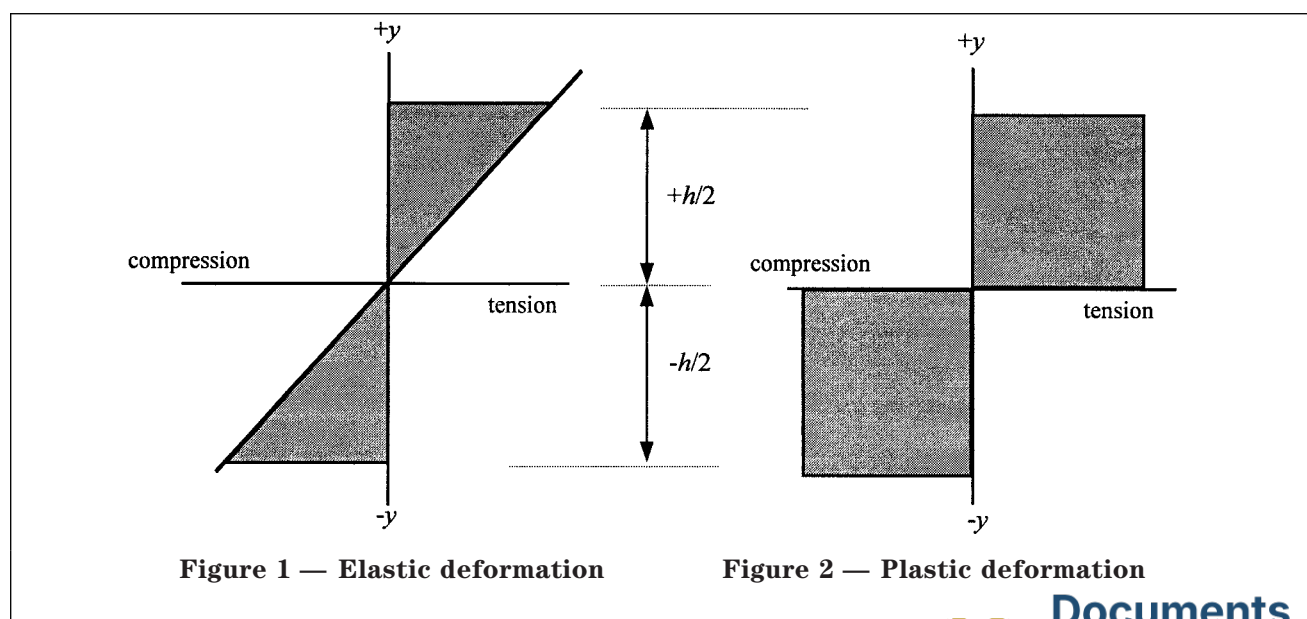
The leading wheels or bodywork of vehicles impacting weak post barriers are expected to make direct contact with the barrier posts. The design strength of the post is such that they collapse on impact in the longitudinal direction of the barrier; wheel snagging is avoided and so the unstable condition 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 $\pm h/2$ 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.



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

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

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

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

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:

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

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

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

If,

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

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

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

Plastic moment of resistance

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

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:

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

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

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

If,

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

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

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

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	
				A-A	B-B	A-A	B-B	A-A	B-B
TCB (Z – post)	1	610 ± 30	$100 \times 32 \times 5$ $110 \times 50 \times 5$	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	$125 \times 100 \times 6$	95.9	51.2	26.4	14.1	43.3	23.1
RHS (100 mm × 100 mm)	3	610 ± 30	$100 \times 32 \times 5$	25.8	5.6	7.1	1.5	11.6	2.5
RHS (200 mm × 100 mm)	4	610 ± 30	$100 \times 32 \times 5$	25.8	5.6	7.1	1.5	11.6	2.5
OBB (Single height)	5	610 ± 30	$110 \times 50 \times 5$	40.0	12.4	11.0	3.4	18.0	5.6
OBB (Double height)	6	610 ± 30 $1\ 200 \pm 30$	$125 \times 90 \times 6$	87.9	42.4	24.2	11.7	39.6	19.1
UCB (BOB, wood)	7	610 ± 30	$125 \times 90 \times 6$ 150×150 (wood)	87.9 —	42.4 —	24.2 —	11.7 —	39.6 —	19.1 —
WRSF (Wire rope)	—	585 ± 10 490 ± 10	$100 \times 32 \times 6$	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).

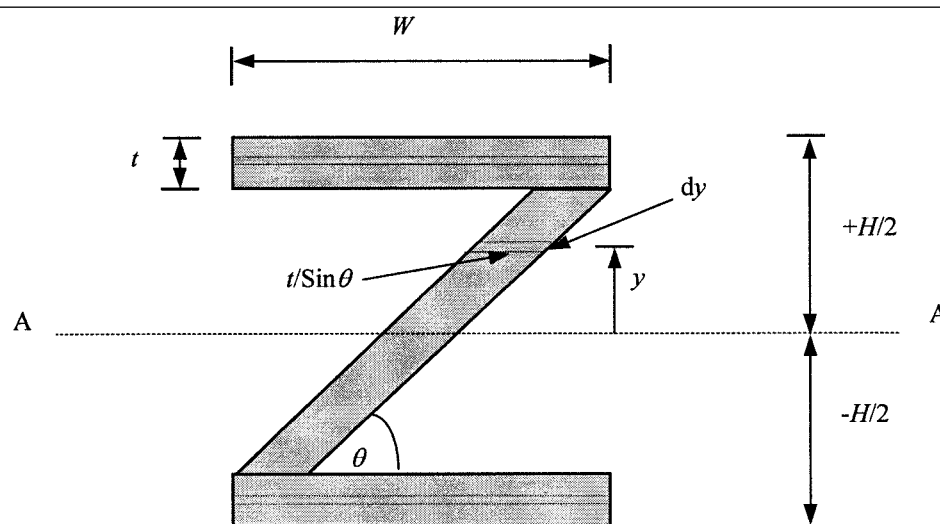
NOTE 3 $M_p = \sigma_p \cdot Z_p$.NOTE 4 $F = M_p/L$.^a Not yet published.

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

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

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

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

$$Z_{p(A-A)} = 2 \int_{(H/2)-t}^{H/2} W \cdot y \cdot dy + 2 \int_0^{(H/2)-t} \frac{t}{\sin \theta} y \cdot dy \quad (11)$$

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

From Figure (3);

$$\sin \theta = \frac{H}{\sqrt{W^2 + H^2}} \quad (12)$$

Integration of equation (11) gives:

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

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

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

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:

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

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/mm²; 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:

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

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 $M_{p(A-A)}$ 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).

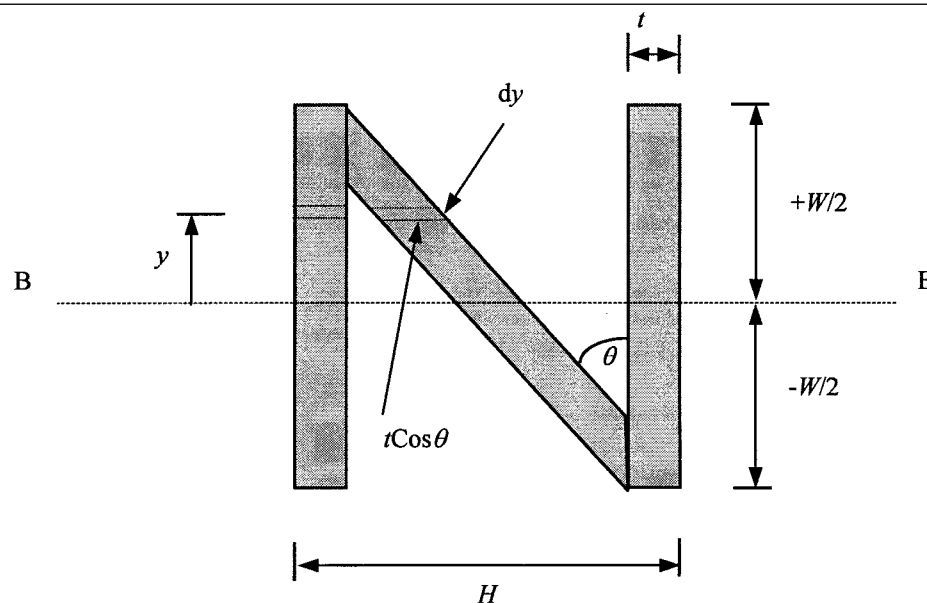
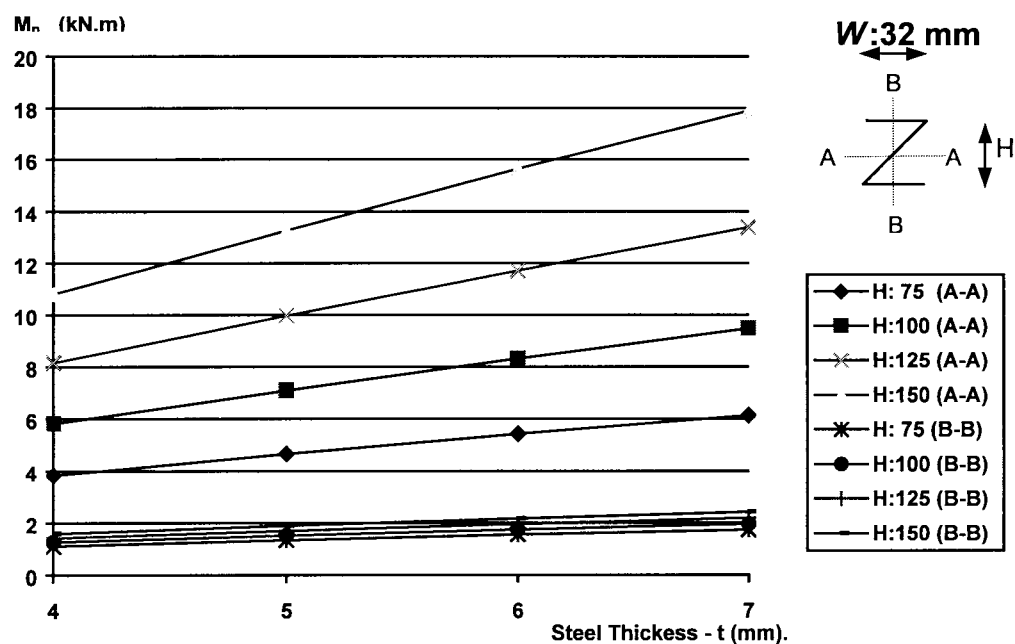


Figure 4 — Cross-section of Z-post on B-B axis

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

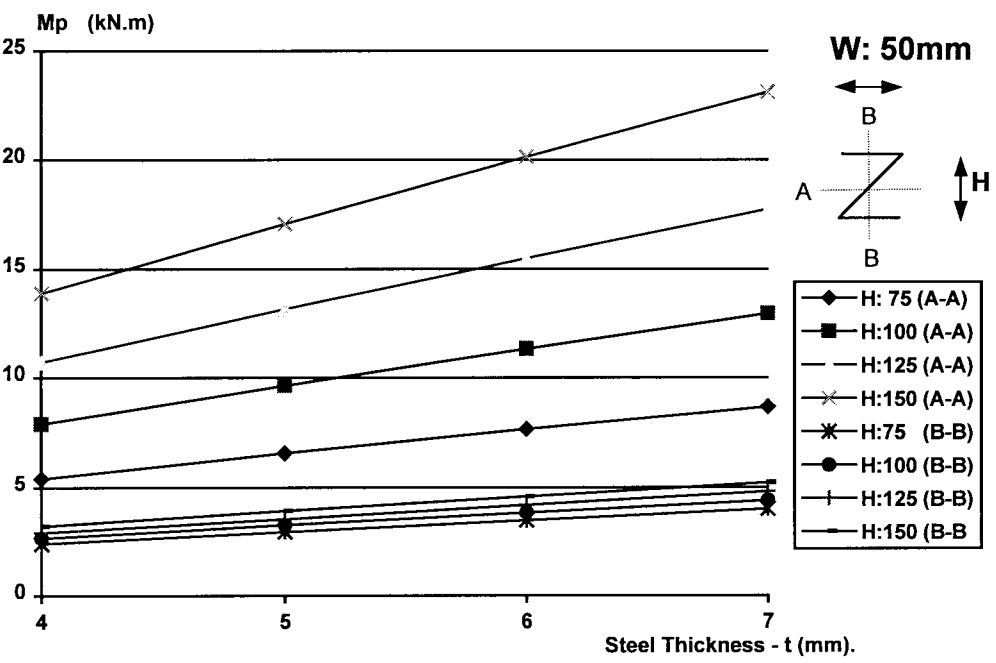


Figure 6 — Effect of H on plastic moment, M_p , for constant $W = 75$ mm

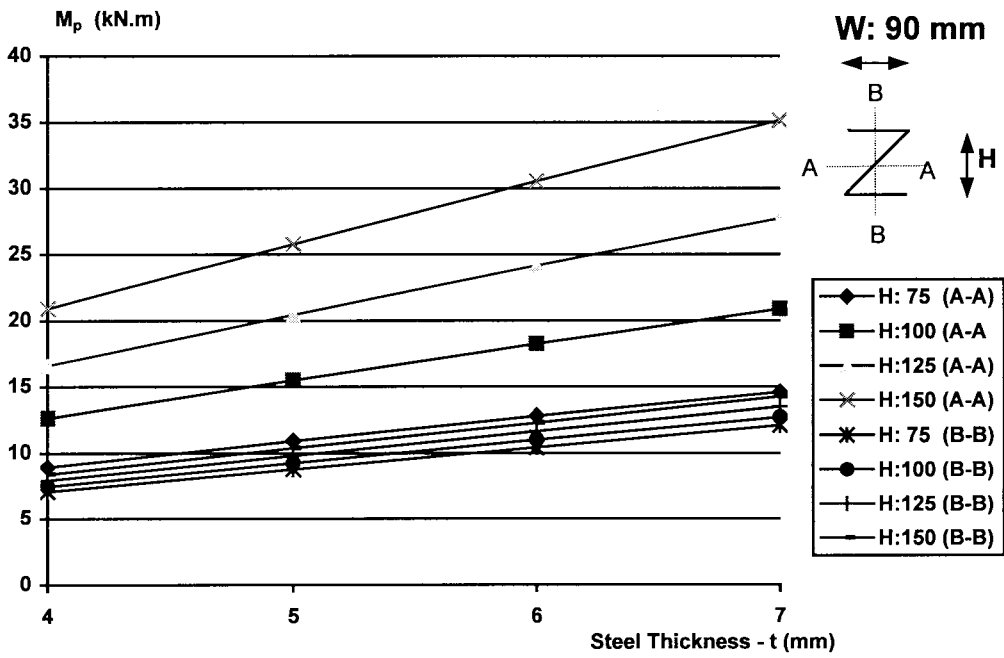


Figure 7 — Effect of H on plastic moment, M_p , for constant $W = 90$ mm

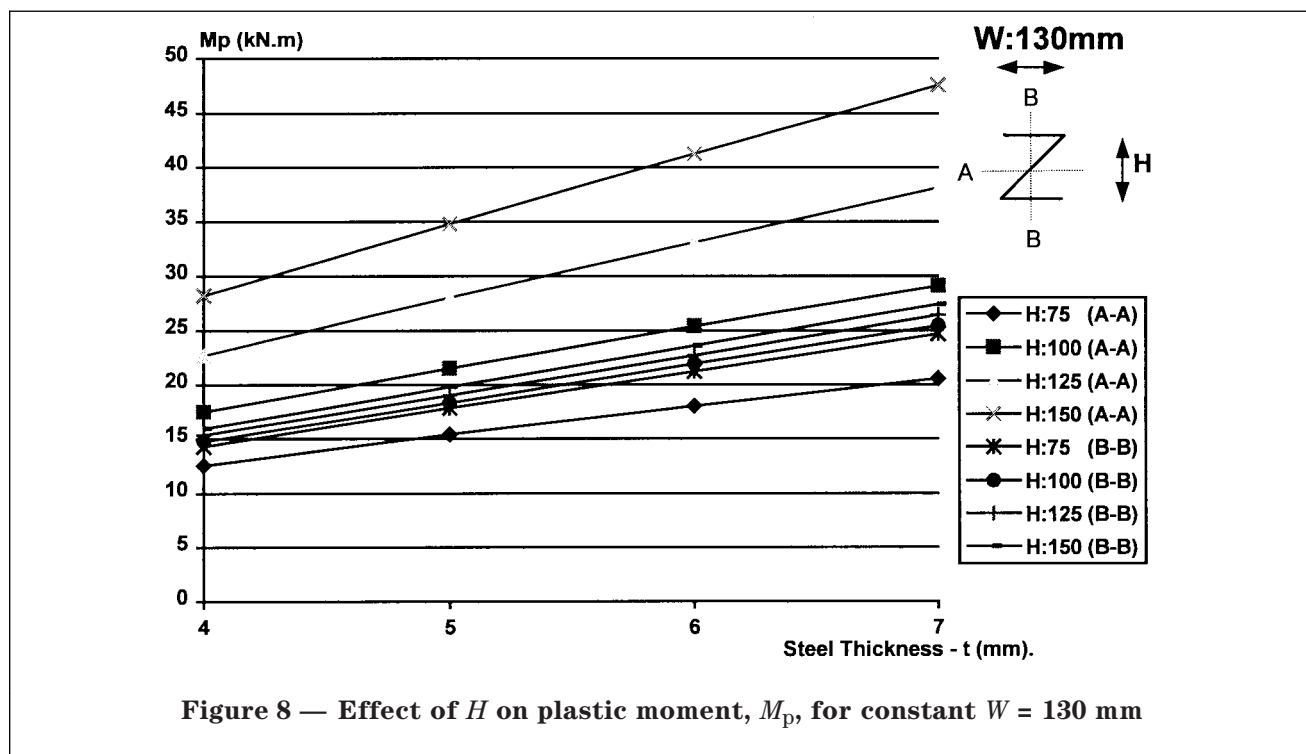


Table 2 — Cross-sectional area of Z-posts for similar bending moments

Height H mm	Metal gauge t mm	Width W mm	Bending moment $M_{p(A-A)}$ kN.m	Area mm ²	% Increase in mass about Z-post (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 $M_{p(A-A)} = 7.1$ 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.

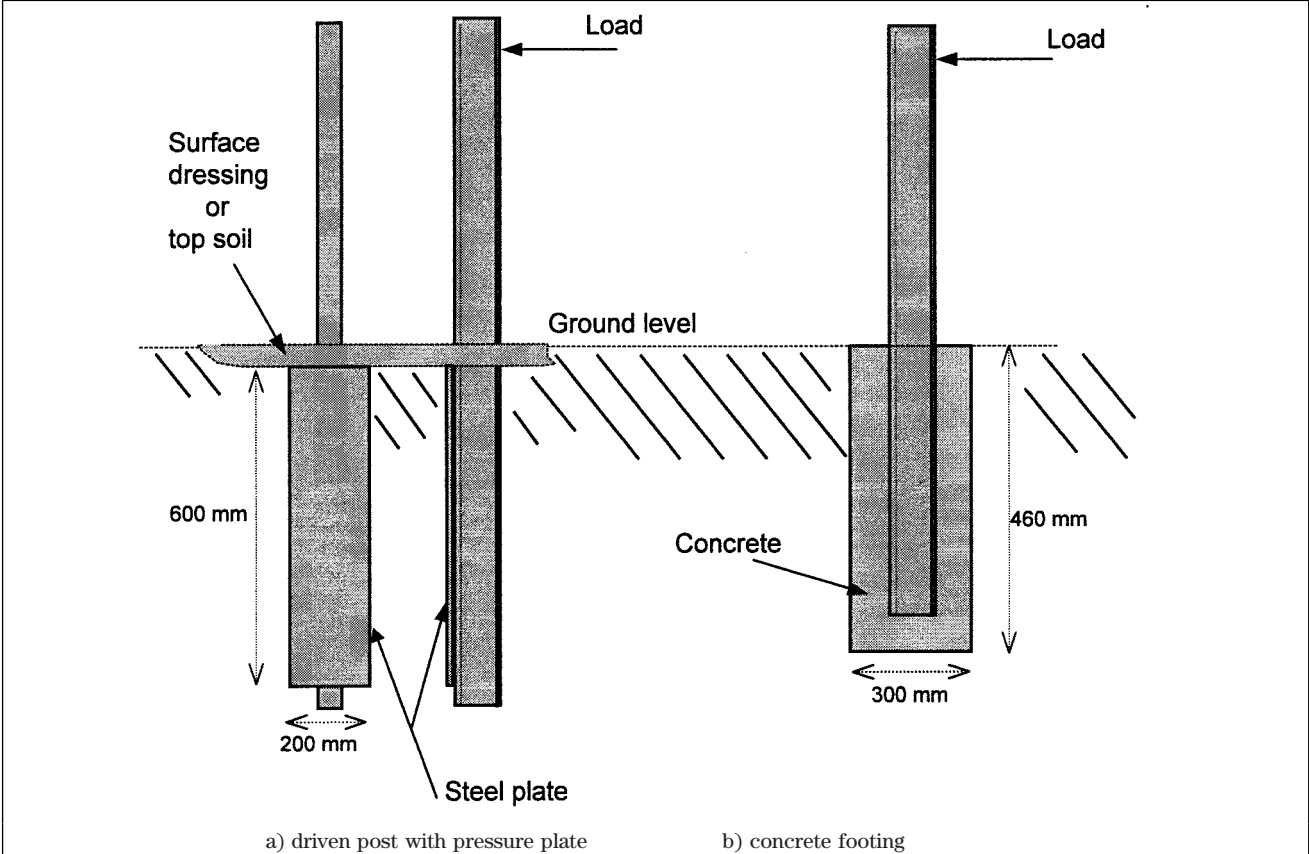


Figure 9 — Z-section post footings

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.