

Vehicle restraint systems —

Part 5: Development of barrier transitions and terminals

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Foreword

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

- *Part 1: Fundamentals — Data base;*
- *Part 2: Fundamentals of highway restraint systems;*
- *Part 3: Development of vehicle highway barriers in the United Kingdom;*
- *Part 4: Development of bridge parapets in the United Kingdom;*
- *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 the 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 18, an inside back cover and a back cover.

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1 Scope

This part of PD 6634 describes the development of barrier transitions and terminals for vehicle highway safety barriers in the United Kingdom. Theoretical designs and practical tests involving vehicle impact into transitions and soft terminals are described.

2 Barrier transition and terminal concepts

The draft European Standard, EN 1317-4, defines a transition as the connection between two safety barriers of different designs and/or impact performance.

A terminal is the end-treatment of a safety barrier. In practice a terminal provides a transition from full impact performance at some point along the barrier where the LoN, begins, down to zero performance at the extreme end of the barrier. Inevitably, the terminal has a lower impact performance than the barrier structure to which it is connected.

The exposed end-post of a high containment barrier or bridge parapet, through its inherent strength, could cause considerable damage to an impacting vehicle, whether private car or heavy commercial vehicle (HCV). Similarly, the physical connection between a low and a high containment barrier could be equally hazardous unless the change in lateral stiffness is smoothed by a graded transition in lateral resistance. In addition, barriers which have identical vehicle containment capabilities, yet have different flexibility or working widths (see EN 1317-2), need to be linked together by a transition length.

By definition, the transition length from a low to a high containment barrier can only successfully function against an impact less violent than that which can be successfully contained by the high containment design. Should the higher level of protection be required on the approaches to a bridge, then the bridge parapet must be extended beyond the minimum bounds of the bridge structure.

The fundamental difficulty in any proposed design of transition is deciding on the length between the end of the lower containment barrier and the beginning of the higher containment structure. In descriptive terms its length needs to be approximately the distance between the end-point of the LoN of the lower and the start-point of the higher containment barrier. On the subject of transition length, draft EN 1317-4 states:

“The distance from the end of a terminal or from the end of a transition, where any particular barrier reaches its full performance (LoN point) depends on the terminal/transition and on the barrier. This distance shall be demonstrated by a test according to EN 1317-2, or by rational thinking”.

The standard goes on to say that rational thinking for concluding the length is to say that the transition cannot be less than one-third of the installed test length. Since there are no restrictions in the standard on the test length that can be installed, other than its length should demonstrate the full performance of the barrier, this prescription does not lead to a unique conclusion. Alternatively, the stipulation that the point of the LoN can be determined by full scale tests is unique but its implementation can be prohibited by the high cost of the number of tests that are likely to be needed in order to determine this definitively.

As a possible solution to the problem of defining the length of a transition or a terminal, the following clauses attempt to apply the results of both practical full scale trials and simple dynamic theory to the design of prototype transitions and terminals; in other words, they attempt to assist the rational thinking process desired by EN 1317-4.

3 Practical trials and simple theoretical design concepts for safety barrier transitions

3.1 Practical vehicle impact trials

Table 1 lists results from full scale vehicle impact testing carried out by TRL, of transitions between barriers of similar containment levels but differing designs and barriers of different containment levels.

Of particular interest are test numbers D155 and D159. A transition was needed to connect a high containment P6 steel bridge parapet (see PD 6634-4, Table 1), intended for the containment of a 30 t HGV impact, to an open box beam (OBB) safety barrier system designed for the containment of a 1 500 kg car impact (Laker 1989 [1]).

The starting point of the transition design began with the knowledge that a double height double sided open box beam (DHDSOBB) safety fence, under test, had contained an 80 km/h, 15°, 16 t HCV impact (test number A106, PD 6634-3, Table 8). By definition, the containment level of the transition would necessarily have to be less than that of the 30 t capability of the P6 bridge parapet to which it was to be connected.

During the 16 t test, about 30 m of the fence was damaged. The maximum lateral deflection of the impact occurred at about 17 m from the point marking the beginning of the barrier damage; that is about halfway along the total damaged length. From this evidence, the presumption was made that a transition from safety barrier to parapet over a similar 17 m length would most probably produce a worst case condition for generating the possibility of an end-on impact with the bridge parapet anchorage.

Table 1 — TRL impact tests results on barrier transitions

Test no.	Date	Mass of vehicle kg	Mass of dummy kg	Speed km/h	Impact angle	Barrier type	Drawings	Contact length m	Maximum deflection m	PHD g	THIV m/s	Comment
Transitions between barriers of similar containment levels												
H215	7.11.90	1 465	75	116.8	20	WRSF/OBB	TRL-1040.00/S45.040 TRL-1040.00/000.S45	14.0	1.4	—	6.1	Satisfactory
H216	15.11.90	1 465	75	114.6	19	WRSF/OBB	TRL-1040.00/S45.040 TRL-1040.00/000.S46	23.5	1.4	—	3.8	Climbed OBB ramp
H0001	19.3.91	1 477	75	114.9	20	WRSF/OBB	TRL-1040.00/S45.040 TRL-1040.00/000.S47	14.0	1.3	—	5.0	Satisfactory
N0020	23.3.95	1 499	75	114.7	20	SHOBB/VCB	TRL-OBB 00/2	7.0	0.3	30.3	10.6	Failed BS 6579 and EN 1317
P0002	24.2.96	1 501	—	114.6	20	SHOBB/VCB	TRL-OBB 00/2	4.0	0.15	10.6	8.8	Complied with BS 6579 and EN 1317
Transitions between barriers of different containment levels												
D155	2.7.87	16 100	—	80.6	15	OBB/P6 steel	TRL-1040.00/000.486 TRL-1040.00/000.463	10.0	0.1	—	3.4	Satisfactory Linear transition
D159	15.9.87	16 300	—	80.3	15	OBB/P6 steel	TRL-1040.00/000.486 TRL-1040.00/000.491	10.0	0.15	—	3.4	Satisfactory Stepped transition
F202	5.1.89	16 000	—	81.6	15	OBB/P6 concrete	TRL-1040.00/000.583 TRL-1040.00/000.584	12.0	0.2	—	3.6	Contained but rolled on exit
L0022	11.3.93	13 283	—	73.2	20	OBB/P6 steel	Babtie Shaw & Morton Drawing S10842/S2	4.5	0.16	2.4	3.6	Satisfactory Exceeds CEN TB42
L0024	25.3.93	13 335	—	71.0	20	OBB/P6 concrete	Babtie Shaw & Morton Drawing S10842/S2	15.0	0.2	2.6	4.5	Severe damage OBB Normal
M0048	21.9.94	12 970	—	70.5	20.5	OBB/P6 concrete	Babtie Shaw & Morton Drawing S10842/13	>20.0	0.2	2.0	3.3	Satisfactory

Table 1 — TRL impact tests results on barrier transitions (*continued*)

Test no.	Date	Mass of vehicle kg	Mass of dummy kg	Speed km/h	Impact angle	Barrier type	Drawings	Contact length m	Maximum deflection m	PHD g	THIV m/s	Comment
L0021	11.3.93	12 599	—	72.4	20	P1/P6 steel	Babtie Shaw & Morton Drawing S10842/S2	9.0	0.16	3.5	4.0	Satisfactory Exceeds CEN TB42
L0023	22.4.93	12 936	—	64.7	20	P1/P6 concrete	Babtie Shaw & Morton Drawing S10842/S3	7.6	0.07	7.25	4.1	BS 6579 and CEN standards not met
N0019	30.3.95	1 504	75	111.0	20	SH/DH-OBB	TRL-OBB 00/2	8.0	0.7	5.9	6.1	Complied with EN 1317
P0003	15.8.96	10 080	—	81.1	15	SH/DH-OBB	TRL-OBB 00/3	12.7	1.1	2.9	3.5	Complied with EN 1317
01FB	10.1.96	1 505	—	113.8	20	SHOBB/P1 Steel	Mouchel 42030/PCON/05 - 06	Stopped in barrier	0.89	20.6	7.9	Failed BS 6579 and EN 1317
03FB	30.1.96	1 497	—	113.2	20	SHOBB/P1 Aluminium	Mouchel 42030/PCON/09	13.0	1.55	9.3	7.2	Failed BS 6579 and EN 1317
05FB	19.12.96	1 501	—	110.9	20	SHOBB/P1 Steel	Mouchel 42030/TRAN/05	3.5 approx.	0.09	6.9	8.2	Satisfactory but exceeded ASI
01GB	20.1.97	1 503	—	112.5	20	SHOBB/P1 Aluminium	Mouchel 42030/TRAN/06	3.5 approx.	0.1	12.9	9.4	Satisfactory but high THIV value

NOTE 1 THIV = theoretical head impact velocity; PHD = post impact head deceleration. See PD 6634-2:1999, **7.6**, for definitions.

NOTE 2 WRSF = wire rope safety fence.

VCB = vertical concrete barrier.

SH = single height.

DH = double height.

Using this concept, the planned impact point on the transition, with a 16 t HCV was arranged to be 17 m from the end-post in order to simulate this worst condition. From these considerations the simple impact criterion, that the length of the transition should be approximately one-half of the vehicle contact length observed during a basic barrier test on the LoN, was adopted.

Given this criterion, selection of transition posts was based on a linear increase in cross-sectional bending strength, over the transitional distance of 17 m from the safety fence end-post to the first anchorage post of the parapet. Post sizes were chosen to fit the linear increase in strength.

Two types of transitions were built. In the first, the increase in post strengths closely followed a linear scale (see Figure 1); test results are given in Table 1 under test number D155.

In the second design, a courser gradation was chosen in the form of stepped increases in the strength of the posts' cross-sections (shown in Figure 1); test number D159, Table 1 gives test results.

Test D155 had eight posts graded in increasing strength from the DHDSOBB, Z-section barrier posts, to the I-section posts at the beginning of the bridge parapet end-anchorage. Test D159 had just three graded levels of posts between the barrier and the parapet.

In both tests, the 16 t vehicle was successfully contained and redirected. Maximum roll angles were recorded to be about 34°. The departure paths were close to the line of the parapet, at 1° and both exit speeds were 70 km/h. The maximum deflection at the top of the transition was 150 mm. In neither test were the in-service repairs regarded as being urgent.

Both designs of transition (D155 and D159) had achieved the objective of protecting the vehicle from impacting the very stiff end-anchorage of the bridge parapet. The transition using just three sizes of post section (D159) is probably the most attractive from the point of view of primary construction and repair costs.

The overall design requirement, that the transition should accommodate a 1 500 kg car impact, was met by reducing the lead into the DHDSOBB fence by a SHDSOBB fence. This design arrangement was confirmed by test N0019 (Table 1) in which a 111 km/h test vehicle was contained and redirected.

Table 1 shows a number of other tests for transitions between various configurations of safety barrier, as listed under barrier type. Reference is made in the table to drawings that highlight a range of designs; these drawings should be examined if detailed information is required.

However, as a general comment, those designs that are listed in Table 1 that did not successfully meet the requirements of vehicle impact testing mostly failed due to either a step change in the stiffness of the transition, such as a flexible metal barrier connected directly to a rigid concrete barrier, or because the gradient of the lateral stiffness was too great over a transition length that was too short.

3.2 A simple analytic design criterion for safety barriers of different lateral stiffness connected by a transition

The concept described in 3.1, wherein the length of the transition should be about one-half of the vehicle's contact length as determined by a basic barrier test, is carried over into the following analytical analysis. Furthermore, it is presumed that the halfway point of the contact length is also the position of the barrier's maximum deflection.

In the development of a new design of safety barrier with an associated transition where a prototype has not been constructed and tested, there is no prior knowledge of the vehicle's contact length to the point of maximum lateral deflection. To overcome this difficulty, the following analysis begins by choosing an acceptable magnitude for the prototype lateral impact deflection. Simple equations of motion are then used to determine the average lateral force experienced by the prototype barrier and so a simple design for the lateral stiffness of the barrier is developed.

The contact length of the colliding car is calculated based on the assumption that it follows a circular horizontal arc, as shown in Figure 2. The length of the transition is then prescribed geometrically as half the length of this circular arc.

To provide an overall design for connecting two or more prototype safety barriers of differing containment levels, the desired lateral deflection of each is selected and the lateral stiffness of each is calculated. The stiffness gradient between the barriers can now be estimated which, along with a knowledge of the calculated half contact length, provides sufficient information for a complete design of the length and stiffness gradient of the transition.