High Containment Steel Bridge Parapet With Transition to a Safety Fence

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The Department of Transport United Kingdom in Technical Memorandum BE5 (July 1982) requires that high containment parapets be provided at certain high-risk locations where the dangers resulting from a vehicle penetrating the parapet are judged to outweigh those from possibly redirecting vehicles back into the traffic stream. Memorandum BE5 gives detailed design requirements for reinforced in-situ and precast concrete parapets; it specifies moments of resistance in bending, horizontal, and transverse shear resistance and minimum wall thickness. No criteria are cited, however, for designs in other materials such as metal or masonry. The purpose of this report is to establish design criteria for high containment metal parapets.

The Department of Transport United Kingdom in Technical Memorandum BE5 (July 1982) requires that high containment parapets be provided at certain high-risk locations where the dangers of a vehicle penetrating the parapet are judged to outweigh those of a more rigid parapet that might redirect a vehicle back into the traffic stream. The memorandum suggests the conditions under which high-containment parapets might be useful: "At certain locations, the nature of the area below the bridge may alone justify High Containment parapets. At other sites, both the circumstances below and on the bridge (or its approaches) will need to be taken into account."

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The purpose of this report is to establish design criteria for high containment metal parapets.

The performance criteria in Memorandum BE5 for high containment parapets include the requirement that a 30-ton, rigid-chassis heavy goods vehicle (HGV) traveling at 64 km/h, which impacts at an angle of 20 degrees, be redirected on a departure path within an angle of 12 degrees to the line of the parapet, without overturning. The memorandum does not address the impact response of a private car, but the safety fence was adopted so that the high containment parapet could safely contain and redirect without overturning, on a similarly restricted departure path, a car traveling 113 km/h, impacting at 20 degrees. Debris from the vehicle and parapet should not fall off the bridge.

This report describes the design and construction of a steel post-and-rail parapet and impact testing with vehicles ranging from a 1-ton car to a 30-ton HGV. Impact performance is examined with and without a 3-mm sheet steel cladding on the parapet. Post spacings varied between 2 and 3.

The very strength of high containment parapets could prove hazardous to those vehicles that run into the end of the parapet. Therefore, transition length, graded in strength to run from the end of the parapet to a normal containment safety fence (containment capacity for a 1.5-ton vehicle impacting at 20 degrees and 113 km/h), has also been designed, constructed, and tested with a 15-degree impact by an HGV traveling at 80 km/h. Eight tests, six using HGVs and two using cars, were conducted on the parapet and transition length.

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HIGH CONTAINMENT PARAPET

Parapet Design

Tests with HGVs into high containment concrete parapets have shown that the parapet receives two impact blows approximately in the same area (*1*). The primary blow occurs on initial impact; the other is delivered by the rear of the vehicle as it yaws into the parapet. In the early design stages of the metal parapet, researchers thought that the first blow might cause such damage to posts near the initial impact point that the second blow would have to be absorbed by the rails alone in bending and tension. Using frangible posts that would break at their base was considered but rejected, because the joints would not release under forces less than their design strength and higher-impact blows could cause posts to fracture and "unzip" the parapet. A rigid design was adopted instead.

Design Constraints

The parapet was designed to the following specifications:

- Test length: 30-m minimum
- Parapet height: 1.5 m
- Number of rails: 4
- Plinth height: 100 mm
- Raised verge width: 600 mm
- Cladding thickness: 3 mm
- Maximum deflection: 800 mm

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

Component Dimensions

The mean lateral force acting on the vehicle was obtained from the following equation (*2*):

$$\text{Mean lateral force} = \frac{m(v \sin \theta)^2}{2[C \sin \theta + b(\cos \theta - 1) + z]}$$

where

m = mass of vehicle,
θ = angle of impact,
v = vehicle forward velocity,
c = distance of center of gravity from front of vehicle,
b = half the width of the vehicle, and
z = deflection of barrier and crumpling of vehicle.

The equation predicts that the mean lateral force required to redirect a 30-ton, 68-km/h HGV impacting at 20 degrees is 230 kN for a given z value of 800 mm. To allow a margin for error, the parapet components were designed to resist a 270-kN force, which is equivalent to a z value of 400 mm.

Figure 1 is a diagram of a four-rail high containment parapet. Rails under 300 mm in height above the running surface are not regarded as effective members; the height adopted in the final design was 315 mm. The lowest rail protects a car wheel from impacting and snagging on the posts. The lateral design load is assumed to be applied equally over the effective longitudinal members for the purpose of deriving a bending moment capacity for the posts.

The bending moment in the posts derived by assuming that only the top three rails are effective is 25 percent greater than

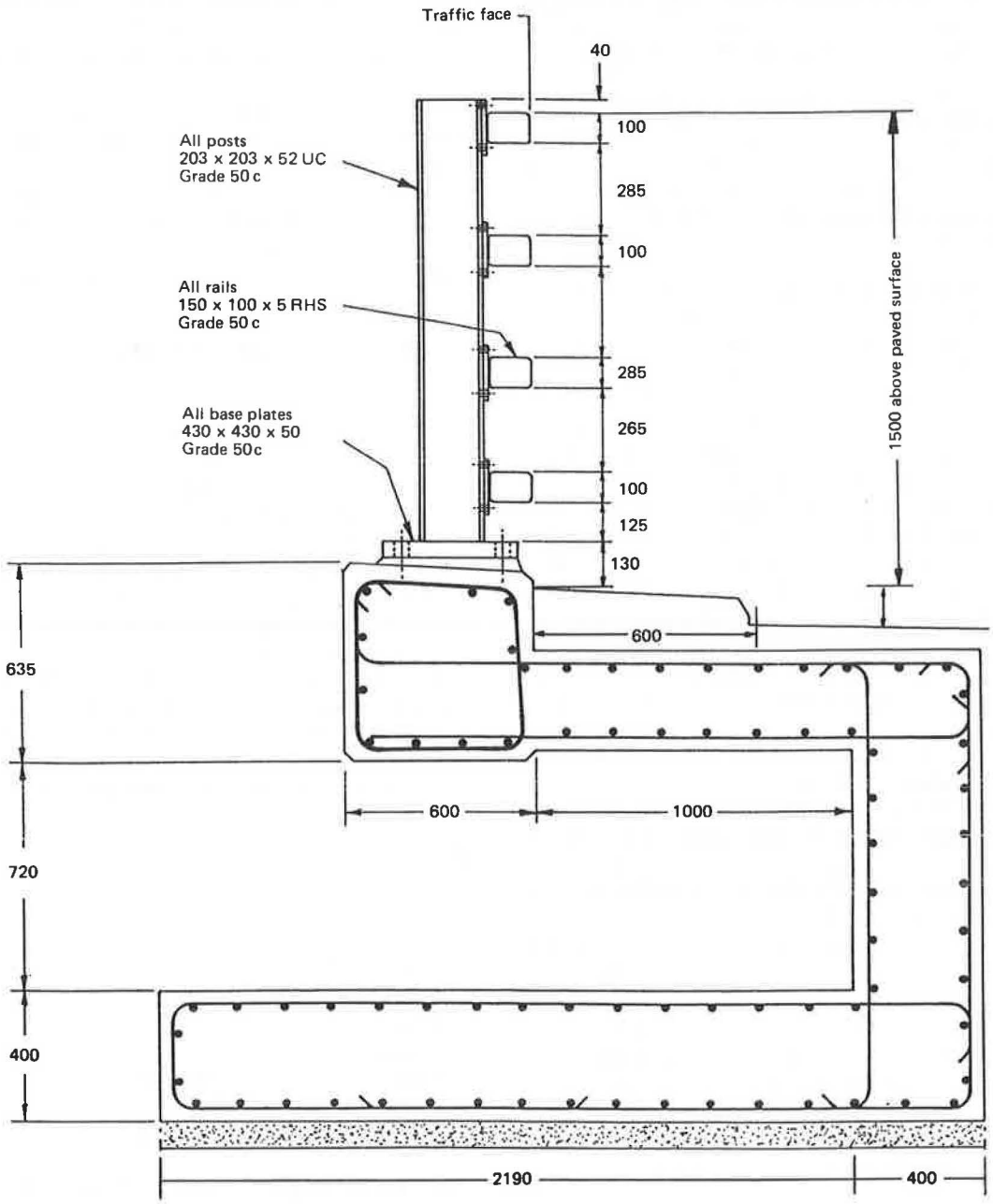


FIGURE 1 Section through parapet and simulated bridge deck.

that developed for four rails. Calculations showed that a 203- by 203- by 60-kg universal column section (UCS) should support 310 kN over four rails, or 248 kN over three rails. Static load tests on the 60-kg-weight posts gave 30 percent higher values than expected, which may be attributed to the section plastic deformation under high load. Consequently, a lighter post size was chosen, 203- by 203- by 52-kg UCS. This posts's theoretical transverse load capacity is 271 kN applied over four rails, 217 kN over the top three rails. Assuming that the same excess strength of 30 percent would be found in practical load tests, the lateral capacities of the posts increase to 352 kN over four rails, 282 kN over three rails. At these values, the 203- by 203- by 52-kg UCS posts are sufficiently strong to withstand the expected impact load of 270 kN.

Given a deflection of 800 mm, the top three rails would be loaded to 76.6 kN per rail, and it was assumed that two posts would be knocked out on impact. The tension in the rails was calculated from a triangle of forces to be 225 kN per rail, with the posts at 3-m centers. A rectangular hollow section (RHS) size of 150 by 100 by 5 mm was selected to meet those requirements (*3*).

Parapet Post Anchorage

The parapet post baseplate was anchored to the in-situ concrete plinth with eight M30 bolts. The bolted connection was designed to transmit 1.5 times the theoretical capacity of the 203- by 203- by 60-kg UCS posts in bending and in shear, which confined damage to the metal parapet.

Parapet Cladding

Cladding was added to discourage people from climbing the parapet and to restrict debris from falling on the area below. Although mesh and solid cladding are both permitted by Memorandum BE5, the British Rail Inspectorate preferred a 3-mm steel plate. Two methods of fixing were tried, one using 6-mm self-tapping screws and the other employing 6.35-mm-diameter stainless steel rivets. The self-tapping screw fixing was adequate for car impacts, but the sheet steel cladding broke loose under HGV impact loading. The 6.35-mm rivets at 150-mm centers securely retained the parapet to the rails in all further impact tests.

Bridge Deck and Post Spacings

The parapet, 30 m in length, was mounted on an elevated platform representing a bridge deck, with provision for fixing posts at 2- or 3-m spacings. (Figures 1–4).

Instrumentation

Monitoring the Parapet

Strains generated in the deck and in the parapet were monitored by strain gauges fixed to the concrete reinforcement mesh and to the posts and rails.

The strain readings provided the means to assess and, if necessary, modify the prototype design. Were the parapet components incorrect or underdesigned, then the metal parapets would yield into the plastic region and nonlinearities would be difficult to interpret. Nevertheless, the degree of distortion or collapse of the metallic components could in themselves provide useful information. On the other hand, if the parapet was significantly overdesigned, then the strain readings would provide the opportunity to correct what would be a costly and impact-aggressive design.

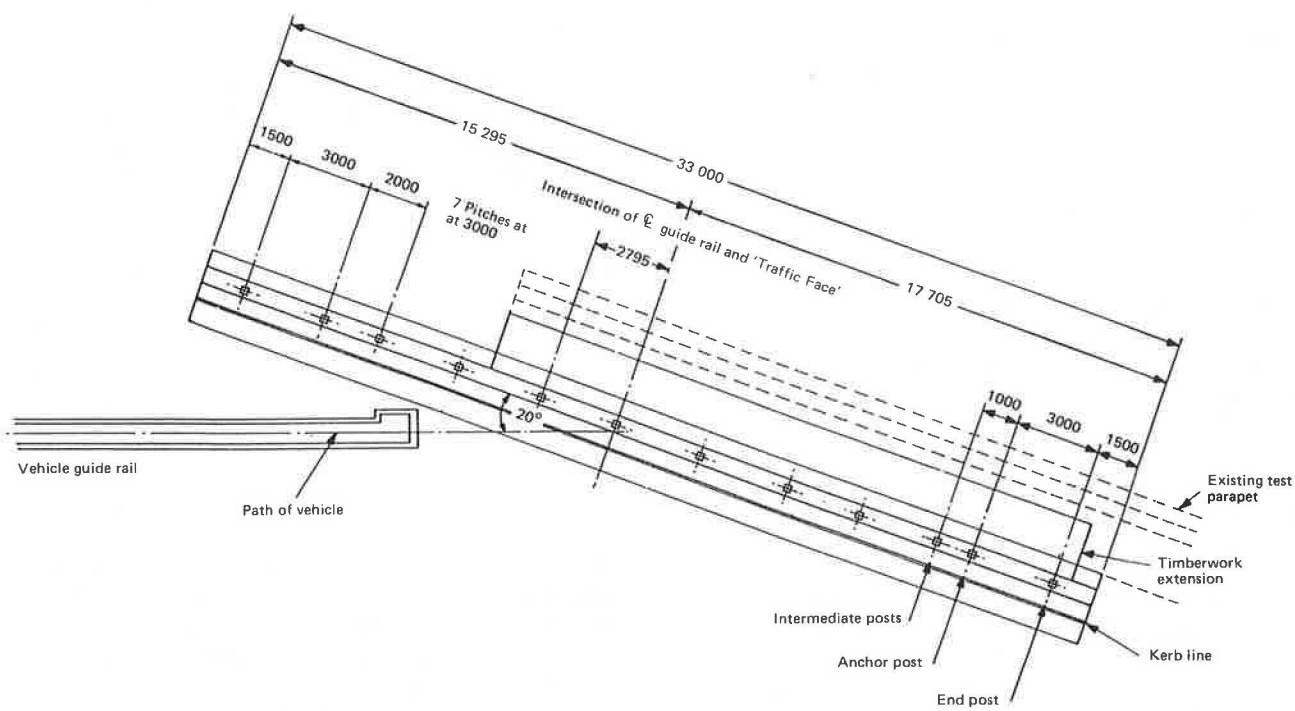


FIGURE 2 Site detail plan for steel high containment parapet (3-m post spacing).

FIGURE 3 Posts on elevated deck.

FIGURE 4 Test vehicle and parapet.

Extensive details on the positions and calibration of the gauges are presented in Atkins & Partners (*3*).

Monitoring the Vehicles

All vehicles were fitted with triaxial accelerometers at the center of gravity, together with rotational rate sensors to measure yaw and roll motions.

Accelerometer outputs were filtered to remove unwanted high frequency components that may, for example, include responses arising from vibration of the vehicle member on which the accelerometer is mounted rather than from the effective mass of the vehicle. Previous work established how much filtering was necessary to remove high frequency oscillations without reducing the total area under the acceleration time trace. Accelerometer records were produced after filtering by a 60-Hz, 12-dB/octave Butterworth filter and by a 10-Hz, 48-dB/octave filter. The second level of filtering more clearly reveals the underlying whole-vehicle movements.

An anthropometric dummy conforming to that described in U.S. *Federal Register*, Part 572, was calibrated and placed in the passenger seat in each car test. Triaxial accelerometers were mounted in the head and chest; accelerometer readings were filtered to SAE J211a.

An array of high speed cameras (approximately ten) provided photographic evidence for analysis and documentary purposes.

Impact Facility

All the tests were carried out by the Motor Industry Research Association under contract to the Transport and Road Research Laboratory. The vehicles were towed to impact speed by a 3-megawatt electric winch. Vehicles were guided by a slipper unit fixed over a long rail and attached to the test vehicle. The tow mechanism was disconnected before impact, permitting the vehicle to run freely into the parapet.

Parametric Study

The high containment parapet was subjected to six impact tests; checks and repairs were made after each test. Vehicle weights ranged from 1-ton cars to 30-ton 4-axle HGVs. Spacings between the posts varied. In some of the tests, sheet metal cladding was fixed to the face of the parapet. All the impacts were made at 20 degrees to the line of the parapet. Details are given in Table 1.

TRANSITION FROM PARAPET TO SAFETY FENCE

Concept

The endpost of a high containment parapet, through its inherent strength, could cause considerable damage to any impacting vehicle, private car or HGV. The purpose of the transition is to provide a structure that minimizes this possibility and provides a level of vehicle containment on the approaches to the bridge.

By definition, the transition could contain only a vehicle less weighty than a 30-ton HGV, for that is the design load of the parapet. Should this high level of containment be required on the approaches to the bridge, the parapet must be extended.

Earlier work had produced a high containment safety fence capable of containing and redirecting an 80 km/h, 16-ton HGV impacting at 15 degrees, known as the double-height, double-sided open box (DHDSOB) safety fence (*4*). A transition capable of sustaining such an impact was designed to connect the high containment parapet to the high containment fence. The normal containment safety fence for private cars, the single-height open box fence (SHOB), would then be linked to the high containment safety fence to complete the assembly.

Transition Design

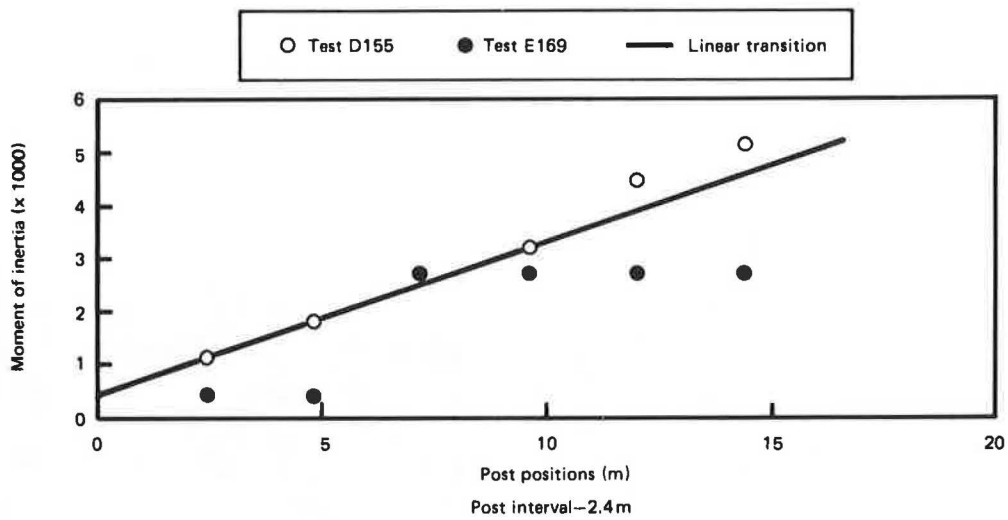
The impact criterion adopted was that the transition should contain an 80 km/h, 16-ton HGV impacting at 15 degrees. The DHDSOB safety fence contained such an impact, with the maximum penetration of the vehicle occurring at 17 m from the impact point. A transition from safety fence to parapet over this same length would then produce a worst case condition for generating an end-on impact into the parapet.

TABLE 1 TEST PARAMETERS

Test No.	Vehicle	Nominal Speed (km/h)	Nominal Weight (tons)	Post Spacing (meters)	Cladding
D139	Car	113	1.0	2	No
D140	Car	113	1.0	2	Yes
D142	HGV (2-axle)	80	16.0	2	No
D144	HGV (4-axle)	68	30.0	2	Yes
D148	HGV (4-axle)	68	30.0	3	Yes
E173	HGV (4-axle)	68	30.0	3	No

The initial impact under test was therefore arranged to occur at the start of the transition.

Post strengths were selected by plotting the linear increase in strength from safety fence to bridge parapet post over the transition length; post sizes were chosen as closely as practicable to suit this linear scale (Figure 5). Two transition fences were built, one with eight sizes of posts (Test D155) and the other with only three sizes (Test E159). Figures 6 and 7 show horizontal rails reducing from three at the attachment to the parapet to two at the connection to the DHDSOB safety fence. Figure 8 shows a cross section through the transition. On making a connection to the SHOB, the discontinued rails of the DHDSOB fence were terminated by a flair back and



Transition length: post inertia from fence at 0 metres to first parapet post at 16.8 metres
M of I about axis longitudinal to the transition length (cm to 4th power)

FIGURE 5 Section moments of inertia of transition posts.

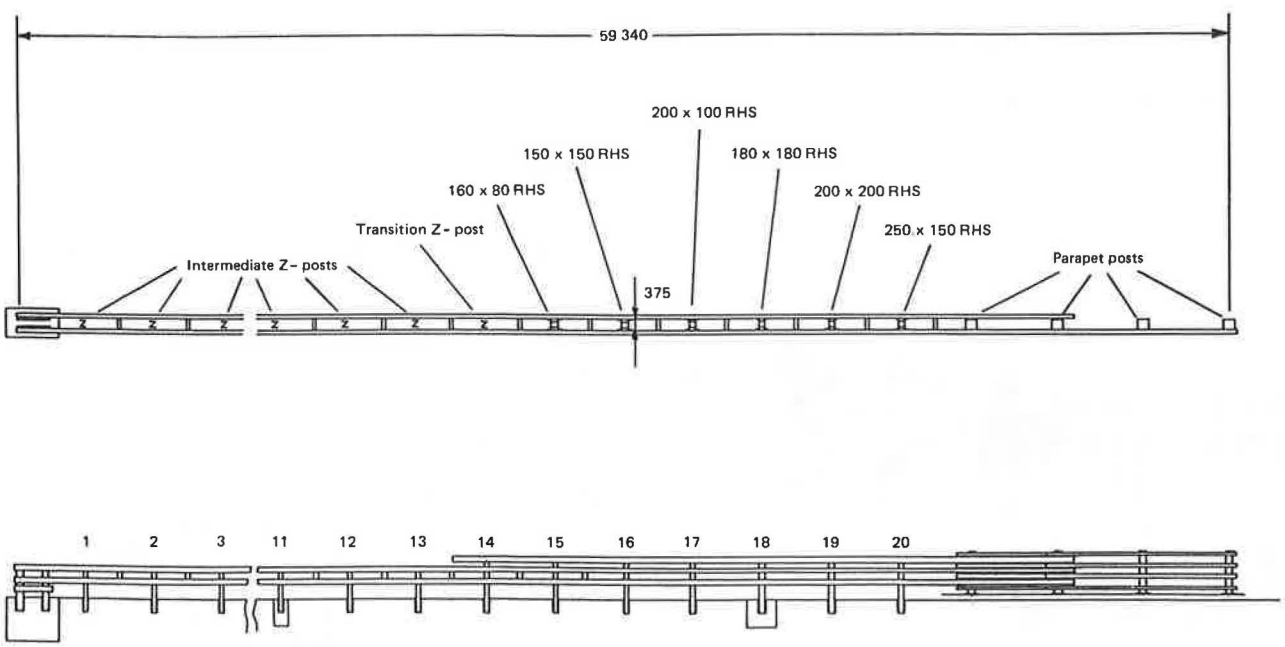


FIGURE 6 Transition from double-height, double-sided OBB safety fence to steel parapet, using eight post sizes.

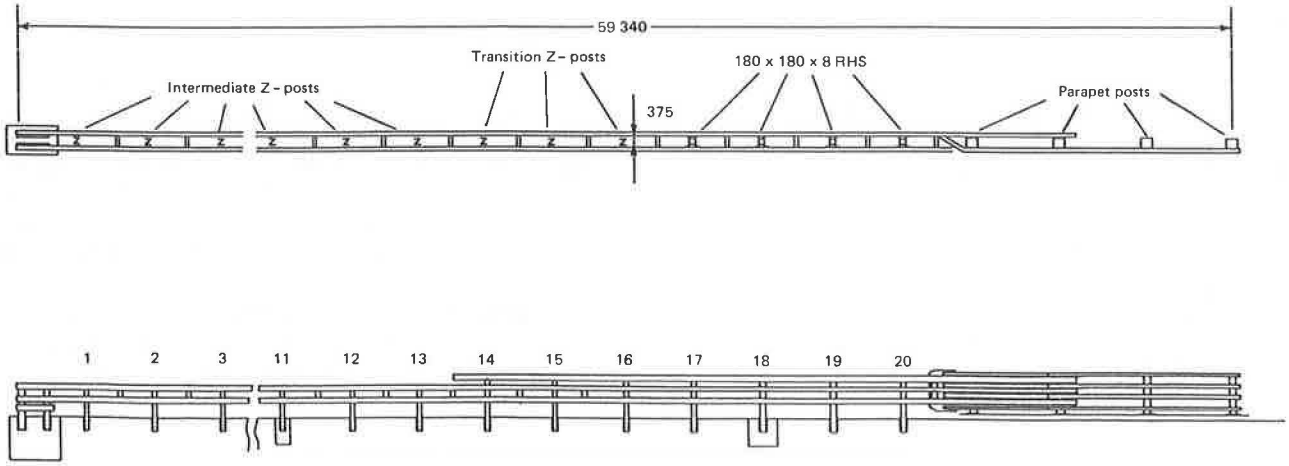


FIGURE 7 Transition from double-height, double-sided OBB safety fence to steel parapet, using three post sizes.

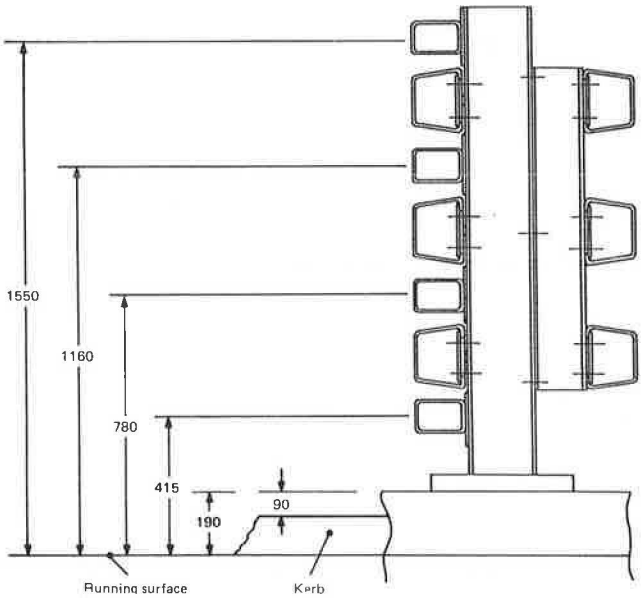


FIGURE 8 Cross section through transition.

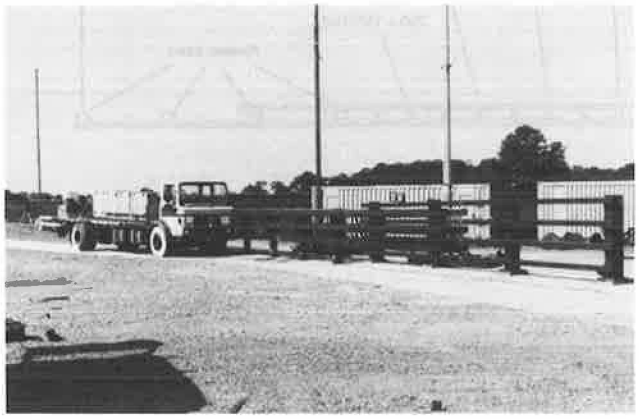


FIGURE 9 Front of transition.

FIGURE 10 Rear of transition.

by ground anchors. Figures 9 and 10 show a transition using eight sizes of posts. Both designs were impacted by 16-ton HGVs.

PARAPET IMPACT TESTS

Table 1 lists the vehicle impact speeds and weights, together with the parapet post spacings; the table also indicates whether the parapet was cladded or not. To keep damage repair between tests to a minimum, the strongest version, with 2-m post spacings, was tested first, starting with the lowest levels of impact energy.

Private Cars

There was no doubt that the high containment parapet would contain the 1-ton car impact at 113 km/h, 20 degrees; the purpose of the test was to determine the vehicle trajectory. Marginal changes of the post spacing in a parapet of this strength would have little influence on a private car; accordingly, car tests were made with the posts at only one interval (2-m centers).

Figures 11 and 12 are summary charts of the impacts on the non-cladded and cladded parapets; Table 2 gives some measured results of the severity of impact. The deceleration forces acting on the vehicles were high in both tests. The value of the theoretical head impact velocity estimates the impact velocity with which a freely moving object, representing an occupant's head, would hit the nearest surface inside the vehicle compartment (*4*). The recorded values of 8 m/s and 11 m/s are high, considering that irreversible injuries are likely to occur at levels in excess of 5 m/s.

Table 2 gives head and chest injury criteria analyzed to the requirements of FMVSS 208. The head injury criteria (HIC) at 1643 exceeded the 1000 limit for the non-cladded impact, and the chest acceleration at 59 g was close to the accepted threshold of 60 g over a duration of 3 m/s. The cladded parapet produced the converse situation: the HIC value was quite low at 269, and the chest acceleration of 110 g exceeded the threshold.

Vehicle trajectories were acceptable in both the non-cladded and cladded versions of the parapet in terms of the exit angle (cladded was 3 degrees, non-cladded, 4 degrees). Neither vehicle overturned.

The relatively soft body work around the impacted wheel penetrated into the depth of the rails on the non-cladded parapet, and in so doing tore off the bonnet. The wheel and suspension were severely damaged, although they remained attached to the car. The car ran clear of the parapet for about 70 m after impact, but then the braking forces acting on the damaged wheel caused the vehicle to gently yaw on soft ground through 180 degrees and stop some 10 m from the line of the parapet.

The vehicle trajectory with the cladded parapet appeared smoother and, although the wheel assembly was severely damaged, the car continued on a steady departure path for about 100 m and stopped about 10 m in front of the parapet.

The data clearly indicate that both impacts were severe. These high levels of impact force occur as a direct consequence of providing for high containment; users of high containment parameters must be aware of this. However, the severity of impact can be reduced by fixing safety fences to the front of the parapet by energy absorbing bracks (*5*); of course, doing so may make the parapet more easily climbed by irresponsible people.

Damage to the parapet was superficial; in-service repainting would be sufficient repair.

Heavy Goods Vehicles

The high containment parapet was subjected to four HGV impacts (Table 1). Three tests with 30-ton, 4-axle rigid tankers were at a nominal 68 km/h; one test, with a 16-ton, 2-axle rigid flat bed HGV, was at 80 km/h. All approach angles were 20 degrees. Two tests were with the post centers at 2-m spacings, and two tests had 3-m spacings. The fixing of 3-mm sheet steel cladding to the face of the parapet was alternated between tests.

High containment safety fences in steel and concrete have been developed using 16-ton HGVs as the target vehicles (*4*); these are representative of a large percentage of the UK commercial vehicle fleet. The first of the HGV parapet tests (D142) also used a 16-ton HGV to form a link between the work on high containment safety fences and the work on high containment bridge parapets. The result was expected to be a success, for the parapet was considerably stronger than the safety fence and should easily contain the HGV. More importantly, such a test would indicate the probable outcome—and any need for modification to the prototype parapet—of a 30-ton test.

Test D142: 16-ton HGV, 2-m post spacing, no cladding

To represent the worst-case condition, no cladding was fitted in anticipation that the vehicle might snag on the exposed posts and rails and so cause heavy loading to the post and rail fixings. Figure 13 shows that the 16-ton HGV, at an actual speed of 82.9 km/h, was successfully contained and redirected on a departure path close to the line of the parapet. The maximum deflection was 200 mm at the top rail.

The strain gauges fixed to the posts and rails recorded the expected double blow from the front and then the rear of the vehicle. What was not expected, however, was that the posts absorbed most of the impact energy in yielding—no tension in the rails was measured at the parapet end anchorages. The impact loads were confined to the damaged area over a length that included four posts. The rails made little contribution in tension, although their help in bending and redirection of the vehicle was clearly evident from high-speed film and examination of the parapet. A concrete payload block broke loose from the lorry and caused more damage to a post than any damage sustained from the main impact.

The 16-ton test showed that the parapet was sufficiently robust to proceed with the 30-ton vehicle tests.

Test D144: 30-ton HGV, 2-m post spacing, cladded

The impact speed was 68.8 km/h. The 3-mm-thick steel cladding was fixed with 6-mm self-tapping screws, which had proved adequate in the car tests. The 30-ton vehicle, however, removed three panels. This was considered unacceptable, and improved fixings were used in later tests.

The vehicle rolled heavily toward the parapet, the container tank was ruptured, and for a brief moment all wheels left the deck. The double impact of vehicle front and rear occurred as expected. The strain gauges recorded very little load transmitted to the parapet end anchorages. Three posts were damaged. The maximum penetration at the top of one post was 250 mm. All four rails in the impact zone were distorted, but not excessively—in-service repair would be necessary but not urgent.

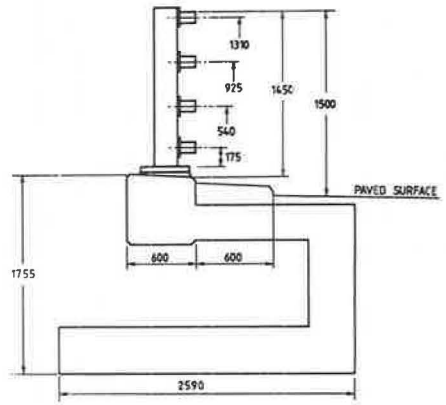
Figure 14 shows the trajectory of the HGV. The vehicle was successfully contained and redirected on a departure angle of 6 degrees at 58 km/h. The tanker was remotely braked to a halt some 30 m beyond the end of the parapet test length.

Test D148: 30-ton HGV, 3-m post spacing, cladded

The post spacings were increased from 2 m to 3 m. Wider post spacings are less expensive and more aesthetically pleasing when viewed from below the bridge than closer spacings.

P6 HIGH CONTAINMENT STEEL PARAPET

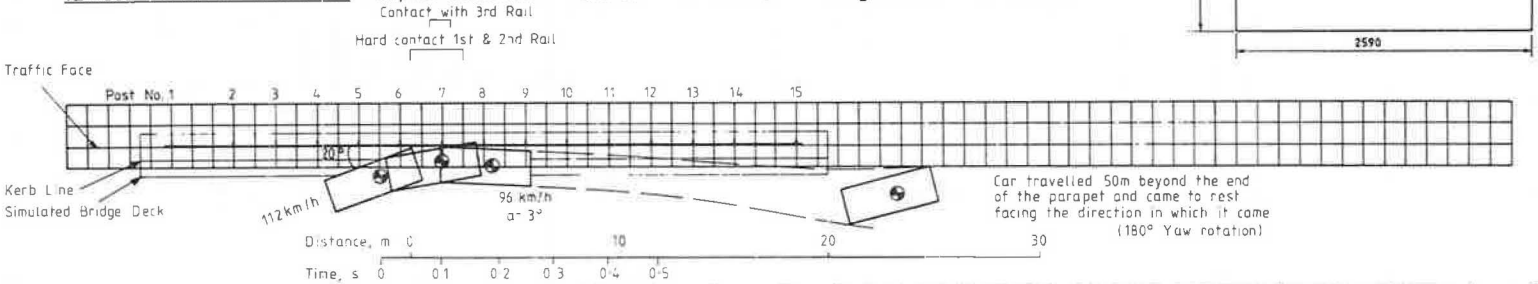
Length: 30·5 m
Static tension: Zero
Maximum deflection: Negligible
Damage: Dent on lower rail about 150 mm long, 5mm max depth



VEHICLE
Type: TALBOT ALPINE 1442cc CAR **Mass:** 1040 kg Plus 75 kg dummy

Damage: Severe on LHS from front to rear, front end displaced to left. LH front subframe and suspension crushed. Bonnet torn off and pushed through LH door window. Screen and side glass broken. A- and B-posts bent on contact with 3rd rail.

VEHICLE PARAPET RESPONSE **Impact velocities:** **Lateral:** 10·62 **m/s** **Longitudinal** 29·19 **m/s**



	Time after impact, s	0·02	0·04	0·06	0·08	0·10	0·12	0·14	0·16	0·18	0·20	0·22	0·24
Vehicle acceleration, *g* from accelerometers Filter: 10Hz, 48dB/oct.	Lateral, *g*	-5·2	-9·1	-11·5	-10·5	-6·5	-1·9	0·7	0·5	-0·8	-1·2	-0·5	0·0
	Longitudinal, *g*	-2·6	-4·9	-6·2	-5·3	-2·8	-0·8	-0·5	-1·0	-0·7	-0·1	-0·1	0·9
	Vertical, *g*	-0·2	0·2	0·4	-0·3	-1·5	-1·8	-0·9	-0·5	-1·3	-2·2	-2·1	-1·3
	Resultant, *g*	5·8	10·3	13·0	11·8	7·3	2·7	1·3	1·2	1·7	2·5	2·2	1·5
Vehicle forces, derived from accel. relative to undeflected barrier	Lateral, kN	63	112	141	126	75	21	-7	-5	9	13	7	0
	Longitudinal, kN	7	18	26	26	16	6	6	11	7	1	1	10

MEAN DECELERATION of vehicle for duration of 0·13 s

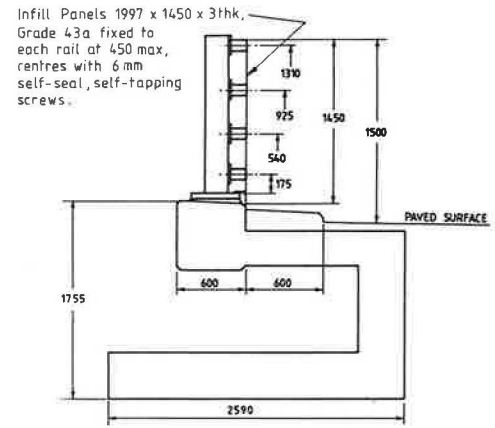
Lateral: 7·03 *g* **Longitudinal:** 3·54 *g*

REMARKS Vehicle was contained

FIGURE 11 Data from Test D139, September 19, 1986.

STEEL P6 HIGH CONTAINMENT PARAPET (WITH CLADDING)

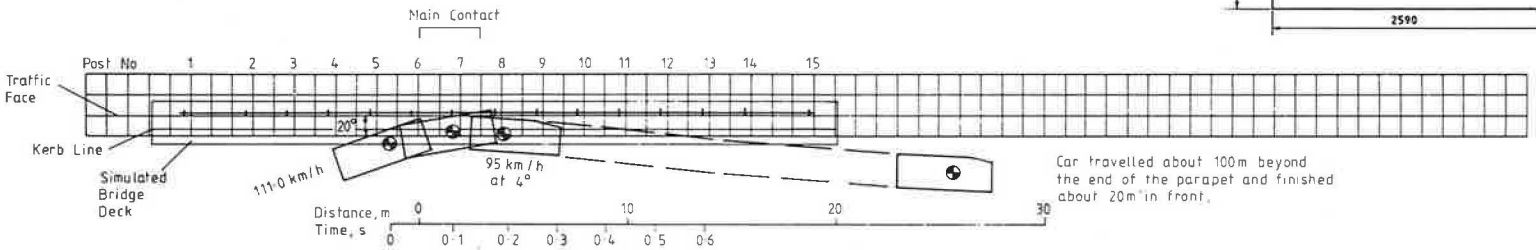
Length: 30·5
Static tension: Zero
Maximum deflection: Negligible
Damage: 6 Screws holding cladding sheared at point of impact. Minor scratches and dents.



VEHICLE
Type: TALBOT ALPINE 1442cc CAR Mass: 1000 kg Plus 75 kg dummy

Damage: Severe damage along whole of LHS, LHS wheel and suspension crushed, Car distorted – front end pushed to right Only RH rear door would open. Screen and sideglass broken.

VEHICLE PARAPET RESPONSE Impact velocities: Lateral: 10·55 m/s Longitudinal 28·98 m/s



	Time after impact, s	0·02	0·04	0·06	0·08	0·10	0·12	0·14	0·16	0·18	0·20
Vehicle acceleration, *g* from accelerometers Filter: 20Hz, 48dB/oct.	Lateral, *g*	-7·2	-17·4	-24·1	-4·3	6·2	-7·7	-8·7	-1·0	0·6	0·7
	Longitudinal, *g*	-3·5	-2·4	-11·5	-11·0	3·7	-5·0	-2·0	3·8	-3·0	1·3
	Vertical, *g*	0·9	-3·6	-2·7	1·3	-2·1	0·4	0·8	-2·1	-0·5	1·1
	Resultant, *g*	8·0	17·9	26·8	11·8	7·5	9·2	8·9	4·4	3·1	1·9
Vehicle forces, derived from accel. relative to undeflected barrier	Lateral, kN	86	186	286	74	-73	87	94	8	-3	
	Longitudinal, kN	9	-37	40	104	-28	47	22	-40	33	

MEAN DECELERATION of vehicle for duration of 0·18 s

Lateral: 7·20 *g* Longitudinal: 3·30 *g*

REMARKS Satisfactory Containment

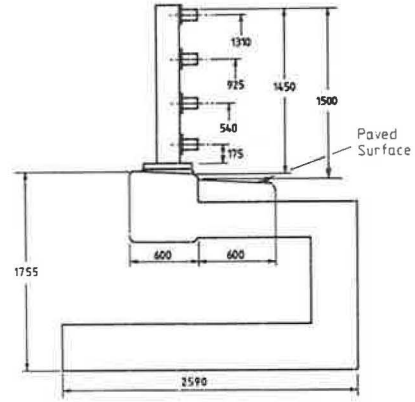
FIGURE 12 Data from Test D140, October 1, 1986.

STEEL P6 HIGH CONTAINMENT PARAPET

Length: 30·5 m
Static tension: Zero
Maximum deflection: 0·2 m approx on top rail
Damage: Caused by lorry and ballast blocks

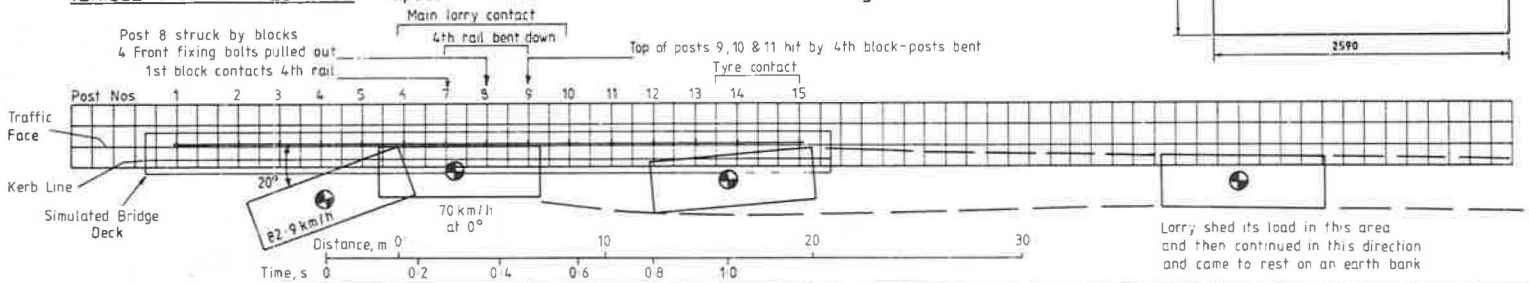
Lorry: Dents in rails - mainly 2nd rail near post 6 which also has 0·5 m split
Post 6 flange bent by lorry flatbed. Post 7 bent back 0·1 m

Ballast Blocks: Post 8 pushed back - 4 fixing bolts stripped. Post 9 pushed sideways by 4th ballast block.
Post 10 pushed sideways by 4th ballast block. Post 11 pushed sideways by 4th ballast block.
4th rail bent down between posts 7 & 9 by blocks.
Rail attachment bolts sheared on posts 6 to 11 inclusive.



VEHICLE
Type: 2-axle Rigid Lorry **Mass:** 15·9 tonne **Damage:** LHS front axle displaced rearwards.
Headboard pushed off by ballast.
Chassis bent and twisted.
Cab unlatched and tilted forward late in run-off.

VEHICLE PARAPET RESPONSE Impact velocities: Lateral: 7·87 m/s Longitudinal 21·63 m/s



	Time after impact, s	0·05	0·10	0·15	0·20	0·25	0·30	0·35	0·40	0·45	0·50	0·55	0·60	0·65	0·70
Vehicle acceleration, *g* from accelerometers Filter: 10Hz, 48dB/oct.	Lateral, *g*	-1·2	-5·9	-2·9	2·1	-3·1	-2·8	-4·5	1·2	-1·1	-1·3	1·3	-0·5	-1·2	-0·7
	Longitudinal, *g*	-0·7	-3·3	-1·5	0·2	-0·7	-0·9	-1·3	0·6	1·3	-0·9	-0·2	-0·9	-0·3	-0·7
	Vertical, *g*	0·4	-0·1	0·2	0·7	-0·6	0·7	-0·9	-1·5	-2·4	-1·3	0·4	0·1	-0·9	-1·0
	Resultant, *g*	1·5	6·8	3·3	2·3	3·3	3·0	4·8	2·0	2·9	2·0	1·3	1·0	1·5	1·4
Vehicle forces, derived from accel. relative to undeflected parapet	Lateral, kN	210	1040	500	-330	490	440	700	-190						
	Longitudinal, kN	40	190	110	20	70	140	200	-90						

MEAN DECELERATION of vehicle for duration of 0·38 s

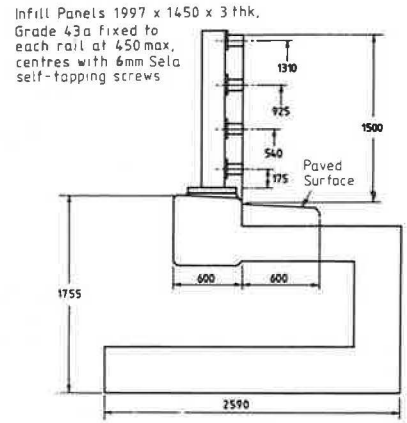
Lateral: 2·37 *g* Longitudinal: 1·08 *g*

REMARKS Lorry was contained and redirected

FIGURE 13 Data from Test D142, October 16, 1986.

STEEL P6 HIGH CONTAINMENT PARAPET (WITH CLADDING)

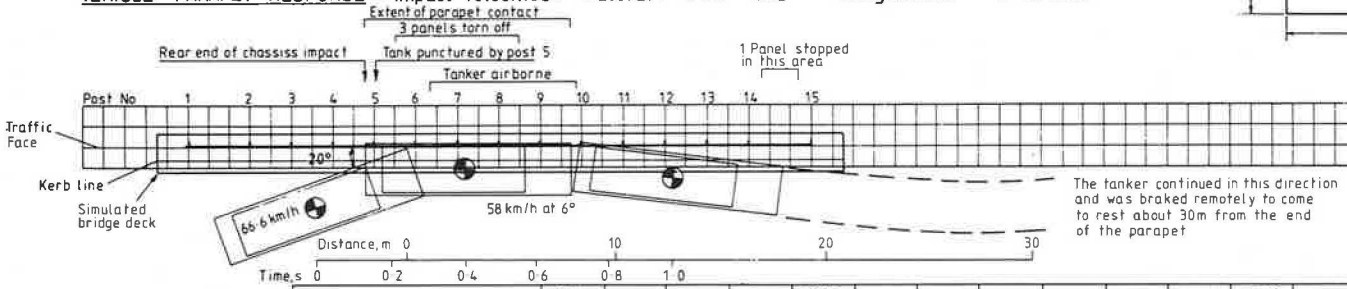
Length : 30·5m
Static tension : zero
Maximum deflection : 0·2m approx. on top rail
Damage : Posts 6, 7, 8 bent rearwards
Gouges and dents on two lower rails near post 6
Localised dent on 2nd rail near post 5
Top rail deformed over 6m length
3 panels torn off



VEHICLE
Type : SEDDON ATKINSON 4-AXLE TANKER Mass : 30·7 tonne

Damage : Chassis bent to RHS
1st axle pushed sideways and rearwards
Front LH and RH spring hanger torn off
Tank grooved on lower LHS by posts and rail 4
Punctured by post 5 at rear of tank
Pierced by panel at front
Cab damaged on LHS

VEHICLE PARAPET RESPONSE Impact velocities : Lateral : 6·33 m/s Longitudinal 17·39 m/s



	Time after impact, s	0·1	0·2	0·3	0·4	0·5	0·6	0·7	0·8	0·9	1·0	1·1	1·2
Vehicle acceleration, g from accelerometers Filter: 10Hz, 48dB/oct.	Lateral, g	-2·3	-5·4	2·0	-0·1	-3·4	-1·0	-0·1	0·7	0·5	-0·7	-0·6	-0·1
	Longitudinal, g	-0·9	-1·0	-0·6	-0·7	-0·3	-0·2	0·1	-0·1	0·0	-0·2	-0·3	-0·3
	Vertical, g	0·2	-0·4	0·7	-0·5	0·12	-0·7	-0·4	-1·1	0·0	0·7	0·7	-0·1
	Resultant, g	2·5	5·5	2·3	0·8	3·4	1·2	0·5	1·3	0·5	0·8	0·9	0·4
Vehicle forces, derived from accel. relative to undeflected parapet	Lateral, kN	740	1640	-570	30	1010	290	Analysis inappropriate					
	Longitudinal, kN	19	-173	270	210	18	28						

MEAN DECELERATION of vehicle for duration of 0·52 s

Lateral : 1·91 g Longitudinal : 0·68 g

REMARKS
Tanker was contained and redirected by the parapet, but the tank was punctured

FIGURE 14 Data from Test D144, November 6, 1986.

TABLE 2 MEASURED IMPACT SEVERITY

Test No.	Thiv m/s	HIC	Head (accel. g) Severity Index: Head	Level over 3 mS	Over 250 mS	Chest (accel. g): Peak	Level over 3 mS	Time over 60 g (sec)
D139–1.0:112:20,[a] non-cladded	8	1643	360	76	514	72	59	2.6
D140–1.0:111:30,[a] cladded	11	269	67	57	857	130	110	6.9

NOTE: Post spacing = 2.0 m. D139: HIC fatal; chest acceleration marginally below 60 g limit. D140: HIC moderate; chest acceleration severe.
[a]Weight:speed:angle.

Stainless steel structural rivets, 6.35 mm in diameter, were used to improve the fixing of the steel cladding. In practice, the fixing proved adequate and no panels were dislodged during impact.

The impact speed was 66.1 km/h (Figure 15). Three posts were taken to yield point. The maximum deflection of 300 mm occurred at the top rail—a value well within the design deflection of 800 mm.

The HGV front suspension was severely damaged and the container tank was ruptured by contact with the top of one post. The vehicle rolled heavily toward the parapet.

Very little load was transmitted through the rails to the end anchorages. Post anchorages were undamaged—the yielding of the posts had contributed mainly to the absorption of the impact. About 9 m of rail needed repair, but this would not be urgent. The test showed that the parapet with a 3-m post spacing was an acceptable design.

Figure 15 shows a plan view of the HGV trajectory. The vehicle was successfully contained and redirected on an exit angle of 2 degrees at 54 km/h in a stable condition. It was braked to rest some 24 m from the end of the parapet.

Test E173: 30-ton HGV, 3-m post spacing, no cladding

The steel-cladded parapet with 3-m post spacings had successfully contained the design impact load. It was anticipated that there would be a demand for the parapet without the steel cladding, but the contribution to the overall parapet strength offered by the cladding acting as a shear panel was unknown. To find out, one further test was made on the parapet, this one using 3-m spacing and no cladding.

The HGV hit the parapet at a speed of 65.3 km/h (Figure 16); it was successfully contained and redirected on a departure path of 1.5 degrees at 44.9 km/h. The HGV tank was ruptured by the tops of three posts, allowing the contents to spill from the tank. The chassis of the tanker was distorted, but only one U-bolt holding the front axle sheared. The tank was spilt over a length of about 1 m. After the HGV left the test area, the remote brakes were applied; the vehicle came to rest and remained on its wheels.

Four rails were damaged over a length of 18 m; they needed replacement, but the repair was not urgent. The top rail was permanently deflected a distance of 400 mm and the maximum post deflection was 200 mm, measured at the top. Some bolts sheared holding the rails to the posts but no station was without some bolted connection. There was no apparent damage to the bolts holding the posts to the deck anchorage.

The parapet had satisfactorily contained and redirected the 30-ton test vehicle.

On several occasions over the series of tests, the tops of the posts had punctured the container tank of the HGV. This is clearly a hazard, particularly if the vehicle is carrying toxic or flammable substances. In service, the posts should be cut short to the level of the top rail or treated with a protective capping piece to reduce the risk of penetrating the tank.

TRANSITION IMPACT TESTS

Figures 6 and 7 show the transitions from safety fence to bridge parapet. Test D155 had eight posts graded in strength from the high containment fence Z-post to the high containment bridge parapet. Test E159 had three graded strength transition posts from fence to parapet.

Each design was impacted at over 80 km/h by a 16-ton, rigid HGV on a 15-degree approach path.

Figures 17 and 18 show the path of each vehicle during and after impact. Both vehicles were successfully contained and redirected. Maximum roll angles measured at the center of gravity were 33 and 34 degrees. The departure paths were close to the line of the fence and the parapet, at 1 degree and less; both exit speeds were at 70 km/h.

In Test D155 (eight grades of post), the vehicle contacted the parapet a second time and then came to rest after the brakes were applied. The lower rail of the transition was extensively damaged and five posts would need in-service replacement. The maximum permanent deflection measured at the top of the post was 75 mm. The vehicle ballast blocks caused some damage to the top rail and to the top of two posts.

In Test E159, the ballast blocks shifted on the lorry bed and displaced one post a longitudinal distance of 300 mm and also caused damage to the top rail. Five posts needed replacement; the maximum lateral post deflection measured at the top was 100 mm.

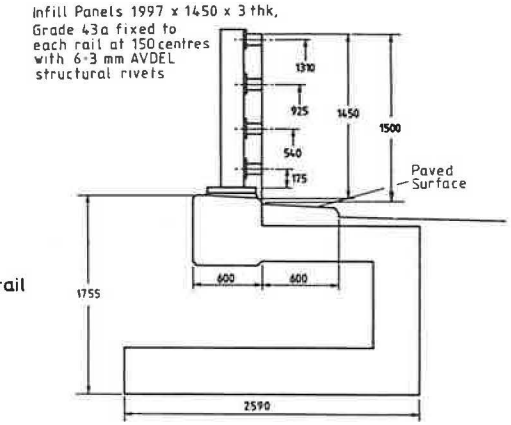
In neither test would the in-service repairs be regarded as urgent.

After the vehicle left the transition in Test E159, it ran in a stable condition onto rough ground. The remote-controlled brakes caused the vehicle to yaw; it then overturned and rolled through 360 degrees. Movement of the ballast blocks on the lorry bed contributed to the overturning motion.

In each test about 10 posts needed replacement, though none urgently. Transition rails were damaged over a length of about 17 m; some could be reused. The maximum rail

STEEL P6 HIGH CONTAINMENT PARAPET (WITH CLADDING)

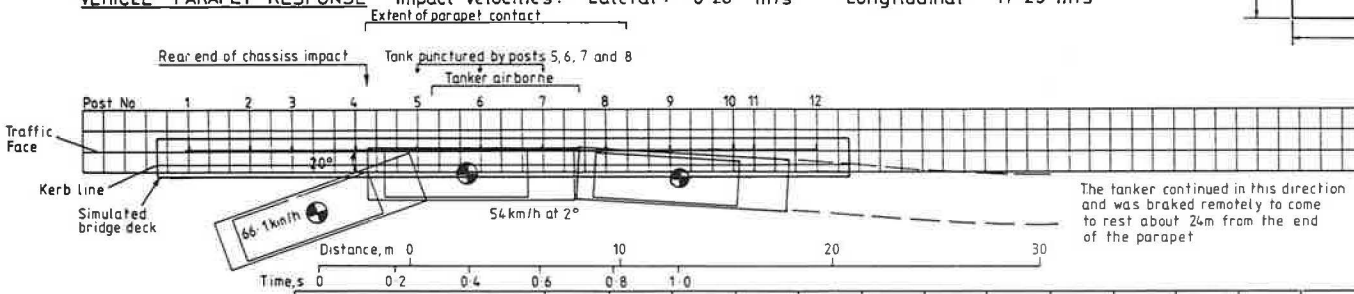
Length: 30·5m
Static tension: zero
Maximum deflection: 0·3m approx. on top rail
Damage: Posts 5,6 & 7 bent rearwards
Gouges in front plate adjacent to post 5
Top of parapet leaning rearward 250 mm between posts 5 and 7
Top rail deformed over 9m length



VEHICLE
Type: SEDDON ATKINSON 4-AXLE TANKER Mass: 31·3 tonne

Damage: Chassis bent to RHS
Both axles pushed rearwards
Front LH and RH spring hangers torn off
Tank grooved on lower LHS by posts and top rail
Punctured tank from front to rear
Pierced by top of support posts
Cab damaged on LHS

VEHICLE PARAPET RESPONSE Impact velocities: Lateral: 6·28' m/s Longitudinal 17·25 m/s



	Time after impact, s	0·1	0·2	0·3	0·4	0·5	0·6	0·7	0·8	0·9	1·0	1·1	1·2
Vehicle acceleration, g from accelerometers Filter: 10Hz, 48dB/oct.	Lateral, g	-1·61	-4·53	-1·28	-1·74	0·10	-0·29	-0·29	0·48	0·06	-1·15	-0·82	-0·70
	Longitudinal, g	-0·70	-1·13	-1·15	-0·81	-0·05	-0·22	-0·25	-0·01	-0·08	-0·07	-0·26	-0·01
	Vertical, g	0·23	0·12	0·24	-0·15	0·45	-0·31	-0·52	-0·88	-0·21	0·43	-0·05	0·06
	Resultant, g	1·77	4·67	1·76	1·96	0·46	0·48	0·94	1·01	0·23	1·23	0·86	0·71
Vehicle forces, derived from accel. relative to undeflected parapet	Lateral, kN	-524	-1393	-433	-523	30	-80	Analysis inappropriate					
	Longitudinal, kN	40	67	-277	-237	-14	-75						

MEAN DECELERATION of vehicle for duration of 0·52 s

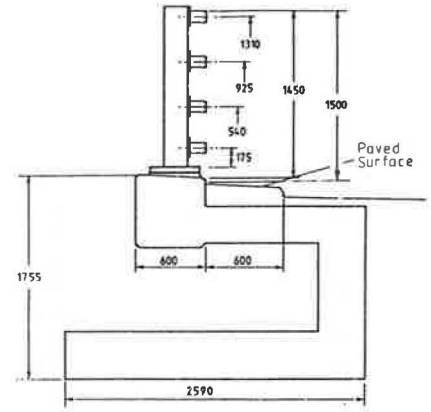
Lateral: -1·85 g Longitudinal: -0·65 g

REMARKS
Tanker was contained and redirected by the parapet; the tank was punctured

FIGURE 15 Data from Test D148.

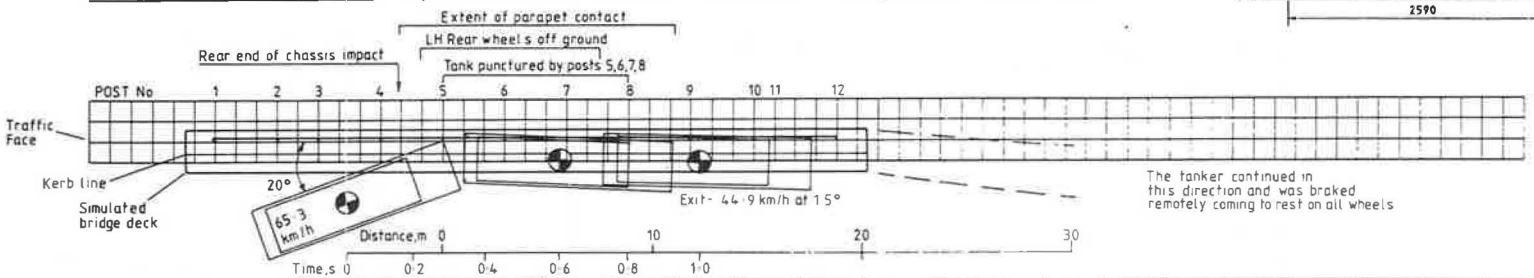
SAFETY FENCE – P6 HIGH CONTAINMENT PARAPET

Length: 30·5m
Static tension: zero
Maximum deflection: 0·4m approx on top rail
Damage: Post 5, 6 and 7 bent rearwards
Deep groove in 2nd rail from ground between posts 5 and 6
Top of parapet leaning rearward
Top rail deformed over length



VEHICLE
Type: ERF 4-AXLE TANKER Mass: 32·1 tonne Damage: Chassis bent to RHS
1st Front axle U-bolt sheared
Axle pushed slightly rearward
Tank grooved on lower LHS by posts and top rail
Tank lower LH front and rear corners ruptured, and 1m slit in LH front quarter of tank
Cab damaged on LHS

VEHICLE BARRIER RESPONSE Impact velocities: Lateral: 6·20 m/s Longitudinal 17·04 m/s



	Time after impact, s	0·1	0·2	0·3	0·4	0·5	0·6	0·7	0·8	0·9	1·0	1·1	1·2
Vehicle acceleration, g from accelerometers Filter: 10Hz, 48dB/oct.	Lateral, g	-0·66	-1·20	-0·93	-1·00	-3·63	-0·83	-0·20	0·38	0·07	-0·36	0·36	0·34
	Longitudinal, g	-0·96	-1·37	-0·76	0·06	-0·22	-0·10	-0·16	0·05	-0·07	0·12	-0·12	0·02
	Vertical, g	0·39	0·08	-0·03	-0·18	0·56	-1·38	-0·52	-1·11	-0·60	0	-0·04	0·99
	Resultant, g	1·23	1·82	1·20	1·02	3·68	1·61	0·58	1·17	0·61	0·38	0·38	1·04
Vehicle forces, derived from accel. relative to undeflected barrier	Lateral, kN	-299	-488	-331	-315	-1137	-257	-61	118	Analysis Inappropiate			
	Longitudinal, kN	-215	-298	-181	27	-148	-53	-53	21				

MEAN DECELERATION of vehicle for duration of 0·74 s

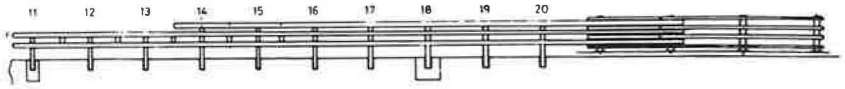
Lateral: 1·13 g Longitudinal: 0·45 g

REMARKS
Tanker was contained and redirected by parapet, LHS of tank was punctured in three places

FIGURE 16 Data from Test E173.

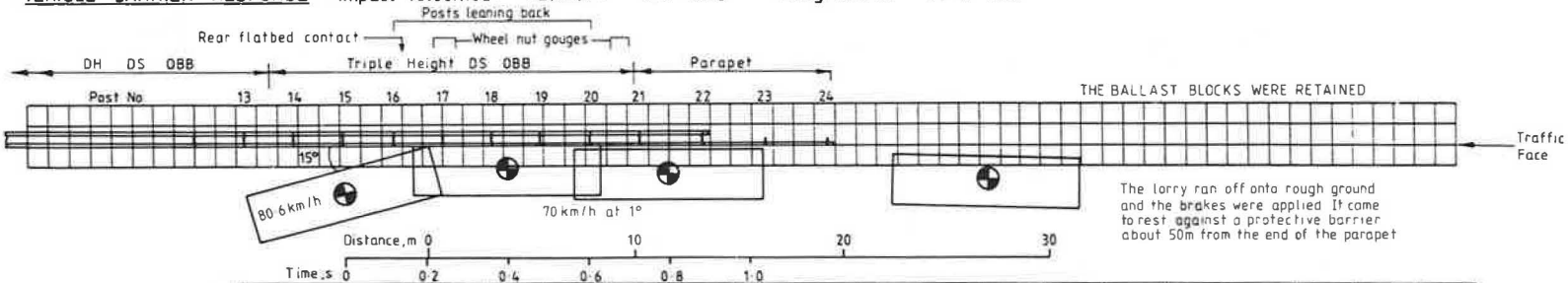
SAFETY FENCE – TRANSITION BETWEEN DOUBLE-HEIGHT DS OBB AND P6 STEEL PARAPET

Length: 59m
Static tension: zero
Maximum deflection: About 0·1m
Damage: Lower beam dent at post 17
Wheel nut gouges at post 19 and near post 21
OBB Flange torn near post 18
Dent on middle beam at post 16
Ballast blocks caused damage to upper beam between posts 18 and 19, and parapet top rail
Posts 16 to 20 leaning back



VEHICLE
Type: 2-AXLE RIGID LORRY Mass: 16·1 tonne Damage: Chassis bent and twisted
Cab dented on LHS
Cargo platform damaged on LHS and headboard pushed forward

VEHICLE BARRIER RESPONSE Impact velocities: Lateral: 5·8 m/s Longitudinal 21·6 m/s



	Time after impact, s	0·05	0·1	0·15	0·2	0·25	0·3	0·35	0·4	0·45	0·5	0·55	0·6
Vehicle acceleration, *g* from accelerometers Filter: 10Hz, 48dB/oct.	Lateral, *g*	-0·6	-2·1	-2·4	-1·0	-1·3	-1·2	-1·8	-1·7	-1·1	-1·7	-2·1	0·3
	Longitudinal, *g*	-0·8	-1·4	-0·3	-0·6	-0·5	-0·5	-0·4	-0·9	-0·9	-0·6	-0·2	0·1
	Vertical, *g*	-0·2	-0·2	-0·2	-0·2	0·6	-0·1	-0·4	-0·9	-0·1	-0·2	0·1	-0·1
	Resultant, *g*	1·0	2·5	2·4	1·2	1·5	1·3	1·9	2·1	1·4	1·8	2·1	0·3
Vehicle forces, derived from accel. relative to undeflected barrier	Lateral, kN	124	372	380	172	202	184	286	261	167	262	325	
	Longitudinal, kN	99	138	33	63	61	75	77	146	147	106	41	

MEAN DECELERATION of vehicle for duration of 0·57 s

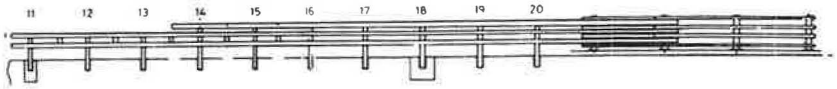
Lateral: 1·47 *g* Longitudinal: 0·62 *g*

REMARKS Satisfactory containment

FIGURE 17 Data from Test D155, July 2, 1987.

SAFETY FENCE – TRANSITION BETWEEN DOUBLE-HEIGHT DS OBB AND P6 STEEL PARAPET – MK 2

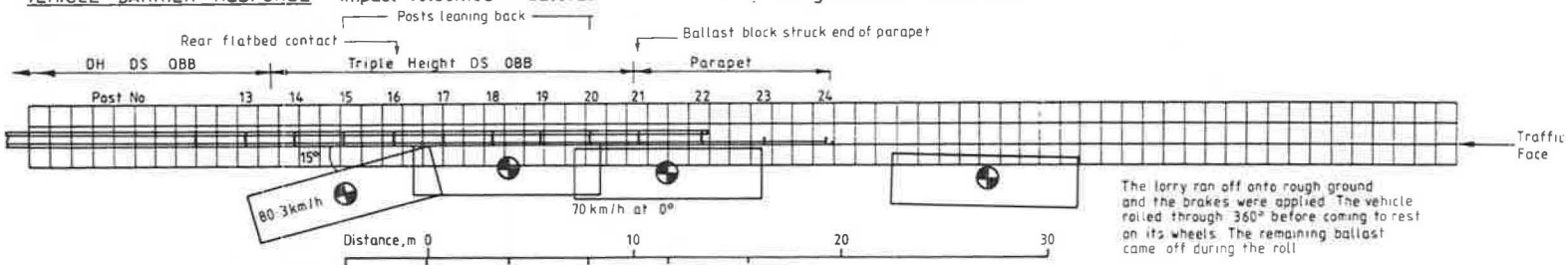
Length: 59m
Static tension: zero
Maximum deflection: About 0·15m
Damage: Lower beam dented between posts 17and 18
Dent on middle beam at post 16
Last ballast block struck start of parapet, damaging top rail and bending post 21 downstream by 0·3m



VEHICLE
Type: 2-AXLE RIGID LORRY , Mass: 16·3 tonne

Damage: During impact with transition:
Chassis bent and twisted
Cab dented LHS
Cargo platform damaged on LHS-headboard dislodged
During roll:
Cab crushed flat

VEHICLE BARRIER RESPONSE Impact velocities: Lateral: 5·8 m/s , Longitudinal 21·5 m/s



The lorry ran off onto rough ground and the brakes were applied. The vehicle rolled through 360° before coming to rest on its wheels. The remaining ballast came off during the roll

	Time after impact, s	0·05	0·1	0·15	0·2	0·25	0·3	0·35	0·4	0·45	0·5	0·55	0·6	0·65
Vehicle acceleration, *g* from accelerometers Filter: 10Hz, 48dB/oct	Lateral, *g*	-0·4	-2·7	-1·9	-1·1	-1·4	-1·4	-3·6	-1·3	-0·2	0·4	-1·4	-0·8	0·3
	Longitudinal, *g*	-0·9	-1·2	-0·6	-0·5	-0·6	-1·3	-0·5	-0·6	-0·4	-0·4	-0·3	-0·4	-0·6
	Vertical, *g*	-0·2	0·2	-0·1	0·3	0·4	-0·3	-0·4	0·0	-0·6	-0·5	-0·6	-0·2	-1·1
	Resultant, *g*	1·0	2·9	2·0	1·2	1·6	1·9	3·6	1·4	0·8	0·8	1·5	0·9	1·3
Vehicle forces, derived from accel. relative to undeflected barrier	Lateral, kN	101	459	318	187	225	223	572	205	30	-67	215	128	
	Longitudinal, kN	116	77	29	55	81	195	88	102	71	67	42	58	

MEAN DECELERATION of vehicle for duration of 0·6 s

Lateral: 1·29 *g* Longitudinal: 0·63 *g*

REMARKS
Satisfactory containment

FIGURE 18 Data from Test E159, September 15, 1987.

deflections were 100 mm and 150 mm in Tests D155 and E159, respectively.

Both the eight-size (Test D155) and the three-size post transitions (Test E159) successfully contained and redirected the 16-ton, 80 km/h test vehicle. Both designs achieved the objective of protecting the vehicle from impacting the parapet endpost. The transition with three sizes of post is probably more attractive from the point of view of primary and repair costs.

CONCLUSIONS

- A steel post-and-rail high containment parapet to withstand a 30-ton, 4-axle, HGV tanker impacting at 64 km/h on an approach path of 20 degrees has been designed and successfully tested.
- The problem of protecting vehicles from impacting the end of the parapet has been solved by the design and development of a transition length about 17 m long, which connects a DHDSOB to the parapet. The transition length successfully contained and redirected a 16-ton, 2-axle HGV, approaching at 15 degrees, at a speed just over 80 km/h.
- Both parapet and transition length redirected the HGVs and 1-ton cars at angles less than the design departure angle of 12 degrees, although lateral deceleration was high, particularly in the case of the private cars.
- Strain gauges in the rails, posts, and simulated bridge deck indicated that the loading was fairly local and did not transfer to the rail end anchorages. Yielding of the posts and rails absorbed the kinetic energy attributable to the lateral velocity of the vehicles.
- Maximum deflection of the parapet was within the design limit of 800 mm. The maximum recorded deflection of a rail was 400 mm and that of a post, measured at the top, was 200 mm.
- The tops of posts penetrated the container tank of the HGV. This would be a hazard for vehicles carrying toxic or flammable material. The tops of the posts should either not protrude above the top rail or have a protective capping to minimize the risk of puncturing the container tank.

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