SAFETY FENCES AND BRIDGE PARAPETS—TRRL PAPERS
FOR THE 1986 TRB ANNUAL MEETING

Papers presented to the 65th Annual Meeting of the Transportation Research Board in Washington DC, 13–16 January 1986

The views expressed in this report are not necessarily those of the Department of Transport

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SAFETY FENCES AND BRIDGE PARAPETS—TRRL PAPERS FOR THE 1986 TRB ANNUAL MEETING

ABSTRACT
Research Report 75 contains the full text of 5 papers which were presented to the 1986 TRB Annual Meeting. These were

Karabi Laker

Severe impacts with motorway safety fences by M D Macdonald

Safety fence post footings by M D Macdonald

Safety fence criteria for all-purpose dual carriageway roads by G R Watts

Vehicle to safety fence impact studies by M M Sadeghi and M P Blake

PREFACE
Since the beginning of 1983 the Transport and Road Research Laboratory has been developing safety barriers and bridge parapets to contain and redirect goods vehicles of the increased maximum gross weight of 38 tonnes that was permitted during 1983. This development has included on-site investigation of accidents in which heavy goods vehicles hit safety barriers and bridge parapets, to determine the design requirements for such equipment; the modelling on computers of vehicles hitting barriers, to enable the implications of changes in design requirements or of barrier design to be assessed; and the full scale testing of steel and concrete safety barriers and bridge parapets. Progress with this development programme was reported to the 65th Annual Meeting of the Transportation Research Board which was held in Washington DC 13–16 January 1986.

This meeting included a session on International Roadside Safety Hardware Research, with Presiding Officer John G Viner, Federal Highway Administration, and two sessions of the TRB Committee on Safety Appurtenances (A2A04), Chairman Hayes E Ross, Texas A & M University.

This report contains the full texts of the five papers for the TRB Meeting on the TRRL safety barrier and bridge parapet development programme. These were presented in Washington by I B Laker of TRRL, and were as follows:

1. High containment safety barriers: steel and concrete by I B Laker, MPhil, CEng, MIEE, MI Mech E—Annual Meeting

2. Severe impacts with motorway safety fences by M D Macdonald—Committee A2A04

3. Safety fence post footings by M D Macdonald—Committee A2A04

4. Safety fence criteria for all-purpose dual carriageway roads by G R Watts, PhD, BSc—Annual Meeting

5. Vehicle to safety fence impact studies by M M Sadeghi, PhD, MSc and M P Blake BA (Cantab)—Committee A2A04

Mr Laker, Mr Macdonald and Dr Watts are members of Vehicle Engineering Division, TRRL. Dr Sadeghi is Director of the Cranfield Impact Centre and Mr Blake is a Project Engineer at the Centre. The work of the Cranfield Impact Centre on modelling vehicle to barrier impacts is conducted under contract to TRRL. The work reported in papers 1, 2 and 3 was carried out by a team of TRRL staff consisting of Mr I B Laker, Mr T Williams, Mr I C P Simmons, Mr B A Broad, Mr M D Macdonald, Mr D J Jacklin, Mr J T Hanley, Mr D Maynard and Mr A Mumford.
ABSTRACT

The development and testing of a steel fence and the construction and testing of a concrete barrier are described; both fence and barrier were impacted with vehicles ranging from a small car to a 38 tonne articulated heavy goods vehicle. The cars at 112 km/hr and the 16 tonne heavy goods vehicles at 80 km/hr were contained and redirected by the fence and the barrier after impacting at an angle of 15 degrees; in addition, a 38 tonne articulated heavy goods vehicle and a 51 seat coach were redirected by the steel fence.

Further work is needed to improve the fence response to 25 degree impacts. Modification to the concrete barrier may be necessary before impact testing at 25 degrees.

1 INTRODUCTION

Safety fences currently in use in the United Kingdom include the tensioned beam, the open box beam Jehu and Pearson (1972) and the rectangular hollow section RHS Safety Fence (1984). Safety fences, usually of the tension beam type, are installed on the median strip of British motorways as a matter of course, and on the median strips of the busier non-motorway dual carriageway roads. All three types in current use are made of steel and were designed to redirect a 1.5 tonne car hitting them at an angle of 20 degrees to the line of the fence at a speed of 112 km/hr so that the car remained close to the side of the fence. The performance of these single height fences was proven by full-scale tests. In addition, a test into a double sided tension beam fence with a passenger coach weighing 5.4 tonne proved satisfactory at 87 km/hr and 13 degrees, although the coach came close to roll-over (Jehu and Pearson 1972).

Over the past decade the total traffic mileage in Britain of heavy goods vehicles (HGVs) has remained constant at about 20 x 10^9 vehicle km, but the proportion of this that is due to the largest vehicles (4 and 5-axle articulated HGVs) has increased from 18 to 26 per cent. On motorways in 1983, 4 and 5-axle articulated vehicles accounted for 45 per cent of all HGVs and 8 per cent of all vehicles. This, plus the increase in 1983 of the authorised maximum gross
weight for HGVs from 32.5 to 38 tonnes has led the Department of Transport to examine the potential of stronger fences and barriers particularly for use in localised applications where a high level of containment is essential. This paper describes two which have been developed, a high containment steel fence and a concrete safety barrier. Both of these have been subjected to full-scale impact tests using cars ranging from a BL Mini at 112 km/hr to a 39.2 tonne truck at 80 km/hr. The objective of the tests described in this paper is to develop a fence which will contain the heaviest vehicles in general use on British roads under realistic impact conditions while being as forgiving as possible to light vehicles, and to cost little more than the current fences to install.

Other work by the Transport and Road Research Laboratory involves on-site accident investigations to determine what impact conditions occur in practice, the development of methods of fixing fence posts in poor soil and the development of high containment bridge parapets.

2 THE HIGH CONTAINMENT FENCES

2.1 THE STEEL FENCE

The high containment steel fence, called the double height double sided open box fence (DHDSOB), has been designed to use, so far as possible, components from the safety fences currently available in Britain. A cross section, plan and elevation of the fence are shown in Figure 1. The fence consists of four parallel open box beams set in pairs on either side of the fence at heights of 610 mm and 1020 mm. These are supported by Z-section steel 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 bolts that are designed to fail during an impact. This is to allow the fence beams to remain upright while the posts fold sideways. Between posts the four beams are connected by rectangular frames braced with cross-struts (Figure 1), placed at each mid-span to hold the beams in position during impact.

For impact testing a 115 metre length of the steel fence was erected, supported at each end by full height steel anchors set in large concrete blocks (Figure 1).

2.2 THE CONCRETE BARRIER

Whereas safety fences are intended to absorb some of the energy of impact and to redirect the errant vehicle so that it follows, with an acceptable angle, the line of the fence in the direction of the traffic, concrete safety barriers are intended to provide containment without significant deflection or deformation under impact (BS6579, 1985).

The barrier impacted in this series of tests, known as the British Concrete Barrier (BCB), is based on early work carried out at TRRL on shaped concrete profiles (Jehu and Pearson, 1977). A British Standard publication (BS6579, 1985) gives the specification of the BCB. The barrier tested consisted of three metre long precast-concrete units fixed by six dowel pins per unit on to a concrete foundation flush with road surface (Figure 2a); alternative methods of mounting are given in the British Standard.

The Cement and Concrete Association funded the supply of the BCB: TRRL funded the installation and testing. The length installed was 60 metres in 3 metre precast units linked together longitudinally by simple tongued and grooved joints as shown in Figure 2b.
3 IMPACT TEST CONDITIONS

3.1 THE TEST VEHICLES

A barrier designed to be sufficiently strong to withstand the impact of a 38 tonne articulated HGV represents a very rigid obstacle to a small private car. A knowledge of the damage to a car and its subsequent trajectory after impact, and of the trajectory of an occupant within the car, is essential to establish the overall performance of the fence or barrier. So the lightest test vehicle was chosen to be a mini car and the following vehicle weights and types, representing the national fleet were chosen to complete the range between a 38 tonne articulated HGV and a mini.

- Small car — BL Mini (weight 750 kg)
- Medium car — Talbot Alpine (weight 1,000 kg)
- Medium commercial — 16 tonne GVW 2-axle rigid
- Heavy commercial — 30 tonne GVW 4-axle rigid
- Heavy articulated — 38 tonne 2-axle tractor, 3-axle trailer
- Passenger coach — 14 tonne GVW

Details of vehicle dimensions and axle loads are given in Tables 1 and 2. The vehicles were all purchased second-hand but were serviceable and had passed MOT tests, and were typical of many vehicles in current use on British roads.

3.2 IMPACT ANGLE

Early work (Jehu and Pearson, 1977) had shown by simple geometric analysis that a 112 km/hr car travelling on the nearside of a three lane carriageway was unlikely to impact a median safety fence at an angle greater than 20 degrees. The impact energy of such a vehicle, due to the velocity component normal to the fence, is about 85 kN metres and safety fences have successfully contained and redirected vehicles of this energy. Also the double height single sided open box fence has satisfactorily contained a 5.2 tonne coach impacting at 80 km/hr at 20 degrees (Jehu and Pearson, 1972).

However the energy normal to the fence for a similar impact with a 16 tonne HGV and a 38 tonne HGV is approximately 3 times and 7 times that of the coach respectively. The successful containment of vehicles at these higher magnitudes of energy could not be predicted from the current knowledge of post and rail fences, so impacts at shallower angles with less energy normal to the fence were considered as a starting point.

An 80 km/hr impact at an angle of 15 degrees with a 16 tonne HGV has about 1.7 times the energy normal to the fence, of the successful test with a 5.2 tonne coach at 20 degrees mentioned above. A fence design which could contain an HGV impact of this higher energy level was considered to be practical.
## TABLE 1
Test vehicle dimensions: steel fence

<table>
<thead>
<tr>
<th>Vehicle type</th>
<th>GVW (tonne)</th>
<th>Length (m)</th>
<th>Height of C of G (m)</th>
<th>Impact speed (km/hr)</th>
<th>Impact angle (deg)</th>
<th>Engine capacity (litres)</th>
<th>Vehicle description</th>
</tr>
</thead>
<tbody>
<tr>
<td>BL Mini</td>
<td>0.78</td>
<td>2.95</td>
<td>0.45</td>
<td>116.5</td>
<td>15</td>
<td>0.85</td>
<td>Private car</td>
</tr>
<tr>
<td>Talbot Alpine</td>
<td>0.99</td>
<td>4.38</td>
<td>0.51</td>
<td>116.3</td>
<td>15</td>
<td>1.44</td>
<td>Private car</td>
</tr>
<tr>
<td>Dodge 2-axle HGV</td>
<td>16.33</td>
<td>9.30</td>
<td>1.10</td>
<td>81.7</td>
<td>15</td>
<td>5.8</td>
<td>Rigid flat bed</td>
</tr>
<tr>
<td>Foden 4-axle HGV</td>
<td>30.75</td>
<td>9.49</td>
<td>1.81</td>
<td>82.5</td>
<td>15</td>
<td>5.8</td>
<td>High sided tipper</td>
</tr>
<tr>
<td>Atkinson 5-axle HGV</td>
<td>39.12</td>
<td>14.30</td>
<td>--</td>
<td>81.0</td>
<td>15</td>
<td>14.0</td>
<td>Articulated-3-axle trailer</td>
</tr>
<tr>
<td>Duple coach</td>
<td>14.29</td>
<td>11.92</td>
<td>0.66</td>
<td>91.6</td>
<td>15</td>
<td>12.5</td>
<td>51-seats</td>
</tr>
<tr>
<td>Talbot Alpine</td>
<td>1.03</td>
<td>4.38</td>
<td>0.41</td>
<td>111.9</td>
<td>25</td>
<td>1.44</td>
<td>Private car</td>
</tr>
<tr>
<td>Dodge 2-axle HGV</td>
<td>16.71</td>
<td>9.05</td>
<td>1.10</td>
<td>80.3</td>
<td>25</td>
<td>5.8</td>
<td>Rigid flat bed</td>
</tr>
</tbody>
</table>

## TABLE 2
Test vehicle dimensions: concrete barrier

<table>
<thead>
<tr>
<th>Vehicle type</th>
<th>GVW (tonne)</th>
<th>Length (m)</th>
<th>Height of C of G (m)</th>
<th>Impact speed (km/hr)</th>
<th>Impact angle (deg)</th>
<th>Engine capacity (litres)</th>
<th>Vehicle description</th>
</tr>
</thead>
<tbody>
<tr>
<td>BL Mini (with dummy)</td>
<td>0.71</td>
<td>2.95</td>
<td>0.49</td>
<td>102.5</td>
<td>15</td>
<td>0.85</td>
<td>Private car</td>
</tr>
<tr>
<td>Talbot Alpine</td>
<td>1.06</td>
<td>4.38</td>
<td>0.51</td>
<td>114.7</td>
<td>15</td>
<td>1.44</td>
<td>Private car</td>
</tr>
<tr>
<td>Dodge 2-axle HGV</td>
<td>16.49</td>
<td>9.15</td>
<td>1.50</td>
<td>80.9</td>
<td>15</td>
<td>5.8</td>
<td>Rigid flat bed</td>
</tr>
<tr>
<td>ERF 5-axle HGV</td>
<td>39.21</td>
<td>14.30</td>
<td>1.61</td>
<td>83.8</td>
<td>15</td>
<td>14.0</td>
<td>Articulated 3-axle trailer</td>
</tr>
</tbody>
</table>
both in terms of performance and cost. Based on this broad strategy a programme was set up to develop a fence which could contain a 16 tonne HGV impacting at 15 degrees; subsequent tests with vehicles ranging from a mini car to a 38 tonne articulated HGV were carried out to establish its overall performance.

It was clear from the analytic work (Jehu and Pearson, 1972) and from data collected from on-road safety fence impacts that further tests at higher angles would be needed to emulate road conditions. To this end the test programme on the steel fence was extended to include 25 degree impacts with a medium car and a 16 tonne HGV. The final programme of tests for the steel and concrete barriers is given in Tables 1 and 2.

4 TEST PROCEDURES

4.1 TOWING AND GUIDANCE

The full-scale impact tests described in this paper were carried out for TRRL at the Motor Industry Research Association (MIRA) at Nuneaton. With the support of TRRL, MIRA developed the high energy impact test facility.

4.2 IMPACT SPEED MEASUREMENT AND VEHICLE INSTRUMENTATION

High speed cameras running at 100 to 250 frames per second filmed the vehicle and fence for analysis of the motion during the impact. Normal speed cine and still cameras recorded documentary coverage.

Tri-axial accelerometers and rotational rate gyroscopes were mounted at the centre of gravity of the vehicle. These instruments recorded, relative to vehicle axes, longitudinal, lateral and vertical accelerations together with angular velocities in the yaw and roll planes. An event switch on the impact corner of the vehicle indicated the moment of first contact with the fence. Velocity, together with the translational and angular positions of the vehicle following impact, were derived by integration of the accelerometer and gyroscope traces. The derived values of distance and speed from the transverse and longitudinal accelerometers were used to estimate the velocity of a free body representing the head of an occupant. This velocity gives a simple measure of the severity of impact as experienced by a vehicle occupant. In later tests an instrumented dummy was seated in the test cars, but not in the heavy vehicles.

The transducer outputs were smoothed by a 60 Hz and a 10 Hz Butterworth filter. The 10 Hz trace revealed whole vehicle movements while the higher frequency content of the 60 Hz trace indicated vibration of the vehicle components. An example is given in Figure 3. An 85 m/sec delay introduced by the 10 Hz filter was compensated for by shifting the time base that amount.

Tension loads generated in the fence horizontal beams were measured by strain gauging the connecting fish plates.

Damage to the vehicle was approximated by the following index:

\[
\text{Damage index} = \frac{\text{current cost of repair to vehicle}}{\text{current cost of new vehicle}}
\]

5 SUMMARY OF IMPACT TESTS

Tables 1 and 2 give the main vehicle characteristics and Tables 3 and 4 give some important vehicle, fence and concrete barrier impact data. For each test a summary sheet was produced showing the trajectory and acceleration of the vehicle, the deflection and loads in the fence and the damage to both the barrier and the vehicle. An example is given in Figure 4 of the 15 degree impact by the 16 tonne HGV into the steel fence.

5.1 THE STEEL FENCE: VEHICLE AND FENCE RESPONSE TO 15 AND 25 DEGREE IMPACTS

5.1.1 15 Degree impacts

Vehicle response

The small and medium cars, the 16 tonne, 30 tonne and 38 tonne articulated HGVs, and the 14 tonne...
<table>
<thead>
<tr>
<th>Test vehicle</th>
<th>Weight (tonne)</th>
<th>Max Roll Angle (deg)</th>
<th>Max yaw velocity (deg/sec)</th>
<th>Exit angle (deg)</th>
<th>Deceleration (g) 10 Hz filter</th>
<th>Fence data</th>
<th>Remarks (vehicle damage index) %</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Speed (km/hr)</td>
<td></td>
<td></td>
<td></td>
<td>Lateral</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Angle (deg)</td>
<td></td>
<td></td>
<td></td>
<td>Peak</td>
<td>Average</td>
<td>Peak</td>
</tr>
<tr>
<td>BL Mini</td>
<td>0.78</td>
<td>116.5</td>
<td>7</td>
<td>140</td>
<td>6</td>
<td>9.5</td>
<td>3.4</td>
</tr>
<tr>
<td>Talbot Alpine</td>
<td>0.99</td>
<td>116.3</td>
<td>5</td>
<td>110</td>
<td>0</td>
<td>8.5</td>
<td>3.0</td>
</tr>
<tr>
<td>2-axle HGV</td>
<td>16.33</td>
<td>81.7</td>
<td>53</td>
<td>62</td>
<td>5</td>
<td>1.7</td>
<td>0.8</td>
</tr>
<tr>
<td>4-axle HGV</td>
<td>30.75</td>
<td>82.5</td>
<td>90</td>
<td>43</td>
<td>0</td>
<td>1.6</td>
<td>0.8</td>
</tr>
<tr>
<td>5-axle HGV</td>
<td>39.12</td>
<td>81.0</td>
<td>TRCT 9</td>
<td>0.6</td>
<td>3</td>
<td>10.0</td>
<td>0.4</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>TRLR 37</td>
<td></td>
<td>4.0</td>
<td>0.3</td>
<td>4.0</td>
</tr>
<tr>
<td>Coach</td>
<td>14.29</td>
<td>91.6</td>
<td>33</td>
<td>57</td>
<td>5</td>
<td>2.8</td>
<td>1.1</td>
</tr>
<tr>
<td>Talbot Alpine</td>
<td>1.03</td>
<td>111.9</td>
<td>9</td>
<td>165</td>
<td>-</td>
<td>9.2</td>
<td>3.5</td>
</tr>
<tr>
<td>2-axle HGV</td>
<td>16.71</td>
<td>80.3</td>
<td>180</td>
<td>82</td>
<td>-</td>
<td>2.0</td>
<td>1.1</td>
</tr>
<tr>
<td>Test vehicle</td>
<td>Weight (tonne)</td>
<td>Speed (km/hr)</td>
<td>Max Roll Angle (deg)</td>
<td>Max yaw velocity (deg/sec)</td>
<td>Exit angle</td>
<td>Deceleration (g) 10 Hz filter</td>
<td>Vehicle damage index (%)</td>
</tr>
<tr>
<td>--------------</td>
<td>---------------</td>
<td>---------------</td>
<td>----------------------</td>
<td>---------------------------</td>
<td>------------</td>
<td>-------------------------------</td>
<td>-------------------------</td>
</tr>
<tr>
<td>BL Mini</td>
<td>0.71/102.5/15</td>
<td>18/183</td>
<td>3</td>
<td>11.3/6.3/4.5/2.6</td>
<td>25</td>
<td>0</td>
<td>Satisfactory</td>
</tr>
<tr>
<td>Talbot Alpine</td>
<td>1.06/114.7/15</td>
<td>5/182</td>
<td>5</td>
<td>12.4/5.8/3.7/1.8</td>
<td>25</td>
<td>0</td>
<td>Satisfactory</td>
</tr>
<tr>
<td>2-axle HGV</td>
<td>16.49/80.9/15</td>
<td>31/50</td>
<td>2</td>
<td>2.8/0.8/1.3/0.4</td>
<td>100</td>
<td>18</td>
<td>Satisfactory</td>
</tr>
<tr>
<td>5-axle HGV</td>
<td>39.21/83.8/15</td>
<td>TRCT 90</td>
<td>106</td>
<td>4.4/0.4/3.1/0.3</td>
<td>100</td>
<td>24</td>
<td>Vehicle breached barrier</td>
</tr>
</tbody>
</table>
Length: 115.2m
Static tension: zero
Maximum deflection: 1.22m
Damage: 40m of fence damage
1st sign of deformation at joint 7
1st post bent, no 14, last no 30
Beam sheared from post 18 to post 28 incl

Vehicle Type: 2-axle rigid lorry Mass: 16.3 tonne Damage: Crush to lower LHS cab
Front axle moved on spring – LHS

Vehicle barrier response Impact velocities: Lateral 5.87 m/s Longitudinal 21.92 m/s

![Diagram of vehicle barrier response](image)

<table>
<thead>
<tr>
<th>Post 14</th>
<th>Wheel stud damage to lower beam</th>
</tr>
</thead>
<tbody>
<tr>
<td>8</td>
<td>Rear end impact</td>
</tr>
<tr>
<td>9</td>
<td>Extent of beam sheared from posts</td>
</tr>
</tbody>
</table>

Contact of ground by rear lower beam dynamically

Light contact

Light contact with fence

Vehicle came to rest here

Joint No.

Line of fence

Distance, m

-9.81 km/h

Vehicle acceleration, g from accelerometers
Filter: 10Hz, 48dB/oct

<table>
<thead>
<tr>
<th>Time after impact, s</th>
<th>0.1</th>
<th>0.2</th>
<th>0.3</th>
<th>0.4</th>
<th>0.5</th>
<th>0.6</th>
<th>0.7</th>
<th>0.8</th>
<th>0.9</th>
<th>1.0</th>
<th>1.2</th>
<th>1.4</th>
<th>1.6</th>
<th>1.8</th>
<th>2.0</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lateral, g</td>
<td>-1.69</td>
<td>-1.13</td>
<td>-1.16</td>
<td>-1.18</td>
<td>-0.33</td>
<td>-1.60</td>
<td>0.01</td>
<td>-0.87</td>
<td>-0.72</td>
<td>-0.63</td>
<td>-0.47</td>
<td>-0.68</td>
<td>-0.66</td>
<td>-0.12</td>
<td>-0.13</td>
</tr>
<tr>
<td>Longitudinal, g</td>
<td>-0.47</td>
<td>-0.63</td>
<td>-0.79</td>
<td>-0.28</td>
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<td>0.78</td>
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Resultant, g

1.76
1.29
1.46
1.22
0.67
1.67
0.54
1.23
0.87
1.01
0.74
0.98
1.17
0.71
0.45

Vehicle forces derived from acceler relative to undeflected barrier

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<td>102</td>
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<td>63</td>
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</table>

Measured loads

(1 tonne = 9.81 kN)

Joint 2 top beam, tonne
3.13
3.74
3.40
4.27

Joint 2 bottom beam, tonne
6.12
6.77
6.10
6.08

Joint 6 top beam, tonne
8.16
8.43
8.54
8.64

Joint 6 bottom beam, tonne
8.79
7.80
7.34
7.63

Joint 6 top rear, tonne
9.59
9.20
9.63
9.59

Mean deceleration of vehicle for duration of 1.8s: Lateral 0.77g Longitudinal 0.44g

Remarks Satisfactory containment

Fig. 4 Data from 16 tonne, 81.8 km/h test on steel fence

I B Laker (Paper 1)
passenger coach were all contained in the 15 degree impacts into the steel fence. All vehicles were redirected at exit angles of less than 7 degrees with the exception of the 30 tonne 4-axle rigid HGV which overturned on to the fence but came to rest within the width of a notional motorway median strip. The coach and the 16 tonne HGV experienced large roll angles before returning to four wheel running. The tractor of the articulated HGV maintained a stable condition throughout the impact, the maximum roll being about 9 degrees; however the trailer carrying the concrete block payload rolled through about 37 degrees before returning to the running surface.

Table 3 gives the lateral and longitudinal decelerations of the centre of gravity (C of G) of the vehicles. Private car decelerations were the highest at a peak of about 9.5g lateral to the fence.

The damage indices for both the Mini and the Alpine were about 100 per cent.

**Fence performance**

Only moderate damage was caused to the steel fence by the small and medium cars; in service the superficial damage from the small car would not need attention.

The highest recorded tensions in any beam were 221 kN for the 30 tonne HGV and 212 kN for the 38 tonne articulated HGV. These figures indicate that the beam and linking fish plates experienced a load of about 40 per cent of the yield strength. The highest tension measured in any fish plate was 161 kN which is equivalent to a tensile stress of 148 N/sq mm across a section through the bolt holes. Taking the yield stress of steel as 255 N/sq mm gives the percentage of yield for the fish plate of about 58 per cent. A similar estimate for the bolts indicates the bolt shear stress to be about 134 per cent of their rated shear strength. In practice none of the bolts fractured but the calculation above suggests that in the worst case the bolts were heavily loaded in shear.

5.1.2 25 Degree impacts

**Vehicle response**

Although the fence contained the Alpine, the car was severely decelerated by the road wheel making direct impact on the base of the post. The peak longitudinal deceleration at 11.0g was 60 per cent higher than that recorded in the 15 degree impact, and the average at 5.5g was nearly double. The lateral deceleration matched closely that of the 15 degree impact (Table 3).

The 16 tonne HGV at 80 km/hr rolled over the fence and, whilst upside down, slewed horizontally through 180 degrees and came to rest on the other side, parallel to the fence and facing the direction it came from. Had the fence been erected as a motorway median barrier the HGV would have stopped in the opposite carriageway.

**Fence performance**

The Talbot Alpine caused only moderate damage to the fence but it was clear that modification was necessary to limit road wheel contact with the posts.

The HGV 25 degree impact tested the fence beyond its limit. The impact energy component normal to the fence was over 2.5 times that of the 15 degree impact. A further test is planned at a lower speed to determine the performance limit of the fence.

5.2 THE CONCRETE BARRIER: VEHICLE AND BARRIER RESPONSE TO 15 DEGREE IMPACTS

**Vehicle response**

The cars were satisfactorily contained and redirected although both rode up the face of the barrier with their wheels clear of the ground and came to rest more than three road lane widths from the line of the barrier. Table 4 shows that the peak lateral decelerations of the Mini (103 km/hr) and the Talbot (115 km/hr) were fairly similar at 11.3g and 12.4g respectively and were the highest levels recorded in any of the impacts into the steel fence or the concrete barrier. The speed of the Mini at 103 km/hr was lower than the target speed of 112 km/hr. This was unfortunate because comparison could not be made with an early test (Jehu and Pearson, 1977) where a Mini had overturned at 112 km/hr on a profile similar to the BCB in a 20 degree impact. The damage index for each car was 25 per cent; all the doors of both cars could be opened after impact.

The 16.5 tonne HGV (80.9 km/hr) was satisfactorily contained and redirected although the roll angle at about 31 degrees was high. The HGV left the barrier at an angle of approximately 2 degrees and came to rest, after the remote braking was applied, about 60 metres from the point of first impact.

The 39.2 tonne articulated HGV (80 km/hr) was redirected but breached a short-length of the barrier. The tractor dislodged three barrier units, struck the exposed end of the next unit, climbed on top and travelled along straddling the top of the barrier. The engine struck the exposed end of the concrete unit and the gear box was torn out; the axles of tractor and trailer were broken off as the underside of the HGV scraped along the top of the barrier. During this time the vehicle rolled on to its side behind the barrier and later righted itself. The straps holding the concrete ballast blocks were broken but most blocks were carried along with the vehicle until it came to rest some 60 metres from impact point.

The damage index for both HGVs was 100 per cent.
Barrier performance

The Mini impact caused only minor tyre marks and surface scratches and, in service, the barrier units would not need replacement. The unit first impacted by the Alpine moved about 20 mm at the top. A vertical crack in the succeeding unit would probably require it to be replaced. The wheel studs of the 16 tonne HGV gouged and cracked the barrier unit first impacted from top to bottom and a section of concrete on the front face broke away at the joint to the preceding unit as did a piece of concrete on the succeeding unit. Overall, 18 metres (6 units) needed replacement, the rest required only cosmetic repairs.

The articulated 39.2 tonne HGV knocked out the first unit contacted, and the following two units remained in place, although pieces of concrete broke away from the first and the second cracked into two pieces. The remaining units were only superficially damaged by the vehicle travelling, straddled, along the barrier. About 24 metres (8 units) needed replacement, the rest were intact and required only slight repairs.

Impact tests at 25 degrees were not completed because other current work on a vertical face concrete barrier has shown that a BL Mini car response, at 113 km/hr and 20 degrees, was more stable throughout the impact compared with the Mini response to the BCB. This work may lead to modification of the BCB profile for testing at a later date.

5.3 THEORETICAL HEAD IMPACT VELOCITIES

Fences for the containment of heavy goods vehicles are necessarily stiff and are likely to generate high deceleration forces within private cars. Values of the deceleration of the centre of gravity of test vehicles impacting the steel fence and the concrete barrier are given in Tables 3 and 4 together with an index of impact severity called the Theoretical Head Impact Velocity (THIV). The THIV is derived from the lateral and longitudinal decelerations of the C of G of the vehicle and it is the theoretical value of velocity with which a freely moving head would impact the nearest surface within the passenger compartment. In safety barrier impacts the surface is most likely to be the door pillar or side window.

The private cars were equipped with instrumented dummies. The measured dummy accelerations were not available for this report but it is hoped to publish this information later and compare the results with the international Head Injury Criteria (HIC) value.

Figure 5 shows a plot of the theoretical head impact velocities (THIV) for all impacts into the steel fence and concrete barrier other than the articulated HGV for which there were no accelerometers installed. General conclusions from

6 CONCLUSIONS

1. Impact tests into a double height double sided open box steel fence and a surface mounted precast British Concrete Barrier have demonstrated that private cars (112 km/hr approx) and 16 tonne heavy goods vehicles (80 km/hr approx) can be contained and redirected at impact angles of 15 degrees. The final position of the cars after impacting the steel fence tended to be closer to the fence compared with the stationary position of the cars after hitting the concrete barrier.
2. The steel fence contained a 30 tonne HGV at 80 km/hr although the vehicle rolled on to its side.

3. A 38 tonne articulated HGV was safely contained and redirected by the steel fence, but a similar impact with an articulated HGV breached the precast concrete barrier; both impacts were at 15 degrees and about 80 km/hr.

4. A medium car was contained by the steel fence during an impact at 25 degrees and 112 km/hr, though the deceleration was severe. At a similar angle and a speed of 80 km/hr a 16 tonne HGV rolled over the fence.

5. Work is continuing on improving the performance of the steel fence for high angle impacts (25 degree).

6. The collision of a BL Mini car at 113 km/hr and 20 degrees into a vertical faced concrete parapet showed the vehicle to have a more stable response than a similar impact into the British Concrete Barrier at 15 degrees.

7. A computed measure of impact severity was derived from vehicle decelerations and is presented as the theoretical head impact velocity (THIV) with which a freely moving object (head) would impact the nearest surface (side window). For the vehicles and speeds tested the THIV values indicate that an occupant would experience similar levels of severity, in collisions with either the steel fence or the concrete barrier; passenger car occupants would experience about twice the severity of HGV occupants, and this higher level would be likely to cause serious injury.

7 REFERENCES


8 ACKNOWLEDGEMENTS

This paper was produced within the Vehicle Engineering Division of the Transport and Road Research Laboratory and is published by permission of the Director.

The Cement and Concrete Association greatly assisted the project by supplying the British Concrete Barrier. Grateful thanks are offered to the staff of TRRL and MIRA whose splendid cooperation permitted the project to be completed within the very short timescale of about 18 months.

The project was initiated at the request of the Department of Transport Engineering Intelligence Division, Marsham Street, London.
SEVERE IMPACTS WITH MOTORWAY SAFETY FENCES

by M D Macdonald, Vehicle Engineering Division, TRRL

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ABSTRACT

To aid the development of safety fences for the containment of heavy goods vehicles where a high level of containment is essential, accidents where fences are damaged are being investigated. The type of accidents visited are all those where a fatality has occurred and those involving heavy goods vehicles within an area of 130 km radius of the Transport and Road Research Laboratory. The data collected have been used to set up the conditions for full-scale controlled tests which relate to actual on-road impacts.

1 INTRODUCTION

The Transport and Road Research Laboratory is developing safety fences particularly for use in localised applications, to restrain heavy goods vehicles. The objectives of these fences are to prevent a vehicle crossing the median strip of a dual carriageway road and to redirect any vehicles that strike the fence on to a path alongside it. To establish the conditions that fences have to withstand in service, the weights, speeds and impact angles of vehicles that strike motorway fences are being determined. As well as the impact conditions, data are collected on the damage to the fence and the performance of the fence in redirecting the vehicle. As the total number of accidents in which vehicles strike the fences is large and the interest is in high energy impacts, data collection has been limited to severe impacts within an area of about 130 km radius from the Laboratory. A severe accident is defined as one involving a fatality or a heavy commercial vehicle (a coach or heavy goods vehicle (HGV)); these form a small proportion of all impacts with fences, but about 10 per cent of impacts involving HGVs.

2 DATA COLLECTION

The Police notify the Laboratory when a motorway fence accident involving a fatality or a heavy vehicle occurs. The nature of the accident is checked and if it falls within the correct category a team of investigators visit the scene of the accident as soon as possible. A reporting form, Figure 1, is used to assist the investigator in collecting the essential data and a brief report is made on the damage to the fence. This includes the type of vehicle, its weight, speed and angle of impact and a description of the accident mechanism. The vehicle description is limited to that of either a car or rigid or articulated goods lorry. The weight for cars is established from the manufacturer's data, but for goods vehicles the unladen plated weight plus payload is used. Vehicle speed is estimated by either the police or witnesses to the incident in the case of cars; for lorries it is generally determined by examination of the vehicle's tachograph. This is a device which simultaneously records vehicle speed and time of day on a card disc. Angle of impact can be estimated in many cases from road marks caused by heavy braking or tyre scuffing. Interviews with the police and on occasions with drivers together with a photographic record of the accident complete the data collection. Although accidents were reported to the Laboratory at all times, manpower resources restricted data collection to normal working hours.

A total of 33 severe accidents have been recorded over a period of 22 months of which 31 involved heavy goods vehicles. This compares with 1063 fence accidents (median and edge) for UK motorways in 1984 of which 152 involved either HGVs (148) or coaches (4). The data therefore represents a sample of about 10 per cent of fence accidents per year involving HGVs, though it is not a random sample.

The data collected for 33 severe impacts are shown in Table 1; they have been divided into three categories, (a) heavy goods: median safety fence, (b) heavy goods: edge fence, (c) cars: median and edge fence. There were 28 incidents of HGV impacts with tensioned corrugated beam safety fences (edge and median). Three of the other five accidents involved HGVs, two of which struck the end of the safety
Fig. 1 Reporting form for motorway safety fence accidents

M D Macdonald (Paper 2)
### TABLE 1

Severe impacts with motorway safety fences

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<th>TRRL No</th>
<th>Laden wt (tonne)</th>
<th>Speed (km/hr)</th>
<th>Angle (degrees)</th>
<th>Lateral vel. (m/sec)</th>
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#### Cars: Median and Edge

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<td>—</td>
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<td>Ramp ing</td>
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fence (ramping) and one struck a concrete parapet. The remaining two were one fatal car impact and one car ramping accident (non-fatal). A total of three ramping accidents have been noted.

In the early stages, a variety of incidents were reported which did not fall within the defined categories (fatal and/or heavy vehicle accidents). Visits were made to familiarise the police with both the activities and intentions of the TRRL; those cases are not reported here. A few accidents outside the operating range of 130 km have also been included. Occasionally the police and motorway maintenance staff had cleared the debris of the accident before the investigating team arrived; where vehicles had been removed, weight and speed were difficult to assess because documentation such as tachograph records had been removed with the vehicle. On some occasions weather conditions or high traffic flow prevented a full investigation.
3 RESULTS AND ANALYSIS

The data in Table 1 for heavy goods vehicles impacting the median fence are plotted in Figure 2 to show the cumulative distributions of vehicle weight, impact speed and impact angle. Detailed comments are given below for those factors:—

Vehicle weight (Figure 2(a))

Of the 31 reported cases of HGV accidents, 18 (58 per cent) were either articulated (17) or draw-bar trailer (1). The distribution shows that, where the GVWs were known or estimated (a total of 21 cases), just over 50 per cent of the vehicles exceeded a GVW of 12 tonnes. The highest weight recorded was 32.5 tonnes (and in this case the impact was at 80 km/hr and 20° impact angle). The legal maximum weight without special permission for lorries in the UK is 38 tonnes.

Impact speed (Figure 2(b))

The vehicle speed distribution indicates that in nearly 10 per cent of the accidents, the vehicles were exceeding the 96 km/hr speed limit for goods vehicles on UK motorways. This compares with the speeds of vehicles measured in 1983 (Department of Transport 1984) where 39 per cent of HGVs were found to exceed the speed limit. The maximum speed noted was 120 km/hr (and the vehicle weight was 12 tonne with a 15° impact angle).

Impact angle (Figure 2(c))

The distribution shows that 75 per cent of the vehicles impacted at angles less than 25°, and nearly half of these impacts occurred within the range of 15°–25°. The highest impact angle recorded was 60° (with a vehicle weight of 15 tonnes and an unknown speed). There is little sign of a correlation between impact speed and angle. One might expect higher speeds to be associated with smaller angles, but this does not appear from the 31 HGV accidents studied. The distribution is shown in Figure 3.

Of the 31 HGV impacts, in 9 cases the HGV crossed over the safety fence. In the remaining 22 impacts, there were 2 cases of HGVs rising up on to the edge of the safety fence (ramping) and 20 instances where they were contained.
There were several reasons for the safety fence being so effective. Firstly, in many cases there was soft ground on the approach side of the safety fence, particularly for the median impacts, and these conditions would have absorbed some vehicular energy before impact. This suggests that the actual impact speed may be less than the estimate made from the vehicle tachometer. Secondly there were reports of vehicles slewing or rotating when impact occurred. It is probable that tyre failure or driver loss of control contributed to this behaviour. This also could have an effect on the severity of impact and the performance of the fence in retaining the vehicle.

Nevertheless it was thought useful to examine the results in Table 1 on the basis of the estimated lateral kinetic energy for the impacts, i.e., the energy normal to a line of the fence. Although the speeds, angle and energy are given in Table 1 to several significant figures, it should be recognised the data does not really allow this degree of precision. Bearing this in mind, the data are presented in Table 2 for HGV median impacts and show the number of contained and cross-over accidents for increasing levels of lateral energy. Table 2 suggests that below an energy level of about 400 k Joules all the accidents were contained and there were no cross-overs. Between 400 k Joules and 700 k Joules about equal numbers of accidents were contained or involved cross-overs. Above 700 k Joules the remaining accidents all resulted in cross-overs. As noted before, however, there are many factors other than impact energy that affect fence performance. These include ground conditions, vehicle wheel size, height of vehicle centre of gravity, and the stiffness of the vehicle body and suspension. Nevertheless, the results in Table 2 give a useful indication of the performance of the fence in terms of nominal lateral energy. It is worth noting that the standard Tension Corrugated Beam safety fence in the UK is designed to provide containment up to a lateral energy of 85 k Joules. The present results show that the highest value of lateral energy recorded with successful containment was about 600 k Joules, and the lowest lateral energy where cross-over occurred was about 400 k Joules. It therefore appears that the safety fence is performing in practice better than might have been expected.

A summary of the occurrences of HGV and car accidents is given in Table 3 for each type of fence, and comments are given on whether the vehicle ramped, was contained, or crossed over. Fatalities are identified within the table.

### TABLE 2

<table>
<thead>
<tr>
<th></th>
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<td>0</td>
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<td>2</td>
<td>1</td>
<td>0</td>
<td>0</td>
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<td>0</td>
<td>3</td>
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### TABLE 3

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<td>Ramp</td>
<td>Contained</td>
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<td>6+2F</td>
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<td>3</td>
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<tr>
<td>Car</td>
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</table>

Note: 1. HGV: Heavy goods vehicle
2. F: Accident involving fatalities
4 CONCLUSIONS

Severe accidents in which there have been either a fatality or a heavy vehicle striking a safety fence have been investigated to determine the impact conditions (vehicle weight, speed and impact angle) and how the fence performed. The 33 accidents reported over a period of 22 months and within an area of 130 km radius of the Transport and Road Research Laboratory can only be regarded as a small sample and it is likely that, in the early stages of the work, not every incident was reported to the Laboratory. The following general conclusions are drawn:—

1. There were 31 accidents involving goods vehicles and 58 per cent of the vehicles concerned were articulated.

2. There were 19 instances (61 per cent) where the goods vehicle was contained by the tensioned corrugated beam safety fence. A contributory factor was probably the presence of soft ground or gravel (french drain) on the approach side to the fence.

3. The highest values recorded for goods vehicle accidents, but each from different accidents were, weight 32\(^{\frac{1}{2}}\) tonne, speed 120 km/hr and impact angle 60 degrees. Conclusions relating to heavy goods vehicles impacting the median safety fence include:—

4. In nearly 10 per cent of these accidents the vehicles were exceeding the maximum permitted speed of 96 km/hr for heavy vehicles on UK motorways.

5. About 75 per cent of goods vehicle impacts occurred at an angle of 25° or less and about 25 per cent of the goods vehicle impacts occurred within an impact angle range of 15 degrees to 25 degrees.

6. The standard Tensioned Corrugated Beam safety fence is in practice containing accidents involving much more impact energy that it was designed to withstand.

5 REFERENCES


6 ACKNOWLEDGEMENTS

Thanks are due to the various police authorities whose assistance was essential for this work to be undertaken. The work carried out in this report forms part of the programme of the Transport and Road Research Laboratory and the report is published with permission of the Director. The author acknowledges with thanks the work of staff of Vehicle Engineering Division staff in visiting sites of accidents and collecting the data on which this paper is based.

Any views expressed in this report are not necessarily those of the Department of Transport.

7 APPENDIX A

DESCRIPTION OF SELECTED ACCIDENTS

Cars
No. 27 Fatal. The car impacted an edge safety fence at high speed and ejected some of the passengers. It was probably unstable at the time due to sudden loss of tyre pressure.

No. 35 Damage only. The car struck the ramped end of a safety fence at a bifurcation formed by a slip road leading from one motorway to another. It appeared that either the driver made a late decision to turn to his nearside or his speed was too high to negotiate the bend.

Heavy goods vehicles
No. 1 Fatal—cross-over. A fully laden two axle 16t lorry travelling at 109 km/hr crossed a double sided tensioned corrugated beam (TCB) safety fence, at about 25 degrees, on the median of a three lane motorway. It collided with a coach in the opposite carriageway and continued further to impact a TCB safety fence at the edge of the motorway. Severe damage was caused to the lorry and coach and there were several fatalities.

No. 6 Straddled. An articulated lorry laden to 22t travelling at 88 km/hr struck a double sided TCB safety fence at about 15 degrees. The vehicle did not cross into the opposite carriageway and there was no personal injury. In this instance some braking was applied before impact and there was soft ground in front of the fence.

No. 41 Retained. A four axle rigid lorry laden to 23t struck a double sided TCB safety fence at 80 km/hr and 5 degrees. The vehicle did not crossover or straddle the fence although it was forced down to ground level. In advance of the fence was a coarse gravel french drain.
Results of investigations at scenes of motorway accidents in which safety fences have received severe impacts have shown that where concrete is used for post footings, the footings are not always made to the correct standard. The British Department of Transport specification calls for the footing to be 350 mm diameter (or 310 mm square) by 950 mm deep; footings are frequently twice the correct diameter and half the required depth. The use of preformed cylinders has been studied, in field trials, as a means of controlling the formation of the footings. A satisfactory performance has been achieved using a prefabricated cylinder to the correct dimensions in very poor ground conditions, where concrete footings would normally be specified.

1 INTRODUCTION

To ensure that post footings are installed to current specifications, a technique has been developed of prefabricating the footing; the method has particular advantages in poor quality soil. The objective of the specification is to ensure that the post footing is at least as strong as the post set into it, so that the post can develop its full strength during an impact on the fence. Concrete footings are used when the ground conditions are inadequate to support driven posts. In the case of concrete footings, the specification requires that they be 310 mm square or 350 mm diameter by 950 mm deep for ‘Z’ section posts (100 mm by 32 mm). Many of the footings inspected at sites, where safety fences had been struck by vehicles, were not always constructed to the correct dimensions; they tended to be of hemispherical or conical form. To achieve maximum effectiveness from the safety fence, it is important that the posts are held firmly in the ground in order that they can develop their full bending strength.

To control the formation of the post footings, the use of preformed cylinders has been studied in field trials when the ground conditions were known to be poor. Standard ‘Z’ section posts were inserted into a variety of cylinders and subjected to horizontal loading until failure occurred.

2 PROCEDURE

An area of ground at the edge of a motorway nearing completion was made available for the footing tests. The soil conditions were known to be poor from tests that had been carried out to assess the soil performance. Holes for the preformed cylinders for the footing were made by a powered auger mounted on the rear of a lorry. To avoid interaction, holes were spaced at 3 metre centres with the line of holes a minimum of 1½ metres from the edge of the paved surface. The preformed cylinders were of either plastic, 255 mm diameter (10 mm wall thickness) or mild steel sheet, 305 mm and 355 mm diameter (1½ mm wall thickness) and each was 950 mm long. For experimental purposes, the use of concrete infill would have been inconvenient. Instead the cylinders were packed with timber in 20 mm layers produced to allow the insertion of 100 mm by 32 mm ‘Z’ section standard fence posts to a depth of 420 mm. A pair of vertical bars was also connected through the full depth to interconnect the timber discs and to aid extraction (Figure 1). This arrangement ensured that the post and cylinder behaved as if the post was embedded in a concrete footing of the same dimensions as the cylinder.

The posts were loaded through a winch cable connected via a load cell to the post at a height of 665 mm above ground level; the load was increased in 1 kN intervals and corresponding deflections were noted at the same heights as the applied load. Loading was increased until either the post or the footing failed, as indicated by increasing deflection for no appreciable increase in load. On completion of the site work, the footings were removed and the excavated soil returned and compacted.
In a preliminary series of tests on posts located in a concrete pavement, the horizontal direction had been determined for which the bending strength of the Z-section post was greatest. Loads were applied in this direction in the post loading field trials, Figure 2.
3 RESULTS

The results for the post loading tests are shown in Figure 3 (a-d) as load deflection curves; they fall into three categories:—

3.1 GROUND EVALUATION

Loading tests on a post driven into the ground show clearly that the ground conditions did not meet the requirements set by the British Department of Transport for driven posts. These are that such a post is required to support a 6000 Nm moment with a deflection not exceeding 250 mm measured 600 mm above ground level. The maximum moment achieved was 5763 Nm when the deflection had reached 250 mm. When these requirements are measured 665 mm above ground level, the minimum load supported by the post should be 9023 N and the maximum deflection should not exceed 277 mm.

Fig. 3a Load: deflection curves for posts in concrete and soil

Fig. 3b Load: deflection curves for posts in 255mm diameter cylinder footings

Fig. 3c Load: deflection curves for posts in 305mm diameter cylinder footings

Fig. 3d Load: deflection curves for posts in 355mm diameter cylinder footings

M D Macdonald (Paper 3)
3.2 STANDARD POST STRENGTH
With a post mounted in a concrete pavement the load deflection characteristics for the post were determined. This indicated that a load of about 10800 N (at a height of 665 mm) could be applied before the post began to fail by a combination of twisting and bending.

3.3 PREFORMED CYLINDERS
Three loading tests were carried out on each of three cylinder sizes, 255 mm, 305 mm and 355 mm diameter, in ground conditions similar to those used for the tests on a driven post (Section 3.1). In one 255 mm and one 305 mm diameter cylinder test, the maximum loads achieved were 6900 N and 7800 N respectively when the cylinders moved through the soil resulting in excessive deflection. In all the remaining cases, the peak loads exceeded the target value of 9023 N with deflection less than 180 mm, i.e. within the limit of 277 mm.

3.4 DISCUSSION
The only cylinder size which consistently supported high loads with low deflections was of 355 mm diameter and this confirms the use of 350 mm diameter concrete footings as currently specified. The smallest cylinder tested, 255 mm diameter, produced the greatest variation in results. This was probably attributable to variations in the soil composition, together with its moisture content, having a proportionally greater effect on the smaller size of footing. The techniques examined, demonstrated the viability of using preformed cylinders to control the formation of the footing to the correct specification. Augering the hole, insertion of the cylinder and then infilling with a support medium for the post, produced in the majority of cases a good performance when subjected to a pulling test. However to allow for variations in soil conditions and tolerances in workmanship, the standard diameter of footing (350 mm) is still recommended.

4 CONCLUSIONS
1. A loading test on a Z-section post, 100 mm by 32 mm, driven into poor soil showed that soil failed before the post developed its maximum strength.

2. Tests on Z-section posts in preformed cylindrical footings in poor soil showed that cylinders of 355 mm diameter and 950 mm long enabled the post to sustain the loading specified by the British Department of Transport (such that the strengths of the footings exceeded that of the posts). Posts in cylinders of 255 mm and 305 mm diameter did not repeatedly achieve this strength.

3. The use of preformed cylinders for post footings set in augered holes much reduces the possibility of sub-standard footings occurring.

5 ACKNOWLEDGEMENTS
The work carried out in this report forms part of the programme of the Transport and Road Research Laboratory and the report is published by permission of the Director. The work reported in this paper could not have been carried out without the assistance of Mr D Jacklin and Mr A Mumford throughout the practical trials. Any views expressed in this report are not necessarily those of the Department of Transport.
SAFETY FENCE CRITERIA FOR ALL-PURPOSE DUAL CARRIAGEWAY ROADS—A FEASIBILITY STUDY

by G R Watts, Vehicle Engineering Division, TRRL

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ABSTRACT

Safety fences on motorway central reserves have been accepted as necessary safety features since 1973. However, on all-purpose dual carriageway roads where design standards vary it was not until 1981 that such barriers were generally accepted and then only on heavily trafficked new dual carriageways. The paper describes the initial results from a study designed to develop installation criteria for such fences. The overall objectives of the study were:

(i) to identify road features and traffic flow parameters which contribute to the causation of cross-over accidents and to quantify their effects;

(ii) to establish on the basis of likely accident cost savings the conditions under which safety fence installations would be cost effective.

The feasibility phase of the study was concerned with reviewing the literature and available accident statistics and developing suitable methodologies for a follow-up study. In this phase accident data for some 700 km of dual carriageway were analysed and geometric data for 64 km of such roads collected.

Accident data collected before and after barrier installation gives an indication of the decrease in number of casualties from median related accidents. Simple regression analysis shows that some casualty rates are significantly related to flow parameters.

Further data will be analysed by more sophisticated multiple regression techniques in the main study, and before and after studies of all recently fenced sections will be made.

1 INTRODUCTION

Safety fences have been installed on motorway central reserves in the UK since 1973. On all-purpose dual carriageway roads it was not until 1981 that central reserve safety fences were generally accepted and then they were installed only on busy new dual carriageways. An early study on a 29 km section of the M1 motorway showed that when all accidents were considered there was an estimated 9 per cent reduction in fatal accidents following installation of the safety fence.

The criteria for installation on dual-carriageway roads used since 1981 was based on this study but could only be considered as tentative since design standards are quite different on these all-purpose roads.

Motorways are limited access dual carriageway roads with grade separation at all junctions, hard shoulders for emergency stops and with use by pedestrians and pedal cyclists prohibited. All-purpose dual carriageway roads in general have no hard shoulders, a mixture of at-grade and grade-separated junctions, more frequent junctions, service stations immediately adjacent to the road and are not prohibited to any class of road user.

As traffic flows, speeds and more importantly cross-over accidents have increased there is considerable pressure to produce more refined criteria. At the request of the Engineering Intelligence Division of the Department of Transport in 1984, the Transport and Road Research Laboratory has since December 1984 funded a study by JMP Consultants Ltd to develop appropriate criteria for the installation of barriers on all-purpose dual carriageway roads. The study is due to finish in the spring of 1986 and this paper gives an outline of the study together with some results from its feasibility phase.
2 OBJECTIVES

The overall objectives of this study are:

1. to identify road features and traffic flow parameters which contribute to the causation of cross-over accidents and to quantify their effects.
2. to establish on the basis of the likely accident cost saving the conditions under which safety fence installations would be cost effective.

The study was divided into two parts i.e. a feasibility study and a follow-up study. The aim of the feasibility study was to review the relevant literature and existing accident statistics and, in the light of this, propose one or more methodologies which could provide the best means of meeting the objectives. In the follow-up study it is proposed to carry out the collection and analysis of data on a sufficient scale to achieve significant results using the methods recommended by the feasibility study.

3 LITERATURE REVIEW

The most relevant British study reported was that carried out on the M1 motorway where a 29 km of safety fence was installed by TRRL in 1964 (TRRL 1974). The accident data for this section for the two years 1962–63 without the fence and the four years 1965–68 with the fence erected were compared with those for a contiguous unfenced length of 61 km. The accident experience on the trial section before the fence was installed and on the control section throughout the before and after periods were then used to estimate the number and severity of those which would have been expected on the fenced section had the fence not been erected. Table 1 shows the actual and expected numbers of accidents during the 4-year period with the barrier erected. Figure 1 illustrates the main findings. It can be seen that serious cross-over accidents were substantially reduced although there was an increase in the number of serious accidents where the central reserve was not involved. Overall fatal accidents were estimated to have been reduced by 9 per cent while minor accidents increased in number. Johnson (1980) estimated the effect of erecting fence on all-purpose dual carriageway using these changes in accident pattern. Employing accident data for nearly 400 km of dual-carriageway road he concluded that in general the erection of safety fence would be likely to reduce the number of fatalities by an estimated 15 per cent and the numbers of serious and slight casualties would change very little. Obviously there are many differences between motorway and dual-carriageway roads so that the assumption that proportional changes in the frequency of the various types of accident following fence erection on these roads will be checked.

The available published information has revealed little of relevance to the question of accident causation on dual carriageways. However there are a number of unpublished studies which have provided valuable background material on costing models and statistical effects.

4 DESIGN OF THE STUDY

METHODOLOGIES

As part of the feasibility study various methods of analysis were considered. These were:

- Regression modelling
- Pairwise comparisons
- Before and after studies

REGRESSION MODELLING

The following steps are necessary in this approach:

- Select a sample of dual carriageway section with fences
- Select a sample of similar sections without fences
- Obtain for both samples: accident data (e.g. severity, number of casualties, type of accident)
- geometric data (e.g. width of central reserve and carriageway gradient)
- traffic data (e.g. total flow, composition, speed limit)
- Analyse the data by fitting an appropriate model.

One such model is: accidents/km = f (traffic, geometry, fence).

If the 'fence' term is significant then a real effect of the presence of the fence is indicated. The geometric and traffic terms are included for two reasons. Firstly to remove the effects of these factors, thus reducing residual variation and increasing the chance of detecting an effect due to fences. Secondly to enable the likely accident savings to be plotted against such a variable as total flow and thus be in a suitable form for setting criteria for installation. By examining data from unfenced sections it should be possible to identify factors which appear to contribute to the causation of cross-over accidents and establish relationships.

One difficulty occurs when the samples of fenced and unfenced sections are found afterwards to be dissimilar. In particular the two samples may not overlap to a reasonable extent when plotted against one of the important independent variables. It would then be virtually impossible to ascribe a difference in accident level to an effect due to the fences rather than to the independent variable.
<table>
<thead>
<tr>
<th>Type of accident</th>
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<td>Severity</td>
<td>Expected\textsuperscript{t}</td>
<td>Reported</td>
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</table>

\textsuperscript{t} Number estimated if fence had not been erected
PAIRWISE COMPARISON

In this analysis the following procedure is followed:

- Select pairs of fenced and unfenced sites matched as far as possible on geometric and traffic variables considered to be important.
- Obtain full accident data.
- For each pair of sites estimate the difference in accident frequency due to the fence. A weighted average of these differences would yield the best estimate.

A difficulty would be finding suitable pairs. Adjacent lengths of fenced and unfenced sections would probably match the traffic variables although any significant differences in geometry would preclude an unbiased estimate of the effects of fences. If enough pairs were found it would be possible to group sites so estimates of accident savings could be made for different ranges of traffic and geometric variables.

BEFORE AND AFTER STUDIES

In this approach the steps are:

- Select pairs of sites matched on geometric and traffic variables considered important such that one site in each pair has been recently fenced and the other (the 'control') has remained unfenced throughout the comparison period.
- For each pair of sites collect full accident data before and after the date of installation.
- Determine the difference between the actual and expected accident frequencies.

The major problem is finding enough suitable pairs. If enough sites are found, estimates of accident savings could again be made in terms of the level of an independent variable such as flow. Another difficulty arises in comparing fenced and unfenced sections if a length was fenced at least partly because it had a high accident frequency. 'Regression-to-mean' effects may operate in this case. This means that such sites tend to experience reductions in accident frequency even if no remedial action is carried out, so the benefits of the fences could be overestimated.

After the completion of the feasibility study it was considered that regression modelling and before and after studies would provide the most appropriate results for setting installation criteria. It was recognised however that there may only be limited scope for before and after studies because of the small total length of recently fenced dual carriageway. Thirty-two km were identified in the initial phase and it is estimated that there is unlikely to be more than a total length of about 100 km in England. The problems of matching were thought likely to limit the usefulness of the pairwise comparison technique. Nevertheless a simple form of analysis will be attempted.
ANALYSIS OF ACCIDENT DATA
The accident data are being dissaggregated into four main categories:

Type (a) Accidents involving a vehicle crossing the central reserve which may or may not collide with a vehicle in the opposite carriageway
(b) Accidents involving a vehicle entering but not crossing the central reserve
(c) Accidents involving a vehicle rebounding from the central reserve
(d) Accidents not involving the central reserve at all.

A safety fence might be expected to reduce the frequencies of type (a) accidents. Types (b) and (c) may increase since situations leading to type (a) without a fence may, with a fence present, produce barrier collisions which produce accidents which are categorised as type (b) or (c). Type (d) accidents may also increase with a barrier since drivers' avoiding actions in an accident situation on the off-side of a carriageway may be inhibited by the fear of colliding with the fence and so the risk of collision or loss of control within the carriageway may increase. The early study of the barriers erected on the M1 motorway (1) suggested that these changes in the accident pattern do actually occur.

It was considered unlikely that the change in total accidents due to safety fences would be very marked so definite conclusions on benefits would be unlikely. A study of total accidents would probably mask a tendency for a very severe type of accident to be replaced by a less severe one. Therefore the number of casualties of various severities in the different types of accident is being recorded and this will enable benefits to be more accurately gauged. A knowledge of the 'before' mix of the four accident types and the way in which they are likely to be affected by the presence of fences is considered important in judging the likely benefits of installation.

TYPES AND SOURCES OF DATA
From the above considerations of the likely changes in accident pattern it was thought likely that data from substantial lengths of fenced and unfenced road would be required if there was to be a reasonable chance of establishing statistically significant criteria.

Three basic types of data are required for the analyses described above:

- Geometric data including road geometry, traffic markings, roadside features, gradient, lighting, safety fence type and position.
- Traffic data including flow of light and heavy vehicles.
- Accident data including casualties, severities, type of accident, attendant circumstances.

In the feasibility study only a small amount of geometric data relating to 64 km of carriageway was collected. In this initial study accident data were collected for approximately 700 km of dual carriageway roads in 7 counties, of which 121 km were fenced. In total there were approximately 100 fatal cross-over accidents on these roads in the 5 year period from 1979 to 1983. Traffic data have been obtained from published data, the counties concerned and the Department of Transport Regional Offices. Accident data for the whole of Great Britain are held on computer files at TRRL. The data are in the form of a summary (Stats 19) of the police accident records. The analysis excluded junction accidents and sections of road where special conditions applied (eg road works). In the feasibility study, roads in both urban and rural areas with various speed limits were included but an examination of the number of median involved accidents showed that these accidents were mainly confined to high speed roads. For this reason only dual carriageways with 60 or 70 mph speed limits were considered for inclusion in the follow-up study.

5 SOME RESULTS OF THE FEASIBILITY STUDY
BEFORE AND AFTER STUDY
At this stage it is only possible to give a limited set of results from the feasibility study.

The results of a before and after study at 5 sites are given in Tables 2 and 3. The total length of these sections is 31.6 km. Table 2 relates to casualties resulting from accidents involving the central reserve and Table 3 gives casualty figures for accidents where the median was not involved. No control sections were included so it is not possible to draw definite conclusions regarding changes in casualty rates.

For casualties resulting from median involved accidents it can be seen from Table 2 that the most marked effect following installation is a reduction in fatal casualties at all sites.

Overall the fatal casualty rate for these accidents decreased 85 per cent following installation. In the case of serious casualties the rate decreased at three sites but increased at one, with the overall rate decreasing by 58 per cent. For slight casualties the rate decreased at three sites but increased at two sites. In this case the overall rate decreased by only 19 per cent.

In Table 3 the changes in casualty rates for accidents not involving the central reserve are listed. For fatal
### TABLE 2
Casualties for median involved accidents on recently fenced sections from before and after study

<table>
<thead>
<tr>
<th>Site</th>
<th>Section length (km)</th>
<th>Date fence installed</th>
<th>Number of months data</th>
<th>Casualties</th>
<th>Casualty rate per 10⁶ veh-kms</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Fatal</td>
<td>Serious</td>
</tr>
<tr>
<td>A</td>
<td>0.7</td>
<td>9/81</td>
<td>b33</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>a27</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>B</td>
<td>4.1</td>
<td>11/80</td>
<td>b23</td>
<td>2</td>
<td>5</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>a37</td>
<td>0</td>
<td>3</td>
</tr>
<tr>
<td>C</td>
<td>8.0</td>
<td>7/82</td>
<td>b43</td>
<td>5</td>
<td>11</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>a17</td>
<td>0</td>
<td>2</td>
</tr>
<tr>
<td>D</td>
<td>12.3</td>
<td>12/82</td>
<td>b48</td>
<td>6</td>
<td>26</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>a12</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>E</td>
<td>6.4</td>
<td>7/82</td>
<td>b43</td>
<td>2</td>
<td>9</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>a17</td>
<td>0</td>
<td>4</td>
</tr>
<tr>
<td>Totals</td>
<td>31.6</td>
<td></td>
<td></td>
<td>15</td>
<td>51</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1</td>
<td>9</td>
</tr>
</tbody>
</table>

### TABLE 3
Casualties for accidents not involving the median on recently fenced sections from before and after study

<table>
<thead>
<tr>
<th>Site</th>
<th>Section length (km)</th>
<th>Date fence installed</th>
<th>Number of months data</th>
<th>Casualties</th>
<th>Casualty rate per 10⁶ veh-kms</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Fatal</td>
<td>Serious</td>
</tr>
<tr>
<td>A</td>
<td>0.7</td>
<td>9/81</td>
<td>b23</td>
<td>1</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>a27</td>
<td>0</td>
<td>2</td>
</tr>
<tr>
<td>B</td>
<td>4.1</td>
<td>11/80</td>
<td>b23</td>
<td>0</td>
<td>7</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>a37</td>
<td>0</td>
<td>4</td>
</tr>
<tr>
<td>C</td>
<td>8.1</td>
<td>7/82</td>
<td>b43</td>
<td>1</td>
<td>11</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>a17</td>
<td>0</td>
<td>9</td>
</tr>
<tr>
<td>D</td>
<td>12.3</td>
<td>12/82</td>
<td>b48</td>
<td>5</td>
<td>30</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>a12</td>
<td>0</td>
<td>5</td>
</tr>
<tr>
<td>E</td>
<td>6.4</td>
<td>7/82</td>
<td>b43</td>
<td>2</td>
<td>9</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>a17</td>
<td>2</td>
<td>4</td>
</tr>
<tr>
<td>Totals</td>
<td>31.6</td>
<td></td>
<td></td>
<td>9</td>
<td>61</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>2</td>
<td>24</td>
</tr>
</tbody>
</table>
casualties the rate is lower following installation at 3 sites and at one site the rate is higher; overall there was a 42 per cent reduction. For serious casualties the rate decreased at 3 sites and increased at 2 sites, and overall the rate was little changed. In the case of slight casualties the rate again decreased at 3 sites but increased at 2 sites and the overall rate was increased by 15 per cent.

REGRESSION ANALYSIS

Only a simple regression analysis was attempted in the feasibility phase of the study. This determined the relationships between the casualties per km of various severities and the traffic flow, for three accident types. Table 4 lists the correlation coefficients and levels of significance.

The highest correlation of 0.75 was obtained by regressing the number of slight casualties per km from accident type (b) (accidents where at least 1 vehicle mounted the central reserve) with traffic flow. Generally, correlations were highest where slight or all casualties were considered. The poorest correlations resulted from regressions involving fatal casualties. The small numbers of fatal accidents per km is one reason for the weak correlations obtained for this class of casualty.

6 DISCUSSION AND CONCLUSIONS

The results of the before and after study can be compared with the M1 motorway study. In both cases the biggest reductions following installation of fences were for the most serious accidents involving the central reserve. In the case of the M1 study (Transport and Road Research Laboratory 1974), although minor accidents increased in number, the erection of the safety fence resulted in the almost complete elimination of cross-over accidents in which there was a collision with a vehicle in the opposite carriageway and a very substantial reduction in cross-reservation accidents without subsequent collision. This resulted in fatal and serious injuries being significantly reduced. In the feasibility study, fatality rates were greatly reduced and other casualty rates were reduced or were similar following installation of safety fences except for slight casualties resulting from accidents not involving the central reserve where there was a modest increase of 15 per cent.

These early results, although of a tentative nature, are encouraging since they suggest that on all-purpose dual carriageway roads the casualties of median-involved accidents are reduced by safety fences while the numbers of casualties from other accidents do not rise substantially.

To obtain statistically significant results, data from greater lengths of recently fenced road is required together with that from appropriate lengths of unfenced road which will act as a control. In the main study it is hoped to collect data for most dual carriageway roads in England that have been recently fenced. It is estimated that the total length of such road is about 100 km.

The results of the regression analysis illustrate the problem of setting appropriate criteria on the basis of cost benefit. By far the most important casualties in accident cost terms are fatalities. These are costed at £150040 compared with £6950 for serious casualties and £170 for slight casualties (Department of Transport, 1984). However, because there are few fatal casualties, the regression relationships between numbers of fatal accidents and an important explanatory variable such as flow are relatively weak.

<table>
<thead>
<tr>
<th>Type of accident in which casualty occurred</th>
<th>Number of casualties</th>
<th>Class of casualty</th>
<th>Correlation Coefficient (r)</th>
<th>( r^2 )</th>
<th>Level of significance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Where at least 1 vehicle crossed over into the opposite carriageway</td>
<td>74</td>
<td>Fatal</td>
<td>0.46</td>
<td>0.20</td>
<td>0.05</td>
</tr>
<tr>
<td></td>
<td>304</td>
<td>Serious</td>
<td>0.63</td>
<td>0.40</td>
<td>0.01</td>
</tr>
<tr>
<td></td>
<td>441</td>
<td>Slight</td>
<td>0.73</td>
<td>0.52</td>
<td>0.01</td>
</tr>
<tr>
<td></td>
<td>819</td>
<td>All</td>
<td>0.67</td>
<td>0.45</td>
<td>0.01</td>
</tr>
<tr>
<td>Where at least 1 vehicle mounted the central reservation</td>
<td>17</td>
<td>Fatal</td>
<td>0.30</td>
<td>0.09</td>
<td>Not significant</td>
</tr>
<tr>
<td></td>
<td>127</td>
<td>Serious</td>
<td>0.48</td>
<td>0.22</td>
<td>0.05</td>
</tr>
<tr>
<td></td>
<td>384</td>
<td>Slight</td>
<td>0.75</td>
<td>0.55</td>
<td>0.01</td>
</tr>
<tr>
<td></td>
<td>528</td>
<td>All</td>
<td>0.72</td>
<td>0.52</td>
<td>0.01</td>
</tr>
<tr>
<td>Where at least 1 vehicle mounted the central reserve and rebounded</td>
<td>7</td>
<td>Fatal</td>
<td>0.11</td>
<td>0.01</td>
<td>Not significant</td>
</tr>
<tr>
<td></td>
<td>29</td>
<td>Serious</td>
<td>0.44</td>
<td>0.18</td>
<td>0.1</td>
</tr>
<tr>
<td></td>
<td>64</td>
<td>Slight</td>
<td>0.39</td>
<td>0.13</td>
<td>0.1</td>
</tr>
<tr>
<td></td>
<td>90</td>
<td>All</td>
<td>0.42</td>
<td>0.18</td>
<td>0.1</td>
</tr>
</tbody>
</table>
For example, the correlation coefficients for fatal casualties with flow vary from 0.11 to 0.46 whereas for slight casualties they vary from 0.39 to 0.75. In an attempt to improve the modelling of accident costs the total length of fenced road included in the sample is being increased to 150 km in the main study. In addition, geometric data is being collected for all roads and will be used to explain variance and increase the degree of association. It is expected that further improvements can be achieved by using more sophisticated regression modelling methods. The generalised linear modelling technique (GLIM) has proved successful in other accident research studies and will be used in the main study to enable a more precise estimate of the effects of safety fence on accident costs to be made.

By employing these techniques the aim is to establish appropriate criteria for the cost-effective installation of median safety fence.

7 ACKNOWLEDGEMENTS

The work described in this report forms part of the programme of the Transport and Road Research Laboratory, and this paper is published by permission of the Director, Road Safety Division, TRRL, provided the accident data and JMP Consultants Ltd were responsible for collecting and analysing the data presented.

8 REFERENCES


1 INTRODUCTION

Safety fences on roads are used to direct an out of control vehicle along a safe path, irrespective of driver input. Design of fences is based on a combination of impact tests under controlled conditions and experience of performance in service. There are two possible methods of checking the performance of fences when struck by different vehicles under a variety of conditions. One is to carry out tests for each variation of every parameter such as vehicle size, mass, direction of impact. Such a study will prove economically prohibitive if it is to cover a sufficient number of accident situations. The other method is to use theoretical simulation where computer programs can be developed to predict the result of a vehicle-fence impact.

The theoretical background for such a simulation is not sufficiently developed to be used in dynamic situations for accurate predictions. The most effective way is to carry out a limited number of tests to aid the development of mathematical models which can then be used to study the effect of changes in any of the significant parameters. A computer program based on a mathematical model of the impact and its consequences will allow safety fence design to be modified by studying the effects of various parameters, and possibly allow comparisons between different types of fence.

The Transport and Road Research Laboratory has funded the Cranfield Impact Centre to develop a suite of computer programs to model the performance of safety fences. This was to be suitable for representing at least two types of barrier, the high containment steel safety fence (HCSF) and the high containment concrete barrier (HCB). The HCSF covers a number of geometrical changes to the fence configuration. The programs should be suitable for modelling the imprints onto these fences of a rigid chassis lorry, an articulated lorry and a passenger car. The rigid chassis lorry was selected for a detailed comparison between test and simulation. To aid the increase in the accuracy of the rigid chassis simulation, lorry tests were carried out to obtain the lorry’s moment of inertia as well as the non-linear properties of the fence rail.
2 MODELLING CONCEPT

In accordance with the objective of the project to provide a suitable tool to simulate vehicle to safety fence impacts, a number of computer programs were considered. It was concluded that no single existing computer program could simulate all the events of a vehicle to safety fence impact.

The major events in such a crash are:

(a) Vehicle to fence contact. A vehicle, particularly an articulated lorry, may have many contact points with the fence at different times during a crash.

(b) Fence deformation. Resulting from each contact, linear and non-linear deformation of the fence may occur. At a point during impact the vehicle may contact the fence at a section already collapsed due to a previous contact.

(c) Vehicle deformation.

(d) Interaction between various vehicle segments or vehicle contents during the crash, and their effects on the vehicle trajectory.

(e) Occupant behaviour throughout the crash.

(f) Vehicle path during and after contact with the fence.

A number of computer programs were considered to cover the above requirements.

Since the project at hand was to cover a variety of vehicle types as well as fence types with the minimum vehicle data available, a combination of CRASH-D, KRASH and CVS programs were considered to be the most cost effective tool for vehicle to safety fence impact.

The analysis was carried out in three stages:

A. Collapse analysis of the steel fence—For this part of the analysis the fence was modelled as a single beam supported by a number of posts at regular intervals. The collapse analyses carried out using CRASH-D enabled the load carrying capability curve of the fence to be determined.

B. Structural and rigid analysis of the vehicle—The vehicle was modelled as a number of masses interconnected by a number of beam elements idealising the vehicle structure. The tyre and suspension were idealised by a set of external springs capable of acting in compression only. The vehicle to fence contact was simulated by an external spring with the collapse properties obtained from the analysis carried out to the fence. The computer program used to carry out this simulation was KRASH. The external spring representing a barrier was assumed to be several magnitudes stiffer than the vehicle model.

C. Simulation of vehicle occupant motion using Calspan CVS.

3 COLLAPSE ANALYSIS OF THE STEEL SAFETY FENCE

The simulation of the collapse behaviour of the fence was conducted using CRASH-D. The simulation was quasi-static, and took into account:

(a) Bending failures in the fence beam (horizontal rails)

(b) Bending failures in the fence posts (vertical members)

(c) Shearing of the connection between the post and the rail.

The purposes of the analysis was two-fold. In the first instance the fence used in the impact tests was analysed in order to provide data for the KRASH dynamic model. Secondly a number of runs were conducted to assess the effects of certain parameter changes in the fence performance.

Ideally the effects of the parameter changes would be assessed by their effects on the KRASH dynamic simulation. Within the time and cost constraints of the present contract a simpler criteria for fence performance was employed.

If a vehicle impacts a fence from an oblique angle, and is successfully re-directed parallel to the fence, then the kinetic energy associated with vehicle motion perpendicular to the fence must be dissipated. It is either dissipated by deformation of the fence, or by deformation of the vehicle. For instance, in the case of a concrete barrier, all the energy is dissipated by deforming the vehicle, and the contact forces are correspondingly high.

Where possible the CRASH-D simulations were continued until tension in the fence rail exceeded 960 kN, the failure load. The higher the energy absorbed by the fence within that loading, the more severe an impact the fence will be able to withstand without being breached. Similarly, the higher the force the fence can withstand, the greater its resistance to impact.

3.1 IDEALISATION AND ANALYSIS

The section of fence used in the tests was idealised as shown in Figure 1a. The model consisted of 48 vertical members (posts) and 49 horizontal members (beams). Thus the complete rail assembly (4 interconnected open box sections) was idealised as a single continuous rail. The properties of this single rail accurately represent the elastic and plastic properties of the array of box section beams, with due consideration given to the way these beams are interconnected. Figure 1b shows the results of collapse analysis of the fence when a single point load is applied.
The vehicle is modelled as a collection of masses interconnected by beam elements. The masses represent the major inertias of the structure i.e. engine, ballast etc. Any mass can be connected to a massless node (a beam end) through a massless rigid link.

The impact parametric studies were carried out for the following impact simulations:

I. 16 tonne rigid chassis lorry to fence impact (model 1)
II. Articulated lorry to fence impact (model 2)
III. Passenger car to fence impact (model 3)

Each model was impacted to both a steel safety fence and a concrete barrier at a variety of impact angles; this paper reports only the results for the steel safety fence.

4.1 IDEALISATION

The basic data required to carry out KRASH analyses is as follows:

(a) External springs representing the fence—The load deflection curve resulting from CRASH-D analysis of the base line steel safety fence is used

The vehicle to fence simulations were carried out using the KRASH computer program. This program monitors the interaction of a vehicle with two plane surfaces set at a given angle. In the case of this project one plane defines the road surface, whilst the other defines the support for the fence. The planes are unyielding and react on the vehicle via non-linear inelastic springs representing the structural behaviour of tyres and the fence.
for this purpose. In accordance with KRASH requirements this curve is idealised by a number of straight lines (Figure 2a). At 760 mm of lateral deformation the fence contacts the ground resulting in a very much higher fence reactive force. This phenomenon is simulated by the last idealised slope of the external spring representing the fence. This slope is also used to simulate the concrete barrier stiffness when impacts to the concrete barrier are modelled.

(b) Vehicle data—The required data which includes beam properties for the vehicle idealisation as well as dynamic data (masses, mass moments of inertia, tyre and suspension data etc.) were not readily available. In the case of the 16 tonne lorry where the comparison with dynamic test was to be carried out, significant effort was put into obtaining as much data as possible. Moment of inertia figures were obtained by testing a very similar vehicle (an identical vehicle could not be found).

The 16 tonne rigid lorry model incorporated 15 masses, 18 massless nodes, 28 beams and 12 external springs (Figure 2b). Information on the test vehicle was limited to mass, location of centre of gravity and general vehicle dimensions.

Fig. 3 Vehicle trajectory base line run
M M Sadeghi and M P Blake (Paper 5)

Fig. 4 Comparison simulation vs. test
M M Sadeghi and M P Blake (Paper 5)
4.2 DYNAMIC ANALYSIS

For the base line run, the 16 tonne rigid lorry model (Figure 2b) was impacted into the steel safety fence at a 15 degree angle with a speed of 80 km/hr. The simulation of this impact was singled out for detailed correlation with the dynamic test.

The vehicle trajectory resulting from this simulation is shown in Figure 3. Compared to observations from the test, from 700 ms onwards the simulation shows a slightly higher yaw rate than that in the tests.

Information from simulation and test are compared in Figure 4. For the first 300 ms the average value of the fore and aft acceleration from simulation is over twice that obtained from the tests. From 300 to 1000 ms however, there is a much better correlation between the two figures. The comparison between the two lateral accelerations (Figure 4) shows that although various peaks do not correlate up to 500 ms the average values compare well, whilst the 500 ms to 1000 ms the simulated value is below 50 per cent of the test value. One reason for the difference between test and simulation may be due to the slack in the beam joints not being included in the model.

The tensile load in the fence rail during the simulated impact was compared with the measurement made at the fish plates connecting the rail sections during dynamic tests (Figure 5). Tension in the complete rail assembly, as given in CRASH-D, was divided by 8 for comparison with the measured fish plate load. Reasons for the discrepancy in the maximum load may be found by considering that, for a simulated fish plate tension of 11.5 tonne, one of the 4.8 m rail sections extends only 2.1 mm—play in the bolt holes at the fish plates is certain to be of this order.

![Fig. 5 Comparison simulation vs. test, base line run, Fence Tension](image)

5 ARTICULATED LORRY TO FENCE IMPACT

5.1 IDEALISATION

This model was developed to simulate a 38 tonne articulated lorry impacting a fence. As only limited
data was available from the test HGV, a similar vehicle weighing 32.5 tonne, from which more data could be measured, forms the basis of this model. The 32 tonne lorry has a 3 axle tractor and a single axle trailer where the trailer is a uniform density box container. In one simulation run the weight was increased to 38 tonne keeping all other parameters constant.

The vehicle's mathematical representation is shown in Figure 6a. It incorporates 3 masses, 27 massless nodes, 4 beams and 20 external springs. Out of 20 external springs 8 represent wheel to ground contact and the other 12 possible fence contacts. The coefficient of friction for the fence and ground were set at 0.57 and 0.5 respectively.

5.2 DYNAMIC ANALYSIS

For the base line run, the 32.5 tonne articulated lorry was impacted into the steel safety fence at an angle of 15 degrees and a speed of 80 km/hr. The maximum shear load the fifth wheel can withstand is 1MN.

The trajectory computed (Figure 6b) shows that although the fifth wheel is allowed to shear under excessive load, it stays intact and the vehicle carried on along the fence and next to it. This simulation run was repeated with a 38 tonne vehicle (Figure 6c).

6 PASSENGER CAR TO FENCE IMPACT

6.1 IDEALISATION

The passenger car’s mathematical model was developed to simulate car to safety fence crash with particular emphasis on the vehicle trajectory during and immediately after the crash. No attempt was made to compare the acceleration and forces experienced by the car or fence with the actual test. To improve the detailed comparison between the model and the test it is necessary to model the vehicle structure and masses in great detail which is beyond the scope of this project. However, to simulate the trajectory and pathway of the vehicle, a simple model (1 mass and 20 massless nodes, see Figure 7a) based on the available data proved to be adequate. The vehicle weighed 960 kg, had a width of 1.48 m and a length of 3.34 m. The coefficient of friction between fence and vehicle was assumed to be 0.3.

6.2 DYNAMIC ANALYSIS

For the base line run the car was impacted to the baseline steel safety fence at an angle of 15 degrees. Figure 7b shows the trajectory of the vehicle during the simulation. In this simulation the vehicle stayed in contact with the fence for a short time before running parallel to it and a few inches from it. A more detailed modelling of the vehicle would have resulted in more lateral energy absorption which would have kept the vehicle in contact with the fence. The simulated trajectory is very close to the test result.

Fig. 7 Passenger car impacts

M M Sadeghi and M M Blake (Paper 5)
MODELLING OF VEHICLE OCCUPANT BEHAVIOUR USING CALSPAN CVS PROGRAM

It has been shown that from information on the fence, vehicle and impact conditions, the program KRASH can provide a simulation of the vehicle motion. It may be required to assess the effect of this motion on the vehicle occupants. The Calspan CVS program provides a means of doing this.

The Calspan CVS (Crash Victim Simulation) program represents the occupants by a series of body segments (having masses and inertias and represented physically by three dimensional ellipses) and joints (having viscous and damping characteristics and ranges of travel similar to those of a human or dummy) which connect together the body segments. Planes that represent interior fittings of a vehicle can be defined such as seats, glass areas and the floor. By allowing contacts between the various body segments and the planes and defining an acceleration or deceleration characteristic which the vehicle experiences, the behaviour of the occupants can be simulated.

7.1 IDEALISATION

The occupant characteristics were for an Aprod 81 side impact dummy. Planes were defined to represent the seat, lorry floor, side and front (see Figures 8a to 8f)

The vehicle motion is that for the 15 degree articulated lorry impact to the steel safety fence (Figure 6)

7.2 RESULTS

The occupant motion is shown in Figure 8. The occupant would either have a severe impact with the door, or be ejected from the window.

8 CONCLUSIONS

The CRASH-D parametric studies indicate that the post properties are extremely important in determining the strength and energy absorption of the steel safety fence. However, there are two important reservations:

1. The tensile strength of the rail is of greater importance than the bending properties of the posts.

2. The CRASH-D model does not take into account any 'give' in the connections between rail sections. It is necessary to check whether this effect would modify the above conclusion.
Detailed comparison between the simulated and test results for one of the KRASH simulations shows that the basic sequence of events is correct, although broadly speaking events happen more quickly in the simulated impact, and the simulated impact is more severe. Correcting some of the limitations of the current vehicle and fence models should result in better correlation.

Comparison between simulated and test vehicle trajectories show many of the predictions match practical test results. Suggestions are given as to how to improve the correlation of those predictions which did not match.

A wide range of vehicle trajectories (jack-knifing of articulated lorries, yawing, rolling) may be simulated.

Parametric studies indicate that friction between vehicle and fence, fence height and fifth wheel strength in the case of the articulated lorry, have been shown to be important parameters.

Simulation of the occupant motion may be carried out using the Calspan CVS program. It is proposed that such predictions may be used to assess the effect of barrier design changes on occupant motion, using either simulated or measured vehicle accelerations. The effect of seat belts may also be studied.

9 REFERENCES


10 ACKNOWLEDGEMENT

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