increased to 150 km in the main study. In addition, geometric data are 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 generalized 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 barriers.

## Acknowledgments

The work described in this report forms part of the program 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 analyzing the data presented.

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## HIGH CONTAINMENT SAFETY BARRIERS: STEEL AND CONCRETE

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## Abstract

The development and testing of steel box beam barrier and the construction and testing of a concrete barrier are described; both barriers were impacted with vehicles ranging from a small car to a 38 ton tractor trailer truck. The cars at $112 \mathrm{~km} / \mathrm{h}$ and the 16 ton trucks at $80 \mathrm{~km} / \mathrm{h}$ were contained and redirected by both barriers after impacting at an angle of 15 degrees; in addition, a 38 ton tractor trailer truck and a 51 seat bus were redirected by the box beam barrier.

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

## Introduction

Median barriers currently in use in the United Kingdom include the tensioned beam, the open box beam (1) and the rectangular hollow section (2). Median barriers, usually of the tension beam type, are installed on the medians of British motorways as a matter of course, and on the medians 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 ton car hitting them at an angle of 20 degrees to the line of the barrier at a speed of $112 \mathrm{~km} / \mathrm{h}$ so that the car remained close to the side of the barrier. The performance of these single height barriers was proven by full scale tests. In addition, a test into a double sided tension beam barrier with a bus weighing 5.4 tons proved satisfactory at $87 \mathrm{~km} / \mathrm{h}$ and 13 degrees although the bus came close to roll-over (1).

Over the past decade the total traffic mileage in Britain of trucks (heavy goods vehicles) (HGVs) has remained constant at about $20 \times 10^{9}$ 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 percent. On motorways in 1983, 4 and 5-axle articulated vehicles accounted for 45 percent of all HGV trucks and eight percent of all vehicles. This, plus the increase in 1983 of the authorized maximum gross weight for HGV trucks from 32.5 to 38 tons has led the Department of Transport to examine the potential of stronger barriers, particularly for use in localized applications where a high level of containment is essential. This paper describes two which have been developed, a high containment box beam barrier and a concrete safety barrier. Both of these have been subjected to full-scale impact tests using vehicles ranging from a BL Mini car at $112 \mathrm{~km} / \mathrm{h}$ to a 39.2 ton truck at $80 \mathrm{~km} / \mathrm{h}$. The objective of the tests described in this paper is to develop a barrier which will contain the heaviest vehicles in general use on British roads under realistic impact conditions while being as forgiving as possible to passenger cars, and to cost little more than the current barriers 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 barrier posts in poor soil and the development of high containment bridge parapets.

## The High Containment Barriers

## The Steel Box Beam Barrier

The high containment steel box beam barrier, called the double height double sided open box barrier (DHBSOB), has been designed to use, so far as possible, components from the safety barriers currently available in Britain. A cross section, plan and elevation of the barrier are shown in Figure 1. The barrier consists of four parallel open box beam set in pairs on either side of the barrier 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 barrier beams to remain upright while the posts fold sideways. Between posts the four beam 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 meter length of the steel barrier was erected, supported at each end by full height steel anchors set in large concrete blocks (Figure 1).

## The Concrete Barrier

Whereas box beam barriers are intended to absorb some of the energy of impact and to redirect the errant vehicle so that it follows, with an


Fig. 1 The double height, double sided open box steel barrier
acceptable angle, the line of the barrier in the direction of the traffic, concrete safety barriers are intended to provide containment without significant deflection or deformation under impact (4).

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 (5). A British Standard publication (4) gives the specification of the $B C B$. The barrier tested consisted of three meter 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 meters in three meter precast units linked together longitudinally by simple tongued and grooved joints as shown in Figure 2b.

## Impact Test Conditions

## The Test Vehicles

A barrier designed to be sufficiently strong to withstand the impact of a 38 ton articulated HGV truck represents a very rigid obstacle to 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 establishing the overall performance of the barrier. So the lightest test


PROFILE TYPE 4: PRECAST UNIT
Fig. 2a British concrete barrier (BCB) - section


All dimensions in mm
Fig. 2b British concrete barrier (BCB)
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 ton articulated $H G V$ and a mini car.

```
Small car - BL Mini (weight 750 kg)
Medium car - Talbot Alpine (weight 1000 kg)
Medium commercial
    truck -
Heavy commercial
    truck - }30\mathrm{ ton GVW 4-axle rigid
Heavy articulated
    truck - 38 ton 2-axle tractor, 3-axle trailer
Passenger bus - 14 ton 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.

## Impact Angle

Early work (5) had shown by simple geometric analysis that a $112 \mathrm{~km} / \mathrm{h}$ car travelling on the nearside of a three lane carriageway was unlikely to impact a median barrier 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 meters and median barriers have successfully contained and redirected vehicles of this energy. Also the double height single sided open box barrier has satisfactorily contained a 5.2 ton bus impacting at $80 \mathrm{~km} / \mathrm{h}$ at 20 degrees (1).

However, the energy normal to the barrier for a similar impact with a 16 ton HGV truck and a 38 ton HGV truck is approximately three times and seven times that of the bus respectively. The successful containment of vehicles at these higher magnitudes of energy could not be predicted from the current knowledge of post and beam barriers, so impacts at shallower angles with less energy normal to the barrier were considered as a starting point.

An $80 \mathrm{~km} / \mathrm{h}$ impact at an angle of 15 degrees with a 16 ton HGV truck has about 1.7 times the energy, normal to the barrier, of the successful test with 5.2 ton bus at 20 degrees mentioned above. A barrier designed which could contain an HGV truck impact of this higher energy level was considered to be practical both in terms of performance and cost. Based on this broad strategy a program was set up to develop a barrier which could contain a 16 ton HGV truck impacting at 15 degrees; subsequent tests with vehicles ranging from a mini car to a 38 ton articulated HGV truck were carried out to establish its overall performance.

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

## Test Procedures

## Towing and Guidance

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

## Impact Speed Measurement and Vehicle Tnstrumentation

High speed cameras running at 100 to 250 frames per second filmed the vehicle and barrier 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 center 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 barrier. Velocity, together with the translational and angular positions of the vehicle following impact, where 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

| Vehicle <br> type | GVU <br> ton | Length <br> (m) | Height <br> of C.G. <br> (m) | Impact <br> speed <br> (km/h) | Impact <br> angle <br> (deg) | Engine <br> capacity <br> (Liters | Vehicle <br> description |
| :--- | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| BL <br> Mini car | 0.78 | 2.95 | 0.45 | 116.5 | 15 | 0.85 | Private car |
| Talbot <br> Alpinecar | 0.99 | 4.38 | 0.51 | 116.3 | 15 | 1.44 | Private car |
| Dodge <br> 2-axle <br> HGV truck | 16.33 | 9.30 | 1.10 | 81.7 | 15 | 5.8 | Rigid <br> flat bed |
| Foden <br> 4-axle <br> HGV truck | 30.75 | 9.49 | 1.34 | 82.5 | 15 | 5.8 | High sided <br> tipper |
| Atkinson <br> 5-axle <br> HGV truck | 39.12 | 14.30 | - | 81.0 | 15 | 14.0 | Articulated- <br> 3-axle <br> trailer |
| Duple <br> bus | 14.29 | 11.92 | 0.66 | 91.6 | 15 | 12.5 | 51-seats |
| Talbot <br> Alpine <br> car | 1.03 <br> $(w i t h$ <br> dummy | 4.38 | 0.41 | 111.9 | 25 | 1.44 | Private car |
| Dodge <br> 2-axle <br> HGV truck | 16.71 | 9.05 | 1.10 | 80.3 | 25 | 5.8 | Rigid <br> flat bed |

Table 1 - Test Vehicle Dimensions: Box Beam Barrier

| Vehicle <br> type | GVW <br> ton | Length <br> (m) | Height <br> of C.G. <br> (m) | Impact <br> speed <br> (km/h) | Impact <br> angle <br> (deg) | Engine <br> capacity <br> (1iters) | Vehicle <br> description |
| :--- | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| BL <br> Mini <br> car | 0.71 <br> (with <br> dummy) | 2.95 | 0.49 | 102.5 | 15 | 0.85 | Private car |
| Talbot <br> Alpine <br> car | 1.06 <br> (with <br> duman) | 4.38 | 0.51 | 114.7 | 15 | 1.44 | Private car |
| Dodge <br> 2-axle <br> HGV truck | 16.49 | 9.15 | 1.50 | 80.9 | 15 | 5.8 | Rigid <br> flat bed |
| ERF <br> 5-axle <br> HGV truck | 39.21 | 14.30 | 1.61 | 83.8 | 15 | 14.0 | Articulated <br> 3-axle <br> trailer |

Table 2 - Test Vehicle Dimensions: Concrete Barrier
instrumented dummy was seated in the test cars, but not in the heavy vehicle.

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 $85 \mathrm{~m} / \mathrm{sec}$ delay introduced by the 10 Hz filer was compensated for by shifting the time base that amount.

$m$

Fig. 3 Lateral accelerometer with $\mathbf{1 0 H z}$ fitter
Tension loads generated in the barrier horizontal beams were measured by strain gauging the connecting splice plates.

Damage to the vehicle was approximated by the following index:
current cost of repair to vehicle
Damage index $=$ current cost of new vehicle

## Summary of Impact Tests

Tables 1 and 2 give the main vehicle characteristics and Tables 3 and 4 give some important vehicle, box beam barrier 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 barrier 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 ton HGV truck into the box beam barrier.

Vehicle barrier response Impact velocities：Lateral $5.87 \mathrm{~m} / \mathrm{s}$ Longitudinal $21.92 \mathrm{~m} / \mathrm{s}$
Damage：Crush to lower LHS cab Rear bolt sheared
post18

$$
4 \begin{array}{r|rl}
\begin{array}{r}
\text { Wheel stud } \\
\text { damage to } \\
\text { lower beam }
\end{array} & \begin{array}{l}
\text { Rear end } \\
\text { imoact }
\end{array} & \left.\begin{array}{c}
\text { Contact of ground by rear lower beam dynamically }
\end{array}\right]
\end{array}
$$

榙苞落


Remarks Satisfactory containment

The Box Beam Barrier: Vehicle and Barrier Response to 15 and 25 Degree Impacts

## 15 Degree Impacts

## Vehicle Response

The small and medium cars, the 16 ton, 30 ton and 38 ton articulated HGV trucks, and the 14 ton bus were all contained in the 15 degree impacts into box beam barrier. All vehicles were redirected at exit angles of less than seven degrees with the exception of the 30 ton 4 -axle rigid HGV truck which overturned on to the barriers but came to rest within the width of a national motorway median. The coach and the 16 ton HGV truck experienced large roll angles before returning to four wheel running. The tractor of the articulated HGV truck maintained a stable condition throughout the impact, the maximum roll being about nine degrees; however the trailer carrying the concrete block payload rolled through about 37 degrees before returning to the running surface.

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

The damage indices for both the Mini and the Alpine cars were about 100 percent.

| Test vehicla | Weight (ton) <br> Speed (km/h) <br> (deg) | Nam <br> Hols <br> Angle <br> (den) | ```May yav velocity (dog/aec)``` | Eat engle (dea) | Accel. (g) 10 Hz filter |  |  |  | Darrier data |  | memaris (vehicle dmene indey) 8 |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  |  |  |  |  | Lataral |  | Longitudinal |  | Max tansion (hM) | Scatic dofl. (dmang lonagth) (meters) |  |
|  |  |  |  |  | Peak | Average | Peak | Avarage |  |  |  |
| BL. Mini car | $\begin{gathered} 0.78 \\ 116.5 \\ 15 \end{gathered}$ | 7 | 140 | 6 | 9.5 | 3.4 | $-3.3$ | - 1.6 | 12.8 | $0.09$ (5) | Satiafactory <br> (100) |
| Telbot Alpine car | $\begin{gathered} 0.99 \\ 116.3 \\ 15 \end{gathered}$ | 5 | 110 | 0 | 8.6 | 3.0 | - 6.8 | -2.9 | 10.6 | $\begin{array}{r} 0.25 \\ (5) \end{array}$ | $\begin{aligned} & \text { Setiefactory } \\ & \text { (100) } \end{aligned}$ |
| 2-anie <br> HFY trk | $\begin{aligned} & 16.33 \\ & 81.7 \\ & 15 \end{aligned}$ | 63 | 62 | 5 | 1.7 | 0.8 | -0.0 | -0.4 | 109.8 | $\begin{aligned} & 1.22 \\ & (80) \end{aligned}$ | $\begin{aligned} & \text { Setisfactory } \\ & \text { (10) } \end{aligned}$ |
| $\begin{aligned} & \text { HGY trk } \end{aligned}$ | $\begin{aligned} & 30.75 \\ & 82.5 \\ & 15 \end{aligned}$ | 80 | 43 | 0 | 1.6 | 0.8 | -0.9 | $-0.5$ | 220.7 | $\begin{aligned} & 1.40 \\ & (80) \end{aligned}$ | Contalned but molled over (25) |
| $\begin{aligned} & \text { 5-arle } \\ & \text { HOY trk } \end{aligned}$ | $\begin{aligned} & 39.12 \\ & 81.0 \\ & 15.0 \end{aligned}$ | tractome $\text { ralis } 37$ | $\begin{aligned} & 1.1 \\ & 0.6 \end{aligned}$ | 3 | $\begin{array}{r} 10.0 \\ 4.0 \end{array}$ | $\begin{aligned} & 0.4 \\ & 0.3 \end{aligned}$ | $\begin{aligned} & -6.5 \\ & -4.0 \end{aligned}$ | $\begin{aligned} & -0.6 \\ & -0.2 \end{aligned}$ | 211.8 | $\begin{aligned} & 1.75 \\ & (67) \end{aligned}$ | Setisfactory $\begin{aligned} & \text { (10) } \\ & \text { (40) }\end{aligned}$ |
| bus | $\begin{aligned} & 14.29 \\ & 91.6 \\ & 15 \end{aligned}$ | 33 | 57 | 5 | 2.8 | 1.1 | -1.4 | -0.4 | 125.5 | $\begin{aligned} & 1.44 \\ & (33) \end{aligned}$ | Estiafectory $(50)$ |
| Alpine car | $\begin{aligned} & 1.03 \\ & 111.8 \\ & 25 \end{aligned}$ | - | 165 | - | 9.2 | 3.5 | -28.0 | -6.5 | 79.4 | $\begin{aligned} & 0.4 \\ & \text { (15) } \end{aligned}$ | Contalned lut eavere (100) |
| $\begin{aligned} & \text { 2-asie } \\ & \text { HGY'trk } \end{aligned}$ | $\begin{aligned} & 26.71 \\ & 80.3 \\ & 25 \end{aligned}$ | 180 | 42 | - | 2.0 | 1.1 | - 1.5 | -0.0 | 278.5 | $\begin{aligned} & 1.6 \\ & (50) \end{aligned}$ | golled over barrieros |

Cable 3 - Vehicle and Barrier Kesponse Data: Box Beam Barrier

## Barrier Performance

Only moderate damage was caused to the box beam barrier 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 ton HGV truck and 212 kN for the 38 ton articulated HGV truck. These figures indicate that the beam and linking splices experienced a load of about 40 percent of the yield strength. The highest tension measured in any splice plate was 161 kN which is equivalent to a tensile stress of $148 \mathrm{~N} / \mathrm{sq} . \mathrm{mm}$ across a section through the bolt holes. Taking the yield stress of steel as $255 \mathrm{~N} / \mathrm{sq} . \mathrm{mm}$ gives the percentage of yield for the splice plate of about 58 percent. A similar estimate for the bolts indicates the bolt shear stress to be about 134 percent 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.

## 25 Degree Impacts

## Vehicle Response

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

The 16 ton HGV truck at $80 \mathrm{~km} / \mathrm{h}$ rolled over the barrier and, while upside down, rotated 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 barrier been erected as a motorway median barrier the HGV truck would have stopped in the opposite carriageway.

## Barrier Performance

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

The HGV truck 25 degree impact tested the barrier beyond its limit. The impact energy component normal to the barrier 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 barrier.

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 accelerations of the Mini ( $103 \mathrm{~km} / \mathrm{h}$ ) and the Talbot ( $115 \mathrm{~km} / \mathrm{h}$ ) cars were fairly similar at 11.3 g and 12.4 g respectively and were the highest levels recorded in any of the impacts into the box beam barrier or the concrete barrier. The speed of the Mini car at 103 $\mathrm{km} / \mathrm{h}$ was lower than the target speed of $112 \mathrm{~km} / \mathrm{h}$. This was unfortunate because comparison could not be made with an early test (5) where a Mini car had overturned a $112 \mathrm{~km} / \mathrm{h}$ on a profile similar to the BCB in a 20 degree impact. The damage index for each car was 25 percent; all the doors

| Teatvehicle | $\begin{aligned} & \text { Weight (ton) } \\ & \text { Speed (km/h) } \\ & \text { Angle (deg) } \end{aligned}$ | $\begin{aligned} & \text { Man } \\ & \text { roll } \\ & \text { ongle } \\ & \text { (dien) } \end{aligned}$ | Mas yav velocity (a/aec) | Enit engla | Accel. (g) 10 Hz filter |  |  |  | Vahicle danage Index (\%) | $\begin{array}{\|c\|} \text { Barr. } \\ \text { damage } \\ \text { (meters) } \end{array}$ | REMARKS |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  |  |  |  |  | Latoral |  | Longitudinal |  |  |  |  |
|  |  |  |  |  | Peak | Averago | Peak | Average |  |  |  |
| 㫙 Mind car | $\begin{gathered} 0.71 \\ 102.5 \\ 15 \end{gathered}$ | 18 | 103 | 3 | 11.3 | 6.3 | -4.5 | -2.6 | 25 | 0 | Satisfactory |
| Talbot Alpine car | $\begin{gathered} 1.06 \\ 13.7 \\ 15 \end{gathered}$ | 8 | 182 | 5 | 12.4 | 5.8 | -3.7 | -1.8 | 25 | 0 | Satinfectory |
| $\begin{aligned} & \text { 2-axla } \\ & \text { HGV tr } \end{aligned}$ | $\begin{aligned} & 16.49 \\ & 80.9 \\ & 15 \end{aligned}$ | 31 | 50 | 2 | 2.8 | 0.8 | -1.3 | -0.4 | 100 | 18 | Satiafactory |
| $\left\|\begin{array}{l} 5-\operatorname{anclo} \\ \mathrm{HGV} \end{array}\right\|$ | $\begin{aligned} & 39.2 \\ & \\ & k \quad \\ & \hline \end{aligned}$ | thet 90 <br> thlan 9 | $\begin{array}{r} 106 \\ 42 \end{array}$ | - | $\begin{aligned} & 4.4 \\ & 1.9 \end{aligned}$ | $\begin{aligned} & 0.4 \\ & 0.5 \end{aligned}$ | $\begin{aligned} & -3.1 \\ & -3.6 \end{aligned}$ | $\begin{aligned} & -0.3 \\ & -0.6 \end{aligned}$ | 100 | 24 | Vehicle breached marrior |

Table 4 - Vehicle and Barrier Response Data: Concrete Barrier
of both cars could be opened after impact.
The 16.5 ton HGV ( $80.9 \mathrm{~km} / \mathrm{h}$ ) was satisfactorily contained and redirected although the roll angle at about 31 degrees was high. The HGV truck left the barrier at an angle of approximately two degrees and came to rest, after the remote braking was applied, about 60 meters from the point of first impact

The 39.2 ton articulated HGV truck ( $80 \mathrm{~km} / \mathrm{h}$ ) 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 the tractor and trailer were broken off as the underside of the HGV truck 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 meters from impact point.

The damage index for both HGV trucks was 100 percent.

## Barrier Performance

The Mini car impact caused only minor tire marks and surface scratches and, in service the barrier units would not need replacement. The unit first impacted by the Alpine car 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 ton HGV truck 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 meters (six units) needed replacement, the rest required only cosmetic repairs.

The articulated 39.2 ton HGV truck 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 meters (eight 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 $113 \mathrm{~km} / \mathrm{h}$ and 20 degrees, was more stable throughout the impact compared with the Mini care response to $B C B$. This work may lead to modification of the BCB profile for testing at a later date.

## Theoretical Head Impact Velocities

Barriers for the containment of HGV trucks are necessarily stiff and are likely to generate high acceleration forces within private cars. Values of the acceleration of the center of gravity of test vehicles impacting the box beam barrier and the concrete barrier are given in Tables 3 and 5 together with an index of impact severity called the Theoretical Head Impact Velocity (THIV). The THIV is derived from the lateral and longitudinal accelerations of the C.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 international Head Injury Criteria (HIC) value.

Figure 5 shows a plot of theoretical head impact velocities (THIV) for all impacts into the steel box beam barrier and concrete barrier other than the articulated HGV truck into the box beam barrier for which there were no accelerometers installed. General conclusions from Figure 5 suggest that at the speeds tested the box beam barrier and concrete barrier offer similar impact severity to vehicle occupants in that they produce fairly similar THIV values for paired vehicles, and that passengers in private cars would experience an impact twice as severe as those in an HGV truck. The THIV values for the 25 degree impact into the box beam barrier are only marginally larger than the 15 degree impacts. The rather unexpectedly small differences may be accounted for by the extra crushing of the Alpine car in the 25 degree test, and the case of the HGV truck the box beam barrier was run down fairly early in the impact thereby offering reduced resistance.

Absolute interpretation of THIV values in terms of occupant injury is difficult. Early work indicates that head impacts in excess of about 5 $\mathrm{m} / \mathrm{sec}$ could cause irreversible injuries. All the car derived THIV values exceeded this level and consequently on this criterion such impacts would be rated in a severe category; the HGV truck impacts produced considerably lower THIV values.

To summarize, THIV values confirm subjectively with the severity of impact that passengers in different types of colliding vehicle might experience. Simple analysis with THIV values may place vehicle impacts of differing weight, speed, and angle in an order of severity from a vehicle occupants viewpoint.

## Conclusions

Impact tests into a double height double sided open box steel barrier and a surface mounted precast British Concrete Barrier have demonstrated that private cars ( $112 \mathrm{~km} / \mathrm{h}$ approx) and 16 ton HGV trucks ( $80 \mathrm{~km} / \mathrm{h}$ approx) can be contained


Fig. 5 Theoretical head impact velocities
and redirected at impact angles of 15 degrees. The final position of the cars after impacting the box beam barrier tended to be closer to the barrier compared with the stationary position of the cars after hitting the concrete barrier.

The box beam barrier contained a 30 ton HGV truck at $80 \mathrm{~km} / \mathrm{h}$ although the vehicle rolled on to its side.

A 38 ton articulated HGV truck was safely contained and redirected by the box beam barrier, but a similar impact with an articulated HGV truck breached the precast concrete barrier; both impacts were at 15 degrees and about 80 km/h.

A medium car was contained by the box beam barrier during an impact at 25 degrees and $112 \mathrm{~km} / \mathrm{h}$, though the acceleration was severe. At a similar angle and a speed of $80 \mathrm{~km} / \mathrm{h}$ a 16 ton HGV truck rolled over the barrier.

Work is continuing on improving the performance of the box beam barrier for high angle impacts ( 25 degrees).

A collision of a BL Mini car at $113 \mathrm{~km} / \mathrm{h}$ 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.

A computer measure of impact severity was derived from vehicle accelerations 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 box beam barrier or the concrete barrier; passenger car occupants would experience about twice the severity of HGV truck occupants, and this higher level would be likely to cause serious injury.

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DEVELOPMENT OF ROADSIDE SAFETY HARDWARE IN SWEDEN
by Thomas Turbell, Swedish Road and Traffic Research Institute

## Introduction

No extensive research and development in the field of roadside safety hardware was done in Sweden before 1970. When our Institute moved to its new laboratories in 1975 we gained the capability of performing full scale crash tests at speeds up to 130 kmph . At the same time several projects were started and this presentation will describe some of them.

## Luminaire Supports

In the directives on road lighting issued by the National Swedish Road Administration a distinction is made between rigid and non-rigid luminaire supports. The accepted minimum distance from the roadway to the obstacle is different depending on the category of obstacle.

Our first goal was to define a test procedure and requirements in order to classify different types of roadside objects, especially luminaire supports (1).

After considering several alternatives we decided to build a deformable moving barrier for these tests. This barrier has the general shape of the roofline of a car, a mass of 1000 kg and a front end that will deform at a specified level.

As for the performance requirements it was felt that more or less filtered peak acceleration values from the impacting vehicles were not significant in determining the injury risk to the occupants. The concept of three impact speeds (V1, V2, V3) was therefore introduced where:

V1 is the impact speed of the vehicle into the obstacle.
V2 is the impact speed into the interior of the vehicle by an unrestrained occupant sitting 0.6 m from the vehicle interior.
V3 is the remaining speed of the vehicle after the collision with the primary object.

