HGV cab strength: investigating the casualty reduction effects of potential regulatory changes

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HGV Cab Strength:
Investigating the casualty reduction effects of potential regulatory changes

by B J Robinson (TRL)
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Executive summary

Background
There are two existing heavy commercial vehicle cab strength regulations but currently neither of these are mandatory requirements of the European Type Approval system. However, this system is being replaced by the General Safety Regulations (GSR) and as part of this process the EC is considering the inclusion of one of them (ECE Regulation 29).

Objectives
The objective of this study was to provide a preliminary assessment of the potential effects of such a decision on GB casualty numbers.

Scope of the study
This was a desk based study of limited scope and duration. It included the following activities:

- A review of the two existing standards;
- Describing the relevance of the test forces and energies to current GB accident scenarios;
- Estimating the casualty reducing potential of various policy options.

Main findings
The main procedural differences and similarities between the two tests (diagrams are presented overleaf) can be summarised as:

- The Swedish Test simulates one complex accident configuration, with a roof crush, oblique A-pillar impact and a rear wall impact all performed on the same cab. ECE R29.02 simulates three separate accident types (frontal impact, rollover and load shift) and the 3 tests can be carried out on three separate cabs.
- For the tests common to both (roof strength and rear wall strength), the Swedish Test is more severe, with a roof strength load of 15 tonnes (up to 10 tonnes in R29.02) and a 29.4 kJ pendulum impact concentrated in the centre of the rear wall of the cab (R29.02 applies a static load across the whole cab rear wall area which varies according to the permissible vehicle load).
- The A-pillar pendulum impact for the Swedish Test uses a cylindrical impactor, whereas the frontal impact for R29.02 uses a flat-faced rectangular impactor.
- The Swedish A-pillar test applies an energy of 29.4 KJ, whereas ECE R29.02 applies either 29.4 kJ (for vehicles ≤ 7 tonnes) or 44.1 kJ for vehicles > 7 tonnes.
- ECE R29.02 allows mathematical calculations to replace physical testing for the roof strength and rear wall tests, whereas the Swedish Test allows physical tests only.

Both the ECE and Swedish tests use a pass/fail criterion of survival space large enough for an occupant, so it is the extent of local deformation that is crucial because if any one part of the structure intrudes into this space, the test is failed. In this way, a test that features a large, flat-faced impactor or static loads being spread over wide areas, as is the case with ECE R29.02, will inevitably be a less severe test, given equal force and
energy inputs, than when loading the structure over smaller areas as in the Swedish test.

It is clear from the analyses that the Swedish tests are generally more severe than the ECE R29.02 standard. Even if it is assumed, though, that cabs are built to just meet one or other of these standards, it does not necessarily follow that a cab meeting the Swedish requirements would be any better at protecting its occupants than one built to the ECE Regulation. The level of protection afforded will depend strongly on whether the tests represent real-world, injury-causing accident situations.

When considering the six individual test procedures proscribed by ECE R29.02 and the Swedish VVFS 2003:29, the accident analyses have indicated that it is only the ECE R29.02 frontal impact test (Test A) that has potential to be representative of real-world accidents causing large numbers of injuries to HGV occupants in GB. Both accident databases (HVCIS and TCIS), independently of each other, produce very similar results regarding the frequencies of the three most common accident scenarios and the relative infrequency (or complete absence) of accidents relevant to the other regulatory tests, simulating roof crush, post-rollover A-pillar impacts and cab rear wall impacts.

In conclusion:

• For the existing regulatory tests (ECE R29.02 and the Swedish Test), this analysis indicates that the roof strength, A-pillar and rear cab wall tests are representative of only a small proportion of real-world accidents in GB involving injury to HGV occupants. The R29.02 frontal impact test (Test A) is potentially representative of a much larger proportion of real-world frontal impact accidents, though there is scope to make the test more severe by increasing the energy level, by using a more aggressive impactor (e.g. a cylindrical or a narrower flat-faced one), or both.

• Raising the frontal impact test energy to 55 kJ would be likely to save somewhere between 0 and 1.4 lives per year in Great Britain, depending on the extent to which existing cab designs would need to be strengthened. The mandatory fitting of AEBS, LDWS and ESC is likely to reduce this potential by about 15%, down to between 0 and 1.2 lives per year.

• The December 2009 proposals from the UNECE’s Cab Strength Informal Group of the Working Party on Passive Safety (GRSP) for a side-load/top-of-roof test (as part of an 03 series of amendments to Regulation 29) better represents real-world accident types, particularly simple (1/4 turn) overturning without other major impacts, and raises the frontal impact test energy to 55 kJ, which would be likely to save up to around one life per year in GB. These proposals thus seem to have better potential for casualty prevention than adopting either the ECE R29.02 or the Swedish Test.

Cab strength tests according to ECE-R29.02 (left) and the Swedish Test (right)
1 Introduction

There are two existing heavy commercial vehicle cab strength regulations but currently neither of these are mandatory requirements of the European Type Approval system. However, this system is being replaced by the General Safety Regulations (GSR) and as part of this process the EC is considering the inclusion of one of them (ECE Regulation 29). This paper is intended to provide a preliminary assessment of the potential effects of such a decision. It reviews these two standards, describes the relevance of the test forces and energies to current accident scenarios, and estimates the casualty reducing potential of various policy options.
2 ECE Regulation 29 and the “Swedish Test”

This section describes the two main existing standards for HGV cab strength in use in the UK and wider European Community, and compares their test procedures, force and energy levels.

2.1 ECE Regulation 29

First developed in the early 1970s, ECE Regulation 29 was last updated with the 02 series of amendments, which came into force in October 2002. Although compliance is, generally speaking, not mandatory, it is understood that most HGVs currently in production do meet this standard. ECE R29.02 involves 3 structural tests; front impact (Test A), roof strength (Test B) and a rear wall strength test (Test C). Figure 2-1 shows these three tests and the required force/energy levels.

In 2009, the Cab Strength Informal Group of the Working Party on Passive Safety (GRSP) proposed an 03 series of amendments. These proposals are discussed later in this report.

2.1.1 General requirements

- Vehicles can be approved, at the discretion of the manufacturer, to all three tests, or just tests A and B (frontal impact and roof strength). Vehicles already approved to ECE regulation 33 (48 km/h frontal impact into a barrier) are deemed to meet Test A;
- A manufacturer can choose to perform each test on a new cab or to perform all the tests on the same cab;
- After each test, a defined survival space must be available, where there is no contact between the non-resilient parts of the cab and the test manikin placed in the driver’s seat. The manikin is dimensionally equivalent to a belted 50th percentile male;
- During the tests, the cab mounts may deform or break, as long as the cab does not become completely detached from its chassis mountings;
- The cab doors must not open during the tests, but do not have to be openable after the tests;
- Tests B and C (roof and rear wall strength tests) do not have to be undertaken if the manufacturer can show by calculation that the cab’s structure would meet the test requirements.
2.1.2 Frontal impact (Test A)
This is the only dynamic test, whereby a 1500 kg pendulum collides with the front centre of the cab. The centre of gravity of the impactor is positioned to be no less than 50mm below the level of the seat’s R-point, and no more than 1400mm above the ground. These requirements help to ensure that for most vehicle designs the impact energy (29 or 44 kJ depending on the gross vehicle weight) is transferred mainly to the cab structure, not to the much stiffer chassis and cab mountings.

2.1.3 Roof strength (Test B)
This is a static test designed to simulate the effects of a full (180°) rollover. The maximum permissible weight acting on the vehicle’s front axle determines the static load applied to the roof, up to a maximum of 98 kN (10 tonnes). The load is distributed evenly over the roof by means of a suitably shaped rigid former, and deformation of the cab suspension is prevented.

2.1.4 Rear wall strength (Test C)
To simulate the effects of post-impact load transfer, a static load of 1.96 kN per tonne of “permissible useful load” is applied. The load is applied by a rigid barrier covering at least the whole of the cab rear wall situated above the chassis frame.

2.2 The Swedish Test (VVFS 2003:29)
First developed in the 1960s, this standard was understood to be mandatory for all vehicles sold new in Sweden until April 2009 (Dennis Eagle, 2009). It is thought to have been designed to offer some protection to HGV occupants in rollover accidents,
particularly for vehicles involved in logging operations. It also involves three structural tests, all simulating different phases of a rollover event; a roof strength test, an A-pillar impact and a rear wall impact. Figure 2-2 shows the three test conditions.

![Diagram of cab strength tests](image)

**Figure 2-2. Cab strength tests according to the Swedish Test**

### 2.2.1 General requirements
- All three tests must be undertaken in order (1, 2 then 3) on the same individual cab;
- After all three tests, a defined occupant survival space must be available;
- The doors must remain closed during the tests;
- All the cab mounts must remain operable.

### 2.2.2 Roof strength (Test 1)
To simulate a full (180°) rollover, a static load is applied to the roof, normally 147 kN (15 tonnes). Manufacturers can, if they wish, choose to apply a load of twice the maximum unladen weight of the vehicle being tested. The cab’s suspension can be left in situ or replaced with solid spacers.

### 2.2.3 A-pillar impact
To simulate an overturned lorry that subsequently collides with a road-side tree or other rigid narrow object, the top of the A-pillar is then subjected to an impact with a rigid 600mm diameter cylindrical pendulum of mass 1000 to 1500 kg possessing kinetic energy of 29.4 kJ. The impact is at a slight (15°) oblique impact to the longitudinal plane of the vehicle and to a point on the A-pillar just below the top opening of the door.
2.2.4 Rear wall impact
To represent the effects of the vehicle’s load moving forward and striking the rear of the cab during the rollover and subsequent A-pillar impact, the final test involves a rigid, flat faced pendulum impactor (500m high x 1600mm wide) striking the centre of the rear wall. Its mass is also 1000-1500 kg and it possesses 29.4 kJ of kinetic energy at impact, which vertically is to a point midway between the cab floor and ceiling.

2.3 A comparison of the two tests
To summarise the main procedural differences and similarities between the two tests:
1. The Swedish Test simulates one complex accident configuration, with a roof crush, oblique A-pillar impact and a rear wall impact all performed on the same cab. ECE R29.02 simulates three separate accident types (frontal impact, rollover and load shift) and the 3 tests can be carried out on three separate cabs.
2. For the tests common to both (roof strength and rear wall strength), the Swedish Test is more severe, with a roof strength load of 15 tonnes (up to 10 tonnes in R29.02) and a 29.4 kJ pendulum impact concentrated in the centre of the rear wall of the cab (R29.02 applies a static load across the whole cab rear wall area which varies according to the permissible vehicle load).
3. The A-pillar pendulum impact for the Swedish Test uses a cylindrical impactor, whereas the frontal impact for R29.02 uses a flat-faced rectangular impactor.
4. The Swedish A-pillar test applies an energy of 29.4 KJ, whereas ECE R29.02 applies either 29.4 kJ (for vehicles ≤ 7 tonnes) or 44.1 kJ for vehicles > 7 tonnes.
5. ECE R29.02 allows mathematical calculations to replace physical testing for the roof strength and rear wall tests, whereas the Swedish Test allows physical tests only.
6. Both tests use a pass/fail criterion of a survival space large enough for a seated adult male occupant.
3 Impact testing energies and deformations

3.1 Basic impact and energy equations

For a vehicle or object of mass \( m_1 \), travelling at velocity \( v_1 \), and colliding with a second vehicle or object of mass \( m_2 \) and travelling in the opposite direction at velocity \( v_2 \), the initial total kinetic energy is given by \( \frac{1}{2}(m_1v_1^2 + m_2v_2^2) \).

If it is assumed that after the collision, both vehicles/objects move together at a velocity \( v_3 \), by the conservation of momentum principle, \( m_1v_1 - m_2v_2 = (m_1+m_2)v_3 \).

So \( v_3 = \frac{(m_1v_1 - m_2v_2)}{(m_1+m_2)} \)

After the impact, the two vehicles/objects have the residual kinetic energy given by \( \frac{1}{2}(m_1+m_2)v_3^2 \), and the overall amount of energy lost in the impact, \( E \) (i.e. used to deform the structures), is thus \( \frac{1}{2}(m_1v_1^2 + m_2v_2^2) - \frac{1}{2}(m_1+m_2)v_3^2 \).

Substituting for \( v_3 \),

\[
E = \frac{1}{2}(m_1v_1^2 + m_2v_2^2) - \frac{1}{2}(m_1v_1 - m_2v_2)^2/(m_1+m_2)
\]

The energy is thus proportional to the pre-impact closing speed of the vehicles/objects and to simplify for the case when \( v_1=0 \) (e.g. when a truck collides with the rear of another, stationary truck), the energy to be absorbed is \( \frac{1}{2}m_1m_2v^2 / (m_1+m_2) \), where \( m_1 \) if the mass of the stationary truck, \( m_2 \) is the mass of the moving truck and \( v \) is its impact velocity.

3.2 Energy absorption

Structures absorb energy as they deform, with the amount of energy absorbed by each part of the structure being proportional to both the force level at which it collapses and the distance through which it deforms. In this way, very stiff structures can absorb large amounts of energy with quite small deformations and conversely very weak structures will deform by very large distances to absorb the same amount of energy. This also means that if, for example, in an impact the truck’s chassis and cab are deformed by similar amounts, it is likely that most of the overall impact energy will have been absorbed by the (much stiffer) chassis, and relatively less by the weaker cab structure.

It is important to note, however, that a very stiff structure like a truck chassis can be effectively rigid, which means it does not deform at all and thus does not absorb any energy. When, again for example, a relatively weak truck cab impacts with the very stiff/rigid load-carrying structure at the rear of another HGV, which is sufficiently high off the ground for the impacting truck’s chassis not to be impacted directly, then almost all the impact energy will go into crushing the impacting cab and even at fairly modest closing speeds, the damage is likely to be severe.

3.3 Impactor shapes and impact configurations

An object possesses kinetic energy by virtue only of its mass and velocity, so two objects with identical mass and velocity will have the same energy. If those two objects are themselves effectively rigid, when they impact into an energy-absorbing structure then that structure will absorb equal amounts of energy in both cases, regardless of the impactor’s shape. The shape, though, is important in determining the local deformation characteristics, with a large-flat faced impactor likely to cause quite small deformations but spread over a large area, and, conversely, a more pointed impactor causing larger deformations over a much more concentrated area of the impacted structure. In this way, the cylindrical impactor used in the Swedish Test (600mm diameter, 1600mm long), will cause more severe local deformations, kJ for kJ, than the ECE R29.02 flat-
faced impactor (800mm high, 2500mm long). Offsetting the impactor to one side of the vehicle, such that some of it misses the vehicle’s structure will have the same effect, i.e. it will cause more severe localised deformation without affecting the overall energy absorbed. The Swedish Test also features an offset in the A-pillar test, with the centre of the impactor striking the A-pillar of the truck (i.e. very near to the outermost edge), whereas the ECE R29.02 frontal impactor strikes the vehicle across its full width.

The overall levels of deformation and energy absorption by individual parts of a structure are determined not just by the forces applied but also by the direction those forces are applied in. Generally speaking, a long, thin structure, e.g. a door panel, will deform less if it is in pure compression (the force is applied directly along its length) than if the same force is applied at an angle sufficient to cause some bending of the structure. For this reason, the oblique (15 degrees to the longitudinal) direction of the Swedish A-pillar impact is a more severe test, particularly of the door remaining closed, than would be the case if the impact energy was applied with exactly the same impactor to the same impact point, but head-on.

Both the ECE and Swedish tests use a pass/fail criterion of survival space large enough for an occupant, so it is the extent of local deformation that is crucial because if any one part of the structure intrudes into this space, the test is failed. In this way, a test that features a large, flat-faced impactor or static loads being spread over wide areas, as is the case with ECE R29.02 will inevitably be a less severe test, kN for kN and kJ for kJ, than when loading the structure over smaller areas as in the Swedish test.
4 Accident scenarios

It is clear from the preceding sections that the Swedish tests are generally more severe than the ECE R29.02 standard. Even if it is assumed, though, that cabs are built to just meet one or other of these standards, it does not necessarily follow that a cab meeting the Swedish requirements would be any better at protecting its occupants than one built to the ECE Regulation. Whether or not the tests represent real-world, injury-causing accident situations is critical to the level of occupant protection offered. This section analyses data from both the Truck Crash Injury Study (TCIS) and the Heavy Vehicle Crash Injury Study (HVCIS) to determine the most common accident configurations.

4.1 HVCIS data

Data has been analysed from all accidents in the database involving an HGV occupant fatality from 1997-2007. The HVCIS database relates to police reports into fatal accidents involving HGVs, LCVs, OMVs and LPVs. The database contains information on 218 HGV occupant fatalities, in vehicles that had a total of 341 impacts and/or rollovers.

4.1.1 Rollover accidents

Of the 218 fatalities, 76 were occupants of vehicles that overturned at some stage in the accident, and those vehicles were involved in a total of 156 individual impact events (including the rollover as an impact event). Table 1 shows how these fatalities were distributed between pre-and post-collision rollover.

<table>
<thead>
<tr>
<th>Total number of impacts in accident</th>
<th>Fatalities</th>
<th>Rollover first event</th>
<th>Rollover after other impact(s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 impact</td>
<td>25</td>
<td>25</td>
<td>-</td>
</tr>
<tr>
<td>2 impacts</td>
<td>30</td>
<td>6</td>
<td>24</td>
</tr>
<tr>
<td>3 impacts</td>
<td>14</td>
<td>2</td>
<td>12</td>
</tr>
<tr>
<td>4 impacts</td>
<td>6</td>
<td>0</td>
<td>6</td>
</tr>
<tr>
<td>5 impacts</td>
<td>1</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>All accidents</td>
<td>76</td>
<td>33</td>
<td>43</td>
</tr>
</tbody>
</table>

This shows that most of the fatalities in simple rollover accidents, i.e those where the HGV overturns without first having hit some other vehicle or object, occur as a result of the rollover only (25 fatalities), whereas only 8 of the fatalities in such accidents involved a subsequent collision with another vehicle or object. Most (43) of the fatalities occurred in accidents in which the HGV overturned after first hitting some other vehicle or object. Only 3 further cases involved a more severe frontal impact after a rollover event that was not the first impact event, so these data tend to suggest that the Swedish A-pillar test, designed to replicate a post-rollover impact to the cab’s front, is representative of only 11 fatalities out of the 218 studied (5.0%).

Table 2 shows the distribution of impact points and objects on the HGVs involved in rollover accidents (both pre and post-collision). The most common points are to the front and sides. Only 5 impacts (resulting in 5 fatalities, 2.3% of all HGV occupant fatalities) occurred to the top/roof of the HGV. Of these five, one occurred in a situation where a rollover of more than 90 degrees was primarily responsible for the roof damage. The remaining four occurred in subsequent collisions with wide objects, such as central barriers, a building or the edge of a ditch. The loading applied by the roof crush tests in both ECE R29.02 and the Swedish test are, therefore, only sure to be representative of
one (0.5%) real-world fatal accident recorded on the HVCIS database but may be partially representative of a further four (2%).

Table 2. Impact points and objects on HGVs in rollover accidents.

<table>
<thead>
<tr>
<th>Impact point on HGV</th>
<th>Number of impacts</th>
<th>Impact objects</th>
</tr>
</thead>
<tbody>
<tr>
<td>Front</td>
<td>46</td>
<td>20 with other vehicles, 25 with roadside objects, 1 other/unknown.</td>
</tr>
<tr>
<td>Back</td>
<td>1</td>
<td>Another HGV</td>
</tr>
<tr>
<td>Left</td>
<td>56</td>
<td>4 with other vehicles, 11 with roadside objects, 39 in a rollover, 2 other/unknown.</td>
</tr>
<tr>
<td>Right</td>
<td>45</td>
<td>9 with other vehicles, 6 with roadside objects, 30 in a rollover.</td>
</tr>
<tr>
<td>Top/Roof</td>
<td>5</td>
<td>4 with roadside objects, 1 in a rollover.</td>
</tr>
<tr>
<td>Other/unknown</td>
<td>3</td>
<td>1 with roadside object, 2 in a rollover.</td>
</tr>
<tr>
<td>All impacts</td>
<td>156</td>
<td></td>
</tr>
</tbody>
</table>

Of the 43 fatalities from impacts involving a rollover after an initial impact with another object or vehicle (Table 1), 25 died where the first point of impact to their HGV was the front, 17 to the left or right side and 1 to the rear (of the HGV, not the cab).

4.1.2 Frontal impacts without overturning

Of the 218 HGV occupant fatalities, 76 died in accidents involving overturning, 4 died in accidents where there was no impact to the HGV (the occupants either fell off or out of the vehicle’s load compartment) and the remaining 138 fatalities were involved in some kind of impact or impacts that did not involve any overturning. Table 3 shows the distribution of most severe impacts on the HGVs involved in these cases.

By far the most common accident configuration is a frontal impact; of the 118 fatalities in such accidents, 79 impacted another HGV, 11 another large vehicle such as a bus, agricultural vehicle, mobile crane or dustcart, 21 hit a wide roadside object such as a bridge parapet, 4 impacted a narrow object such as a tree or lamp post and 3 collided with a light commercial vehicle. Of the 79 frontal impacts with another HGV, 53 (67%) collided with the rear of the other HGV.

Frontal impacts to the rear of other HGVs are therefore the most frequent cause of HGV occupant fatality. If the 21 impacts with wide objects are added along with the 6 impacts into the backs of other large vehicles (which would tend to produce similar damage patterns), the total is 80 fatalities in frontal impacts with large objects or other large vehicles, 37% of all HGV occupant fatalities, indicating that the ECE R29.02 frontal impact test simulates by far the most common fatal accident scenario.
Table 3. Most severe impact points on HGVs in non-rollover accidents.

<table>
<thead>
<tr>
<th>Impact point on HGV</th>
<th>Number of fatalities</th>
</tr>
</thead>
<tbody>
<tr>
<td>Front</td>
<td>118</td>
</tr>
<tr>
<td>Back</td>
<td>6</td>
</tr>
<tr>
<td>Left</td>
<td>4</td>
</tr>
<tr>
<td>Right</td>
<td>8</td>
</tr>
<tr>
<td>Other/unknown</td>
<td>2</td>
</tr>
<tr>
<td>All impacts</td>
<td>138</td>
</tr>
</tbody>
</table>

4.1.3 **HVCIS summary**

The analysis of 218 HGV occupant fatalities in the HVCIS database indicates that the three most common accident scenarios are:

1. Frontal impact into the back of another HGV, other large vehicle, or large road-side object, without subsequent overturning (37% of all HGV occupant fatalities), as potentially represented by ECE R29.02 Test A;
2. Frontal impact into another vehicle or road-side object, followed by overturning on to the left or right side only (18%);
3. Overturning onto left or right side, without other major impacts (11%).

Accident scenarios represented by the other ECE R29.02 and Swedish tests were much less common, as follows:

- Swedish Tests 1 and 2 - full overturning onto roof with subsequent frontal impact 0 cases, 0%, though there were 11 cases, 5.0% with a 90 degree rollover first);
- Swedish Test 1 and ECE R29.02 Test B – full overturn onto roof without any other major impacts (1 case, 0.5%);
- Swedish Test 3 and ECE R29.02 Test C – impact to cab rear wall (0 cases, 0%).

4.2 **TCIS data**

Detailed information on accidents involving HGVs in defined geographic areas forms the TCIS database. In accidents occurring between 1995 and 2008, the database contains information on 269 accidents where cab strength was coded as a topic of relevance, involving 336 HGVs and 355 HGV occupants. 14 of these occupants were fatally injured, 124 seriously, 135 slightly and the remaining 82 were either uninjured or their injuries were not known. Of the 273 injured occupants, the basic collision details were known in 266 cases. 211 of which involved an impact as the first event (with or without subsequent rollover) and the remaining 55 involved a rollover as the first event (with or without subsequent impact). Table 4 shows the distribution of injury severities amongst the HGV occupants in these cases.
Table 4. HGV occupant injury levels by first event.

<table>
<thead>
<tr>
<th>Injury level</th>
<th>Impact first event</th>
<th>Rollover first event</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fatal</td>
<td>12 (92%)</td>
<td>1 (8%)</td>
</tr>
<tr>
<td>Serious</td>
<td>94 (78%)</td>
<td>26 (22%)</td>
</tr>
<tr>
<td>Slight</td>
<td>105 (79%)</td>
<td>28 (21%)</td>
</tr>
<tr>
<td>All</td>
<td>211 (79%)</td>
<td>55 (21%)</td>
</tr>
</tbody>
</table>

4.2.1 Rollover as first event cases

Of the 55 rollover as first event casualties, full accident configuration details were only known in 13 cases. In just one of those cases (involving the 1 fatality, who was not wearing a seat belt), did the vehicle overturn fully onto its roof, having rolled down/into a ditch. In all the remaining 12 cases, the HGV rolled by a ¼ turn onto its left or right side only. In 4 of these cases, there was a subsequent impact with another vehicle or road-side object, leaving 8 cases involving a simple ¼ overturn without any other impacts.

4.2.2 Impact as first event

Of the 211 impact as first event casualties, full accident details were known in 53 cases. In most (46) of these cases, the first impact was to the front of the HGV, with the remaining 7 cases being impacts to the side or rear of the HGV. The frontal impacts were distributed as shown in Table 5. 18 of the casualties where an impact was the first event were in vehicles that rolled over after the first impact; only two of those cases were known to involve rollovers of more than a ¼ turn.

Table 5. Impact objects for frontal HGV impacts.

<table>
<thead>
<tr>
<th>Impact opponent</th>
<th>Number of HGV occupant casualties</th>
</tr>
</thead>
<tbody>
<tr>
<td>Car/Car derived van</td>
<td>11</td>
</tr>
<tr>
<td>HGV or other large vehicle</td>
<td>22</td>
</tr>
<tr>
<td>Narrow object</td>
<td>1</td>
</tr>
<tr>
<td>Wide object</td>
<td>9</td>
</tr>
<tr>
<td>Other/unknown</td>
<td>3</td>
</tr>
<tr>
<td>All frontal impacts</td>
<td>46</td>
</tr>
</tbody>
</table>

4.2.3 TCIS summary

The analysis of 266 HGV occupant casualties in the TCIS database indicates that the three most common accident scenarios are:

1. Frontal impact into another HGV, other large vehicle, or large road-side object, without subsequent overturning (31% of all HGV occupant casualties), as potentially represented by ECE R29.02 Test A;
2. Frontal impact into another vehicle or road-side object, followed by overturning on to the left or right side only (24%);
3. Overturning onto left or right side, without other major impacts (13%).

Accident scenarios represented by the other ECE R29.02 and Swedish tests were much less common, as follows:
• Swedish Tests 1 and 2 - full overturning onto roof with subsequent frontal impact (0 cases, 0%);
• Swedish Test 1 and ECE R29.02 Test B – full overturn onto roof without any other major impacts (1 case, 2%);
• Swedish Test 3 and ECE R29.02 Test C – impact to cab rear wall (1 case, 2%).
5 Discussion

When considering the six individual test procedures proscribed by ECE R29.02 and the Swedish VVFS 2003:29, the accident analyses have indicated that the ECE R29.02 frontal impact test (Test A) is representative of the most common real-world accidents causing significant numbers of injuries to HGV occupants in GB. Both accident databases, independently of each other, paint very similar pictures of the frequencies of the three most common accident scenarios and the relative infrequency of accidents relevant to the other regulatory tests, simulating roof crush, post-rollover A-pillar impacts and cab rear wall impacts.

The next point to consider, though, is whether the ”Test A” conditions do actually represent realistic impact conditions. By their very nature, though, HGV frontal impacts will inevitably involve a very wide range of impact objects, speeds and geometries; the HVCIS and TCIS data both show HGV’s impacting various other HGVs, of differing sizes and loading configurations, as well as various different road-side objects and other vehicles. Standardisation on any one impact type is therefore very difficult and any option chosen will inevitably be open to the criticism that it is not representative of most accident scenarios. That said, frontal impacts into the rear of another HGV or other large vehicle are commonplace, and it is probably reasonable to assume that a high proportion of those involve impacts with fairly rigid and fairly flat structures, e.g. load platforms, load boxes and chassis members. It is therefore likely that the flat-faced, rectangular pendulum impactor used in ECE R29.02 Test A is a reasonable approximation, though more complex shapes may improve realism further.

The complex and varied impact configurations also make an assessment of an appropriate test impact energy very difficult. Of particular importance is the extent to which the main chassis members of the cab interact with the similarly stiff structures on the impacted vehicle or object because this will have a strong influence on how much of the residual impact energy has to be absorbed by deformation of the cab/occupant compartment.

Ongoing research for the DfT (as yet unpublished) on longer semi-trailers and articulated vehicle combinations has found from an international literature review that existing HGVs (assumed here to meet ECE Reg29) can probably absorb about 500 kJ in a front of HGV to rear of another similar HGV impact while still providing a level of protection for a belted occupant that would make fatal injuries unlikely (equivalent, for example to a 12 tonne truck hitting the rear of another, stationary 12 tonne truck at about 46 km/h). When set against the 44 kJ maximum energy imparted by Test A, one might think that the existing test is far from severe. The relative energies absorbed by the cab and the chassis, though, might well mean that only a small proportion of the 500 kJ overall energy goes into deforming the cab. Research by Anderson (2003) found that the cab absorbed about 20-25% of the total energy absorbed by the whole truck in various frontal impact scenarios modelled. This would suggest, that a 500 KJ overall energy impact might involve somewhere between 100 and 125 kJ going into deforming the cab. With those figures, the 44 kJ of ECE R29.02 looks rather more reasonable (assuming the impact is high enough to mean almost all the energy is absorbed by the cab, and not its mountings or chassis), though it is still well below the levels likely to threaten fatal injuries to a belted occupant.

In summary, for the existing regulatory tests (ECE R29 and the Swedish Test), this analysis indicates that the roof strength, A-pillar and rear cab wall tests are not representative of significant numbers of real-world accidents in GB involving injury to HGV occupants. The R29.02 frontal impact test (Test A) is potentially representative of real-world frontal impact accidents, though there is scope to make the test more severe by increasing the energy level, by using a more aggressive impactor (e.g. a cylindrical or a narrower flat-faced one), or both.
Having established the relevance of the existing rollover tests, and found them to be representative of only a small proportion of real-world rollover accidents in GB, is it possible to propose alternative test methods that would be more representative? The main impact configuration that the existing tests do not simulate is the 90 degree, ¼ turn rollover. The accident studies indicate that this occurs in something like 29 - 37% of HGV occupant injuries, with about two-thirds of those being after an initial frontal impact and the rest being simple overturns with no other major impacts. There is, therefore, scope to include some test of the integrity of the sides of the cab, especially near the top of the door/roof line which would be likely to take the highest loads in such an event. In this context, the December 2009 proposals from the UNECE’s Cab Strength Informal Group of the Working Party on Passive Safety (GRSP) for an 03 series of amendments to Regulation 29 seem a potentially sensible development. Amongst various changes, it is proposed that the existing roof strength test be modified to include an initial impact to the upper edge of the cab’s side, angled at 20 degrees and imparting 17.6 kJ of energy (see Figure 5-1), prior to the 97 kN load being applied as per the existing Regulation. These proposals also suggest raising the frontal impact test energy for vehicles over 7.5 tonnes to 55 kJ (from 44.1 kJ), another step in the right direction.

![Figure 5-1. Modified roof strength test proposals (source: UNECE, GRSP)](image)

Another relevant issue when it comes to considering the appropriateness and potential benefits and costs of making changes to the cab strength requirements is the extent to which other measures might be influential, particularly those where some of the injuries from accidents amenable to cab strength changes could be prevented or mitigated by other means. Three accident-prevention measures are discussed here; Lane Departure Warning Systems (LDWS), Automatic Emergency Braking Systems (AEBS) and Electronic Stability Control (ESC).

The HVCIS data collection routinely involves assessing the potential effectiveness of these and many other countermeasures in preventing the fatal injuries added to the database. A review of these data for the years 1997-2007 indicates that the measures were considered to have the potential to save the proportions of HGV occupant casualties shown in Table 6.
Table 6. Countermeasure potential in HGV occupant fatality accidents.

<table>
<thead>
<tr>
<th>Countermeasure</th>
<th>Percentage of HGV occupant fatalities likely to be prevented</th>
</tr>
</thead>
<tbody>
<tr>
<td>AEBS</td>
<td>2%</td>
</tr>
<tr>
<td>LDWS</td>
<td>10%</td>
</tr>
<tr>
<td>ESC</td>
<td>3%</td>
</tr>
</tbody>
</table>

For AEBS, these data assume that the system is only able to reduce the severity of an accident, by applying emergency braking when it detects that an impact is unavoidable. The potential benefits of a full collision avoidance system, able to detect a likely collision sufficiently well in advance to prevent it altogether, would be likely to save around 24% of all HGV occupant fatalities.

In combination, the analysis suggests that HGVs equipped with first-generation AEBS, LDWS and ESC would have about 15% fewer HGV occupant fatality accidents than conventional vehicles not equipped with such systems.

The ongoing, unpublished research for the Department for Transport into longer articulated vehicles indicates that if, for example, existing trucks could be built to be able to absorb 1000 kJ and still provide the same degree of protection for their occupants as current designs do when absorbing 500 kJ, then this extra strength would be likely to save on average about 2.5 HGV occupant lives per year, assuming all HGV occupants wore seat belts. In the 12 tonne truck hitting the rear of another 12 tonne truck example used earlier, this would be the equivalent of raising the critical impact speed from 46 km/h to 65 km/h. Fitment of AEBS, LDWS and ESC would be likely to reduce the savings to about 2.1 lives per year.

Without detailed information on existing cab designs, it is very difficult to speculate on the likely casualty saving benefits of the small increase in frontal impact test energy (from 44.1 kJ to 55 kJ) proposed for the 03 series of amendments to Regulation 29. This is because it is conceivable that many existing designs would already meet such a requirement and thus, for these vehicles, a change in the standard would have no benefit. In the most extreme case, though, if it is assumed that all existing designs only just meet the existing standard, and thus all new designs would have to be strengthened to be able to absorb about 25% more energy to meet the new standard, this would be equivalent to taking the critical impact energy from about 500 kJ to 625 kJ. The research into longer articulated vehicles indicates that this would be likely to save about 1.4 HGV occupant lives per year in Great Britain, assuming all HGV occupants wore seat belts, which would reduce to about 1.2 lives per year when the effects of AEBS, LDWS and ESC are taken into account.
6 Conclusions

1. For the existing regulatory tests (ECE R29.02 and the Swedish Test), this analysis indicates that the roof strength, A-pillar and rear cab wall tests are not representative of common real-world accidents in GB involving injury to HGV occupants. The R29.02 frontal impact test (Test A) is potentially representative of the most frequent real-world frontal impact accidents, though there is scope to make the test more severe by increasing the energy level, by using a more aggressive impactor (e.g. a cylindrical or a narrower flat-faced one), or both.

2. Raising the frontal impact test energy to 55 kJ would be likely to save somewhere between 0 and 1.4 lives per year in Great Britain, depending on the extent to which existing cab designs would need to be strengthened. The mandatory fitting of AEBS, LDWS and ESC is likely to reduce this potential by about 15%, down to between 0 and 1.2 lives per year.

3. The December 2009 proposals from the UNECE’s Cab Strength Informal Group of the Working Party on Passive Safety (GRSP) for a side-load/top-of-roof test (as part of an 03 series of amendments to Regulation 29) better represents real-world accident types, particularly simple (1/4 turn) overturning without other major impacts, and raises the frontal impact test energy to 55 kJ, which would be likely to save up to around one life per year in GB. These proposals thus seem to have better potential for casualty prevention than adopting either the ECE R29.02 or the Swedish Test.
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References


There are two existing heavy commercial vehicle cab strength regulations but currently neither of these are mandatory requirements of the European Type Approval system. However, this system is being replaced by the General Safety Regulations (GSR) and as part of this process the EC is considering the inclusion of one of them (ECE Regulation 29).

The objective of this study was to provide a preliminary assessment of the potential effects of such a decision on GB casualty numbers. It includes a review of the two existing standards, describes the relevance of the test forces and energies to current GB accident scenarios and estimates the casualty reducing potential of various policy options.