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Preventing passenger ejection from buses, coaches and minibuses
(Use of laminated safety glazing on buses and coaches)

A piece of recently completed UK research concentrated on investigating potential measures to prevent passengers being ejected from buses, coaches and minibuses in rollovers. It used Regulation No. 66 as a basis protocol in its evaluations; its purpose was not to evaluate Regulation No. 66 itself. This research was completed in 2006, and has been published recently. The full report is available for viewing on the Cranfield Impact Centre's website at http://www.cicl.co.uk/pdf_files/a-final%20report.pdf. For information, key messages have been highlighted, and the Appendix below contains a copy of the Executive Summary from the report. Any views expressed in this report are those of the Authors, and not necessarily those of the UK Department for Transport.

Key Messages

- For Great Britain, for the 11-year period 1994 to 2004 inclusive, it can be calculated that bus and coach occupants accounted for:
  - 0.49% of all ‘killed’;
  - 1.45% of all ‘killed or seriously injured’; and
  - 3.07% of ‘all severities’ (killed, seriously injured and slightly injured)

- It was estimated that, for Great Britain, a maximum of some 3 fatalities and 184 serious injuries per year are due to full or partial ejection from coaches and minibuses. It is not possible to distinguish the individual contribution of coaches and minibuses to this total of ejection related casualties from the available sources.

- The literature search indicated various technologies that have been considered for reducing passenger ejection from car side windows. Of these, the use of seat belts and bonded laminated side glazing was of most relevance to this study in that these fulfilled the projects’ mandate to identify practical and cost-effective means for limiting passenger ejection.

- Finite Element analyses indicated that:
  - For the coach model:
    - Toughened glass was unable to offer any retentive capability for the unrestrained occupant;
    - 3-point seat belts were more effective than 2-point belts during the selected rollover condition
    - Installation and routing of the shoulder belt on the seats nearest to windows should be considered, as outboard installations may be vulnerable to damage from the ground or other intrusion during rollover;
    - The use of a seat side bolster, as a form of compartmentalisation for an unrestrained occupant, restricted the occupant from possible ejection, but redirected the occupant into a severe head impact with the overhead luggage rack;
    - Laminated glass bonded to the vehicle rather than toughened glass mounted in a flexible gasket demonstrated that the strength limits of the adhesive bond were always exceeded and this caused the window to be released from the structure. It was concluded that standard laminated glass which was

adhesively bonded to the structure was insufficient to retain an unbelted occupant within the vehicle under the accident conditions simulated here.
    - A series of modifications to improve the fixing strength of the window to the vehicle proved unsuccessful. This was believed to be due to the deflection of the structure around the window during the impact. Ultimately, the inclusion of a bolting system as well as adhesive bonding preserved the bond, but transferred the failure into the laminated glass around the bolts. On this basis, the use of standard laminated glass as a mandatory recommendation was not put forward.
    - However, the results indicated that the voluntary use of laminated glass may be beneficial over toughened glass in rollover (and other) accidents where the impact severity was not as high as that used in the simulations conducted here.
    - The parametric study also indicated that the reduced height of current window designs may also have some benefit in retaining an unrestrained occupant although it is likely that they will be redirected to an impact with some other object within the vehicle.
  - For the minibus model:
    - The occupants were not ejected but were subject to impacts with the interior of the vehicle.

- It was concluded that 3-point inertia reel seat belts remain the best option for preventing ejection and partial ejection.

- With the introduction in 2006 of compulsory seat belt wearing in the UK on coaches and minibuses for all occupants over 3 years, the project concluded with the two following recommendations:
  - That future coach and minibus accident data should be monitored following the introduction of compulsory seat belts wearing to measure the effect that this has on rollover ejection casualty numbers
  - As part of the above, current ECE R-66 technical requirements should be reviewed with regard to the increased energy that passengers wearing seat belts will impart to a vehicle's structure during a rollover accident. If excessive roof crush is observed from accidents involving R-66 compliant vehicles (and where passengers wore their seat belts), it may be necessary to increase the energy and strength requirements of roof structures to resist increased roof loading from belted passengers.

Preventing Passenger Ejection from Buses, Coaches and Minibuses
A C Walton, S M R Hashemi, J C Anderson (August 2006, Cranfield Impact Centre)

EXECUTIVE SUMMARY

In the UK, bus, coach and minibus occupant casualties comprise a small portion of the total number of casualties when all road users are considered. From Department for Transport data for Great Britain for the 11-year period 1994 to 2004 inclusive, it can be calculated that bus and coach occupants accounted for 0.49% of all ‘killed’, 1.45% of all ‘killed or seriously injured’ and 3.07% of ‘all severities’ (killed, seriously injured and slightly injured).

Coach and minibus rollover accidents are relatively infrequent. Bus rollover accidents are rarer still due to the predominantly urban conditions in which they operate. However, for coaches, rollover accidents have, in the past, resulted in higher levels of injury per accident than other types of coach accident due to inadequate roof structural strength. In 1993, the UK adopted UN-ECE Regulation 66 (R-66) for roof strength. However R-66 has no requirement to demonstrate that an occupant would be retained within the survival space. With regard to minibuses, no equivalent rollover roof strength standard exists although there is no indication from accident data that current designs have inadequate roof strength.

The aim of this project was to examine the scale of injury attributable to the ejection and partial ejection of passengers during rollover from buses, coaches and minibuses in the UK. Following on from this, the project was to address whether the retention of passengers could be improved upon over current levels with the aim of providing recommendations for improved legislation, where appropriate.

In order to fulfill the project aim, the following objectives were defined in the project specification as;

- Conduct a study of accident data to define injuries related to rollover
- Review the effectiveness of 2-point and 3-point seat belts with regard to ejection and injury
- Identify the risk of ejection and partial ejection and the use of breakable (toughened) glass in relation to existing requirements for passenger evacuation
- Identify practical and cost-effective methods for increasing protection against ejection
- Assess any new method(s) of occupant ejection prevention in terms of other safety considerations
- Deliver an Initial and Partial Regulatory Impact Assessment relating to measures arising from the study

Due to the scale and cost associated with full-scale crash testing of heavy vehicles, it was planned that the project would use Finite Element analysis as a means of simulating parametric studies of vehicle rollover accidents, allied to window impact testing where required to support the analytical modeling.

In the initial plan of this study, it was proposed that five areas of activity would be required to meet the overall aim of the study. These were;

- A survey of accident data to identify the frequency, cause and level of injuries due to passenger ejection from buses, coaches and minibuses

- A search of relevant literature which included glass material data, other accident studies involving bus, coaches and minibuses, modeling techniques and full-scale test methods
- The application of Finite Element modelling to simulate a generic coach and minibus rollovers – this represented a major part of the study
- Impact tests of a laminated side window of a coach to validate the modelling analysis
- An Initial and Partial Regulatory Impact Assessment of the issues associated with this study

All of these tasks were subsequently carried out.

From the accident survey it was determined that precise numbers of bus coach and minibus occupants who are ejected, or partially ejected, are unknown because this information is not collected by the national STATS 19 accident data collation system or other surveys. It was estimated by this study for Great Britain that a maximum of some 3 fatalities and 184 serious injuries per year are due to full or partial ejection from coaches and minibuses. It is not possible to distinguish the individual contribution of coaches and minibuses to this total of ejection related casualties from the available sources.

The literature search indicated various technologies that have been considered for reducing passenger ejection from car side windows. These included the use of seat belts, laminated glass, advanced plastics and side airbags. Of these, the use of seat belts and bonded laminated side glazing was of most relevance to this study in that these fulfilled the projects' mandate to identify practical and cost-effective means for limiting passenger ejection.

The project used Finite Element modeling to analyse a baseline rollover accident for a coach and a minibus. The coach and minibus models were developed from models generated in previous studies conducted for the DfT and which had been previously validated against full scale tests. The vehicle models were expanded to include a range of crash dummies of varying sizes, as well as seats, seat belts, interior surfaces and representations of both toughened and laminated side glazing. The accident condition chosen for both the coach and the minibus was based on the vertical component of a typical R-66 rollover test with the addition of a forward velocity component of 8.94 metres per second (20 mph) and secondly, 17.88 metres per second, to represent an overturned vehicle sliding on its' side.

A series of parametric studies were conducted using these two models. For the coach model, this indicated that toughened glass was unable to offer any retentive capability for the unrestrained occupant. It also demonstrated that 3-point seat belts were more effective than 2-point belts during the selected rollover condition. However, the results also indicated that consideration should be given to the installation and routing of the shoulder belt on the seats nearest to windows as this is outboard installations may be vulnerable to damage from the ground or other intrusion during rollover. The use of a seat side bolster, as a form of compartmentalisation for an unrestrained occupant, restricted the occupant from possible ejection but redirected the occupant into a severe head impact with the overhead luggage rack. For the minibus model, the results indicated that the occupants were not ejected but were subject to impacts with the interior of the vehicle.

The coach model was then used to explore a further series of parametric studies using a representation of laminated glass bonded to the vehicle rather than toughened glass mounted in a flexible gasket, as in the previous model. Prior to running these simulations, a model of the laminated glass and coach side structure was developed from the full coach model as a standalone test-rig. This was used to simulate an adult dummy falling within the vehicle onto the glass and side structure of a coach on its side. In addition, an identical full-scale test rig was developed and the drop test was repeated. The results of the full-scale test were used to validate the model of the glass and adhesive prior to installing them in the full coach model.

The results from applying laminated glass to the coach model under the chosen rollover condition was that the strength limits of the adhesive bond were always exceeded and this caused the window to be released from the structure. Thus, it was concluded that standard laminated glass which was adhesively bonded to the structure was insufficient to retain an unbelted occupant within the vehicle under the accident conditions simulated here. A series of modifications to improve the fixing strength of the window to the vehicle were attempted with the model but none of these proved successful. This was believed to be due to the deflection of the structure around the window during the impact. Ultimately, the inclusion of a bolting system as well as adhesive bonding preserved the bond but transferred the failure into the laminated glass around the bolts. On this basis, the use of standard laminated glass as a mandatory recommendation was not put forward. However, the results indicated that the voluntary use of laminated glass may be beneficial over toughened glass in rollover (and other) accidents where the impact severity was not as high as that used in the simulations conducted here. The parametric study also indicated that the reduced height of current window designs may also have some benefit in retaining an unrestrained occupant although it is likely that they will be redirected to an impact with some other object within the vehicle.

It was concluded that 3-point inertia reel seat belts remain the best option for preventing ejection and partial ejection. With the introduction of compulsory seat belt wearing in coaches and minibuses for all occupants over 3 years in 2006, the project concluded with the two following recommendations;

- That future coach and minibus accident data should be monitored following the introduction of compulsory seat belts wearing to measure the effect that this has on rollover ejection casualty numbers

- As part of the above, current ECE R-66 technical requirements should be reviewed with regard to the increased energy that passengers wearing seat belts will impart to a vehicle's structure during a rollover accident. If excessive roof crush is observed from accidents involving R-66 compliant vehicles (and where passengers wore their seat belts), it may be necessary to increase the energy and strength requirements of roof structures to resist increased roof loading from belted passengers.

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