MOTOR COACH GLAZING RETENTION TEST DEVELOPMENT FOR OCCUPANT IMPACT DURING A ROLLOVER

John Crocker, Ken MacKay, Simon Yang, Phil Rushton, Martec Limited

Ed Fournier, Matthew Keown, Michael Wonnacott, Biokinetics and Associates Ltd.

William Gardner, Transport Canada

ABSTRACT

This paper presents the work performed to develop a draft test procedure for glazing retention from unrestrained occupant impact during a motor coach rollover. Crash investigation reports from NTSB and TC were researched to identifying a rollover event most likely to produce the worst-case occupant/glazing loads. A numerical US-SID FE model was calibrated for impact load prediction based upon the results of experimental testing, and occupant/glazing impact loads were predicted from LS-DYNA simulations of the identified motor coach rollover event. Indirect glazing loads from bus torsion during rollover were also predicted. A motor coach glazing impact test procedure was developed and full-scale glazing impact load testing was performed on a bus section. A recommended procedure for impact testing of glazing was developed.

INTRODUCTION

Transport Canada (TC) and the US National Highway Traffic Safety Administration (NHTSA) have been conducting research on the dynamics of unrestrained occupants within the bus interior during a rollover event. More specifically, the interaction of passengers with window glazing was determined (by TC) as an area that required more extensive investigation to mitigate passenger injury during a rollover.

The overall study was initiated to gain an understanding of the loads generated between a coach passenger and the glazing during a rollover, and to use these loads in the development of a physical test to help coach manufactures design glazing that will not fail under these loads.

The objective of this work was to improve the level of safety protection of passengers in motor coach crashes by reducing the likelihood of being ejected during vehicle collision or rollover as such ejections are associated with a high probability of fatality. To this end, passive safety features such as structural window glazing and overall structural integrity must be optimized to withstand crash and occupant loading.

IDENTIFICATION OF ROLLOVER EVENT

NTSB (National Transportation Safety Board) and TC crash investigation reports (between 1980 and 2004) were reviewed to find the representative worst-case event for occupant/glazing impact loads. This review revealed that the most common scenario was where the bus yaws while trying to negotiate a turn and rolls over.. While slightly different from crash to crash, a broadside 90-degree rollover event was evident in many bus crashes.

The crash investigation report review also showed one crash as most likely to produce the worst indirect glazing loads to be encountered during a bus rollover. In this crash, the bus yawed and the side/rear of the bus crashed into a car before rolling. With the car impact loading the lower portion of the bus at one end only,the other end and upper part of the bus will maintain momentum and create a torsion load on the bus structure. The most important consideration in this type of event is whether or not this torsion effect will occur at the same time as the occupant impact with the glazing. If so, this was considered to be the most likely cause of indirect loading that could affect glazing integrity.

DETERMINATION OF OCCUPANT GLAZING IMPACT LOADS

DIRECT DUMMY LOAD ON GLAZING

Information was gathered on several numerical dummies for load prediction including the EuroSID, WorldSID, and US-SID. The EuroSID and/or WorldSID were considered to be the dummies most representative of the human body. However, the cost to obtain the EuroSID dummy was outside the project budget, and the WorldSID dummy was considered too complex for the required application. Since the primary output required from the numerical dummy was the contact force with the glazing and not the dummy response, it was considered that the US-SID would be suitable for this work. This numerical dummy was attainable from NHTSA.

US-SID Numerical Model Impact Load Verification

A verification test was performed to ensure that the numerical US-SID model predicted the same force time history from impacting a surface as a physical US-SID dummy. This was achieved by setting up an experimental drop test, performing a corresponding numerical analysis, comparing the results of the two, and modifying the numerical dummy to match the results of the physical dummy.

The physical drop test set-up for one configuration is shown in Figure 1, however, as shown in the figure, the test set-up included varying drop heights, dummy orientations, and plate thicknesses. Following completion of the physical drop test, a replication of the physical drop test was set up numerically within LS-Dyna [1]. The numerical US-SID model was then modified to produce impact load prediction similar to measured loads in the physical drop test. The set-up for one of the numerical analyses in LS-Dyna is shown in Figure 2.

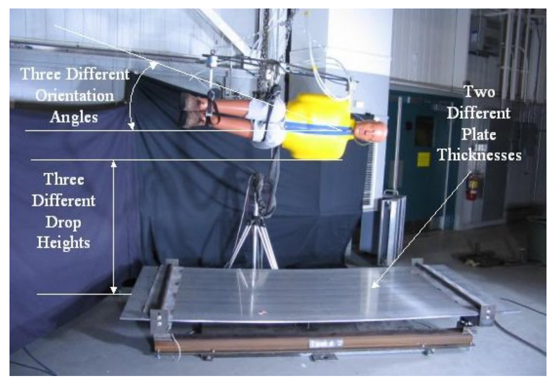


Figure 1. Test for US-SID Model Validation

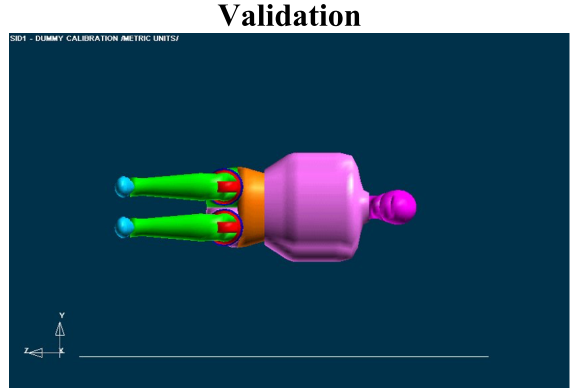


Figure 2. Numerical US-SID Set-up For LS-Dyna Drop Test

A comparison of the plate total reaction loads from the experimental and numerical drop tests is shown in Figure 3 for Test # 1. The results show very good agreement. A further comparison of all tests showed very good agreement

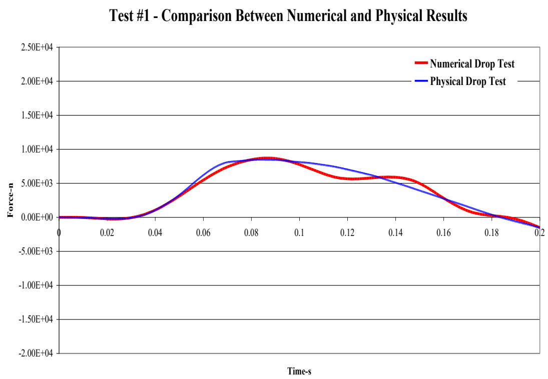


Figure 3. Comparison of Filtered Reactions for Physical and Numerical Drop Test # 1

Prediction of Dummy/Glazing Impact Load

The LS-Dyna numerical set-up of the rollover event with the calibrated US-SID is shown in Figure 4. The side rollover was executed at a yawing speed of 30 kph. The dummy impacting the glazing during the rollover is shown in Figure 5. A plot of the contact force versus time from the dummy impact with glazing is shown in Figure 6.

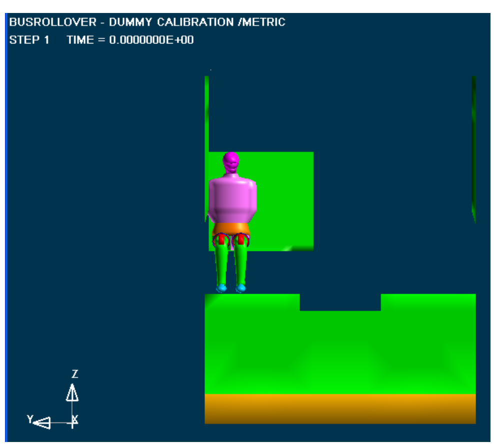


Figure 4. LS-Dyna Rollover Analysis Setup With Calibrated US-SID Dummy

Two distinct peaks are shown in the curve. As indicated in the plot, the first peak occurs when the head impacts the glazing and the second is when the shoulder/torso impacts. A filtered curve of the raw contact force data is also shown in this plot.

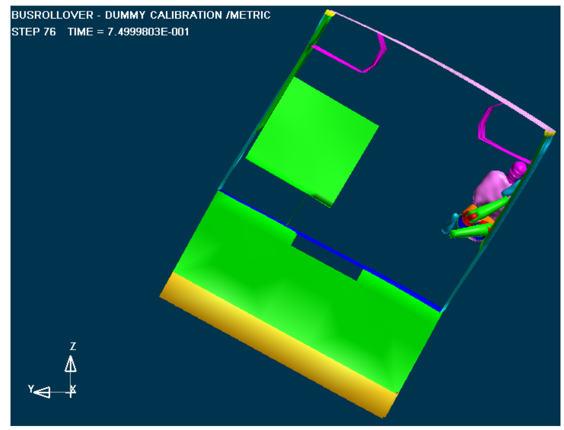


Figure 5. Point of Dummy/Glazing Contact During LS-Dyna Rollover Analysis

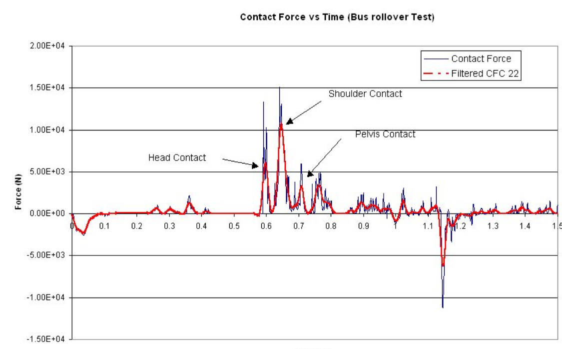


Figure 6. Dummy/Glazing Contact Force During LS-Dyna Rollover Analysis

INDIRECT LOADS ON GLAZING DURING ROLLOVER

An investigation was conducted to determine if glazing loads other than the direct dummy impact could potentially affect the glazing integrity. From the review of the NHTSA/NTSB documents, it was discovered that one type of rollover event could produce an additional "indirect" load on the glazing that occurs at the same time as the occupant impacts the glazing. This event was a bus crash where the bus yawed (similar to the events already studied), however, in this case, one end of the bus crashes into a car before rolling over.

To perform this rollover event, the FE model of the bus was expanded to full length as shown in Figure 7. The numerical representation of the actual crash event required applying a lateral velocity to the bus with the front end of the bus impacting the barrier. The barrier is also shown in Figure 7. The required velocity to achieve this was 50 kph.

The FE bus model had a representation that included window glazing that was rigidly attached to the window posts. This was overly conservative. Consequently, two analyses were performed in order to assess glazing stiffness effects. The first analysis had a rigid connection between the glazing and window frame. In the second analysis, the window glazing was effectively removed by decreasing the modulus of elasticity to a small value. This equates to an infinitely flexible connection between the glazing and window frame.

The position of the dummy at the time of glazing impact (during the rollover) is shown in Figure 8. This occurs at a time of approximately 0.26 seconds.

Curves showing the predicted torsional displacement versus time at the window frame with and without the glazing stiffness are shown in Figure 9.

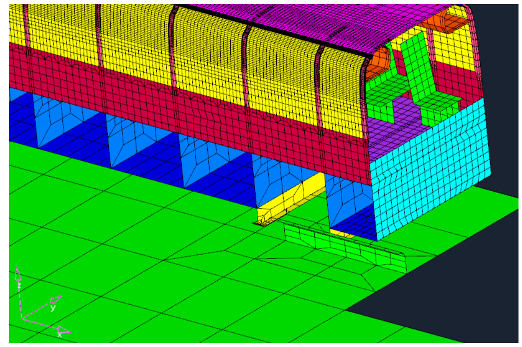


Figure 7: FE Model of Full Bus

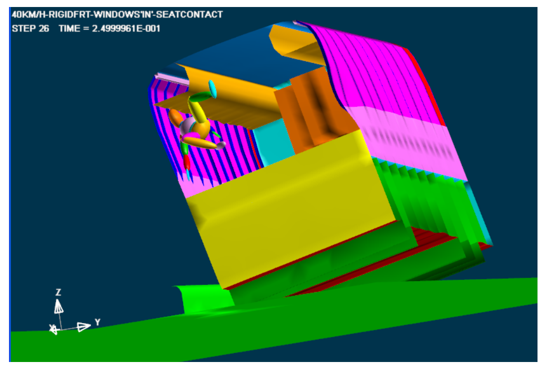
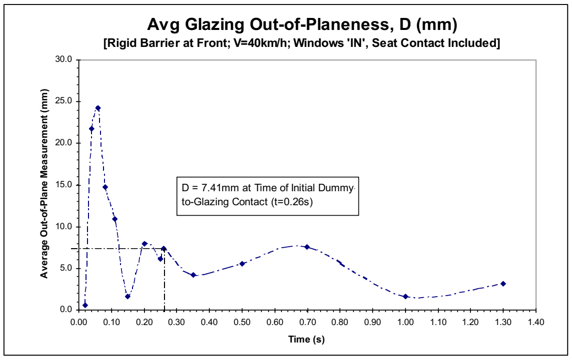


Figure 8: Dummy Position in Rollover Sequence from Indirect Load Event

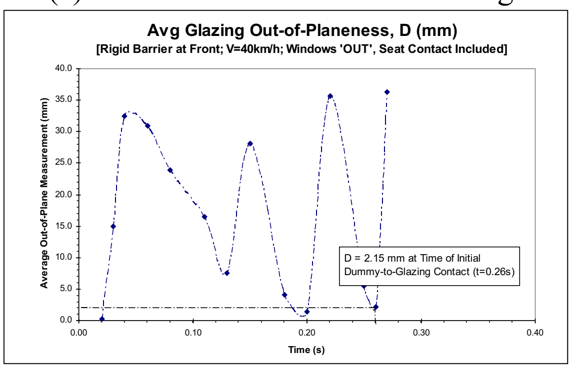
As shown in both of these curves, the maximum displacement occurs between 0.05 and 0.07 seconds. This is well before the dummy impact time of 0.26 seconds (as indicated in the plots). Consequently, at the time of dummy impact, the torsional effect is decreasing and the dummy impact does not occur at the maximum window torsion condition.

From these results, the most likely "low" torsion value was determined, from Figure 9(a), to be approximately 7 mm. The most likely "high" torsion value would be the peak displacement near the impact time of 0.26 s as determined from Figure 9(b). This is approximately 38 mm.

If this range of torsional deformation is applied in combination with the occupant impact load, the deformations and associated stress state at the glazing/ window frame will be more significant.



(a) Window Distortion with Glazing



(b) Window Distortion with No Glazing

Figure 9: Window Frame Distortion from Indirect Load Event

DEVELOPMENT OF GLAZING TEST PROCEDURE

Following the prediction of glazing loads from the calibrated numerical FE model, a series of tests were performed on an actual bus section before development of the draft test procedure. The details of the testing and the development of the test procedure are presented in the following sections.

TESTING OF GLAZING ON BUS SECTION

A series of tests were performed on a complete bus section containing glazing installed to factory specifications. This bus section was obtained from Prevost Car and represents a structural section of the H45 motor coach. A photo of the bus section is shown in Figure 10. This section of the bus contained the tubular structure around the window frame, and the components and adhesive holding the glazing in place. As shown, other structural members were used to represent the bus cross-section.

Figure 10: Motor Coach Section Used for Glazing Test

The purpose of this test was to impact the glazing with a force and impactor consistent with that used in the dummy/bus numerical analysis, and to perform a test on an actual bus section including glazing to show that the proposed test procedure can be accomplished.

The test set-up is shown in Figure 11. Pressurized air in the storage tank is released suddenly to activate the piston, which in turn drives the impacting rod toward the glazing. The impacting head, situated on the leading end of the rod, makes direct, flush contact with the glazing. The impacting head was designed to match the stiffness of the US SID impact interaction from the glazing simulations.

A series of tests were performed with the velocity at impact, the peak force, and maximum deflection measured for each test. An example of the glazing response to the impact load is shown in Figure 12. This shows the foam compressing under loading and the accompanying glazing deflection.

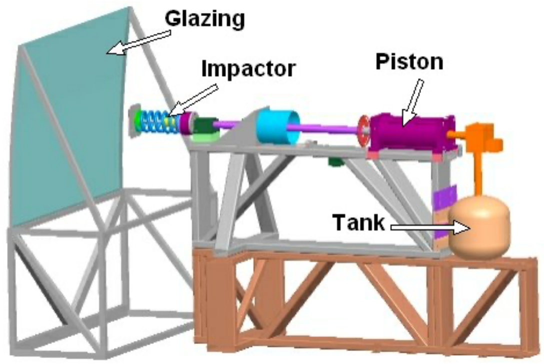


Figure 11: Motor Coach Glazing Test Setup

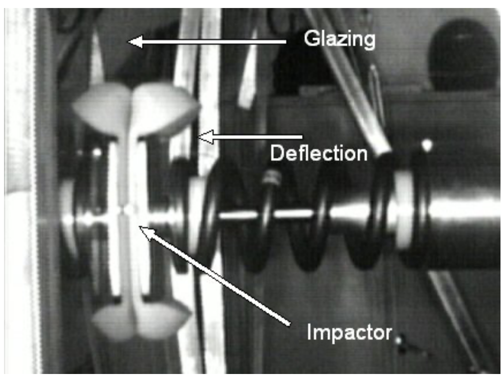
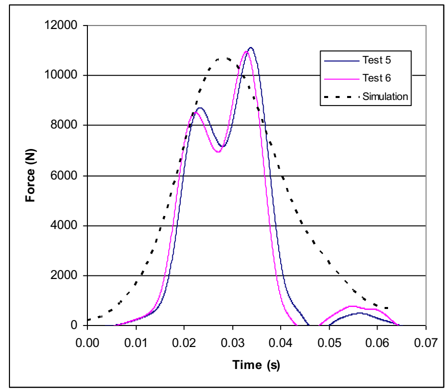


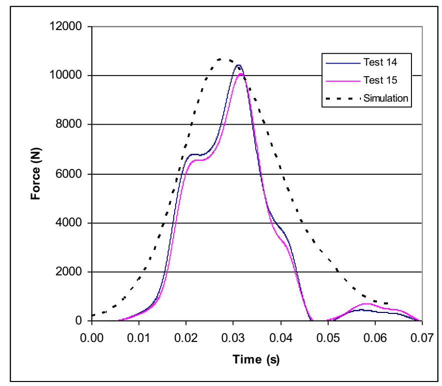
Figure 12: Example of Motor Coach Glazing Response

A comparison of the impact force time history between the numerical analysis and "Window 5 & 6", and "Window 14 & 15" of the experimental test is shown in Figure 13 a and b.

As shown in these plots, the FEA predicted impact loads match well with the experimentally measured loads. This close agreement provides further validation of the numerical model prediction of glazing impact forces and shows that the test set-up is a reasonable representation of the glazing impact by an occupant during a rollover.



(a) Test 5&6 - Higher Spring Stiffness



(b) Test 14&15 - Lower Spring Stiffness

Figure 13: Comparison of FEA and Test Impact Forces

The maximum impact force from the test was insufficient to break, eject or even damage the sample glazing. However, only one type of glazing was evaluated and it may be possible that even a moderate increase in severity could result in a glazing failure. Additionally, the same impact force used in the current work may be sufficient to cause damage in glazing of different size, material, configuration, or attachment method.

During testing, a configuration was exercised that introduced torsion on the support frame prior to impact. The amount of torsion was also based on results from the numerical simulation work. Under these test conditions, the pre-loaded frame did not result in any damage to the glazing and the test results were similar to the standard test configuration. The sample glazing, however, is only affixed at the top and bottom edges and it is possible that frame torsion would have a more significant effect on glazing that is bonded on all four edges.

DEVELOPMENT OF RECOMMENDED TEST PROCEDURE

Based upon the results of the numerical simulations and full scale glazing testing, a recommended test methodology for evaluating the impact resistance of motor coach glazing was developed.

The test equipment for testing motor coach glazing comprises two main components. The first is an impact anvil and the second is the mechanism for propelling the anvil at a motor coach glazing installation. The test equipment must meet the following requirements:

i. Be actuated by air or any other means and must be capable of propelling the impact anvil in a linear direction at the specified impact speed.
ii. Be constrained to linear motion throughout the test.
iii. The mechanism for propelling the impact anvil must disengage prior to anvil contact with the glazing.
iv. The test equipment shall be capable of achieving an impact speed of 6.0±0.1 m/s.
v. The test equipment must have a stroke length that permits a minimum of 100 mm of stroke beyond the original point of impact.
vi. The total mass of the impact anvil shall be 25.9±1 kg. The shape of the impact anvil face shall conform to the specifications defined in the test procedure.
vii. One shoulder foam part from the US-SID as described by FMVSS Part 572 Subpart M shall be affixed to the impact face using double-sided tape.

CONCLUSIONS AND RECOMMENDATIONS

While a method for evaluating glazing strength was established by the current test series, additional testing is recommended before a complete standard can be produced. Glazing from different manufacturers should be tested to further evaluate the peak load requirements. Testing of fully bonded glazing would provide a better understanding of the effects of frame torsion. Data from additional testing would also supply further support to show that the proposed impact is suitably representative of occupant loading. Glazing with latches, like in an emergency window, should also be tested.

ACKNOWLEDGEMENTS

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REFERENCES

1. LS-DYNA version 970, 2004, Livermore Software Technology Corporation, Livermore, California, USA.