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Motorcoach Side Glazing Retention Research

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16. Abstract

In 2003, NHTSA and Transport Canada entered into a joint research program conducted by Martec Limited that focused on preventing unrestrained occupant ejections during motorcoach rollovers by improving standard window glazing and retention. Through computer simulation the Martec study (MS) determined that the impact velocity of an occupant striking the glazing was as much as 21.6 km/h (13.4 mph). Results from this research aided in the development of a dynamic test device of 26 kg (57 lb) mass that represents the torso of the 50th percentile adult male side impact dummy (US-SID).

A section of a Motor Coach Industries (MCI) 1993 102D motorcoach was used by the Vehicle Research and Test Center (VRTC) to conduct impact tests at the center of the window and near the latch at different impact speeds. In center impacts, no windows with tempered glass broke and no windows opened under the MS impact conditions (26 kg at 21.6 km/h). In near-latch impacts, all latches opened when struck at the MS conditions.

Testing was expanded to other motorcoach manufacturers and coach series to establish fleet baseline performance. Market share studies indicated that the fleet was well represented by conducting tests on a Prevost model H3-45, Van Hool model C2045, and MCI E/J-series, in addition to the MCI D-series line. Testing was conducted on glazing mounted to test frames that represented the side passenger window frames for each of the three manufacturers. Windows from all three manufacturers exhibited latch openings in near-latch tests on production latches at MS conditions.

An attempt was made to modify the latch systems with simple designs to see if the impactor could be contained when tested at the MS conditions. In near-latch tests on countermeasure latches at MS conditions, the MCI E/J-series latches required the simplest modification to improve its performance. The MCI E/J-series countermeasure latch and glass remained intact. However, no simple countermeasures were identified for the Van Hool and Prevost latches.

A study was conducted and a test procedure developed to address the glazing strength in the event the window is broken in a rollover crash prior to occupant loading.

A series of tests was performed on fixed windows from the MCI E/J-series to determine their performance under MS conditions. Tests near the retaining clips on unbroken glazing produced partial window openings. For tests conducted at the center of the daylight opening, the unbroken single-glazed window opened, but neither the unbroken or pre-broken double-glazed windows opened.

Finally, a series of tests was conducted to compare the setups of the MCI D-series bus section tests and window frame tests. Determining the relative stringency of the two test methods was inconclusive. In five comparison tests, the event of window opening or remaining closed was similar. Also, the peak forces from the frame tests were higher than those from the bus section tests, but there was no clear trend for the peak excursion measurements.

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Executive Summary

In 2003, NHTSA and Transport Canada entered into a joint research program conducted by Martec Limited, which focused on preventing unrestrained occupant ejections during motorcoach rollovers by improving standard window glazing and retention. Computer simulation established the occupant forces exerted on the motorcoach window during a motorcoach side rollover, with an occupant on one side of the bus impacting the glazing on the opposite side of the bus. The Martec study determined that the impact velocity of an occupant striking the glazing was as much as 21.6 km/h.

Results from this research aided in the development of a dynamic test device that represents the torso of the 50th percentile adult male side impact dummy (US-SID) to evaluate the effectiveness of glazing materials and bonding techniques in preventing ejections. The impactor design consisted of a 26 kg mass guided through a nylon bearing attached to two supporting rails. A spring with a stiffness of 258 N/mm was used to replicate the compression of the thorax. The impactor face consisted of a rectangle with rounded corners measuring 177 mm x 212 mm. A shoulder foam part from the US-SID was affixed to the impactor face to replicate the compression of the foam located beneath the dummy's chest jacket.

A section of a Motor Coach Industries (MCI) 1993 102D motorcoach was purchased from MCI by the Vehicle Research and Test Center (VRTC). Side window candidates were selected to evaluate a range of glazing and bonding characteristics on preventing ejection. The single-glazed windows included glazing similar to conventional windshields, where a plastic polyvinyl butyral (PVB) film is laminated between two glass plies. Windows with monolithic tempered glass and rigid plastic (acrylic and polycarbonate) panes were also tested. The second construction was a double-glazed design where two panes of laminated and tempered glazing are separated by a space of air. Two adhesive methods used to bond the glazing material to the window frame were evaluated, glue and rubber.

Impact tests were conducted at the center of the window and near the latch at different impact speeds. In center impacts, rubber mounted windows produced lower forces and higher displacements. Windows with tempered glass produced higher forces than those with laminated glass. Polycarbonate windows produced lower forces and higher displacements compared to similar windows with single-glazed glass. Acrylic windows produced lower forces compared to most other compositions. Windows with greater PVB thickness produced reduced excursions. No windows with tempered glass broke, and no windows opened under the Martec study impact conditions (26 kg at 21.6 km/h) in center impacts. In near-latch impacts, all latches opened when impacted at the Martec study conditions.

The testing was then expanded to other motorcoach manufacturers and coach series to establish fleet baseline performance. Market share studies indicated that the fleet was well represented by conducting tests on a Prevost model H3-45, Van Hool model C2045, and MCI E/J-series, in addition to the MCI D-series line. Testing was conducted on glazing mounted to test frames that represented the side passenger window frame for each of the three manufacturers. MCI was the only manufacturer offering laminated glass in their window designs.

Windows from all three manufacturers exhibited latch openings in near-latch tests on production latches at Martec study conditions. Van Hool exhibited latch opening in the 9 – 10 km/h range, Prevost exhibited latch opening in the 11 – 12 km/h range, and MCI E/J-series exhibited latch opening in the 18

– 21 km/h range. In the center-of-daylight opening tests on production latches at the Martec study conditions, the Van Hool latches opened, producing window opening, and the exterior tempered pane shattered. The Prevost latches opened, producing window opening with the tempered glass panes remaining intact.

An attempt was made to modify the latch systems with simple designs to see if the impactor could be contained when tested at the Martec study conditions.

In near-latch tests on countermeasure latches at Martec study conditions, the MCI E/J-series latches required the simplest modification to improve its performance. The MCI E/J-series countermeasure latch and glass remained intact. The Van Hool primary countermeasure latch opened, but the secondary latch did not. Only a partial window opening occurred, as the tempered glass remained intact. Failure occurred due to shearing of the bolts holding the slider mechanism to the reinforcing bar. The production Prevost latch had three failure modes: striker post fracture, plastic locator tab shearing, and latch bar fracture. Only the latch post and locator tabs could be modified by VRTC. The Prevost countermeasure latch opened due to fracture of the latch bar. The modified striker post and locator tabs did not fail, and the tempered glass panes remained intact.

In the center-of-daylight opening tests on countermeasure latches at Martec study conditions, the MCI E/J-series latches remained intact, and the laminated inside pane broke. The Van Hool latches remained intact, and the tempered glass panes shattered. While the Prevost latches remained intact, the Prevost window bowed outward during impact, but the tempered glass panes did not break.

A study was initiated to address the glazing strength in case the window is pre-broken prior to occupant loading in a rollover. The goal was to develop a procedure for breaking the glass prior to impacting the window. The pre-broken windows were then tested at the Martec study conditions to compare impactor excursion values.

Various methods were used to break the advanced glazing prior to the impact tests. These methods included an impact with a hammer (pummeled), as well as several patterns of breakage using an automatic center punch and an electric staple gun. The patterns included punching holes in both the interior and exterior sides of the laminated glazing with the holes spaced a known distance apart. Grids with 50 mm and 75 mm spacing were used in the study.

Center-of-daylight opening impacts at the Martec study conditions into fully pummeled production glazing from MCI resulted in an average maximum excursion of 214 mm. The 50 mm diagonally offset breakage pattern produced an average maximum excursion of 184 mm (86% of fully pummeled). The 75 mm diagonally offset breakage pattern produced an average maximum excursion of 175 mm (82% of fully pummeled). The 75 mm horizontally offset breakage pattern used in FMVSS No. 226 produced an average maximum excursion of 151 mm (71% of fully pummeled). Center-of-daylight opening impacts (Martec study conditions) into pre-broken glazing with a 100-percent thicker PVB interlayer produced maximum excursions that were 13 percent less than similar impacts into the pre-broken production glazing. These results are specific to the type of window used in the testing (from MCI).

A series of tests was performed on fixed windows from the MCI E/J-series to determine their performance under the Martec study conditions. For tests conducted on unbroken glazing near the retaining clip, the primary clips (near the impact location) bent backwards. The secondary clips (the non-impacted retaining clips) bent but did not release, allowing the window to only partially open. For tests conducted at the center of the daylight opening on unbroken glazing, the retaining clips bent, but the window opening result depended on the type of glazing impacted. The single-glazed window fully opened, but the double-glazed window did not open. For tests conducted at the center of the daylight opening on pre-broken double-glazed windows, there was no damage to the retaining clips, and the windows did not open.

Finally, a series of tests was conducted to compare the setups of the MCI D-series bus section tests and window frame tests, to determine whether the frame tests are more or less stringent than the bus section tests. For this comparison, the deflections of the bus section and frame during impacts were measured. Results showed that the frame flexes more initially and has a shorter period of vibration than the bus section. Determining the relative stringency of the two test methods was inconclusive. In five comparison tests, the event of window opening or remaining closed was similar. Also, the peak forces from the frame tests were higher than those from the bus section tests, but there was no clear trend for the peak excursion measurements.

1. Introduction

Rollovers cause 63 percent of motorcoach occupant fatalities due to partial or full ejections through side windows because of windows opening or glazing failures.[1] On average, nine occupants per year are ejected through windows. To improve occupant protection, the National Highway Traffic Safety Administration studied how to reduce the risk of passenger ejection through improved rollover structural integrity, seat belt restraint requirements, and anti-ejection safety countermeasures. The agency has proposed requirements for seat belts on motorcoaches, however there remains a need to assess the window latch design and glazing retention of current production windows during a motorcoach rollover event.

1.1. Background

In 2003, NHTSA and Transport Canada entered into a joint research program that was conducted by Martec Limited (subsequently referred to as the Martec study), which focused on preventing unrestrained occupant ejections during motorcoach rollovers by improving standard window glazing and retention. Results from this research established the occupant forces exerted on the motorcoach window during rollover events, which aided in the development of a dynamic test device to evaluate the effectiveness of glazing materials and bonding techniques in preventing ejections.[2]

Using a numerical analysis of a motorcoach rollover, the Martec study determined that the impact velocity of an occupant striking the glazing was as much as 21.6 km/h. A 50th percentile adult male US-SID was used to determine peak loading and duration under this worst case scenario. The US-SID was seated on the far side and fell with its head making first contact on the glazing, followed closely by its shoulder/torso (shown in Figure 1.1). The largest load on the glazing came from the torso impact and was subsequently used as the target load/load profile in the dynamic impact test device development. The details of this process are described below.

[1] FARS 2002-2011: All fatalities by bus type and events for buses with GVWR > 26,000 lbs.
[2] Martec Limited. (2006, August). "Motorcoach Glazing Retention Test Development for Occupant Impact During a Rollover." Docket No. NHTSA-2002-11876. Washington, DC: National Highway Traffic Safety Administration.

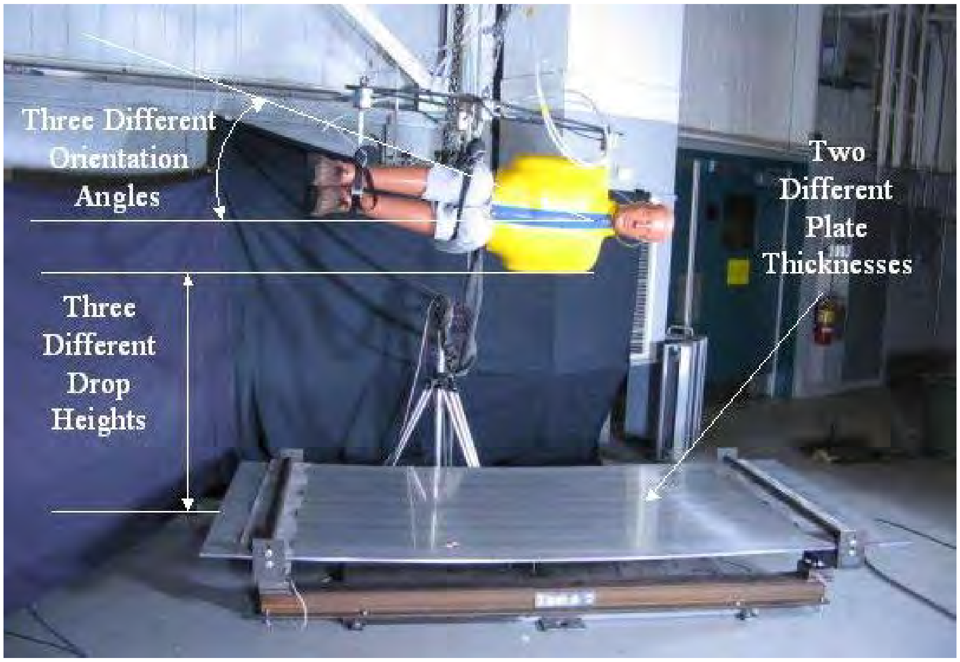

Figure 1.1 Drop Test for US-SID Model Validation

An LS-DYNA finite element model (FEM) of the US-SID was calibrated to the physical dummy through comparison of the plate reactions at the four corners and used to predict loads by comparing simulated drop tests with the physical US-SID dummy drop tests (shown in Figure 1.2).

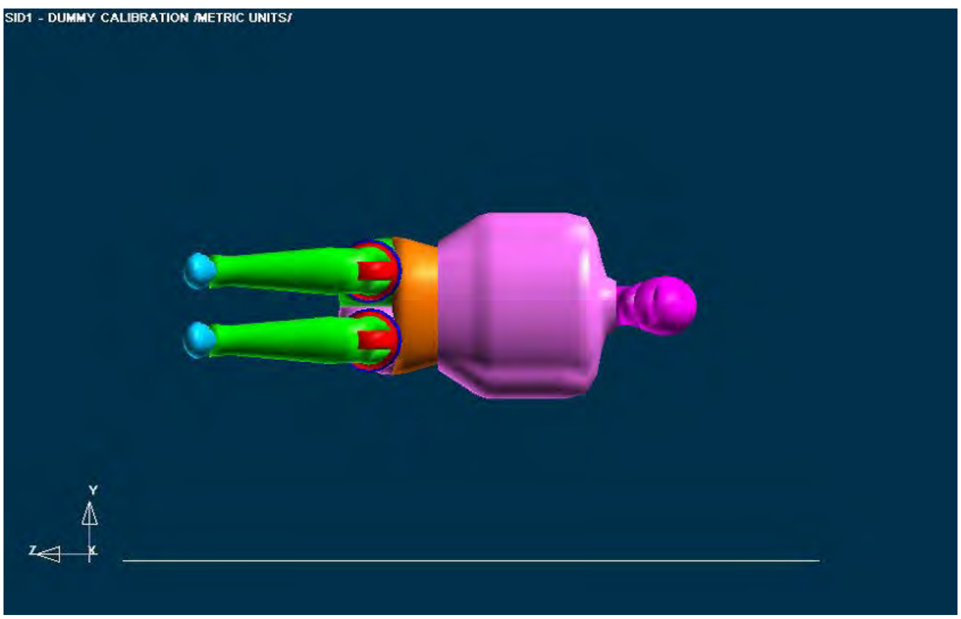

Figure 1.2 FEM of US-SID Setup for LS-DYNA Drop Test

Using the calibrated US-SID model, the direct load on the window was predicted for an occupant seated on the far side during a 90-degree rollover with a lateral speed of 30 kph. The simulation produced a dummy impact velocity of 21.6 km/h (Figure 1.3).

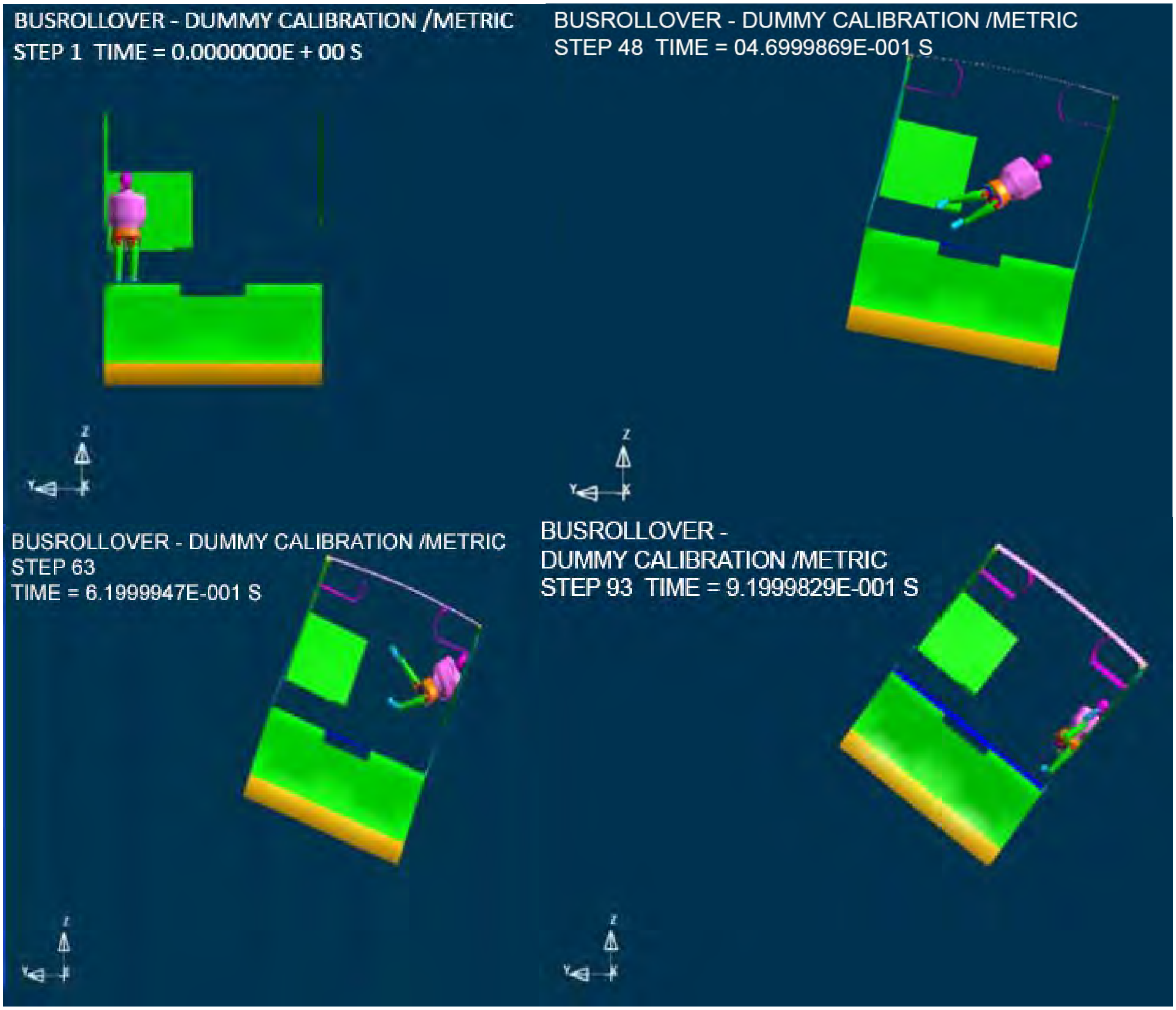

Figure 1.3 Dummy Motion During LS-DYNA Rollover Analysis of 90-Deg Roll With a 30 kph Lateral Speed

Indirect window loads from the twisting of the bus under yaw were also simulated using a FEM of the full bus. The front of the bus was stopped abruptly, similar to an impact into a car or fixed object, while the rear of the bus swung around and produced a yawing motion which led to the roll. The sequence is shown in Figure 1.4. A dummy seated near the front of the bus, on the far side, struck the window area as shown in Figure 1.5.

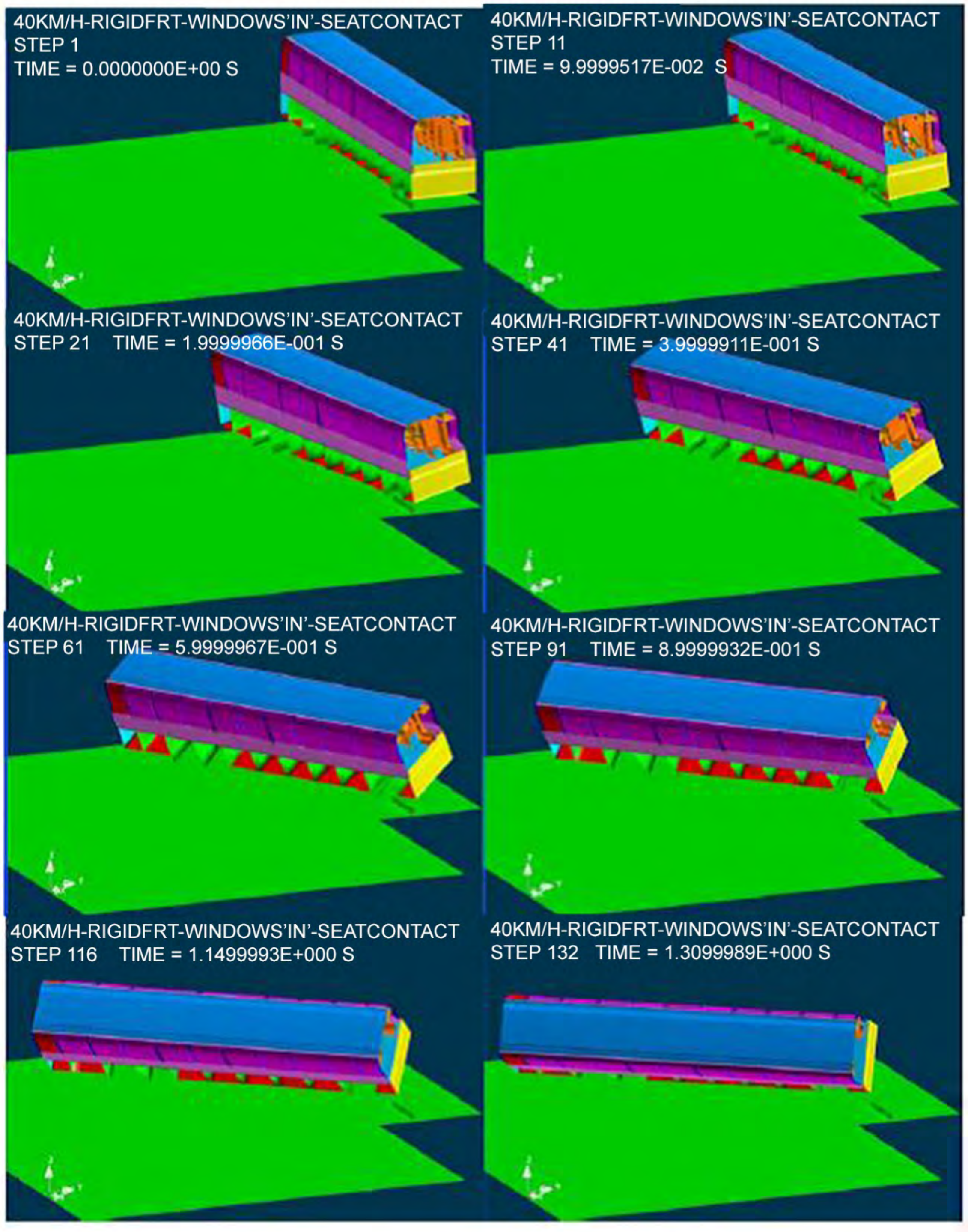

Figure 1.4 Rollover Sequence From Indirect Load Event

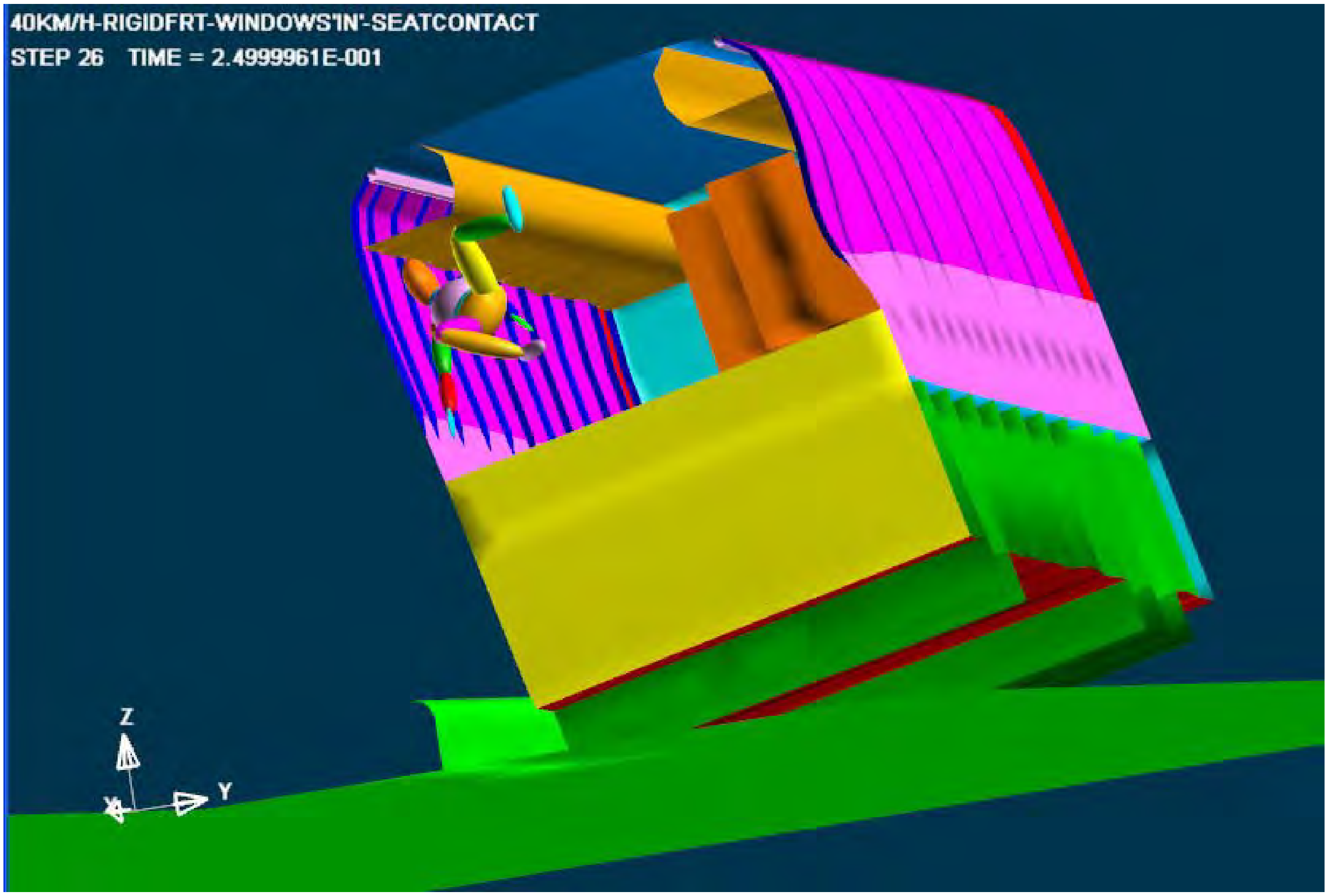

Figure 1.5 Dummy Position in Rollover Caused by Yaw Event

The full bus simulation showed that the maximum deformation of the glazing caused by torsion of the bus occurred between 0.05 and 0.07 sec, which was well before the dummy impact at 0.26 seconds. Based on this information, the effect of bus torsion was not considered in designing the impactor test procedure.

Consequently, an impact test was developed which represented direct loading from the upper torso of a US-SID striking the window at 21.6 km/h. The physical drop tests in the Martec study determined the effective mass of the upper torso to be 28 kg and the spring stiffness to be 330 N/mm. A spring with a lower stiffness (258 N/mm) was eventually chosen to match the force-time history calculated in the computer simulations, which resulted in a decrease in overall mass to 26 kg.

A dynamic impact device was built that represented the torso of the US-SID dummy, and an initial test procedure was developed for testing motorcoach side windows for retention strength. In the Martec study, only limited testing was performed in a test fixture representing a motorcoach side window structure with one glazing composition that was fixed to the top and bottom. No testing was done to determine the variability or repeatability of the test procedure. Also, no testing was done to establish the motorcoach fleet performance. The study recommended that further simulation and testing be performed using other configurations (different glazing types, such as laminated glass and polycarbonates, and mechanical latching methods) common in the bus industry before finalizing a test procedure. The Martec study concluded that considerable more effort was needed to establish baseline motorcoach fleet performance, determine the effect of motorcoach structural integrity on window retention and emergency egress, and identify potential improvements for window retention purposes.

1.2. Objectives

The objectives of this study were: (1) to develop a test procedure to assess glazing retention of current production designs from occupant impact loading during a motorcoach rollover, (2) to explore countermeasures for current window latches that open during such impacts, and (3) to develop test procedures to assess the occupant retention provided by current and advanced glazing materials for emergency exit and fixed side windows.

2. Test Apparatus and Instrumentation

2.1. Motorcoach Section Description

A section of an MCI 1993 102D motorcoach was purchased from MCI by the Vehicle Research and Test Center. The section, shown in Figure 2.1 consisted of the middle three windows and was 5 meters long. Square steel tubing was attached to the open ends for increased rigidity and additional bracing was applied internally to stiffen the motorcoach section as seen in Figure 2.2.

Figure 2.1 MCI D-Series Motorcoach Section

Figure 2.2 Internal Bracing Added to Stiffen Motorcoach Section

Glazing installation was performed by first forcibly pressing the window frame into the bus structure's opening. An interior aluminum clamp ring secured the window frame to the bus structure by metal fasteners as shown in Figure 2.3. The latching mechanism, referred to as a crash bar, is shown in Figure 2 4. The crash bar has two areas, known as crash bar keepers, which provide the latching forces. The various glazings were installed in as repeatable a manner as possible.

Figure 2.3 MCI D-Series Glazing Installation

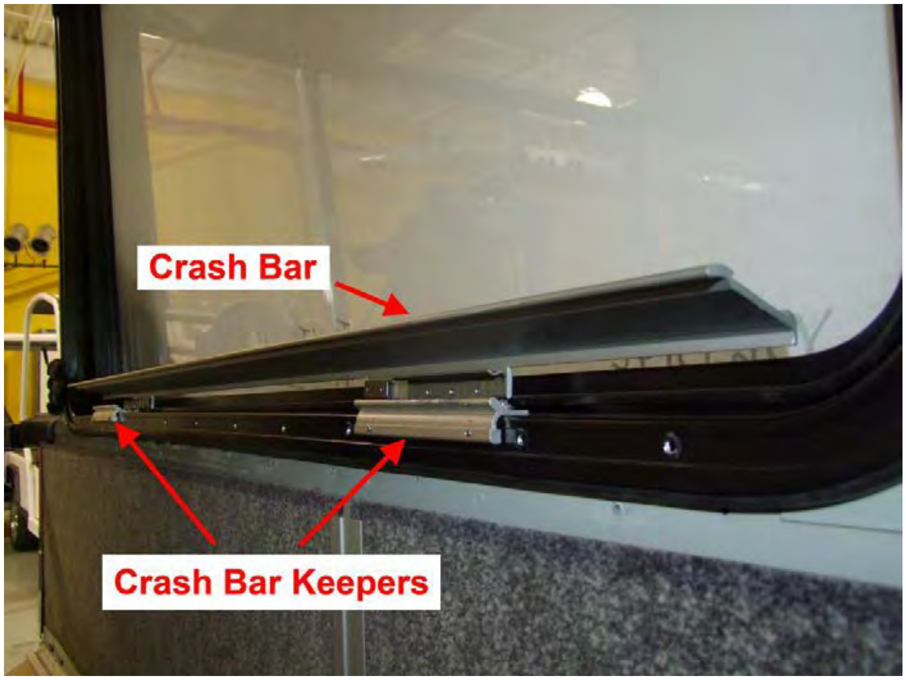

Figure 2.4 MCI D-Series Crash Bar and Keepers

2.2. Side Window Candidates

The side window candidates were selected to evaluate a range of glazing and bonding characteristics on containment capabilities and occupant injury mitigation.

The glazings used in this test series, which measured approximately 1.5 m by 1.0 m, incorporated two general material constructions. The first construction consisted of a single-glazed design. The single-glazed windows included two candidates similar to conventional windshields, where a plastic film is laminated between two glass plies, monolithic tempered glass, and rigid plastic (acrylic and polycarbonate). The second construction was a double-glazed design where two panes of glazing are separated by a space of air. Various combinations of laminated and tempered glass in the double-glazed configuration were tested including MCI production windows 3L-27-107 and 3L-27-133.

Two adhesive methods used to bond the glazing material to the window frame were evaluated: glue and rubber. The combination of different glazing constructions and bonding techniques produced 11 test candidates. The glazing candidates are shown in Figure 2.5 through Figure 2.15.

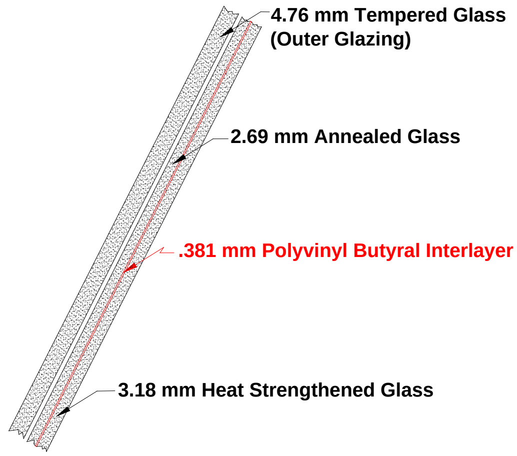

Figure 2.5 Double-Glazed - Tempered Outboard/Laminated Inboard - Glue Bonded (Candidate 03-27-1474)

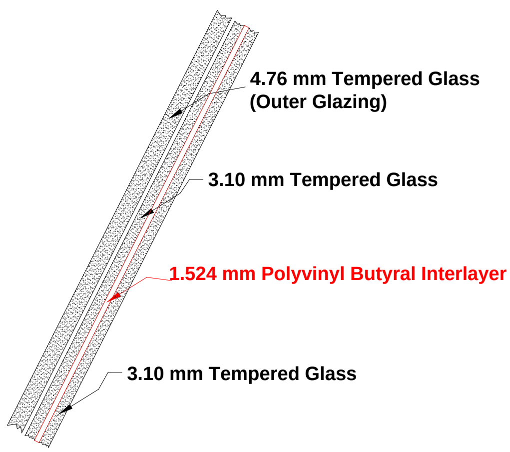

Figure 2.6 Double-Glazed –Tempered Outboard/Laminated Inboard – Glue Bonded (Candidate V369SP-TTL060)

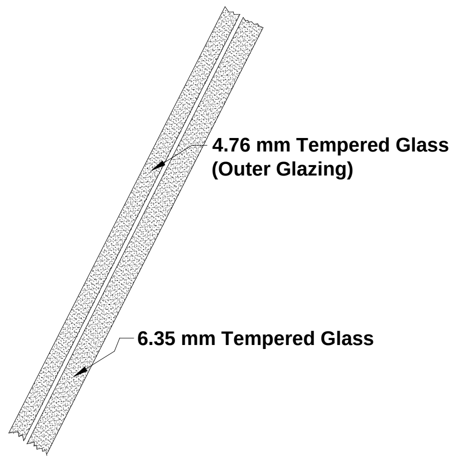

Figure 2.7 Double-Glazed – Tempered Outboard/Tempered Inboard – Glue Bonded (Candidate V369L4)

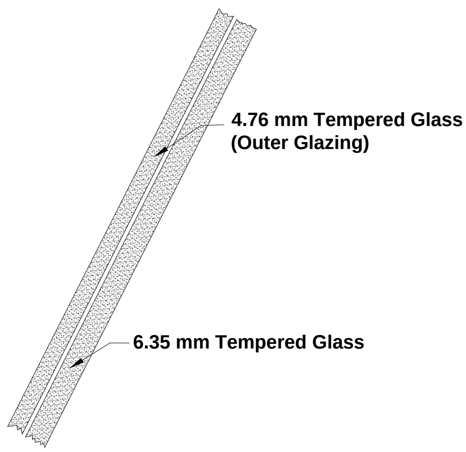

Figure 2.8 Double-Glazed – Tempered Outboard/Tempered Inboard – Rubber Bonded (Candidate T868-L4)

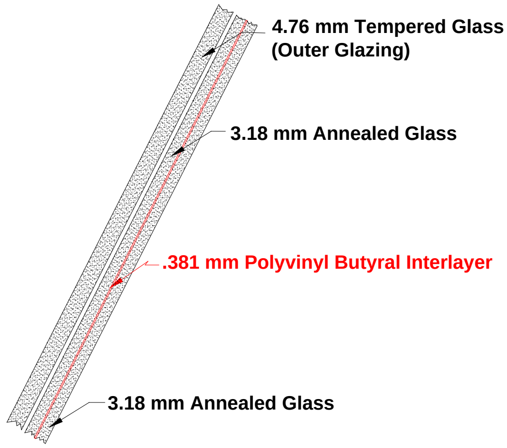

Figure 2.9 Double-Glazed - Tempered Outboard/Laminated Inboard - Rubber Bonded (Candidate 3L-27-107)

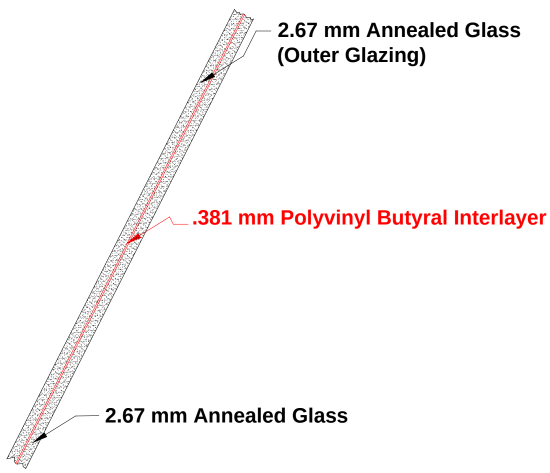

Figure 2.10 Single-Glazed Laminated Glass -Rubber Bonded (Candidate 3L-27-133)

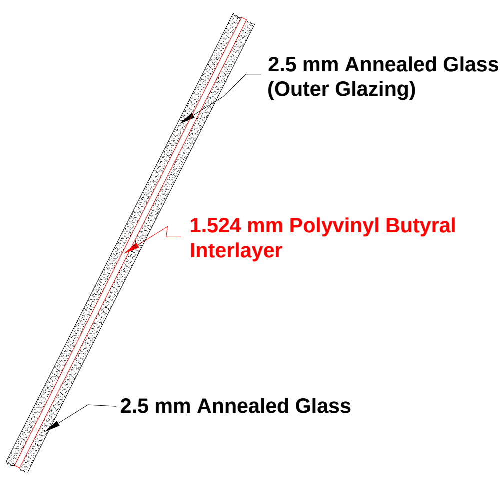

Figure 2.11 Single-Glazed Laminated Glass - Glue Bonded (Candidate V369SP-LM)

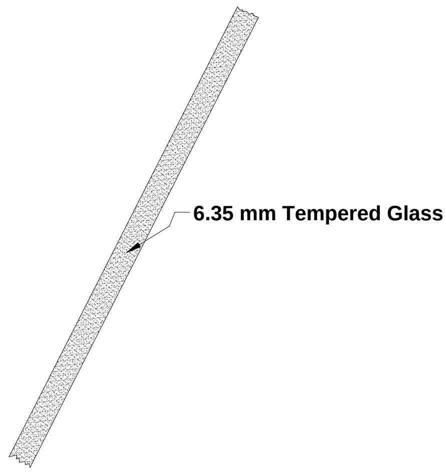

Figure 2.12 Single-Glazed Tempered Glass – Rubber Bonded (Candidate T822G2)

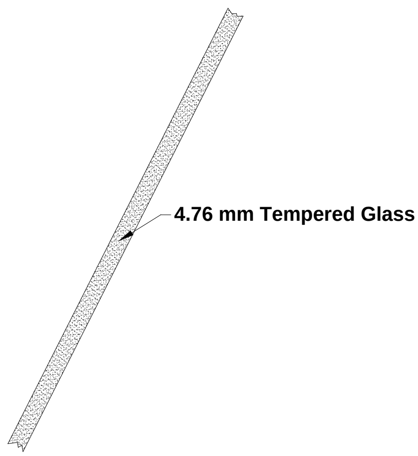

Figure 2.13 Single-Glazed –Tempered Glass – Glue Bonded (Candidate V36SP-SG)

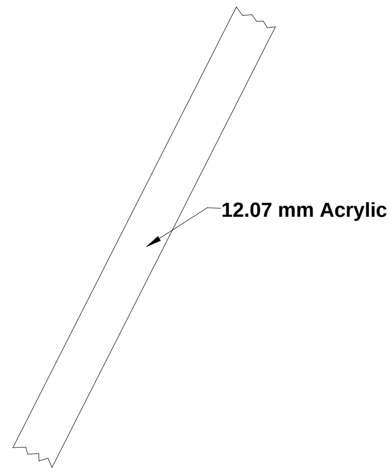

Figure 2.14 Single-Glazed – Acrylic – Rubber Bonded (Candidate 37-27-136)

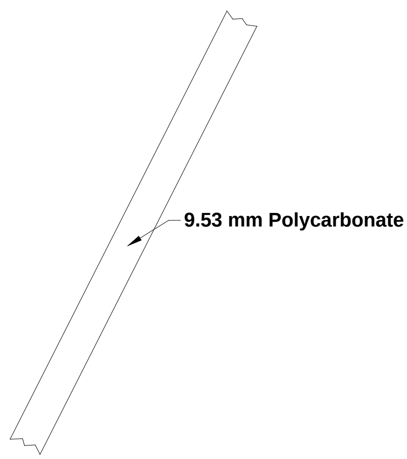

Figure 2.15 Single-Glazed Polycarbonate – Glue Bonded (Candidate V369SP-PC)

2.3. Impactor Description

A component impactor test was used to evaluate the motorcoach emergency egress side glazing retention capability. The pneumatic impactor, shown in Figure 2.16, was originally designed in NHTSA's Ejection Mitigation research program. The featureless rigid headform was replaced with the impactor anvil developed in the Martec study. The propulsion unit was based on a device by the General Motors Corporation,[3] scaled to accommodate a heavier mass. Pressurized nitrogen pushed a piston which drove an impacting rod guided through a nylon bearing. The impactor was attached to the rod and could be placed inside the bus section for testing the side windows at various locations. It was instrumented with a linear potentiometer and piezoelectric transducer to measure displacement and force. Only uniaxial motion was measured because the impactor was guided. Impact velocity was

[3] Griswold, C. J. (1982). "Side Impact Component Test Development." Presented at the 9th International Technical Conference of Experimental Safety Vehicles, Kyoto, Japan, November 1982.

measured by an optical sensor that recorded the time a beam of light was interrupted when a “flag,” attached to the impactor rod, passed through it.

Figure 2.16 26 Kg Guided Linear Impactor

The impactor was designed to replicate the loading (mass and stiffness) that a 50th percentile US-SID’s upper torso exerted on the side window during a rollover event modeled in computer simulations. The impactor design consisted of the 26 kg (57 lb) mass guided through a nylon bearing attached to two supporting rails. A spring with a stiffness of 258 N/mm was used to replicate the compression of the thorax. The impactor face, shown in Figure 2.17 approximates the contact area between the US-SID’s shoulder and glazing estimated in the computer simulations. The impactor face consisted of a rectangle with rounded corners measuring 177 mm x 212 mm. A shoulder foam part from the US-SID was affixed to the impactor face to replicate the compression of the foam located beneath the dummy’s chest jacket.

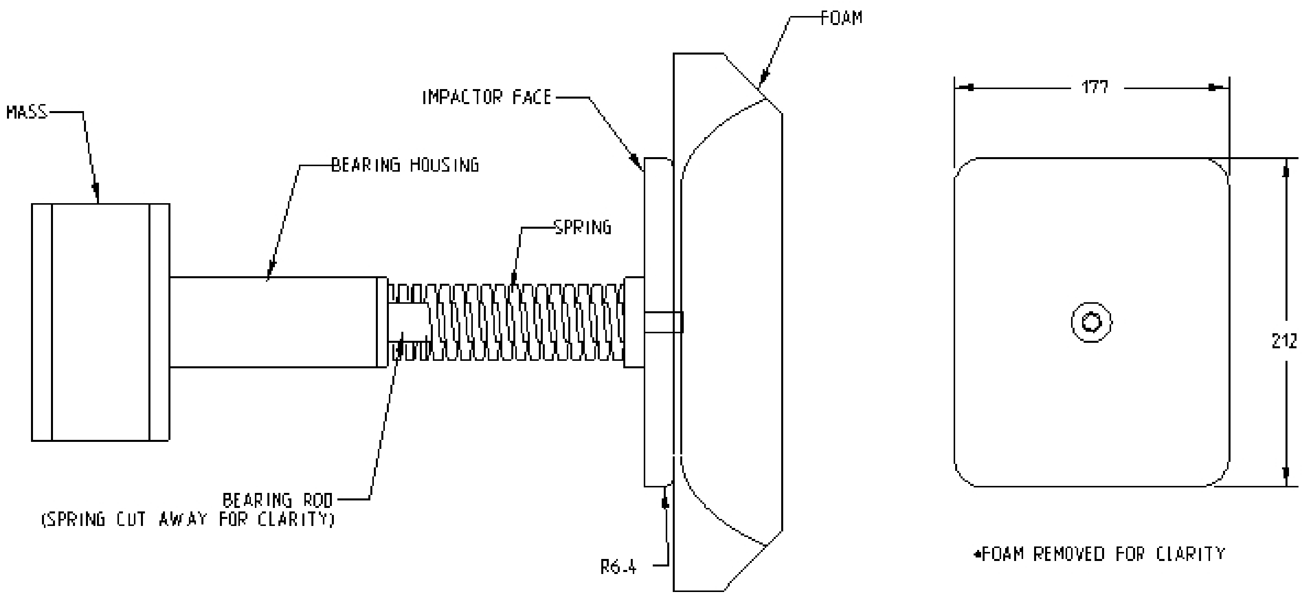

Figure 2.17 Impact Anvil Details

3. Center Window Testing on Motorcoach Section

3.1. Methods and Results

A series of tests using the 26 kg impactor was conducted on the 11 glazing candidates to determine their retention characteristics. The impactor was positioned perpendicular to the bus section's middle window and aligned with the glazing's geometric center as shown in Figure 3.1. The impact velocity was 21.6 km/h based on the speed obtained in the Martec study simulations. Data from the force and displacement transducers were captured with a data acquisition system sampling at 20,000 Hz. A single-axis, piezoelectric load cell was installed behind the face plate, and the force data was filtered at channel frequency class (CFC) 60. The linear potentiometer recorded the impactor face displacement measured from first contact of the impactor face plate with the glazing through maximum dynamic displacement. This measurement was a combination of both the glazing material and window frame deflection. The face plate was chosen because no glazing or frame displacement was observed until the foam was fully compressed.

Photographs were taken to document the test set-up and post-test observations. High-speed video was used to capture the impact during each test. The video was focused on the interior side of the glazing at the point of impact and along the exterior longitudinal axis.

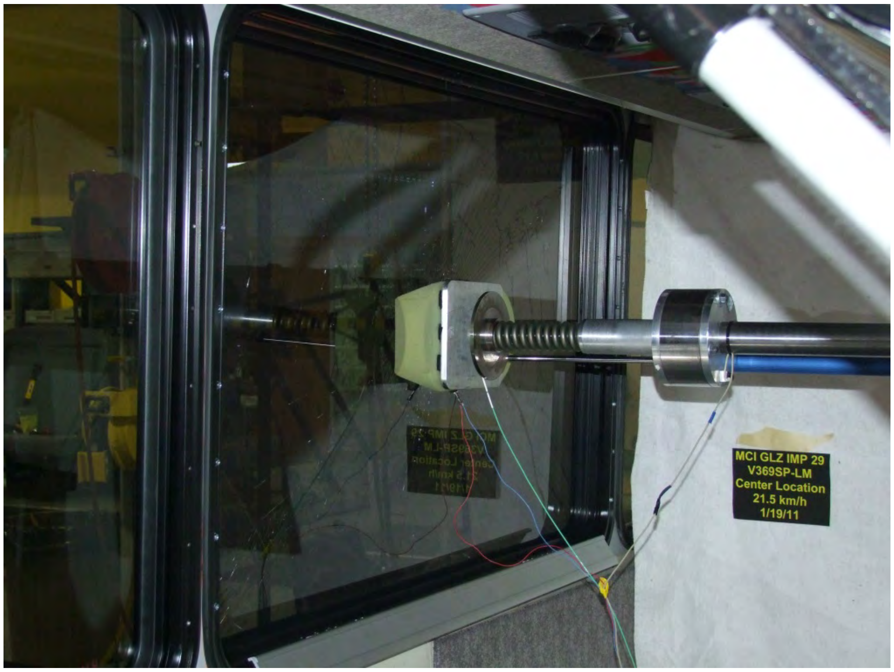

Figure 3.1 Impactor Positioned for Center Impacts

The results for this test series are shown in Table 3.1 and note whether the glass broke due to impact. “Interior Glass Pane” refers to the pane adjacent to the bus interior. “NA” (Not Applicable) was recorded in the column headed with “Exterior Glass Pane” for single-glazed candidates. Later in the test series, the forces needed to unlatch the latch bar and push the unlatched window out a given distance were recorded. These forces were obtained using a Chatillon mechanical force gauge as shown in Figure 3.2. To measure the unlatching force, the force gauge was positioned at the mid-point of the latch bar and pulled vertically upward. The device was then positioned on the midpoint of the glazing, 25 mm above the bonding material, and pushed horizontally to measure the window opening force. These forces were recorded as a measure of the repeatability of the window installation on to the bus body section.

Table 3.1 Glazing Retention Testing With 26 Kg Impactor

TEST NO.	GLAZING PART NO.	GLAZING CONFIGURATION (FRAME BONDING METHOD)	ACTUAL IMPACT VELOCITY (km/h)	PEAK FORCE (N)	PEAK IMPACTOR FACE EXCURSION (mm)	INTERIOR GLASS PANE BROKEN	EXTERIOR GLASS PANE BROKEN	LATCH OPENED	UNLATCHING FORCE (N)	WINDOW OPENING FORCE (N)
MCI GLZ IMP 01	3L-27-107	Double-Glazed - Tempered Outside/Laminated Inside (Rubber)	23.6	8,105	73	Yes	No	No	Not Available	Not Available
MCI GLZ IMP 02	3L-27-133	Single-Glazed - Laminated Glass (Rubber)	21.5	4,780	116	Yes	NA	No	Not Available	Not Available
MCI GLZ IMP 03	3L-27-133	Single-Glazed - Laminated Glass (Rubber)	21.2	5,879	106	Yes	NA	No	Not Available	Not Available
MCI GLZ IMP 04	T868-L4	Doubled Glazed - Tempered Outside/Tempered Inside (Rubber)	21.4	8,824	42	No	No	No	Not Available	Not Available
MCI GLZ IMP 05	T822G2	Single-Glazed - Tempered Glass (Rubber)	21.3	8,030	49	No	NA	No	Not Available	Not Available
MCI GLZ IMP 06	3L-27-136	Single-Glazed - Acrylic (Rubber)	21.4	6,211	66	No	NA	No	Not Available	Not Available
MCI GLZ IMP 07	V369L4	Double-Glazed - Tempered Outside/Tempered Inside (Glued)	21.4	9,284	39	No	No	No	Not Available	Not Available
MCI GLZ IMP 08	03-27-1474	Double-Glazed - Tempered Outside/Laminated Inside (Glued)	21.2	7,846	47	Yes	No	No	Not Available	Not Available
MCI GLZ IMP 27	V369SP-TTL060	Double-Glazed - Tempered / Laminated Tempered (Glued)	21.3	9,660	36	No	No	No	89	400
MCI GLZ IMP 28	V369SP-SG	Single-Glazed - Tempered Glass (Glued)	20.8	8,518	41	No	NA	No	36	267
MCI GLZ IMP 29	V369SP-LM	Single-Glazed - Laminated Glass (Glued)	20.9	7,592	57	Yes	NA	No	27	356
MCI GLZ IMP 30	V369SP-PC	Single-Glazed - Polycarbonate (Glued)	21.2	6,822	69	No	NA	No	40	334

Figure 3.2 Chatillon Force Gauge Measuring Unlatching Force (top) and Window Opening Force

3.2. Discussion

The occupant retention assessment results are rearranged in Table 3.2 to illustrate a number of observations. The first four rows compare similar glazing constructions with different methods of bonding the glazing to the frame. The single-glazed laminated glass candidates broke in both tests while the tempered glass candidates experienced no damage. The glazings with the rubber attachment produced higher displacements and lower forces. The polyvinyl butyral (PVB) interlayer in the laminated glass tested in MCI IMP GLZ 29 was thicker (1.5 mm vs. 0.4 mm), which leads to the observation that greater PVB thickness played a role in reducing the excursion measurement.

Rows five through eight compare single-glazed candidates with different material construction similarly bonded to the window frame. In both like-comparison tests, the tempered glass candidate produced higher forces and less excursion than the laminated glass.

The ninth and tenth rows compare tempered glass material in single and double-glazed arrangement which were bonded similarly to the window frame. While the test on the heavier double-glazed window produced higher peak forces and less excursion than that on the single-glazed window, the magnitude of the difference between these values and the limited testing do not allow a conclusion to be made as to whether the double-glazed tempered construction will reduce excursion measurements.

The final three rows compare the monolithic rigid plastic candidates with the thicker laminated glass. The polycarbonate produced lower peak forces and higher excursion compared to the laminated glass when bonded similarly to the window frame. The acrylic produced lower forces compared to most material compositions, with the exception of the thinner laminated glass candidate with a thinner PVB layer. Tempered glass did not break in any configuration.

Table 3.2 Comparison of Like Tests

TEST NO.	GLAZING PART NO.	GLAZING CONFIGURATION (FRAME BONDING METHOD)	IMPACT VELOCITY (km/h)	PEAK FORCE (N)	PEAK IMPACTOR FACE EXCURSION (mm)	INTERIOR GLASS PLY BROKEN	EXTERIOR GLASS PLY BROKEN	LATCH OPENED	UNLATCHING FORCE (N)	WINDOW OPENING FORCE (N)
MCI GLZ IMP 02	3L-27-133	Single-Glazed - Laminated Glass (Rubber)	21.5	4780	116	Yes	NA	No	Not Available	Not Available
MCI GLZ IMP 29	V369SP-LM	Single-Glazed - Laminated Glass (Glued)	20.9	7592	57	Yes	NA	No	27	356
MCI GLZ IMP 05	T822G2	Single-Glazed - Tempered Glass (Rubber)	21.3	8030	49	No	NA	No	Not Available	Not Available
MCI GLZ IMP 28	V369SP-SG	Single-Glazed - Tempered Glass (Glued)	20.8	8518	41	No	NA	No	36	267
MCI GLZ IMP 02	3L-27-133	Single-Glazed - Laminated Glass (Rubber)	21.5	4780	116	Yes	NA	No	Not Available	Not Available
MCI GLZ IMP 05	T822G2	Single-Glazed - Tempered Glass (Rubber)	21.3	8030	49	No	NA	No	Not Available	Not Available
MCI GLZ IMP 29	V369SP-LM	Single-Glazed - Laminated Glass (Glued)	20.9	7592	57	Yes	NA	No	27	356
MCI GLZ IMP 28	V369SP-SG	Single-Glazed - Tempered Glass (Glued)	20.8	8518	41	No	NA	No	36	267
MCI GLZ IMP 28	V369SP-SG	Single-Glazed - Tempered Glass (Glued)	20.8	8518	41	No	NA	No	36	267
MCI GLZ IMP 07	V369L4	Double-Glazed - Tempered Outside/Inside (Glued)	21.4	9284	39	No	No	No	Not Available	Not Available
MCI GLZ IMP 29	V369SP-LM	Single-Glazed - Laminated Glass (Glued)	20.9	7592	57	Yes	NA	No	27	356
MCI GLZ IMP 30	V369SP-PC	Single-Glazed - Polycarbonate (Glued)	21.2	6822	69	No	NA	No	40	334
MCI GLZ IMP 06	3L-27-136	Single-Glazed - Acrylic (Rubber)	21.4	6211	66	No	NA	No	Not Available	Not Available

4. Near-Latch Testing on Motorcoach Section

4.1. No Torsion Test Methods and Results

A second series of impact tests using the 26 kg impactor was conducted on the 11 glazing candidates near the latching mechanism to determine if opening would occur, and if so, under what conditions. The impactor was positioned perpendicular to the bus section’s middle window with the center of the impactor face aligned with the center of the left latch bar keeper. The bottom of the impactor face was positioned 25 mm above the top of the crash bar as shown Figure 4.1. The 25 mm offset (also used in FMVSS No. 226) provided a buffer to assure that the impactor would not strike the window frame structure.

Figure 4.1 Near-Latch Testing Impact Location

Maximum dynamic load, peak excursion, and glazing damage were recorded in the same manner as the previous test series. High speed video captured the dynamic interaction between the crash bar and keeper. The results from this test series are presented Table 4.1.

Table 4.1 Near-Latch Impact Test Results

TEST NO.	GLAZING PART NO.	GLAZING CONFIG. (FRAME BONDING METHOD)	TARGET IMPACT VELOCITY (km/h)	ACTUAL IMPACT VELOCITY (km/h)	PEAK FORCE (N)	PEAK IMPACTOR FACE EXCURSION (mm)	INTERIOR GLASS PLY BROKE	EXTERIOR GLASS PLY BROKE	STRUCK LATCH OPENED	UNLATCHING FORCE (N)	WINDOW OPENING FORCE (N)	NOTE
MCI GLZ IMP 09	3L-27-133	Single-Glazed - Laminated Glass (Rubber)	21.6	21.3	6,844	58	No	NA	Yes	67	Not Avail.	Secondary latch and window opened
MCI GLZ IMP 10	3L-27-133	Single-Glazed - Laminated Glass (Rubber)	10.0	10.3	2,205	9	No	NA	No	53	Not Avail.	
MCI GLZ IMP 11	3L-27-133	Single-Glazed - Laminated Glass (Rubber)	12.0	11.9	3,018	15	No	NA	No	44	Not Avail.	2nd Test on Glazing
MCI GLZ IMP 12	3L-27-133	Single-Glazed - Laminated Glass (Rubber)	15.0	14.3	4,251	23	No	NA	No	36	Not Avail.	3rd Test on Glazing
MCI GLZ IMP 13	3L-27-133	Single-Glazed - Laminated Glass (Rubber)	15.0	14.7	4,402	27	No	NA	Yes	31	Not Avail.	4th Test on Glazing; Secondary latch did not open
MCI GLZ IMP 14	3L-27-133	Single-Glazed - Laminated Glass (Rubber)	15.0	15.5	4,897	27	No	NA	No	80	Not Avail.	
MCI GLZ IMP 15	3L-27-133	Single-Glazed - Laminated Glass (Rubber)	15.0	15.8	4,793	34	No	NA	Yes	36	Not Avail.	2nd Test on Glazing; Secondary latch did not open
MCI GLZ IMP 16	3L-27-107	Double-Glazed – Temp Out/Lam Inside (Rubber)	15.0	15.3	5,185	28	No	No	Yes	40	Not Avail.	Secondary latch did not open
MCI GLZ IMP 17	V369L4	Double-Glazed – Temp Out/Inside (Glued)	15.0	15.2	4,872	24	No	No	Yes	80	Not Avail.	Secondary latch did not open
MCI GLZ IMP 18	03-27-1474	Double-Glazed - Tem Out/Lam Inside (Glued)	15.0	14.1	4,613	21	No	No	No	80	Not Avail.	

Table 4.1 – Near-Latch Impact Test Results (continued)

TEST NO.	GLAZING PART NO.	GLAZING CONFIG. (FRAME BONDING METHOD)	TARGET IMPACT VELOCITY (km/h)	ACTUAL IMPACT VELOCITY (km/h)	PEAK FORCE (N)	PEAK IMPACTOR FACE EXCURSION (mm)	INTERIOR GLASS PLY BROKE	EXTERIOR GLASS PLY BROKE	STRUCK LATCH OPENED	UNLATCHING FORCE (N)	WINDOW OPENING FORCE (N)	NOTE
MCI GLZ IMP 19	03-27-1474	Double-Glazed - Temp Out/Lam Inside (Glued)	15.0	13.8	4,220	22	No	No	No	62	Not Avail.	2nd Test on Glazing
MCI GLZ IMP 20	3L-27-136	Single-Glazed - Acrylic (Rubber)	15.0	13.9	3,655	27	No	NA	Yes	71	Not Avail.	Secondary latch did not open
MCI GLZ IMP 21	T868-L4	Doubled Glazed - Tempered Out/ Inside (Rubber)	15.0	14.7	4,913	24	No	No	No	89	Not Avail.	
MCI GLZ IMP 22	T868-L4	Doubled Glazed - Tempered Out/ Inside (Rubber)	15.0	14.9	4,650	28	No	No	Yes	53	Not Avail.	2nd Test on Glazing; Secondary latch did not open
MCI GLZ IMP 23	T822G2	Single-Glazed - Tempered Glass (Rubber)	15.0	14.4	4,158	28	No	NA	No	71	262	
MCI GLZ IMP 24	T822G2	Single-Glazed - Tempered Glass (Rubber)	14.0	14.0	4,151	30	No	NA	Yes	31	200	2nd Test on Glazing; Secondary latch did not open
MCI GLZ IMP 25	V369SP-LM	Single-Glazed - Laminated Glass (Glued)	14.0	14.2	4,410	26	No	NA	Yes	40	334	Secondary latch and window opened
MCI GLZ IMP 26	V369SP-PC	Single-Glazed - Polycarbonate (Glued)	14.0	14.1	4,442	28	No	NA	Yes	53	156	Secondary latch did not open
MCI GLZ IMP 31	V369SP-TTL060	Double-Glazed – Temp Out / Lam Temp (Glued)	15.0	15.5	4,302	24	Yes	No	Yes	93	400	Secondary latch did not open
MCI GLZ IMP 32	V369SP-SG	Single-Glazed - Tempered Glass (Glued)	15.0	15.5	4,831	31	No	No	Yes	71	245	Secondary latch did not open

4.2. Discussion

The first test was performed on a single-glazed laminated window construction at 21.6 km/h, the velocity determined in the Martec study. Both latching mechanisms unlatched and the window swung open at this speed, but there was no damage to the glass material. Based on the observed damage to the latching mechanism, it was inferred that this speed would produce similar results on all compositions. A series of tests was performed on this construction to determine the unlatching threshold velocity. Because of limited testing samples, impact tests were sometimes conducted on previously tested windows, which increased the likelihood of the latch opening. This limitation made it difficult to determine if the latch mechanisms were compromised in the previous tests, where the window remained latched, and possibly led to unlatching at a lower speed during the subsequent testing. Despite this limitation, the unlatching threshold velocity for the single-paned laminated glazing construction was determined to be 15 to 16 km/h.

A target impact velocity of 15 km/h was chosen to test the other glazing compositions. Friction in the impactor rod made it difficult to always achieve the desired speed. Given this condition and the limited quantity of test samples, the results on all glazing compositions indicated that the unlatching threshold velocity was in the range of 14 to 16 km/h.

The only case of glazing material failure occurred in test MCI GLZ IMP 31 in which the laminated inner glass ply broke. This led to the conclusion that impacts to this location can determine if the latch design alone is capable of keeping the emergency window closed when loaded by an occupant. In one test (MCI GLZ IMP 25), both latches unlatched and the window opened fully. In all other cases, the latch near the impact point unlatched, but the window did not fully open because the non-struck latch appeared to remain latched.

4.3. Testing Under Torsion Description

The effect of glazing frame torsion on latch activation was evaluated by introducing and maintaining a twist on the motorcoach frame during the impact test. One entire end of the bus section and one corner of the opposite end were loaded by applying a 4,250 lb. mass to each end. The non-fixed corner force was applied using a floor jack as shown in Figure 4.2 and Figure 4.3. The amount of torsion, measured by the angle of a steel frame cross member attached to the motorcoach floor, was based on the torsion achieved by lifting the left front tire of a full-sized MCI D-series motorcoach approximately 1 meter using a hydraulic wheel lift. The wheel was lowered and the right rear tire was raised in a similar manner. An angle of 4 degrees about the vehicle’s longitudinal axis was observed in both lifting operations. This work was performed by MCI.

Figure 4.2 No Torsional Load Applied

Figure 4.3 Torsional Load Applied

4.4. Discussion

Based on the unlatching threshold, an impact speed of 15 km/h was chosen to test all the window compositions under torsional loading. Table 4.2 compares similar window construction and bonding methods tested under torsional loading and non-loading conditions. In 6 of the 11 pairs of comparison tests, the presence of torsion did not have an effect on whether the struck latch unlatched. However, in tests MCI GLZ IMP 36 and MCI GLZ IMP 37, both latches unlatched and the window swung open, while the comparison tests (MCI GLZ IMP 25 and MCI GLZ IMP 26) resulted in just the struck latch unlatching. In the other five pairs of comparison tests, the presence of torsional loading made it more difficult for the window to unlatch as a result of the impact loading. In the tests where the struck latch unlatched, the window did not open because the other latch remained latched.

Table 4.2 Torsion Versus Non-Torsion Comparisons

TEST NO.	GLAZING TYPE	GLAZING WEIGHT (kg)	LOADING MODE	IMPACT SPEED (km/h)	PEAK FORCE (N)	PEAK IMPACTOR FACE EXCURSION (mm)	STRUCK LATCH OPENED	UNLATCH STRENGTH (N)	
								NO TORSION	TORSION
MCI GLZ IMP 25	(V369SP-LM) Single-Glazed - Laminated Glass (Glued)	29	No Torsion	14.2	4,410	26	Yes*	40	N/A
MCI GLZ IMP 37	(V369SP-LM) Single-Glazed - Laminated Glass (Glued)	29	Under Torsion	15.3	4,823	40	Yes*	31	18
MCI GLZ IMP 18	(03-27-1474) Double glazed - Tempered Outside/Laminated Inside (Glued)	42	No Torsion	14.1	4,613	21	No	80	N/A
MCI GLZ IMP 40	(03-27-1474) Double-Glazed - Tempered Outside/Laminated Inside (Glued)	42	Under Torsion	14.6	4,540	24	No	89	111
MCI GLZ IMP 23	(T822G2) Single-Glazed - Tempered Glass (Rubber)	27	No Torsion	14.4	4,158	28	No	71	N/A
MCI GLZ IMP 41	(T822G2) Single-Glazed - Tempered Glass (Rubber)	27	Under Torsion	15.1	4,585	30	No	67	71
MCI GLZ IMP 14	(3L-27-133) Single-Glazed - Laminated Glass (Rubber)	26	No Torsion	15.5	4,897	27	No	80	N/A
MCI GLZ IMP 42	(3L-27-133) Single-Glazed - Laminated Glass (Rubber)	26	Under Torsion	15.2	3,864	53	No	71	80
MCI GLZ IMP 21	(T868-L4) Doubled Glazed - Tempered Outside/Tempered Inside (Rubber)	42	No Torsion	14.7	4,650	24	No	89	N/A
MCI GLZ IMP 43	(T868-L4) Doubled Glazed - Tempered Outside/Tempered Inside (Rubber)	42	Under Torsion	15.2	4,751	27	No	76	67
MCI GLZ IMP 26	(V369SP-PC) Single-Glazed - Polycarbonate (Glued)	25	No Torsion	14.1	4,442	28	Yes*	53	N/A
MCI GLZ IMP 36	(V369SP-PC) Single-Glazed - Polycarbonate (Glued)	25	Under Torsion	15.2	4,118	43	Yes*	40	49

* Secondary latch and window opened

Table 4.2 Torsion Versus Non-Torsion Comparisons (continued)

TEST NO.	GLAZING TYPE	GLAZING WEIGHT (kg))	LOADING MODE	IMPACT SPEED (km/h)	PEAK FORCE (N)	PEAK IMPACTOR FACE EXCURSION (mm)	STRUCK LATCH OPENED	UNLATCH STRENGTH (N)	
								NO TORSION	TORSION
MCI GLZ IMP 17	(V369L4) Double-Glazed - Tempered/Tempered (Glued)	42	No Torsion	15.2	4,872	24	Yes	80	N/A
MCI GLZ IMP 33	(V369L4) Double-Glazed - Tempered/Tempered (Glued)	42	Under Torsion	14.9	5,076	29	No	53	89
MCI GLZ IMP 31	(V369SP-TTL060) Double-Glazed - Tempered / Laminated Tempered (Glued)	47	No Torsion	15.5	5,469	24	Yes	93	N/A
MCI GLZ IMP 34	(V369SP-TTL060) Double-Glazed - Tempered / Laminated Tempered (Glued)	47	Under Torsion	15.2	5,031	26	No	71	68
MCI GLZ IMP 32	(V369SP-SG) Single-Glazed - Tempered Glass (Glued)	25	No Torsion	15.5	4,831	31	Yes	71	N/A
MCI GLZ IMP 35	(V369SP-SG) Single-Glazed - Tempered Glass (Glued)	25	Under Torsion	15.2	4,596	32	No	76	71
MCI GLZ IMP 20	(3L-27-136) Single glazed - Acrylic (Rubber)	27	No Torsion	13.9	3,655	27	Yes	71	N/A
MCI GLZ IMP 38	(3L-27-136) Single glazed - Acrylic (Rubber)	27	Under Torsion	15.4	4,306	37	No	49	45
MCI GLZ IMP 16	(3L-27-107) Double-Glazed - Tempered Outside/Laminated Inside (Rubber)	43	No Torsion	15.3	5,185	28	Yes	40	N/A
MCI GLZ IMP 39	(3L-27-107) Double-Glazed - Tempered Outside/Laminated Inside (Rubber)	43	Under Torsion	14.6	4,319	49	No	44	36

4.5. Near-Latch Testing With Modified Window Installation Method

FMVSS No. 217 specifies that emergency exit windows on motorcoaches be able to be opened at a force no greater than 89 N. The force needed to push open the window after it was unlatched manually exceeded this value in the reported testing, raising concern that the forces exerted on the window frame due to the installation method may have influenced the conditions that produced an unlatching event for a given impact velocity. Personnel from MCI visited VRTC and demonstrated a window installation method which produced opening forces that met the regulation performance criteria. A short test series was performed to see the effect of reducing the opening force. The results are summarized in Table 4.3.

Table 4.3 Modified Window Installation Results

Test No.	Glazing Configuration	Glazing Weight (kg)	Loading Mode	Impact Speed (km/h)	Peak Force (N)	Peak Impactor Face Excurs. (mm)	Struck Latch Opened	Unlatching Force (N)	Opening Force (N)
MCI GLZ IMP 44	(3L-27-107) Double-Glazed - Tempered Outside/Laminated Inside (Rubber)	43	No Torsion	16.3	4,647	-11	Yes**	49	106
MCI GLZ IMP 47	(3L-27-107) Double-Glazed - Tempered Outside/Laminated Inside (Rubber)	43	Under Torsion	16.8	4,849	25	No	27/31*	58/45*
MCI GLZ IMP 45	(3L-27-133) Single-Glazed - Laminated Glass (Rubber)	26	No Torsion	15.9	4,716	-6	No	45	98
MCI GLZ IMP 49	(3L-27-133) Single-Glazed - Laminated Glass (Rubber)	26	Under Torsion	15.5	4,329	29	No	49/67*	107/102*
MCI GLZ IMP 46	(03-27-1474) Double-Glazed - Tempered Outside/Laminated Inside (Glued)	42	No Torsion	15.3	2,273	25	No	58	107
MCI GLZ IMP 48	(03-27-1474) Double-Glazed - Tempered Outside/Laminated Inside (Glued)	42	Under Torsion	15.7	4,429	23	No	31/67*	133/245*

*Measured after impact while under torsion

**Secondary latch remained closed

A comparison of similar glazing constructions installed with the different installation methods, shown in Table 4.4, shows that reducing the window opening force and the unlatching force did not have an effect on whether the latch opened.

Table 4.4 Comparison of Like Tests With Different Installation Methods

TEST NO.	GLAZING TYPE	GLAZING WEIGHT (kg)	LOADING MODE	IMPACT SPEED (km/h)	PEAK FORCE (N)	PEAK IMPACTOR FACE EXCURSION (mm)	STRUCK LATCH OPENED	LATCH STRENGTH (N)		OPENING FORCE (N)	
								NO TORSION	TORSION	NO TORSION	TORSION
MCI GLZ IMP 16	(3L-27-107) Double-Glazed - Temp Outside/Laminated Inside (Rubber)	43	No Torsion	15.3	5,185	28	Yes*	40	N/A	N/A	N/A
MCI GLZ IMP 44	(3L-27-107) Double-Glazed - Temp Outside/Laminated Inside (Rubber)	43	No Torsion	16.3	4,647	-11	Yes*	49	N/A	106	N/A
MCI GLZ IMP 14	(3L-27-133) Single-Glazed - Laminated Glass (Rubber)	26	No Torsion	15.5	4,897	27	No	80	N/A	N/A	N/A
MCI GLZ IMP 45	(3L-27-133) Single-Glazed - Laminated Glass (Rubber)	26	No Torsion	15.9	4,716	-6	No	45	N/A	98	N/A
MCI GLZ IMP 18	(03-27-1474) Double-Glazed - Temp Outside/Laminated Inside (Glued)	42	No Torsion	14.1	4,613	21	No	80	N/A	N/A	N/A
MCI GLZ IMP 46	(03-27-1474) Double-Glazed - Temp Outside/Laminated Inside (Glued)	42	No Torsion	15.3	2,273	25	No	58	N/A	107	N/A
MCI GLZ IMP 39	(3L-27-107) Double-Glazed - Tempered Outside/Laminated Inside (Rubber)	43	Under Torsion	14.6	4,319	28	No	49	44	214	N/A
MCI GLZ IMP 47	(3L-27-107) Double-Glazed - Tempered Outside/Laminated Inside (Rubber)	43	Under Torsion	16.8	4,849	25	No	27	31	58	45
MCI GLZ IMP 42	(3L-27-133) Single-Glazed - Laminated Glass (Rubber)	26	Under Torsion	15.2	3,864	53	No	71	80	93	N/A
MCI GLZ IMP 49	(3L-27-133) Single-Glazed - Laminated Glass (Rubber)	26	Under Torsion	15.5	4,329	29	No	49	67	107	102
MCI GLZ IMP 40	(03-27-1474) Double-Glazed - Temp Outside/Laminated Inside (Glued)	42	Under Torsion	14.6	4,540	24	No	89	111	N/A	N/A
MCI GLZ IMP 48	(03-27-1474) Double-Glazed - Temp Outside/Laminated Inside (Glued)	42	Under Torsion	15.7	4,429	23	No	31	67	133	245

*Secondary latch remained closed

5. Initial Fleet Testing on Test Frames

The test conditions developed in the previous testing were expanded to other motorcoach manufacturers and coach series to establish fleet baseline performance. According to sales and market share estimates provided by MCI for 2007, MCI, Prevost, ABC/Van Hool, and Setra had market shares of 56 percent, 23 percent, 19 percent, and 2 percent of the industry-wide fleet of 43,493 units, respectively. MCI had 38 percent of annual sales (1,794) in the private coach segment in 2007. For 2008, the annual sales market share for MCI, Prevost, ABC/Van Hool, and Setra were 49 percent, 21 percent, 22 percent, and 8 percent of annual sales, respectively. These estimates indicated that the fleet was well represented by conducting tests on a Prevost model H3-45, Van Hool model C2045, and MCI E/J-series, in addition to the MCI D-series line. Due to cost and time constraints in securing a motorcoach section from each of the manufacturers, testing was conducted on glazing mounted to test frames that represented the side passenger window frame for each of the three manufacturers:

5.1. MCI E/J-Series Test Frame and Glazing Description

The test frame representing the E/J-series motorcoach was purchased from MCI. It was constructed from stainless steel square tubing with the vertical members shaped to match the contour of the side glazing (see Figure 5.1). Additional tubing provided rigidity to the frame, and the frame was secured to the floor using two, 1,928 kg. concrete blocks on each side. A drip rail from an actual motorcoach was fastened to the top of the frame, and a track attached to the top of the glazing, shown in Figure 5.2, hooked into the drip rail allowing the window to swing open when unlatched.

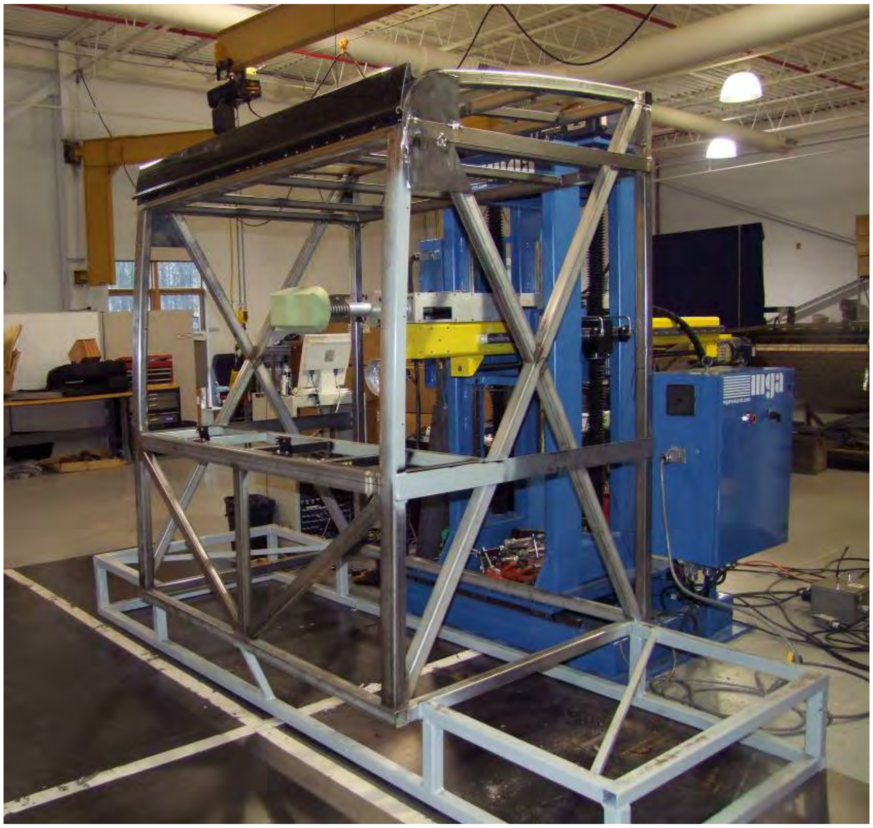

Figure 5.1 MCI E/J-Series Test Frame

Figure 5.2 MCI E/J-Series Drip Rail and Window Hinge

The latching mechanism, shown in Figure 5.3, is similar to passenger vehicle doors where a detent lever latches around a striker post press fit into a latch plate. The latch plate/striker post is secured with rivets to the lower sash at two locations. A latch bar is rotated upwards to unlatch the emergency windows. Cams constructed of hard rubber are mounted near each latch and provide guidance to the latch bar as shown in Figure 5.4. The two latching mechanisms are spaced equally apart from the center of the window.

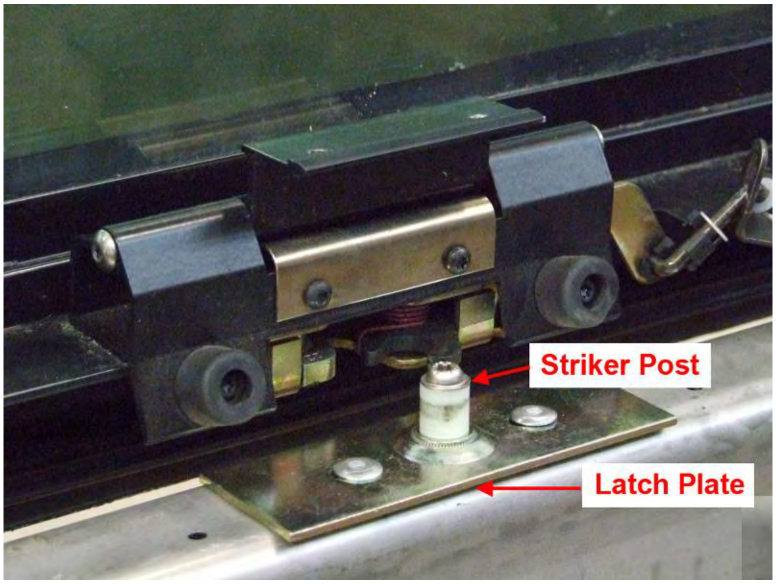

Figure 5.3 Latching Mechanism for MCIE/J-Series (Latch Bar Not Shown)

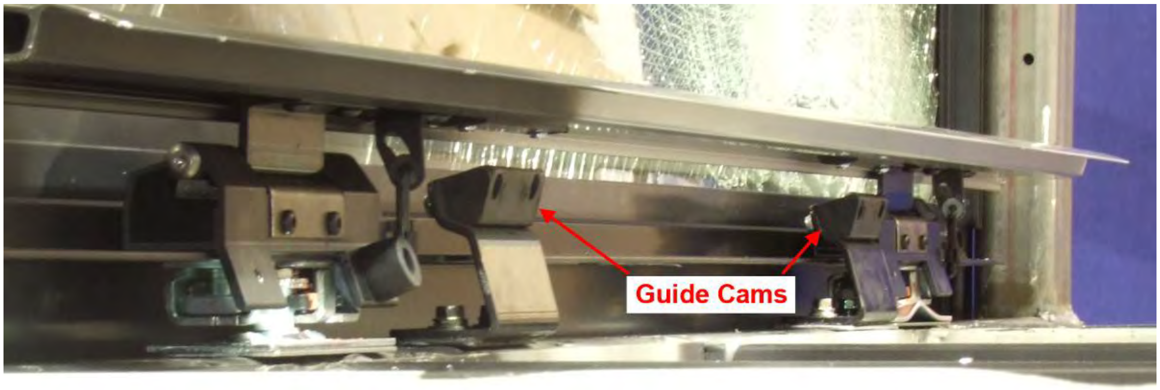

Figure 5.4 MCI E/J-Series Latching System Showing Guide Cams

Both glazing compositions available for the MCI E/J-series were tested. They are considerably larger and heavier than the windows found on the D-series, measuring approximately 1.74 m by 1.1 m. The first is a single-glazed laminated glass (35 kg), bonded to the window frame with glue. The second is a double-glazed construction (51 kg) with laminated glass on the inboard side and tempered glass on the outside, also bonded with glue. Appendix A contains a list of the weights and dimensions of the various glazings tested.

5.2. Prevost H3-45 Test Frame and Glazing Description

The test frame for the Prevost H3-45 windows, shown in Figure 5.5 was fabricated at VRTC with steel square tubing. A drip rail was purchased from Prevost and attached to the top cross member. The top of the window was attached to the frame in a similar manner to the MCI E/J-series window. Latching is achieved by rotating a bar constructed of a composite material downward and over two fixed latch posts made of cast aluminum as seen in Figure 5.6. Prevost provided just one type of glazing construction for the H3-45 model, a double-glazed configuration consisting of tempered glass in both panes. Each pane is 5 mm thick separated by a 9 mm air gap. The window measured 1.7 m by 1.2 m and weighed approximately 50 kg.

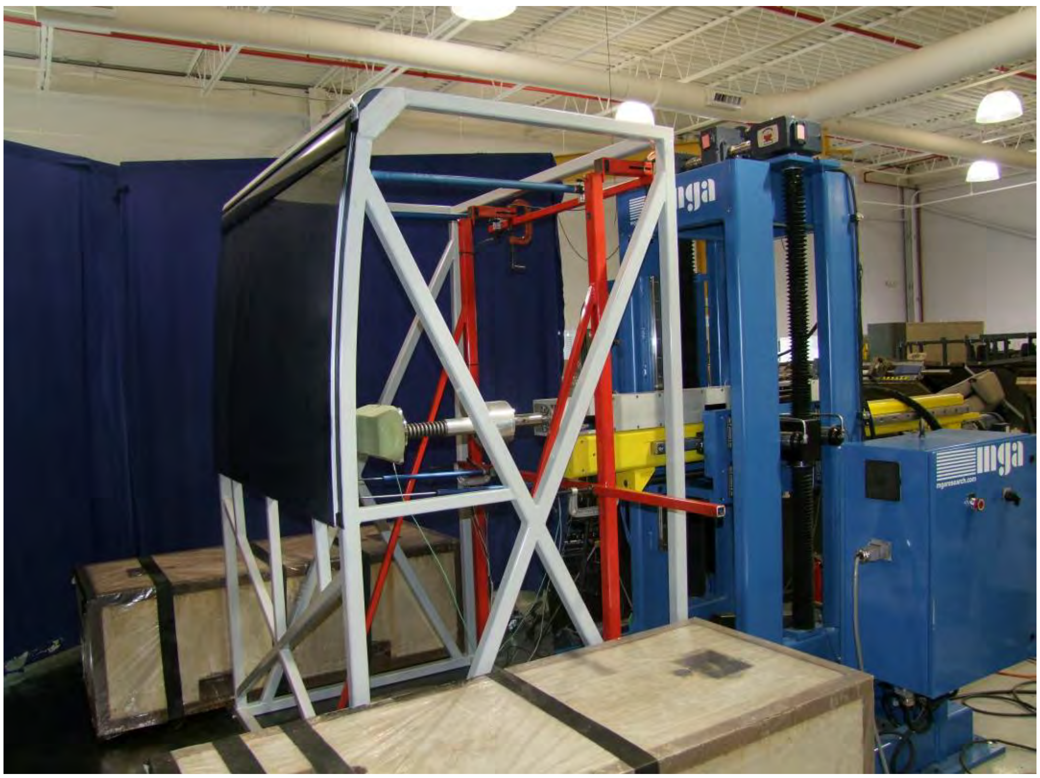

Figure 5.5 Prevost H3-45 Model Test Frame

Figure 5.6 Latching Mechanism for Prevost H3-45 Model

5.3. Van Hool C2045 Test Frame and Glazing

A section of a crashed Van Hool C2045 motorcoach containing the window frame and drip rail was obtained from ABC Companies. Steel square tubing was added to provide rigidity as shown in Figure 5.7. The top of the window fits into a hinge located in the drip rail in a manner similar to the Prevost and MCI buses. Latching is achieved by two slider/catch mechanisms. An emergency handle located on the side of the glazing’s frame activates each sliding mechanism located on the bottom of the frame. Spring clips, secured with rivets onto the motorcoach frame, “catch” the sliding mechanisms when the handle is in the neutral position (Figure 5.8 and Figure 5.9). The window composition used exclusively in the Van Hool model C2045 is a double-glazed, tempered glass design. Each glass pane is 5 mm thick and they are separated by a 5 mm thick air gap. The window measured 1.74 m by 1.1 m and weighed 45 kg.

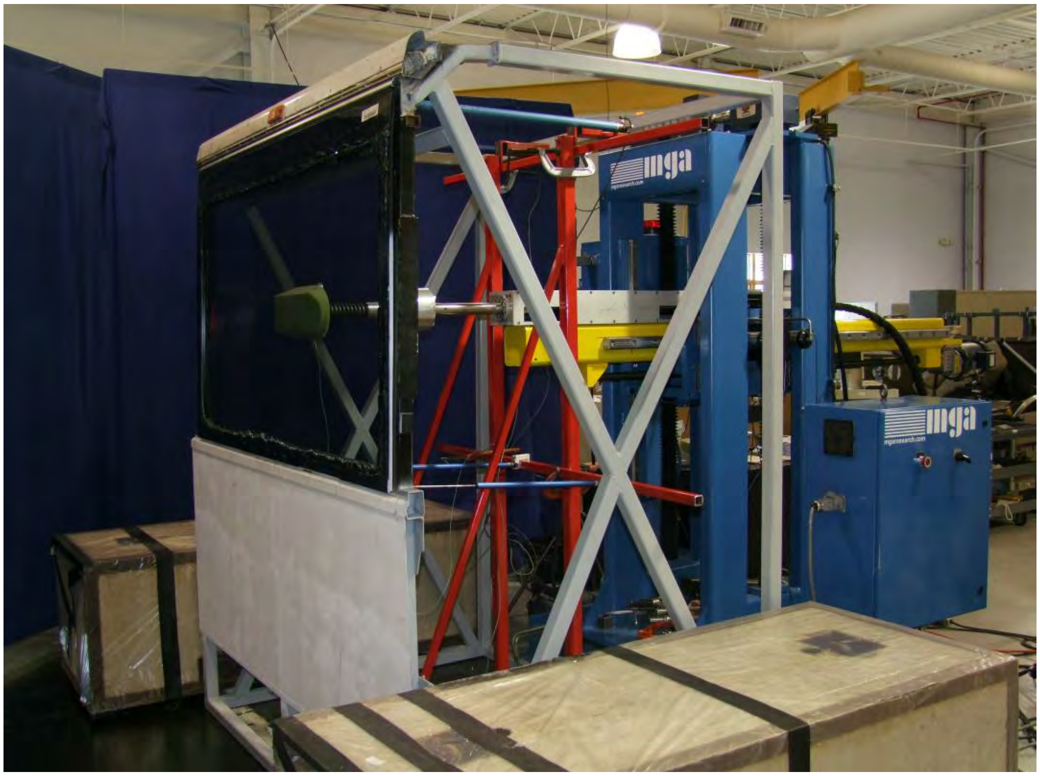

Figure 5.7 Van Hool Model C2045 Test Frame

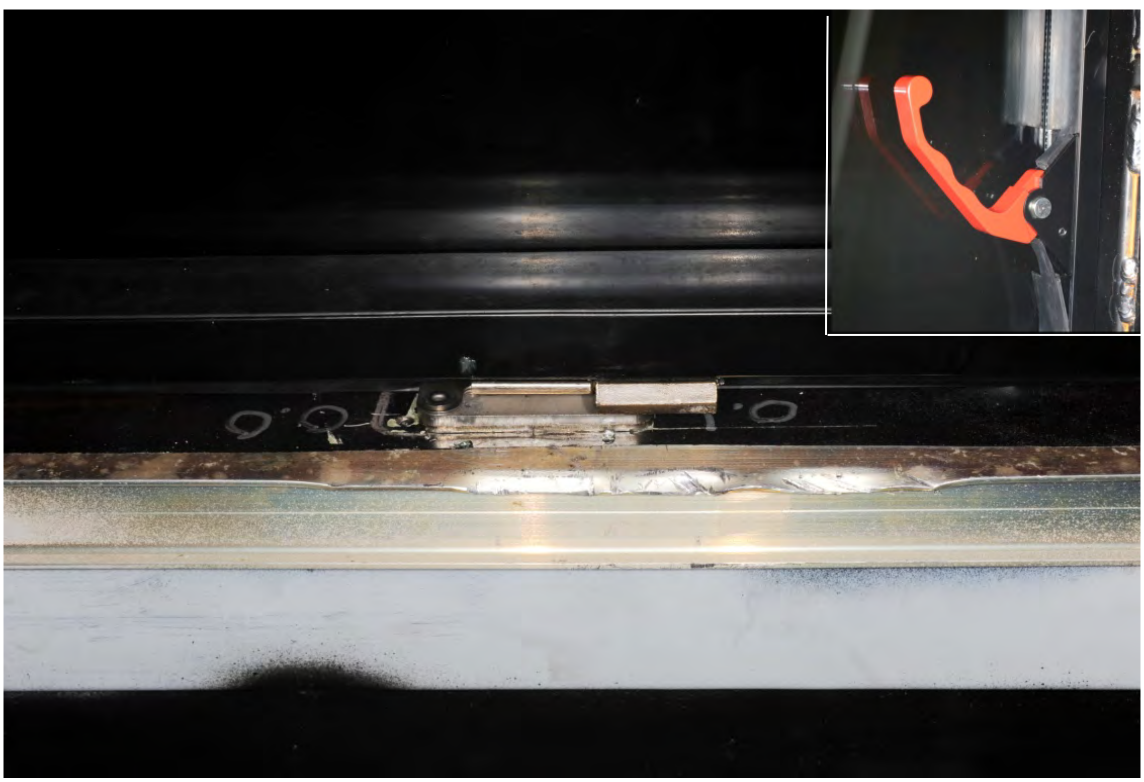

Figure 5.8 Van Hool Latching Mechanism Partially Latched With Emergency Handle (Inset)

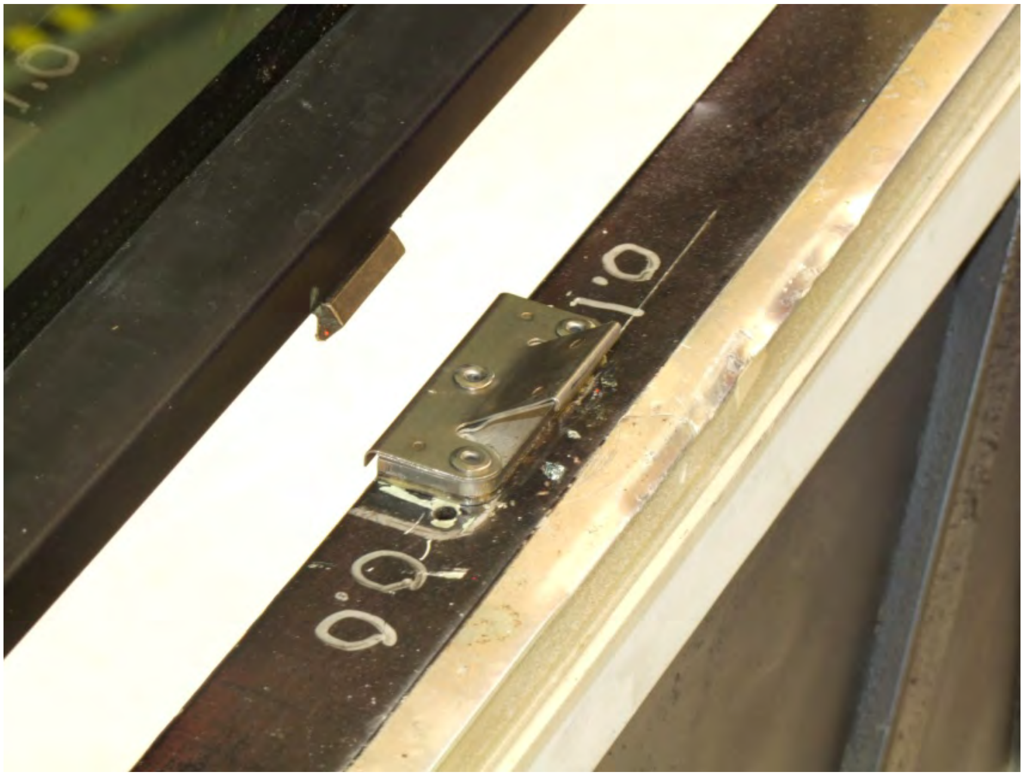
Figure 5.9 Van Hool Latching Mechanism

5.4. MCI D-Series Test Frame and Glazing

The middle section of the MCI 1993 102D motorcoach clip used in the previous testing was removed and fabricated into a test frame similar to the Van Hool setup, shown in Figure 5.10.

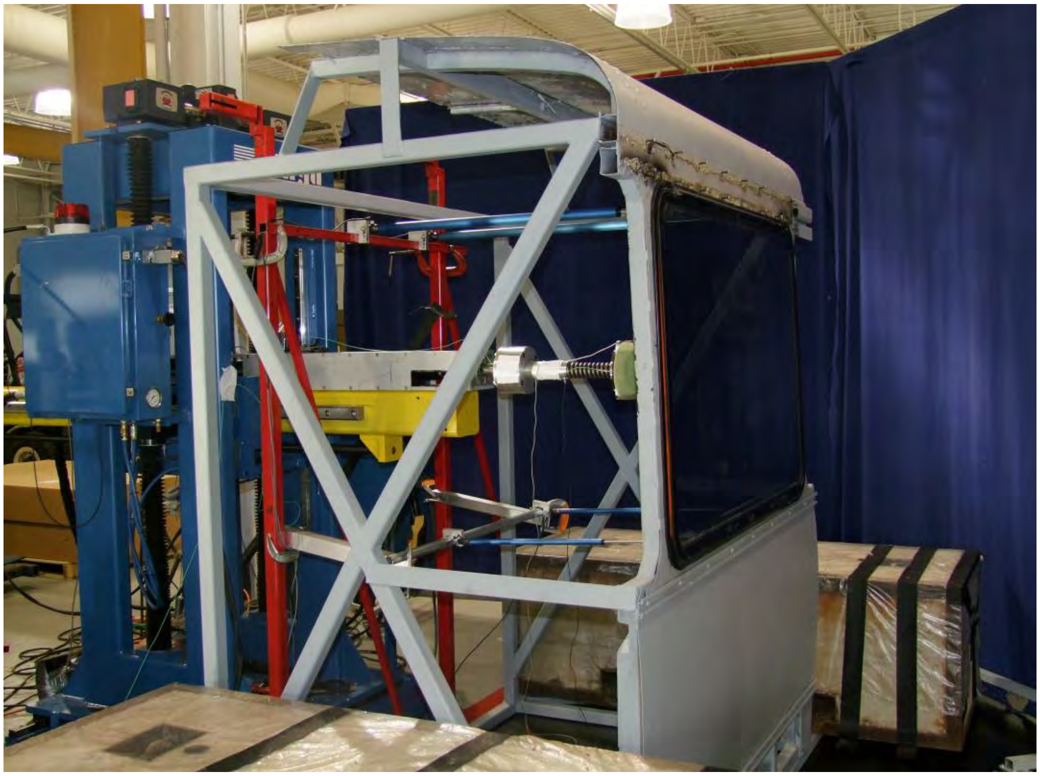

Figure 5.10 MCI D-Series Test Frame

Because testing was performed on glazings that were previously impacted, glazing selection was limited to two production window compositions: the single-glazed, laminated glass construction weighing 26 kg and a double-glazed construction with a laminated glass inner pane and tempered outer pane weighing 43 kg.

5.5. Test Methods and Results

The impactor anvil was affixed to the propulsion unit and support frame that VRTC purchased from MGA during NHTSA's ejection mitigation research program and is shown in Figure 5.11. During the conversion from the impactor propulsion unit described in section 2.3, the impactor anvil was inadvertently assembled with a ballast mass made from aluminum. The correct ballast mass is made of steel and is 3.3 kg heavier. The impactor unit was delivered to VRTC with both ballasts to provide flexibility in assembling the impactor to the desired weight. The results presented and discussed in the following section were obtained using the Martec study impactor, but with a mass of 22.7 kg.

The MGA impactor had been certified to have a coefficient of friction of no greater than 0.25 when the 18 kg ejection impactor is used. In addition to low friction characteristics, the impactor was capable of obtaining a desired velocity in a highly repeatable manner and maintains the desired velocity over a longer travel length. Impact velocity was measured by a similar method as that described in section 2.3 in which an optical sensor recorded the time a beam of light was interrupted as a "flag" attached to the impactor rod passed through it. A linear variable differential transformer (LVDT) recorded the displacement of the impactor mass (shown in Figure 2.7) and calculated the velocity to provide a redundant impact speed. The impactor had a maximum stroke length of 700 mm.

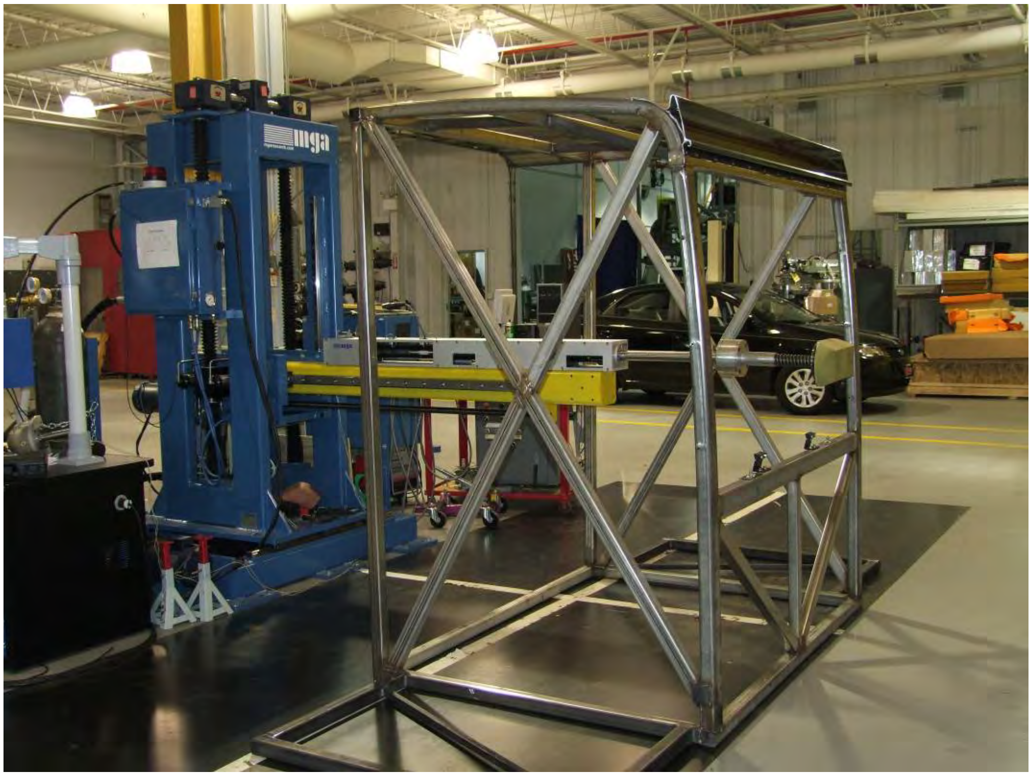

Figure 5.11 22.7 Kg Impactor Affixed to MGA Propulsion Unit

There were three targeted impact locations: 25 mm above the left latching mechanism, 25 mm above the latching mechanism and centered between the two mechanisms, and at the center of the window's daylight opening (DLO) as measured from the interior window frame (see Figure 5.12). Two linear potentiometers were fastened to both upper and lower sashes to monitor any permanent deformation occurring in the four test frames used in this test series.

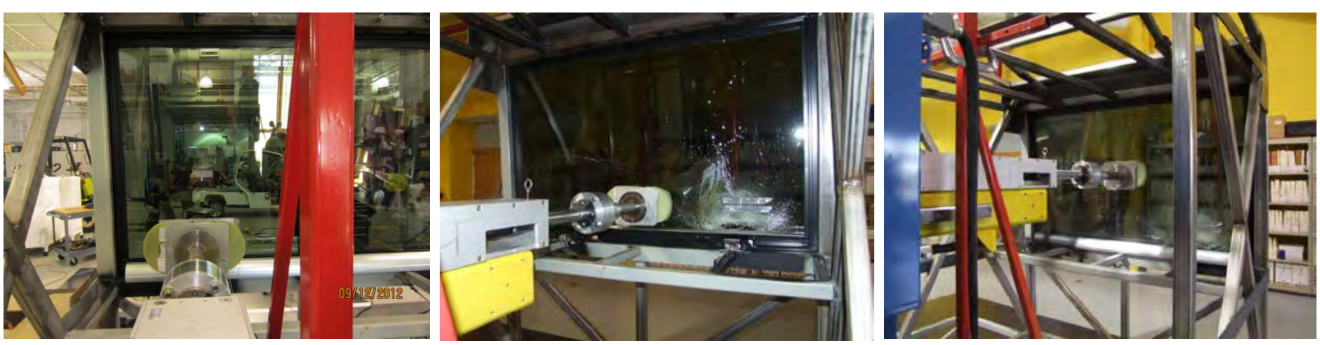

Figure 5.12 Impact Locations: Near-Latch (left), Center of Latches (middle) and Center of DLO

The test results are summarized in Table 5.1. The first test for each impact location in the MCI E/J-series, Prevost, and Van Hool test series was conducted at the Martec study velocity of 21.6 km/h (previous testing on the MCI D-series coach showed that unlatching would occur at this impact speed).

For the near-latch tests, depending on whether unlatching occurred, the impact velocity for subsequent tests was gradually reduced in order to find the unlatching threshold velocity. It is noted in Table 5.1 if unlatching occurred only at the latch nearest to the impact or if both latches unlatched resulting in the window fully opening. For discussion purposes, the latching mechanism nearest the impact point is referred to as the primary latch, and the latch furthest from the impact point is referred to as the secondary latch.

Table 5.1 Test Frame Results - 22.7 Kg Impactor Mass

TEST NO.	GLAZING CONFIGURATION	IMPACT LOCATION	IMPACT VELOCITY (km/h)	PEAK FORCE (N)	PEAK IMPACTOR MASS EXCURSION (mm)	INTERIOR GLASS PLY BROKEN	EXTERIOR GLASS PLY BROKEN	LATCH OPENED	UNLATCHING FORCE (N)	WINDOW OPENING FORCE (N)	COMMENTS
MCI GLZ FRM 01	Double-Glazed - Tempered Outside/Laminated Inside	Near-Latch	21.7	No Data	72	No	No	Yes	18	15	Window unlatched at both mechanisms; detent lever on primary latch slid over post
MCI GLZ FRM 04	Double-Glazed - Tempered Outside/Laminated Inside	Near-Latch	15.1	4,829	21	No	No	No	18	16	
MCI GLZ FRM 05	Double-Glazed - Tempered Outside/Laminated Inside	Near-Latch	18.0	6,373	49	No	No	No	14	20	Detent lever on secondary latch mechanism seen in open position in post test inspection
MCI GLZ FRM 06	Double-Glazed - Tempered Outside/Laminated Inside	Near-Latch	19.5	6,868	54	No	No	Yes	15	20	Detent lever on primary latch slid over post
MCI GLZ FRM 11	Double-Glazed - Tempered Outside/Laminated Inside	Near-Latch	18.0	No Data	49	No	No	Yes	15	20	Detent lever on primary latch slid over post; Detent lever on secondary latch opened during impact
MCI GLZ FRM 12	Double-Glazed - Tempered Outside/Laminated Inside	Near-Latch	16.5	6,009	44	No	No	Yes	15	21	Detent lever on primary and secondary latch opened during impact event
MCI GLZ FRM 13	Double-Glazed - Tempered Outside/Laminated Inside	Between Latch	21.6	8,827	60	Yes	No	No	16	20	
MCI GLZ FRM 15	Double-Glazed - Tempered Outside/Laminated Inside	Center of DLO	21.5	14,121	61	No	No	Yes	16	20	Detent lever on primary latch opened during impact event; detent lever on secondary latch slid over post
MCI GLZ FRM 02	Single-Glazed - Laminated	Near-Latch	21.8	6,796	60	Yes	N/A	Yes	18	10	Window unlatched at both mechanisms; Primary latch's detent lever slid over post
MCI GLZ FRM 03	Single-Glazed - Laminated	Near-Latch	15.0	4,791	37	No	N/A	No	13	9	
MCI GLZ FRM 07	Single-Glazed - Laminated	Near-Latch	19.0	6,599	No Data	Yes	N/A	No	16	20	Glazing material separated from aluminum frame at bottom of window

Table 5.1 Test Frame Results - 22.7 kg Impactor Mass (continued)

TEST NO.	GLAZING CONFIGURATION	IMPACT LOCATION	IMPACT VELOCITY (km/h)	PEAK FORCE (N)	PEAK IMPACTOR MASS EXCURSION (mm)	INTERIOR GLASS PLY BROKEN	EXTERIOR GLASS PLY BROKEN	LATCH OPENED	UNLATCHING FORCE (N)	WINDOW OPENING FORCE (N)	COMMENTS
MCI GLZ FRM 08	Single-Glazed - Laminated	Near-Latch	20.1	7,576	55	No	N/A	Yes	14	21	Detent lever on primary and secondary latch slid over post
MCI GLZ FRM 09	Single-Glazed - Laminated	Near-Latch	19.0	7,263	53	No	N/A	Yes	15	24	Detent lever on primary latch slid over post; detent lever on secondary latch opened during impact
MCI GLZ FRM 10	Single-Glazed - Laminated	Near-Latch	17.0	No Data	59	Yes	N/A	Yes	13	21	Glazing material separated from aluminum frame; primary latch detent lever slid over post; secondary latch detent lever opened during impact
MCI GLZ FRM 14	Single-Glazed - Laminated	Between Latch	21.6	9,753	60	No	N/A	Yes	15	19	Detent lever on primary and secondary latch slid over post
MCI GLZ FRM 16	Single-Glazed - Laminated	Center of DLO	21.5	11,641	63	Yes	N/A	Yes	18-22	17	Detent lever on primary and secondary latch slid over post
VH GLZ FRM 01	Double-Glazed - Tempered Outside/Inside	Near-Latch	21.6	8,250	617	No	No	Yes	34	21	
VH GLZ FRM 02	Double-Glazed - Tempered Outside/Inside	Near-Latch	15.0	3,714	85	No	No	Yes		20	Added 1 mm shim to both spring clips
VH GLZ FRM 03	Double-Glazed - Tempered Outside/Inside	Near-Latch	8.8	2,152	0	No	No	No		26	
VH GLZ FRM 04	Double-Glazed - Tempered Outside/Inside	Near-Latch	14.1	3,220	78	No	No	Yes		20	Failure at both clips
VH GLZ FRM 05	Double-Glazed - Tempered Outside/Inside	Near-Latch	13.0	3,226	50	No	No	Yes	36	21	Secondary latch did not open
VH GLZ FRM 06	Double-Glazed - Tempered Outside/Inside	Near-Latch	11.1	2,852	28	No	No	No	21	21	

Table 5.1 Test Frame Results - 22.7 Kg Impactor Mass (continued)

TEST NO.	GLAZING CONFIGURATION	IMPACT LOCATION	IMPACT VELOCITY (km/h)	PEAK FORCE (N)	PEAK IMPACTOR MASS EXCURSION (mm)	INTERIOR GLASS PLY BROKEN	EXTERIOR GLASS PLY BROKEN	LATCH OPENED	UNLATCHING FORCE (N)	WINDOW OPENING FORCE (N)	COMMENTS
VH GLZ FRM 07	Double-Glazed - Tempered Outside/Inside	Between Latch	21.6	7,285	67	No	No	Yes	20	27	
VH GLZ FRM 08	Double-Glazed - Tempered Outside/Inside	Center of DLO	21.5	7,919	67	No	Yes	Yes	20	20	
PV GLZ FRM 01	Double-Glazed - Tempered Outside/Inside	Near-Latch	21.6	7,375	258	No	No	Yes	19	25	Primary latch post rivets (2) sheared off
PV GLZ FRM 02	Double-Glazed - Tempered Outside/Inside	Near-Latch	21.6	No Data	490	No	No	Yes	18	24	Latch bar pulled from window frame/tore along top
PV GLZ FRM 03	Double-Glazed - Tempered Outside/Inside	Near-Latch	15.0	4,841	40	No	No	Yes	17	24	Latch bar tore along top edge/remained on frame
PV GLZ FRM 04	Double-Glazed - Tempered Outside/Inside	Near-Latch	11.1	3,325	26	No	No	No	19	23	
PV GLZ FRM 05	Double-Glazed - Tempered Outside/Inside	Near-Latch	13.1	4,243	33	No	No	No	19	20	Striker post damage
PV GLZ FRM 06	Double-Glazed - Tempered Outside/Inside	Near-Latch	14.1	4,476	37	No	No	No	19	19	
PV GLZ FRM 07	Double-Glazed - Tempered Outside/Inside	Near-Latch	15.0	4,910	40	No	No	Yes	16	20	Top of left striker post sheared off
PV GLZ FRM 08	Double-Glazed - Tempered Outside/Inside	Near-Latch	14.0	4,666	37	No	No	Yes	19	20	Top of left striker post sheared off
PV GLZ FRM 09	Double-Glazed - Tempered Outside/Inside	Between Latch	21.6	8,575	64	Yes	No	No	19	19	No camera views
PV GLZ FRM 10	Double-Glazed - Tempered Outside/Inside	Center of DLO	21.6	11,101	62	No	No	No	19	20	Much deflection of glazing

Table 5.1 Test Frame Results – 22.7 Kg Impactor Mass (continued)

TEST NO.	GLAZING CONFIGURATION	IMPACT LOCATION	IMPACT VELOCITY (km/h)	PEAK FORCE (N)	PEAK IMPACTOR MASS EXCURSION (mm)	INTERIOR GLASS PLY BROKEN	EXTERIOR GLASS PLY BROKEN	LATCH OPENED	UNLATCHING FORCE (N)	WINDOW OPENING FORCE (N)	COMMENTS
MCID GLZ FRM 01	Single-Glazed - Laminated	Near-Latch	15.0	4,567	39	No	N/A	Yes	13	22	Both latches unlatched
MCID GLZ FRM 02	Single-Glazed - Laminated	Near-Latch	12.9	3,865	28	No	N/A	No	15	19	
MCID GLZ FRM 03	Double-Glazed - Tempered Outside/Laminated Inside	Near-Latch	15.0	4,488	43	Yes	No	Yes	12	22	Both latches unlatched
MCID GLZ FRM 04	Double-Glazed - Tempered Outside/Laminated Inside	Near-Latch	13.0	4,237	30	Yes	No	Yes	19	50	Both latches unlatched
MCID GLZ FRM 05	Double-Glazed - Tempered Outside/Laminated Inside	Near-Latch	11.1	3446	24	Yes	No	Yes	19	50	Same glass and clamp ring used from previous test/Both latches unlatched
MCID GLZ FRM 06	Double-Glazed - Tempered Outside/Laminated Inside	Near-Latch	13.0	4,096	34	No	No	Yes	7	20	Both latches unlatched
MCID GLZ FRM 07	Double-Glazed - Tempered Outside/Laminated Inside	Near-Latch	11.1	3,378	25	No	No	No	8	29	
MCID GLZ FRM 08	Double-Glazed - Tempered Outside/Laminated Inside	Between Latch	21.6	7,941	67	Yes	No	Yes	19	26	Much damage to both frames
MCID GLZ FRM 09	Double-Glazed - Tempered Outside/Laminated Inside	Center of DLO	21.6	9,273	61	Yes	No	Yes	8	20	Much damage to both frames

5.6. Discussion

Figure 5.1 shows the results of each motorcoach type grouped according to whether the window remained latched or unlatched for tests conducted near the primary latch. Shaded bands are overlaid to show the transition velocity where unlatching occurs. That transition speed for the MCI E/J-series was in the 15 - 16 km/h range. Unlatching occurred by one of two slightly different events. In some of the tests, the primary latch's detent lever, under impact loading, transferred a force great enough to deform the striker plate and unseat the striker post from the plate. The post rotated in the direction of impact allowing the lever to slide over the post as seen in Figure 5.14. In other tests, the latch bar rotated upward during the impact event, which opened the primary latch's detent lever prior to the lever sliding over the post.

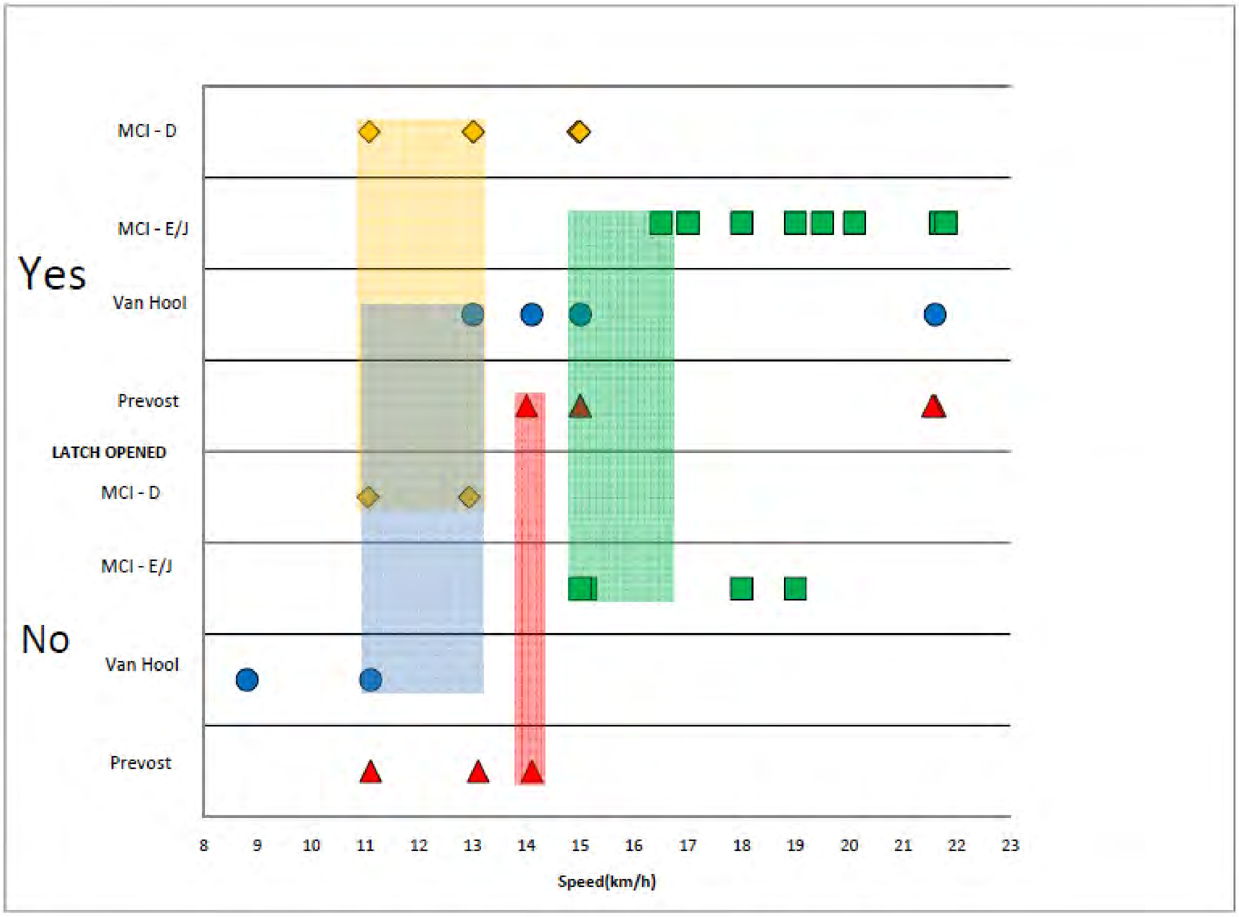

Figure 5.13 Primary Latch Unlatching Threshold Velocities Using 22.7 kg Mass

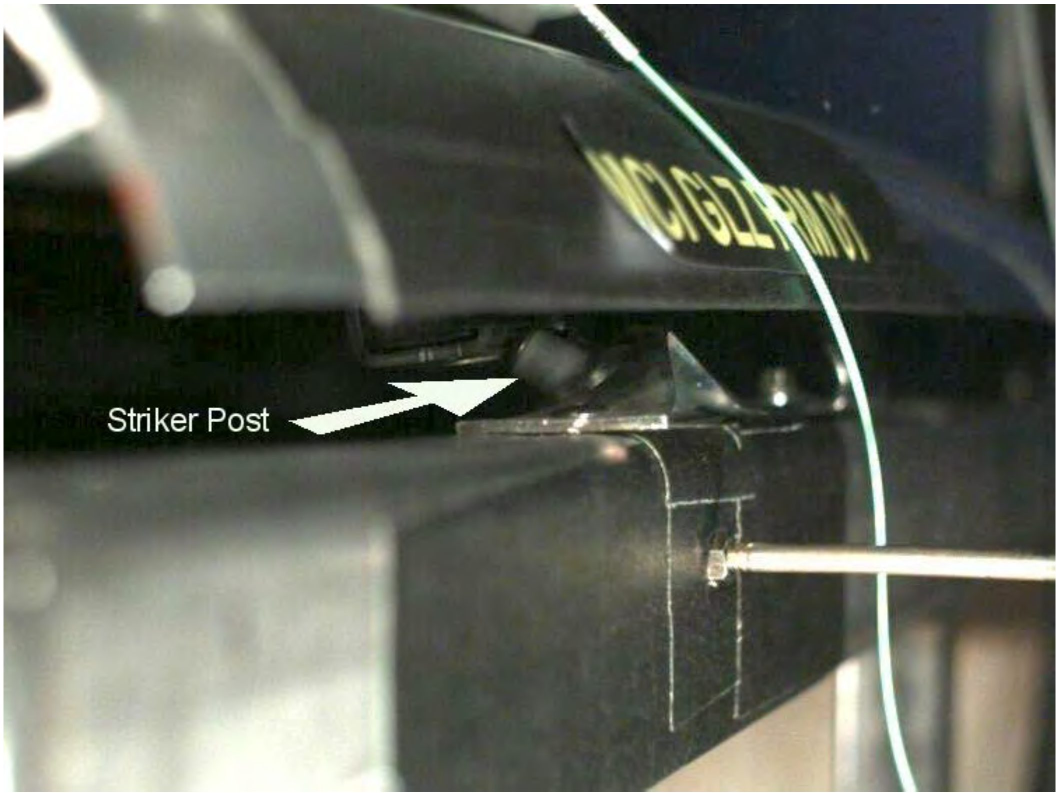

Figure 5.14 MCI E/J-Series Unlatching Event at Primary Latch

Unlatching of the secondary latch occurred in the same manner and is noted in the results table. It is difficult to observe the dynamics of the secondary latch in tests MCI GLZ FRM 01 – 06 due to the lack of a high speed camera focused on this position. A high speed camera was added to capture the secondary latch's dynamics beginning with test MCI GLZ FRM 07.

High speed video analysis showed that the primary latch's detent lever nearly slid over the striker post in test MCI GLZ FRM 05, conducted at 18 km/h, and the post-test inspection revealed that the detent lever on the secondary latch was in the open position. MCI GLZ FRM 11 repeated the test conditions and unlatching was observed at both latches. In test MCI GLZ FRM 07, conducted at 19 km/h, the glazing material separated from the frame at the bottom of the window as shown in Figure 5.15. This reduced the energy imparted on the latching mechanisms, and the window remained latched. Test MCI GLZ FRM 09 was run to repeat the conditions of MCI GLZ FRM 07. The glazing material and bonding remained intact. The detent lever on the primary latch slid over the latch plate post and opened on the secondary latch during the impact event, allowing the window to swing open.


Figure 5.15 Laminate Material Separated From Window Frame

The double-glazed construction did not unlatch in the test conducted at 25 mm above the daylight opening between the latching mechanisms at 21.6 km/h (MCI GLZ FRM 13). Both detent levers slid over the posts, resulting in the window opening when this test condition was run on the single-glazed construction (MCI GLZ FRM 14). Impacts to the center of the daylight opening at 21.6 km/h (MCI GLZ FRM 15 and MCI GLZ FRM 16) pulled the detent levers on both latches over the striker post resulting in the window opening on both the single-glazed and double-glazed constructions.

The transition velocity for the Prevost window was 14 km/h. Three different failure modes were seen in this latch design which resulted in the window unlatching. In tests PV GLZ FRM 01, PV GLZ FRM 07, and PV GLZ FRM 08, the top of the primary latch post sheared off due to loading of the latch bar. An example of this failure is shown in Figure 5.16. In test PV GLZ FRM 02, the composite latch bar tore along the top perforated surface, as shown in 5.17, while in test PV GLZ FRM 03 the latch bar also tore along this surface and separated from the window frame. The windows remained latched in the two tests conducted at the center positions. The inner tempered glass ply completely shattered in test PV GLZ FRM 09, conducted at the center of the latching mechanisms at 21.6 km/h.

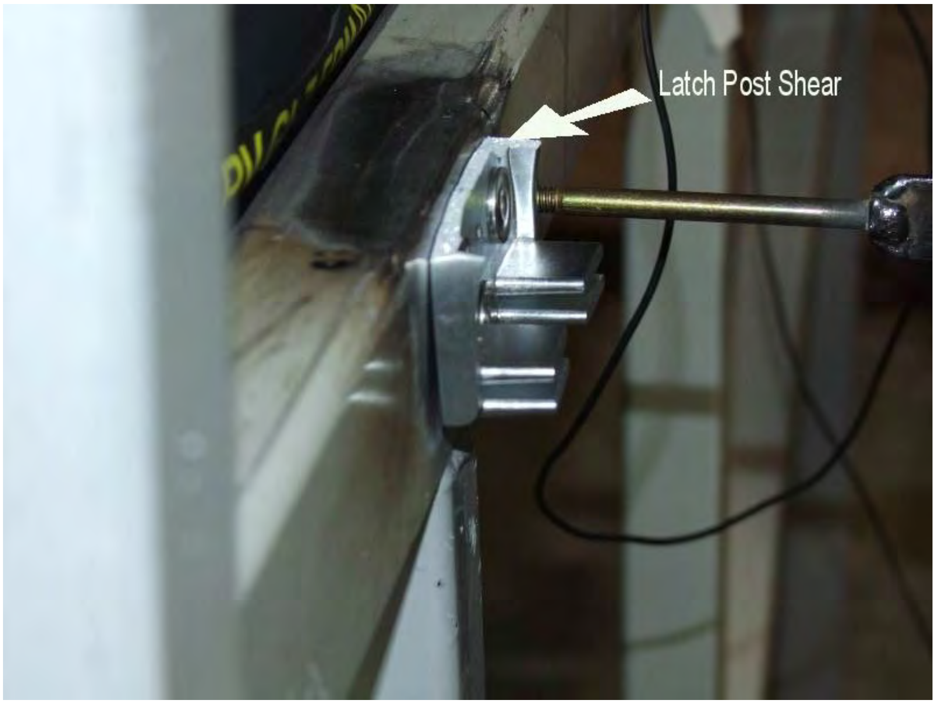

Figure 5.16 Prevost Primary Latch Post Shear Failure

Figure 5.17 Prevost Latch Bar Failure

There was one failure mode in the Van Hool latching system that allowed unlatching to occur. According to the manufacturer, the spring clip's thickness and stiffness are designed to allow the slider mechanisms to push downward and pass over the clips when the window returns to its closed position after being pushed outward. This allows the window to be latched without having to activate the emergency handle. Unlatching occurred when the spring clips bent backward during the impact, as seen in Figure 5.18, allowing the window to open. The spring clip design offered less resistance than other latch designs, and the transition velocity for unlatching was in the 11 - 13 km/h range.

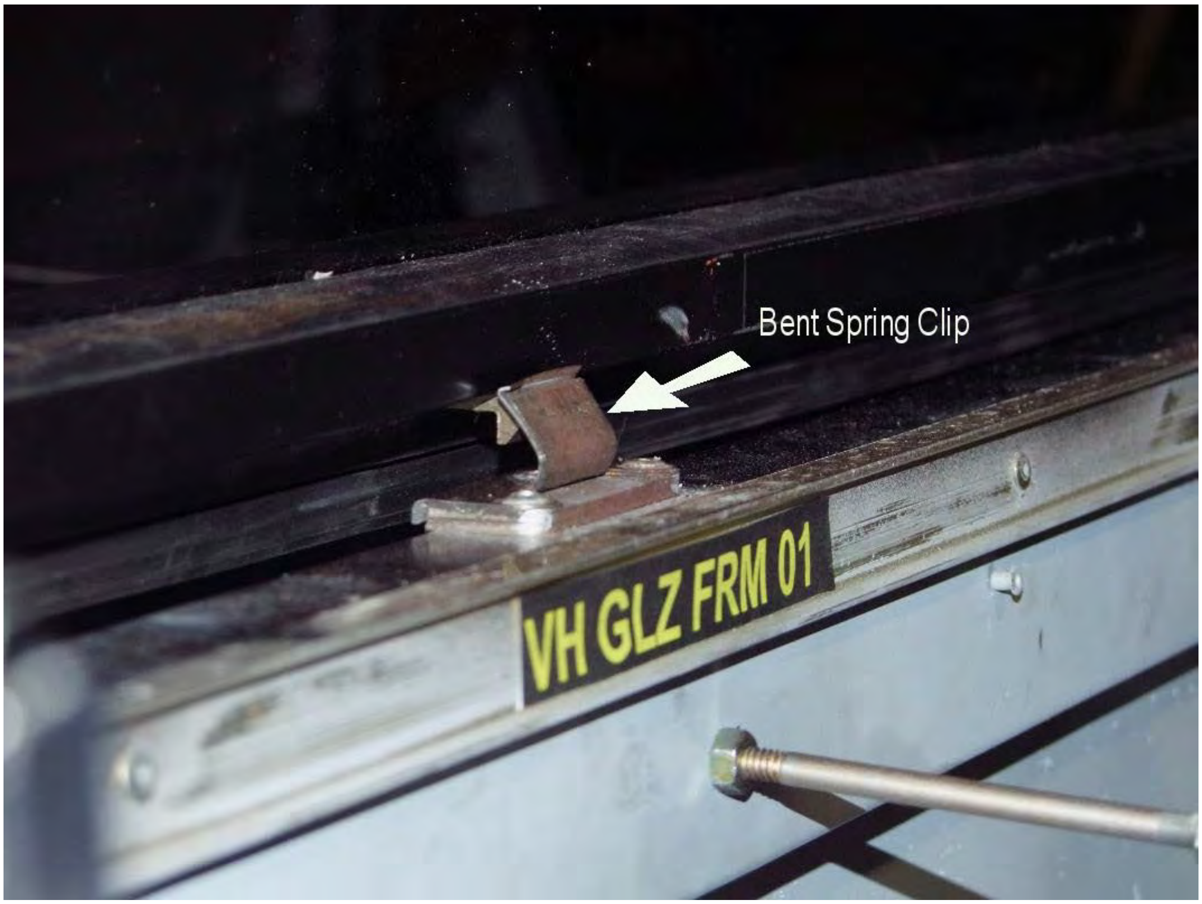

Figure 5.18 Van Hool Primary Latch Spring Clip Failure

5.7. Modified MCI E/J-Series Latch

VRTC evaluated two modifications designed around the latch plate/striker piece. Modification A is shown in Figure 5.19 along with a previously tested production plate. The modified plate was thicker, and a short vertical leg was added for increased bending strength. A metal striker post was welded to the plate, and the plate attached to the window opening with four rivets (the production striker post had a plastic sleeve over a metal post).

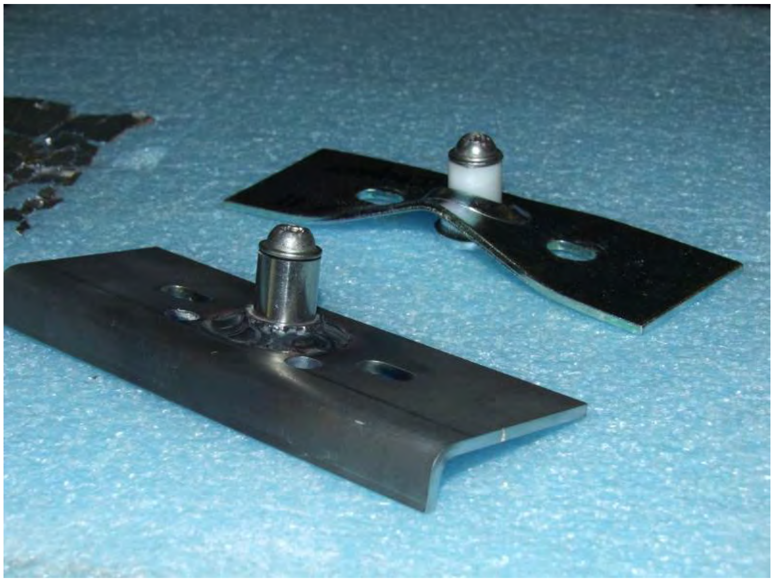

Figure 5.19 MCI E/J-Series Latch Plate Modification "A" Shown in Foreground

Modification B, shown in Figure 5.20, consisted of two production plates spot welded together. The striker post press fit into the bottom plate, and four rivets secure the plate to the window opening.

Figure 5.20 MCI E/J-Series Latch Plate Modification "B" Shown in Foreground

The production latch plates were replaced with the modifications and tested separately at the near-latch position at 21.6 km/h. Both modifications failed to keep the window closed. There was no deformation in the Modification A plate, but the post on the primary latch rotated slightly in the direction of impact. Both detent levers were pulled over the posts resulting in the window opening. The Modification B plate also remained intact. The detent lever on the primary latch pulled over the post while the secondary latch remained latched.

Steel washers were added to the top of the post in each modification to see if this could prevent the detent lever from sliding over the post (referred to as Modification A1 and Modification B1). Figure 5.21 shows Modification A1 with the window in the latched position. The detent lever was painted orange for clarity purposes. Impact tests were conducted at the near-latch position at 21.6 km/h.

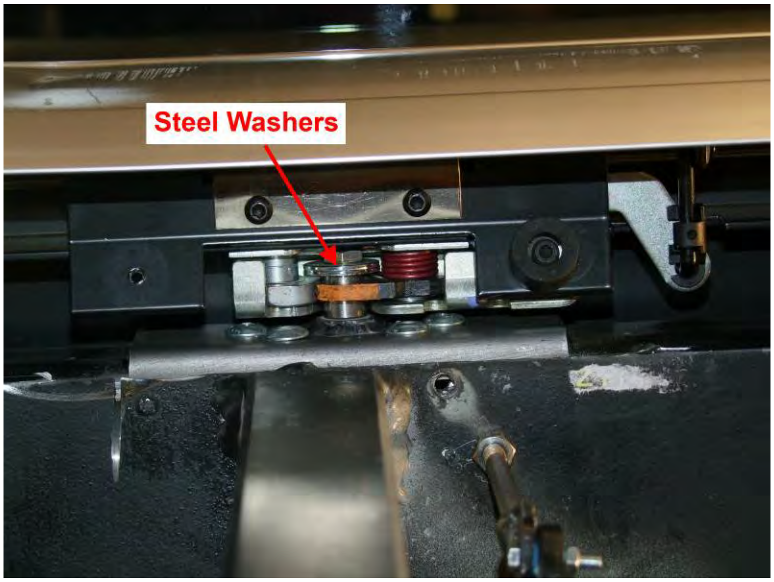

Figure 5.21 Modification A1 With Window Latched

The results of all modification testing are shown in Table 5.2. Both Modification A1 (MCI GLZ FRM 19) and Modification B1 (MCI GLZ FRM 20) prevented the window from unlatching. A final modification involved adding steel washers to the post on a production latch plate assembly, which was also tested at 21.6 km/h. Deformation was seen in the primary latch plate, but the washers prevented the detent lever from sliding over the post and the window remained latched.

Table 5.2 MCI E/J-Series Modified Latch/Striker Plate Test Results

TEST NO.	GLAZING CONFIGURATION	IMPACT LOCATION	TARGET IMPACT VELOCITY (km/h)	ACTUAL IMPACT VELOCITY (km/h)	PEAK FORCE (N)	PEAK IMPACTOR MASS EXCURSION (mm)	INTERIOR GLASS PLY BROKEN	EAXTERIOR GLASS PLY BROKEN	STRUCK LATCH OPENED	UNLATCHING FORCE (N)	WINDOW OPENING FORCE (N)	COMMENTS
MCI GLZ FRM 17	Double-Glazed - Tempered Outside/Laminated Inside	Near-Latch	21.6	21.7	9,126	58	Yes	No	Yes	18	18	Testing latch plate Modification A; Secondary latch and window opened
MCI GLZ FRM 18	Double-Glazed - Tempered Outside/Laminated Inside	Near-Latch	21.6	21.7	9,277	59	No	No	Yes	16	20	Testing latch plate Modification B; Secondary latch and window opened
MCI GLZ FRM 19	Double-Glazed - Tempered Outside/Laminated Inside	Near-Latch	21.6	21.6	8,371	60	Yes	No	No	15	20	Testing latch plate Modification A1; Used previously tested window above right latch
MCI GLZ FRM 20	Double-Glazed - Tempered Outside/Laminated Inside	Near-Latch	21.6	21.6	9,051	60	Yes	No	No	16	20	Testing latch pate Modification B1; Used previously tested window above right latch
MCI GLZ FRM 21	Double-Glazed - Tempered Outside/Laminated Inside	Near-Latch	21.6	21.6	7,650	60	Yes	No	No	16	20	Testing original latch plate with washers as hat; Used previously tested window above right latch

6. Additional Near-Latch Impacts With Production Latches on Test Frames

The test setup and conditions described in Section 5 were repeated on MCI E/J-series, Prevost, and Van Hool emergency egress windows with production latches using the correct mass from the Martec study (26 kg). As before, the purpose of these tests was to determine the unlatching threshold conditions (refer to sections 5.1 through 5.3 for a description of the test frames, glazing compositions, production latch systems, and window installation method). The latching systems are shown again in Figure 6.1. It was expected that the unlatching threshold velocity would decrease due to the increase in impactor mass.

Figure 6.1 Production Latches for MCI E/J-Series (left), Prevost H3-45 (center), and Van Hool C2045

6.1 Test Results

The impactor was positioned with the bottom edge of the impactor face 25 mm above the interior window frame that defines the daylight opening, as seen in Figure 5.12 (left). Two linear potentiometers were fastened to both upper and lower sashes to monitor any permanent deformation occurring in the four test frames used in this test series.

The results are summarized in Table 6.1. The initial test in the MCI E/J, Prevost, and Van Hool test series was conducted near the respective latch-opening threshold speed determined in the previous test series using the lighter mass (22.7 kg). Depending on whether unlatching occurred, the impact velocity for subsequent tests was gradually reduced in order to find the unlatching threshold velocity. It is noted if unlatching occurred only at the latch nearest the impact or if both latches unlatched, resulting in the window fully opening. For discussion purposes, the latching mechanism nearest the impact point is referred to as the primary latch, and the latch furthest from the impact point as the secondary latch. A linear potentiometer was fastened to the impactor face to obtain excursion values in a study looking at the effect of pre-breaking the glazing discussed later in the report (Figure 6.2). Some tests in this series were run after the glass breakage study, and impactor face displacement values are listed in the results table. The impactor face displacement is always less than the impactor displacement when measured under a loading due to spring compression.

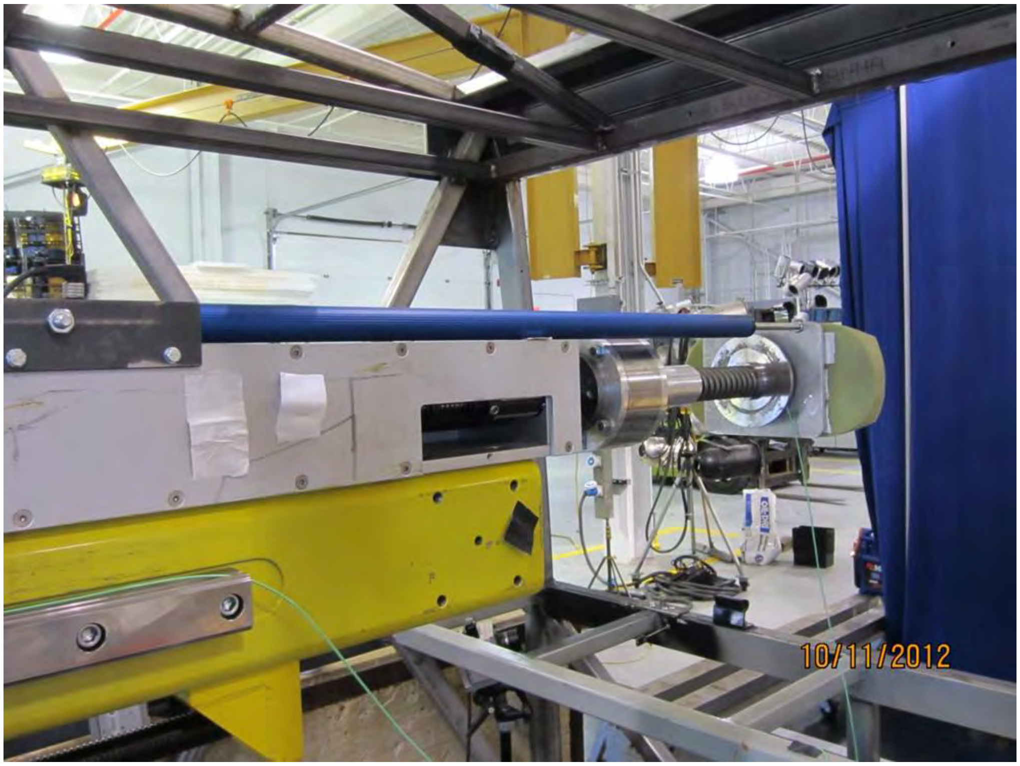

Figure 6.2 Impactor Face Displacement Transducer

Table 6.1 Production Latch Results – Near-Latch Impacts (26 kg Impactor Mass)

TEST NO.	GLAZING CONFIGURATION	ACTUAL IMPACT VELOCITY (kmph)	UNLATCHING FORCE (N)	WINDOW OPENING FORCE (N)	PEAK FORCE (N)	PEAK IMPACTOR MASS EXCURSION (mm)	PEAK IMPACTOR FACE EXCURSION (mm)	INTERIOR GLASS PLY BROKEN	EXTERIOR GLASS PLY BROKEN	LATCH OPENED	Comments
PV GLZ FRM 11	Double Glazed - Tempered/Tempered	12.5	20	35	NA	NA	n/a	no	no	Yes	Primary Post Sheared off allowing latch bar to unlatch at both latching areas and window swung open; Load cell did not work properly; LVDT did not work properly
PV GLZ FRM 12	Double Glazed - Tempered/Tempered	12	20	35	n/a	20	n/a	no	no	Yes	Latch bar dislodged from track on primary side allowing window to open on this side. Secondary latch remained latched. Load cell did not work properly
PV GLZ FRM 13	Double Glazed - Tempered/Tempered	12	22	33	2015	19	n/a	no	no	No	Repeat of previous test conditions. No damage to any latching component
PV GLZ FRM 14	Double Glazed - Tempered/Tempered	12	22	33	1937	21	n/a	no	no	Yes	Repeat of previous two test conditions. Primary Post Sheared off allowing latch bar to unlatch at both latching areas and window swung open
PV GLZ FRM 15	Double Glazed - Tempered/Tempered	11.2	20	33	1808	17	n/a	no	no	Yes	Plastic locator tab sheared off during impact. Latch bar dislodged from track on primary side allowing window to open on this side. Secondary latch remained latched.
PV GLZ FRM 16	Double Glazed - Tempered/Tempered	8.9	20	31	2812	7	n/a	no	no	No	No damage to any latch component
PV GLZ FRM 17	Double Glazed - Tempered/Tempered	8.9	20	33	2855	7	n/a	no	no	No	Repeat of previous test. No damage to any latch component
PV GLZ FRM 18	Double Glazed - Tempered/Tempered	11.2	21	30	3939	16	n/a	no	no	No	Repeat of previous test "15" conditions. No damage to any latch component
PV GLZ FRM 21	Double Glazed - Tempered/Tempered	21.6	20	40	6309	321	315	no	no	Yes	Both plastic locactor tabs sheared off. Entire latch bar pulled out from track allowing window to open
VH GLZ FRM 09	Double Glazed - Tempered/Tempered	11.2	20	20	3092	38	n/a	no	no	Yes	Primary spring clip bent backwards allowing window to open on this side. Secondary latch held. Window did not relatch
VH GLZ FRM 10	Double Glazed - Tempered/Tempered	8.9	22	20	2430	25	n/a	no	no	No	Window stayed latched. Primary spring clip bent backwards but held on to sliding mechanism. Secondary latching system remained latched.
VH GLZ FRM 11	Double Glazed - Tempered/Tempered	10.1	25	36	2797	30	n/a	no	no	Yes	Primary spring clip bent backwards allowing window to open on this side. Secondary latch held. Window did not relatch
VH GLZ FRM 12	Double Glazed - Tempered/Tempered	8.9	23	34	2567	24	n/a	no	no	No	Repeat of test "10" conditions.Window stayed latched. Primary spring clip bent backwards but held on to sliding mechanism. Secondary latching system remained latched.
VH GLZ FRM 13	Double Glazed - Tempered/Tempered	10.1	25	34	2567	30	n/a	no	no	Yes	Repeat of test "11" conditions. Primary spring clip bent backwards allowing window to open on this side. Secondary latching system remained latched. Window did not relatch
MCI GLZ FRM 22	Double Glazed - Temp Exterior/Lam Interior	15.2	n/a	n/a	5840	44	n/a	no	no	No	Primary latch plate bent upwards but detent lever did not slide over post
MCI GLZ FRM 23	Double Glazed - Temp Exterior/Lam Interior	14.2	n/a	n/a	5166	40	n/a	no	no	No	Primary latch plate bent upwards but detent lever did not slide over post
MCI GLZ FRM 24	Double Glazed - Temp Exterior/Lam Interior	16.2	22	35	6390	48	n/a	no	no	No	Primary latch plate bent upwards but detent lever did not slide over post
MCI GLZ FRM 25	Double Glazed - Temp Exterior/Lam Interior	18	18	40	7258	55	n/a	no	no	No	Primary latch plate bent upwards, striker post bent backwards and disloged from plate but detent lever did not slide over post
MCI GLZ FRM 30	Single Glazed - Laminated	21.6	22	30	6312	226	230	n/a	yes	Yes	Unlatched at both locations. Glass separated from window frame at impact area.
MCI GLZ FRM 31	Single Glazed - Laminated	17.9	18	34	3539	94	87	n/a	yes	No	Window remained latched at both locations. Glass separated fom window frame. More stretching of PVB interlayer seen in this test.

6.2 Discussion

Figure 6.3 shows the results of each motorcoach type grouped according to whether the window remained latched or unlatched for tests conducted near the primary latch. Shaded bands are used to show the transition velocity where unlatching occurs. As expected, the transition velocities were lower for both the Van Hool and Prevost windows: 9 – 10 km/h and 11 - 12 km/h respectively. An increase in transition velocity was unexpectedly measured in the MCI E/J-series: 18 - 21.6 km/h.

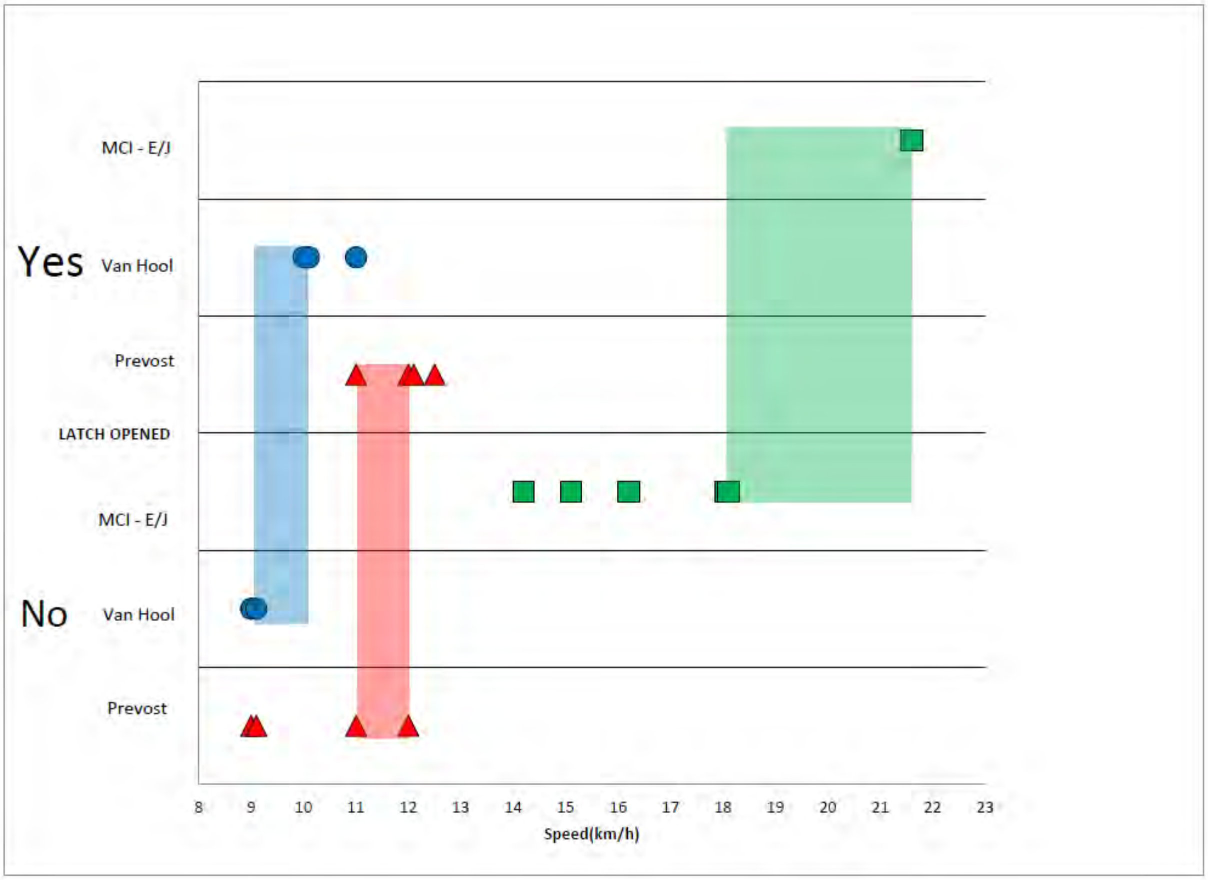

Figure 6.3 Unlatching Threshold Velocities for Production Latches Using the 26 Kg Impactor

The three different failure modes observed in impact testing on the Prevost windows with the lighter mass were also seen in this test series, with the correct heavier mass resulting in the window unlatching. In tests PV GLZ FRM 11 and PV GLZ FRM 14, the top of the primary latch post sheared off due to loading of the latch bar (see Figure 5.16). In tests PV GLZ FRM 12 and PV GLZ FRM 15, the composite latch bar partially separated from the window frame, while in test PV GLZ FRM 21 the entire latch bar separated from the window frame resulting in the window opening.

As for the lower mass tests, there was one failure mode in the Van Hool latching system that allowed unlatching to occur. Unlatching occurred when the spring clips bent backward during the impact, as seen in Figure 5.18, allowing the window to open. This event was seen in tests VH GLZ FRM 09, VH GLZ

FRM 11, and VH GLZ FRM 13. Bending occurred in the primary spring clip in tests VH GLZ FRM 10 and VH GLZ FRM 12, but the sliding mechanism did not slide over the clip.

Unlatching in the MCI E/J-series occurred when the primary latch's detent lever, under impact loading, transferred a force great enough to deform the striker plate and unseat the striker post from the plate. The post then rotated in the direction of impact, allowing the lever to slide over the post (see Figure 5.14). This event occurred in test MCI GLZ FRM 30, which was conducted at the conditions in the Martec report (26 kg, 21.6 km/h). In tests where the window did not unlatch, bending of the latch plate was observed, but the detent lever did not slide over the striker post as seen in tests MCI GLZ FRM 22 through 25.

7. Additional Center Window Impacts With Production Latches on Test Frames

Impact tests using the higher mass (26 kg) were conducted at the center of the glazing to determine the performance of production latches with impacts further away, and potentially to determine the strength of the glazing and the attachment of the glazing to the window frame.

7.1 Test Description and Results

The impactor was positioned at the center of the window's daylight opening as measured from the interior window frame (Figure 7.1). A linear potentiometer attached to the impactor face recorded its displacement relative to the impactor.

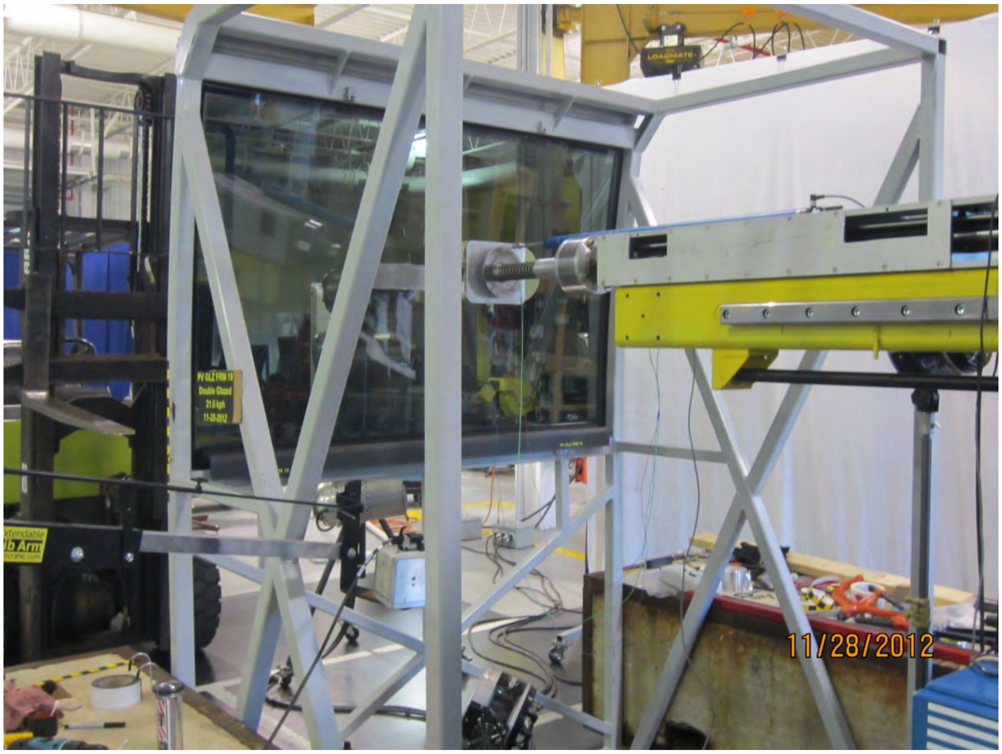

Figure 7.1 Center of Daylight Opening Impact Test Setup

The test results are shown in Table 7.1. The Van Hool and Prevost production latches were unable to keep the windows closed.. Both spring clips on the Van Hool window bent backwards, and the window fully opened (VH GLZ FRM 18). The plastic locator tabs on the Prevost window sheared in half, and the latch bar pulled out entirely from the track on the window frame allowing the window to open (PV GLZ FRM 19 and PV GLZ FRM 20). Both tempered panes remained intact in two Prevost tests, while the exterior glass ply shattered in the Van Hool test. The MCI production latches kept the laminated window closed. No damage was seen in the striker plates and posts. The impact broke both glass panes and stretching of the PVB interlayer occurred. Because of the latch failure, an assessment of the strength of the glazings could not be made.

Table 7.1 Production Latch Results – Center of DLO Impacts (26 kg Impactor Mass)

TEST NO.	GLAZING CONFIGURATION	IMPACT VELOCITY (kmph)	UNLATCHING FORCE (N)	WINDOW OPENING FORCE (N)	PEAK FORCE (N)	PEAK IMPACTOR MASS EXCURSION (mm)	PEAK IMPACTOR FACE EXCURSION (mm)	INTERIOR GLASS PLY BROKEN	EXTERIOR GLASS PLY BROKEN	LATCH OPENED	COMMENTS
VH GLZ FRM 18	Double Glazed - Temp Exterior/Tmp Interior	21.5	200	142	9,046	72	61	No	Yes	Yes	Both spring clips bent backwards allowing window to fully open
PV GLZ FRM 19	Double Glazed - Temp Exterior/Tmp Interior	21.4	89	178	9,779	69	64	No	No	Yes	Both plastic locactor tabs sheared off. Entire latch bar pulled out from track allowing window to open
PV GLZ FRM 20	Double Glazed - Temp Exterior/Tmp Interior	21.6	94	240	8,774	69	64	No	No	Yes	Repeat of test PV GLZ FRM 19. Both plastic locactor tabs sheared off. Entire latch bar pulled out from track allowing window to open
MCI GLZ FRM 46	Single Glazed - Laminated	21.7	89	178	6,241	115	104	NA	Yes	No	No visible damage to latch plate or striker post
MCI GLZ FRM 49	Single Glazed - Laminated	21.7	107	147	10,086	72	64	NA	Yes	Yes	No visible damage to latch plate or striker post

8. Additional Impacts With Countermeasure Latches on Test Frames

Previous testing at the center of the daylight opening and near the latch identified various failure modes for each latching system that enabled the emergency egress windows to partially or fully open. An attempt was made to modify the latch systems with simple designs to see if the impactor could be contained when tested at the Martec study conditions (26 kg mass). The latch countermeasures for the MCI E/J-series, Prevost, and Van Hool windows are described below.

8.1 MCI Countermeasure Description and Test Results

As described in section 5.7, Modifications A1 and B1 demonstrated that they were capable of remaining latched when tested with the lighter mass (22.7 kg) at 21.6 km/h. Modification A1 was also evaluated under Martec impact conditions, and the results are shown in Table 8.1.

Table 8.1 MCI E/J-Series Latching System Countermeasure Test Results

TEST NO.	GLAZING CONFIGURATION	IMPACT LOCATION	IMPACT VELOCITY (kmph)	UNLATCHING FORCE (N)	WINDOW OPENING FORCE (N)	PEAK FORCE (N)	PEAK IMPACTOR MASS EXCURSION (mm)	PEAK IMPACTOR FACE EXCURSION (mm)	INTERIOR GLASS PLY BROKEN	EXTERIOR GLASS PLY BROKEN	LATCH OPENED	COMMENTS
MCI GLZ FRM 26	Double Glazed - Temp Exterior/Interior	Near Latch	21.7	25	42	8,918	69	45	yes	no	no	MCI latch plate modification A1 used at primary and secondary positions
MCI GLZ FRM 27	Double Glazed - Temp Exterior/Interior	Near Latch	21.8	24	41	9,178	69	44	yes	no	no	Repeat of previous test conditions (TC)
MCI GLZ FRM 33	Single Glazed - Laminated	Center of DO	21.6	22	33	7,784	101	99	n/a	yes	no	MCI latch plate modification A1 used at primary and secondary positions. Glazing intact - not pre-broken.

The countermeasure was installed at both latching locations. Pre-breaking the glass was not done prior to testing in order to produce the highest impact forces on the latch countermeasures. Modification A1 prevented the window from unlatching when tested to the Martec study conditions, both near the latch and at the center of the daylight opening.

8.2 Van Hool Countermeasure Description and Test Results

Failure in the Van Hool latching system occurred when the spring clip mounted on the bus body bent backwards due to impact forces allowing the window to open (see Figure 5.18). The production clip is made from stainless steel with a thickness of 0.058 inch. Modified spring clips were fabricated out of cold rolled steel with a thickness measuring 0.130 inch. The modification is shown in Figure 8.1 on the left. Two additional rivets were used to attach the modified spring clips to the bus body. Both production spring clips were replaced with this modification. A series of impact tests were conducted at the Martec study conditions and are summarized in Table 8.2. Subsequent modifications were made to the latching system based on test observations and are described below.

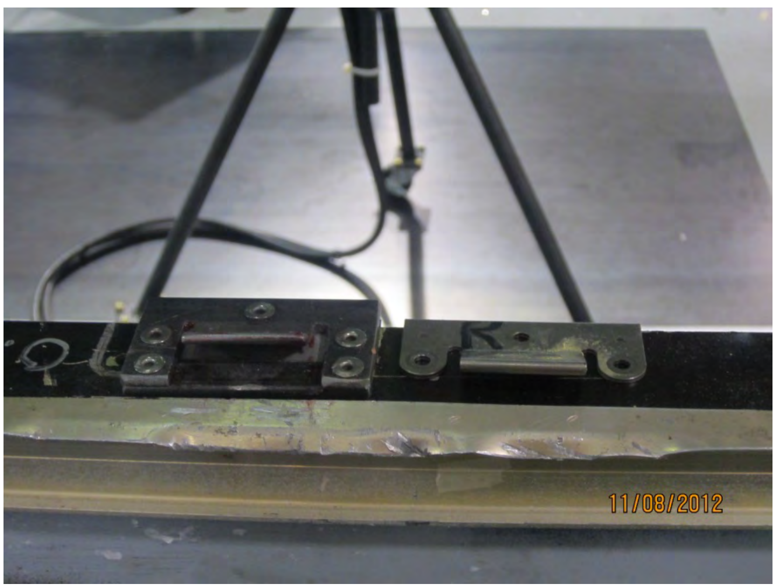

Figure 8.1 Van Hool Modified Spring Clip (left) Versus Production Spring Clip

Table 8.2 Van Hool Latching System Countermeasure Test Results

TEST NO.	GLAZING CONFIGURATION	IMPACT LOCATION	IMPACT VELOCITY (kmph)	UNLATCHING FORCE (N)	WINDOW OPENING FORCE (N)	PEAK FORCE (N)	PEAK IMPACTOR MASS EXCURSION (mm)	PEAK IMPACTOR FACE EXCURSION (mm)	INTERIOR GLASS PLY BROKEN	EXTERIOR GLASS PLY BROKEN	LATCH OPENED	COMMENTS
VH GLZ FRM 14	Double Glazed - Temp Exterior/Interior	Near Latch	21.5	35	35	5,971	398	NA	no	no	yes	Spring clips made of thicker steel installed at both latching locations. Slider mechanisms pulled partially out from track and rotated allowing them to slide over spring clips
VH GLZ FRM 15	Double Glazed - Temp Exterior/Interior	Near Latch	21.5	35	37	7,365	379	371	no	no	yes	Aluminum Angle bar fastened to window track containing sliding mechanism to stiffen window frame. Sliding mechanism slid out from track and rotated
VH GLZ FRM 16	Double Glazed - Temp Exterior/Interior	Near Latch	21.6	>40	35	7,819	92	87	no	no	yes	Spring clips made of thicker steel installed at both latching locations. Slider mechanisms pulled partially out from track and rotated allowing them to slide over spring clips
VH GLZ FRM 17	Double Glazed - Temp Exterior/Interior	Center of DO	21.5	n/a	n/a	9,778	72	69	yes	yes	no	Used modifed latches developed for test VH GLZ FRM 16. Both window panes shattered but latches remained latched

An impact (VH GLZ FRM 14) was conducted 25 mm above the primary countermeasure latch at 21.6 km/h. The window unlatched at both locations and swung open. The glass did not break. The failure occurred when the sliding mechanism located under the window pulled partially out from the track, rotated, and slid over the spring clips. There was no visible damage to the modified spring clips. An angled aluminum bar was fastened to the window track at both latch locations to provide stiffness, and the impact conditions were repeated (VH GLZ FRM15). Similar results were seen in the latch failure, and the window opened while the glass remained intact. Modifications were subsequently made to the slider mechanism. The brass production mechanisms were replaced with ones fabricated out of steel containing a longer lip to catch more of the spring clip. A steel reinforcing bar measuring 6 inches in length was inserted into the window frame channel and attached to the slider mechanism with stainless steel screws. Figure 8.2 shows the modifications made to both latching mechanisms. Increasing the spring clip stiffness prevented the window from closing on itself when released from an open state as designed in the prodution units. The emergency handle could still be used to slide the mechanisms for latching purposes but unlatching required a force greater than 40 lbs.

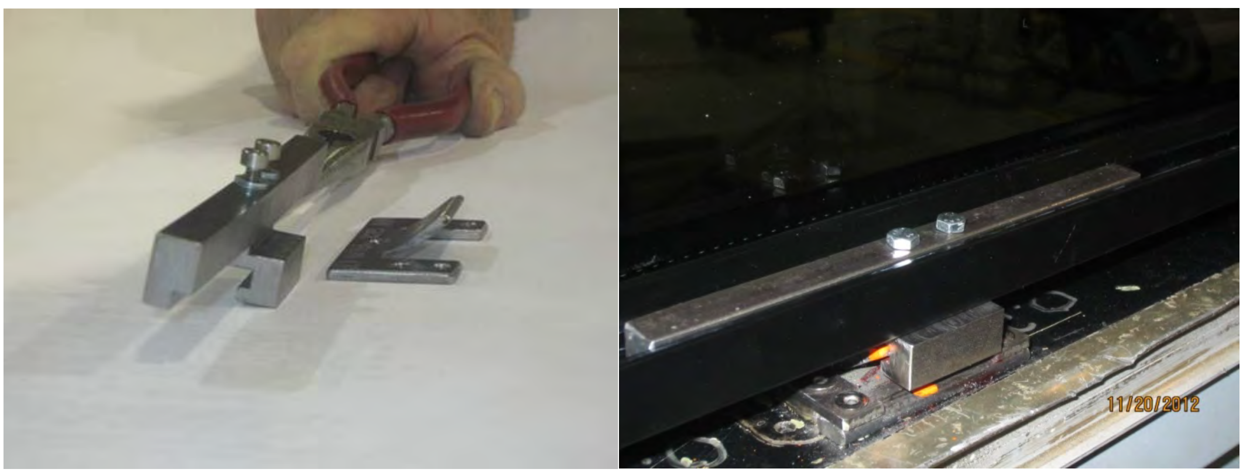

Figure 8.2 Van Hool Latch Countermeasure System

An impact (VH GLZ FRM 16) was conducted near the primary latch with the latest modifications, including the modified spring clips used in the previous tests. The modified latch at the impact location failed due to shearing of the bolts holding the slider mechanism to the reinforcing bar and the window partially opened. There was significant damage to the window frame channel and the spring clip also bent backwards (seen in Figure 8.3). The secondary latch with the latest modifications remained latched and the glass remained intact.

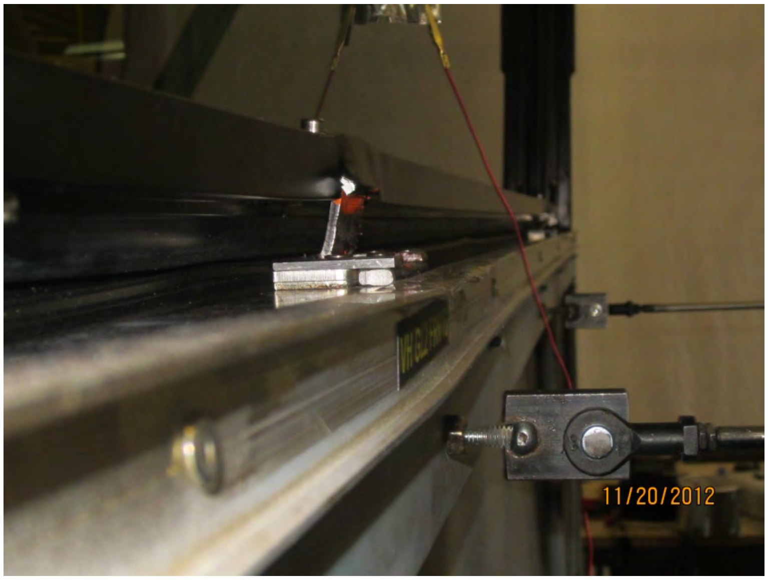

Figure 8.3 Damage to Window Channel and Modified Spring Clip

A new set of the spring clip countermeasures tested in VH GLZ FRM 16 were fabricated, and an impact test (VH GLZ FRM 17) was then conducted at the center of the daylight opening using them. Both tempered glass panes shattered and the latches remained latched.

8.3 Prevost Countermeasure Description and Test Results

Failure in the Prevost latching system occurred by three different modes: shearing of the aluminum striker post which allowed the latch bar to swing open, shearing of the plastic locator tabs which help to secure the latch bar to the window frame channel, and shearing of the composite latch bar. Striker post and locator tab countermeasures were fabricated out of steel at VRTC to provide increased strength (VRTC did not have the in-house capability to fabricate a suitable latch bar countermeasure). The modifications are shown in Figure 8.4.

Figure 8.4 Prevost Striker Post and Locator Tab Countermeasures

Impact tests were conducted with the countermeasures installed at both latching locations with the results shown in Table 8.3.

Table 8.3 Prevost Latching System Countermeasure Test Results

TEST NO.	GLAZING CONFIGURATION	IMPACT LOCATION	IMPACT VELOCITY (kmph)	UNLATCHING FORCE (N)	WINDOW OPENING FORCE (N)	PEAK FORCE (N)	PEAK IMPACTOR MASS EXCURSION (mm)	PEAK IMPACTOR FACE EXCURSION (mm)	INTERIOR GLASS PLY BROKEN	EXTERIOR GLASS PLY BROKEN	LATCH OPENED	COMMENTS
PV GLZ FRM 22	Double Glazed - Temp Exterior/Interior	Near Latch	21.6	20	45	7,781	254	247	no	no	yes	Latch posts and bar locator tabs made at VRTC from steel. Locator tab screws failed allowing latch bar to pull out entirely from track
PV GLZ FRM 23	Double Glazed - Temp Exterior/Tmp Interior	Near Latch	21.6	18	40	7,998	213	208	no	no	yes	Locator tabs modified and longer screws added. Composit latch bar sheared along top and allowing window to open
PV GLZ FRM 24	Double Glazed - Temp Exterior/Tmp Interior	Center of DO	21.7	15	45	8,941	69	64	no	no	no	Window bowed out but did not break. Latches held

An impact test (PV GLZFRM 22) was performed above the primary latch using the countermeasures described above. The components were attached to the window and bus frame similar to the production pieces: 3 rivets secured the striker posts to the bus frame/sash, and 2 screws secured the locator pins to the aluminum window frame channel. During the impact, the screws attaching the locator pins pulled out of the channel allowing the tabs to fall away. The latch bar pulled from the channel allowing the window to open. The tempered glass panes remained intact.

A refinement in the locator tab modification was made by welding a bar to the underside, allowing the tab to be secured to the channel with two additional screws. Production screws were replaced with longer ones to provide more grip into the aluminum channel, and the impact test conditions were repeated (PV GLZ FRM 23) on a new window. The locator tabs remained fixed to the channel, and no damage was seen in either the tabs or striker posts. The latch bar, however, was damaged and split along the perforated top surface (Figure 8.5) allowing the window to open. The tempered glass panes remained intact.

Figure 8.5 Prevost Latch Bar Failure With Countermeasures

In an impact test conducted at the center of the daylight opening (PV GLS FRM 24), the latch countermeasures remained latched. The window bowed outward and the impactor face displacement measured 69 mm, but there was no damage to the tempered glass panes. Figure 8.6 shows the maximum dynamic deflection captured from high speed video.

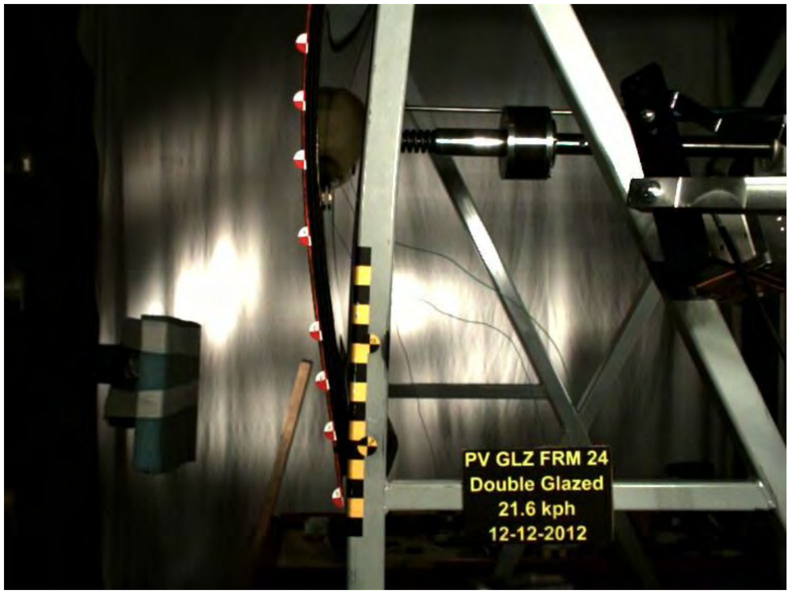

Figure 8.6 Prevost Maximum Dynamic Deflection in Center of DLO Impact

9. Fixed Window Testing on Test Frames

A series of tests was performed on production fixed windows from the MCI E/J-series to determine their performance under the Martec study conditions. The windows were attached to the E/J-series test frame in similar fashion to the egress windows, such that the vertical window edges were not fixed to the frame body. The mechanism holding the fixed window closed is shown in Figure 9.1. A retaining clip made of thin steel (shown in white) was fastened to the bus body and pressed up against a rubber window retainer fastened to the window frame. A track attached to the top of the glazing hooks into the drip rail, allowing the window to rotate outward if the retaining mechanism was removed or failed. There are two similar mechanisms spaced equally apart from the center of the window to keep the window fixed to the bus frame.

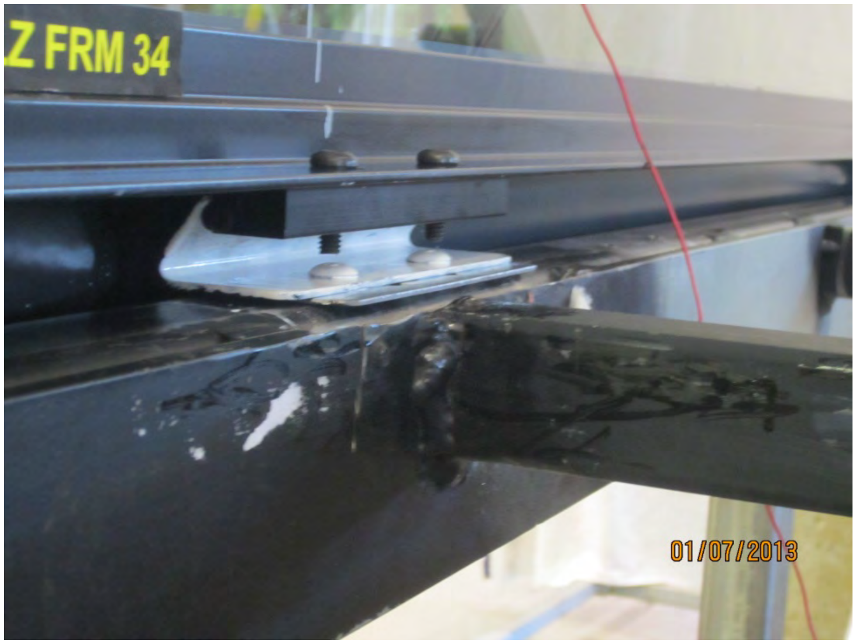

Figure 9.1 Retaining Clip Securing MCI E/J-Series Fixed Window

9.1 Test Methods and Results

Impact tests were conducted near the primary locking mechanism and and at the center of daylight opening as measured from the interior window frame. For impacts near the retaining clip, the bottom edge of the impactor face was positioned 25 mm above the lower interior window frame (similiar to emergency window testing near the latch). The test results are shown in Table 9.1. In the two tests conducted near the retaining clip (MCI GLZ FRM 34 and MCI GLZ FRM 35), the primary retaining clip on the test frame bent backwards allowing the window to partially open. The secondary retaining clip away from the impact location bent backwards but remained “locked” to the rubber retainer. An impact at the center of the daylight opening with the single-glazed composition, glass intact, (MCI GLZ FRM 36), resulted in failure at both retaining clips allowing the window to fully open as seen in Figure 9.2. A similar test to the double-glazed composition (MCI GLZ FRM 37) did not result in the window opening, although bending did occur in both retainer clips. Two tests using the double-glazed composition were conducted at the center of the daylight opening (MCI GLZ FRM 38 and MCI GLZ FRM 39) in which the laminated glass was pre-broken using the 50 mm diagonal offset grid (to be described in section 11). The exterior tempered pane in the double glazed window was removed prior to the test. The window remained closed in both tests with no damage seen in the retainer clips. An average impactor face displacement of 202 mm was recorded.

Table 9.1 MCI E/J-Series Fixed Window Results for Impacts Conducted at Martec Impact Conditions

TEST NO.	GLAZING CONFIGURATION	IMPACT LOCATION	IMPACT VELOCITY (kmph)	PEAK FORCE (N)	PEAK IMPACTOR MASS EXCURSION (mm)	PEAK IMPACTOR FACE EXCURSION (mm)	INTERIOR GLASS PLY BROKEN	EXTERIOR GLASS PLY BROKEN	LATCH OPENED	COMMENTS
MCI GLZ FRM 34	Double Glazed - Tempered Exterior/Laminated Interior	Near Latch	21.7	8,143	84	82	no	no	Partially	Impact bent retainer clip on sash backwards at primary location alowing partial window opening. Secondary retainer clip bent backwards slightly but held window closed
MCI GLZ FRM 35	Single Glazed - Laminated	Near Latch	21.8	8,421	137	132	n/a	Yes	Partially	Impact bent retainer clip on sash backwards at primary location alowing partial window opening. Secondary retainer clip bent backwards slightly but held window closed
MCI GLZ FRM 36	Single Glazed - Laminated	Center of DO	21.6	8,396	88	87	n/a	Yes	Fully	Glass was intact prior to test. Both retainer clips bent backwards allowing the window to open.
MCI GLZ FRM 37	Double Glazed - Tempered Exterior/Laminated Interior	Center of DO	21.6	10,162	44	17	No	No	No	Glass was intact prior to test. Additional contact switches added to oppisite frame edge (2 places) and bottom edge at DO center. Both retainer clips bent backwards but held window closed.
MCI GLZ FRM 38	Double Glazed - Tempered Exterior/Laminated Interior	Center of DO	21.6	3,027	200	186	Pre-Broke	Pre-Broke	No	50 mm diagonally offset grid patter used to pre-break glass. Secondary retainer did not hold and window was partially open on this side but did not engage contact switch. No tearing of PVB interlayer
MCI GLZ FRM 39	Single Glazed - Laminated	Center of DO	25.2	3,550	204	187	Pre-Broke	Pre-Broke	No	50 mm grid pattern staggered diagonally used to pre-break glass. No tearing of PVB interlayer post impact

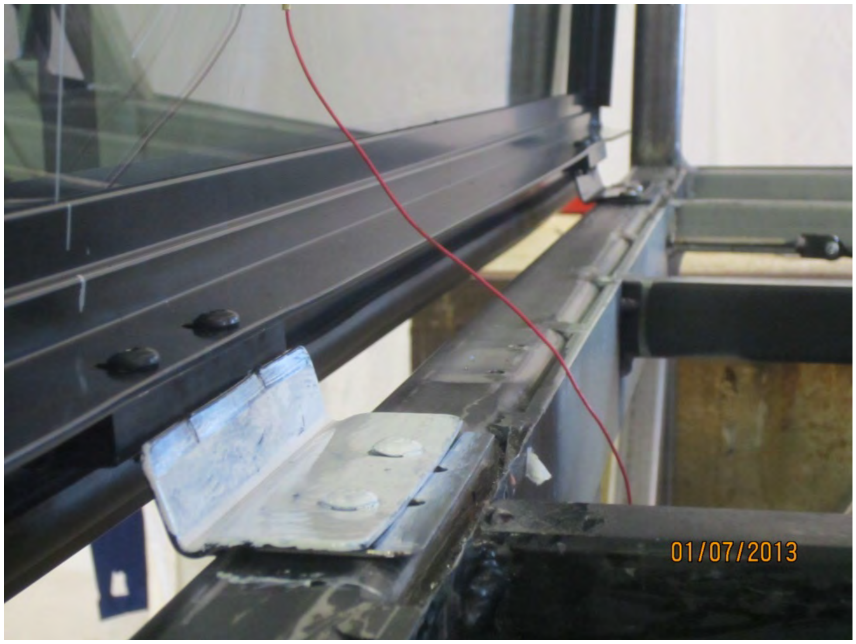

Figure 9.2 Failure of Retaining Clips Resulting in Window Opening

10. Glass Breakage Procedure

A study was initiated to address the glazing strength in case the window is pre-broken prior to occupant loading in a rollover. The goal was to develop a procedure for breaking the glass prior to impacting the window. The pre-broken windows were then tested at the Martec study conditions to compare impactor excursion values.

Various methods were used to break the advanced glazing prior to the impact tests. These methods included an impact with a hammer (pummeled) as well as several patterns of breakage using an automatic center punch and an electric staple gun. The patterns included punching holes in both the interior and exterior sides of the laminated glazing with the holes spaced a known distance apart. Grids with 50 mm and 75 mm spacing were used in the study. The resulting breakage patterns for pummeled and the 50 mm grid are shown in Figure 10.1. The 75 mm grid had 53 percent fewer punch holes. MCI single and double-glazed windows from the E/J-series motorcoach were tested. The exterior tempered glass pane in the double-glazed window was broken prior to marking the grid, which resulted in a window that was similar in construction to the single-glazed laminated window.

Figure 10.1 Resulting Breakage Patterns From Pummeling and 50 mm Grid Using Staple Gun

The first step in the process was to mark the glazing surface in a horizontal and vertical grid separated by 50 or 75 mm, with the first point coincident with center of the daylight opening. To avoid tearing the PVB interlayer, the grid on the outer glass surface was staggered. For example, a 75 mm "diagonally offset" pattern had a 75 mm x 75 mm pattern on the inside and the same pattern, offset by 37.5 mm horizontally and vertically, on the outside surface. The breakage pattern developed for the Ejection Mitigation regulation (FMVSS No. 226), where the 75 mm pattern is "horizontally offset," was also studied (See Figure 10.2).

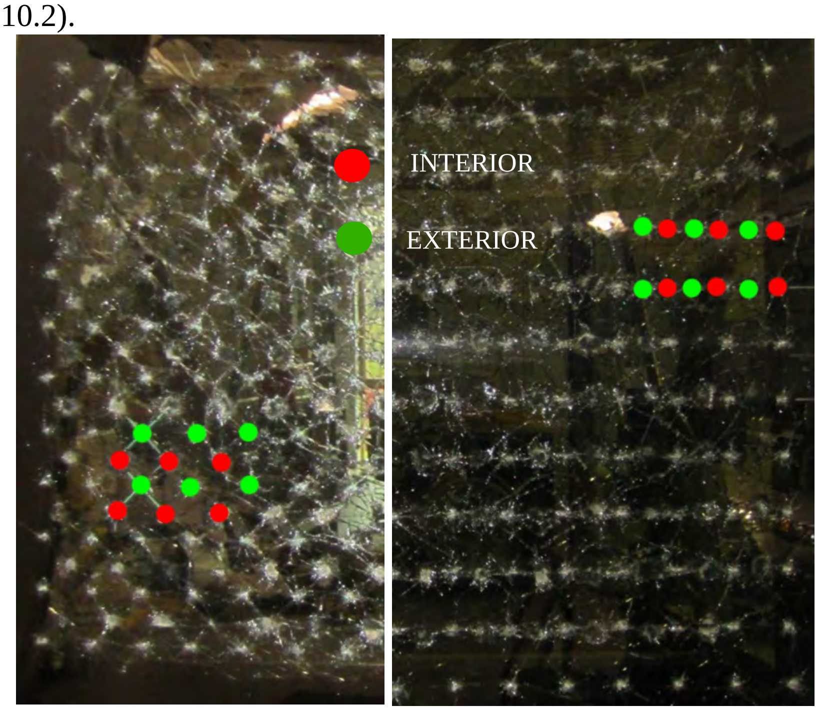

Figure 10.2 Diagonally and Horizontally Offset Breakage Patterns

10.1 Test Description and Results

The impact tests were performed with the impactor positioned to strike the window at its center of daylight opening, as measured on the interior window frame, and the test speed was 21.6 km/h. Latch

Modification A1, described in section 5.7, was used to ensure the windows did not unlatch. A linear potentiometer was attached to the impactor face to measure its displacement from first contact with the window surface through maximum impactor face dynamic displacement. It was quickly determined that the automatic center punch used in FMVSS No. 226 was not practical for large bus windows and was not tested in this study. An electric staple gun without any staples, shown in Figure 10.3, allowed for single person operation and did not produce tears in the PVB interlayer.

Figure 10.3 Electric Staple Gun

The results are shown in Table 10.1. The impacts did not produce any tearing in the PVB, and the windows remained latched in all tests. The results followed the expected trend that more glass breakage yields more peak excursion. The three pummeled tests (MCI GLZ FRM 28, MCI GLZ FRM 29, and MCI GLZ FRM 32) established the upper bound of displacement (the lower bound displacement of 101 mm was established with an unbroken laminated glazing test (MCI GLZ FRM 33, reported in section 8.1). There did not appear to be a significant difference in displacment between the 50 and 75 mm diagonally offset patterns: the 50 mm pattern (tests GPD_50mm_OS_D_03 and GPD_50mm_OS_D_04) achieved 86 percent of the maximum displacement seen in the pummeled tests while the 75 mm pattern (tests GPD_75mm_OS_D_01 and GPD_75mm_OS_D_01) achieved 82 percent. The 75 mm horizontally offset grid (tests MCI GLZ FRM 40 and MCI GLZ FRM 41) achieved 71 percent of the maximum value measured in the pummeled tests.

It is believed that the 50 and 75 mm matrix hole punching methods are more controllable and objective than pummeling the window with a hammer, while also creating very extensive breakage patterns.

Table 10.1 Impactor Excursion for Glass Breakage Procedures

TEST NO.	GLAZING CONFIGURATION	PEAK FORCE (N)	PEAK IMPACTOR FACE EXCURSION (mm)	LATCH OPENED	COMMENTS
MCI GLZ FRM 28	Double-Glazed - Laminated Single Pane	n/a	211	No	Pummeled; Tempered Exterior Glass Removed
MCI GLZ FRM 29	Double-Glazed - Laminated Single Pane	2,976	217	No	Pummeled; Tempered Exterior Glass Removed
MCI GLZ FRM 32	Single-Glazed - Laminated	2,473	215	No	Pummeled; Tempered Exterior Glass Removed
			AVG. 214		
GPD_75mm_OS_D_01	Single-Glazed - Laminated	2,441	182	No	75 mm Diagonally Offset Grid; No Tearing of PVB
GPD_75mm_OS_D_02	Single-Glazed - Laminated	2,894	168	No	75 mm Diagonally Offset Grid; No Tearing of PVB
			AVG. 175		
MCI GLZ FRM 40	Single-Glazed - Laminated	3535	154	No	75 mm Horizontally Offset Grid; No Tearing of PVB
MCI GLZ FRM 41	Single-Glazed - Laminated	3674	148	No	75 mm Horizontally Offset Grid; No Tearing of PVB
			AVG. 151		
GPD_50mm_OS_D_03	Single-Glazed - Laminated	2,851	191	No	50 mm Diagonally Offset Grid; No Tearing of PVB
GPD_50mm_OS_D_04	Single-Glazed - Laminated	3,082	176	No	50 mm Diagonally Offset Grid; No Tearing of PVB
			AVG. 184		

Single-glazed laminates with a thicker PVB intertlayer were also tested at the Martec study conditions to determine if a reduction in impactor excursion could be obtained. Thicker laminates are available in production side windows for the MCI E/J-series with thicknessess of 1.14 and 1.5 mm (vs 0.76 mm standard thickness). The PVB thickness studied in this test series was 1.52 mm, and each glass ply measured 2.5 mm - the same thickness in the standard production window. Four glass breakage procedures were examined: fully pummeled, 75 mm diagonally offset, 50 mm diagonally offset, and 75 mm horizontally offset grids.

The results are shown in Table 10.2. The impacts did not produce any tearing in the PVB, and the windows remained latched in all tests. Compared to the standard thickness PVB laminates, the excursions were reduced by an average of 14 percent for the four breakage methods.

Table 10.2 Impactor Excursion for Thicker PVB Laminates

TEST NO.	GLAZING CONFIGURATION	PEAK FORCE (N)	PEAK IMPACTOR FACE EXCURSION (mm)	LATCH OPENED	COMMENTS
MCI GLZ FRM 42	Single Glazed - Laminated	3,154	186	No	Glass Pummeled
MCI GLZ FRM 43	Single Glazed - Laminated	3,559	144	No	75 mm Diagonally Offset Grid; No Tearing of PVB
MCI GLZ FRM 44	Single Glazed - Laminated	3,641	147	No	75 mm Diagonally Offset Grid; No Tearing of PVB
MCI GLZ FRM 45	Single Glazed - Laminated	3,319	166	No	50 mm Diagonally Offset Grid; No Tearing of PVB
MCI GLZ FRM 47	Single Glazed - Laminated	9,227	67	No	Glass intact-no pre-breaking
MCI GLZ FRM 48	Single Glazed - Laminated	3,508	152	No	75 mm Horizontally Offset Grid; No Tearing of PVB

11. MCI D-Series Frame and Motorcoach Section Comparisons

This section compares the setups of the MCI D-series bus section tests and window frame tests to determine whether the frame tests are more or less stringent than the bus section tests (the middle section of the MCI D motorcoach bus body was removed and fabricated into the test frame as explained in Section 5.4). For this comparison, the deflections of the bus section and frame during impacts were measured, and the test results from the bus section and frame tests were compared, for tests which were performed under similar conditions.

The effect of internally bracing the section was measured during the initial testing on the MCI D-series bus section. Linear string pots were attached to the external upper portion of the bus frame at two locations (left and right). Impacts were conducted at the center of the daylight opening at 21.6 km/h, with and without the bracings. Polycarbonate windows were used to allow for multiple and repeatable impacts. This same setup was applied to the MCI D-series frame (Figure 11.1). Polycarbonate windows were tested using a new inner clamp ring for each test.

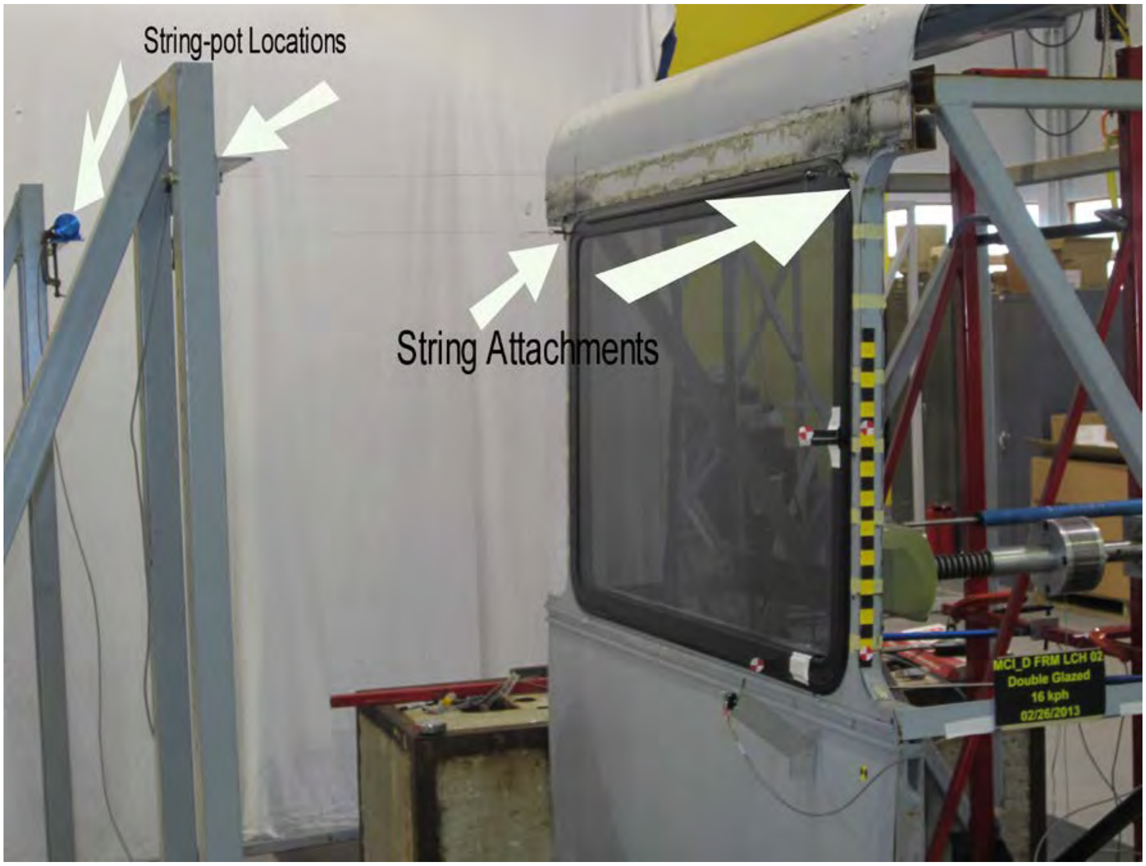

Figure 11.1 MCI D-Series Frame Deflection Setup

The results are shown in Table 11.1. The windows unlatched and swung open in every test. In previous testing (in the bus body section, Table 3.1), the polycarbonate window remained latched when it was tested under these impact conditions (see Table 11.1), and the window frame was slightly distorted in this test series due to multiple impacts which most likely contributed to its opening. The deflection measurements were averaged and compared for the left and right sides and are shown in Figure 11.2. The results show that while the frame flexes more initially, it is more rigid and has a shorter period of vibration than the bus section. The more massive bus section (with its smaller peak deflection) was placed on, but not physically anchored to the floor, while the test frame section was “anchored” to the floor by heavy concrete blocks.

Table 11.1 Impact Test Results Comparing MCI D-Series Motorcoach Section and Test Frame

TEST NO.	TEST PLATFORM	ACTUAL IMPACT VELOCITY (km/h)	PEAK FORCE (N)	PEAK IMPACTOR FACE EXCURSION (mm)	PRIMARY STRING POT MAX DEFLECTION (mm)	SECONDARY STRING POT MAX DEFLECTION (mm)	LATCH OPENED
MCI Bus flex WB1	Bus Section	21.7	6,964	No Data	5.7	4.8	Yes
MCI Bus flex WB2	Bus Section	21.7	5,645	97	4.4	3.7	Yes
MCI D FRM PC 01	Test Frame	21.6	6,257	79	7.9	5.6	Yes
MCI D FRM PC 02	Test Frame	21.6	5,724	90	6.4	5.4	Yes

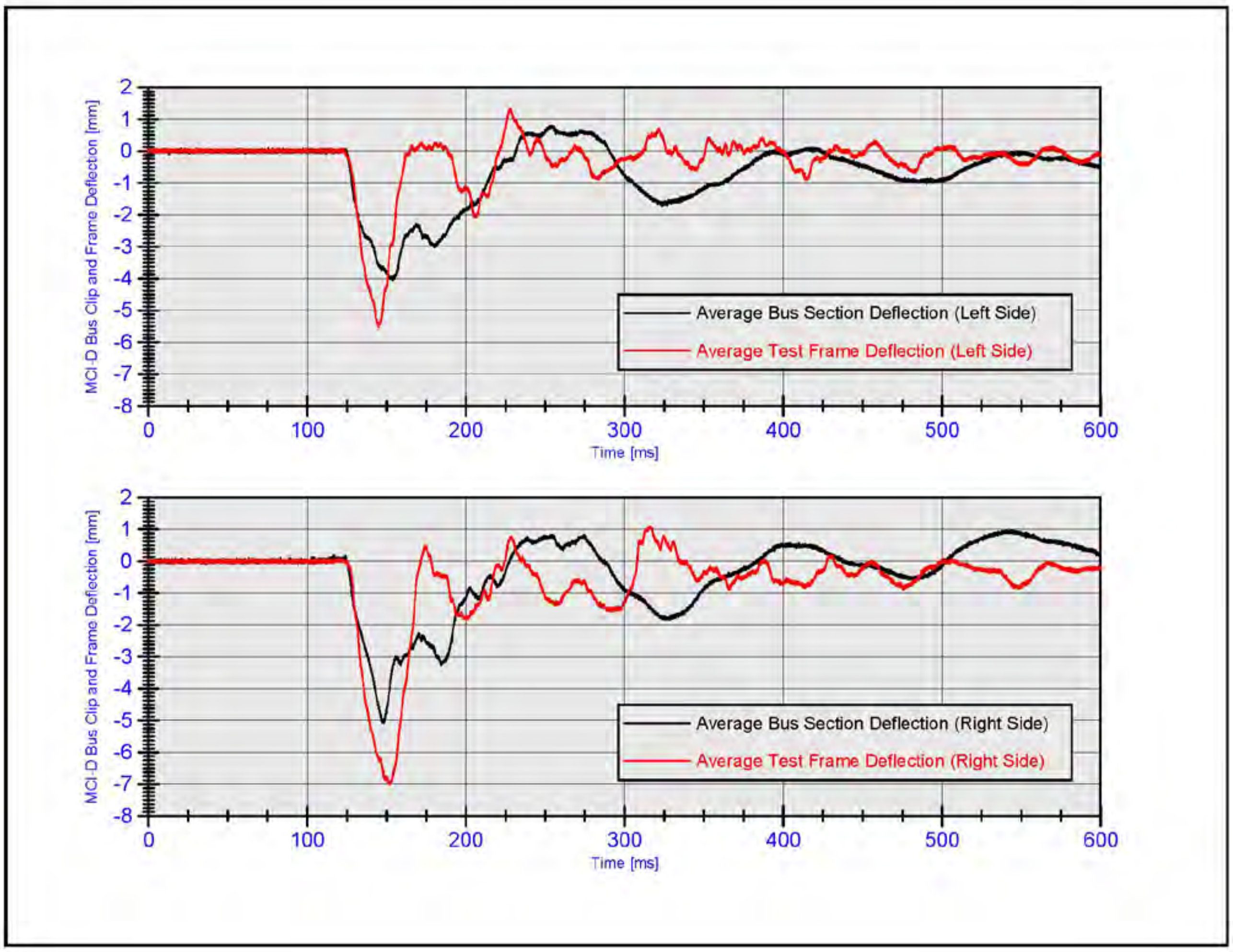

Figure 11.2 MCI D-Series Motorcoach Section Versus Frame Average Deflection Plots

A sample of tests performed on the MCI D-series bus section was replicated on the test frame and the results compared. Single and double-glazed production windows were used in impacts conducted near the latch and at the center of the daylight opening. Tests conditions resulting in both window opening and remaining closed were selected for comparison. The results are listed in Table 11.2. The peak forces from the frame tests were higher than those from the bus section tests, but there was no clear trend for the peak excursion measurements. This made determining the relative stringency of the two test methods inconclusive.

Table 11.2 Comparison of Like Tests Performed on MCI D Series Bus Section and Test Frame

TEST PLATFORM	TEST NO.	GLAZING CONFIGURATION (FRAME BONDING METHOD)	IMPACT LOCATION	IMPACT VELOCITY (kmph)	PEAK FORCE (N)	PEAK IMPACTOR FACE EXCURSION (mm)	INTERIOR GLASS PANE BROKEN	EXTERIOR GLASS PANE BROKEN	LATCH OPENED	UNLATCHING FORCE (N)	WINDOW OPENING FORCE (N)	COMMENTS
MCI D Bus Clip	MCI GLZ IMP 01	Double Glazed - Tempered Outside/Laminated Inside (Rubber)	Center of Daylight Opening	23.6	8,105	73	Yes	No	No	Not Available	Not Available	New window
MCI D Test Frame	MCI D FRM CTR 04	Double Glazed - Temp Exterior/Lam Interior (Rubber)	Center of Daylight Opening	21.6	9,130	45	Yes	No	No	30	40	New window
MCI D Bus Clip	MCI GLZ IMP 02	Single Glazed - Laminated Glass (Rubber)	Center of Daylight Opening	21.5	4,780	116	n/a	Yes	No	Not Available	Not Avail	
MCI D Bus Clip	MCI GLZ IMP 03	Single Glazed - Laminated Glass (Rubber)	Center of Daylight Opening	21.2	5,879	106	n/a	Yes	No	Not Available	Not Avail	
MCI D Test Frame	MCI D FRM CTR 05	Single Glazed - Laminated Glass (Rubber)	Center of Daylight Opening	21.6	Not Avail.	108	n/a	Yes	No	25	25	New window
MCI D Test Frame	MCI D FRM CTR 06	Single Glazed - Laminated Glass (Rubber)	Center of Daylight Opening	21.6	6,761	133	n/a	Yes	No	20	22	New window
MCI D Bus Clip	MCI GLZ IMP 09	Single Glazed - Laminated Glass (Rubber)	Near Latch	21.3	6,844	58	n/a	No	Yes	67	Not Avail	New window; Both struck and secondary latch opened
MCI D Test Frame	MCI D FRM LCH 01	Double Glazed - Temp Exterior/Lam Interior (Rubber)	Near Latch	21.3*	7,586	74	Yes	No	Yes	21	29	New window; Both struck and secondary latch opened
MCI D Bus Clip	MCI GLZ IMP 14	Single Glazed - Laminated Glass (Rubber)	Near Latch	15.5	4,897	27	n/a	No	No	80	Not Avail	New window
MCI D Bus Clip	MCI GLZ IMP 45	Single Glazed - Laminated Glass (Rubber)	Near Latch	15.9	4,716	-6	n/a	No	No	45	98	New window
MCI D Test Frame	MCI D FRM LCH 03	Single Glazed - Laminated Glass (Rubber)	Near Latch	16.0	5,760	37	n/a	No	Yes	20	22	New window; Both struck and secondary latch opened
MCI D Bus Clip	MCI GLZ IMP 44	Double Glazed - Tempered Outside/Laminated Inside (Rubber)	Near Latch	16.3	4,647	-11	No	No	Yes	49	106	New window; Secondary latch remained closed
MCI D Test Frame	MCI D FRM LCH 02	Double Glazed - Temp Exterior/Lam Interior (Rubber)	Near Latch	16.0	6,214	-44	No	No	Yes	25	25	New window; Both struck and secondary latch opened

12. Defining the Vertical Reference Plane

In some tests described earlier, the window unlatched during the impact event causing the window to partially open, and then the window re-latched when it returned to the window frame. This made it difficult to confirm an opening post-test unless the event was observed with high speed video. In some latching systems, an unlatching event could only be confirmed with a strategically placed high speed camera. After most of the tests described previously in this report were already completed, a study was initiated to develop a more objective procedure for determining window opening during dynamic testing. The window retention requirement for buses in FMVSS No. 217 specifies that during the application of a quasi-static load to the window glazing, no opening is created that is large enough to admit the passage of a 4-inch diameter sphere. Using a similar concept, window opening during the dynamic test was determined by establishing a vertical reference plane using a 100 mm diameter sphere prior to testing.

For impact testing conducted near the latch, the vertical reference plane was defined using the following procedure:

- The window was unlatched and allowed to hang freely under its own weight and gravity.
- From the interior of the window, the perimeter of the window frame (daylight opening perimeter) was probed with the 100 mm diameter sphere while pushing outwards.
- The first location where the 100 mm sphere first passed through a gap with the window minimally opened was found.
- The 100 mm sphere was placed at this location, and the maximum horizontal distance between the farthest point of glazing and the window frame was determined (see Figure 12.1).
- This distance established the vertical reference plane (parallel to the window) for evaluating if a latch opened in a dynamic test conducted near the latch.

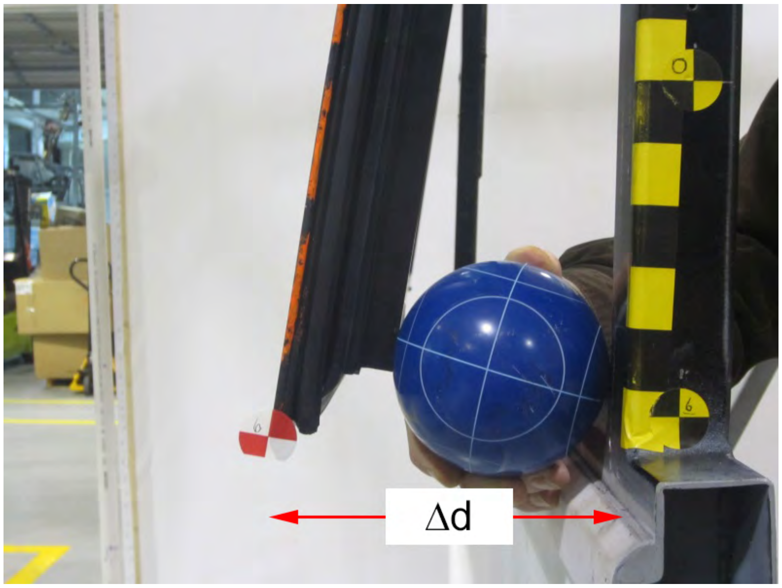

Figure 12.1 Defining Vertical Reference Plane

The location where the sphere first passed through a gap occurred along the side of the window near the bottom for all three window manufacturers, and the farthest point of the glazing that defined the new plane was the bottom edge of the window. The location and resulting gap for the MCI E/J-series, Prevost, and Van Hool windows are shown in Figures 12.2 through 12.4. The latch bar was placed in the down position for the MCI E/J-series and Prevost windows. The established plane was measured to be 139 mm for MCI E/J-series, 106 mm for Prevost, and 129 mm for Van Hool. The Van Hool and MCI window have interior frames that influenced the gap produced by the 100 mm sphere.

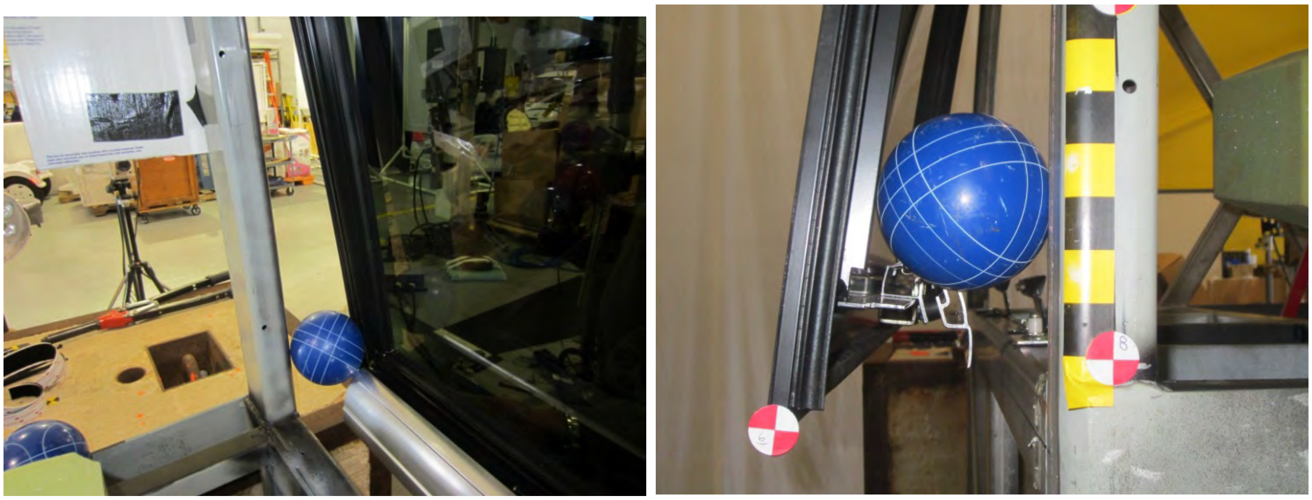

Figure 12.2 Establishing the Vertical Reference Plane – MCI E/J-Series

Figure 12.3 Establishing the Vertical Reference Plane – Prevost

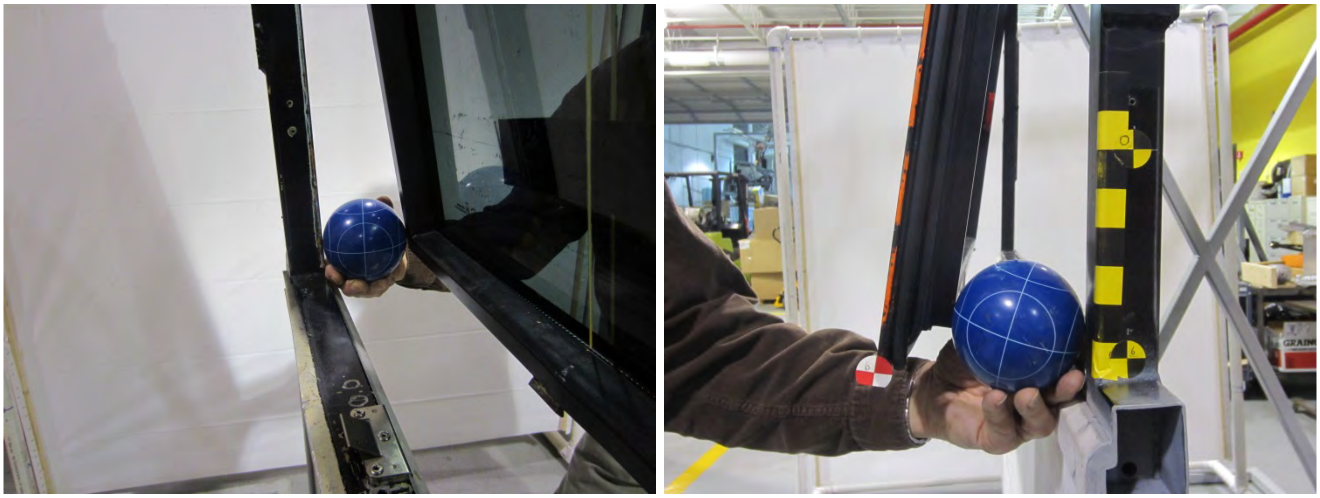

Figure 12.4 Establishing the Vertical Reference Plane – Van Hool

For impacts to the center of the daylight opening, the vertical reference plane was defined using the following procedure:

- The window was unlatched and allowed to hang freely under its own weight and gravity.
- The 100 mm sphere was placed between the test frame vertical member and the window, at a height corresponding to the measured center of daylight opening, where the sphere first passed through a gap with the window minimally open.
- The maximum horizontal distance at this height between the farthest point on the glazing and the window frame was determined (see Figure 12.5).
- This distance established the vertical reference plane (parallel to the window) for evaluating if an opening of 100 mm is created at the side of the window in a dynamic test conducted at the center of the daylight opening.

Additionally, tests at the center of the daylight opening would also require vertical reference planes at the bottom of the window (defined earlier in this section), in case the latches opened in such impacts.

Figure 12.5 Establishing the Vertical Reference Plane for Center Impacts

Two methods for measuring window displacement were used in this study: (1) tracking a target on the window edge with high speed cameras and using motion analysis software to calculate the displacement and (2) physical contact switches placed at the established plane to produce an electric signal if contact was made, as shown in Figure 12.6.

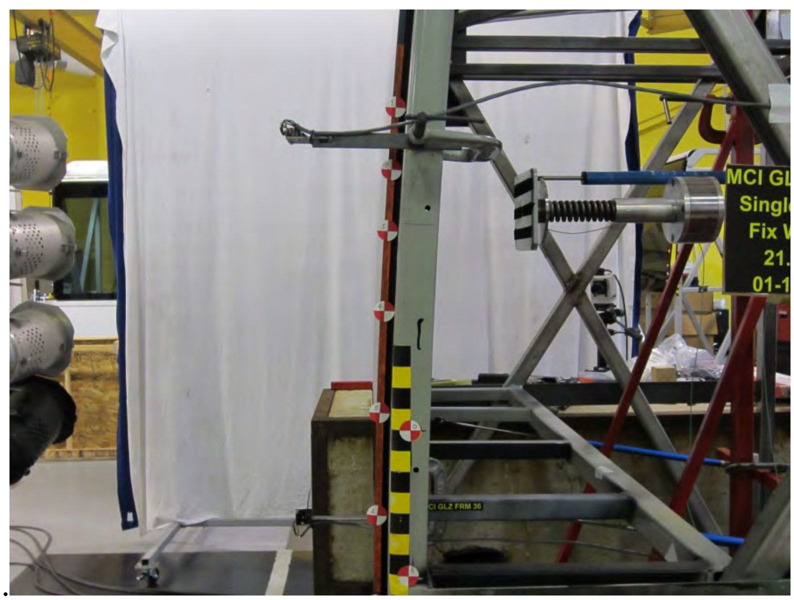

Figure 12.6 Contact Switch Placed at the Vertical Reference Plane

13. Summary of Results

13.1 Testing on the MCI D-Series Motorcoach Section:

Center Impacts:

- Rubber mounted windows produced lower forces and higher displacements.
- Windows with tempered glass produced higher forces than those with laminated glass.
- No windows with tempered glass broke in center impacts.
- Polycarbonate windows produced lower forces and higher displacements compared to similar windows with single-glazed glass.
- Acrylic windows produced lower forces compared to most other compositions.
- Windows with greater PVB thickness produced reduced excursions.
- No windows opened under the Martec study impact conditions (26 kg at 21.6 km/h).

Near-Latch Impacts:

- Impacts at Martec study conditions would open all latches.
- In 6 of the 11 pairs of comparison tests, the presence of torsion on the bus section did not have an effect on whether the struck latch unlatched. In the other five pairs of comparison tests, the presence of torsion made it harder to open the latch.
- In all but one case, when the impacted latch opened, the window did not open because the far side latch remained closed.
- Multiple impacts on same window increased the likelihood of the latch opening.
- Window installation procedure influenced the window opening force and the unlatching force.
- Reducing window opening force and unlatching force through modified installation did not influence latch opening under impact.

13.2 Testing of MCI, Prevost, and Van Hool Windows and Latches on Test Frames:

Near-Latch Tests on Production Latches (Martec study conditions):

- Windows from all three manufacturers exhibited latch openings.
    - Van Hool exhibited latch opening in the 9 – 10 km/h range.
    - Prevost exhibited latch opening in the 11 – 12 km/h range.
    - MCI E/J-series exhibited latch opening in the 18 – 21 km/h range.

Center of Daylight Opening Tests on Production Latches (Martec study conditions):

- The Van Hool latches opened, producing window opening, and the exterior tempered pane shattered.
- The Prevost latches opened, producing window opening, and the tempered glass panes remained intact.

Near-Latch Tests on Countermeasure Latches (Martec study conditions):

- MCI E/J-series latches required the simplest modification to improve its performance.
- The MCI E/J-series countermeasure latch and glass remained intact.

- The Van Hool primary countermeasure latch opened, but the secondary latch did not. Only a partial window opening occurred, as the tempered glass remained intact.
  - Failure occurred due to shearing of the bolts holding the slider mechanism to the reinforcing bar.
- The production Prevost latch had three failure modes: striker post fracture, plastic locator tab shearing, and latch bar fracture. Only the latch post and locator tabs could be modified by VRTC.
- The Prevost countermeasure latch opened due to fracture of the latch bar. The modified striker post and locator tabs did not fail, and the tempered glass panes remained intact.

Center of Daylight Opening Tests on Countermeasure Latches (Martec study conditions)

- MCI E/J-series latches remained intact, and the laminated inside pane broke.
- Van Hool latches remained intact, and the tempered glass panes shattered.
- Prevost latches remained intact. The window bowed outward during impact, but the tempered glass panes did not break.

13.3 Glass Breaking Method:

- Center of daylight opening impacts (Martec study conditions) into fully pummeled production glazings resulted in an average maximum excursion of 214 mm.
  - The 50 mm diagonally offset breakage pattern produced an average maximum excursion of 184 mm (86 percent of fully pummeled).
  - The 75 mm diagonally offset breakage pattern produced an average maximum excursion of 175 mm (82 percent of fully pummeled).
  - The 75 mm horizontally offset breakage pattern produced an average maximum excursion of 151 mm (71 percent of fully pummeled).
- The 50 and 75 mm breakage pattern methods are more objective than the fully pummeled method.
- There was little difference in maximum excursions between the 50 and 75 mm diagonally offset pattern methods.
  - The 75 mm horizontally offset pattern method produced less maximum excursion than the diagonally offset methods.
- Use of an electric staple gun (without the staples) to pre-break the glass panes was practical, allowed for single person operation, and did not produce tears in the PVB layer.
- Center of daylight opening impacts (Martec study conditions) into pre-broken glazings with a thicker PVB interlayer produced maximum excursions that were 13 percent less than similar impacts into the pre-broken production glazings.

13.4 Testing of MCI E/J-Series Fixed Windows (Martec study conditions):

- For tests conducted on unbroken glazings near the retaining clip, the primary clips bent backwards. The secondary clips bent but did not release, allowing the window to only partially open.

- For tests conducted at the center of the daylight opening on unbroken glazing, the retaining clips bent, but the window opening result depended on the type of glazing impacted.
    - The single-glazed window fully opened.
    - The double-glazed window did not open.
- For tests conducted at the center of the daylight opening on pre-broken double-glazed windows, there was no damage to the retaining clips, and the windows did not open.

13.5 Equivalency of the MCI D-Series Motorcoach Section and Test Frame Setups.

- The frame flexes more initially and has a shorter period of vibration than the bus section.
- Determining the relative stringency of the two test methods was inconclusive.
    - In five comparison tests, the event of window opening or remaining closed was similar.
    - The peak forces from the frame tests were higher than those from the bus section tests, but there was no clear trend for the peak excursion measurements.

Appendix. Motorcoach Window Weights and Dimensions

MANUFACTURER	BUS MODEL	GLAZING COMPOSITON	PART NUMBER	WEIGHT (kg)	WIDTH (m)	HEIGHT (m)
Motor Coach Industries	102D	Double Glazed - Tempered Exterior/Laminated Interior	03-27-1474	42	1.5	1.0
Motor Coach Industries	102D	Double Glazed - Tempered Exterior/Laminated Interior	V369SP-TTL060	47	1.5	1.0
Motor Coach Industries	102D	Double-Glazed – Tempered Exterior/Tempered Interior	V369L4	42	1.5	1.0
Motor Coach Industries	102D	Double Glazed – Tempered Exterior/Tempered Interior	T868-L4	42	1.5	1.0
Motor Coach Industries	102D	Double Glazed - Tempered Exterior/Laminated Interior	3L-27-107	43	1.5	1.0
Motor Coach Industries	102D	Single Glazed - Laminated Glass	3L-27-133	26	1.5	1.0
Motor Coach Industries	102D	Single Glazed - Laminated Glass	V369SP-LM	29	1.5	1.0
Motor Coach Industries	102D	Single Glazed - Tempered Glass	T822G2	27	1.5	1.0
Motor Coach Industries	102D	Single Glazed - Tempered Glass	V36SP-SG	25	1.5	1.0
Motor Coach Industries	102D	Single Glazed - Acrylic	37-27-136	27	1.5	1.0
Motor Coach Industries	102D	Single Glazed - Polycarbonate	V369SP-PC	25	1.5	1.0
Motor Coach Industries	E/J	Double Glazed - Tempered Exterior/Laminated Interior	03-27-1387	51	1.74	1.1
Motor Coach Industries	E/J	Single Glazed - Laminated Glass	03-27-1951	35	1.74	1.1
Prevost	H3-45	Double Glazed – Tempered Exterior/Tempered Interior	293606	50	1.7	1.2
Van Hool	C2045	Double Glazed – Tempered Exterior/Tempered Interior	10891115	45	1.74	1.1

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