Center for Accessibility and Safety for an Aging Population

Florida State University

In Partnership with Florida A&M University and University of North Florida

RESEARCH FINAL REPORT

Improving Cutaway Bus Safety for Aging Passengers

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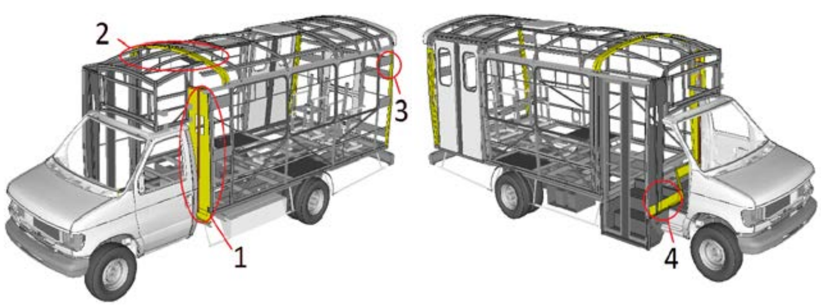

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IMPROVING CUTAWAY BUS SAFETY FOR AGING PASSENGERS

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16. Abstract
The main objective of this project was to improve safety of elderly passengers in paratransit buses in Florida and possibly, nationwide. Until now, crashworthiness of paratransit buses and safety of their passengers were assessed using the Federal Motor Vehicle Safety Standard (FMVSS) 220. This assessment was made based on quasi static roof tests of the buses. However, research studies revealed that such tests did not help at all in assessing crashworthiness of the buses during dynamic, rollover test. Instead, dynamic rollover tests, implemented in Europe (ECE R66) and worldwide (UN R66) were proven to have beneficial impact on improved passenger safety and they were adopted, in large part, into so called Florida Standard. This standard was used to assist a paratransit bus manufactured in constructing a prototype of a safer bus, which would meet the stringent dynamic, rollover standard at almost the same cost. A Champion bus was selected as a target for this study. This choice had the strongest impact on improved safety as Champion buses represent over 50% of over 300 paratransit buses acquired annually by the State of Florida. The new and crashworthy design of the bus was presented to Champion Bus Inc. Company and a new prototype was built. It was shipped for testing to Tallahassee. A rollover test was carried out in June 2014. While the new design of the frontal ring of the bus showed significant improvement, the back wall was weaker and failed the test. The researchers will continue to assist the Champion Bus Inc. in improving their bus.

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Abstract

The main objective of this project was to improve safety of elderly passengers in paratransit buses in Florida and possibly, nationwide. Until now, crashworthiness of paratransit buses and safety of their passengers were assessed using the Federal Motor Vehicle Safety Standard (FMVSS) 220. This assessment was made based on quasi static roof tests of the buses. However, research studies revealed that such tests did not help at all in assessing crashworthiness of the buses during dynamic, rollover test. Instead, dynamic rollover tests, implemented in Europe (ECE R66) and worldwide (UN R66) were proven to have beneficial impact on improved passenger safety and they were adopted, in large part, into so called Florida Standard. This standard was used to assist a paratransit bus manufactured in constructing a prototype of a safer bus, which would meet the stringent dynamic, rollover standard at almost the same cost. A Champion bus was selected as a target for this study. This choice had the strongest impact on improved safety as Champion buses represent over 50% of over 300 paratransit buses acquired annually by the State of Florida. The new and crashworthy design of the bus was presented to Champion Bus Inc. Company and a new prototype was built. It was shipped for testing to Tallahassee. A rollover test was carried out in June 2014 in Tallahassee. While the new design of the frontal ring of the bus showed significant improvement, the back wall was weaker and failed the test. As well, a literature review was conducted to examine human factors issues in design of the cutaway bus to accommodate the needs of older users. The researchers will continue to assist the Champion Bus Inc. in improving their bus.

Chapter 1. Introduction

Concerns about paratransit bus rollover led the Florida Department of Transportation to begin sponsoring the Crashworthiness and Impact Analysis Laboratory (CIAL) in 1999 to conduct research on improving the overall crashworthiness of paratransit buses. These efforts have progressed from an initial finite element method (FE) feasibility study to the development, implementation, and administration of the Florida Paratransit Bus Crash And Safety Test Standard (known as the Florida Standard). A primary focus of this standard is a dynamic rollover test based on the Economic Commission for Europe Regulation 66 (*1*).

Rollover crashworthiness of cutaway buses is of particular safety concern due to a combination of a Gross Vehicle Weight Rating (GVWR) commonly exceeding 10,000 lbs., and a build process involving two manufacturers (one for the chassis/cab and one for the body) that exempts them from most federal crash safety standards. In absence of a dedicated standard, most manufacturers choose to undergo voluntary testing to the quasi-static FMVSS 220 School Bus roof strength standard (*2*).

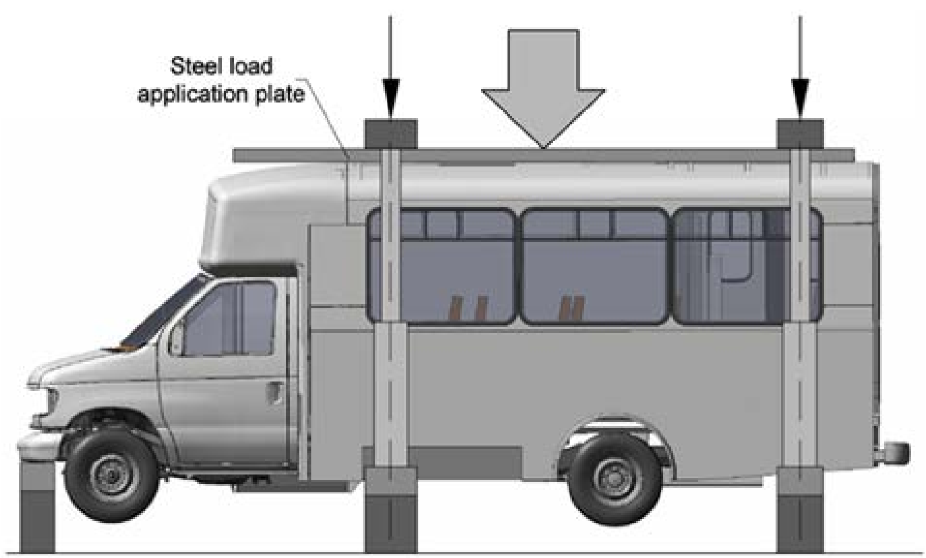


Figure 1.1. FMVSS 220. Roof strength testing for school buses (US DOT, 1998)

CIAL's evaluation of five different manufacturers' designs using both FE analyses and physical testing has revealed that in order to pass the FMVSS 220 (*2*), every evaluated manufacturer is using an unbalanced design in which a very strong roof structure is supported by relatively weak columns and connections. This design performs well on the quasi-static FMVSS 220 (*2*) test but will perform significantly worse in actual rollover accidents where side loading is present. This result has been shown by CIAL's testing of six decommissioned cutaway buses from various manufacturers to the Florida Standard dynamic rollover test which resulted in all buses failing. The pass-fail criteria for Florida Standard is based on the concept of Residual Space (RS). In order for the bus to gain approval, the RS cannot be penetrated by any part of the bus body during the structural deformation caused by the rollover impact.

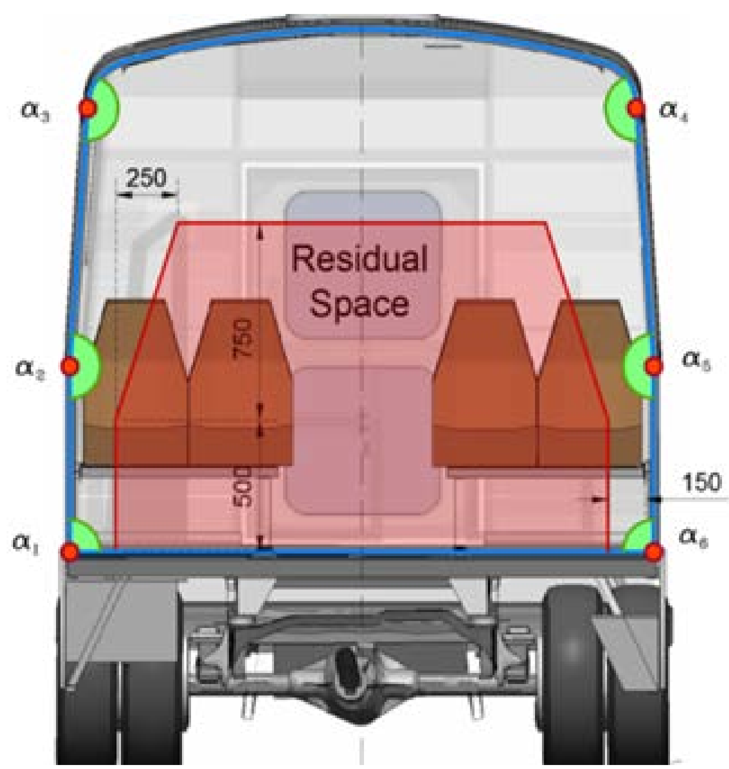


Figure 1.2. Residual space (RS) definition by ECE R66 and Florida Standard (dimensions in mm)

The failure mode of all six CIAL tested buses was one in which a weak frontal structure allowed for excessive deformation to occur in the front portion of the bus body. In order to investigate whether the frontal structure can be re-designed to reduce deformation without significantly increasing weight or manufacturing cost, a partnership was formed with Champion Bus. CIAL and Champion Bus agreed to jointly design reinforcements to the bus body structure, build a prototype body and attach it to a used chassis, and rollover test the prototype bus following the requirements of the FDOT Florida rollover standard.

Chapter 2. Older Adult Human Factors and Rollover Injury Risk

With aging, we begin to have mobility issues and our bodies become frailer. Chronic disorders such as arthritis make transportation more difficult to access and travel less comfortable. Mitchell's 1988 report (*3*) is a useful resource focused on improving accessibility and comfort in mainstream public transportation for those with mobility issues, which includes many older adults. Older adults' increased frailty puts them at risk for more severe injury in cutaway buses. Increased skeletal fragility with age can be due to changes in bone material properties such as fracture toughness, regional changes in rib cross-sectional geometry (*4, 5*), and the calcification of the costal cartilage (*6*). Osteoporosis's high prevalence, particularly in older women, is well established (*7*) and contributes to older adults' poor injury outcomes in car crashes. Osteoporosis and obesity were the most common comorbid factors to thoracic injury severity in MVCs (motor vehicle crashes; *8*). The energy required to cause an injury reduces with age, and older adults are several times more likely to sustain a life-threatening chest injury than younger adults when involved in relatively moderate crashes (*9*). Not only are older adults more susceptible to injury, they also take longer to recover from injuries, having more surgical, medical, and therapy workloads before being discharged from the hospital, significantly more complications, as well as significantly longer hospital stays (*10*). We now review the injury scenarios that older adults may encounter in cutaway buses.

It is important to note that most injuries in STS (special transportation services) are not due to MVCs, but rather non-collision injuries sustained by older, frailer passengers tripping or slipping on suboptimal floor surfaces during wet weather while boarding or alighting the bus, or hard acceleration or braking by the driver (e.g., *11*). More than half of the 284 injury cases included in Björnstig et al. (*12*) were due to non-collision events, 41% of which resulted in MAIS (maximum abbreviated injury scale) 2+ injuries.

Collisions are a significant source of MAIS 3+ injury for older adults while using cutaway buses. Ridella, Rupp, and Poland (*8*) found that the largest age effect was for thoracic injury to females involved in frontal crashes and that age was found to increase the risk of injury to all body regions that had sufficient sample size for frontal impacts, it significantly increased risk of head and thorax injury in every crash mode, and the most common thoracic injury type changes from soft to bony tissue with increasing age. Older females in this analysis also had an increased risk for head injuries in near-side crashes, thoracic injuries in far-side crashes and spine injuries in rollover crashes.

Rollover crashes, despite their low-occurrence, are an area of extra concern when it comes to designing for the safety of bus passengers due to their potential for lethality. Bus passengers are at a disproportionate risk of dying in rollover crashes (30.12%) than passenger car occupants (15.45%), despite their low occurrence (4.57% of all fatal crashes involving buses) according to FARS data for crashes with bus passenger fatalities from the years 2010-2012 (*13*). Bus rollover crashes, while rare, have an increased probability (42%) of severe injury or passenger fatality (*14*), and this pattern seems to be robust internationally. French bus crash statistics collected from 1980-2005 show that in crashes in which at least one bus occupant was seriously injured, frontal collision and rollover rates were almost the same (45% and 42%, respectively; *15*). Intrusion caused by deformation of the superstructure is the main cause of fatal and serious injury during rollover, and accounts for 18% of all of the injuries reported in this dataset. The trip purpose was transporting the elderly on just 4% of the bus crashes in which one individual was seriously injured in this dataset, which would most likely be larger in the United States due to a greater number of older adults relying on buses for their primary transportation.

Finally, we suggest ways of improving older adult passengers' safety on cutaway buses, focusing on seat belts. A seat belt's greatest usefulness is in rollover crashes and in preventing ejection from the vehicle (*16*). The other causes of mechanical injury during rollover can be mitigated by proper seat belt usage: complete ejection (8%) and partial ejection (5%) are responsible for a significant number of the observed serious/fatal injuries, while projection within the passenger compartment resulted in a majority of slight injury (63%) during rollover (*15*). After analyzing a severe coach crash in Sweden, Albertsson and Björnstig (*17*) found that 2-point safety belts would have reduced injuries for two-thirds of all those who sustained 2-4 MAIS injuries, and that 3-point belts could have possibly reduced injury 28% more. Though overall injury severity is mitigated with proper seatbelt use, seat belt syndrome (*18*) refers to injuries to the lumbar spine as well as intra-abdominal organs due to hyperflexion over the fulcrum of the seatbelt during a MVC, and is most common in lap belts. It is important to note that during the literature search there was no documented evidence that older adults were more susceptible to seat belt syndrome, but it follows logically that their frailty merits some additional consideration and investigation.

Chapter 3. Test Plan and Schedule

Several design meetings were conducted between CIAL and Champion Bus, to decide on various budget issues and test parameters. It was decided that the test bus would be a FDOT

Figure 3.1. Decommissioned 2005 Champion E450 12/2 bus ECE R66 tested

contract approved 12/2 flat floor body on 158" WB E450 chassis (fig. 3.1) that as closely as possible matched a decommissioned 2005 Champion bus tested by CIAL in 2011.

The following test schedule during the year 2014 was agreed to and followed by CIAL and Champion Bus:

- February - Update CIAL finite element model using provided drawings of FDOT 12/2 flat floor body.

- March - Design/Optimize front structure body modifications. Visit to CIAL by a Champion Bus Manufacturing Engineer to discuss modifications, tour the test facilities, and to ensure modifications are practical from a production standpoint.
- April – Convert chassis to 158” (it had been stretched to 189”), build and attach new modified body. Visit to Champion Bus by a CIAL researcher to observe and document bus build.
- May – Transport, prepare, and rollover test the bus.
- June, July, and August – Evaluate data
- September, October, and November - prepare a final report.

Chapter 4. Improve Bus Rollover Crashworthiness (CIAL)

Before any numerical analysis could be conducted the CIAL Champion Challenger FE model required updating to match the design that Champion Bus is currently building for the FDOT contract. Using 3D drawings provided by Champion Bus, the existing FE model and its material properties were checked and modified as necessary. The updated bus model is shown in fig. 4.1 and consists of 1,009,129 finite elements.

A series of simulated ECE R66 rollover tests was then conducted using the updated FE model of the bus. Champion Bus had independently improved the front cap area design several years prior, which improved its rollover performance compared to the previous CIAL FE model. These design revisions created a very good base for further development of the designed bus. The simulated rollovers were analyzed in order to determine areas with excessive deformation. Specific parts within these high deformation areas were then identified in order to be used as targets for structural improvement. The four most critical areas were chosen (fig. 4.2):

Figure 4.1. Overall view of the updated Finite Element Champion bus model

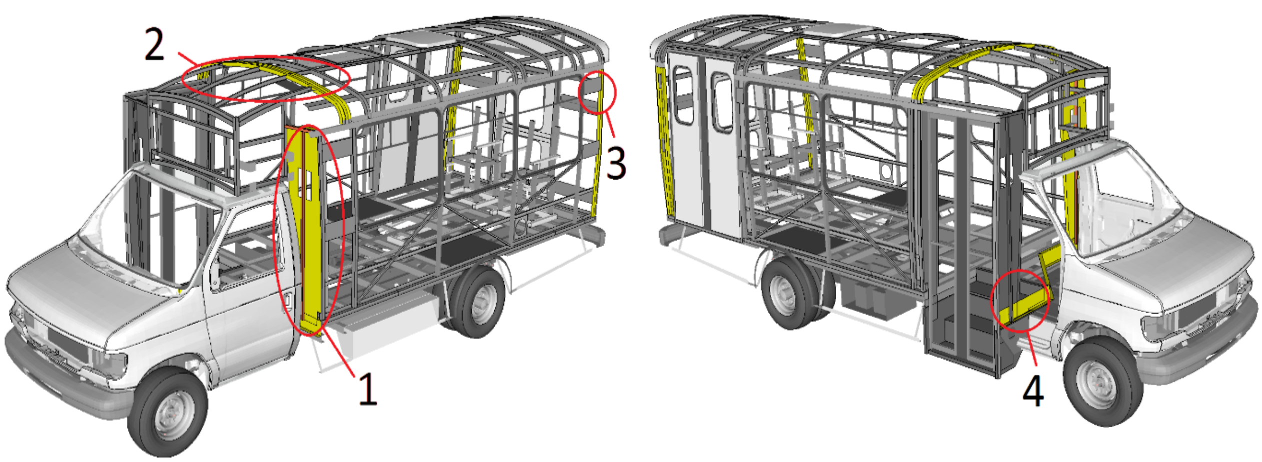
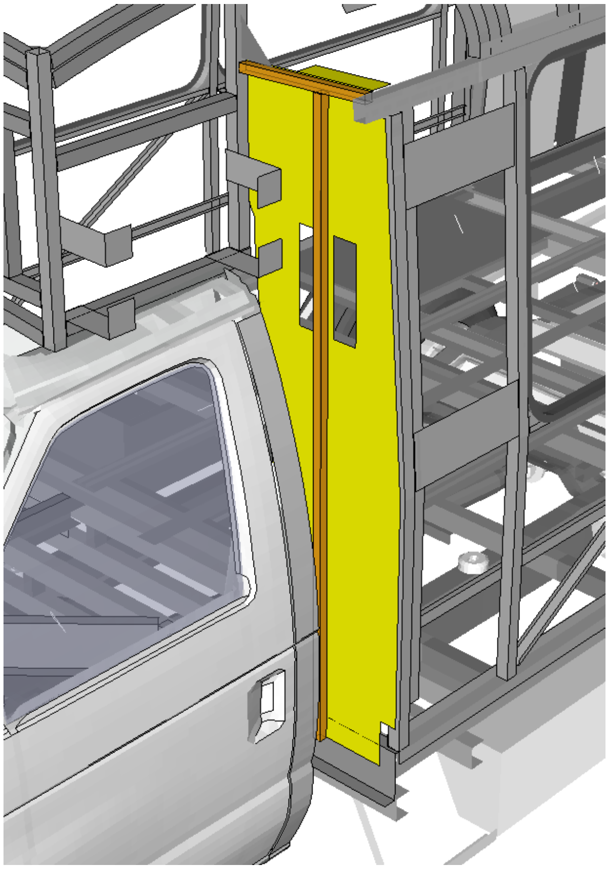


Figure 4.2. Areas for improvement - side panel (1), roof bow (2), back wall holes (3), and stairway (4).

- The side panel behind the driver’s seat (1).
- The front roof bow structure (2).
- The position of the openings in the tubes in the back wall (3).
- Reinforcement of the staircase z-channel (4).

An optimization study was conducted using LS-OPT software to determine the most efficient methods of reinforcing the indicated elements. After a series of additional numerical rollovers and consultation with a Champion Bus engineer, the improved bus design was finalized and sent to Champion Bus, Inc. for implementation. The list below describes these changes in detail:

1. **Side Panel** - The side panel (yellow) and the square section tubing (both vertical and horizontal, orange) located next to the driver’s seat were all made of 14 gauge steel in the original model (fig. 4.3). The agreed upon modifications were to increase the thickness of the two square tubes and the steel sheet panel to 11 gauge and to specify additional welds. Fig. 6 highlights the region in which the welding is crucial with the new welds indicated by black lines. The bottom part of the column should be welded to the panel from both sides with a minimum of two welds 2 in. long with a 2 in. spacing between them. In addition, the bottom edges of the panel should be welded to the z-section below with at least 1 in. welds every 2 inches.
2. **Front Roof Bow Structure** - The original front roof bow structure (fig. 4.4, left) underwent extensive buckling during the roll-over test. The agreed upon modifications were to add an 11 gauge steel plate, 3.5 inch wide and 67 inches long, on the top of the two front roof bows as indicated in fig. 4.4 (right, green). The plate should be welded from each side to the roof bows with at least a 1 inch weld every 13 inches.



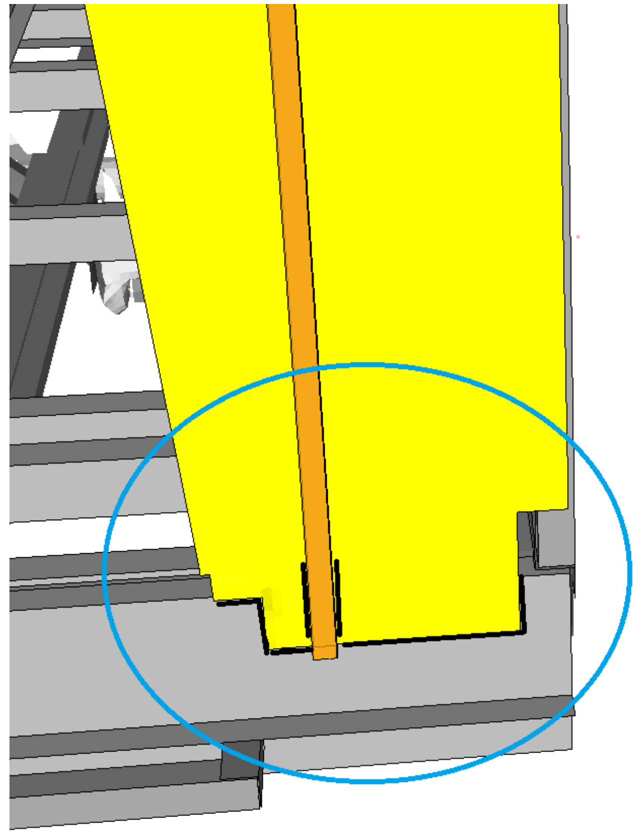


Figure 4.3. Side panel improvements (left), additional column, and panel welding required (right).

3. **Back Wall Column Openings -** The position of the openings cut into the outer vertical columns of the original back wall structure are shown in fig. 4.5 (left). It was agreed that the position of these holes should be changed so that there is no overlap with the horizontal member. Fig. 4.5 (right) shows the new position of the openings. They are cut 1 inch above the horizontal member of the back wall structure (indicated in brown). The relocated openings maintain their original dimensions of 1.5 in by 2.5 in.

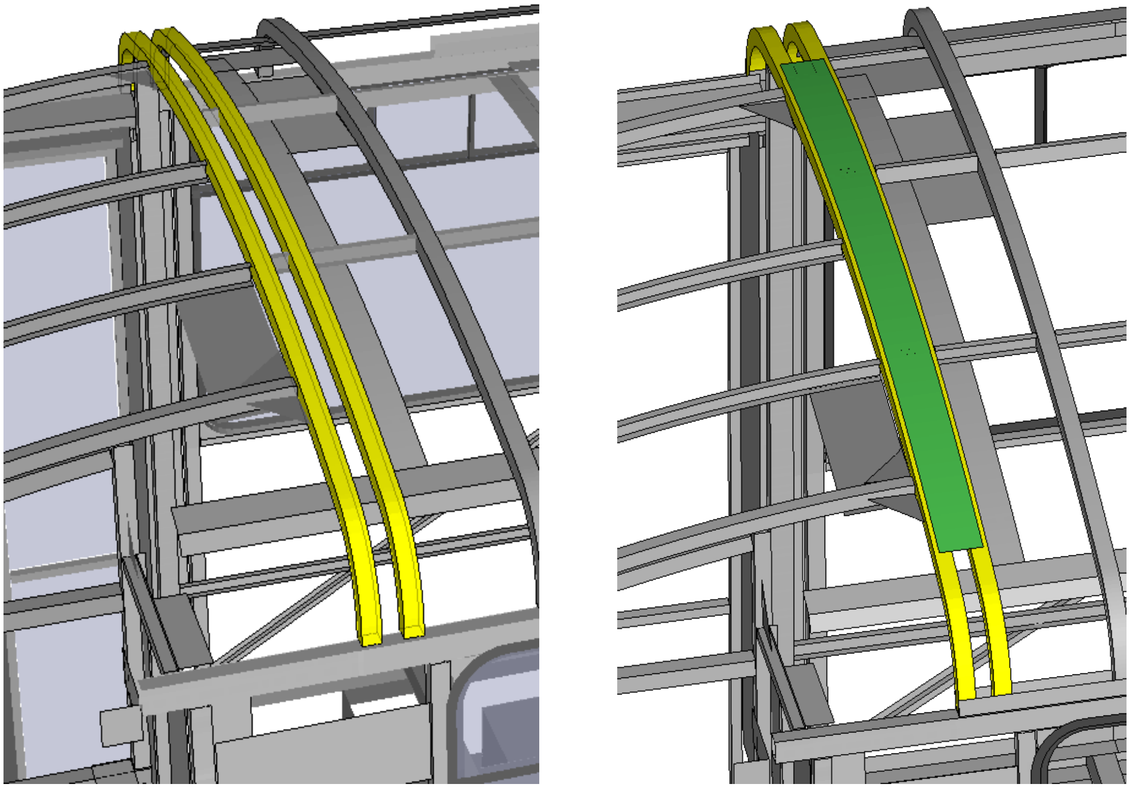


Figure 4.4. Original front roof bow structure (left), proposed 11 gauge steel plate (right).

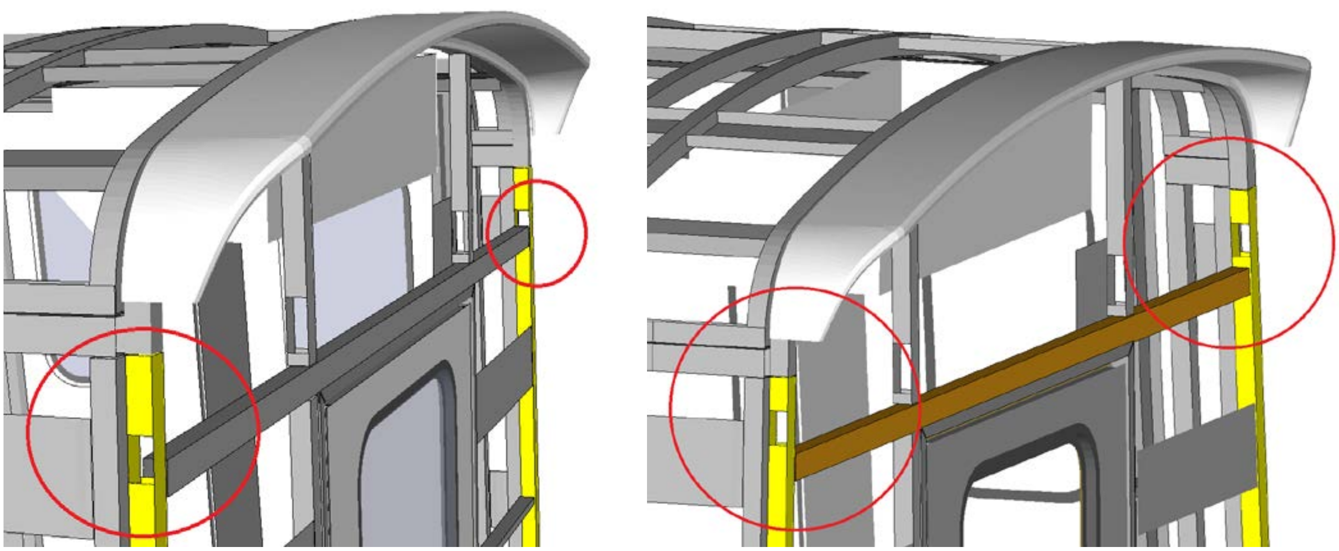


Figure 4.5. Position of cable pass through in the original back wall structure (left) and in the revised design (right).

4. **Reinforcement of the Stairway Z-channel** - During the numerical rollover analysis, the z-section with the cut off top lip located near the staircase undergoes large deformations due to concentrated loads from the frontal ring section. It was agreed that this section should be reinforced. The location of this element is shown in fig. 4.6 (yellow). The solution was to add a horizontal square tube (11 gauge, 1.5" x 1.5' x 23.5") on top of the lower flange of the indicated z-section. This element (fig. 4.6, green) is welded to the bottom flange and the web of the z-section with at least 2 in. welds every 9 inches (red lines).

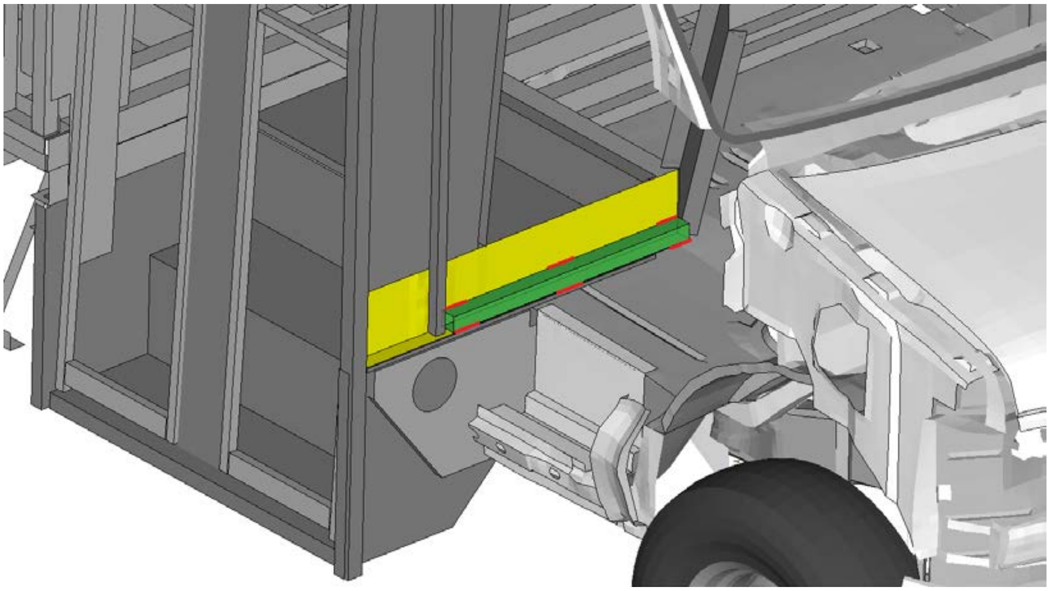


Figure 4.6. Position of the z-section (yellow) which was reinforced by a horizontal tube (green) and welded (red).

5. Build and Attach Prototype Body (Champion Bus)

A used Champion Challenger, acquired by Champion Bus, was the source for the chassis on which to build the prototype body. The old body was stripped from the bus, and the wheelbase was shortened to 158" in order to prepare it for the prototype body. The following build requirements were agreed upon in order to reduce cost while maintaining crashworthiness equivalency with a normal production bus:

This list is intended as a starting point and should not be considered inclusive. The cost/suitability of particular parts should be discussed as they become available. All structural and high mass items should be included. Parts do not need to be new, cosmetically perfect, or (in some cases) operational. However, although appearance is of secondary concern, it is still important -- the closer it looks to a real bus, the better. For example, the inclusion of exterior and interior lights is preferred, although they do not need to be operational or connected. The body should be built using normal production methods and include the following items:

- *Interior and exterior skin and windows*
- *Loaded suspension ride hide should be normal for FDOT 12/2 build*
- *Wheel chair lift (does not need to be functional)*
- *Interior handrails*
- *RCA rubber flooring*
- *Rear A/C (does not need to be functional)*
- *Full FDOT battery compartment*
- *Electric front door opening mechanism (does not need to be operational)*
- *Roof escape hatch*
- *Rubber exterior moldings and rear bumper*
- *Interior and exterior lights (do not need to be wired)*
- *Exterior A/C condenser and interior unit (do not need to be connected / wired)*
- *Seats*
- *Non-structural or low weight items can be omitted. For example:*
    - *Internal body electrical and A/C wiring does not need to be included*

- *Floor heater not required*

The prototype bus passenger compartment was built and attached to the used 158" chassis on the normal Champion Bus production line. Figures below illustrate the process, with the final result pictured in fig. 5.1. With assembly complete, the bus was then transported by truck to the FDOT Springhill Road Test Facility in Tallahassee, Florida where it arrived on the 8th of May, 2014.

Figure 5.1. First stage of the floor welding process (left) and final assembly and welding of the floor steel elements (right).

Figure 5.2. Roof structure manufacturing process (left) and assembly of the passenger compartment cage (right).

Figure 5.3. Overview of the completed Champion prototype.

Chapter 6. Prototype Bus Pre-Test Preparation

Pre-test preparation conducted at Springhill included the following major activities:

- The bus was washed, and a high friction epoxy coating was applied to the driver side (left) roof corner to prevent excessive sliding during impact.
- All seats were filled with water ballast dummies -- each filled with water to simulate a 150 lb. passenger. These were belted using two point seatbelts, as shown below.
- Two "wheelchairs" were filled with water ballast dummies (250 lb. each) and secured using wheelchair retention straps in the rear of the vehicle.
- The vehicle's suspension system was locked using a combination of welded steel tubes and tie-down straps in order to avoid unnecessary movement or oscillations during the test.

- The center of gravity and the total weight of the bus was measured using scales accurate to 1 lb. The measurements were carried out using a recently built center of gravity measuring frame located at Springhill. The bus was placed in the frame, the results for individual wheel weights were recorded, and the center of gravity position calculated. The bus was positioned on the tilt table so that impact would be to the driver's (left) side.
- The fuel tank was drained of its gasoline and then replaced with an equal amount of water to maintain the mass previously measured. The batteries were removed and replaced with welded steel of equal mass.
- Eight string transducers were installed into the passenger compartment to measure sidewall deformation and multiple cameras were placed both inside and outside the bus. Data acquisition wiring was run from the bus to the tilt table control station.

Figure 6.1. Finding the weight and COG for the prototype Champion bus.

Figure 6.2. The prototype Champion bus placed on the tilt table before the rollover test.

Figure 6.3. Water ballast dummies placed inside the bus (left) and front string transducers (right).

Chapter 7. Rollover Test

The rollover test was held on May 28th, 2014 at the FDOT Springhill Bus Testing & Inspection Facility. The tilt table was slowly rotated until the bus overbalanced (at approximately 44 degrees) and fell to the concrete slab located 31.5 in. below the starting plane of the tilt table. Fig. 7.1 shows front and back views of the bus after the rollover.

Figure 7.1. Front and rear view of the Champion prototype bus after rollover.

The string transducer data was analyzed and plotted as a time history of deformation index (DI). The DI uses the deformation angles of the floor-to-wall connection and waistrail (area just below the windows) to calculate relative intrusion into the residual space. A DI value greater than one indicates intrusion into the residual space and test failure, while a value of less than one indicates a successful test. The DI time history for both the 2014 and 2011 Champion rollovers is shown in fig. 7.2 for the frontal ring and fig 7.4 for the back wall. Time is measured from the moment of impact (t = 0.0).

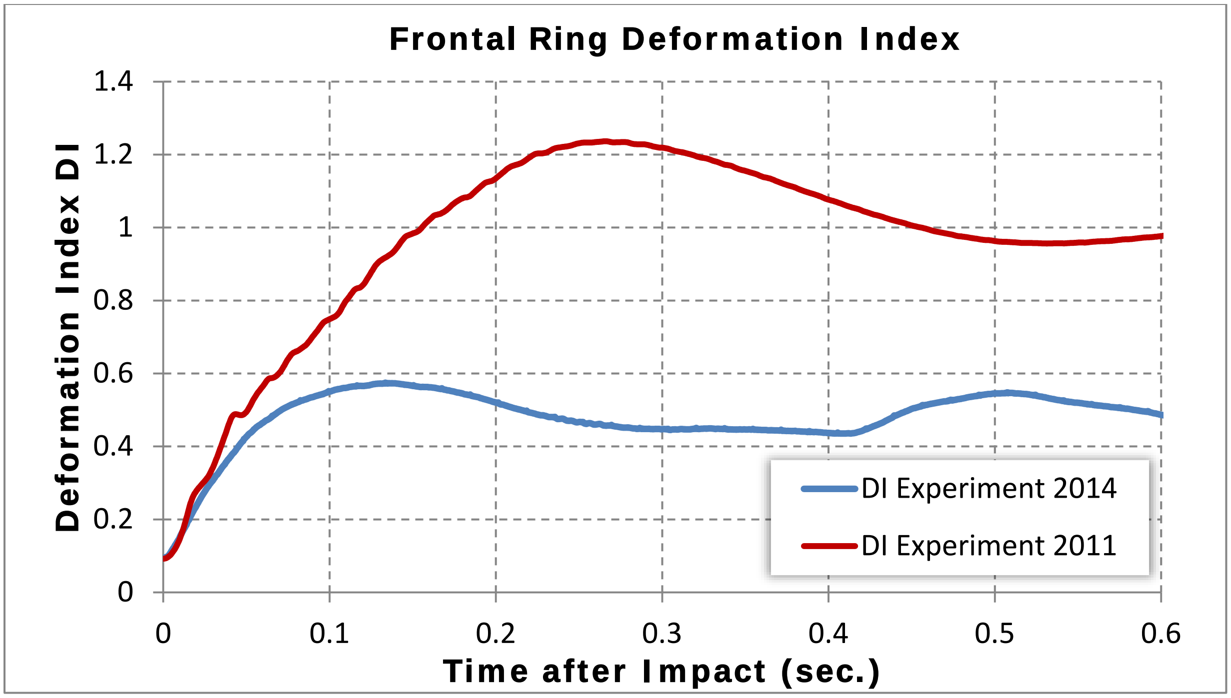


Figure 7.2. Frontal ring deformation index versus time.

The results show that the frontal structure of the bus body reaches a max DI of <0.6 and easily passes. This result is a significant improvement over the bus rolled over in 2011, which had a maximum DI of >1.2. The improvement is also very visually apparent, as shown in fig. 7.3 that compares the two tests at 0.25 seconds after impact.

Figure 7.3. Front view at 0.25 seconds after impact, 2014 rollover (left) and 2011 rollover (right).

The results for the back wall structure of the bus, however, differ substantially from what was predicted by the FE simulation and from the 2011 rollover. As can be seen in fig. 7.4 the back wall Deformation Index reaches a maximum value of DI > 1.3 indicating substantial intrusion into the residual space and failure of the rollover test.

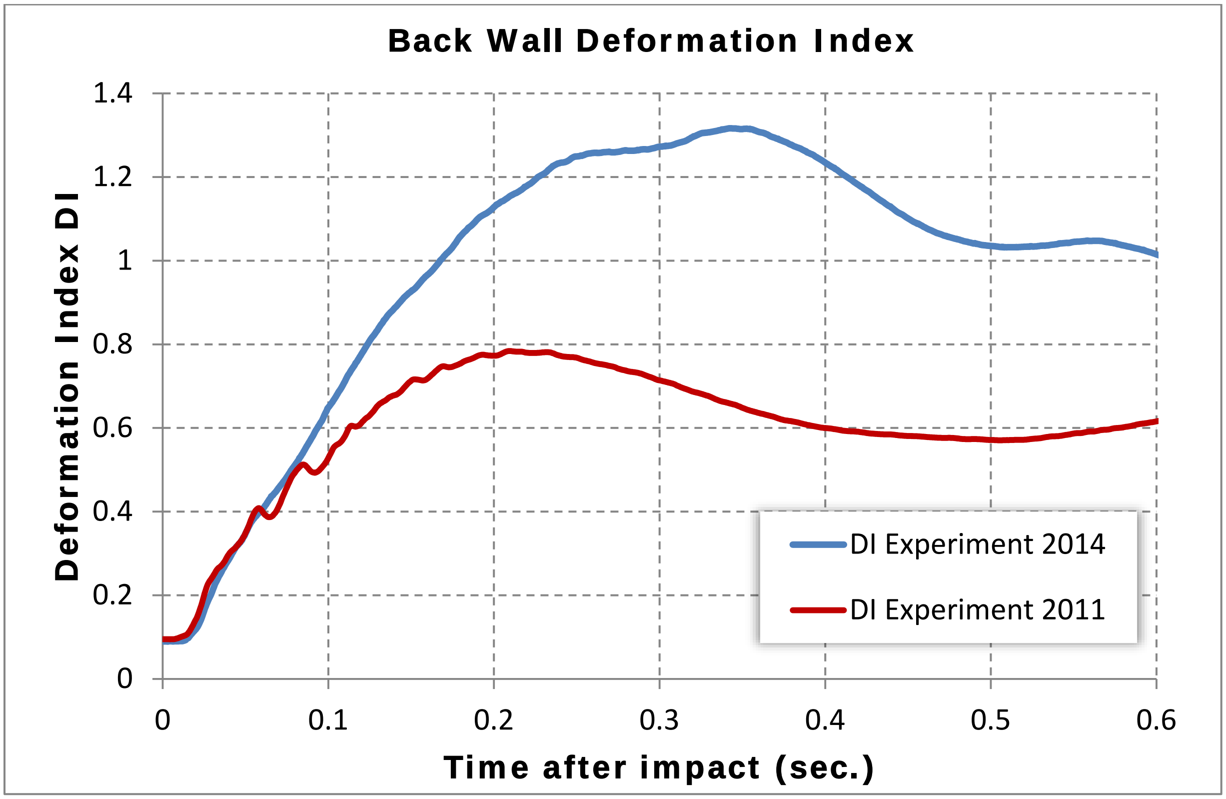


Figure 7.4. Back wall deformation index versus time.

The relatively poor performance of the 2014 bus back wall when compared with the 2011 test is easily seen in fig. 7.5 which shows both buses at 0.25 seconds after impact. Though it was expected that the back wall might perform slightly worse than the 2011 test due to the stronger front structure, a test failure was not anticipated. In order to determine the reasons for the deviation from the predicted results a post-test analysis was conducted on the bus structure.

Figure 7.5. Rear view at .25 seconds after impact, 2014 rollover (left) and 2011 rollover (right).

Chapter 8. Prototype Bus Post-Test Teardown

The prototype bus was stripped of its external skin and other non-structural components in order to allow a direct investigation of the body frame as shown in fig. 8.1. The frame was then checked for compliance with the design drawings obtained from Champion, Inc. A major difference between the tested bus and the FE model used in the rollover simulation was the substitution of a Fiber Reinforced Polymer (FRP) rear cap for the bus body. The skin used in all past FE simulations, including the optimization runs, was modelled as a plywood-metal sheet material reinforced by a spray-on polyurethane foam and screwed directly to the back wall frame. A small separate extended ABS cap was attached at the top of the back wall. This was replaced with a new, one piece FRP rear cap wraps around the back wall and is screwed to the sidewall. Both of these can be seen in fig. 7.5, where the 2014 rollover uses the FRP cap and the 2011 rollover uses the plywood/metal skin. The combination of the different attachment method of the FRP cap (to the sidewall) and the brittle failure mode of the FRP, together provided significantly less reinforcement of the back wall frame when

Figure 8.1. Back wall structure with rear skin removed.

compared to the previous style back wall. The importance of this change in the back wall skin was underestimated in advance of the test.

Every sidewall column tube was missing the inside face weld where it connects to the sidewall cantrail (not fully welded).The result on the road (driver) side was a joint that was too weak to withstand the moment load applied during the rollover and that opened approximately 0.25” along each column down the entire sidewall. This is contrasted with the performance of the same joint 2011 rollover in fig. 8.2 where it can be seen that the four sided weld on the same column/cantrail connection remained completely intact.

Figure 8.2. Column to cantrail joint not fully welded on 2014 bus (left) vs. fully welded on 2011 bus (right).

The rear door contributes to the strength of the back wall during the initial portion of the rollover induced deformation. Because no new drawing was provided for this door its design was assumed to be the same and was carried over from the previous FE model. The modeled door was built from 11 gauge aluminum tubes - 2”x 1” at the top, bottom, and middle with 1”x 1” tubes on the sides and 11 gauge gussets at the corners, fig. 8.3. The door on the test bus also used 11 gauge aluminum tubing but with doubled 1”x 1” tubes at the top and bottom and no center tube(s) or gussets. The insufficient welding of the test bus door tubing was not able to withstand any dynamic loading. Together the reduced structure and insufficient welding resulted in a much weaker door that, when compared to the previous design, was capable of dissipating only a fraction of the energy during rollover before complete structural failure.

Figure 8.3. Door model used in the FE model (left), test bus rear door showing the missing aluminum center tubes and gussets (center), and close up of upper door tubes showing insufficient welding (right).

The back wall was missing the uppermost horizontal channel sections, which, according to the drawings, were to be located behind the upper horizontal steel plates (fig. 8.4 - red). The horizontal channels located in the middle of the back wall were included but were welded only on the bottom (fig. 8.4 – green and fig. 8.5 right) which resulted in them functioning as a hinge and unable to provide any resistance to moment loading. Nearly all back wall tubing connections were insufficiently welded, with welds on only three (or sometimes two) sides. Fig. 8.5 and fig. 8.6 show some examples of these connections.

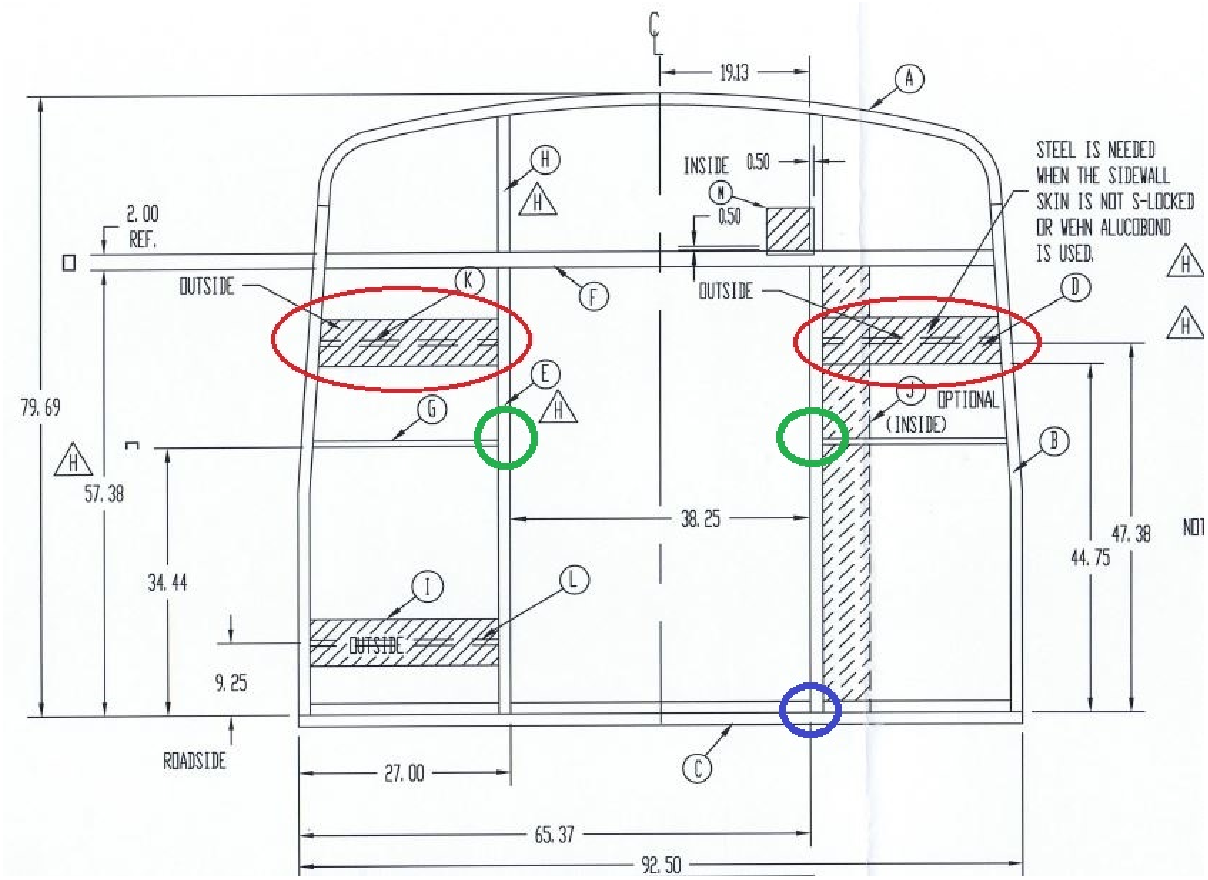


Figure 8.4. Back wall drawing with indicated missing elements (indicated in red) and insufficient welds (green, blue).

Figure 8.5. Insufficient welding on back wall column to floor (left) and horizontal channel to column (right).

Figure 8.6. Insufficient welding on back wall middle column to horizontal tube (left) and horizontal tube to side column (right).

The back wall column openings discussed in the Improve Bus Rollover Crashworthiness section (#3) above were not cut into the back wall column tubes. This can be seen in fig. 8.6 (left) above in which the opening should have been visible in the column tube just above the horizontal tube.

Chapter 9. Conclusion

The main goal of this project was to identify ways to improve the frontal crashworthiness of paratransit buses using a small number of targeted, affordable modifications. As well, a literature review was conducted to identify specific risks for injuries for older users. This goal was accomplished. The large, measurable, and visual improvement in passenger space intrusion was easily the best result of any bus tested to-date by CIAL. It is hoped that Champion Bus Company will incorporate these modifications into future production, as our results indicate that they significantly improve the rollover crashworthiness of the bus.

Disappointingly our results also revealed the converse to be true – i.e., that multiple small changes/omissions from a previously proven design when taken together can result in a large decrease in crashworthiness. The combination of the reduction in support from the new FRP rear cap, omission of structural members, weaker door, and the multiple instances of insufficient welding resulted in a back wall substantially weaker than the apparently identical one on the 2011 bus.

An unintended outcome of this test was to illustrate the superior ability of dynamic testing to quantitatively reveal differences in rollover crashworthiness vs. static tests such as FMVSS 220. Both buses would have most likely passed FMVSS 220 as issues such as the insufficient welding would not be revealed by the one directional static loading. However, the dynamic side loading of the Florida Standard rollover test reveals that even small changes can result in very large differences in the structures' ability to resist intrusion into the passenger space.

Chapter 10. Dissemination of Results

Research presented in this Final Report resulted in the following papers:

1. Gepner, B., Siervogel, J., Wekezer, J. Crashworthiness evaluation of paratransit buses (presented only, not published). UTC Conference for the Southeastern Region March 2014, Atlanta, Ga., USA.
2. Souders, D.J., Gepner, B., Charness, N., Wekezer, J., "A User-centered Literature Review of Safety and Human Factors Issues Involving Older Adults as Cutaway Bus Passengers". Paper approved for oral presentation at the 94-th Annual Meeting of the Transportation Research Board. Washington D.C., January 11 - 15, 2015.

3. Gepner, B., Gleba, M., Jung, S., Wekezer, J., "Strain Rate Dependency in Paratransit Bus Rollover". Paper submitted for possible publication in the International Journal of Heavy Vehicle Systems. October 15, 2014.
4. Gleba, M., "Issues in Paratransit Transportation". Presented (not published) during ASAP UTC Transportation Day at FAMU-FSU College of Engineering, October 24, 2014.

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