Inspection and Assessment of Crash Test Protocols:
Task 3.1-Task 3.2 Report – Part II (31" ET-Plus System Crash Tests)

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Background

The goal of this report is to evaluate the performance of the ET-Plus end terminal when tested to the NCHRP 350 Test Level 3 (TL-3) crash test procedure. In December 2014 and January 2015, Southwest Research Institute (SWRI) conducted two series of crash tests of the ET-Plus end terminal – (1) a series of TL-3 tests with the ET-Plus end terminal installed with a 27-3/4” height w-beam guardrail system, and (2) a series of TL-3 tests with the ET-Plus end terminal installed with a 31” height w-beam guardrail system.

SWRI conducted four tests of the ET-Plus end terminal at each guardrail height to NCHRP 350 Test Level 3. Together, the 27-3/4” and 31” test series comprised a total of eight (8) crash tests. The test matrix for each guardrail height is shown in Table 1.

Table 1. ET-Plus Test Matrix – repeated for each guardrail height

NCHRP Test	**Test Vehicle**	**Impact Speed (km/hr)**	**Impact Angle**	**Impact Location**
3-30	820C	100	0°	Vehicle front offset ¼ vehicle width from vehicle centerline
3-31	2000P	100	0°	Vehicle front at centerline
3-32	820C	100	15°	Vehicle front at centerline
3-33	2000P	100	15°	Vehicle front at centerline

This report provides an analysis of the crash test results for the 31” height w-beam guardrail system as required by Task 3.1 and Task 3.2 of our FHWA contract. This report is the second of two parts of the Task 3 analysis. Our February 3, 2015 report presented an evaluation of the results from the 27-3/4” system crash tests.

Approach

The approach was to assess the following crash test results by review of the following:

- Test reports, prepared by SWRI (Ferren, 1/2015; Ferren, 2/2015), documenting the results of the NCHRP 350 3-30, 3-31, 3-32, and 3.33 crash tests

- Videos of each test, prepared by SWRI
- Electronic data included in the test reports for data quality.

In addition, on December 16-17, 2014, I visited the SWRI crash testing facility in San Antonio, Texas to inspect and assess the crash test procedures and protocols used to conduct crash tests to the NCHRP Report 350 procedures for Terminals and Crash Cushions. During this visit, I also witnessed two crash tests (the 3-31 and 3-32 crash tests) of the ET-Plus end terminal installed for the 27-3/4” rail system. On January 14-16, 2015, I visited SWRI again to observe the pre-test preparation and the actual conduct of the 3-31 and 3-33 crash tests of the ET-Plus end terminal installed for the 31” rail system.

The analysis included comparison of the actual test conditions against the NCHRP 350 test conditions tolerances, and assessment of the test results using the NCHRP 350 evaluation criteria. Inspection of the electronic data plotted in the crash test report showed that no sensors failed during the test, and all data from these sensors was suitable for computation of occupant impact velocity and occupant ridedown acceleration.

Results

<u>Test 3-30, ET-Plus installed with 31” guardrail system</u>

This test involved a 820C vehicle (a 1998 Geo Metro) which impacted an ET-Plus end terminal at a nominal speed of 100 km/hr at an angle of zero degrees. The impact point on the vehicle front was offset approximately one-quarter of the vehicle width to the right of the vehicle centerline.

Table 2 shows the actual test conditions as documented in the test report. This table also shows the deviations from the nominal NCHRP 350 test conditions.

Table 2. Test Conditions for Test 3-30 for 31” system

Test Parameter	**Test Value**	**Nominal Value**	**Deviation**
Total Mass – vehicle + ballast+ dummy (kg)	883	895	-12
Impact Velocity (km/hr)	102.8	100	2.8
Impact Angle (degrees)	0.2	0	0.2
Impact Severity (KJ)	329.9	316.4	13.5

For this test, the NCHRP 350 preferred tolerance is +/- 4.0 km/hr for impact speed, +/- 25 kg for mass, and +/- 1.5 degrees for impact angle. The tolerance for impact severity (IS) is -24.8 to 25.8 kJ. The actual values for vehicle mass, impact speed, impact angle, and impact severity were all within these tolerance ranges.

Table 3 compares the crash test results with the corresponding NCHRP 350 evaluation criteria. The intrusion of the door into the occupant compartment was closely examined for the potential of serious injury. My conclusion is that this test would not be likely to cause serious injury to an occupant exposed to these crash conditions. Appendix A presents an analysis of the potential for serious injury risk in this crash test.

Table 3. Test Results for Test 3-30 for 31" system

Test	NCHRP 350 Evaluation Criteria	Test Result	Pass/Fail
Structural Adequacy	C) Acceptable Test Article Performance may be by redirection, controlled penetration, or controlled stopping of the vehicle	Test article slowed the vehicle in a controlled manner after which the vehicle left the system and yawed to a stop.	Pass
Occupant Risk	D) Detached elements, fragments, or other debris from the test article should not penetrate or show potential for penetrating the occupant compartment or present an undue hazard to other traffic, pedestrians, or personnel in a work zone. Deformations of, or intrusions into, the occupant compartment that could cause serious injuries should not be permitted	Folded rail struck driver door. There was no penetration of the test article into the occupant compartment. However, occupant compartment intrusion was 6.75"	Pass
Occupant Risk	F) The vehicle should remain upright during and after collision although moderate roll, pitching and yawing are acceptable.	Vehicle remained upright throughout the test	Pass
Occupant Risk	H1) Occupant Impact Velocity, Longitudinal (< 9m/s preferred, <=12 m/s max)	OIV=8.2m/s	Pass
Occupant Risk	H2) Occupant Impact Velocity, Lateral (<= 9m/s preferred, <=12 m/s max)	OIV=0.4m/s	Pass
Occupant Risk	I1) Occupant Ridedown Accel, Longitudinal (< 15 G preferred, <=20 max)	ORA=-11.8G	Pass
Occupant Risk	I2) Occupant Ridedown Accel, Lateral (< 15 G preferred, <=20 max)	ORA=8.7G	Pass
Vehicle Trajectory	K) After collision, it is preferable that the vehicle's trajectory not intrude into adjacent lanes	Vehicle spun out on traffic side of test article, and potentially into adjacent traffic lane	**
Vehicle Trajectory	N) Vehicle trajectory behind the test article is acceptable	Vehicle remained on traffic side of test article	Pass

** Note that this evaluation criteria is preferred, but not required. Vehicle spinout is typical behavior for this type of offset test.

Test 3-31, ET-Plus installed with 31" guardrail system

This test involved a 2000P vehicle (a 1998 Chevrolet C2500 Pickup truck) which impacted the ET-Plus end terminal at a nominal speed of 100 km/hr at an angle of zero degrees. The impact point on the vehicle front was approximately on the vehicle centerline.

Table 4 shows the actual test conditions as documented in the test report. This table also shows the deviations from the nominal NCHRP 350 test conditions.

Table 4. Test Conditions for Test 3-31 for 31" system

Test Parameter	Test Value	Nominal Value	Deviation
Total Mass – vehicle + ballast (kg)	2023	2000	23
Impact Velocity (km/hr)	103.8	100	3.8
Impact Angle (degrees)	0.3	0	0.3
Impact Severity (KJ)	840.7	771.7	69.1

For this test, the NCHRP 350 preferred tolerance is +/- 4.0 km/hr for impact speed, +/- 45 kg for mass, and +/- 1.5 degrees for impact angle. The tolerance for impact severity (IS) is -60.4 kJ to 62.9 kJ. The actual values for vehicle mass, impact speed, and impact angle were all within these tolerance ranges. The impact severity exceeded the positive tolerance on impact severity. However, NCHRP 350 (section 3.3.3) states that exceeding the positive tolerance on impact severity is acceptable if all other evaluation criteria are met. This was the case in this crash test.

Table 5 compares the crash test results with the corresponding NCHRP 350 evaluation criteria. My conclusion is that the test article passed this test.

Table 5. Test Results for Test 3-31 for 31" system

Test	**NCHRP 350 Evaluation Criteria**	**Test Result**	**Pass/Fail**
Structural Adequacy	C) Acceptable Test Article Performance may be by redirection, controlled penetration, or controlled stopping of the vehicle	Test article stopped the vehicle in a controlled manner.	Pass
Occupant Risk	D) Detached elements, fragments, or other debris from the test article should not penetrate or show potential for penetrating the occupant compartment or present an undue hazard to other traffic, pedestrians, or personnel in a work zone. Deformations of, or intrusions into, the occupant compartment that could cause serious injuries should not be permitted	No intrusion into the occupant compartment	Pass
Occupant Risk	F) The vehicle should remain upright during and after collision although moderate roll, pitching and yawing are acceptable.	Vehicle remained upright throughout the test	Pass
Occupant Risk	H1) Occupant Impact Velocity, Longitudinal (< 9m/s preferred, <=12 m/s max)	OIV=5.9m/s	Pass
Occupant Risk	H2) Occupant Impact Velocity, Lateral (<= 9m/s preferred, <=12 m/s max)	OIV=0.2 m/s	Pass
Occupant Risk	I1) Occupant Ridedown Accel, Longitudinal (< 15 G preferred, <=20 max)	ORA = -8.0G	Pass
Occupant Risk	I2) Occupant Ridedown Accel, Lateral (< 15 G preferred, <=20 max)	ORA = 7.0 G	Pass
Vehicle Trajectory	K) After collision, it is preferable that the vehicle's trajectory not intrude into adjacent lanes	Test article brought the vehicle to a complete stop while still in contact with the end terminal head.	Pass
Vehicle Trajectory	N) Vehicle trajectory behind the test article is acceptable	Vehicle did not travel behind the test article	Pass

Test 3-32, ET-Plus installed with 31" guardrail system

This test involved a 820C vehicle (a 1996 Chevrolet/Geo Metro) which impacted the ET-Plus end terminal at a nominal speed of 100 km/hr at an angle of 15 degrees. The impact point on the vehicle front was approximately on the vehicle centerline.

Table 6 shows the actual test conditions as documented in the test report. This table also shows the deviations from the nominal NCHRP 350 test conditions.

Table 6. Test Conditions for Test 3-32 for 31" system

Test Parameter	Test Value	Nominal Value	Deviation
Total Mass – vehicle + ballast+ dummy (kg)	892.4	895	-2.6
Impact Velocity (km/hr)	98.5	100	-1.5
Impact Angle (degrees)	15.2	15	0.2
Impact Severity (KJ)	305.9	316.4	-10.5

For this test, the NCHRP 350 preferred tolerance is +/- 4.0 km/hr for impact speed, +/- 25 kg for mass, and +/- 1.5 degrees for impact angle. The tolerance for impact severity (IS) is -24.8 to 25.8 kJ. The actual values for vehicle mass, impact speed, impact angle, and impact severity were all within these tolerance ranges.

Table 7 compares the crash test results with the corresponding NCHRP 350 evaluation criteria. My conclusion is that the test article passed this test.

Table 7. Test Results for Test 3-32 for 31" system

Test	NCHRP 350 Evaluation Criteria	Test Result	Pass/Fail
Structural Adequacy	C) Acceptable Test Article Performance may be by redirection, controlled penetration, or controlled stopping of the vehicle	Test article allowed the vehicle to gate in a controlled manner through the end terminal as designed.	Pass
Occupant Risk	D) Detached elements, fragments, or other debris from the test article should not penetrate or show potential for penetrating the occupant compartment or present an undue hazard to other traffic, pedestrians, or personnel in a work zone. Deformations of, or intrusions into, the occupant compartment that could cause serious injuries should not be permitted	No intrusion into the occupant compartment. There was some tearing of the external sheetmetal of the driver door from contact with the end terminal, but the terminal did not intrude or penetrate into the occupant compartment.	Pass

Occupant Risk	F) The vehicle should remain upright during and after collision although moderate roll, pitching and yawing are acceptable.	Vehicle remained upright throughout the test	Pass
Occupant Risk	H1) Occupant Impact Velocity, Longitudinal (< 9m/s preferred, <=12 m/s max)	OIV = 7.9m/s	Pass
Occupant Risk	H2) Occupant Impact Velocity, Lateral (<= 9m/s preferred, <=12 m/s max)	OIV =-1.3m/s	Pass
Occupant Risk	I1) Occupant Ridedown Accel, Longitudinal (< 15 G preferred, <=20 max)	ORA=-6.4G	Pass
Occupant Risk	I2) Occupant Ridedown Accel, Lateral (< 15 G preferred, <=20 max)	ORA=6.3G	Pass
Vehicle Trajectory	K) After collision, it is preferable that the vehicle's trajectory not intrude into adjacent lanes	Vehicle gated through the end terminal and travelled behind the test article.	Pass
Vehicle Trajectory	N) Vehicle trajectory behind the test article is acceptable	Vehicle gated through the end terminal and travelled behind the test article.	Pass

Test 3-33, ET-Plus installed with 31” guardrail system

This test involved a 2000P vehicle (a 1994 GMC C2500 Pickup truck) which impacted the ET-Plus end terminal at a nominal speed of 100 km/hr at an angle of 15 degrees. The impact point on the vehicle front was approximately on the vehicle centerline.

Table 8 shows the actual test conditions as documented in the test report. This table also shows the deviations from the nominal NCHRP 350 test conditions.

Table 8. Test Conditions for Test 3-33 for 31” system

Test Parameter	Test Value	Nominal Value	Deviation
Total Mass – vehicle + ballast (kg)	1981	2000	-19
Impact Velocity (km/hr)	93	100	-7
Impact Angle (degrees)	15.2	15	0.2
Impact Severity (KJ)	661.4	771.7	-110.3

NCHRP 350 preferred tolerance for impact speed is +/- 4.0 km/hr, +/- 45 kg for mass, and +/- 1.5 degrees for impact angle. The tolerance for impact severity (IS) is -60.4 kJ to 62.9 kJ. The actual values for vehicle mass and impact angle were both within these tolerance ranges. However, the actual value for impact speed of 93 km/hr was 3 km/hr outside the negative tolerance range specified by NCHRP 350. Likewise, impact severity, which is a function of impact speed, was outside the negative tolerance range.

We considered two aspects of whether the evaluation of the 31” system would have changed if the vehicle speed had been 3 km/hr faster (1.8 miles/hour). First, because the end terminal system gated properly even at this lower speed, it would be expected to break away and gate at a slightly higher speed. Second, the occupant risk metrics OIV and ORA would be expected to increase slightly with higher impact speed. However, the OIV and ORA values in the actual 3-33 test were well below the preferred values. If the test were run at a speed of 3km/hr higher, these occupant risk metrics would not be expected to exceed either the preferred limits or the maximum limits. In my judgment, the evaluation of the 31” system would not have changed if the vehicle speed had been 3 km/hr higher.

Table 9 compares the crash test results with the corresponding NCHRP 350 evaluation criteria. My conclusion is that the test article passed this test.

Table 9. Test Results for Test 3-33 for 31” system

Test	NCHRP 350 Evaluation Criteria	Test Result	Pass/Fail
Structural Adequacy	C) Acceptable Test Article Performance may be by redirection, controlled penetration, or controlled stopping of the vehicle	Test article allowed the vehicle to gate in a controlled manner through the end terminal as designed.	Pass

Test	NCHRP 350 Evaluation Criteria	Test Result	Pass/Fail
Occupant Risk	D) Detached elements, fragments, or other debris from the test article should not penetrate or show potential for penetrating the occupant compartment or present an undue hazard to other traffic, pedestrians, or personnel in a work zone. Deformations of, or intrusions into, the occupant compartment that could cause serious injuries should not be permitted	No intrusion into the occupant compartment. There was some contact between the terminal and the side of the truck forward of the driver door which slightly dented the side of the vehicle. The terminal did not however intrude or penetrate into the occupant compartment.	Pass
Occupant Risk	F) The vehicle should remain upright during and after collision although moderate roll, pitching and yawing are acceptable.	Vehicle remained upright throughout the test	Pass
Occupant Risk	H1) Occupant Impact Velocity, Longitudinal (< 9m/s preferred, <=12 m/s max)	OIV=4.7m/s	Pass
Occupant Risk	H2) Occupant Impact Velocity, Lateral (<= 9m/s preferred, <=12 m/s max)	OIV = -2 m/s	Pass
Occupant Risk	I1) Occupant Ridedown Accel, Longitudinal (< 15 G preferred, <=20 max)	ORA = -9 G	Pass
Occupant Risk	I2) Occupant Ridedown Accel, Lateral (< 15 G preferred, <=20 max)	ORA = 6.7 G	Pass
Vehicle Trajectory	K) After collision, it is preferable that the vehicle's trajectory not intrude into adjacent lanes	Vehicle gated through the end terminal and travelled behind the test article.	Pass
Vehicle Trajectory	N) Vehicle trajectory behind the test article is acceptable	Vehicle gated through the end terminal and travelled behind the test article.	Pass

Conclusions

The objectives of this report were to evaluate the crash results of the ET-Plus end terminal installed with a 31” rail system when tested to the NCHRP 350 Test Level 3 (TL-3) crash test conditions. Under this test series, SWRI conducted the NCHRP 350 tests 3-30, 3-31, 3-32, and 3-33. The results are summarized in the Table 10. My conclusion is that the test article successfully met the evaluation criteria for NCHRP Report 350 tests 3-30, 3-31, 3-32, and 3-33.

Table 10. Test Results for Test 3-33 for ET-Plus installed with 31” rail system

Test	NCHRP 350 Evaluation Criteria	3-30	3-31	3-32	3-33
Structural Adequacy	C) Acceptable Test Article Performance may be by redirection, controlled penetration, or controlled stopping of the vehicle	Pass	Pass	Pass	Pass
Occupant Risk	D) Detached elements, fragments, or other debris from the test article should not penetrate or show potential for penetrating the occupant compartment or present an undue hazard to other traffic, pedestrians, or personnel in a work zone. Deformations of, or intrusions into, the occupant compartment that could cause serious injuries should not be permitted	Pass	Pass	Pass	Pass
Occupant Risk	F) The vehicle should remain upright during and after collision although moderate roll, pitching and yawing are acceptable.	Pass	Pass	Pass	Pass
Occupant Risk	H1) Occupant Impact Velocity, Longitudinal (< 9m/s preferred, <=12 m/s max)	Pass	Pass	Pass	Pass
Occupant Risk	H2) Occupant Impact Velocity, Lateral (<= 9m/s preferred, <=12 m/s max)	Pass	Pass	Pass	Pass
Occupant Risk	I1) Occupant Ridedown Accel, Longitudinal (< 15 G preferred, <=20 max)	Pass	Pass	Pass	Pass
Occupant Risk	I2) Occupant Ridedown Accel, Lateral (< 15 G preferred, <=20 max)	Pass	Pass	Pass	Pass
Vehicle Trajectory	K) After collision, it is preferable that the vehicle's trajectory not intrude into adjacent lanes	**	Pass	Pass	Pass
Vehicle Trajectory	N) Vehicle trajectory behind the test article is acceptable	Pass	Pass	Pass	Pass

** Vehicle spun out on traffic side of test article, and potentially into adjacent traffic lane. Note that this evaluation criteria is preferred, but not required. Vehicle spinout is typical behavior for this type of offset test.

References

Ferren J, “NCHRP Report 350 Test Report Compilation: Full-Scale Crash Evaluations of the ET-Plus End Terminal with 4-inch Wide Guide Channel Installed with a Rail Height of 27 ¾ Inches – Test Level 3, Test 3-33, 3-31, 3-32, and 3-30”, SWRI Document Number 18.20887.03.100FR0, Issue 1 (January 23, 2015)

Ferren J, “NCHRP Report 350 Test Report Compilation: Full-Scale Crash Evaluations of the ET-Plus End Terminal with 4-inch Wide Guide Channel Installed with a Rail Height of 31 Inches – Test Level 3, Test 3-33, 3-31, 3-32, and 3-30”, SWRI Document Number 18.20887.05.100FR0, Issue 1 (February 17, 2015)

Appendix A

Evaluation of the Potential for Serious Occupant Injury in

SWRI Test ET31-30

The NCHRP 350 evaluation criterion D states that “Deformations of, or intrusions into, the occupant compartment that could cause serious injuries should not be permitted”. This section analyzes the potential for occupant injury due to intrusion of the test article into the occupant compartment in SWRI test ET31-30.

The discussion below first describes the mechanical loading of the occupant and then assesses the potential for serious injury from this loading. Because the dummy in the ET31-30 test was not instrumented, my approach was to assess the potential for injury from 4 different perspectives:

a) Feasibility of Serious Lower Extremity using the Abbreviated Injury Scale
b) MASH Intrusion Criteria
c) IIHS Side Crash Structural Criteria
d) IIHS Lower Extremity Injury Criteria

Mechanical Loading of the Occupant

During the ET31-30 test, the rail folded outward toward the traffic side of the system after impact. Simultaneously, the car began to spin clockwise after impact. The folded rail struck the driver door between the driver door forward hinge, and the leading edge of the driver seat. The impact drove the door in as far as the steering wheel. There was no penetration of the door by the rail. Post-crash measurements of intrusion showed that the folded rail impact with the door resulted in 6.75” of static deformation of the door into the occupant compartment. From the videos and post-crash photos, there did not appear to be any deformation of the B-pillar. The driver door became unlatched during the test and bowed outward. This was likely the result of the force of the folded rail on the door forward of the dummy torso directed inward combined with the loading from the occupant torso onto the door near the B-pillar directed outward.

Examination of the video shows that the peak intrusion was between the driver door forward hinge, and the leading edge of the driver seat. Prior to the rail-door impact, the clockwise spin of the vehicle appears to have flung the torso of the belted driver against the door. The position of the legs was not visible in the pre-crash portion of the video. Likewise, the position of the left arm was not visible in the pre-crash portion of the video. However, the pre-crash photos shows that the left arm was positioned at the side of the driver torso.

As part of this project, we conducted an analysis of the video of the crash test and estimated that the folded rail struck the driver door at approximately 41 km/hr. The impact of the folded rail with the door appeared to directly strike the distal end of the upper leg. The folded rail struck the door at the approximate location of the steering wheel. Examination of the external videos shows that the top of the folded rail at impact was at approximately the height of the seat pan. The location of impact and the fact that the arms were initially at the side of the dummy suggests that the left arm was out of the region of maximum intrusion. Likewise, the rail did not appear to directly engage either the torso or the head of the dummy. As the dummy torso was in contact with the door at the time of impact and no door intrusion was observed at the point of torso-door contact, my assumption is that the acceleration experienced by the dummy torso was approximately the same as the vehicle. Because the lateral ORA was well within the preferred range, there would not appear to be an unacceptable risk of serious torso injury. The question of serious injury risk to the legs remains to be answered.

Are Serious Injuries of the Legs and Arms possible?

Examination of the video shows that the intruding door directly struck the lower extremities. The question is whether an impact to the lower or upper extremities can ever result in a serious injury. NCHRP 350 does not precisely define what is meant by 'serious injury'. In this study, my approach was to use the Abbreviated Injury Scale (AIS).

The AIS is an injury coding system developed by the Association for the Advancement of Automotive Medicine [AAAM, 2001]. AIS is a trauma-specific, anatomically-based coding scale that is widely used to describe the type and severity of injuries arising from motor vehicle crashes. NHTSA uses AIS as the injury severity foundation for both its regulatory and research programs. Each injury incurred by a person or subject is coded on a six point scale which ranges from 1 for minor injuries to 6 for unsurvivable injuries as shown in Table 11. The AIS system is based on the assessment of threat to life, which was developed by a consensus of trauma surgeons. Note that under the AIS, a serious injury to fatal injury is denoted by an AIS score of 3 or higher.

Table 11. Abbreviated Injury Scale

AIS Score	Injury Severity
1	Minor
2	Moderate
3	Serious
4	Severe
5	Critical
6	Unsurvivable

The first aim was to determine whether the impact of the intruding rail/door with the legs could have resulted in serious injury. Amputation of the leg above the knee would be scored as AIS 4, a severe injury. However, without penetration of the rail through the door, amputation seems unlikely. However, even without amputation, femur fractures are rated as a serious injury with an AIS score of AIS=3. Amputation of the leg below the knee, unlikely in this test, has a score of AIS=3. Fractures of the lower leg, i.e. the tibia and fibula, have a maximum of AIS = 2. My conclusion is that the risk of serious injury cannot be discounted simply because the impact is to the legs. An AIS 3 femur fracture could occur as a result of an impact to the upper legs and would be considered serious injury.

Injuries to the arms range from AIS=1 for minor lacerations and contusions, AIS=2 for a closed fracture, to AIS=3 for open, displaced, or comminuted fractures of the bones of the upper arm, i.e. the humerus, the ulna, and the radius. Amputation of the arm during a crash has an AIS score of 3. However, as the rail did not penetrate through the door or window opening, amputation of the arm seems unlikely. Note that AIS-90 (update 1998), the scale used here, scores an amputation of the arm at the same severity as an open, displaced, or comminuted fracture of the upper arm. Although an amputation is unlikely, a serious (AIS 3) upper arm fracture would be possible under direct lateral loading.

MASH Intrusion Criteria

The newly developed MASH crash test procedures add additional evaluation criteria to better define what intrusion is acceptable in roadside hardware crash tests. The MASH criteria acknowledge the fact that injury risk is likely to be a strong function of the location of any intrusion. MASH also emphasizes the need to differentiate between (1) penetration of the test article into the occupant compartment which MASH states is unacceptable and (2) intrusion or deformation of the occupant compartment under crash loading which may be acceptable within limits. Table 12 presents the limits on occupant compartment intrusion under MASH:

Table 12. MASH Intrusion Limits

Deformation Area	**Intrusion limit (inches)**	**Notes**
Roof	4.0	
Windshield	3.0	No tear of plastic liner
Window		No shattering of side window from direct contact with test article
Wheel/foot well and toe pan areas	9.0	
Side front panel (forward of A-pillar)	12.0	
Front side door area (above seat)	9.0	
Front side door area (below seat)	12.0	
Floor pan and transmission tunnel areas	12.0	

Under the MASH Intrusion limits, it would appear at first glance that the ET31-30 max intrusion of 6.75” would be acceptable. However, the MASH intrusion limits may not be applicable to the side impact loading observed in the ET31-30 crash tests. Appendix A5.3 of the MASH procedure indicates that these intrusion values were based upon the recommended guidelines developed by the Insurance Institute for Highway Safety (IIHS) for evaluating structural performance of vehicles in offset frontal crash tests. The IIHS frontal-offset crash tests primarily load the front of the vehicle structure along the longitudinal axis of the vehicle. The door is not directly struck in IIHS frontal offset crash tests. In contrast, the folded rail impact in Test ET31-30 primarily loaded the driver door along the lateral axis of the vehicle. The MASH intrusion criteria do not appear to be applicable to the ET31-30 rail to door impact.

IIHS Side Crash Structural Rating

The IIHS conducts side crashes which may be more relevant to the ET31-30 test than the frontal-offset crashes referenced in MASH. The side crashes are conducted by impacting a 1500 kg movable deformable barrier (MDB) at an angle of 90 degrees into the side of a stationary car at 50 km/hr (31.1

mph). Among other evaluation criteria, the IIHS scores the crash test outcomes with a structural rating. The structural rating is based upon the post-crash position of the struck side B-pillar in relationship to the centerline of the seat pan. Table 13 presents the IIHS side crash structural rating system:

Table 13. IIHS Side Crash Structural Rating Levels

Lateral distance between B-pillar (post-crash) and driver seat centerline (pre-crash)	Rating
>= 12.5”	Good
>=5.0”	Acceptable
>= 0”	Marginal
Intrusion beyond seat centerline	Poor

Examination of the video and post-crash photos in the ET31-30 test showed little to no deformation of the B-pillar. Again, the IIHS structural criteria may not be the most relevant to the point loading of the ET31-30 test. Although both the IIHS test and the ET31-30 test both engage the side of a car, they differ in the area which was loaded. Because the IIHS MDB is 1.676 meters in width, it involves a broad distributed loading ranging across essentially the entire side of the occupant compartment. In this distributed loading, basing structural integrity upon the deformation of the B-pillar is appropriate. In contrast, the folded rail impact in the ET31-30 loaded only a narrow area of the door forward of the torso. Although such a narrow loading could produce injury, it would not be expected to deform the B-pillar.

IIHS Side Crash Test Upper and Lower Extremity Injury Criteria

The IIHS side crash test described above also prescribes limits on the loads to an instrumented dummy seated in the driver location. For the lower extremities, the IIHS test procedure defines the threshold between poor and marginal performance at the distal end of the femur as a moment in the anterior-posterior or lateral-medial axis of 356 N-m, and a lateral force on the distal end of the femur of 3.9 kN. The threshold between good and acceptable performance at the distal end of the femur is defined as a moment in the anterior-posterior or lateral-medial axis of 254 N-m, and a lateral force on the distal end of the femur of 2.8 kN.

Because the ET31-30 dummy was not instrumented, my approach was instead to look for measurements of these values in a comparable crash test in which the dummy had been instrumented. NHTSA test 3444 conducted in August 2000 subjected a 1996 Geo Metro 3 door to a side impact by a 950-kg movable deformable barrier at 50 km/hr (MGA, 2000). Instrumented EuroSid-2 dummies were seated in the driver and the left rear passenger positions.

The impact in the NHTSA test drove the door into the occupant compartment, striking the driver. External door crush at the approximate position of the left upper leg was approximately 195 mm (7.6 inches). The electronic data for the femur channels was downloaded from the NHTSA Vehicle Crash Test Database and filtered at 600 Hz. The peak lateral force on the distal end of the left femur was 1.7

kN.   The peak bending moment of the left femur was 186 N-m. Both bending moment and peak lateral force are within the IIHS good-acceptable region.

The IIHS side crash test described above prescribes limits on shoulder deflection.   However, test 3444 did not measure shoulder deflection, but measured shoulder load instead. Regardless, the shoulder was not directly impacted in the ET31-30 test. Hence, any shoulder measurements from test 3444 would not be relevant to the ET31-30 test. Likewise, neither the humerus nor the lower arm were instrumented in test 3444, and hence no measure of injury to these body regions could be assessed. But as noted above, the left arm of the dummy, although flung away from the door on impact, did not appear to be in the region of maximum intrusion which should reduce the potential for serious injury.

Although the NHTSA test is not identical to the ET31-30 door impact, the two are similar in several respects. First, the Geo Metro in the NHTSA test is the same model used in the ET31-30 test. The deformation at the location of the femur was also similar: the external door crush was 7.6” in the NHTSA test vs. 6.75” intrusion in the ET31-30 test.   Because the width of the door (typically 3-4”) usually collapses to some extent before external impacts result in intrusion, my expectation is that the external door crush to be somewhat higher than the intrusion for a similar level of intrusion.   Finally, the impact speed was similar. The impact speed in the NHTSA test was 50 km/hr. This is somewhat higher, but of similar magnitude to the ET31-30 door impact speed which we estimated to be 41 km/hr based on video analysis.   There are also important differences between the two tests. Most notable is that the ET31-30 test involved a narrow loading of the door by the folded rail, whereas the side structure in the NHTSA test was subjected to a distributed loading across the A-pillar, door, and B-pillar.

Conclusion

Based on this analysis, my conclusion is that a driver exposed to the crash conditions of SWRI test ET31-30 would have been unlikely to have been at risk of serious injury from the folded rail impact to the driver door.

References

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