U.S. Department of Transportation
Federal Highway Administration

March 13, 2015

Full Scale Crash Testing of the ET-Plus 31-inch Guardrail Terminal

Executive Summary

From January 15 to January 27, 2015, the ET-Plus guardrail end terminal manufactured by Trinity Highway Products was crash tested in accordance with NCHRP Report 350 criteria. These tests were conducted at the Southwest Research Institute (SwRI) in San Antonio, Texas. All of these tests were conducted with the terminal installed on a guardrail with a nominal height of 31 inches above the ground. This second round of tests is in addition to the first round of crash tests completed at 27¾ inches. The results of the 27¾ inch tests can be found at http://www.fhwa.dot.gov/guardrailsafety/et27crashtestingsummary.pdf

The Federal Highway Administration (FHWA), SwRI, and Dr. H. Clay Gabler, a Professor and Chair for Biomedical Engineering Graduate Studies in the Department of Biomedical Engineering and Mechanics at Virginia Polytechnic Institute and State University, each independently evaluated the crash test results, both the test report and the video documentation, and determined that all 4 tests passed the NCHRP Report 350 criteria.

Crash Test Summary

The crash tests conducted at SwRI in January 2015 were:

NCHRP Report 350 Test (SwRI Test)	Test Vehicle	Impact Speed (km/hr)	Impact Angle	Impact Location
3-30 (31-30)	820C	100	0 degree	Vehicle front offset ¼ vehicle width from vehicle centerline
3-31 (31-31)	2000P	100	0 degree	Vehicle front at centerline
3-32 (31-32)	820C	100	15 degree	Vehicle front at centerline
3-33 (31-33)	2000P	100	15 degree	Vehicle front at centerline

FHWA extended the opportunity to all the State DOTs to witness the tests and to examine the test articles and test set-up. The following States took advantage of this opportunity for these four tests – New Hampshire, Virginia, Georgia, Texas, Delaware, and Arizona. The State DOT representatives evaluated the set-up including the extruder heads and the guardrail posts and either individually measured or concurred in the measurements of heads and the height of the guardrails. For those that witnessed the tests, they were provided full access to the devices that had been previously crash tested. Dr. Gabler witnessed two of the 31-inch tests and was provided the same access to the test articles, set-up and post-crash test examination as provided to the State DOT representatives.

At FHWA's encouragement, the opportunity for the media to be present at the crash tests was provided to two members of the media. FHWA and a representative of AASHTO provided media availability after each crash test for the media to ask questions about the test.
The observers for each test were:

	Jan 15 ET31 Test 3-33	Jan 16 ET31 Test 3-31	Jan 21 ET31 Test 3-32	Jan 27 ET31 Test 3-30
U.S. DOT				
Eduardo Arispe			X	X
Dick Albin	X	X		X
Tony Furst	X	X	X	X
Brian Fouch	X	X		
Michael Griffith			X	
States				
Todd Emery - Arizona DOT			X	
Shanté Hastings – Delaware DOT	X	X		
Keith Cota - New Hampshire DOT	X	X		
Andy Casey – Georgia DOT			X	
Mark Marek – Texas DOT			X	X
Charles W. Patterson - Virginia DOT	X	X		X

Michael C. Brown - Virginia DOT			X	
Matt Barret - Virginia DOT	X	X	X	
AASHTO				
Jim McDonnell				X
Independent Expert				
Clay Gabler – Virginia Tech	X	X		
Media Representatives				
Tonya Kerr – ABC News	X	X	X	X

A summary of the results is shown below as reported by SwRI, FHWA, and Dr. H. Clay Gabler concur with these results.

Evaluation Factor	**Evaluation Criteria**	**Test Results**			
		ET31-33[3]	**ET31-31**	**ET31-32**	**ET31-30**
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
	F. The vehicle should remain upright during and after collision although moderate roll, pitching and yawing are acceptable.	Pass	Pass	Pass	Pass
	H. Occupant Impact Velocity (OIV) limits: Preferred= 9m/s Maximum=12 m/s	Pass	Pass	Pass	Pass
	I. Occupant Ridedown Accel (ORA) Limits: Preferred = 15 G Maximum = 20 G	Pass	Pass	Pass	Pass
Vehicle Trajectory	K. After collision, it is preferable that the vehicle's trajectory not intrude into adjacent lanes	See Note [1]	See Note [1]	See Note [1]	See Note [1, 2]
	N. Vehicle trajectory behind the test article is acceptable	Pass	Pass	Pass	Pass

Note [1]: As stated in Report 350, this criterion is preferable, but not required.

Note [2]: The design of Test 3-30 of Report 350 will cause the test vehicle to spin-out on the traffic side of the installation when the vehicle is initially offset towards the traffic side.

Note [3]: The impact speed of Test 31-33 was below the tolerance band by 3 km/hr (1.9 mph); it is unlikely that an impact speed 3 km/hr higher would have a significant effect on the ridedown acceleration or impact velocity levels recorded, all of which were well below acceptable limits. Further, an impact speed of 3 km/hr higher would not affect the results of the 'Structural Adequacy' or 'Vehicle Trajectory' evaluation.

FHWA's analysis of the test report found:

- **NCHRP Report 350 Test Criteria** - The tests were conducted in conformity with Report 350.
- **Vehicle impact speeds –** Impact speeds for all four tests were within tolerance with the exception of test 31-33, which was below the nominal speed tolerance band of 4 km/hr by an order of 3 km/hr. (1.9 mph)[a]
- **Vehicle impact angles -** Impact angles for all four tests were within the recommended tolerance.
- **Test vehicle specifications –** All of the vehicle specifications were within the allowable tolerances.
- **Occupant Impact Velocity Values –** Values for all four tests were within the preferred limits.
- **Ridedown Acceleration Values -** Values for all four tests were within the preferred limits.
- **Vehicle penetration – There was no penetration** of the vehicle by the test article in any of the four tests. Nor was there any penetration, or the potential for penetration, of any of the detached elements, fragments, or other debris from the test article.
- **Vehicle post-impact trajectory –** This measure was found to be acceptable with no rollover in all four tests.
- **Impact severity (IS) –** Impact severity for all four tests was within tolerance with the exception of test 31-31, which was above the upper limit tolerance of 834.6 KJ by 6.1 KJ (or 0.7 percent).[b]

Footnotes

[a] FHWA finds that it is unlikely that an impact speed 3 km/hr higher would have a significant effect on the ridedown acceleration or impact velocity levels recorded, all of which were well below acceptable limits. Further, an impact speed 3 km/hr higher would likely not affect the results of the 'Structural Adequacy' or 'Vehicle Trajectory' evaluation.

[b] FHWA finds the higher impact severity is acceptable as noted by SwRI on page 30 of the ET-31-31 section in its report ("Section 3.3.3 of Report 350 stipulates that a test where the IS exceeds the positive tolerance is acceptable provided the test results meet recommended evaluation criteria, as was the case for this test.").

- **Compartment deformation –** One of the four tests, Test 31-30, resulted in compartment deformation. In this test, the vehicle impacted a bend in the guardrail, causing deformation in the occupant compartment that measured approximately 17.2cm (6.75 in) at the closest point of the interior door panel located approximately 2.2cm (0.85 inches) below the center of gravity and approximately 5.1cm (2 inches) aft of the instrumentation panel, roughly even with the height of the front edge of the seat.

  FHWA staff met with the SwRI test facility manager to confirm the measurements and to learn how the laboratory measured the level of occupant compartment deformation. SwRI documented the methodology used to measure post-test deformation of the vehicle used in Test 31-30. A detailed description of this methodology can be found in Appendix A titled "Post-Test Occupant Compartment Measurement Methodology for ET Plus Test ET31-30."

  To assist in FHWA's evaluation of the potential for serious injury based on the location and extent of the deformation, FHWA sought the expertise of the National Highway Traffic Safety Administration's (NHTSA) Office of Vehicle Crashworthiness Research. NCHRP 350 does not define "serious injury." In conducting this evaluation, FHWA and NHTSA used the Abbreviated Injury Scale (AIS) to define serious injury. The AIS coding system was developed by the Association for the Advancement of Automotive Medicine and is used to describe injuries resulting from motor vehicle crashes. An AIS score of 3 defines a serious injury. Given the location and the extent of deformation in the lower door panel, it was determined that the highest potential for serious injury was in the lower extremity.

  NHTSA's engineers and scientists with strong expertise in injury biomechanics queried 17 years of data contained in the National Automotive Sampling System - Crashworthiness Data System (NASS-CDS) to extract crashes that had levels of deformation to the driver's side door at the same location as the location in Test 31-30. This analysis evaluated levels of deformation at the lower door panel ranging from 3-7 cm (1.2" - 2.8") to 61 cm (24"), with corresponding serious injuries as measured on the AIS scale. That analysis of the data found that the risk of serious lower leg injury to the driver (i.e., measuring 3 on the AIS scale) from the occupant compartment deformation in this test - 6.75" or 17.1 cm - is 0.3%. NHTSA's analysis is in Appendix B titled "National Highway Traffic Safety Administration's Deformation Evaluation." FHWA concludes that the location and level of occupant compartment deformation in this test would not be likely to cause serious injury.

  Dr. Gabler evaluated the potential for serious injury from multiple perspectives related to the deformation of the occupant compartment. He first evaluated the mechanical loading of the occupant and then assessed the potential for serious injury from this loading. In evaluating the potential for serious injury, his analysis primarily focused on the use of side crash structural rating and side crash test lower extremity injury evaluation criteria from the Insurance Institute for Highway Safety.

Dr. Gabler's analysis is posted with these crash test results at website http://www.fhwa.dot.gov/guardrailsafety/et31crashtestprotocols.pdf. His report concludes "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.'"

SwRI determined that the 6.75 inch deformation equated to a reduction in the width of the occupant compartment of 14 percent and an Occupant Compartment Deformation Index rating of LF0000200. Based on the location and magnitude of the deformation and the fact that there was no vehicle penetration, SwRI indicated there was no indication of serious or life-threatening injury due to the occupant compartment reduction.