

**Inspection and Assessment of Crash Test Protocols:
Task 3.1-Task 3.2 Report – Part I (27 ¾” ET-Plus System Crash Tests)**

Submitted to

Federal Highway Administration
U.S. Department of Transportation
Washington, DC

By

H. Clay Gabler, PhD
Virginia Tech
Blacksburg, VA

On

3 February 2015

Inspection and Assessment of Crash Test Protocols: Task 3.1-Task 3.2 Report Part I (27 3/4" ET-Plus System Crash Tests)

H. Clay Gabler, PhD
Virginia Tech
3 February 2015

Background

The goal of this report is to evaluate the crash test results of the ET-Plus end terminal when tested to the NCHRP 350 Test Level 3 (TL-3) crash test procedure. Two series of crash tests were conducted as part of this effort at Southwest Research Institute (SWRI) – (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. Together, the 27-3/4" and 31" test series comprise a total of eight (8) crash tests. The nominal test conditions are shown in Table 1 for each guardrail height.

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 our analysis of the crash test results for the 27-3/4" height w-beam guardrail system as required by Task 3.1 and Task 3.2 of our FHWA contract. Note that this report is the first of two parts of the Task 3 analysis. This report is restricted to evaluation of crash test results from the 27-3/4" system. A follow-on report will discuss the evaluation of the results from the 31" system crash tests.

Approach

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

- Test reports, prepared by SWRI (Ferren, 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, the PI 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, the PI 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.

Our analysis included assessment of the actual test conditions and comparison against NCHRP 350 test conditions tolerances, and assessment of the test results using the NCHRP 350 evaluation criteria. Our 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

Test 3-30, ET-Plus installed with 27-3/4" guardrail system

This test involved a 820C vehicle (a 1999 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 27-3/4" system

Test Parameter	Test Value	Nominal Value	Deviation
Total Mass – vehicle + ballast+ dummy (kg)	871	895	-24
Impact Velocity (km/hr)	102.5	100	2.5
Impact Angle (degrees)	0.1	0	0.1
Impact Severity (KJ)	323.3	316.4	6.9

NCHRP 350 preferred tolerance for impact speed is +/- 4.0 km/hr and +/- 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. Our conclusion is that the test article passed this test.

Table 3. Test Results for Test 3-30 for 27-3/4" 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	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=7.5m/s	Pass
Occupant Risk	H2) Occupant Impact Velocity, Lateral (< 3 m/s preferred, <=5 m/s max)	OIV=0.4m/s	Pass
Occupant Risk	I1) Occupant Ridedown Accel, Longitudinal (< 15 G preferred, <=20 max)	ORA=-14.0 G	Pass
Occupant Risk	I2) Occupant Ridedown Accel, Lateral (< 15 G preferred, <=20 max)	ORA = 6.8 G	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 of test.

Test 3-31, ET-Plus installed with 27-3/4" guardrail system

This test involved a 2000P vehicle (a 1994 Chevrolet 2500 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 27-3/4" system

Test Parameter	Test Value	Nominal Value	Deviation
Total Mass – vehicle + ballast (kg)	1998	2000	-2
Impact Velocity (km/hr)	97.5	100	-2.5
Impact Angle (degrees)	0.1	0	0.1
Impact Severity (KJ)	733.7	771.7	-37.9

For this test, the 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, impact speed, impact angle, and impact severity were all within these tolerance ranges.

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

Table 5. Test Results for Test 3-31 for 27-3/4" 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

Test	NCHRP 350 Evaluation Criteria	Test Result	Pass/Fail
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=7.1m/s	Pass
Occupant Risk	H2) Occupant Impact Velocity, Lateral (< 3 m/s preferred, <=5 m/s max)	OIV= -0.3m/s	Pass
Occupant Risk	I1) Occupant Ridedown Accel, Longitudinal (< 15 G preferred, <=20 max)	ORA=-9.2 G	Pass
Occupant Risk	I2) Occupant Ridedown Accel, Lateral (< 15 G preferred, <=20 max)	ORA=-5.0 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 27-3/4" guardrail system

This test involved a 820C vehicle (a 1997 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 27-3/4" system

Test Parameter	Test Value	Nominal Value	Deviation
Total Mass – vehicle + ballast+ dummy (kg)	917	895	22
Impact Velocity (km/hr)	98.3	100	-1.7
Impact Angle (degrees)	15.2	15	0.2
Impact Severity (KJ)	313.8	316.4	-2.6

NCHRP 350 preferred tolerance for impact speed is +/- 4.0 km/hr, +/- 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. Our conclusion is that the test article passed this test.

Table 7. Test Results for Test 3-32 for 27-3/4" 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 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=8.5m/s	Pass
Occupant Risk	H2) Occupant Impact Velocity, Lateral (< 3 m/s preferred, <=5 m/s max)	OIV=-1.5ms	Pass
Occupant Risk	I1) Occupant Ridedown Accel, Longitudinal (< 15 G preferred, <=20 max)	ORA=-4.1G	Pass
Occupant Risk	I2) Occupant Ridedown Accel, Lateral (< 15 G preferred, <=20 max)	ORA = 3.3 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

Test 3-33, ET-Plus installed with 27-3/4" guardrail system

This test involved a 2000P vehicle (a 1995 GMC 2500 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 27-3/4" system

Test Parameter	Test Value	Nominal Value	Deviation
Total Mass – vehicle + ballast (kg)	1974	2000	-26
Impact Velocity (km/hr)	103.3	100	3.3
Impact Angle (degrees)	14.9	15	-0.1
Impact Severity (KJ)	813	771.7	41.4

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, impact speed, impact angle, and impact severity were all within these tolerance ranges.

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

Table 9. Test Results for Test 3-33 for 27-3/4" 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 near the door from contact with the end terminal, but the terminal did not penetrate into the occupant compartment.	Pass

Test	NCHRP 350 Evaluation Criteria	Test Result	Pass/Fail
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 = 4.5m/s	Pass
Occupant Risk	H2) Occupant Impact Velocity, Lateral (< 3 m/s preferred, <=5 m/s max)	OIV = -1.5m/s	Pass
Occupant Risk	I1) Occupant Ridedown Accel, Longitudinal (< 15 G preferred, <=20 max)	ORA = -7.6g	Pass
Occupant Risk	I2) Occupant Ridedown Accel, Lateral (< 15 G preferred, <=20 max)	ORA = 4.6g	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 27-3/4” 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 each of these NCHRP Report 350 tests.

Table 10. Test Results for Test 3-33 for ET-Plus installed with 27-3/4” 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 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 (< 3 m/s preferred, <=5 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 ¼ 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)