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

Tests: ET31-33, ET31-31, ET31-32 and ET31-30

SwRI® Project No. 18.20887

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Issue 1

Prepared for:
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ACCREDITED
TESTING CERT.#1110.02

Included within this report compilation are four individual reports covering testing performed on the ET Plus® End Terminal with 4-inch wide guide channel installed with a rail height of 31 inches. Testing was conducted in accordance with NCHRP Report 350 at Southwest Research Institute in San Antonio, Texas.

Table 0.1 provides a list of the tests described in this report in the order in which testing was performed; this is also the order in which the reports are found within this document. Each individual report is bookmarked in the electronic file to facilitate review, and the electronic bookmarks are in numerical order by test identification.

Table 0.1: Tests Conducted

TEST ID	REPORT 350 TEST	TEST DATE	TEST VEHICLE	IMPACT Θ
ET31-33	Test 3-33	1/15/2015	2000P	15°
ET31-31	Test 3-31	1/16/2015		0°
ET31-32	Test 3-32	1/21/2015	820C	15°
ET31-30	Test 3-30	1/27/2015		0°

A summary of the performance of the ET Plus End Terminal during the four tests performed in the ET31 test series is provided in Table 0.2. As reflected in the table, the ET Plus End Terminal with 4-inch wide guide channel installed with a rail height of 31 inches meets NCHRP Report 350 criteria for Tests 3-30, 3-31, 3-32 and 3-33.

Table 0.2: Summary of Test Evaluation Results (NCHRP Report 350 Evaluation Criteria) for ET31 Test Series

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.	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 Velocities (OIV) limits: Preferred = 9 m/s Maximum = 12 m/s	Pass	Pass	Pass	Pass
	I. Occupant Ridedown Acceleration (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 traffic 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 3 km/hr higher would likely not affect the results of the 'Structural Adequacy' or 'Vehicle Trajectory' evaluation.

NCHRP Report 350 Test Report

Full-Scale Crash Evaluation 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
Test Identification: ET31-33

SwRI® Project No. 18.20887

SwRI Document Number: 18.20887.05.100.FR1
Issue 1

Prepared for:
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Below is a table documenting the various changes recorded in this report. Each issuance of the report is clearly marked with the revision number and date of issue.

Table 0.1: Revision Table

ISSUE	EXPLANATION	PAGE NUMBERS	DATE EFFECTIVE
1	Original report	All	February 17, 2015

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1 INTRODUCTION

The purpose of Crash Test ET31-33 was to evaluate the performance of the Trinity Highway Products ET Plus End Terminal with 4-inch wide guide channel installed with a rail height of 31”. To test the performance of this terminal, Test 3-33 was conducted according to National Cooperative Highway Research Program (NCHRP), Report 350. The total system installation length for the test was nominally 49.5 m (162’-6”), including the 16.2 m (53’-1½”) ET Plus terminal length.

Test 3-33 is intended primarily to evaluate occupant risk and vehicle trajectory criteria. The test consists of a 2000 kg (4409 lb) pickup truck approaching the traffic side of the installation at a 15° angle to the roadway, and impacting the end terminal at 100 km/hr (62.1 mph). The vehicle will impact at the vehicle's centerline.

Crash Test ET31-33 was conducted on January 15, 2015, at the Crash Test Site at Southwest Research Institute (SwRI) by SwRI personnel. This report presents information on the test parameters, a discussion of the test, and an assessment of the test results based on the criteria set forth in NCHRP Report 350.

2 TEST PARAMETERS

Test Facility

The full-scale crash testing was performed by Southwest Research Institute (SwRI), on the campus located at the following address:

Southwest Research Institute
6220 Culebra Road
San Antonio, Texas 78238

SwRI is ISO/IEC 17025 accredited by A2LA (American Association for Laboratory Accreditation) to perform this testing under Testing Laboratory Certificate #1110.02.

Test Article – Design and Construction

The full-scale crash test was performed on the ET Plus End Terminal which included the ET Plus extruder head with 4-inch wide guide channel and W-Beam guardrail installed with a rail height of 78.7 cm (31 in.). The ET Plus End Terminal installation tested uses standard AASHTO M180 Type 2, 12-gauge W-Beam guardrail panels mounted with the top of the rail 78.7 cm (31 in.) above the ground, two wooden breakaway posts in foundation sleeves without soil plates at Posts 1 and 2, and CRT posts at Posts 3 through 8. The end terminal included 15.2 cm x 30.5 cm (6" x 12") wood blockouts at Posts 3 through 8.

During installation, holes approximately 61 cm (2 ft) in diameter were drilled into the soil and then backfilled around the posts using "standard soil" as defined by NCHRP Report 350, Section 2.2.1.1. The base material was compacted in 15.2 cm (6 in) lifts, and was added until the surface was flush with the surrounding soil.

The guardrail line posts are 15.2 cm x 20.3 cm (6" x 8") wood posts with 15.2 cm x 20.3 cm (6" x 8") wood blockouts. The blockouts are toenailed, and the guardrail panels are mounted to the posts using 1.6 cm (5/8 in) diameter post bolts beginning with Post 2; the bolt for Post 2 is 25.4 cm (10 in) long, the bolts for Posts 3 through 8 are 55.9 cm (22 in) long, and all other post bolts are 45.7 cm (18 in) long. The post spacing is 1.9 m (6'-3"), and each splice joint used eight (8) 1.6 cm (5/8 in) diameter x 3.2 cm (1-¼ in) splice bolts and nuts; the splice bolts have a nominal total length of 4.1 cm (1-5/8 in) including the bolt head. The installation uses 1.9 cm (3/4 in) diameter x 25.4 cm (10 in) bolts through the soil tube, post, and strut at Post 1 and Post 2. An anchor cable is also installed at Post 1. The installation has a guardrail splice at Post 3. Subsequent guardrail splices are mid-span between Posts 5 and 6, and every 3.8 m (12'-6") afterward to the end of the system.

The total system installation length for the test was nominally 49.5 m (162'-6"), including the 16.2 m (53'-1½") ET Plus terminal length, 30.5 m (100 ft) of guardrail, and a 2.9 m (9'-4½") long downstream anchor terminal. Detailed drawings of the test article provided by Trinity Highway Products are provided in Appendix A.

The ET Plus end terminal extruder head was one of eight production samples CalTrans (California DOT) pulled from their inventory for testing at SwRI. The heads were inspected by CalTrans, FHWA, and Trinity Highway Products personnel at the CalTrans yard, and were stamped with identifiers "Kit #1" through "Kit #8". SwRI arranged for shipment of the heads to the test site in San Antonio, and the heads remained in controlled storage until they were installed for testing. The dimensions of the specific ET Plus end terminal extruder head used for Test ET31-33 are provided in Table 2.1 below; dimensions measured with a tape measure are listed in fractional inches, and dimensions measured with a digital caliper are listed as decimals. Copies of the datasheets reviewed by representatives from the FHWA, US DOT and various state Departments of Transportation (DOT) prior to testing are located in Appendix B.

The performance goal for the ET Plus is to achieve controlled vehicle deceleration in compliance with NCHRP Report 350 criteria for post-impact vehicle trajectory and occupant risk. Figure 2.3 through Figure 2.19 present photographs of the guardrail installation.

Table 2.1: Key ET Plus Head Dimensions

Extruder Head Stamp ID	7	
Exit Gap	2.9 cm	1.1435"
Entrance Gap	11.94 cm	4.6990"
Guide Chute Exit Height	38.1 cm	15"
Guide Chute Entrance Height	36.83 cm	14-1/2"
Channel Width (see Figure 2.2)	10.25 cm	4.0355"

Figure 2.1: ET Plus Head Sample Identification Number

Figure 2.2: Measurement of Channel Width of Head

Figure 2.3: Test Installation for ET Plus Test ET31-33

Figure 2.4: ET Plus End Terminal

Figure 2.5: ET Plus Head Height Above Ground – Top

Figure 2.6: ET Plus Head Height Above Ground – Bottom

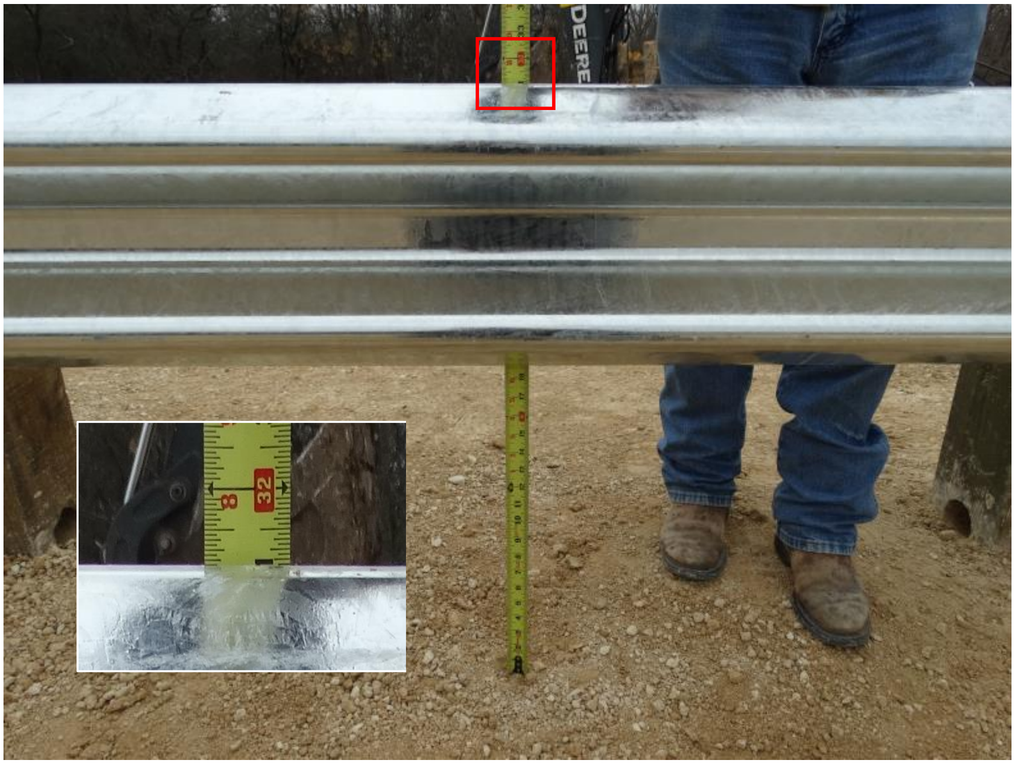


Figure 2.7: Measurement of Guardrail Installation Height

Figure 2.8: ET Plus Head and Anchor Cable Assembly

Figure 2.9: End Terminal Cable Anchor at Upstream End – Post 1

Figure 2.10: End Terminal Cable Anchor at Downstream End

Figure 2.11: First Guardrail Panel Splice Joint – Traffic Side (Splice Bolts Painted for Visibility in Video)

Figure 2.12: First Guardrail Panel Splice Joint – Back Side (Nuts Painted for Visibility in Video)

Figure 2.13: Second Guardrail Panel Splice Joint Mid-Span between Posts 5 & 6 – Traffic Side (Splice Bolts Painted for Visibility in Video)

Figure 2.14: Second Guardrail Panel Splice Joint Mid-Span between Posts 5 & 6 – Back Side (Nuts Painted for Visibility in Video)

Figure 2.15: ET Plus Head and Post 1 – Traffic Side

Figure 2.16: ET Plus Head with Posts 1 & 2 and Strut

Figure 2.17: ET Plus Head Side View (see Appendix B for Dimensions)

Figure 2.18: Downstream Anchor Terminal at Posts 26 and 27 – Traffic Side

Figure 2.19: Downstream Anchor Terminal at Posts 26 and 27 – Non-Traffic Side

Test Vehicle

The test vehicle was a 1994 GMC C2500 pickup truck, shown in Figure 2.20; the vehicle data sheet is provided in Appendix B. Figure 2.21 and Figure 2.22 show the relationship between the height of the vehicle bumper and the end terminal. Figure 2.23 shows the test vehicle positioned at the impact point of the end terminal, and Figure 2.24 shows an overhead view of the test vehicle positioned at the intended crash angle of 15° and at the vehicle's centerline. Figure 2.25 shows the ballast weight that was added to the vehicle, bolted to the bed of the pickup near the cab.

The test inertial mass of the vehicle, including 100 kg (220.5 lbs) of added ballast weight, was 1981 kg (4,367 lbs) as reflected in Table 4.2.

Figure 2.20: Test Vehicle for Test ET31-33

Figure 2.21: Test Vehicle Bumper Height

Figure 2.22: Test Vehicle Bumper Relative to ET Plus Head

Figure 2.23: Test Vehicle Impact Trajectory

Figure 2.24: Test Vehicle Impact Trajectory – Overhead View

Figure 2.25: Test Vehicle Ballast

Test Vehicle Guidance

The test vehicle was towed into the end terminal using two tow vehicles and a series of pulleys and sheaves. A steel cable was attached to a quick-release pin under the front of the vehicle and was passed around a sheave and secured to the rear of the first tow vehicle. The first tow vehicle was equipped with an adjustable ignition restrictor that attenuated the tow vehicle's engine RPM when a pre-set speed was attained; this vehicle was connected with a steel cable to a second tow vehicle. The test vehicle was guided by means of a taught steel cable attached to a sliding shoe which was attached to the front spindle of the test vehicle shown in Figure 2.26. Just prior to impact, the sliding shoe and tow cable were stripped from the vehicle allowing the test vehicle to free wheel into the end terminal.

Figure 2.26: Test Vehicle Steering Guidance Assembly

Test Vehicle Data Acquisition

The data acquisition consisted of recording the acceleration and angular velocities of the test vehicle. The measurement of these two parameters allows SwRI engineers to perform an occupant risk evaluation. The device used to record the vehicle acceleration and angular velocities was a six (6) degree-of-freedom Instrumented Sensor Technology Electronic Data Recorder, henceforth referred to as the EDR-4.

The EDR-4 recorder unit is a compact package used for stand-alone recording of shock and vibration, and is able to record six channels of data. The three acceleration channels were recorded from a built-in triaxial accelerometer used to record the test vehicle's accelerations in three orthogonal directions (x, y, and z). The three angular velocity channels were recorded from built-in rate gyro transducers used to record the test vehicle's angular velocities in three orthogonal directions (roll, pitch, and yaw).

The data acquisition package was rigidly attached to the test vehicle. A metal bracket was welded onto the test vehicle's body. This bracket was attached inside the passenger compartment of the vehicle, as close as possible to the vehicle's center of gravity, without significantly modifying the vehicle's interior components (i.e., center console, bench seats). The data acquisition package was then bolted to the metal bracket as shown in Figure 2.27 and Figure 2.28. Because of the configuration of the EDR-4 as manufactured, the orientation of the data acquisition package within the vehicle matches the general axis designation given in Figure 4.6 of NCHRP Report 350, but the signs for the Y and Z axes had to be reversed during post-test processing to comply with the NCHRP and TRAP sign convention.

Figure 2.27: EDR Mounted in Test Vehicle for Test ET31-33

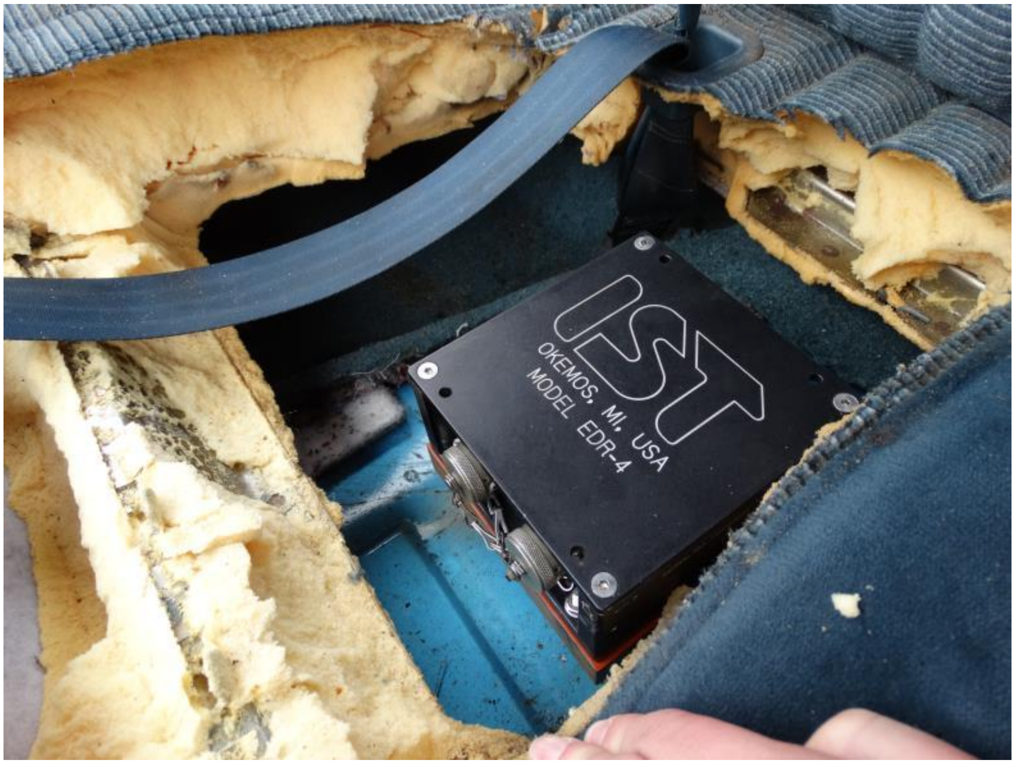


Figure 2.28: Close-up of EDR Mounted in Vehicle

The sign convention used for data processing is as follows:

Table 2.2: Sign Convention for Vehicle Motion

X:	Positive in the normal forward motion direction
Y:	Positive toward the right
Z:	Positive vertically downward
ROLL:	Positive using right hand rule about +X direction
PITCH:	Positive using right hand rule about +Y direction
YAW:	Positive using right hand rule about +Z direction

The EDR-4 data recorder unit was configured with a sample rate of 2944 samples per second (per channel), and with a low pass filter setting of 300 Hz. After the data had been downloaded from the data acquisition package, the data was processed using Test Risk Assessment Program (TRAP) Version 2.3.11, (Texas A&M Transportation Institute and Capsher Technology, Inc.). The TRAP program was designed to determine the effectiveness of a roadside safety feature by analyzing data from a vehicle crash test of the feature and calculating standardized occupant risk factors. TRAP calculates occupant risk factors in accordance with the NCHRP Report 350 guidelines.

Auxiliary Cameras

During pre-test checks prior to the start of testing, test personnel noted that the remote braking system was not functioning properly, and that it would not be possible to remotely trigger the vehicle brakes following the impact event. Discussions with personnel from Trinity Highway Systems and FHWA resulted in the decision to proceed with the test with the expectation that the trees surrounding the test site would be used to stop the vehicle. To ensure that damage to the vehicle resulting from the impact with the ET Plus could be distinguished from the damage caused by the subsequent impact with the tree(s), several auxiliary cameras were employed as described below. Examples of the field of view for each camera prior to impact are provided in Figure 2.30 through Figure 2.33.

- Two digital cameras were mounted directly to the roof of the vehicle cab as shown in Figure 2.29; one camera was behind the driver's seat and one camera was behind the passenger's seat, and both were aimed at their respective dashboard and floorboard.

- One digital video camera was mounted to a tripod and setup in the treed area past the runoff clearing viewing upstream towards the original vehicle trajectory and approximately 20 feet towards the traffic side from the expected point of entry into the trees.

- One high-definition digital camera was mounted to a drone quad-copter and flown over the expected post-impact vehicle path.

Table 2.3: Auxiliary Cameras to Capture Post-Test Vehicle Damage

Camera Location	Field of View
Onboard – Driver	Figure 2.30
Onboard – Passenger	Figure 2.31
In-line with Vehicle Trajectory	Figure 2.32
Overhead Drone	Figure 2.33

Photographs of the vehicle from each of these vantage points will be reviewed for determination of post-impact damage.

Figure 2.29: Onboard Cameras

Figure 2.30: View from Onboard Camera – Driver's Side

Figure 2.31: View from Onboard Camera – Passenger's Side

Figure 2.32: View from Camera In-line with Vehicle Trajectory

Figure 2.33: View from Overhead Drone Camera

Soil Conditions

The soil complied with the NCHRP Report 350 "Standard Soil" as described in the *Test Article – Design and Construction* section of this report. The day of testing, soil moisture content was measured by a certified environmental engineering firm. The maximum moisture content measured was 9.6% measured near Post 1, and the readings at Posts 2, 3 and 4 were between 7.0% and 8.8%. There was no rainfall between when the moisture reading was taken and when the testing was conducted. Detailed results of the soil testing and moisture content evaluation are provided in Appendix E.

Calibrated Test Equipment

Test equipment used to perform the tests and acquire data during this testing program is listed in the table below.

Table 2.4: Equipment Used During Testing

Description	Manufacturer	Model	Asset No.	Due Date[1]
Data Recorder	IST	EDR-4-6DOF-200	S/N 40048	2/5/15
Wheel Scales	Longacre	72634	015238	11/5/15
Measuring Tape	Stanley	33-725	015324	11/7/15
Caliper	Starrett	721	020504	3/18/15
Speed Trap DAQ	NI	USB-6008	S/N 14D4376	8/27/15

[1]Unless otherwise specified, all equipment is calibrated or verified on an annual basis.

Test Observers

Representatives from the following organizations were among those present at the SwRI Crash Test Site and observed Test ET31-33 on January 15, 2015:

- Federal Highway Administration (FHWA)
- Delaware DOT
- Virginia DOT
- New Hampshire DOT (AASHTO Representative)

Observers from FHWA and AASHTO were permitted to visually inspect and measure the ET Plus installation before and after the test. All other observers were allowed to visually inspect the ET Plus installation before and after the test. All observers were allowed to visually inspect the vehicle following the test.

3 TEST CONDITIONS AND RESULTS

Test Description

The purpose of Test ET31-33 was to evaluate the performance of Trinity Highway Products ET Plus End Terminal with 4-inch wide guide channel installed with a rail height of 31". To test the performance of this terminal, Test 3-33 was conducted according to NCHRP Report 350. The test installation length for the test was 49.5 m (162'-6"), and the terminal length was 16.2 m (53'-1½").

Test 3-33 is intended primarily to evaluate occupant risk and vehicle trajectory criteria. The test consists of a 2000 kg (4409 lb) pickup truck approaching the traffic side of the installation at a 15° angle to the roadway, and impacting the end terminal at 100 km/hr (62.1 mph). The vehicle will impact at the vehicle's centerline. The test configuration is shown in Figure 3.1, which is from Figure 3.2 of NCHRP Report 350.

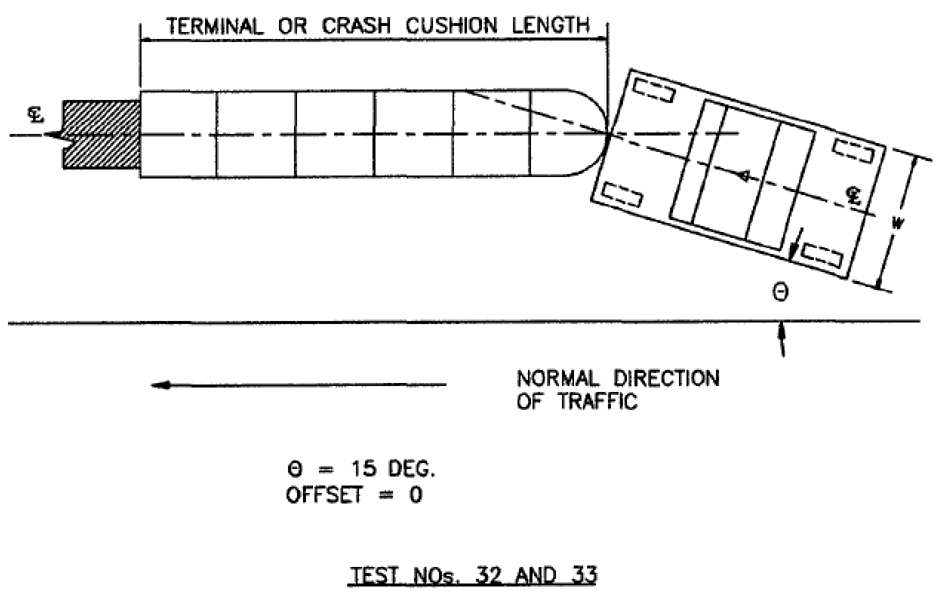


Figure 3.1: Impact Configuration *[from Figure 3.2 of NCHRP Report 350]*

The weather on the day of the test was mostly sunny, with temperatures ranging from 3.3-14.4°C (38-58°F). The temperature at the time of the test was approximately 13.3°C (56°F). The soil was dry as discussed in the *Soil Conditions* section of this report.

Impact Description/Vehicle Behavior

Figure 3.2 is an overhead photograph showing the post-test condition and location of the test article and test vehicle. Figure 3.3 through Figure 3.5 show that the test vehicle impacted the end terminal at a nominal 15° angle. The impact velocity of the test as measured by SwRI's speed trap system and verified by high-speed film analysis was determined to be 93.0 km/hr (57.8 mph); this speed is 3 km/hr (1.9 mph) below the 100±4 km/hr (62.1±2.5 mph) target speed specified in Report 350. As a result of the test, the ET Plus extruder head moved 9.1 m (30.0 ft) longitudinally (downstream) and 1.1 m (3.7 ft) laterally as measured from its as-installed position. The total system deformation (i.e. longitudinal distance to closest point) measured after the impact was 6.25 m (20.5 ft) from the initial point of contact.

After the initial impact event, the ET Plus extruder head stroked along the guardrail, extruding approximately 2.9 m (9.5 ft) of guardrail. Before the guide channel entrance end of the head reached Post 2 the head began to rotate, following the angled path of the vehicle; this rotation caused a fold to form in the W beam at Post 3. As the vehicle continued its angled trajectory, the channel guide portion of the ET Plus extruder head was pushed further on the W beam up to Post 3; the extruder head had rotated approximately 45° when the channel guide entrance reached Post 3. As the vehicle continued forward the head continued to rotate, allowing the vehicle to pass (or gate) through to the non-traffic side of the system. The ET Plus extruder head gated before any rail splices extruded through the head, and ended up roughly parallel to the guardrail and facing in the downstream direction.

As the vehicle passed by the gated extruder head, the corner of the fold in the W beam at the guide channel made contact with the quarter panel forward of the driver's side door creating a dent but not penetrating the sheet metal. There was no intrusion or potential for intrusion of the test article into the occupant compartment based on the position of the extruder head relative to the vehicle trajectory.

The ET Plus extruder head directly contacted and sheared-off Posts 1 and 2. As the guardrail gated at Post 3, the motion sheared Posts 3 and 4 at ground-level. The splice at Post 3 remained intact but disconnected from the post. The W beam released from the post bolts at Posts 5, 6, 7, 8, and 9, although all posts and blockouts downstream of Post 4 appeared undamaged. There was no appreciable movement of the downstream anchor terminal observed. Additionally, the anchor cable at Post 1 broke free of the installation and came to rest near Post 5. There was no penetration of the vehicle by the test article, and there was no deformation of the occupant compartment resulting from the test. The only debris thrown from the installation as a result of the impact included parts of the vehicle and pieces of posts and blockouts from the first four posts; the majority of the debris fell to the non-traffic side of the guardrail. There was no significant deformation of the 4" guide channels as a result of the impact, and they remained attached to the impact head.

The vehicle continued to travel along the non-traffic side of the guardrail. Without remotely-actuated brakes, the vehicle continued outside of the cleared runout area, finally coming to rest after impacting trees at each side and one nearly head-on; this secondary impact caused significant damage to the test vehicle that was unrelated to the test article and will not be used to judge performance of the ET Plus. The vehicle was not operable after the test.

The test vehicle experienced a maximum 50 millisecond moving average acceleration of -5.5g in the longitudinal direction, 2.5g in the lateral direction, and -1.7g in the vertical direction. The impact velocities and ridedown accelerations were below the preferred limits and well below the maximum limits listed in NCHRP Report 350.

- Occupant impact velocities were 4.7 m/s in the longitudinal direction, and -2.0 m/s in the lateral direction.
- Occupant ridedown accelerations were -9.0g in the longitudinal direction, and 6.7g in the lateral direction.

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 occupant ridedown acceleration or impact velocity levels recorded, all of which were well below acceptable limits

The following sections provide photographs of the post-impact condition of the test article as well as the vehicle. Table 4.2 presents a summary of the onboard data, and plots of the accelerometer and angular velocity transducers are provided in Appendix D.

Figure 3.2: Post-Impact Condition of the Test Article and Vehicle

Impact Severity

NCHRP Report 350 states that the recommended impact severity for Test Level 3, Test 3-33 is 771.7 kJ, with a suggested tolerance of -60.4/+62.9 kJ. The actual impact severity of test ET31-33 was 661.4 kJ, a deviation of -110.3 kJ from the nominal impact severity recommended in NCHRP Report 350. *Note that for Test 3-33, Sin θ is set to 1 in accordance with Section 3.3.1 of Report 350.*

Impact Severity $= \frac{1}{2}\cdot M\cdot(V\cdot \sin\theta)^2$

$= \frac{1}{2}\cdot M\cdot V^2$

$= 0.5\cdot(1981\ \text{kg})\cdot(25.8\ \text{m/s})^2$

$= 771.7\ \text{kJ}$

The equivalent impact speed of a 2000 kg vehicle impacting the end terminal at 15 degrees would be 92.6 km/hr (57.5 mph).

Note that the impact speed of Test ET31-33 was 93 km/hr (57.8 mph), which is 3 km/hr (1.9 mph) below the tolerance band in Report 350. The below-target speed resulted in an Impact Severity that was below the recommended tolerance presented in NCHRP Report 350.


Time = 0.000 seconds (Impact)


Time = 0.050 seconds


Time = 0.100 seconds


Time = 0.150 seconds


Time = 0.200 seconds


Time = 0.250 seconds


Time = 0.300 seconds


Time = 0.350 seconds


Time = 0.400 seconds

Figure 3.3: Sequential Photographs, as Viewed from Overhead


Time = 0.000 seconds (Impact)


Time = 0.050 seconds


Time = 0.100 seconds


Time = 0.150 seconds


Time = 0.200 seconds

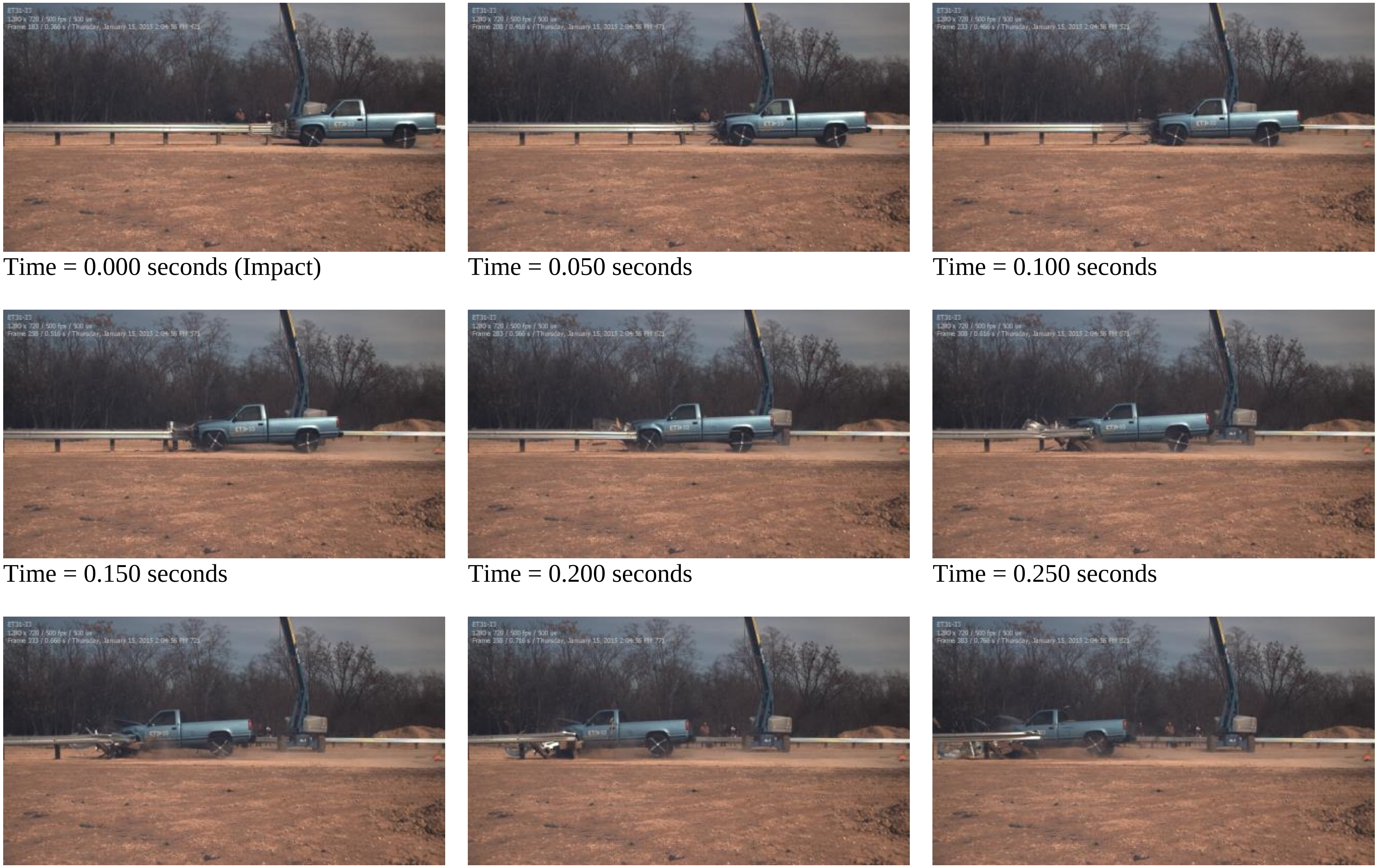

Time = 0.250 seconds


Time = 0.300 seconds


Time = 0.350 seconds


Time = 0.400 seconds

Figure 3.4: Sequential Photographs, as Viewed from Downstream



Time = 0.000 seconds (Impact)

Time = 0.050 seconds

Time = 0.100 seconds

Time = 0.150 seconds

Time = 0.200 seconds

Time = 0.250 seconds

Time = 0.300 seconds

Time = 0.350 seconds

Time = 0.400 seconds

Figure 3.5: Sequential Photographs, as Viewed from Traffic Side of the End Terminal

End Terminal Damage

Figure 3.6: Post Test – Debris Field on Non-Traffic Side and Vehicle Path (Orange Paint)

Figure 3.7: Post Test – Overhead View of Gated Terminal

Figure 3.8: Post Test – Traffic Side of Extruder Head

Figure 3.9: Post Test – Traffic Side of Guide Channel Entrance (Post 4 in Foreground)

Figure 3.10: Post Test – Side View of Gated Terminal

Figure 3.11: Post Test – Extruded Guardrail

Figure 3.12: Post Test – Posts 1, 2 and 3

Figure 3.13: Post Test – Foundation Sleeve at Post 1

Figure 3.14: Post Test – Foundation Sleeve at Post 2

Figure 3.15: Post Test – Post 3

Figure 3.16: Post Test – Traffic Side View of First Splice (Bolts Painted for Visibility in Video)

Figure 3.17: Post Test – W Beam Fold and Post 4

Figure 3.18: Post Test – Traffic Side View of W Beam Fold at Post 4

Figure 3.19: Post Test – Traffic Side View of Post 5

Figure 3.20: Post Test – Side View of Post 5 and Anchor Cable

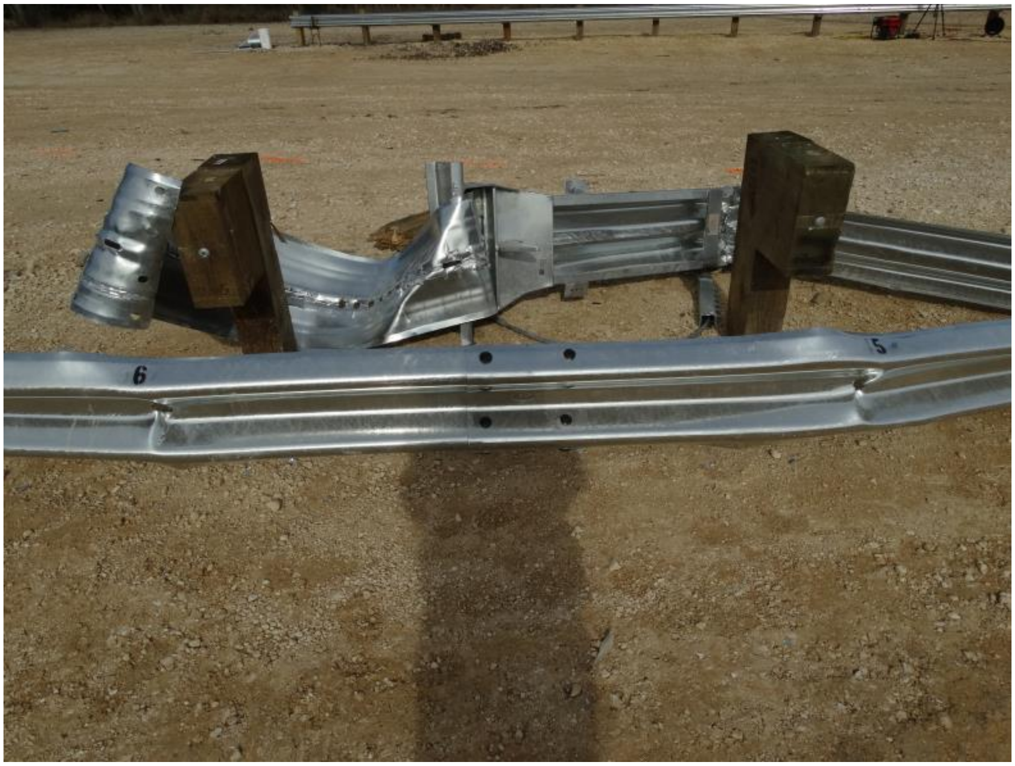


Figure 3.21: Post-Test – Traffic Side View of Splice between Post 5 and Post 6

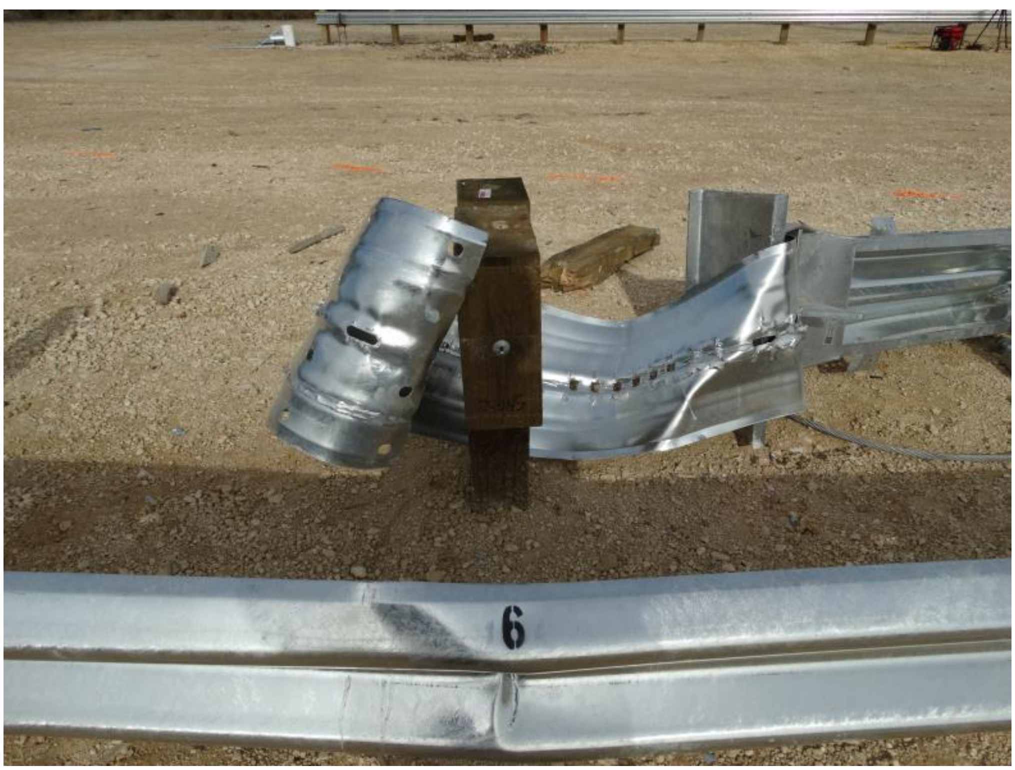


Figure 3.22: Post Test – Traffic Side View of Post 6

Figure 3.23: Post Test – Side View of Post 6

Figure 3.24: Post Test – Traffic Side View of Post 7

Figure 3.25: Post Test – Side View of Post 7

Figure 3.26: Post Test – Traffic Side View of Post 8

Figure 3.27: Post Test – Side View of Post 8

Figure 3.28: Post Test – Traffic Side View of Post 9

Figure 3.29: Post Test – Side View of Post 9

Figure 3.30: Post Test – ET Plus Head and Extruded Rail, Non-Traffic Side

Figure 3.31: Post Test – ET Plus Head Guide Channels, Traffic Side

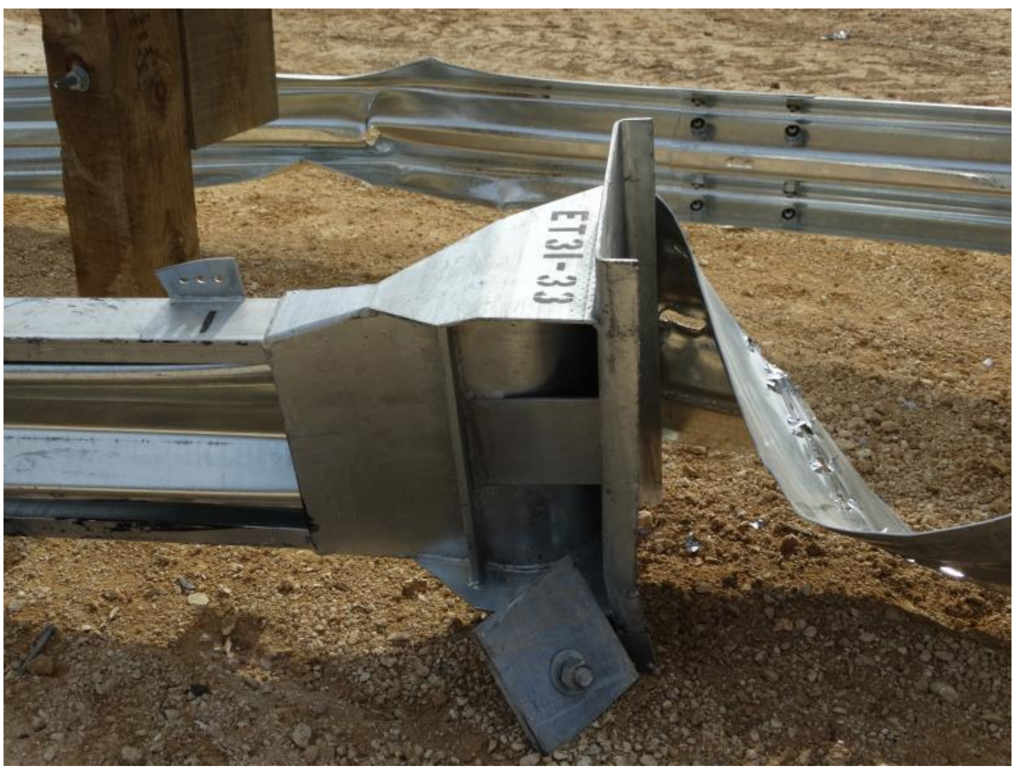


Figure 3.32: Post Test – ET Plus Head, Traffic Side

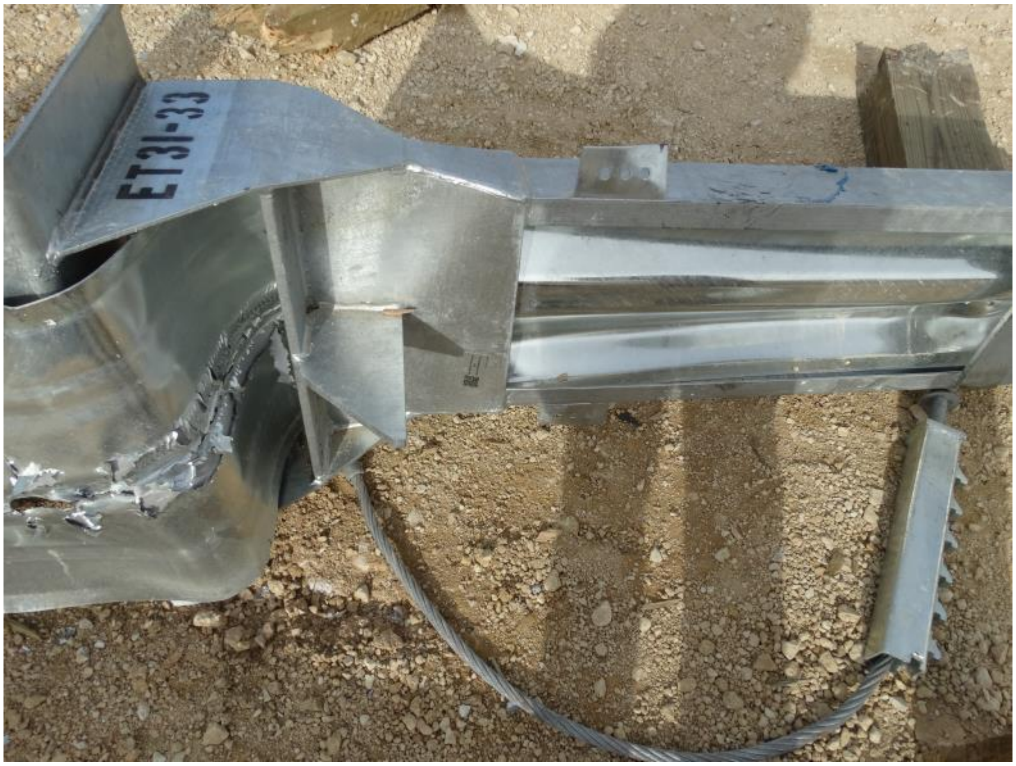


Figure 3.33: **Post Test – ET Plus Head, Non-Traffic Side**

Figure 3.34: **Post Test – ET Plus Head Guide Channel Entrance, Non-Traffic Side**

Figure 3.35: Post Test – Debris Field on Non-Traffic Side

Figure 3.36: Post Test – Debris Field on Non-Traffic Side Viewed from Downstream

Figure 3.37: Post-Test Verification of Extruder Head 7

Vehicle Damage

Figure 3.38: Impact Viewed from Traffic Side

Figure 3.39: Impact Viewed from Traffic Side

Figure 3.40: Impact Viewed from Traffic Side

Figure 3.41: Impact Viewed from Traffic Side

Figure 3.42: Post-Test Location of Test Vehicle

Figure 3.43: Post-Impact Path of Right Tire (Orange Paint)

Figure 3.44: Post-Impact Path of Test Vehicle

Figure 3.45: Test Vehicle Impacted Tree

Figure 3.46: Test Vehicle Impacted Tree

Figure 3.47: Test Vehicle Impacted Tree

Figure 3.48: Test Vehicle Damage due to Impact with Tree

Figure 3.49: Left Side Test Vehicle Damage Following Impact with Tree

Figure 3.50: Right Side Test Vehicle Damage Following Impact with Tree (Note: Hood Ripped off by Tree Impact)

Figure 3.51: Front End Damage to Vehicle Following ET Plus Impact (Drone Camera)

Figure 3.52: Front End Damage to Vehicle Following ET Plus Impact (In-Line Camera)

Figure 3.53: Left Side Damage to Vehicle Following ET Plus Impact (see Figure 3.3 at T=0.300seconds)

Figure 3.54: Right Side Damage to Vehicle During ET Plus Impact

Figure 3.55: Right Side Damage to Vehicle Following ET Plus Impact

Figure 3.56: Occupant Compartment Following ET Plus Impact (Onboard Camera, Left)

Figure 3.57: Occupant Compartment Following ET Plus Impact (Onboard Camera, Right)

Figure 3.58: Post-Test – Driver Side Floorboard (Damage due to Impact with Tree)

Figure 3.59: Post-Test – Passenger Side Floorboard (Damage due to Impact with Tree)

4 ASSESSMENT OF TEST RESULTS

A comparison of the test results of Test ET31-33 against the evaluation criteria set forth in NCHRP Report 350 for Test 3-33 is provided in Table 4.1. A summary of the test results is provided in Table 4.2.

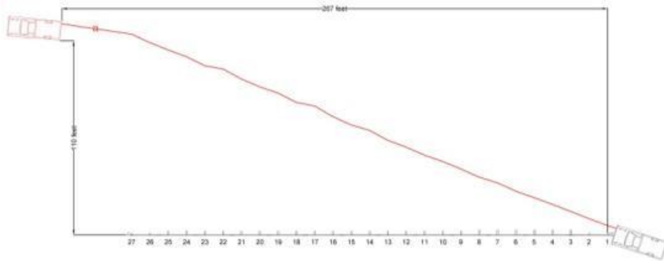
Table 4.1: Summary of Test Evaluation Results (NCHRP Report 350 Evaluation Criteria) for Test ET31-33

Evaluation Factor	Evaluation Criteria	Crash Test Result	Result
Structural Adequacy	C. Acceptable test article performance may be by redirection, controlled penetration, or controlled stopping of the vehicle.	Vehicle was decelerated in a controlled manner and gated through the system in a controlled fashion.	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.	No penetration or potential penetration of the occupant compartment or undue hazard presented by test article debris. See photos for post-test location of debris.	Pass
	F. The vehicle should remain upright during and after collision although moderate roll, pitching and yawing are acceptable.	Vehicle remained stable and upright during and after the collision.	Pass
	H. Occupant Impact Velocities (OIV) limits: Preferred = 9 m/s Maximum = 12 m/s	Occupant impact velocities: Longitudinal: 4.7 m/s Lateral: -2.0 m/s	Pass[2]
	I. Occupant Ridedown Acceleration (ORA) limits: Preferred = 15 g Maximum = 20 g	Occupant Ridedown Accelerations: Longitudinal: -9.0 g Lateral: 6.7 g	Pass[2]
Vehicle Trajectory	K. After collision it is preferable that the vehicle's trajectory not intrude into adjacent traffic lanes.	See photos; vehicle path post-impact was on non-traffic side of the guardrail.	See Note[1]
	N. Vehicle trajectory behind the test article is acceptable.	See photos; vehicle path post-impact was on non-traffic side of the guardrail.	Pass

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

Note[2]: 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 occupant ridedown acceleration or impact velocity levels recorded, all of which were well below acceptable limits.

Table 4.2: Summary of Test Results and Conditions for Test ET31-33



General Information		**Impact Conditions**		**Extruder Head Position from Start**	
Test Agency	Southwest Research Institute	Speed (km/hr)	93.0	Longitudinal	9.1 m (30.0 ft)
Test Number	ET31-33	Angle (degrees)	15.2	Lateral	1.1 m (3.7 ft)
Test Date	January 15, 2015	**Exit Conditions**		**Total System Deformation (Closest Point)**	
Test Category	3-33	Speed (km/hr)	72.5	Longitudinal	6.26 m (20.5 ft)
Test Article		Angle (degrees)	17.8	**Post Impact Vehicular Behavior**	
Type	End Terminal			Max Vehicle Rotation (degrees)	
Terminal Length	16.2 m (53’-1½”)	**Occupant Risk Values**		Max. Roll	4.3 @ 0.6471 sec.
Installation Length	49.5 m (162’-6”)	Impact Velocity (m/s)		Max. Pitch	-3.9 @ 1.9694 sec.
Nom. Barrier Height	78.7 cm (31 in.)	x-direction	4.7	Max. Yaw	9.3 @ 2.8448 sec.
Type of Primary Barrier	W beam guardrail	y-direction	-2.0	Max 50ms Moving Average Accelerations (g)	
Soil	Stable, Dry - “Standard” Soil	Ridedown Accelerations (g)		x-direction	-5.5 @ 0.2675-0.3175 sec.
Test Vehicle		x-direction	-9.0	y-direction	2.5 @ 0.4645-0.5145 sec.
Type	¾ ton pickup truck	y-direction	6.7	z-direction	-1.7 @ 0.4801-0.5301 sec.
Designation	2000P	**Target Conditions**			
Model	1994 GMC C2500	Nominal Speed	100 km/hr (62.1 mph)		
Curb Mass (kg)	1881 as-received	Nominal Angle	0°		
Ballast Mass (kg)	100	**Tolerances**			
Test Inertial Mass (kg)	1981	Nominal Speed	±4 km/hr		
Dummy Mass (kg)	0	Nominal Angle	±1.5˚		
Gross Static Mass (kg)	1981				

5 CONCLUSIONS

The performance of the ET Plus during Test ET31-33 against Structural Adequacy, Occupant Risk, and Vehicle Trajectory criteria specified in NCHRP Report 350 was as-follows:

Structural Adequacy

- The vehicle was decelerated in a controlled manner and gated through the system in a controlled fashion.

Occupant Risk

- There was no penetration of the vehicle by the test article, and no deformation of the occupant compartment resulting from the test.
- There was no undue hazard presented by test article debris outside of the immediate impact zone; the only debris thrown from the installation included pieces of posts and blockouts, the majority of which fell to the non-traffic side of the guardrail.
- The vehicle remained upright during and following the impact.
- The test article provided for controlled deceleration with impact velocity and ridedown acceleration values within allowable limits.

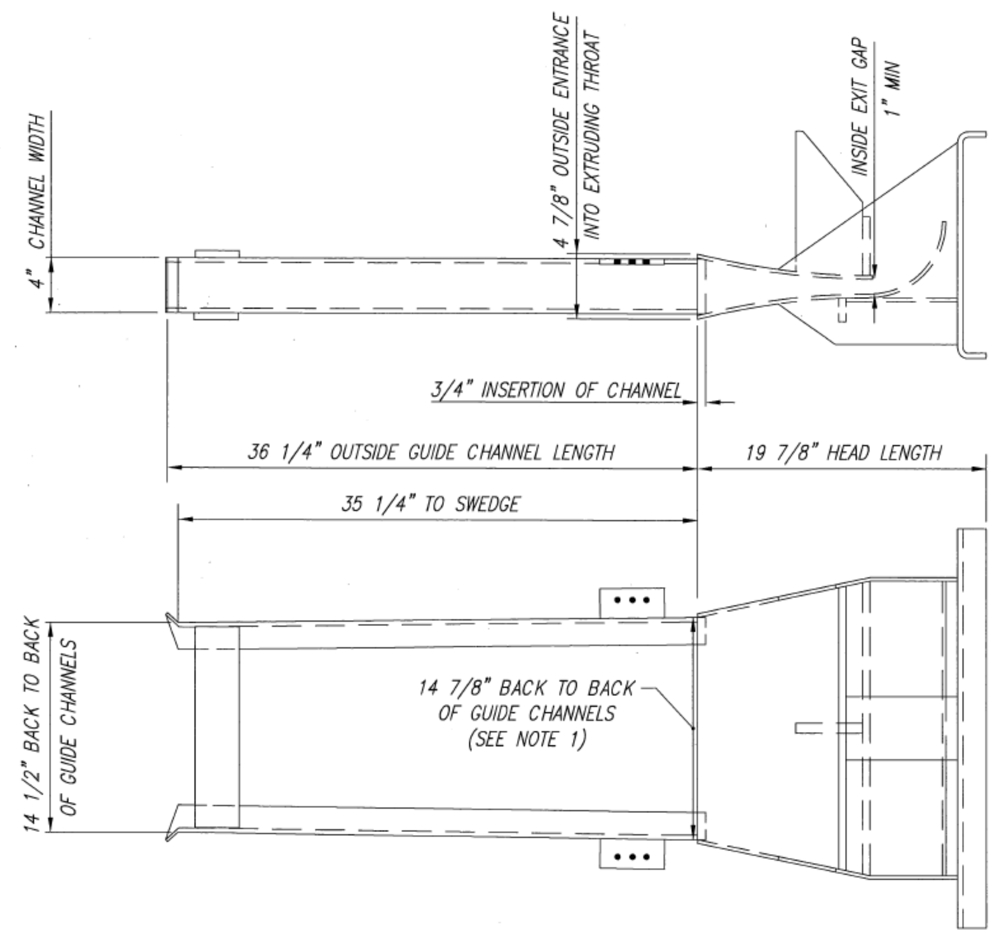
Vehicle Trajectory

- The vehicle was decelerated in a controlled manner, gated through the system in a controlled fashion, and came to a stop on the non-traffic side of the installation.

Based on the information provided in this report, the ET Plus End Terminal with 4-inch wide guide channel installed with a rail height of 31” meets the Test Level 3, Test 3-33 criteria for NCHRP Report 350. [1]

[1] 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 3 km/hr higher would likely not affect the results of the ‘Structural Adequacy’ or ‘Vehicle Trajectory’ evaluation.

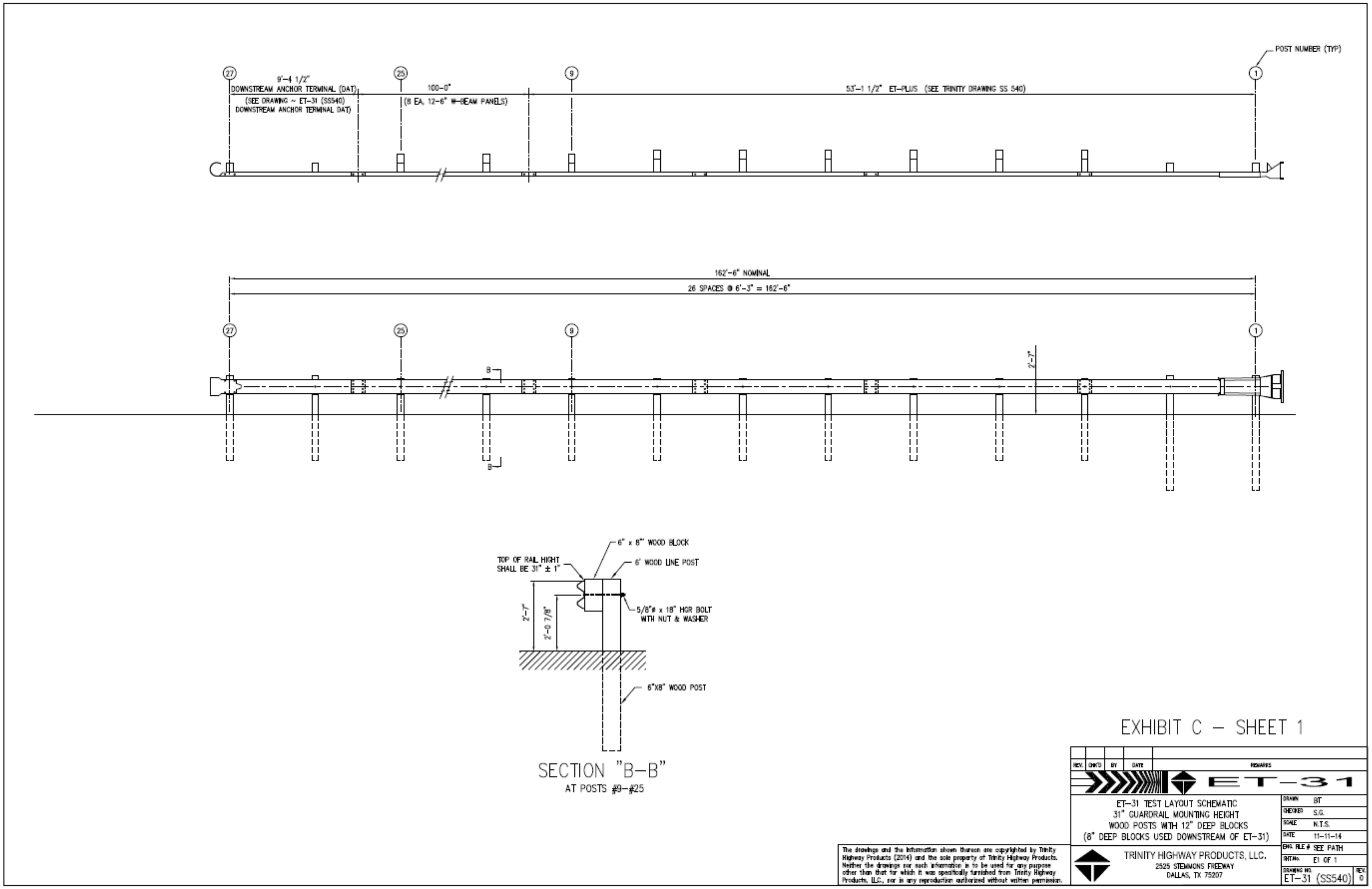
Appendix A: Test Article Drawings

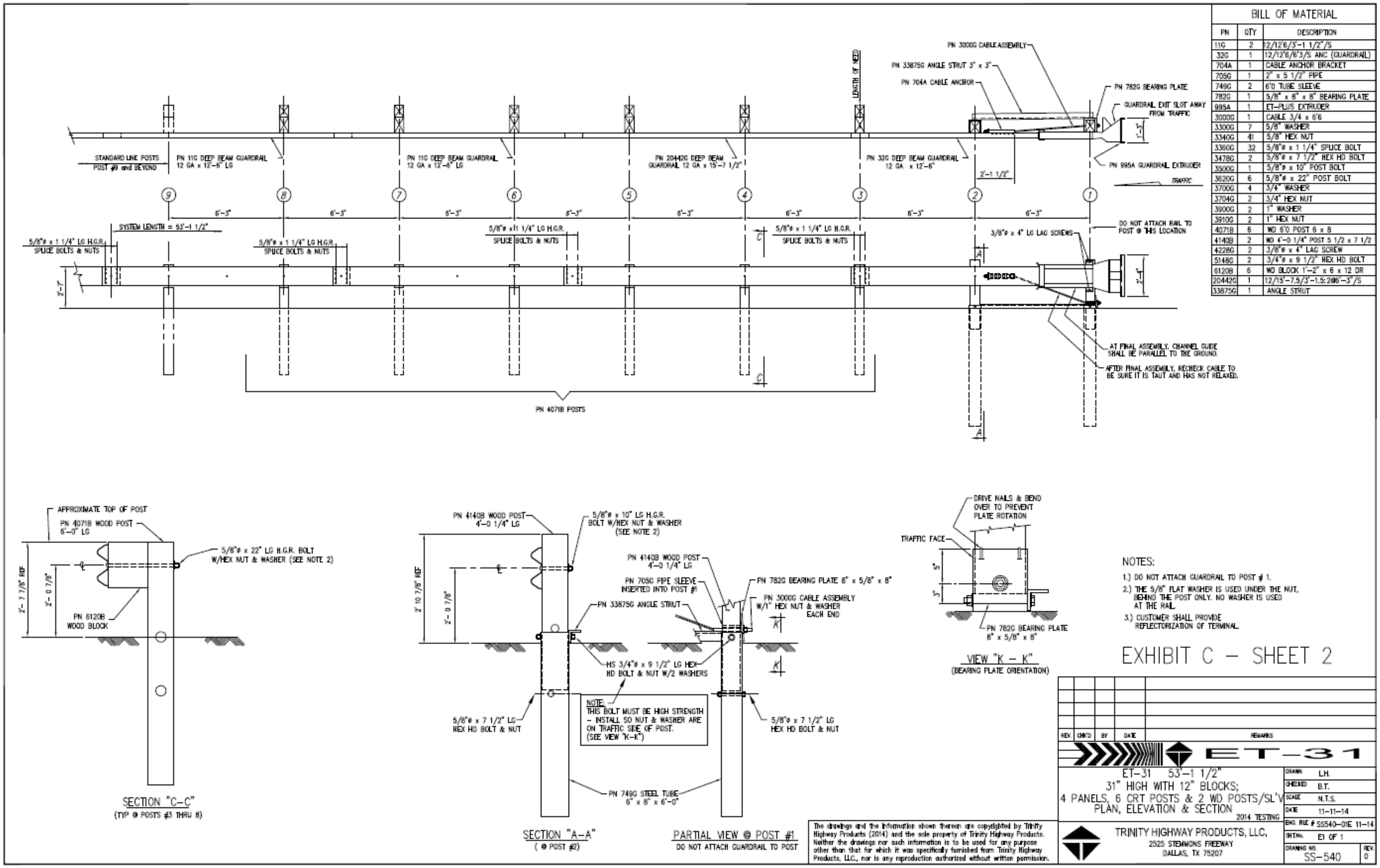


ET PLUS EXTRUDER HEAD (PN 995 REV 13)

NOTE 1: 14 7/8" DIMENSION BACK TO BACK OF GUIDE CHANNELS IS MEASURED AT SUB-ASSEMBLY BEFORE WELDING TO CHUTE. ACTUAL CHUTE VERTICAL OPENING DIMENSION IS 15".

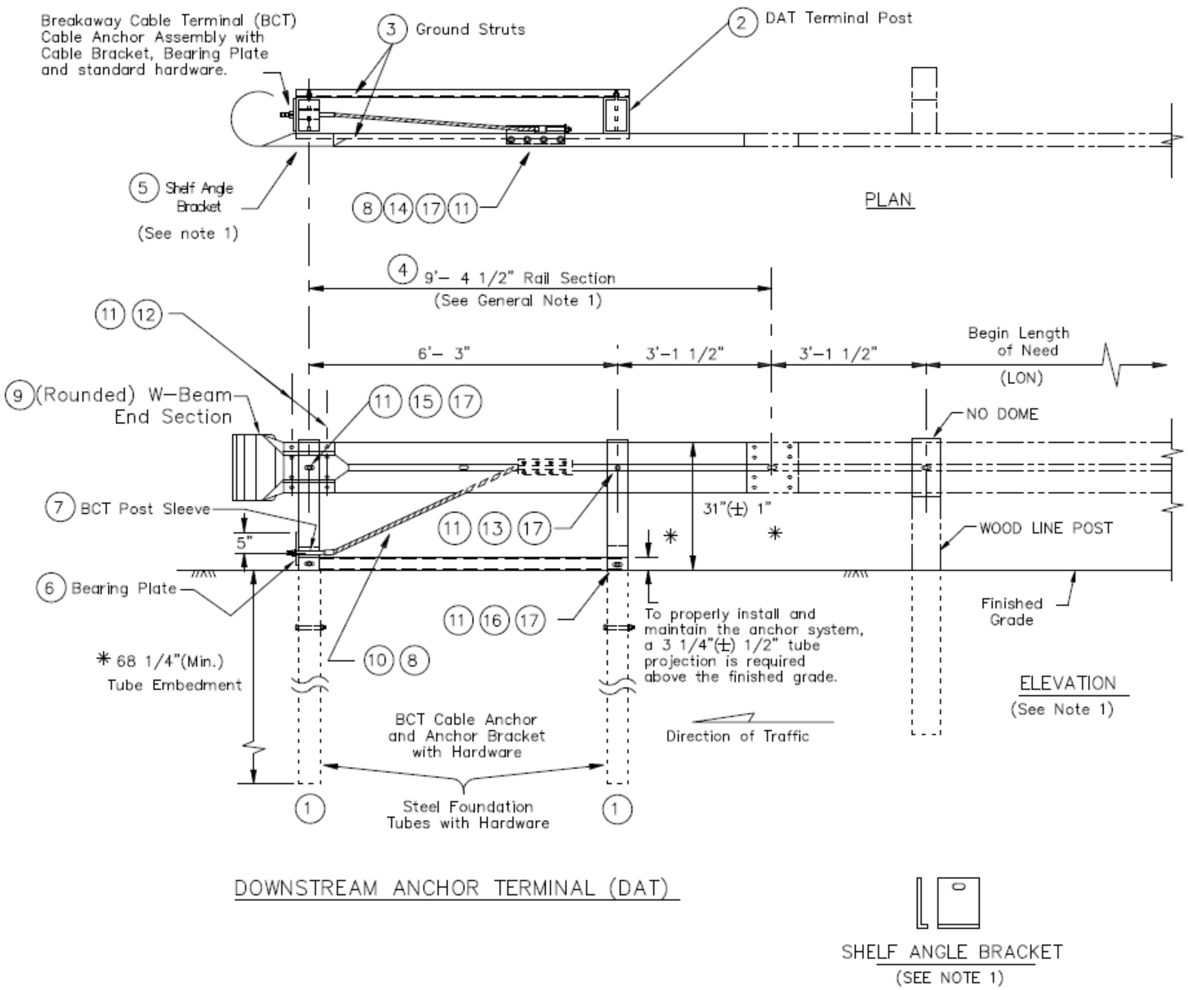
TRINITY HIGHWAY PRODUCTS, LLC.
2525 STEMMONS FREEWAY
DALLAS, TX 75207


POST NUMBER (TYP)
9'-4 1/2"
DOWNSTREAM ANCHOR TERMINAL (DAT)
100'-0"
53'-1 1/2" ET-PLUS (SEE TRINITY DRAWING SS 540)
162'-6" NOMINAL
26 SPACES @ 6'-3" = 162'-6"
2'-7"
6" x 8" WOOD BLOCK
6' WOOD LINE POST
TOP OF RAIL HIGHT SHALL BE 31" ± 1"
5/8"ø x 18" HGR BOLT WITH NUT & WASHER
6"X8" WOOD POST
SECTION "B-B"
AT POSTS #9-#25
EXHIBIT C – SHEET 1
ET-31
ET-31 TEST LAYOUT SCHEMATIC
31" GUARDRAIL MOUNTING HEIGHT
WOOD POSTS WITH 12" DEEP BLOCKS
(8" DEEP BLOCKS USED DOWNSTREAM OF ET-31)
TRINITY HIGHWAY PRODUCTS, LLC.
2525 STEMMONS FREEWAY
DALLAS, TX 75207
ET-31 (SS540)



BILL OF MATERIAL

PN	QTY	DESCRIPTION
11G	2	12/12'6/3'-1 1/2"/S
32G	1	12/12'6/6'3/S ANC (GUARDRAIL)
704A	1	CABLE ANCHOR BRACKET
705G	1	2" x 5 1/2" PIPE
749G	2	6'0 TUBE SLEEVE
782G	1	5/8" x 8" x 8" BEARING PLATE
995A	1	ET-PLUS EXTRUDER
3000G	1	CABLE 3/4 x 6'6
3300G	7	5/8" WASHER
3340G	41	5/8" HEX NUT
3360G	32	5/8"ø x 1 1/4" SPLICE BOLT
3478G	2	5/8"ø x 7 1/2" HEX HD BOLT
3500G	1	5/8"ø x 10" POST BOLT
3620G	6	5/8"ø x 22" POST BOLT
3700G	4	3/4" WASHER
3704G	2	3/4" HEX NUT
3900G	2	1" WASHER
3910G	2	1" HEX NUT
4071B	6	WD 6'0 POST 6 x 8
4140B	2	WD 4'-0 1/4" POST 5 1/2 x 7 1/2
4228G	2	3/8"ø x 4" LAG SCREW
5148G	2	3/4"ø x 9 1/2" HEX HD BOLT
6120B	6	WD BLOCK 1'-2" x 6 x 12 DR
20442G	1	12/15'-7.5/3'-1.5:206'-3"/S
33875G	1	ANGLE STRUT



PN	#	(DAT) PARTS LIST	QTY
724	1	Steel Foundation Tube	2
4140	2	DAT Terminal Post	2
19481	3	Channel Strut	2
20207	4	Terminal Rail Element	1
9713	5	Shelf Angle Bracket	1
782	6	BCT Bearing Plate	1
705	7	BCT Post Sleeve	1
700	8	Guardrail Anchor Bracket	1
907	9	(Rounded)W–Beam End Section	1
3000	10	BCT Cable Anchor	1
	11	Recessed Nut, Guardrail	20
	12	1 1/4" Button Head Bolt	4
	13	10" Button Head Bolt	2
	14	5/8" x 2" Hex Head Bolt	8
	15	5/8" x 8" Hex Head Bolt	4
	16	5/8" x 10" Hex Head Bolt	2
	17	5/8" Flat Washer	18

GENERAL NOTES

1. The rail section at the end post is supported by the Shelf Angle Bracket. The rail element is not attached to the end post.

EXHIBIT C – SHEET 3

METAL BEAM GUARD FENCE
ET–31 (SS540) 2014 TESTING
DOWNSTREAM ANCHOR TERMINAL (DAT)

REF: TxDOT, GF31DAT14.DGN

Appendix B: SwRI Data Sheets for Test ET31-33

EXHIBIT D-1: Installation Checklist

Test Number: 31-33 Test Date: 1/15/2015

*Record the following impact head dimensions:

1/5/2015 OH

head stamp "7"

Dimension	*Pre-Test Measurements
Exit Gap (middle - inside)	1.1435"
Entrance Gap (middle - outside)	4.6990"
Guide Chute Exit Height (outside)	15" ✓ Front side
Guide Chute Entrance Height (outside)	14.5" ✓
Channel Width (outside)	4.0355"
Channel Insertion into Extruder	0.2640" 0.2330" 0.2460" 0.2145"
Outside Guide Channel Length	36 3/8" ✓
Outside Guide Channel Length – Chute to start of swedge	35 9/16" ✓
Head length	56 5/8"

a. Guardrail height as measured from the ground to the top of the guardrail at mid-span for the first eight spans:
   a. Between post 1 and 2:_____ inches Between post 5 and 6:_____ inches
   b. Between post 2 and 3:_____ inches Between post 6 and 7:_____ inches
   c. Between post 3 and 4:_____ inches Between post 7 and 8:_____ inches
   d. Between post 4 and 5:_____ inches Between post 8 and 9:_____ inches
   e. (ET27 series: all heights to be greater than or equal to 27-3/4" and less than 28-3/4")
   f. (ET31 series: all heights to be greater than 30-1/2" and less than 31-1/2")
b. Distance from the ground to the bottom of the impact face: _________ inches.
c. Distance from the ground to the top of the impact face: _____________ inches.
d. Soil in the area around impact area and runout area is smooth and flat: YES NO (circle one).
e. Backfill around the posts has been re-compacted: YES NO (circle one).
f. Distance from the ground to the top of the first foundation tube: ______ inches (Must be 4 inches or less).
g. Distance from the ground to the top of the second foundation tube: ______ inches (Must be 4 inches or less).
h. Bolts at the top of the foundation tubes at posts one and two are not overtightened and the walls of the steel tube are not collapsed or deformed: YES NO (circle one).
i. The ET-PLUS extruder head is pushed as far as it will go on the guardrail panel. The guardrail extends into the extruder ________ inches.

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RBA 1/14/2015 1/14/15

KAU 1/14/15 WMB 1/14/15 [illegible] 1/14/15

EXHIBIT D-1: Installation Checklist

Test Number: ET31-33 Test Date: 1/14/2015

*Record the following impact head dimensions:

head stamp "7" 1/5/2015 OK

Dimension	*Pre-Test Measurements
Exit Gap (middle - inside)	1.1435"
Entrance Gap (middle - outside)	4.6990"
Guide Chute Exit Height (outside)	15"
Guide Chute Entrance Height (outside)	14.5"
Channel Width (outside)	4.0355"
Channel Insertion into Extruder	0.2640" 0.2330" 0.2460" 0.2145"
Outside Guide Channel Length	36 3/8"
Outside Guide Channel Length – Chute to start of swedge	35 9/16"
Head length	56 5/8"

a. Guardrail height as measured from the ground to the top of the guardrail at mid-span for the first eight spans:
   a. Between post 1 and 2: 30 7/8 inches Between post 5 and 6: 30 7/8 inches
   b. Between post 2 and 3: 31 inches Between post 6 and 7: 31 1/8 inches
   c. Between post 3 and 4: 31 1/4 inches Between post 7 and 8: 31 1/8 inches
   d. Between post 4 and 5: 31 inches Between post 8 and 9: 31 1/8 inches
   e. (ET27 series: all heights to be greater than or equal to 27-3/4" and less than 28-3/4")
   f. (ET31 series: all heights to be greater than 30-1/2" and less than 31-1/2")
b. Distance from the ground to the bottom of the impact face: 9 3/4 inches.
c. Distance from the ground to the top of the impact face: 37 5/8 inches.
d. Soil in the area around impact area and runout area is smooth and flat: YES NO (circle one).
e. Backfill around the posts has been re-compacted: YES NO (circle one).
f. Distance from the ground to the top of the first foundation tube: 2 1/4 inches (Must be 4 inches or less).
g. Distance from the ground to the top of the second foundation tube: 2 1/4 inches (Must be 4 inches or less).
h. Bolts at the top of the foundation tubes at posts one and two are not overtightened and the walls of the steel tube are not collapsed or deformed: YES NO (circle one).
i. The ET-PLUS extruder head is pushed as far as it will go on the guardrail panel. The guardrail extends into the extruder 2 3/8 inches.

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j. The two bolts (top and bottom) holding the extruder head to post one are snug and the extruder channel is approximately parallel to the finished grade (i.e., level): YES NO (circle one).
k. The cable anchor bracket is locked into place by pulling the bracket toward the impact end of the unit: YES NO (circle one). Make sure the hooks/lugs are well seated into the square holes on the guardrail.
l. The hex nuts on the cable ends are tightened such that the cable is taut: YES NO (circle one). The cable is taut when it does not deflect more than 1 inch when hand pressure is applied perpendicular to the mid-span of the cable.
m. The bearing plate is placed on the impact side of post 1 where the cable extends through the post: YES NO (circle one).
n. The cable bearing plate is oriented with the long dimensions turned up (from top of plate to center of cable hole is 5"): YES NO (circle one).
o. Wood blockouts have been toe-nailed to the posts: YES NO (circle one).
p. The CRT post top hole is located with the center of the hole approximately at the ground line (± 2"): YES NO (circle one).
q. The guardrail panels are lapped correctly: YES NO (circle one).

Completed by: Oliver Harrison 1/13/2015

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Blue Yellow's

43

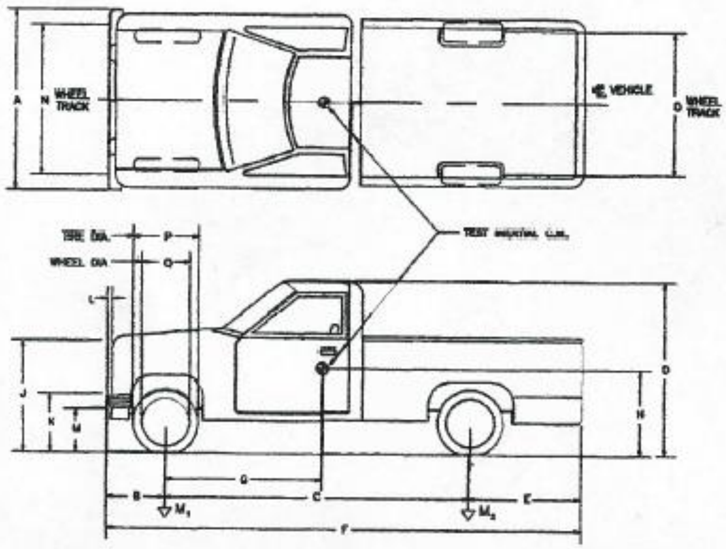
DATE: 12-23-14 TEST NO.: ET-31-33 VIN NO.: 1GTFC24K9R2556197 MAKE: GMC
MODEL: 2500 YEAR: 1994 ODOMETER: 116465 GVW: 7200 LBS
TIRE SIZE: P245/75 R16 TIRE INFLATION PRESSURE: 35 TREAD TYPE:

MASS DISTRIBUTION (kg) LF 1206 RF 1262 LR 963 RR 937

220 lb Ballast Total 4367

DESCRIBE ANY DAMAGE TO VEHICLE PRIOR TO TEST:

N/A



ENGINE TYPE: GAS
ENGINE CID: 5.7 L
TRANSMISSION TYPE:
✓ AUTO
— MANUAL
OPTIONAL EQUIPMENT:

DUMMY DATA:
TYPE:
MASS:
SEAT POSITION:

GEOMETRY – (cm)

A 75 1/2"	D 70 1/4"	G 57.4	K 23 1/4"	N 62 1/2"	Q 17 1/2"
B 35"	E 51"	H 25.9	L 4"	O 63 1/4"	
C 132	F 218"	J 39"	M 15"	P 30"	

cfa = 11.9"

MASS – (kg)	CURB	TEST INERTIAL	GROSS STATIC
M_1			
M_2			
M_T			

EDR FROM FRONT SPINDLE 54" FROM GROUND 28 1/8"

Figure 4.2. 2000P parameters.

DH 1/13/2015

Appendix C: Laboratory Statement

SOUTHWEST RESEARCH INSTITUTE®

6220 CULEBRA ROAD 78238-5166 • P.O. DRAWER 28510 78228-0510 • SAN ANTONIO, TEXAS, USA • (210) 684-5111 • WWW.SWRI.ORG

Refer to: 18.20887
January 15, 2015

TRINITY HIGHWAY PRODUCTS LLC
2525 Stemmons Freeway
Dallas, Texas 75207

Subject: Proposal and Fixed-Price Contract for Services No. 18-73314
SwRI® Project No. 18.20887

To Whom It May Concern:

Southwest Research Institute hereby attests to the following:

- SwRI is listed on FHWA's roster of laboratories suitable for performing NCHRP Report 350 and MASH crash tests.
- SwRI is currently ISO 17025 accredited by A2LA to perform NCHRP Report 350 and MASH crash tests (Testing Laboratory Certificate 1110.02).
- SwRI has not previously conducted crash testing of the ET-Plus End Terminal system.
- SwRI does not own intellectual property and does not receive royalty-related revenue associated with any of the roadside safety hardware involved in this test program or any guardrail terminal products competing with the ET-Plus End Terminal system.
- SwRI is financially independent from Trinity Highway Products and the Texas Transportation Institute (TTI) at Texas A&M University.

I, R. B. Kalmbach, Executive Director of Contracts, certify on behalf of Southwest Research Institute that the above representations are current, accurate and complete as of the date of this letter.

Should you have any questions, please contact Ms. Mary Lepel at 210/522-3026, by facsimile at 210/522-3559, or email mary.lepel@swri.org.

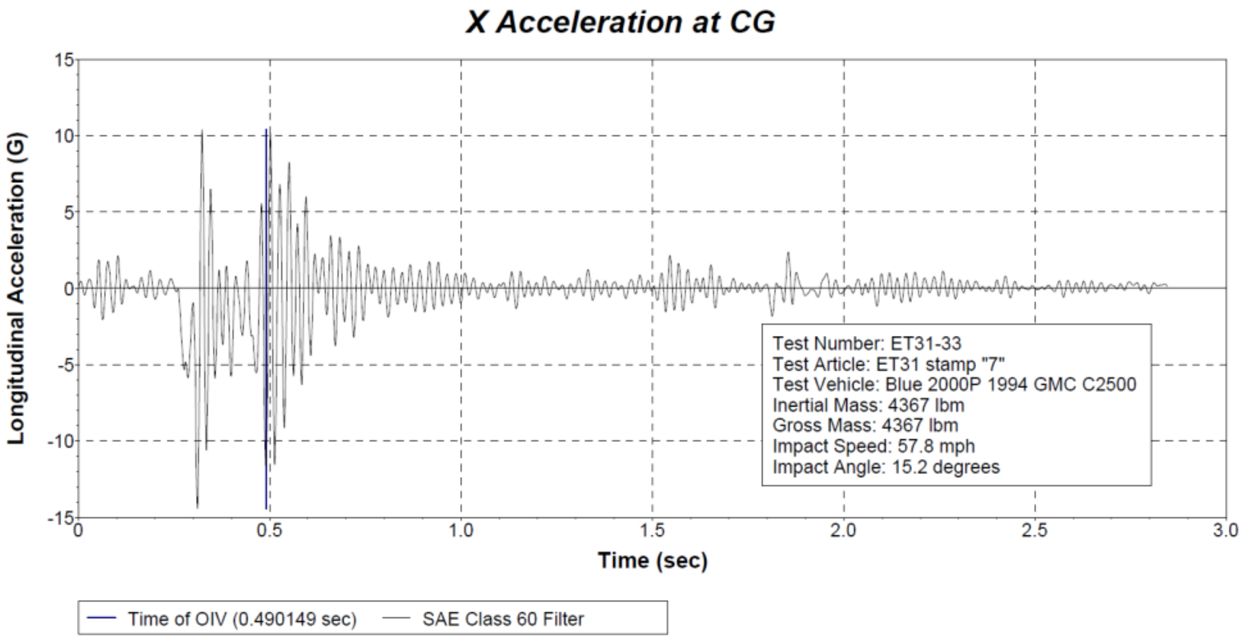
Sincerely,

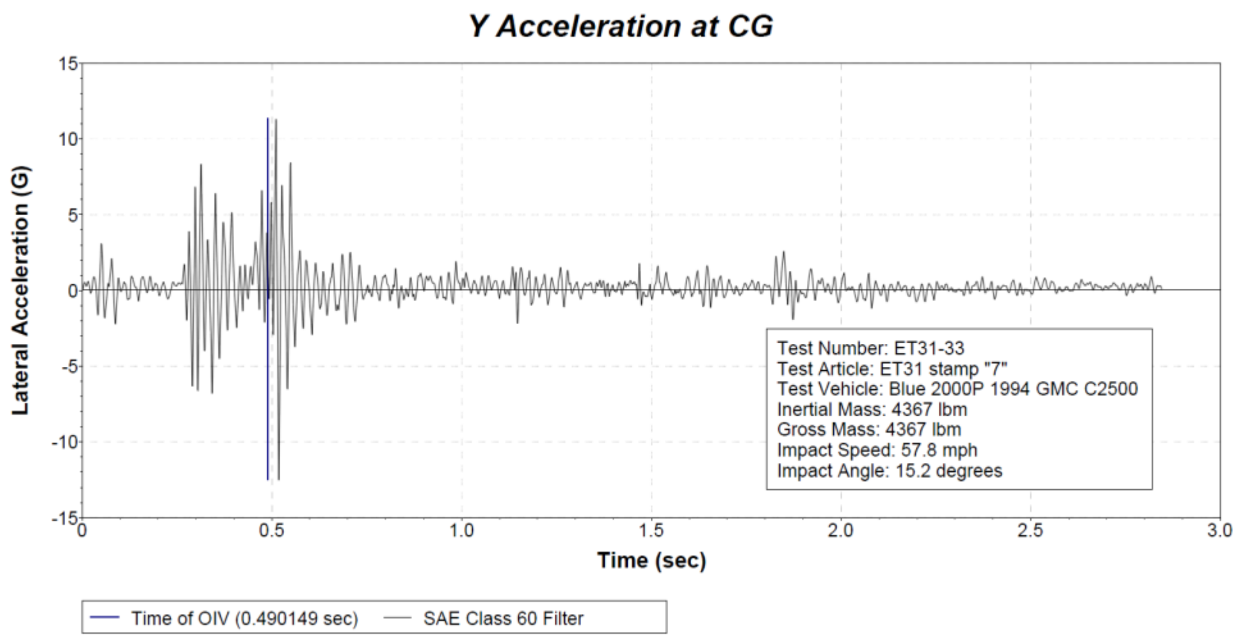
R. B. Kalmbach
Executive Director, Contracts

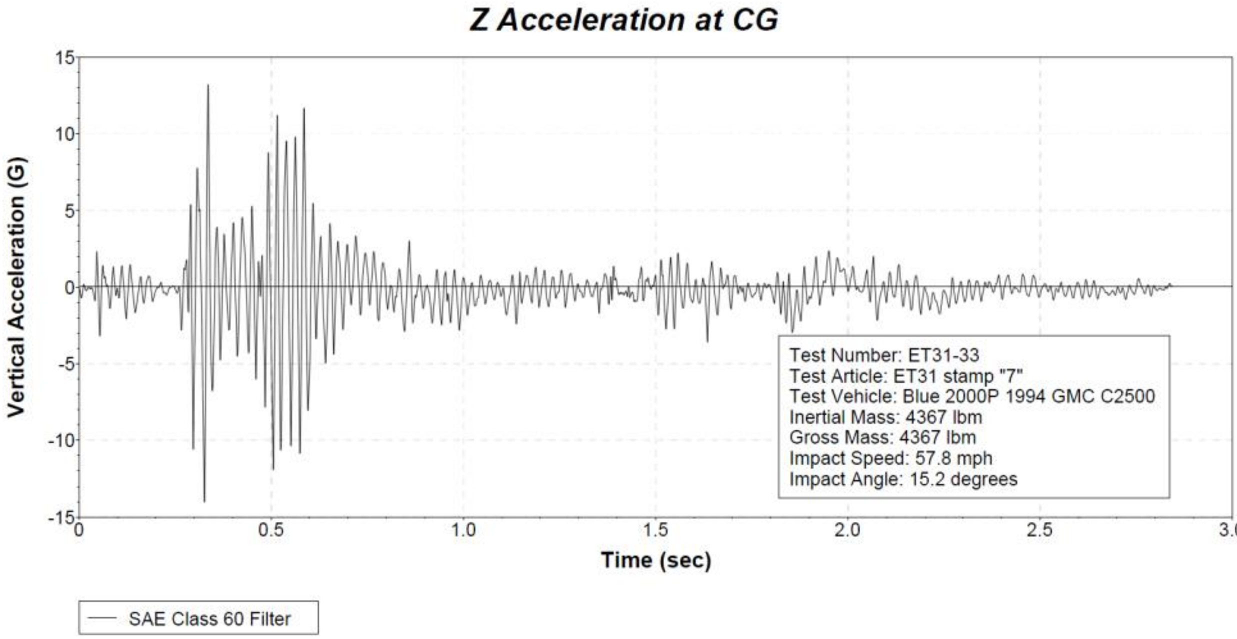
RBK/MKL/jms
cc: J. Ferren, SwRI (via email)

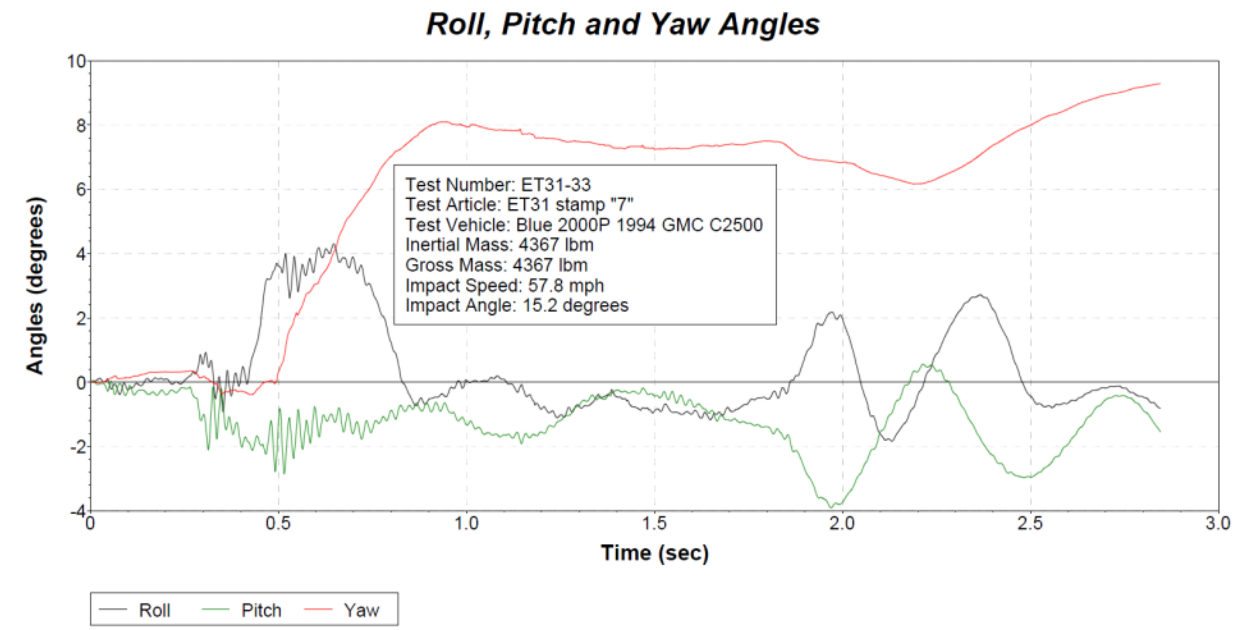
Benefiting government, industry and the public through innovative science and technology

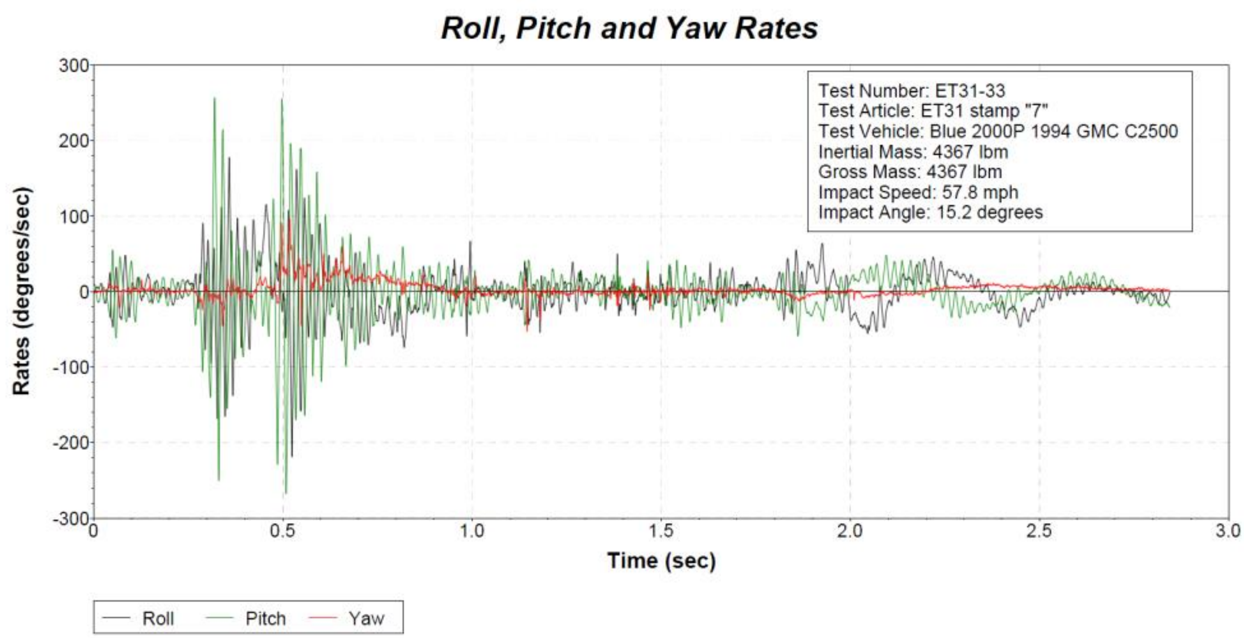
Appendix D: Test Data Plots


X Acceleration at CG
Longitudinal Acceleration (G)
Time (sec)
Test Number: ET31-33
Test Article: ET31 stamp "7"
Test Vehicle: Blue 2000P 1994 GMC C2500
Inertial Mass: 4367 lbm
Gross Mass: 4367 lbm
Impact Speed: 57.8 mph
Impact Angle: 15.2 degrees
Time of OIV (0.490149 sec)
SAE Class 60 Filter


Y Acceleration at CG
Lateral Acceleration (G)
Time (sec)
Test Number: ET31-33
Test Article: ET31 stamp "7"
Test Vehicle: Blue 2000P 1994 GMC C2500
Inertial Mass: 4367 lbm
Gross Mass: 4367 lbm
Impact Speed: 57.8 mph
Impact Angle: 15.2 degrees
Time of OIV (0.490149 sec)
SAE Class 60 Filter


Z Acceleration at CG
Vertical Acceleration (G)
15
10
5
0
-5
-10
-15
0
0.5
1.0
1.5
2.0
2.5
3.0
Time (sec)
Test Number: ET31-33
Test Article: ET31 stamp "7"
Test Vehicle: Blue 2000P 1994 GMC C2500
Inertial Mass: 4367 lbm
Gross Mass: 4367 lbm
Impact Speed: 57.8 mph
Impact Angle: 15.2 degrees
SAE Class 60 Filter


Roll, Pitch and Yaw Angles
Angles (degrees)
Time (sec)
Test Number: ET31-33
Test Article: ET31 stamp "7"
Test Vehicle: Blue 2000P 1994 GMC C2500
Inertial Mass: 4367 lbm
Gross Mass: 4367 lbm
Impact Speed: 57.8 mph
Impact Angle: 15.2 degrees
Roll
Pitch
Yaw


Roll, Pitch and Yaw Rates
Rates (degrees/sec)
Time (sec)
Test Number: ET31-33
Test Article: ET31 stamp "7"
Test Vehicle: Blue 2000P 1994 GMC C2500
Inertial Mass: 4367 lbm
Gross Mass: 4367 lbm
Impact Speed: 57.8 mph
Impact Angle: 15.2 degrees
Roll
Pitch
Yaw

Appendix E: Soil Test Data

LABORATORY COMPACTION CHARACTERISTICS OF SOIL REPORT

Report Number: 90141414.0001
Service Date: 12/03/14
Report Date: 12/10/14

Terracon
6911 Blanco Road
San Antonio, TX 78216-6164
210-641-2112 Reg No: F-3272

Client
Southwest Research Institute
Attn: Jenny Ferren
6220 Culebra Road
San Antonio, TX 78228

Project
Southwest Research Institute-Moisture Testing
6220 Culebra Rd
San Antonio, TX

Project Number 90141414

Material Information
Source of Material: Project Site
Proposed Use: Fill

Sample Information
Sample Date: 12/03/14
Sampled By: Benjamin Butler
Sample Location: Project Site

Sample Description: Crushed Limestone

Laboratory Test Data
Test Procedure: ASTM D698
Test Method: Method C
Sample Preparation: Wet
Rammer Type: Mechanical

	Result	Specifications
Liquid Limit:	22	
Plastic Limit:	13	
Plasticity Index:	9	
In-Place Moisture (%):		

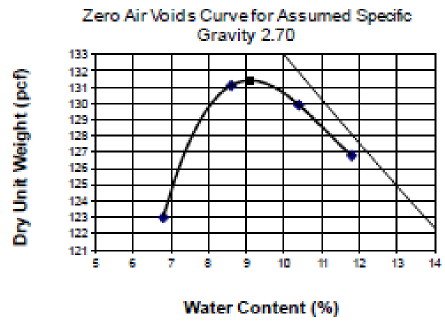
USCS:

Oversized Particles (%): 14.5
Moisture (%): 2.8
Sieve for Oversize Fraction: 3/4

Assumed Bulk Specific Gravity of Oversized Particles: 2.7

Corrected for Oversized Particles (ASTM D4718)
Maximum Dry Unit Weight (pcf): 131.4
Optimum Water Content (%): 9.1

Uncorrected Values
Maximum Dry Unit Weight (pcf): 126.6
Optimum Water Content (%): 10.2



Comments:

Services: Obtain a sample of treated subgrade at the project site and return it to the laboratory. Prepare and test the sample for moisture-density relationship and plasticity index.

Terracon Rep.: Benjamin Butler
Reported To:
Contractor:
Report Distribution:

(1) Southwest Research Institute, jenny.ferren@swri.org

(1) Terracon Consultants, Inc., dejacobs@terracon.com

Reviewed By: Daniel E. Jacobs

Daniel E. Jacobs
Senior Project Manager

Test Methods: ASTM

The tests were performed in general accordance with applicable ASTM, AASHTO, or DOT test methods. This report is exclusively for the use of the client indicated above and shall not be reproduced except in full without the written consent of our company. Test results transmitted herein are only applicable to the actual samples tested at the location(s) referenced and are not necessarily indicative of the properties of other apparently similar or identical materials.

CR0006, 10-16-13, Rev.7 Page 1 of 1

LABORATORY COMPACTION CHARACTERISTICS OF SOIL REPORT

Report Number: 90141414.0001
Service Date: 12/03/14
Report Date: 12/10/14

Terracon
6911 Blanco Road
San Antonio, TX 78216-6164
210-641-2112 Reg No: F-3272

Client
Southwest Research Institute
Attn: Jenny Ferren
6220 Culebra Road
San Antonio, TX 78228

Project
Southwest Research Institute-Moisture Testing
6220 Culebra Rd
San Antonio, TX

Project Number: 90141414

SIEVE ANALYSIS

Sieve Size	% Retained	TXDOT Item 247.2 Type A Grade 2 Specifications % Retained
1 ¾	0	0-10
7/8	11	---
3/8	35	---
#4	50	45-75
#40	75	60-85
#200	84	----

Remarks: The indicated laboratory tests were performed in general accordance with applicable ASTM standards unless otherwise noted. All test results meet the reference specification requirements unless noted by an asterisk *.

Services: Obtain a sample of treated subgrade at the project site and return it to the laboratory. Prepare and test the sample for moisture-density relationship and plasticity index.
Terracon Rep.: Benjamin Butler
Reported To:
Contractor:
Report Distribution:
(1) Southwest Research Institute, jenny.ferren@swri.org
(1) Terracon Consultants, Inc., dejacobs@terracon.com

Reviewed By: Daniel E. Jacobs
Daniel E. Jacobs
Senior Project Manager

The tests were performed in general accordance with applicable ASTM, AASHTO, or DOT test methods. This report is exclusively for the use of the client indicated above and shall not be reproduced except in full without the written consent of our company. Test results transmitted herein are only applicable to the actual samples tested at the location(s) referenced and are not necessarily indicative of the properties of other apparently similar or identical materials.
CT0001, 9-28-10, Rev.8
Page 1 of 1

FIELD DENSITY TEST REPORT

Report Number: 90141414.0011
Service Date: 01/15/15
Report Date: 01/16/15
Task:

Terracon
6911 Blanco Road
San Antonio, TX 78216-6164
210-641-2112 Reg No: F-3272

Client

Southwest Research Institute
Attn: Jenny Ferren
6220 Culebra Road
San Antonio, TX 78228

Project

Southwest Research Institute-Moisture Testing
6220 Culebra Rd
San Antonio, TX

Project Number: 90141414

Material Information

Mat. No.	Proctor Ref. No.	Classification and Description	Laboratory Test Method	Lab Test Data: Optimum Water Content (%)	Lab Test Data: Max. Lab Density (pcf)	Project Requirements: Water Content (%)	Project Requirements: Compaction (%)
1	90141414.0001	Crushed Limestone	ASTM D698	9.1	131.4	10% Max	N/A

Field Test Data

Test No.	Test Location	Lift / Elev.	Mat. No.	Probe Depth (in)	Wet Density (pcf)	Water Content (pcf)	Water Content (%)	Dry Density (pcf)	Percent Compaction (%)
	Guardrail Posts								
1	Post #1	Final	1	6	138.4	12.1	9.6	126.3	96.1
2	Post #2	Final	1	6	129.6	8.5	7.0	121.1	92.2
3	Post #3	Final	1	6	138.0	11.2	8.8	126.8	96.5
4	Post #4	Final	1	6	134.3	10.5	8.5	123.8	94.2

Datum: **Serial No:** 37115 **Std. Cnt. M:** 694 **Std. Cnt. D:** 2228

Comments: **Test and/or retest results on this report meet project requirements as noted above.**

Services: Perform in-place density and moisture content tests to determine degree of compaction and material moisture condition.
Terracon Rep.: Lance Lamb
Reported To:
Contractor:
Report Distribution:
(1) Southwest Research Institute, jenny.ferren@swri.org
(1) Terracon Consultants, Inc., dejacobs@terracon.com

Reviewed By: Daniel E. Jacobs
Daniel E. Jacobs
Senior Project Manager

Test Methods: *, ASTM D6938

The tests were performed in general accordance with applicable ASTM, AASHTO, or DOT test methods. This report is exclusively for the use of the client indicated above and shall not be reproduced except in full without the written consent of our company. Test results transmitted herein are only applicable to the actual samples tested at the location(s) referenced and are not necessarily indicative of the properties of other apparently similar or identical materials.

CR0007, 11-16-12, Rev.7

Page 1 of 1

NCHRP Report 350 Test Report

Full-Scale Crash Evaluation of the ET Plus® End Terminal with 4-inch Wide Guide Channel Installed with a Rail Height of 31 Inches

Test Level 3, Test 3-31
Test Identification: ET31-31

SwRI® Project No. 18.20887

SwRI Document Number: 18.20887.05.100.FR2
Issue 1

Prepared for:
Trinity Highway Products
2525 Stemmons Freeway
Dallas, TX 75207

February 17, 2015

Authored by:

Jenny Ferren, Manager
Mechanical Engineering Division

Reviewed and Approved by:

Timothy A. Fey, P.E., Director
Mechanical Engineering Division

Southwest Research Institute®
6220 Culebra Road • Post Office Drawer 28510
San Antonio, Texas 78228-0510

ACCREDITED
TESTING CERT.#1110.02

Below is a table documenting the various changes recorded in this report. Each issuance of the report is clearly marked with the revision number and date of issue.

Table 0.1: Revision Table

ISSUE	EXPLANATION	PAGE NUMBERS	DATE EFFECTIVE
1	Original report	All	February 17, 2015

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

1 INTRODUCTION

The purpose of Crash Test ET31-31 was to evaluate the performance of the Trinity Highway Products ET Plus End Terminal with 4-inch wide guide channel installed with a rail height of 31". To test the performance of this terminal, Test 3-31 was conducted according to National Cooperative Highway Research Program (NCHRP), Report 350. The total system installation length for the test was nominally 49.5 m (162'-6"), including the 16.2 m (53'-1½") ET Plus terminal length.

Test 3-31 is intended primarily to evaluate the capacity of the device to absorb the kinetic energy of the vehicle in a safe manner as judged by the occupant risk and vehicle trajectory criteria. The test consists of a 2000 kg (4409 lb) pickup truck approaching parallel to the roadway (0 degree angle) and impacting the end terminal at 100 km/hr (62.1 mph) at the vehicle's centerline.

Crash Test ET31-31 was conducted on January 16, 2015, at the Crash Test Site at Southwest Research Institute (SwRI) by SwRI personnel. This report presents information on the test parameters, a discussion of the test, and an assessment of the test results based on the criteria set forth in NCHRP Report 350.

2 TEST PARAMETERS

Test Facility

The full-scale crash testing was performed by Southwest Research Institute (SwRI), on the campus located at the following address:

Southwest Research Institute
6220 Culebra Road
San Antonio, Texas 78238

SwRI is ISO/IEC 17025 accredited by A2LA (American Association for Laboratory Accreditation) to perform this testing under Testing Laboratory Certificate #1110.02.

Test Article – Design and Construction

The full-scale crash test was performed on the ET Plus End Terminal which included the ET Plus extruder head with 4-inch wide guide channel and W-Beam guardrail installed with a rail height of 78.7 cm (31 in.). The ET Plus End Terminal installation tested uses standard AASHTO M180 Type 2, 12-gauge W-Beam guardrail panels mounted with the top of the rail 78.7 cm (31 in.) above the ground, two wooden breakaway posts in foundation sleeves without soil plates at Posts 1 and 2, and CRT posts at Posts 3 through 8. The end terminal included 15.2 cm x 30.5 cm (6" x 12") wood blockouts at Posts 3 through 8.

During installation, holes approximately 61 cm (2 ft) in diameter were drilled into the soil and then backfilled around the posts using "standard soil" as defined by NCHRP Report 350, Section 2.2.1.1. The base material was compacted in 15.2 cm (6 in) lifts, and was added until the surface was flush with the surrounding soil.

The guardrail line posts are 15.2 cm x 20.3 cm (6" x 8") wood posts with 15.2 cm x 20.3 cm (6" x 8") wood blockouts. The blockouts are toenailed, and the guardrail panels are mounted to the posts using 1.6 cm (5/8 in) diameter post bolts beginning with Post 2; the bolt for Post 2 is 25.4 cm (10 in) long, the bolts for Posts 3 through 8 are 55.9 cm (22 in) long, and all other post bolts are 45.7 cm (18 in) long. The post spacing is 1.9 m (6'-3"), and each splice joint used eight (8) 1.6 cm (5/8 in) diameter x 3.2 cm (1-¼ in) splice bolts and nuts; the splice bolts have a nominal total length of 4.1 cm (1-5/8 in) including the bolt head. The installation uses 1.9 cm (3/4 in) diameter x 25.4 cm (10 in) bolts through the soil tube, post, and strut at Post 1 and Post 2. An anchor cable is also installed at Post 1. The installation has a guardrail splice at Post 3. Subsequent guardrail splices are mid-span between Posts 5 and 6, and every 3.8 m (12'-6") afterward to the end of the system.

The total system installation length for the test was nominally 49.5 m (162'-6"), including the 16.2 m (53'-1½") ET Plus terminal length, 30.5 m (100 ft) of guardrail, and a 2.9 m (9'-4½") long downstream anchor terminal. Detailed drawings of the test article provided by Trinity Highway Products are provided in Appendix A.

The ET Plus end terminal extruder head was one of eight production samples CalTrans (California DOT) pulled from their inventory for testing at SwRI. The heads were inspected by

CalTrans, FHWA, and Trinity Highway Products personnel at the CalTrans yard, and were stamped with identifiers "Kit #1" through "Kit #8". SwRI arranged for shipment of the heads to the test site in San Antonio, and the heads remained in controlled storage until they were installed for testing. The dimensions of the specific ET Plus end terminal extruder head used for Test ET31-31 are provided in Table 2.1 below; dimensions measured with a tape measure are listed in fractional inches, and dimensions measured with a digital caliper are listed as decimals. Copies of the datasheets reviewed by representatives from the FHWA, US DOT and various state Departments of Transportation (DOT) prior to testing are located in Appendix B.

The performance goal for the ET Plus is to achieve controlled vehicle deceleration in compliance with NCHRP Report 350 criteria for post-impact vehicle trajectory and occupant risk. Figure 2.1 through Figure 2.20 present photographs of the guardrail installation.

Table 2.1: Key ET Plus Head Dimensions

Extruder Head Stamp ID	6	
Exit Gap	2.83 cm	1.1145"
Entrance Gap	11.95 cm	4.7065"
Guide Chute Exit Height	38.26 cm	15-1/16"
Guide Chute Entrance Height	36.99 cm	14-9/16"
Channel Width (see Figure 2.2)	10.26 cm	4.0375"

Figure 2.1: ET Plus Head Sample Identification Number

Figure 2.2: Measurement of Channel Width of Head

Figure 2.3: Test Installation for ET Plus Test ET31-31

Figure 2.4: ET Plus End Terminal

Figure 2.5: ET Plus Head Height Above Ground – Top

Figure 2.6: ET Plus Head Height Above Ground – Bottom

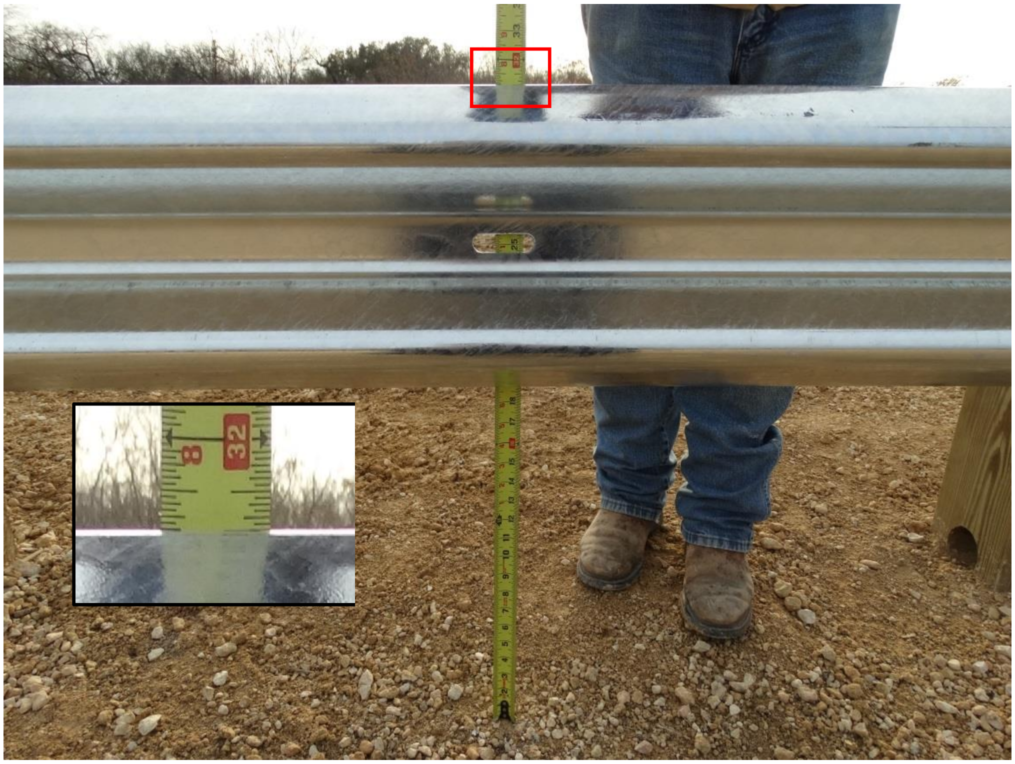


Figure 2.7: Measurement of Guardrail Installation Height

Figure 2.8: ET Plus Head and Anchor Cable Assembly

Figure 2.9: End Terminal Cable Anchor at Upstream End – Post 1

Figure 2.10: End Terminal Cable Anchor at Downstream End

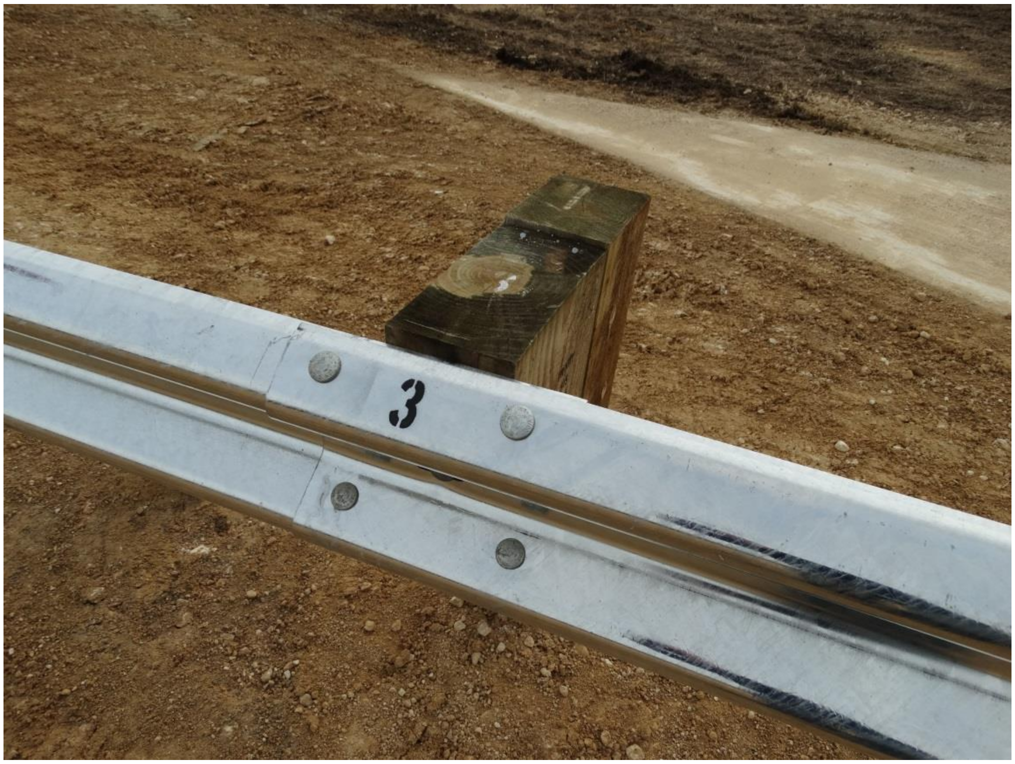


Figure 2.11: First Guardrail Panel Splice Joint – Traffic Side

Figure 2.12: First Guardrail Panel Splice Joint – Non-Traffic Side

Figure 2.13: Second Guardrail Panel Splice Joint Mid-Span between Posts 5 & 6 – Traffic Side

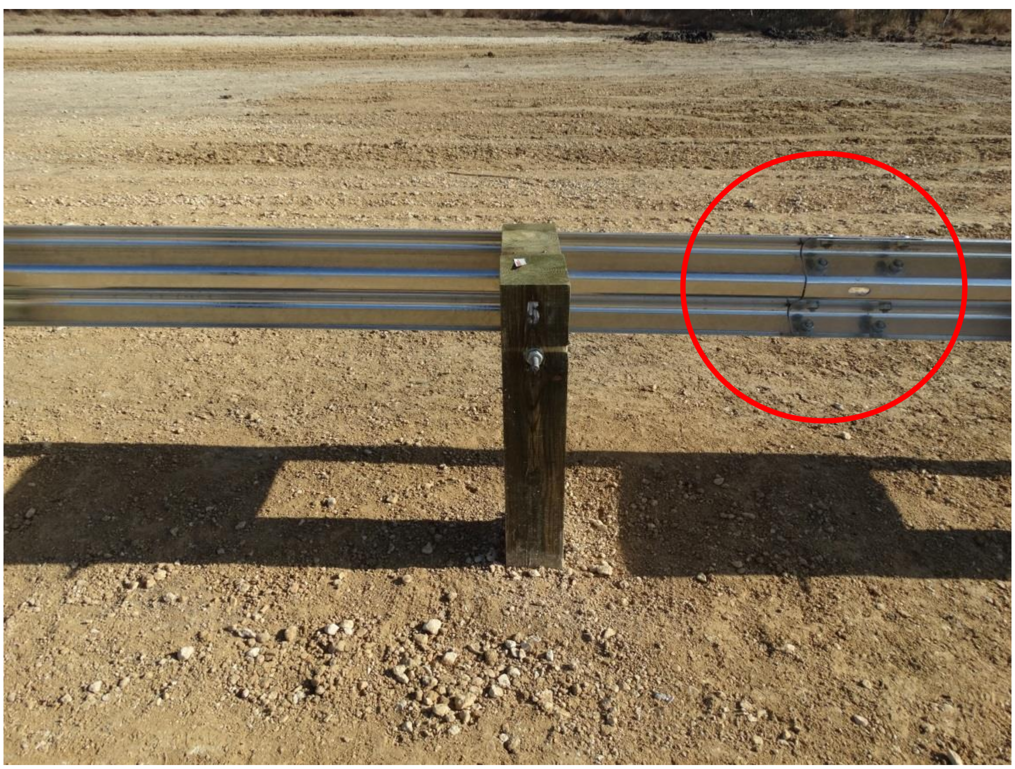


Figure 2.14: Second Guardrail Panel Splice Joint Mid-Span between Posts 5 & 6 – Non-Traffic Side

Figure 2.15: ET Plus Head and Post 1 – Traffic Side

Figure 2.16: ET Plus Head and Post 1 – Non-Traffic Side

Figure 2.17: ET Plus Head with Posts 1 & 2 and Strut

Figure 2.18: ET Plus Head Looking Upstream at Post 1 (see Appendix B for Dimensions)

Figure 2.19: Downstream Anchor Terminal at Posts 26 and 27 – Traffic Side

Figure 2.20: Downstream Anchor Terminal at Posts 26 and 27 – Non-Traffic Side

Test Vehicle

The test vehicle was a 1998 Chevrolet C2500 pickup truck, shown in Figure 2.21; the vehicle data sheet is provided in Appendix B. Figure 2.22 shows the relationship between the height of the vehicle bumper and the end terminal. Figure 2.23 shows the test vehicle positioned at the impact point of the end terminal, and Figure 2.24 shows an overhead view of the test vehicle positioned at the intended crash angle of 0° and at the vehicle's centerline. Figure 2.25 shows the ballast weight that was added to the vehicle, bolted to the bed of the pickup near the cab.

The test inertial mass of the vehicle, including 100 kg (220.5 lbs) of added ballast weight, was 2023 kg (4,460 lbs) as reflected in Table 4.2.

Figure 2.21: Test Vehicle for Test ET31-31

Figure 2.22: Test Vehicle Bumper Height

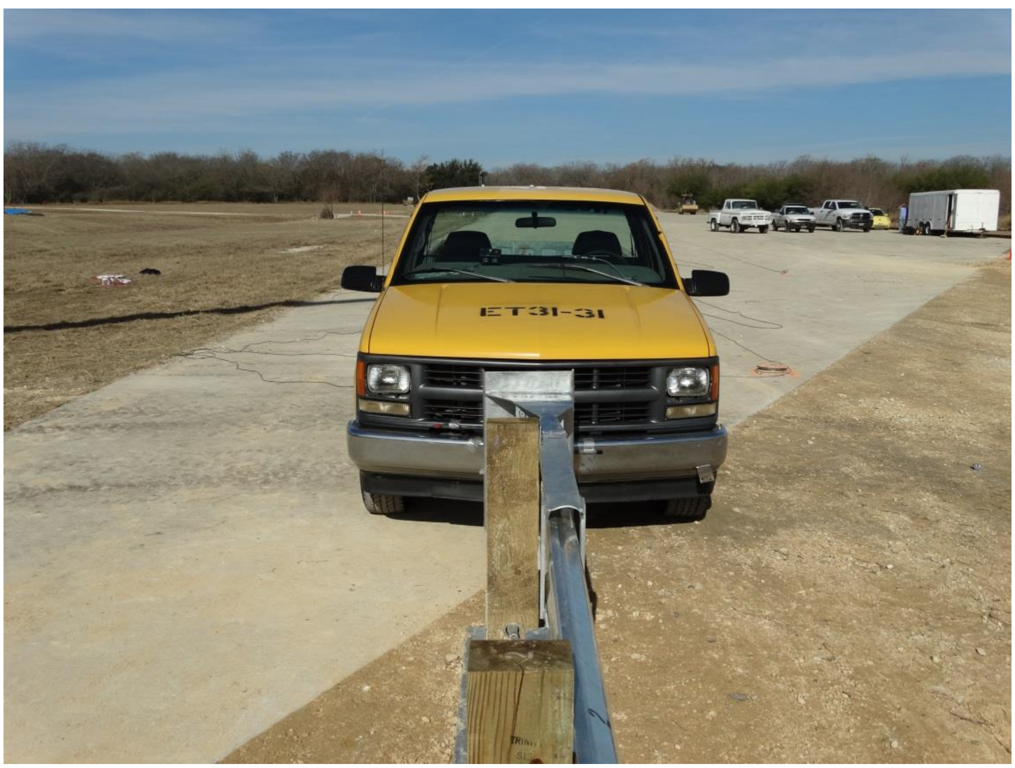


Figure 2.23: Test Vehicle Impact Trajectory

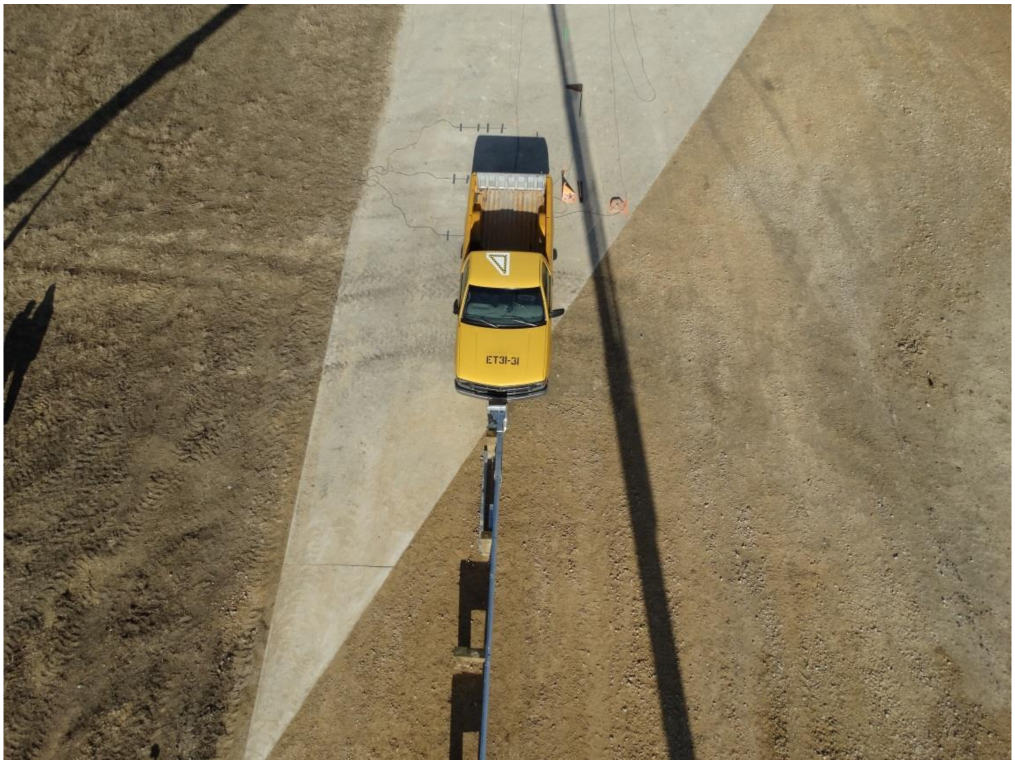


Figure 2.24: Test Vehicle Impact Trajectory – Overhead View

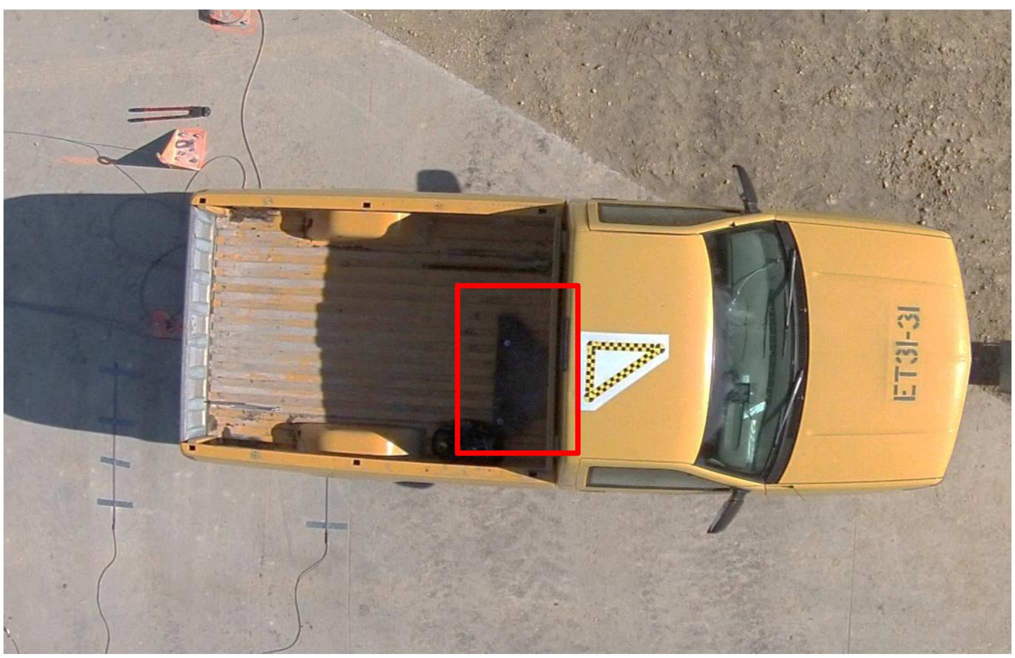


Figure 2.25: Test Vehicle Ballast

Test Vehicle Guidance

The test vehicle was towed into the end terminal using two tow vehicles and a series of pulleys and sheaves. A steel cable was attached to a quick-release pin under the front of the vehicle and was passed around a sheave and secured to the rear of the first tow vehicle. The first tow vehicle was equipped with an adjustable ignition restrictor that attenuated the tow vehicle's engine RPM when a pre-set speed was attained; this vehicle was connected with a steel cable to a second tow vehicle. The test vehicle was guided by means of a taught steel cable attached to a sliding shoe which was attached to the front spindle of the test vehicle shown in Figure 2.26. Just prior to impact, the sliding shoe and tow cable were stripped from the vehicle allowing the test vehicle to free wheel into the end terminal. Note: to maintain adequate steering control of the test vehicle prior to impact, the vehicle ignition was on during this test; this resulted in activation of the airbag upon impact as reflected in the onboard videos discussed later in this report.

Figure 2.26: Test Vehicle Steering Guidance Assembly

Test Vehicle Data Acquisition

The data acquisition consisted of recording the acceleration and angular velocities of the test vehicle. The measurement of these two parameters allows SwRI engineers to perform an occupant risk evaluation. The device used to record the vehicle acceleration and angular velocities was a six (6) degree-of-freedom Instrumented Sensor Technology Electronic Data Recorder, henceforth referred to as the EDR-4.

The EDR-4 recorder unit is a compact package used for stand-alone recording of shock and vibration, and is able to record six channels of data. The three acceleration channels were recorded from a built-in triaxial accelerometer used to record the test vehicle's accelerations in three orthogonal directions (x, y, and z). The three angular velocity channels were recorded from built-in rate gyro transducers used to record the test vehicle's angular velocities in three orthogonal directions (roll, pitch, and yaw).

The data acquisition package was rigidly attached to the test vehicle. A metal bracket was welded onto the test vehicle's body. This bracket was attached inside the passenger compartment of the vehicle, as close as possible to the vehicle's center of gravity, without significantly modifying the vehicle's interior components (i.e., center console, bench seats). The data acquisition package was then bolted to the metal bracket as shown in Figure 2.27 and Figure 2.28. Because of the configuration of the EDR-4 as manufactured, the orientation of the data acquisition package within the vehicle matches the general axis designation given in Figure 4.6 of NCHRP Report 350, but the signs for the Y and Z axes had to be reversed during post-test processing to comply with the NCHRP and TRAP sign convention.

Figure 2.27: EDR Mounted in Test Vehicle for Test ET31-31

Figure 2.28: Close-up of EDR Mounted in Vehicle

The sign convention used for data processing is as follows:

Table 2.2: Sign Convention for Vehicle Motion

X:	Positive in the normal forward motion direction
Y:	Positive toward the right
Z:	Positive vertically downward
ROLL:	Positive using right hand rule about +X direction
PITCH:	Positive using right hand rule about +Y direction
YAW:	Positive using right hand rule about +Z direction

The EDR-4 data recorder unit was configured with a sample rate of 2944 samples per second (per channel), and with a low pass filter setting of 300 Hz. After the data had been downloaded from the data acquisition package, the data was processed using Test Risk Assessment Program (TRAP) Version 2.3.11, (Texas A&M Transportation Institute and Capsher Technology, Inc.). The TRAP program was designed to determine the effectiveness of a roadside safety feature by analyzing data from a vehicle crash test of the feature and calculating standardized occupant risk factors. TRAP calculates occupant risk factors in accordance with the NCHRP Report 350 guidelines.

Test Vehicle Onboard Cameras

For informational purposes, two digital cameras were mounted to a rail such that one camera was behind the driver, and one camera was behind the passenger; each camera was aimed at its respective floorboard area. A photograph of the camera locations is provided in Figure 2.29.

Figure 2.29: Onboard Cameras Mounted in Vehicle

Soil Conditions

The soil complied with the NCHRP Report 350 "Standard Soil" as described in the *Test Article – Design and Construction* section of this report. The day of testing, soil moisture content was measured by a certified environmental engineering firm. The maximum moisture content measured was 9.0% near both Post 1 and Post 2. There was no rainfall between when the moisture reading was taken and when the testing was conducted. Detailed results of the soil testing and moisture content evaluation are provided in Appendix E.

Calibrated Test Equipment

Test equipment used to perform the tests and acquire data during this testing program is listed in the table below.

Table 2.3: Equipment Used During Testing

Description	Manufacturer	Model	Asset No.	Due Date[1]
Data Recorder	IST	EDR-4-6DOF-200	S/N 40048	2/5/15
Wheel Scales	Longacre	72634	015238	11/5/15
Measuring Tape	Stanley	33-725	015324	11/7/15
Caliper	Starrett	721	020504	3/18/15
Speed Trap DAQ	NI	USB-6008	S/N 14D4376	8/27/15

[1]Unless otherwise specified, all equipment is calibrated or verified on an annual basis.

Test Observers

Representatives from the following organizations were among those present at the SwRI Crash Test Site and observed Test ET31-31 on January 16, 2015:

- Federal Highway Administration (FHWA)
- Virginia DOT
- Delaware DOT
- New Hampshire DOT (AASHTO Representative)

Observers from FHWA and AASHTO were permitted to visually inspect and measure the ET Plus installation before and after the test. All other observers were allowed to visually inspect the ET Plus installation before and after the test. All observers were allowed to visually inspect the vehicle following the test.

3 TEST CONDITIONS AND RESULTS

Test Description

The purpose of Test ET31-31 was to evaluate the performance of Trinity Highway Products ET Plus End Terminal with 4-inch wide guide channel installed with a rail height of 31”. To test the performance of this terminal, Test 3-31 was conducted according to NCHRP Report 350. The test installation length for the test was 49.5 m (162’-6”), and the terminal length was 16.2 m (53’-1½”).

Test 3-31 is intended primarily to evaluate the capacity of the device to absorb the kinetic energy of the vehicle in a safe manner as judged by the occupant risk and vehicle trajectory criteria. The test consists of a 2000 kg (4409 lb) pickup truck approaching parallel to the roadway (0 degree angle) and impacting the end terminal at 100 km/hr (62.1 mph) at the vehicle’s centerline. The test configuration is shown in Figure 3.1, which is from Figure 3.2 of NCHRP Report 350.

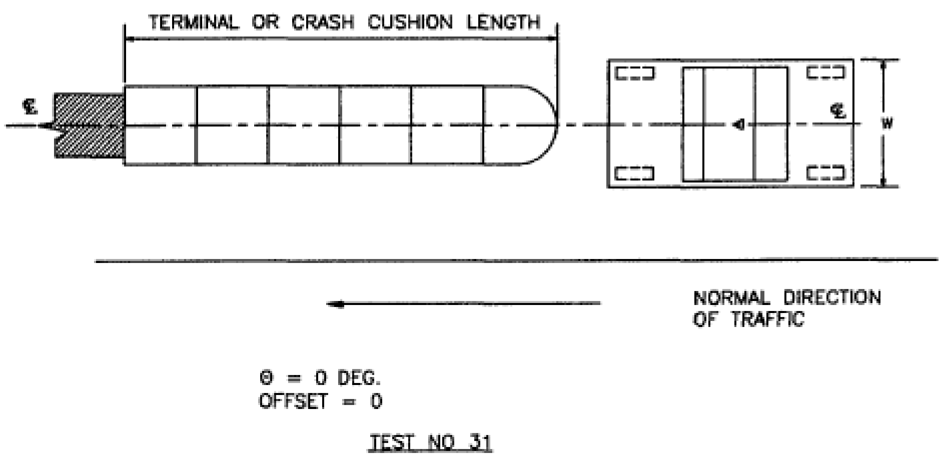


Figure 3.1: Impact Configuration *[from Figure 3.2 of NCHRP Report 350]*

The weather on the day of the test was mostly sunny, with temperatures ranging from 36-64°F. The temperature at the time of the test was approximately 60°F. The soil was dry as discussed in the *Soil Conditions* section of this report.

Impact Description/Vehicle Behavior

Figure 3.2 is an overhead photograph showing the post-test condition and location of the test article and test vehicle. Figure 3.3 through Figure 3.5, show that the test vehicle impacted the end terminal at a nominal 0° angle. The impact velocity of the test as measured by SwRI's speed trap system and verified by high-speed film analysis was determined to be 103.8 km/hr (64.5 mph). As a result of the test, the ET Plus extruder head moved 15.5 m (50.9 ft) longitudinally (downstream) as measured from its as-installed position, which is also the total system deformation (i.e. longitudinal distance to closest point) measured after the impact from the initial point of contact. There was slight lateral movement of the head towards the non-traffic side at the very end of the stroke.

After the impact event, the ET Plus extruder head stroked along the guardrail, extruding approximately 48.5 feet of guardrail including the first splice at Post 3, the second splice between Posts 5 and 6, and the third splice between Posts 7 and 8. The vehicle slowed and came to a stop when the channel guide entrance was past Post 9. The vehicle remained in contact with the ET Plus extruder head until it came to rest. The vehicle was not operable after the test.

The ET Plus extruder head directly contacted and sheared Posts 1 through 8, and damaged Post 9 at the end of the stroke. After the vehicle came to rest, Posts 1 through 4 were on the ground near the rear of the vehicle, and Posts 5 through 8 were grouped in front of the vehicle. The base of Post 9 was still intact and in its original position, but the blockout had sheared off and the post was split lengthwise from the top to near ground level. Post 10 appeared to be undamaged, but the blockout was slightly twisted and the W beam had pulled off of the bolt attaching it to the blockout as a result of the guardrail movement. All posts and blockouts downstream of Post 10 appeared undamaged, and no appreciable movement of the downstream terminal anchor was observed. Additionally, the anchor cable at Post 1 broke free of the installation and came to rest at Post 10. The extruded portion of the guardrail came to rest parallel to the installation on the non-traffic side, and the tail end of the coil was located between Posts 14 and 15. There was no penetration of the vehicle by the test article, and there was no deformation of the occupant compartment resulting from the test. The only debris thrown from the installation as a result of the impact included pieces of posts from the first eight posts; the majority of the debris fell to the non-traffic side of the guardrail, and the only debris landing on the traffic side were a couple of post fragments and the blockout from Post 5 that rolled along the ground parallel to the installation, and came to rest near Post 18. There was no significant deformation of the 4” guide channels as a result of the impact, and they remained attached to the impact head.

The test vehicle experienced a maximum 50 millisecond moving average acceleration of -5.2g in the longitudinal direction, 1.2g in the lateral direction, and 2.8g in the vertical direction. The impact velocities and ridedown accelerations were below the preferred limits and well below the maximum limits listed in NCHRP Report 350.

- Occupant impact velocities were 5.9 m/s in the longitudinal direction, and 0.2 m/s in the lateral direction.
- Occupant ridedown accelerations were -8.0g in the longitudinal direction, and 7.0g in the lateral direction.

The following sections provide photographs of the post-impact condition of the test article as well as the vehicle. Table 4.2 presents a summary of the onboard data, and plots of the accelerometer and angular velocity transducers are provided in Appendix D.

Figure 3.2: Post-Impact Condition of the Test Article and Vehicle

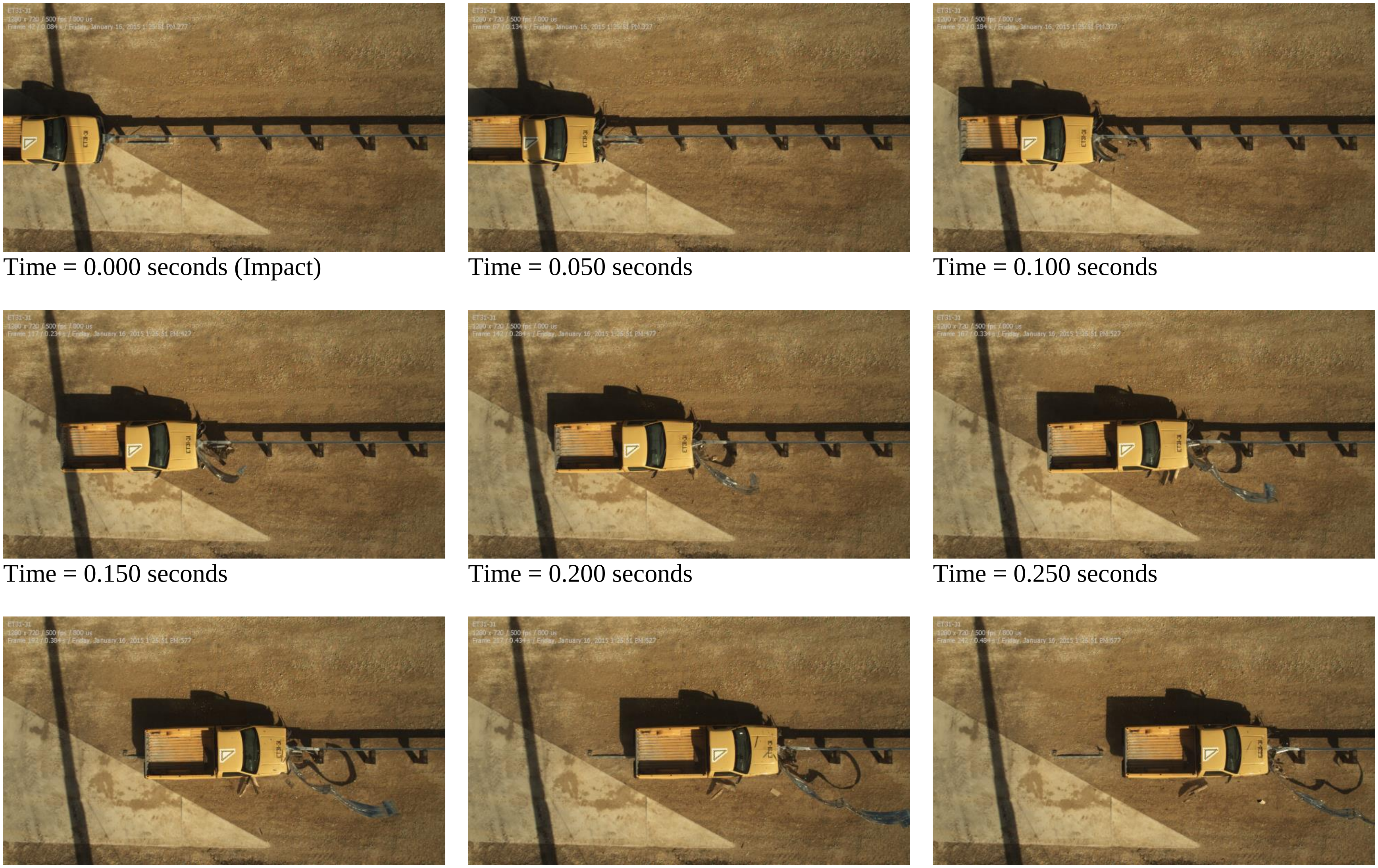
Impact Severity

NCHRP Report 350 states that the recommended impact severity for Test Level 3, Test 3-31 is 771.7 kJ, with a suggested tolerance of -60.4/+62.9 kJ. The actual impact severity of test ET31-31 was 840.7 kJ, a deviation of +69.0 kJ from the nominal impact severity recommended in NCHRP Report 350. *Note that for Test 3-31, Sin θ is set to 1 in accordance with Section 3.3.1 of Report 350.*

$$\begin{aligned}\text{Impact Severity (IS)} &= \tfrac{1}{2}\cdot M\cdot(V\cdot \sin\theta)^2\\ &= \tfrac{1}{2}\cdot M\cdot V^2\\ &= 0.5\cdot(2023\text{ kg})\cdot(28.83\text{ m/s})^2\\ &= 840.7\text{ kJ}\end{aligned}$$

The equivalent impact speed of a 2000 kg vehicle impacting the end terminal at 0 degrees would be 104.4 km/hr (64.8 mph).

Note: The impact severity for test ET31-31 slightly exceeds the suggested tolerance listed in NCHRP Report 350; however, 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.



Time = 0.000 seconds (Impact) Time = 0.050 seconds Time = 0.100 seconds

Time = 0.150 seconds Time = 0.200 seconds Time = 0.250 seconds

Time = 0.300 seconds Time = 0.350 seconds Time = 0.400 seconds

Figure 3.3: Sequential Photographs, as Viewed from Overhead


Time = 0.000 seconds (Impact)


Time = 0.050 seconds


Time = 0.100 seconds


Time = 0.150 seconds


Time = 0.200 seconds


Time = 0.250 seconds


Time = 0.300 seconds


Time = 0.350 seconds


Time = 0.400 seconds

Figure 3.4: Sequential Photographs, as Viewed from Downstream


Time = 0.000 seconds (Impact)


Time = 0.050 seconds


Time = 0.100 seconds


Time = 0.150 seconds


Time = 0.200 seconds


Time = 0.250 seconds


Time = 0.300 seconds


Time = 0.350 seconds


Time = 0.400 seconds

Figure 3.5: Sequential Photographs, as Viewed from Non Traffic Side of the End Terminal

End Terminal Damage

Figure 3.6: Post-Impact Condition of the Test Article and Vehicle

Figure 3.7: Post Test – Post 1 and 2 Foundation Sleeves and Strut

Figure 3.8: Post Test – Post 1 Foundation Sleeve

Figure 3.9: Post Test – Post 2 Foundation Sleeve

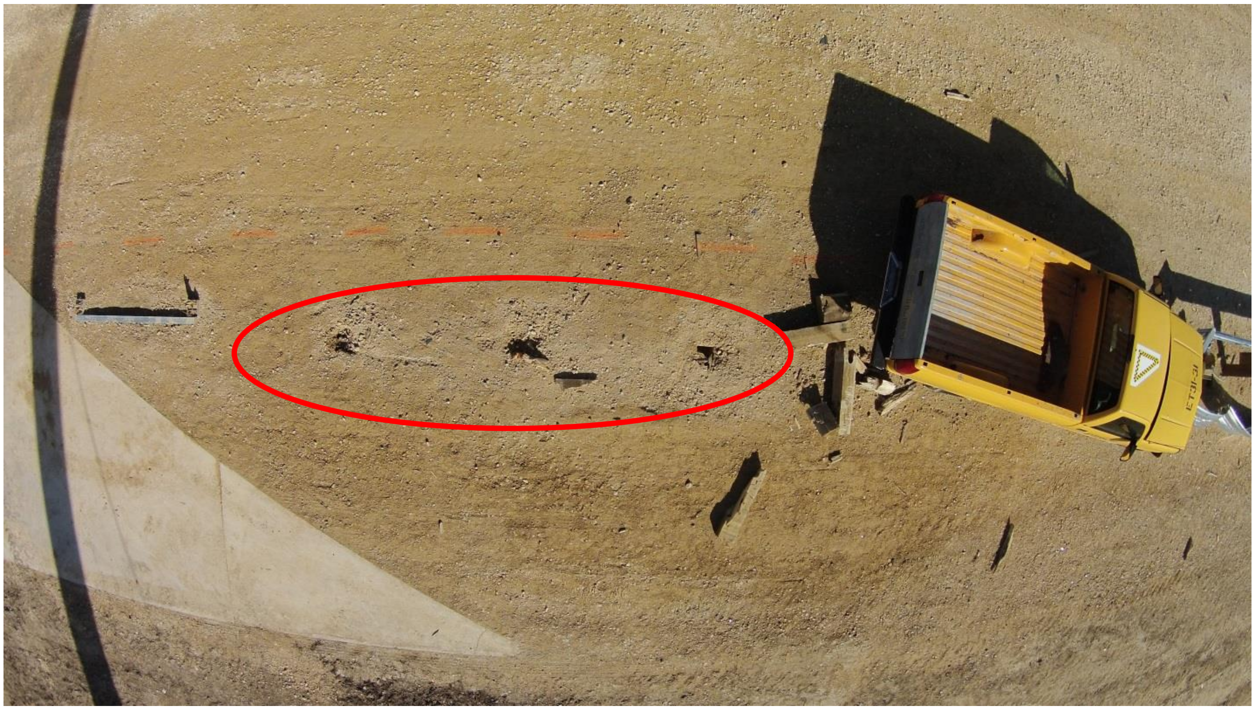


Figure 3.10: Post Test – Posts 3, 4, and 5

Figure 3.11: Post Test – Posts 1, 2, 3 and 4 at Rear of Truck

Figure 3.12: Post Test – Posts 3 and 4 at Rear of Vehicle

Figure 3.13: Post Test – Post Debris at Front of Truck

Figure 3.14: Post Test – Post 9 Damage

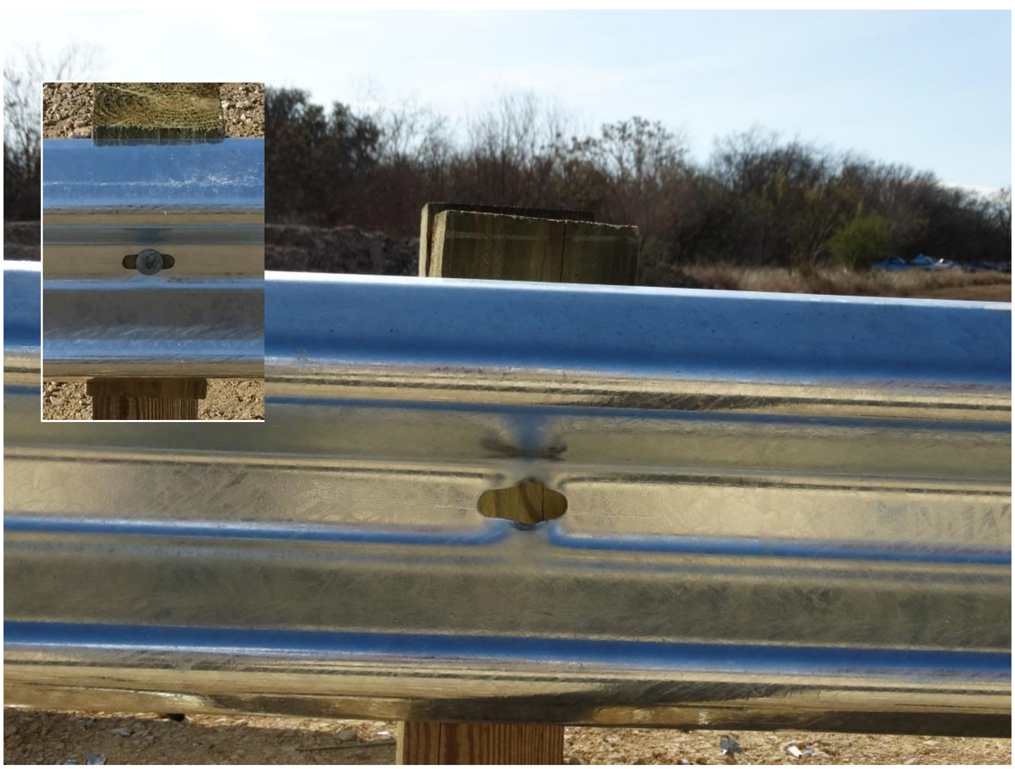


Figure 3.15: Post Test – Post 10, W Beam Pulled off Blockout (Pre-Test Photo Inset)

Figure 3.16: Post Test – Non-Traffic Side of Extruder Head

Figure 3.17: Post Test – Guide Channel Entrance, Traffic Side

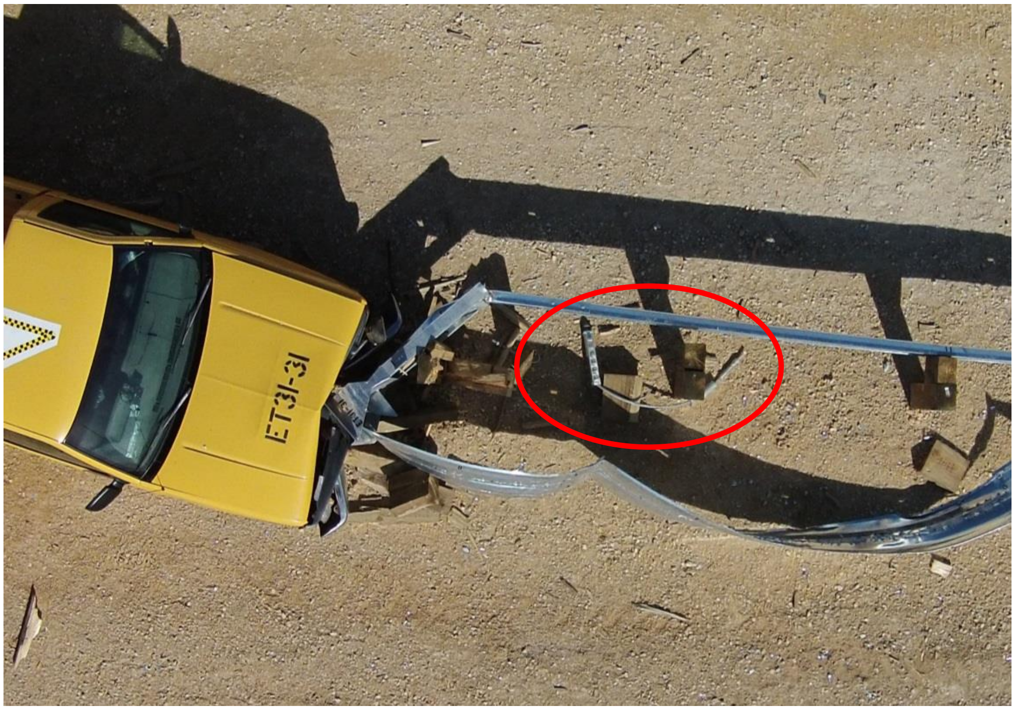


Figure 3.18: Post Test Location of Anchor Cable

Figure 3.19: Post Test Location of Anchor Cable Bolt

Figure 3.20: Post Test – Extruded Guardrail

Figure 3.21: Post Test – Extruded Guardrail Coil

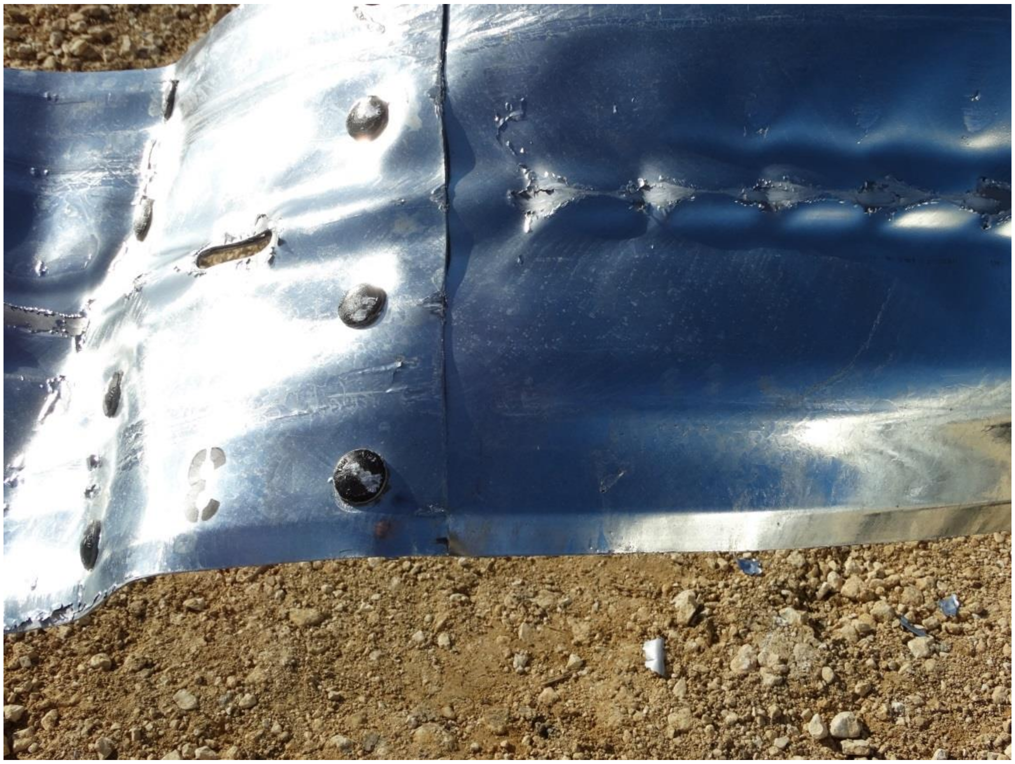


Figure 3.22: Post Test – Extruded Guardrail Splice from Post 3 (Splice Bolts Painted Pre-Test for Visibility in Video)

Figure 3.23: Post Test – Extruded Guardrail Splice from Post 3 (Splice Nuts Painted Pre-Test for Visibility in Video)

Figure 3.24: Post Test – Extruded Guardrail Splice from between Posts 5 & 6 (Splice Bolts Painted Pre-Test for Visibility in Video)

Figure 3.25: Post Test – Extruded Guardrail Splice from between Posts 5 & 6 (Splice Nuts Painted Pre-Test for Visibility in Video)

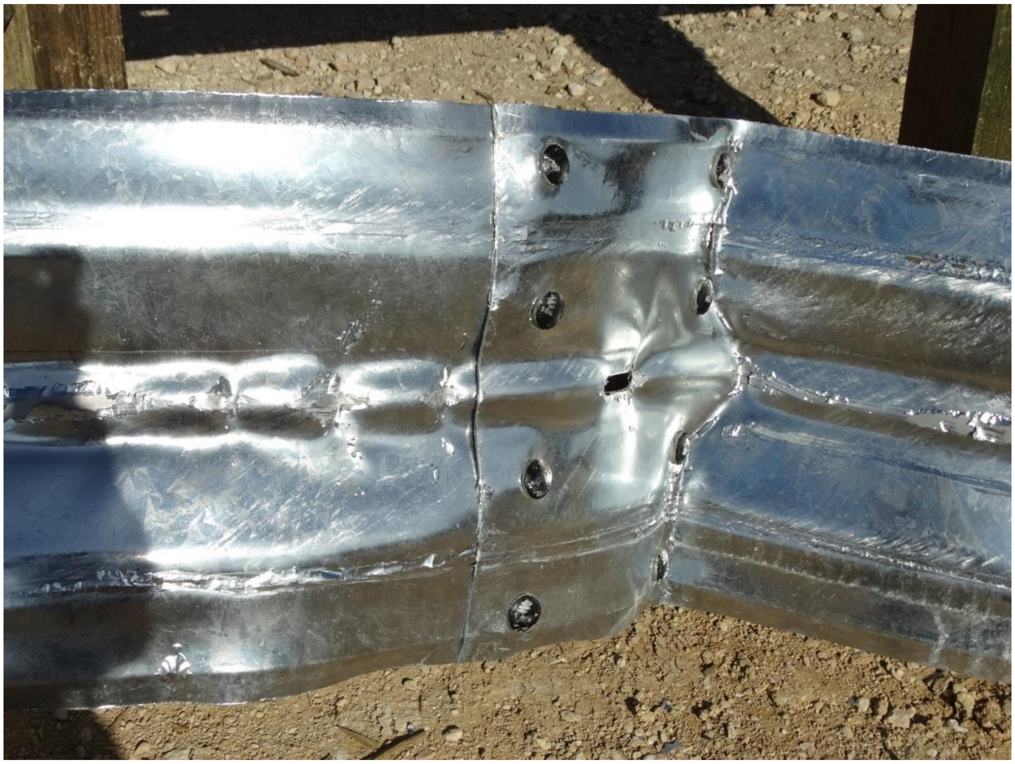


Figure 3.26: Post Test – Extruded Guardrail Splice from between Posts 7 & 8 (Splice Bolts Painted Pre-Test for Visibility in Video)

Figure 3.27: Post Test – Extruded Guardrail Splice from between Posts 7 & 8 (Splice Nuts Painted Pre-Test for Visibility in Video)

Figure 3.28: Post-Test – Extruder Exit

Figure 3.29: Post-Test –Guide Channel Entrance, Traffic Side

Figure 3.30: Post-Test –Guide Channel Entrance, Non-Traffic Side

Figure 3.31: Post-Test – ET Plus Head, Non-Traffic Side

Figure 3.32: Post-Test – ET Plus Head, Non-Traffic Side, Close-up

Figure 3.33: Post-Test – ET Plus Head, Traffic Side

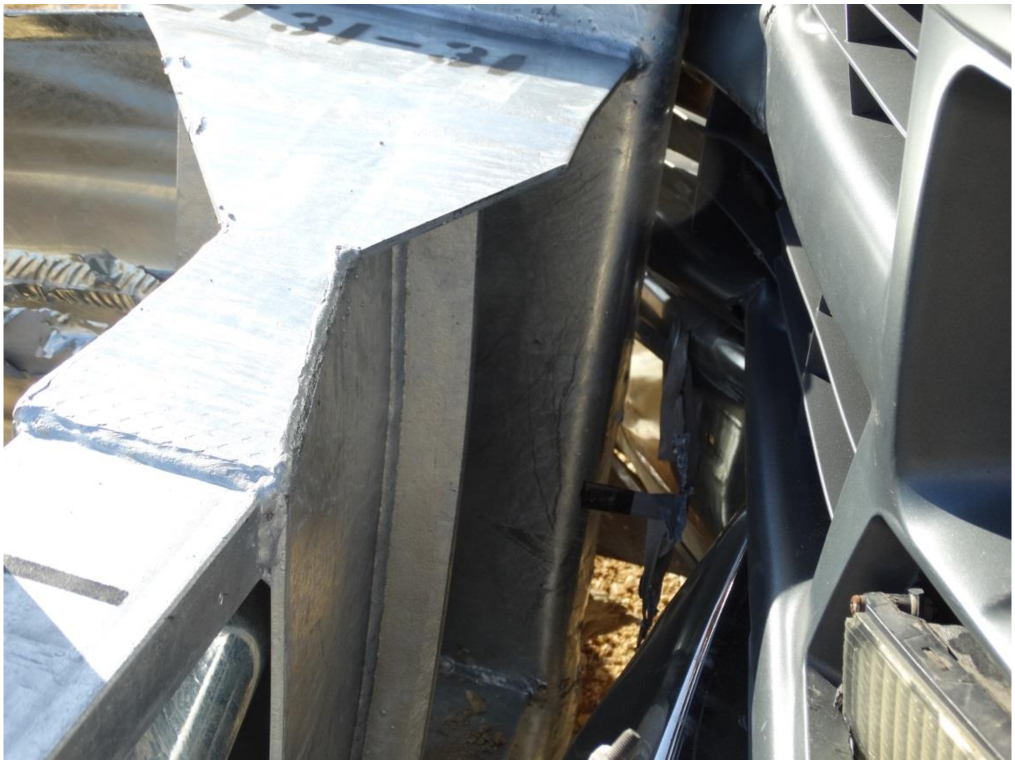


Figure 3.34: Post-Test – ET Plus Head, Traffic Side, Close-up

Figure 3.35: Post-Test – ET Plus Head at Front of Vehicle

Figure 3.36: Post Test – Debris Field

Figure 3.37: Post-Impact Test Article after Vehicle Removed

Figure 3.38: Post-Impact Test Article after Vehicle Removed – Traffic Side View

Figure 3.39: Post-Impact Test Article after Vehicle Removed – Non-Traffic Side View

Figure 3.40: Post-Impact Test Article after Vehicle Removed – Impact Plate

Figure 3.41: Post Test Verification of Extruder Head 6

Vehicle Damage

Figure 3.42: Test Vehicle Post-Test Location

Figure 3.43: Post Test Vehicle – Overhead View

Figure 3.44: Post Test Vehicle – Front View

Figure 3.45: Post Test Vehicle – Front View Close-up

Figure 3.46: Post Test Vehicle – Left Side

Figure 3.47: Post Test Vehicle – Right Side

Figure 3.48: Post Test Vehicle – Accumulated Posts at Front of Vehicle

Figure 3.49: Post Test Vehicle – Accumulated Posts at Rear of Vehicle

Figure 3.50: Post Test Vehicle – ET Plus Head at Front of Vehicle

Figure 3.51: Post Test Vehicle – Front View after Removal from Guardrail

Figure 3.52: Post Test Vehicle – Left Side after Removal from Guardrail

Figure 3.53: Post Test Vehicle – Occupant Compartment, Airbag Deployment

Figure 3.54: Post Test Vehicle – Driver Side Floorboard

Figure 3.55: Post Test Vehicle – Passenger Side Floorboard

4 ASSESSMENT OF TEST RESULTS

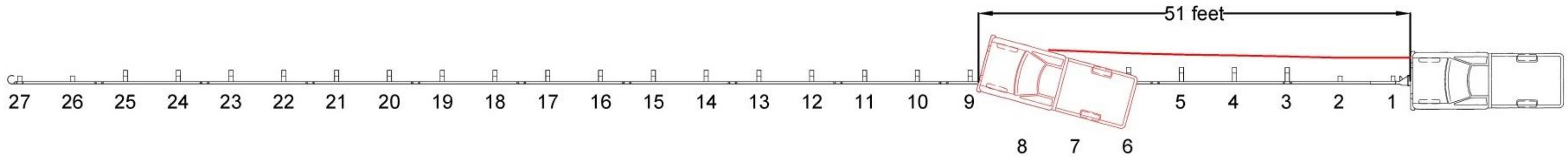
A comparison of the test results of Test ET31-31 against the evaluation criteria set forth in NCHRP Report 350 for Test 3-31 is provided in Table 4.1. A summary of the test results is provided in Table 4.2.

Table 4.1: Summary of Test Evaluation Results (NCHRP Report 350 Evaluation Criteria) for Test ET31-31

Evaluation Factor	Evaluation Criteria	Crash Test Result	Result
Structural Adequacy	C. Acceptable test article performance may be by redirection, controlled penetration, or controlled stopping of the vehicle.	Test article provided controlled deceleration and stopping of the vehicle.	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.	No penetration or potential penetration of the occupant compartment or undue hazard presented by test article debris. See photos for post-test location of debris.	Pass
	F. The vehicle should remain upright during and after collision although moderate roll, pitching and yawing are acceptable.	Vehicle remained stable and upright during and after the collision.	Pass
	H. Occupant Impact Velocities (OIV) limits: Preferred = 9 m/s Maximum = 12 m/s	Occupant impact velocities: Longitudinal: 5.9 m/s Lateral: 0.2 m/s	Pass
	I. Occupant Ridedown Acceleration (ORA) limits: Preferred = 15 g Maximum = 20 g	Occupant Ridedown Accelerations: Longitudinal: -8.0 g Lateral: 7.0 g	Pass
Vehicle Trajectory	K. After collision it is preferable that the vehicle's trajectory not intrude into adjacent traffic lanes.	See photos; vehicle remained in contact with guardrail following impact.	See Note[1]
	N. Vehicle trajectory behind the test article is acceptable.	See photos; vehicle remained in contact with guardrail following impact.	Pass

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

Table 4.2: Summary of Test Results and Conditions



General Information	
Test Agency	Southwest Research Institute
Test Number	ET31-31
Test Date	1/16/2015
Test Category	3-31
Test Article	
Type	End Terminal
Terminal Length	16.2 m (53’-1½”)
Installation Length	49.5 m (162’-6”)
Nom. Barrier Height	78.7 cm (31 in.)
Type of Primary Barrier	W-beam guardrail
Soil	Stable, Dry - “Standard” Soil
Test Vehicle	
Type	Pickup truck
Designation	2000P
Model	1998 GMC PU2500
Curb Mass (kg)	1923 as received
Ballast Mass (kg)	100
Test Inertial Mass (kg)	2023
Dummy Mass (kg)	N/A
Gross Static Mass (kg)	2023

Impact Conditions	
Speed (km/hr)	103.8
Angle (degrees)	0.3
Exit Conditions	
Speed (km/hr)	N/A
Angle (degrees)	N/A
Occupant Risk Values	
Impact Velocity (m/s)	
x-direction	5.9
y-direction	0.2
Ridedown Accelerations (g)	
x-direction	-8.0
y-direction	7.0
Target Conditions	
Nominal Speed	100 km/hr (62.1 mph)
Nominal Angle	0°
Tolerances	
Nominal Speed	±4 km/hr
Nominal Angle	±1.5˚

Extruder Head Position from Start	
Longitudinal	15.5 m (50.9 ft)
Lateral	~0.7 m (2.2 in)
Total System Deformation (Closest Point)	
Longitudinal	15.5 m (50.9 ft)
Post Impact Vehicular Behavior	
Max Vehicle Rotation (degrees)	
Max. Roll	-6.0 @ 1.0296 sec.
Max. Pitch	-3.2 @ 1.0129 sec.
Max. Yaw	12.9 @ 1.5323 sec.
Max 50ms Moving Average Accelerations (g)	
x-direction	-5.2 @ 0.2661-0.3161 sec.
y-direction	1.2 @ 0.8453-0.8952 sec.
z-direction	2.8 @ 0.6370-0.6870 sec.

5 CONCLUSIONS

The performance of the ET Plus during Test ET31-31 against Structural Adequacy, Occupant Risk, and Vehicle Trajectory criteria specified in NCHRP Report 350 was as-follows:

Structural Adequacy

- The vehicle was decelerated and stopped in a controlled manner.

Occupant Risk

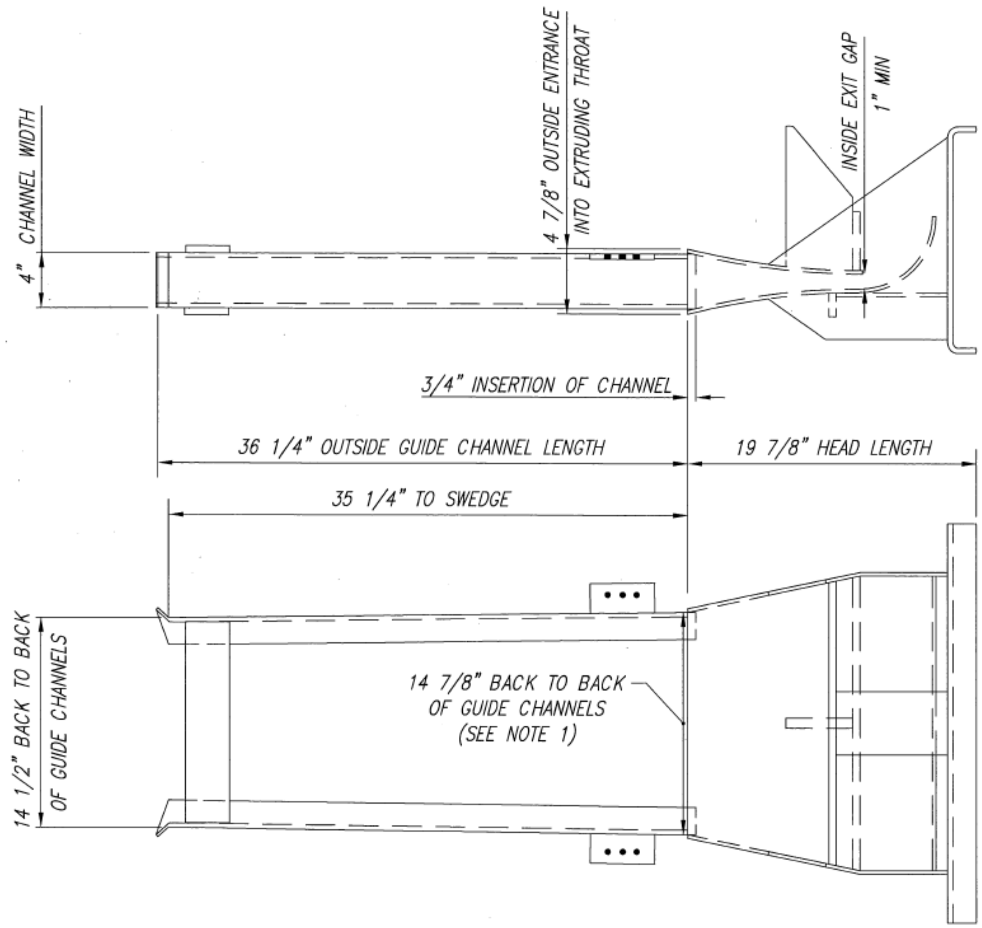
- There was no penetration of the vehicle by the test article, and no deformation of the occupant compartment resulting from the test.
- There was no undue hazard presented by test article debris outside of the immediate impact zone; the only debris thrown from the installation included pieces of posts and blockouts, the majority of which fell to the non-traffic side of the guardrail.
- The vehicle remained upright during and following the impact.
- The test article provided for controlled deceleration with impact velocity and ridedown acceleration values within allowable limits.

Vehicle Trajectory

- The vehicle was smoothly decelerated and remained in contact with the guardrail until it came to rest.

Based on the information provided in this report, the ET Plus End Terminal with 4-inch wide guide channel installed with a rail height of 31” meets the Test Level 3, Test 3-31 criteria for NCHRP Report 350.

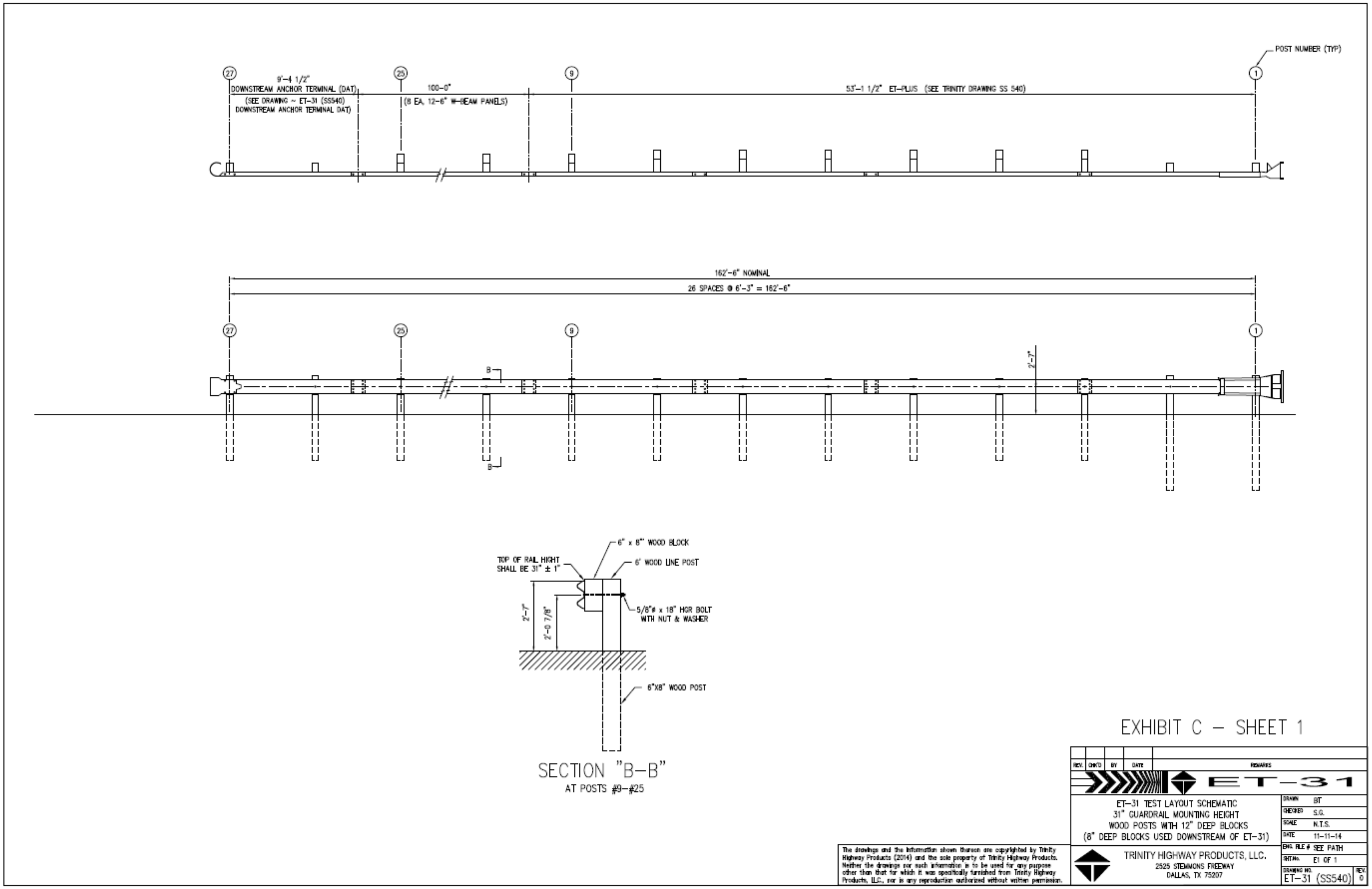
Appendix A: Test Article Drawings

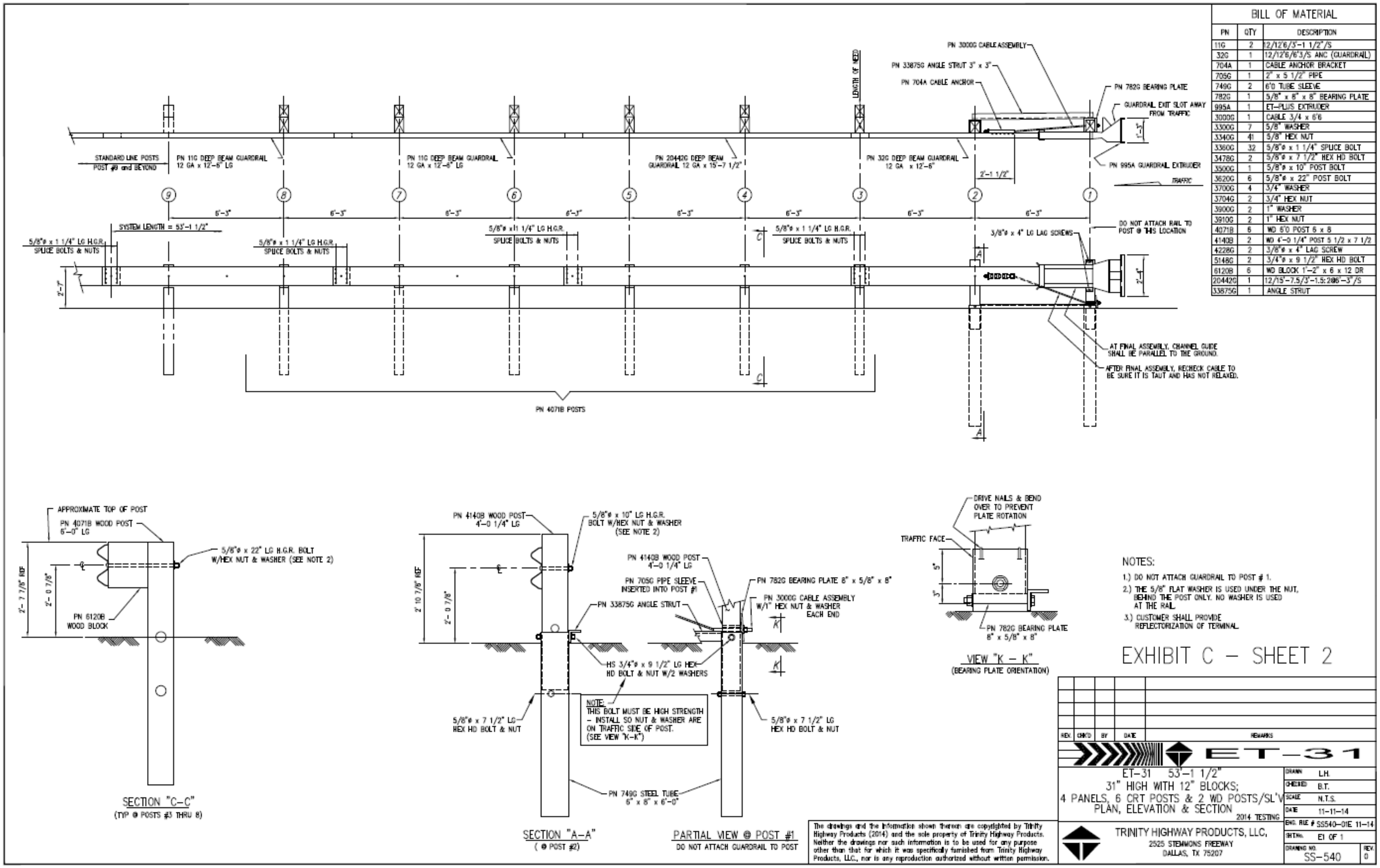


ET PLUS EXTRUDER HEAD (PN 995 REV 13)

NOTE 1: 14 7/8" DIMENSION BACK TO BACK OF GUIDE CHANNELS IS MEASURED AT SUB-ASSEMBLY BEFORE WELDING TO CHUTE. ACTUAL CHUTE VERTICAL OPENING DIMENSION IS 15".

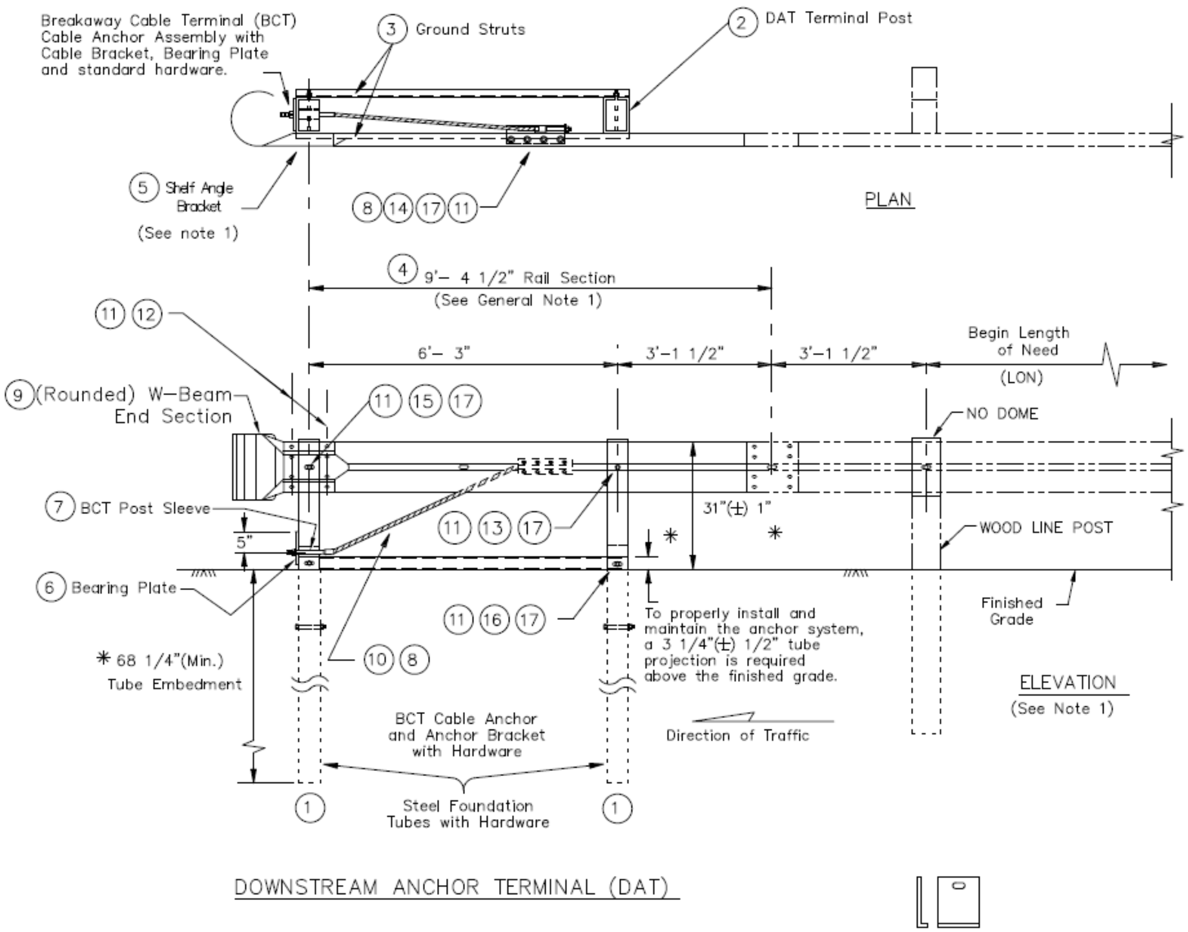
TRINITY HIGHWAY PRODUCTS, LLC.
2525 STEMMONS FREEWAY
DALLAS, TX 75207


POST NUMBER (TYP)
9'-4 1/2"
DOWNSTREAM ANCHOR TERMINAL (DAT)
(SEE DRAWING ~ ET-31 (SS540)
DOWNSTREAM ANCHOR TERMINAL DAT)
100'-0"
(8 EA. 12'-6" W-BEAM PANELS)
53'-1 1/2" ET-PLUS (SEE TRINITY DRAWING SS 540)
162'-6" NOMINAL
26 SPACES @ 6'-3" = 162'-6"
2'-7"
6" x 8" WOOD BLOCK
TOP OF RAIL HIGHT SHALL BE 31" ± 1"
6' WOOD LINE POST
5/8"ø x 18" HGR BOLT WITH NUT & WASHER
2'-7"
2'-0 7/8"
6"X8" WOOD POST
SECTION "B-B"
AT POSTS #9-#25
EXHIBIT C – SHEET 1
ET-31
ET-31 TEST LAYOUT SCHEMATIC
31" GUARDRAIL MOUNTING HEIGHT
WOOD POSTS WITH 12" DEEP BLOCKS
(8" DEEP BLOCKS USED DOWNSTREAM OF ET-31)
TRINITY HIGHWAY PRODUCTS, LLC.
2525 STEMMONS FREEWAY
DALLAS, TX 75207
BT
S.G.
N.T.S.
11-11-14
SEE PATH
E1 OF 1
ET-31 (SS540)
0
The drawings and the information shown thereon are copyrighted by Trinity Highway Products (2014) and the sole property of Trinity Highway Products. Neither the drawings nor such information is to be used for any purpose other than that for which it was specifically furnished from Trinity Highway Products, LLC., nor is any reproduction authorized without written permission.



BILL OF MATERIAL

PN	QTY	DESCRIPTION
11G	2	12/12'6/3'-1 1/2"/S
32G	1	12/12'6/6'3/S ANC (GUARDRAIL)
704A	1	CABLE ANCHOR BRACKET
705G	1	2" x 5 1/2" PIPE
749G	2	6'0 TUBE SLEEVE
782G	1	5/8" x 8" x 8" BEARING PLATE
995A	1	ET-PLUS EXTRUDER
3000G	1	CABLE 3/4 x 6'6
3300G	7	5/8" WASHER
3340G	41	5/8" HEX NUT
3360G	32	5/8"ø x 1 1/4" SPLICE BOLT
3478G	2	5/8"ø x 7 1/2" HEX HD BOLT
3500G	1	5/8"ø x 10" POST BOLT
3620G	6	5/8"ø x 22" POST BOLT
3700G	4	3/4" WASHER
3704G	2	3/4" HEX NUT
3900G	2	1" WASHER
3910G	2	1" HEX NUT
4071B	6	WD 6'0 POST 6 x 8
4140B	2	WD 4'-0 1/4" POST 5 1/2 x 7 1/2
4228G	2	3/8"ø x 4" LAG SCREW
5148G	2	3/4"ø x 9 1/2" HEX HD BOLT
6120B	6	WD BLOCK 1'-2" x 6 x 12 DR
20442G	1	12/15'-7.5/3'-1.5:286'-3"/S
33875G	1	ANGLE STRUT



PN	#	(DAT) PARTS LIST	QTY
724	1	Steel Foundation Tube	2
4140	2	DAT Terminal Post	2
19481	3	Channel Strut	2
20207	4	Terminal Rail Element	1
9713	5	Shelf Angle Bracket	1
782	6	BCT Bearing Plate	1
705	7	BCT Post Sleeve	1
700	8	Guardrail Anchor Bracket	1
907	9	(Rounded)W–Beam End Section	1
3000	10	BCT Cable Anchor	1
	11	Recessed Nut, Guardrail	20
	12	1 1/4" Button Head Bolt	4
	13	10" Button Head Bolt	2
	14	5/8" x 2" Hex Head Bolt	8
	15	5/8" x 8" Hex Head Bolt	4
	16	5/8" x 10" Hex Head Bolt	2
	17	5/8" Flat Washer	18

GENERAL NOTES

1. The rail section at the end post is supported by the Shelf Angle Bracket. The rail element is not attached to the end post.

EXHIBIT C – SHEET 3

METAL BEAM GUARD FENCE
ET–31 (SS540) 2014 TESTING
DOWNSTREAM ANCHOR TERMINAL (DAT)

REF: TxDOT, GF31DAT14.DGN

Appendix B: SwRI Data Sheets for Test ET31-31

EXHIBIT D-1: Installation Checklist

Test Number: 31-31 Test Date: 1/16/2015

TEST 86 - 2000p Head on

1/5/2015 OH

head stamp "6"

*Record the following impact head dimensions:

Dimension	*Pre-Test Measurements
Exit Gap (middle - inside)	1.1145" ✓
Entrance Gap (middle - outside)	4.7065"
Guide Chute Exit Height (outside)	15 1/16" ✓
Guide Chute Entrance Height (outside)	14 9/16" ✓
Channel Width (outside)	4.0375" ✓
Channel Insertion into Extruder	0.3710" 0.4325" 0.4455" 0.4790"
Outside Guide Channel Length	36 3/8" ✓
Outside Guide Channel Length – Chute to start of swedge	35 7/16" ✓
Head length	56 5/8"

a. Guardrail height as measured from the ground to the top of the guardrail at mid-span for the first eight spans:
   a. Between post 1 and 2:_____ inches Between post 5 and 6:_____ inches
   b. Between post 2 and 3:_____ inches Between post 6 and 7:_____ inches
   c. Between post 3 and 4:_____ inches Between post 7 and 8:_____ inches
   d. Between post 4 and 5:_____ inches Between post 8 and 9:_____ inches
   e. (ET27 series: all heights to be greater than or equal to 27-3/4" and less than 28-3/4")
   f. (ET31 series: all heights to be greater than 30-1/2" and less than 31-1/2")
b. Distance from the ground to the bottom of the impact face: _________ inches.
c. Distance from the ground to the top of the impact face: _____________ inches.
d. Soil in the area around impact area and runout area is smooth and flat: YES NO (circle one).
e. Backfill around the posts has been re-compacted: YES NO (circle one).
f. Distance from the ground to the top of the first foundation tube: ______ inches
   (Must be 4 inches or less).
g. Distance from the ground to the top of the second foundation tube: ______ inches
   (Must be 4 inches or less).
h. Bolts at the top of the foundation tubes at posts one and two are not overtightened and the walls of the steel tube are not collapsed or deformed: YES NO (circle one).
i. The ET-PLUS extruder head is pushed as far as it will go on the guardrail panel. The guardrail extends into the extruder ________ inches.

HIGHLY CONFIDENTIAL

RSA 1/14/2015 KAC 1/14/15
MMD 1/14/15
CWP 1/14/15

EXHIBIT D-1: Installation Checklist

Test Number: ET31-31 Test Date: 1/16/2015

*Record the following impact head dimensions:

head stamp "6" 1/5/2015 OK

Dimension	*Pre-Test Measurements
Exit Gap (middle - inside)	1.1145"
Entrance Gap (middle - outside)	4.7065"
Guide Chute Exit Height (outside)	15 1/16"
Guide Chute Entrance Height (outside)	14 9/16"
Channel Width (outside)	4.0375"
Channel Insertion into Extruder	0.3710" 0.4325" 0.4455" 0.4790"
Outside Guide Channel Length	36 3/8"
Outside Guide Channel Length – Chute to start of swedge	35 7/16"
Head length	56 5/8"

a. Guardrail height as measured from the ground to the top of the guardrail at mid-span for the first eight spans:
   a. Between post 1 and 2: 30 3/4 inches
   b. Between post 2 and 3: 30 1/4 inches
   c. Between post 3 and 4: 30 7/8 inches
   d. Between post 4 and 5: 30 5/8 inches
   Between post 5 and 6: 30 5/8 inches
   Between post 6 and 7: 30 3/4 inches
   Between post 7 and 8: 31 1/4 inches
   Between post 8 and 9: 31 1/8 inches
   e. (ET27 series: all heights to be greater than or equal to 27-3/4" and less than 28-3/4")
   f. (ET31 series: all heights to be greater than 30-1/2" and less than 31-1/2")
b. Distance from the ground to the bottom of the impact face: 10 3/8 inches.
c. Distance from the ground to the top of the impact face: 38 1/4 inches.
d. Soil in the area around impact area and runout area is smooth and flat: YES NO (circle one).
e. Backfill around the posts has been re-compacted: YES NO (circle one).
f. Distance from the ground to the top of the first foundation tube: 2 1/8 inches (Must be 4 inches or less).
g. Distance from the ground to the top of the second foundation tube: 2 1/4 inches (Must be 4 inches or less).
h. Bolts at the top of the foundation tubes at posts one and two are not overtightened and the walls of the steel tube are not collapsed or deformed: YES NO (circle one).
i. The ET-PLUS extruder head is pushed as far as it will go on the guardrail panel. The guardrail extends into the extruder 2 1/2 inches.

j. The two bolts (top and bottom) holding the extruder head to post one are snug and the extruder channel is approximately parallel to the finished grade (i.e., level): YES NO (circle one).
k. The cable anchor bracket is locked into place by pulling the bracket toward the impact end of the unit: YES NO (circle one). Make sure the hooks/lugs are well seated into the square holes on the guardrail.
l. The hex nuts on the cable ends are tightened such that the cable is taut: YES NO (circle one). The cable is taut when it does not deflect more than 1 inch when hand pressure is applied perpendicular to the mid-span of the cable.
m. The bearing plate is placed on the impact side of post 1 where the cable extends through the post: YES NO (circle one).
n. The cable bearing plate is oriented with the long dimensions turned up (from top of plate to center of cable hole is 5"): YES NO (circle one).
o. Wood blockouts have been toe-nailed to the posts: YES NO (circle one).
p. The CRT post top hole is located with the center of the hole approximately at the ground line (± 2"): YES NO (circle one).
q. The guardrail panels are lapped correctly: YES NO (circle one).

Completed by: Oliver Hanson 1/13/2015

Yellow 1GTFC24M5WZ519799

43

DATE: 1-9-14 TEST NO.: ET-31-31 VIN NO.: ↑ MAKE: GMC

MODEL: PU 2500 YEAR: 1998 ODOMETER: 200084 GVW: 7200

TIRE SIZE: LT245/75R16 TIRE INFLATION PRESSURE: 35 PSI TREAD TYPE:

MASS DISTRIBUTION (kg) LF 1297 RF 1230 LR 910 RR 1023

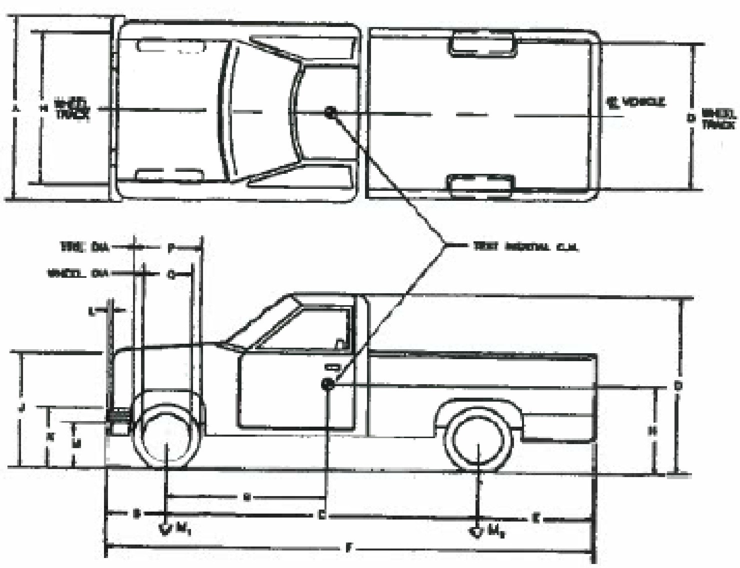
Ballast 220 lbs Total 4460 lbs With Ballast

DESCRIBE ANY DAMAGE TO VEHICLE PRIOR TO TEST:

Rust Hole's Right & Left Rear corners of bed only

C/G = 28.1"

C/G HEIGHT 13.6"



ENGINE TYPE: GAS

ENGINE CID: 5.0 L

TRANSMISSION TYPE:

X AUTO

— MANUAL

OPTIONAL EQUIPMENT:

DUMMY DATA:

TYPE:

MASS:

SEAT POSITION:

GEOMETRY – (cm)

A 75 1/2"	D 70"	G 57.2"	K 23 1/2"	N 62"	Q 17 1/2"
B 35"	E 51 1/2"	H 28.1"	L 3 1/2"	O 63 1/2	
C 132	F 218 1/2"	J 39 1/2"	M 15"	P 30"	

MASS – (kg)	CURB	TEST INERTIAL	GROSS STATIC
M_1			
M_2			
M_T			

EDR Behind Front Spindle ~~54 1/2"~~ 56 1/2" OH 1/20/2015 Above Ground 27 3/4" OH 1/15/2015

Figure 4.2. 2000P parameters.

Appendix C: Laboratory Statement

SOUTHWEST RESEARCH INSTITUTE®

6220 CULEBRA ROAD 78238-5166 • P.O. DRAWER 28510 78228-0510 • SAN ANTONIO, TEXAS, USA • (210) 684-5111 • WWW.SWRI.ORG

Refer to: 18.20887
January 15, 2015

TRINITY HIGHWAY PRODUCTS LLC
2525 Stemmons Freeway
Dallas, Texas 75207

Subject: Proposal and Fixed-Price Contract for Services No. 18-73314
SwRI® Project No. 18.20887

To Whom It May Concern:

Southwest Research Institute hereby attests to the following:

- SwRI is listed on FHWA's roster of laboratories suitable for performing NCHRP Report 350 and MASH crash tests.
- SwRI is currently ISO 17025 accredited by A2LA to perform NCHRP Report 350 and MASH crash tests (Testing Laboratory Certificate 1110.02).
- SwRI has not previously conducted crash testing of the ET-Plus End Terminal system.
- SwRI does not own intellectual property and does not receive royalty-related revenue associated with any of the roadside safety hardware involved in this test program or any guardrail terminal products competing with the ET-Plus End Terminal system.
- SwRI is financially independent from Trinity Highway Products and the Texas Transportation Institute (TTI) at Texas A&M University.

I, R. B. Kalmbach, Executive Director of Contracts, certify on behalf of Southwest Research Institute that the above representations are current, accurate and complete as of the date of this letter.

Should you have any questions, please contact Ms. Mary Lepel at 210/522-3026, by facsimile at 210/522-3559, or email mary.lepel@swri.org.

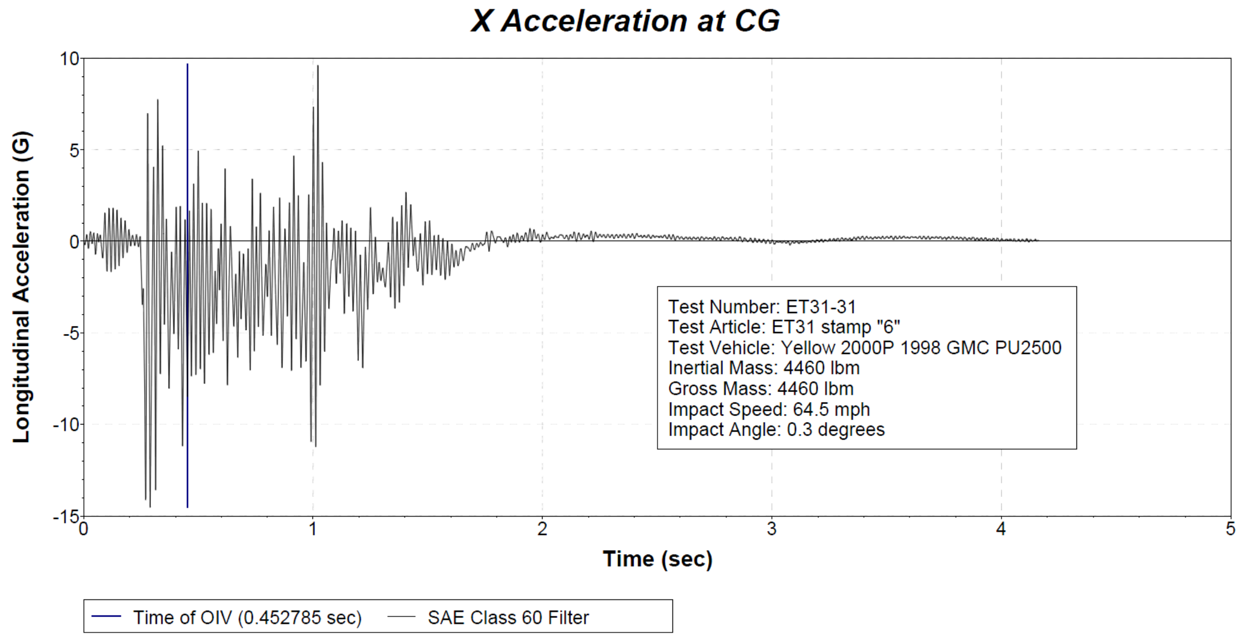
Sincerely,

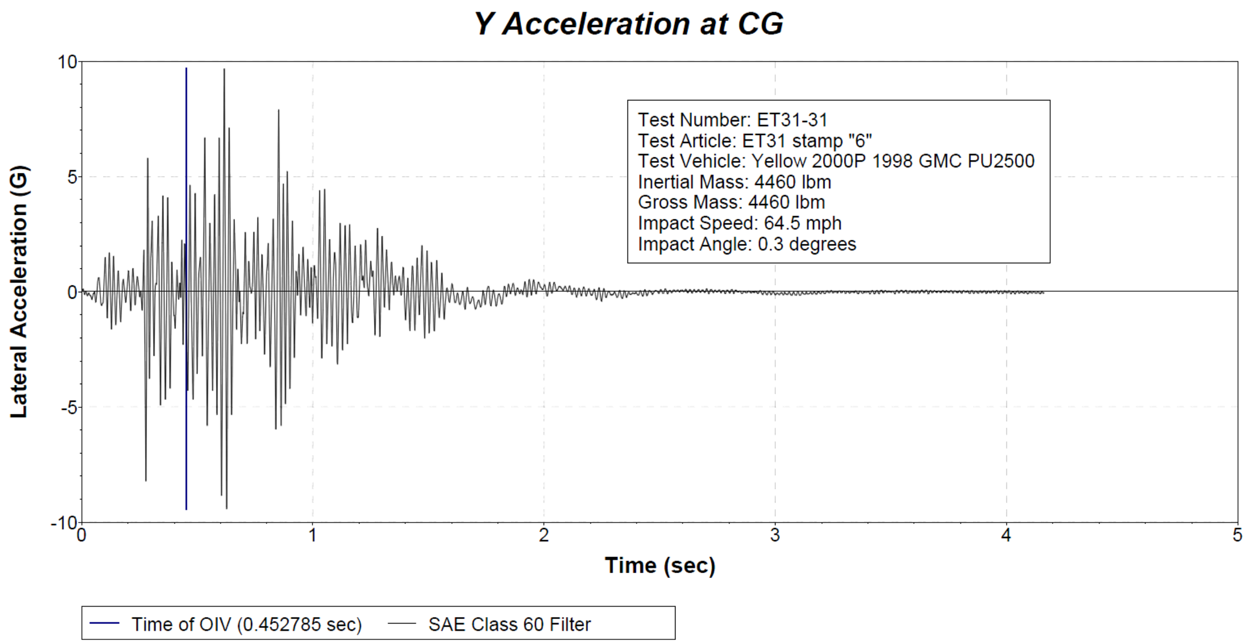
R. B. Kalmbach
Executive Director, Contracts

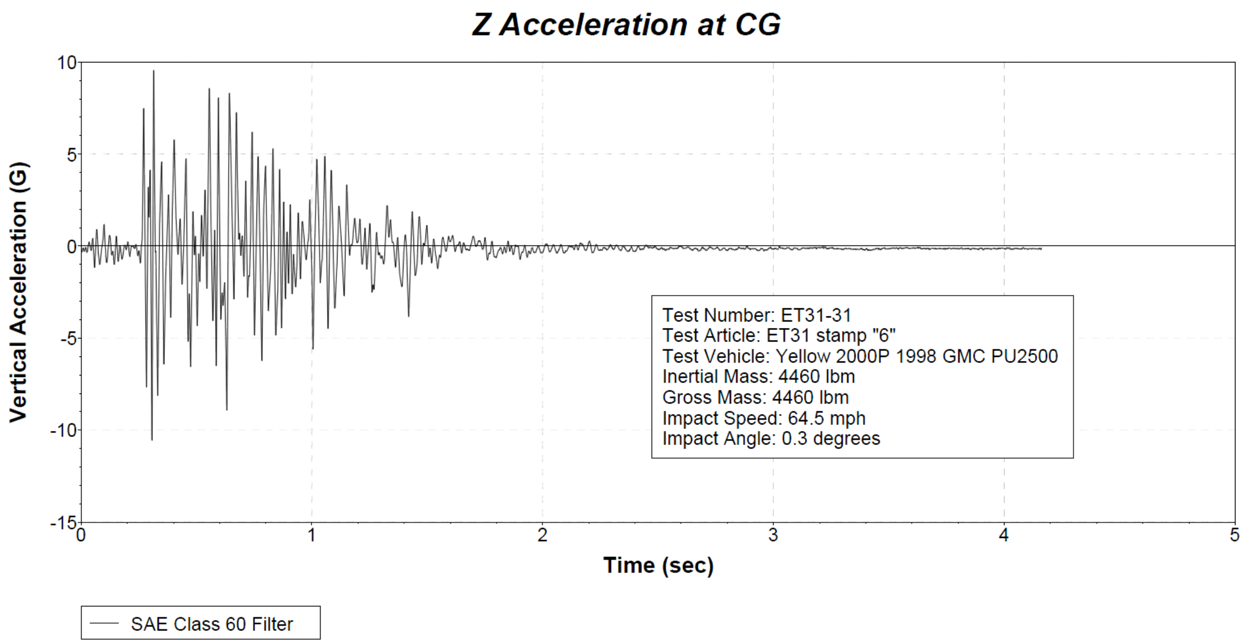
RBK/MKL/jms
cc: J. Ferren, SwRI (via email)

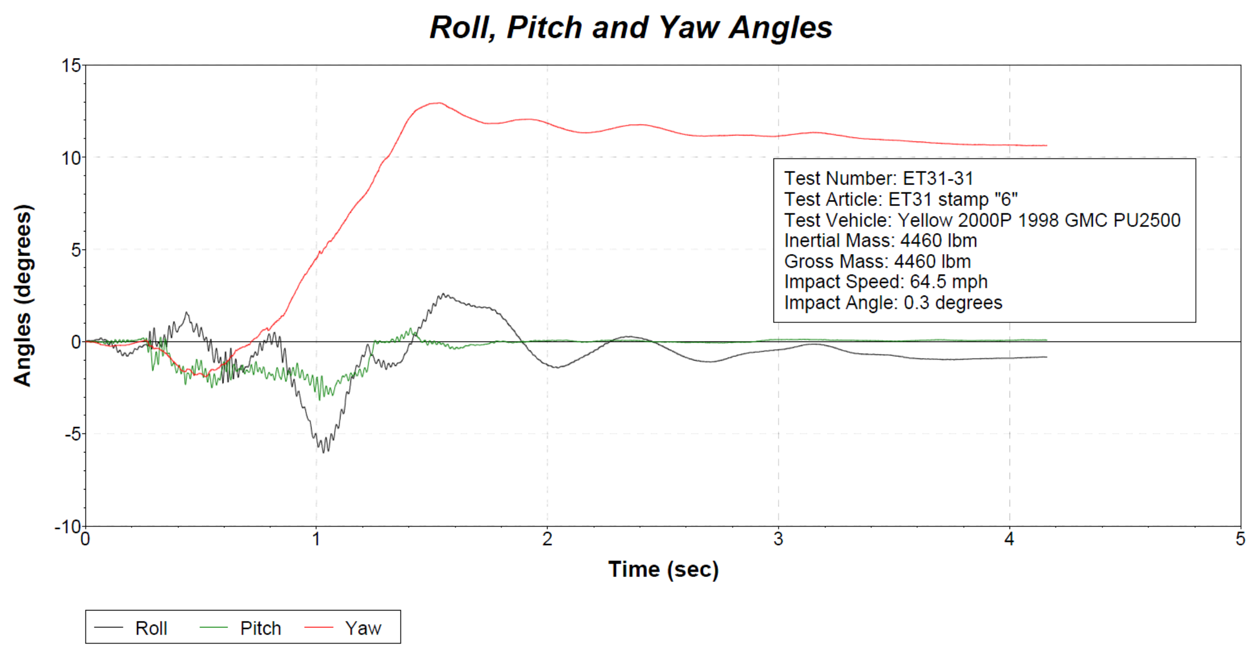
Benefiting government, industry and the public through innovative science and technology

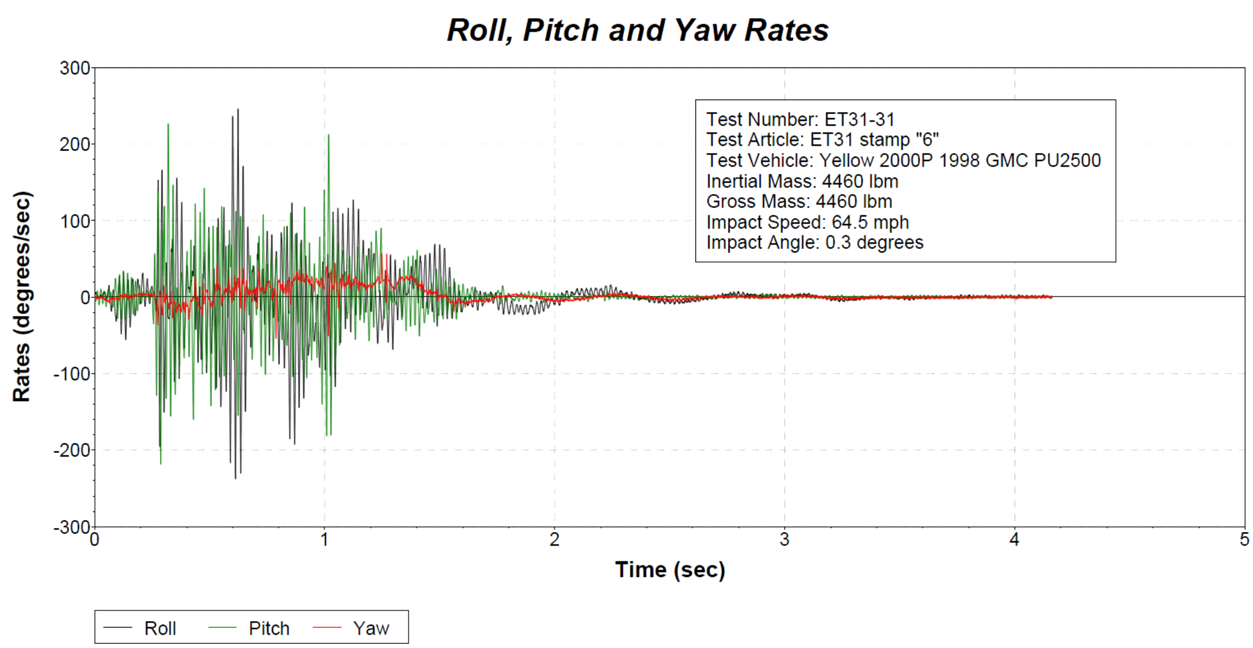
Appendix D: Test Data Plots


X Acceleration at CG
Longitudinal Acceleration (G)
10
5
0
-5
-10
-15
0
1
2
3
4
5
Time (sec)
Test Number: ET31-31
Test Article: ET31 stamp "6"
Test Vehicle: Yellow 2000P 1998 GMC PU2500
Inertial Mass: 4460 lbm
Gross Mass: 4460 lbm
Impact Speed: 64.5 mph
Impact Angle: 0.3 degrees
Time of OIV (0.452785 sec)
SAE Class 60 Filter


Y Acceleration at CG
Lateral Acceleration (G)
10
5
0
-5
-10
0
1
2
3
4
5
Time (sec)
Test Number: ET31-31
Test Article: ET31 stamp "6"
Test Vehicle: Yellow 2000P 1998 GMC PU2500
Inertial Mass: 4460 lbm
Gross Mass: 4460 lbm
Impact Speed: 64.5 mph
Impact Angle: 0.3 degrees
Time of OIV (0.452785 sec)
SAE Class 60 Filter


Z Acceleration at CG
Vertical Acceleration (G)
Time (sec)
Test Number: ET31-31
Test Article: ET31 stamp "6"
Test Vehicle: Yellow 2000P 1998 GMC PU2500
Inertial Mass: 4460 lbm
Gross Mass: 4460 lbm
Impact Speed: 64.5 mph
Impact Angle: 0.3 degrees
SAE Class 60 Filter


Roll, Pitch and Yaw Angles
Test Number: ET31-31
Test Article: ET31 stamp "6"
Test Vehicle: Yellow 2000P 1998 GMC PU2500
Inertial Mass: 4460 lbm
Gross Mass: 4460 lbm
Impact Speed: 64.5 mph
Impact Angle: 0.3 degrees
Angles (degrees)
Time (sec)
Roll
Pitch
Yaw


Roll, Pitch and Yaw Rates
Test Number: ET31-31
Test Article: ET31 stamp "6"
Test Vehicle: Yellow 2000P 1998 GMC PU2500
Inertial Mass: 4460 lbm
Gross Mass: 4460 lbm
Impact Speed: 64.5 mph
Impact Angle: 0.3 degrees
Rates (degrees/sec)
Time (sec)
Roll
Pitch
Yaw

Appendix E: Soil Test Data

LABORATORY COMPACTION CHARACTERISTICS OF SOIL REPORT

Report Number: 90141414.0001
Service Date: 12/03/14
Report Date: 12/10/14

Terracon
6911 Blanco Road
San Antonio, TX 78216-6164
210-641-2112 Reg No: F-3272

Client
Southwest Research Institute
Attn: Jenny Ferren
6220 Culebra Road
San Antonio, TX 78228

Project
Southwest Research Institute-Moisture Testing
6220 Culebra Rd
San Antonio, TX

Project Number 90141414

Material Information
Source of Material: Project Site
Proposed Use: Fill

Sample Information
Sample Date: 12/03/14
Sampled By: Benjamin Butler
Sample Location: Project Site

Sample Description: Crushed Limestone

Laboratory Test Data
Test Procedure: ASTM D698
Test Method: Method C
Sample Preparation: Wet
Rammer Type: Mechanical

	Result	Specifications
Liquid Limit:	22	
Plastic Limit:	13	
Plasticity Index:	9	
In-Place Moisture (%):		

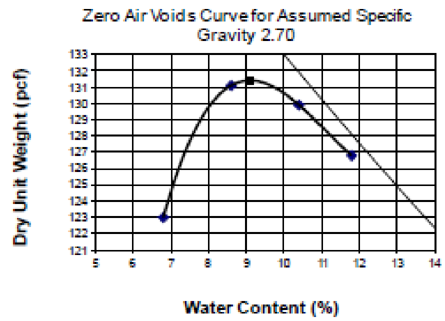
USCS:

Oversized Particles (%): 14.5
Moisture (%): 2.8
Sieve for Oversize Fraction: 3/4

Assumed Bulk Specific Gravity of Oversized Particles: 2.7

Corrected for Oversized Particles (ASTM D4718)
Maximum Dry Unit Weight (pcf): **131.4**
Optimum Water Content (%): **9.1**

Uncorrected Values
Maximum Dry Unit Weight (pcf): **126.6**
Optimum Water Content (%): **10.2**



Comments:

Services: Obtain a sample of treated subgrade at the project site and return it to the laboratory. Prepare and test the sample for moisture-density relationship and plasticity index.

Terracon Rep.: Benjamin Butler
Reported To:
Contractor:
Report Distribution:

(1) Southwest Research Institute, jenny.ferren@swri.org
(1) Terracon Consultants, Inc., dejacobs@terracon.com

Reviewed By: Daniel E. Jacobs

Daniel E. Jacobs
Senior Project Manager

Test Methods: ASTM

The tests were performed in general accordance with applicable ASTM, AASHTO, or DOT test methods. This report is exclusively for the use of the client indicated above and shall not be reproduced except in full without the written consent of our company. Test results transmitted herein are only applicable to the actual samples tested at the location(s) referenced and are not necessarily indicative of the properties of other apparently similar or identical materials.

CR0006, 10-16-13, Rev.7

Page 1 of 1

LABORATORY COMPACTION CHARACTERISTICS OF SOIL REPORT

Report Number: 90141414.0001
Service Date: 12/03/14
Report Date: 12/10/14

Terracon
6911 Blanco Road
San Antonio, TX 78216-6164
210-641-2112 Reg No: F-3272

Client
Southwest Research Institute
Attn: Jenny Ferren
6220 Culebra Road
San Antonio, TX 78228

Project
Southwest Research Institute-Moisture Testing
6220 Culebra Rd
San Antonio, TX

Project Number: 90141414

SIEVE ANALYSIS

Sieve Size	% Retained	TXDOT Item 247.2 Type A Grade 2 Specifications % Retained
1 ¾	0	0-10
7/8	11	---
3/8	35	---
#4	50	45-75
#40	75	60-85
#200	84	----

Remarks: The indicated laboratory tests were performed in general accordance with applicable ASTM standards unless otherwise noted. All test results meet the reference specification requirements unless noted by an asterisk *.

Services: Obtain a sample of treated subgrade at the project site and return it to the laboratory. Prepare and test the sample for moisture-density relationship and plasticity index.

Terracon Rep.: Benjamin Butler
Reported To:
Contractor:
Report Distribution:
(1) Southwest Research Institute, jenny.ferren@swri.org
(1) Terracon Consultants, Inc., dejacobs@terracon.com

Reviewed By: Daniel E. Jacobs
Daniel E. Jacobs
Senior Project Manager

The tests were performed in general accordance with applicable ASTM, AASHTO, or DOT test methods. This report is exclusively for the use of the client indicated above and shall not be reproduced except in full without the written consent of our company. Test results transmitted herein are only applicable to the actual samples tested at the location(s) referenced and are not necessarily indicative of the properties of other apparently similar or identical materials.

CT0001, 9-28-10, Rev.8

Page 1 of 1

FIELD DENSITY TEST REPORT

Report Number: 90141414.0012
Service Date: 01/16/15
Report Date: 01/19/15
Task:

Terracon
6911 Blanco Road
San Antonio, TX 78216-6164
210-641-2112 Reg No: F-3272

Client

Southwest Research Institute
Attn: Jenny Ferren
6220 Culebra Road
San Antonio, TX 78228

Project

Southwest Research Institute-Moisture Testing
6220 Culebra Rd
San Antonio, TX

Project Number: 90141414

Material Information

Mat. No.	Proctor Ref. No.	Classification and Description	Laboratory Test Method	Lab Test Data: Optimum Water Content (%)	Lab Test Data: Max. Lab Density (pcf)	Project Requirements: Water Content (%)	Project Requirements: Compaction (%)
1	90141414.0001	Crushed Limestone	ASTM D698	9.1	131.4	10% Max	N/A

Field Test Data

Test No.	Test Location	Lift / Elev.	Mat. No.	Probe Depth (in)	Wet Density (pcf)	Water Content (pcf)	Water Content (%)	Dry Density (pcf)	Percent Compaction (%)
	Guardrail Post Backfill								
1	Post #1	Final	1	6	130.0	10.7	9.0	119.3	90.8
2	Post #2	Final	1	6	138.1	11.4	9.0	126.7	96.4
3	Post #3	Final	1	6	131.7	8.2	6.6	123.5	94.0
4	Post #4	Final	1	6	140.9	9.6	7.3	131.3	99.9

Datum: **Serial No:** 37115 **Std. Cnt. M:** 718 **Std. Cnt. D:** 2175

Comments: Test and/or retest results on this report meet project requirements as noted above.

Services: Perform in-place density and moisture content tests to determine degree of compaction and material moisture condition.
Terracon Rep.: Lance Lamb
Reported To:
Contractor:
Report Distribution:
(1) Southwest Research Institute, jenny.ferren@swri.org
(1) Terracon Consultants, Inc., dejacobs@terracon.com

Reviewed By: Daniel E Jacobs
Daniel E. Jacobs
Senior Project Manager

Test Methods: *, ASTM D6938

The tests were performed in general accordance with applicable ASTM, AASHTO, or DOT test methods. This report is exclusively for the use of the client indicated above and shall not be reproduced except in full without the written consent of our company. Test results transmitted herein are only applicable to the actual samples tested at the location(s) referenced and are not necessarily indicative of the properties of other apparently similar or identical materials.

CR0007, 11-16-12, Rev.7

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NCHRP Report 350 Test Report

Full-Scale Crash Evaluation of the ET Plus® End Terminal with 4-inch Wide Guide Channel Installed with a Rail Height of 31 Inches

Test Level 3, Test 3-32
Test Identification: ET31-32

SwRI® Project No. 18.20887

SwRI Document Number: 18.20887.05.100.FR3
Issue 1

Prepared for:
Trinity Highway Products
2525 Stemmons Freeway
Dallas, TX 75207

February 17, 2015

Authored by:

Jenny Ferren, Manager
Mechanical Engineering Division

Reviewed and Approved by:

Timothy A. Fey, P.E., Director
Mechanical Engineering Division

Southwest Research Institute®
6220 Culebra Road • Post Office Drawer 28510
San Antonio, Texas 78228-0510

ACCREDITED
TESTING CERT.#1110.02

Below is a table documenting the various changes recorded in this report. Each issuance of the report is clearly marked with the revision number and date of issue.

Table 0.1: Revision Table

ISSUE	EXPLANATION	PAGE NUMBERS	DATE EFFECTIVE
1	Original report	All	February 17, 2015

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

1 INTRODUCTION

The purpose of Crash Test ET31-32 was to evaluate the performance of the Trinity Highway Products ET Plus End Terminal with 4-inch wide guide channel installed with a rail height of 31”. To test the performance of this terminal, Test 3-32 was conducted according to National Cooperative Highway Research Program (NCHRP), Report 350. The total system installation length for the test was nominally 49.5 m (162’-6”), including the 16.2 m (53’-1½”) ET Plus terminal length.

Test 3-32 is intended primarily to evaluate occupant risk and vehicle trajectory criteria. The test consists of an 820 kg (1808 lb) small passenger car approaching the traffic side of the installation at a 15° angle to the roadway, and impacting the end terminal at 100 km/hr (62.1 mph). The vehicle will impact at the vehicle’s centerline.

Crash Test ET31-32 was conducted on January 21, 2015, at the Crash Test Site at Southwest Research Institute (SwRI) by SwRI personnel. This report presents information on the test parameters, a discussion of the test, and an assessment of the test results based on the criteria set forth in NCHRP Report 350.

2 TEST PARAMETERS

Test Facility

The full-scale crash testing was performed by Southwest Research Institute (SwRI), on the campus located at the following address:

Southwest Research Institute
6220 Culebra Road
San Antonio, Texas 78238

SwRI is ISO/IEC 17025 accredited by A2LA (American Association for Laboratory Accreditation) to perform this testing under Testing Laboratory Certificate #1110.02.

Test Article – Design and Construction

The full-scale crash test was performed on the ET Plus End Terminal which included the ET Plus extruder head with 4-inch wide guide channel and W-Beam guardrail installed with a rail height of 78.7 cm (31 in.). The ET Plus End Terminal installation tested uses standard AASHTO M180 Type 2, 12-gauge W-Beam guardrail panels mounted with the top of the rail 78.7 cm (31 in.) above the ground, two wooden breakaway posts in foundation sleeves without soil plates at Posts 1 and 2, and CRT posts at Posts 3 through 8. The end terminal included 15.2 cm x 30.5 cm (6” x 12”) wood blockouts at Posts 3 through 8.

During installation, holes approximately 61 cm (2 ft) in diameter were drilled into the soil and then backfilled around the posts using “standard soil” as defined by NCHRP Report 350, Section 2.2.1.1. The base material was compacted in 15.2 cm (6 in) lifts, and was added until the surface was flush with the surrounding soil.

The guardrail line posts are 15.2 cm x 20.3 cm (6” x 8”) wood posts with 15.2 cm x 20.3 cm (6” x 8”) wood blockouts. The blockouts are toenailed, and the guardrail panels are mounted to the posts using 1.6 cm (5/8 in) diameter post bolts beginning with Post 2; the bolt for Post 2 is 25.4 cm (10 in) long, the bolts for Posts 3 through 8 are 55.9 cm (22 in) long, and all other post bolts are 45.7 cm (18 in) long. The post spacing is 1.9 m (6’-3”), and each splice joint used eight (8) 1.6 cm (5/8 in) diameter x 3.2 cm (1-¼ in) splice bolts and nuts; the splice bolts have a nominal total length of 4.1 cm (1-5/8 in) including the bolt head. The installation uses 1.9 cm (3/4 in) diameter x 25.4 cm (10 in) bolts through the soil tube, post, and strut at Post 1 and Post 2. An anchor cable is also installed at Post 1. The installation has a guardrail splice at Post 3. Subsequent guardrail splices are mid-span between Posts 5 and 6, and every 3.8 m (12’-6”) afterward to the end of the system.

The total system installation length for the test was nominally 49.5 m (162’-6”), including the 16.2 m (53’-1½”) ET Plus terminal length, 30.5 m (100 ft) of guardrail, and a 2.9 m (9’-4½”) long downstream anchor terminal. Detailed drawings of the test article provided by Trinity Highway Products are provided in Appendix A.

The ET Plus end terminal extruder head was one of eight production samples CalTrans (California DOT) pulled from their inventory for testing at SwRI. The heads were inspected by

CalTrans, FHWA, and Trinity Highway Products personnel at the CalTrans yard, and were stamped with identifiers "Kit #1" through "Kit #8". SwRI arranged for shipment of the heads to the test site in San Antonio, and the heads remained in controlled storage until they were installed for testing. The dimensions of the specific ET Plus end terminal extruder head used for Test ET31-32 are provided in Table 2.1 below; dimensions measured with a tape measure are listed in fractional inches, and dimensions measured with a digital caliper are listed as decimals. Copies of the datasheets reviewed by representatives from the FHWA, US DOT and various state Departments of Transportation (DOT) prior to testing are located in Appendix B.

The performance goal for the ET Plus is to achieve controlled vehicle deceleration in compliance with NCHRP Report 350 criteria for post-impact vehicle trajectory and occupant risk. Figure 2.1 through Figure 2.20 present photographs of the guardrail installation.

Table 2.1: Key ET Plus Head Dimensions

Extruder Head Stamp ID	8	
Exit Gap	3.27 cm	1.2855"
Entrance Gap	11.91 cm	4.6880"
Guide Chute Exit Height	38.26 cm	15-1/16"
Guide Chute Entrance Height	36.99 cm	14-9/16"
Channel Width (see Figure 2.2)	10.22 cm	4.0240"

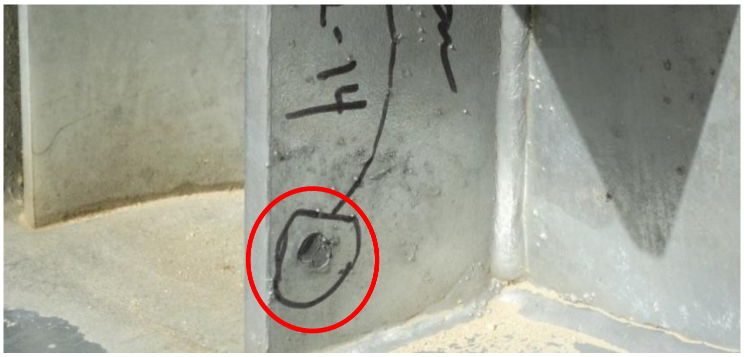


Figure 2.1: ET Plus Head Sample Identification Number

Figure 2.2: Measurement of Channel Width of Head

Figure 2.3: Test Installation for ET Plus Test ET31-32

Figure 2.4: ET Plus End Terminal

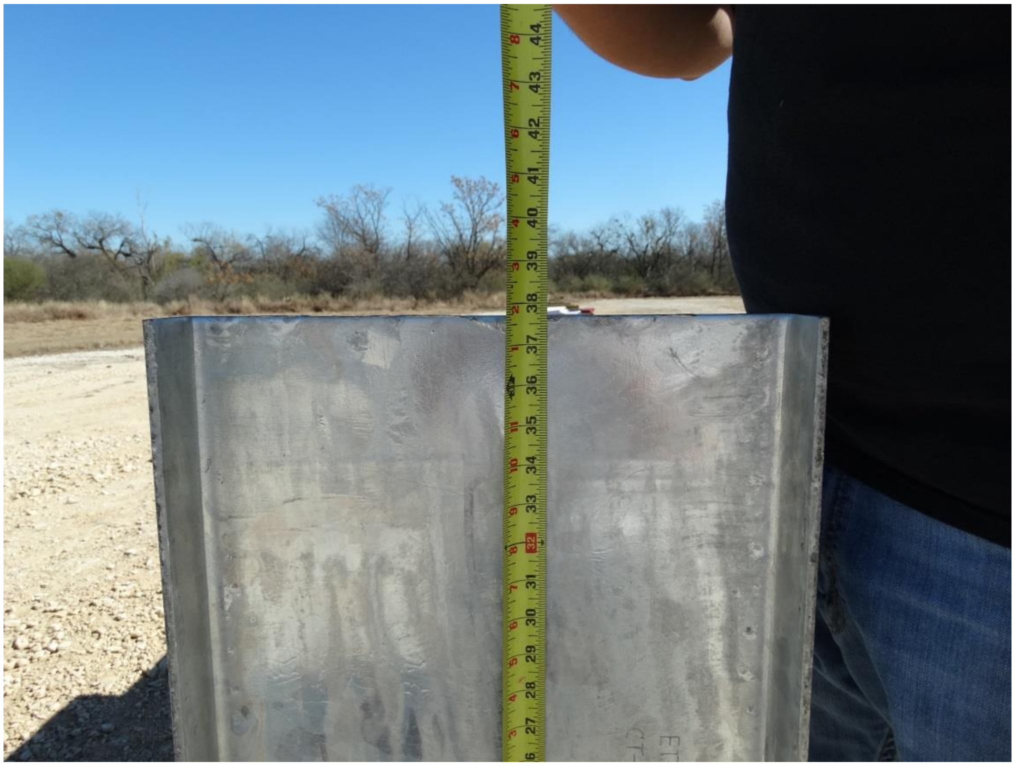


Figure 2.5: ET Plus Head Height Above Ground – Top

Figure 2.6: ET Plus Head Height Above Ground – Bottom

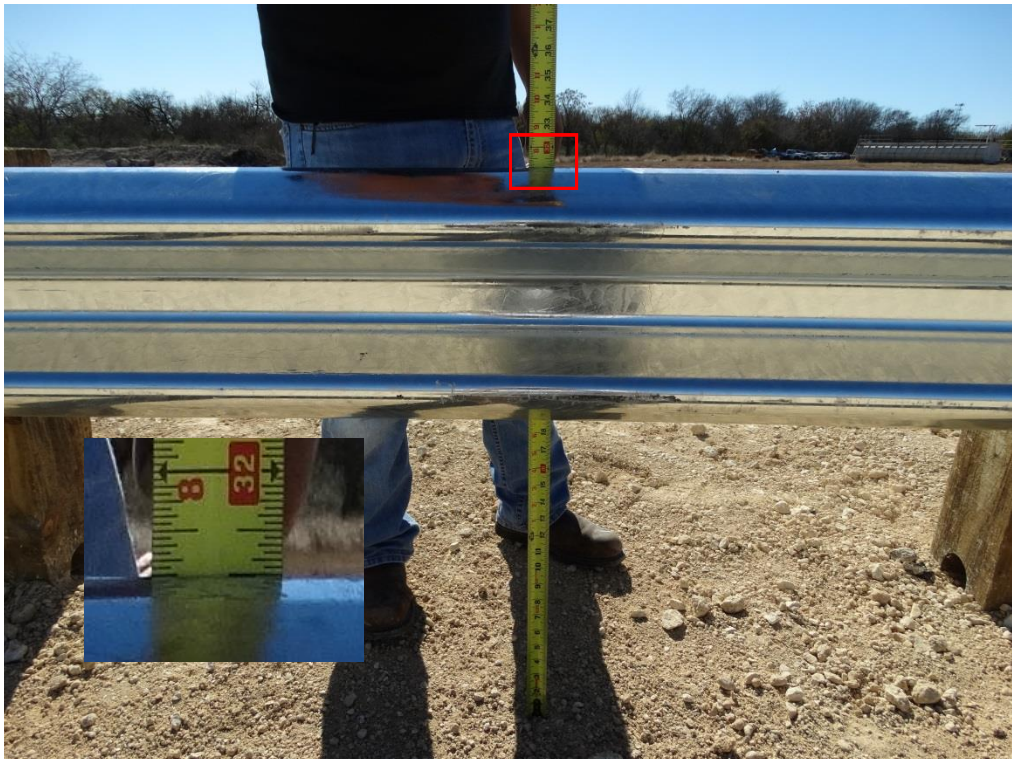


Figure 2.7: Measurement of Guardrail Installation Height

Figure 2.8: ET Plus Head and Anchor Cable Assembly

Figure 2.9: End Terminal Cable Anchor at Upstream End – Post 1

Figure 2.10: End Terminal Cable Anchor at Downstream End

Figure 2.11: First Guardrail Panel Splice Joint – Traffic Side (Splice Bolts Painted for Visibility in Video)

Figure 2.12: First Guardrail Panel Splice Joint – Non-Traffic Side (Nuts Painted for Visibility in Video)

Figure 2.13: Second Guardrail Panel Splice Joint Mid-Span between Posts 5 & 6 – Traffic Side (Splice Bolts Painted for Visibility in Video)

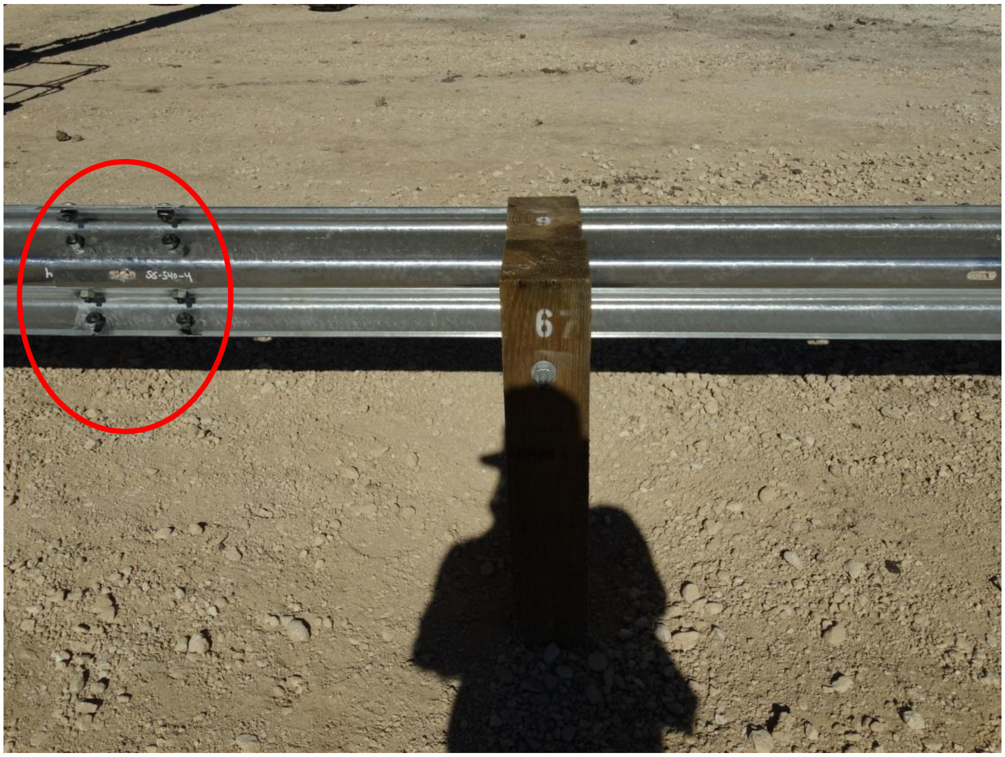


Figure 2.14: Second Guardrail Panel Splice Joint Mid-Span between Posts 5 & 6 – Non-Traffic Side (Nuts Painted for Visibility in Video)

Figure 2.15: ET Plus Head and Post 1 – Traffic Side

Figure 2.16: ET Plus Head and Post 1 – Non-Traffic Side

Figure 2.17: End Terminal Head with Posts 1 & 2 and Strut

Figure 2.18: ET Plus Head Looking Upstream at Post 1 (see Appendix B for Dimensions)

Figure 2.19: Downstream Anchor Terminal at Posts 26 and 27 – Traffic Side

Figure 2.20: Downstream Anchor Terminal at Posts 26 and 27 – Non-Traffic Side

Test Vehicle

The test vehicle was a 1996 Chevrolet/Geo Metro, shown in Figure 2.21; the vehicle data sheet is provided in Appendix B. Figure 2.22 shows the relationship between the height of the vehicle bumper and the end terminal. Figure 2.23 shows the test vehicle positioned at the impact point of the end terminal, and Figure 2.24 shows an overhead view of the test vehicle positioned at the intended crash angle of 15° and at the vehicle's centerline.

A 75 kg (165 lb) anthropometric dummy was utilized for this test, and was placed in the passenger seat with the seatbelt secured as shown in Figure 2.25 to contribute to the vehicle's post-impact instability as specified in NCHRP Report 350. No additional ballast mass was added to the vehicle.

The test inertial mass of the vehicle was 817.4 kg (1,802 lbs) as reflected in Table 4.2. Note that the test inertial mass does not include the weight of the anthropometric dummy.

Figure 2.21: Test Vehicle for Test ET31-32

Figure 2.22: Test Vehicle Bumper Height

Figure 2.23: Test Vehicle Impact Trajectory

Figure 2.24: Test Vehicle Impact Trajectory – Overhead View

Figure 2.25: Test Dummy Positioned in Passenger Seat

Test Vehicle Guidance

The test vehicle was towed into the end terminal using a tow vehicle and a series of pulleys and sheaves. A steel cable was attached to a quick-release pin under the front of the vehicle and was passed around a sheave and secured to the rear of a tow vehicle. The tow vehicle was equipped with an adjustable ignition restrictor that attenuated the tow vehicle's engine RPM when a pre-set speed was attained. The test vehicle was guided by means of a taught steel cable attached to a sliding shoe which was attached to the front spindle of the test vehicle shown in Figure 2.26. Just prior to impact, the sliding shoe and tow cable were stripped from the vehicle allowing the test vehicle to free wheel into the end terminal.

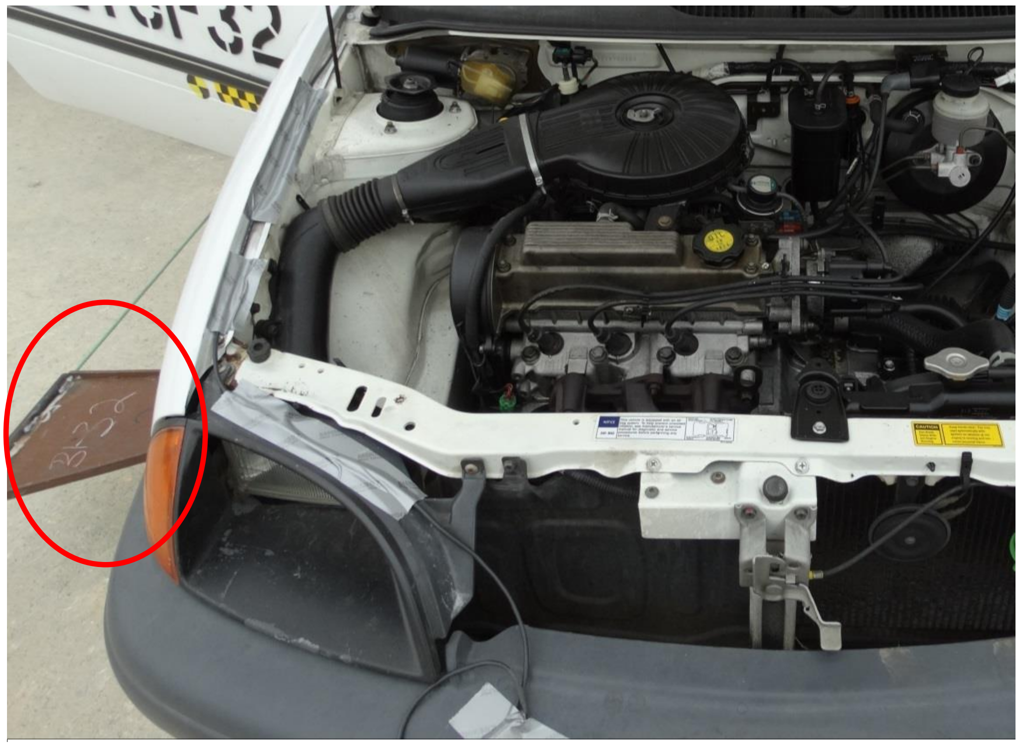


Figure 2.26: Test Vehicle Steering Guidance Assembly

Test Vehicle Data Acquisition

The data acquisition consisted of recording the acceleration and angular velocities of the test vehicle. The measurement of these two parameters allows SwRI engineers to perform an occupant risk evaluation. The device used to record the vehicle acceleration and angular velocities was a six (6) degree-of-freedom Instrumented Sensor Technology Electronic Data Recorder, henceforth referred to as the EDR-4.

The EDR-4 recorder unit is a compact package used for stand-alone recording of shock and vibration, and is able to record six channels of data. The three acceleration channels were recorded from a built-in triaxial accelerometer used to record the test vehicle's accelerations in three orthogonal directions (x, y, and z). The three angular velocity channels were recorded from built-in rate gyro transducers used to record the test vehicle's angular velocities in three orthogonal directions (roll, pitch, and yaw).

The data acquisition package was rigidly attached to the test vehicle. A metal bracket was welded onto the test vehicle's body. This bracket was attached inside the passenger compartment of the vehicle, as close as possible to the vehicle's center of gravity without significantly modifying the vehicle's interior components (i.e., center console, bench seats). The data acquisition package was then bolted to the metal bracket as shown in Figure 2.27. Because of the configuration of the EDR-4 as manufactured, the orientation of the data acquisition package within the vehicle matches the general axis designation given in Figure 4.6 of NCHRP Report 350, but the signs for the Y and Z axes had to be reversed during post-test processing to comply with the NCHRP and TRAP sign convention.

Figure 2.27: EDR Mounted in Test Vehicle for Test ET31-32

The sign convention used for data processing is as follows:

Table 2.2: Sign Convention for Vehicle Motion

X:	Positive in the normal forward motion direction
Y:	Positive toward the right
Z:	Positive vertically downward
ROLL:	Positive using right hand rule about +X direction
PITCH:	Positive using right hand rule about +Y direction
YAW:	Positive using right hand rule about +Z direction

The EDR-4 data recorder unit was configured with a sample rate of 2944 samples per second (per channel), and with a low pass filter setting of 300 Hz. After the data had been downloaded from the data acquisition package, the data was processed using Test Risk Assessment Program

(TRAP) Version 2.3.11, (Texas A&M Transportation Institute and Capsher Technology, Inc.). The TRAP program was designed to determine the effectiveness of a roadside safety feature by analyzing data from a vehicle crash test of the feature and calculating standardized occupant risk factors. TRAP calculates occupant risk factors in accordance with the NCHRP Report 350 guidelines.

Test Vehicle Onboard Cameras

Two digital cameras were mounted to a rail such that one camera was behind the driver's seat, and one camera was behind the passenger's seat but aimed at the driver location. A photograph of the camera locations is provided in Figure 2.28.

Figure 2.28: Onboard Cameras

Soil Conditions

The soil complied with the NCHRP Report 350 "Standard Soil" as described in the *Test Article – Design and Construction* section of this report. The day of testing, soil moisture content was measured by a certified environmental engineering firm. The maximum moisture content measured was 10.7% at a location near Post 3; while this moisture level exceeds the recommended ideal conditions, there were two additional readings taken near Posts 1 and 2 that were below 9%, and the decision was made to proceed. There was no rainfall between when the moisture reading was taken and when the testing was conducted. Detailed results of the soil testing and moisture content evaluation are provided in Appendix E.

Calibrated Test Equipment

Test equipment used to perform the tests and acquire data during this testing program is listed in the table below.

Table 2.3: Equipment Used During Testing

Description	Manufacturer	Model	Asset No.	Due Date[1]
Data Recorder	IST	EDR-4-6DOF-200	S/N 40048	2/5/15
Wheel Scales	Longacre	72634	015238	11/5/15
Measuring Tape	Stanley	33-725	015324	11/7/15
Caliper	Starrett	721	020504	3/18/15
Speed Trap DAQ	NI	USB-6008	S/N 14D4376	8/27/15

[1]Unless otherwise specified, all equipment is calibrated or verified on an annual basis.

Test Observers

Representatives from the following organizations were among those present at the SwRI Crash Test Site and observed Test ET31-32 on January 21, 2015:

- Federal Highway Administration (FHWA)
- Virginia DOT
- Georgia DOT (AASHTO Representative)
- Arizona DOT
- Texas DOT

Observers from FHWA and AASHTO were permitted to visually inspect and measure the ET Plus installation before and after the test. All other observers were allowed to visually inspect the ET Plus installation before and after the test. All observers were allowed to visually inspect the vehicle following the test.

3 TEST CONDITIONS AND RESULTS

Test Description

The purpose of Test ET31-32 was to evaluate the performance of Trinity Highway Products ET Plus End Terminal with 4-inch wide guide channel installed with a rail height of 31". To test the performance of this terminal, Test 3-32 was conducted according to NCHRP Report 350. The test installation length for the test was 49.5 m (162'-6"), and the terminal length was 16.2 m (53'-1½").

Test 3-32 is intended primarily to evaluate occupant risk and vehicle trajectory criteria. The test consists of an 820 kg (1808 lb) small passenger car approaching the traffic side of the installation at a 15° angle to the roadway, and impacting the end terminal at 100 km/hr (62.1 mph). The vehicle will impact at the vehicle's centerline. The test configuration is shown in Figure 3.1, which is from Figure 3.2 of NCHRP Report 350.

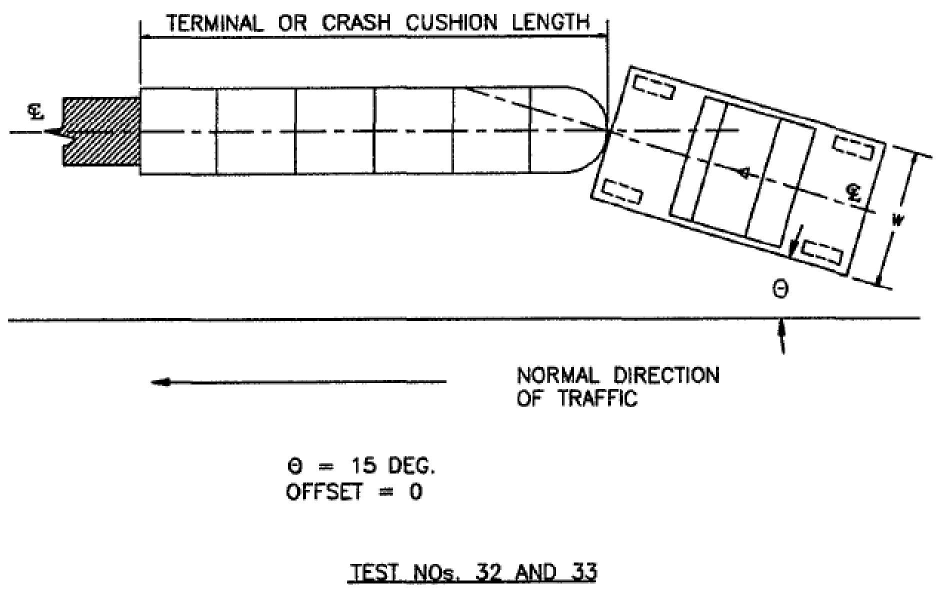


Figure 3.1: Impact Configuration *[from Figure 3.2 of NCHRP Report 350]*

The weather on the day of the test was mostly cloudy with some light drizzle, with temperatures ranging from 10.6-15.6°C (51-60°F). The temperature at the time of the test was approximately 12.8°C (55°F). The soil was considered dry as discussed in the *Soil Conditions* section of this report.

Impact Description/Vehicle Behavior

Figure 3.2 is an overhead photograph showing the post-test condition and location of the test article and test vehicle. Figure 3.3 through Figure 3.5 show that the test vehicle impacted the end terminal at a nominal 15° angle. The impact velocity of the test as measured by SwRI's speed trap system and verified by high-speed film analysis was determined to be 98.5 km/hr (61.2 mph). As a result of the test, the ET Plus extruder head moved 9.0 m (29.4 ft) longitudinally (downstream) and 2.1 m (6.9 ft) laterally as measured from its as-installed position. The total system deformation (i.e. longitudinal distance to closest point) measured after the impact was 6.24 m (20.5 ft) from the initial point of contact.

After the initial impact event, the ET Plus extruder head stroked along the guardrail, extruding approximately 2.9 m (9.5 ft) of guardrail. Before the guide channel entrance end of the head reached Post 2 the head began to rotate, following the angled path of the vehicle; this rotation caused a fold to form in the W beam at Post 3. As the vehicle continued its angled trajectory, the channel guide portion of the ET Plus extruder head was pushed further on the W beam up to Post 3; the extruder head had rotated approximately 65° when the channel guide entrance reached Post 3. As the vehicle continued forward the head continued to rotate, allowing the vehicle to pass (or gate) through to the non-traffic side of the system. The ET Plus extruder head ended up roughly parallel to the guardrail and facing in the downstream direction.

As the vehicle passed by the gated extruder head, the corner of the fold in the W beam at the guide channel entrance scraped the driver’s side door creating two small tears totaling approximately 5” long in the door surface. The tear affected the sheet metal but there was no damage caused to the interior door panel, and no intrusion or potential for intrusion of the test article into the occupant compartment based on the position of the extruder head relative to the vehicle trajectory.

The ET Plus extruder head directly contacted and sheared-off Posts 1 and 2. As the guardrail gated at Post 3, the motion sheared Posts 3 and 4 at ground-level. The splice at Post 3 remained intact but disconnected from the post. The W beam pulled away from Post 5 and impacted the blockout at the end of the gating process causing superficial damage to the blockout; a small gap at the soil interface at ground-level indicated slight movement of Post 5 towards the non-traffic side. All posts and blockouts downstream of Post 5 appeared undamaged, and no appreciable movement of the downstream anchor terminal was observed. Additionally, the anchor cable at Post 1 broke free of the installation and came to rest in the path of the vehicle and even with Post 7 after being pushed downstream during the impact. There was no penetration of the vehicle by the test article, and there was no deformation of the occupant compartment resulting from the test. The only debris thrown from the installation as a result of the impact included parts of the vehicle and pieces of posts and blockouts from the first four posts; the majority of the debris fell to the non-traffic side of the guardrail. There was no significant deformation of the 4” guide channels as a result of the impact, and they remained attached to the impact head.

As the vehicle continued to travel behind the guardrail, it began a counter-clockwise spin due to the gating motion and the asymmetrical mass due to the dummy positioned in the passenger seat. The vehicle came to rest past Post 17 facing towards the upstream direction of the guardrail and at an angle of approximately 55 degrees to the guardrail installation. After the vehicle came to rest, the perpendicular distance between the guardrail and the closest part of the vehicle (front right corner) was approximately 15 feet. The vehicle was not operable after the test.

The test vehicle experienced a maximum 50 millisecond moving average acceleration of -11.2g in the longitudinal direction, 3.5g in the lateral direction, and -4.2g in the vertical direction. The impact velocities and ridedown accelerations were below the preferred limits and well below the maximum limits listed in NCHRP Report 350.

- Occupant impact velocities were 7.9 m/s in the longitudinal direction, and -1.3 m/s in the lateral direction.
- Occupant ridedown accelerations were -6.4g in the longitudinal direction, and 6.3g in the lateral direction.

The following sections provide photographs of the post-impact condition of the test article as well as the vehicle. Table 4.2 presents a summary of the onboard data, and plots of the accelerometer and angular velocity transducers are provided in Appendix D.

Figure 3.2: Post-Impact Location of the Test Article and Vehicle

Impact Severity

NCHRP Report 350 states that the recommended impact severity for Test Level 3, Test 3-32 is 316.4 kJ, with a suggested tolerance of -24.8/+25.8 kJ. The actual impact severity of test ET31-32 was 305.9 kJ, a deviation of -10.5 kJ from the nominal impact severity recommended in NCHRP Report 350. *Note that for Test 3-32, Sin θ is set to 1 in accordance with Section 3.3.1 of Report 350.*

Impact Severity $= \frac{1}{2} \cdot M \cdot (V \cdot \sin\theta)^2$

$= \frac{1}{2} \cdot M \cdot V^2$

$= 0.5 \cdot (817.4 \text{ kg}) \cdot (27.36 \text{ m/s})^2$

$= 305.9 \text{ kJ}$

The equivalent impact speed of an 820 kg vehicle impacting the end terminal at 15 degrees would be 98.4 km/hr (61.1 mph).

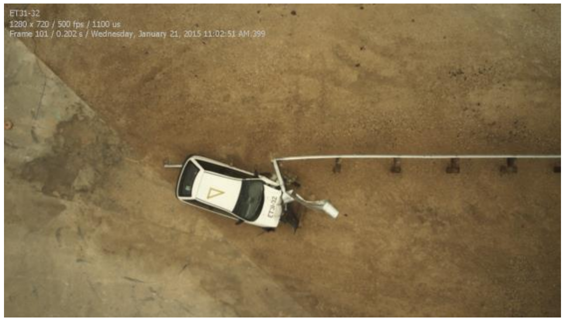

Time = 0.000 seconds (Impact)


Time = 0.050 seconds


Time = 0.100 seconds


Time = 0.150 seconds


Time = 0.200 seconds


Time = 0.250 seconds


Time = 0.300 seconds


Time = 0.350 seconds


Time = 0.400 seconds

Figure 3.3: Sequential Photographs, as Viewed from Overhead


Time = 0.000 seconds (Impact)


Time = 0.050 seconds


Time = 0.100 seconds


Time = 0.150 seconds


Time = 0.200 seconds


Time = 0.250 seconds


Time = 0.300 seconds


Time = 0.350 seconds


Time = 0.400 seconds

Figure 3.4: Sequential Photographs, as Viewed from Downstream


Time = 0.000 seconds (Impact)


Time = 0.050 seconds


Time = 0.100 seconds


Time = 0.150 seconds


Time = 0.200 seconds


Time = 0.250 seconds


Time = 0.300 seconds


Time = 0.350 seconds


Time = 0.400 seconds

Figure 3.5: Sequential Photographs, as Viewed from Non-Traffic Side of the End Terminal

End Terminal Damage

Figure 3.6: Post-Impact Condition of the Test Article and Vehicle

Figure 3.7: Post-Impact Condition of Posts 1 through 6

Figure 3.8: Post Test – Right Vehicle Track Shown in Green

Figure 3.9: Post Test – Foundation Sleeve at Post 1

Figure 3.10: Post Test – Foundation Sleeve at Post 2

Figure 3.11: Post Test – Post 3

Figure 3.12: Post Test – Post 4

Figure 3.13: Post Test – Post 5, Side View

Figure 3.14: Post Test – Post 5 Movement

Figure 3.15: Post Test – Post 5, Traffic Side View

Figure 3.16: Post Test – Splice between Posts 5 & 6 (Splice Bolts Painted Black for Visbility)

Figure 3.17: Post Test – Post 6, Side View

Figure 3.18: Post Test – Gated Guardrail, View from Traffic Side

Figure 3.19: Post Test – Gated Guardrail

Figure 3.20: Post Test – Gated Guardrail

Figure 3.21: Post Test – Extruded Guardrail

Figure 3.22: Post Test – Extruded Guardrail

Figure 3.23: Post Test – Extruded Guardrail

Figure 3.24: Post Test - Extruder Head Impact Plate

Figure 3.25: Post Test – Traffic Side of Extruder Head

Figure 3.26: Post Test – Traffic Side of Guide Channels

Figure 3.27: Post Test – Traffic Side of Guide Channel Entrance

Figure 3.28: Post Test – Non-Traffic Side of Guide Channel Entrance

Figure 3.29: Post Test – Non-Traffic Side of Guide Channels

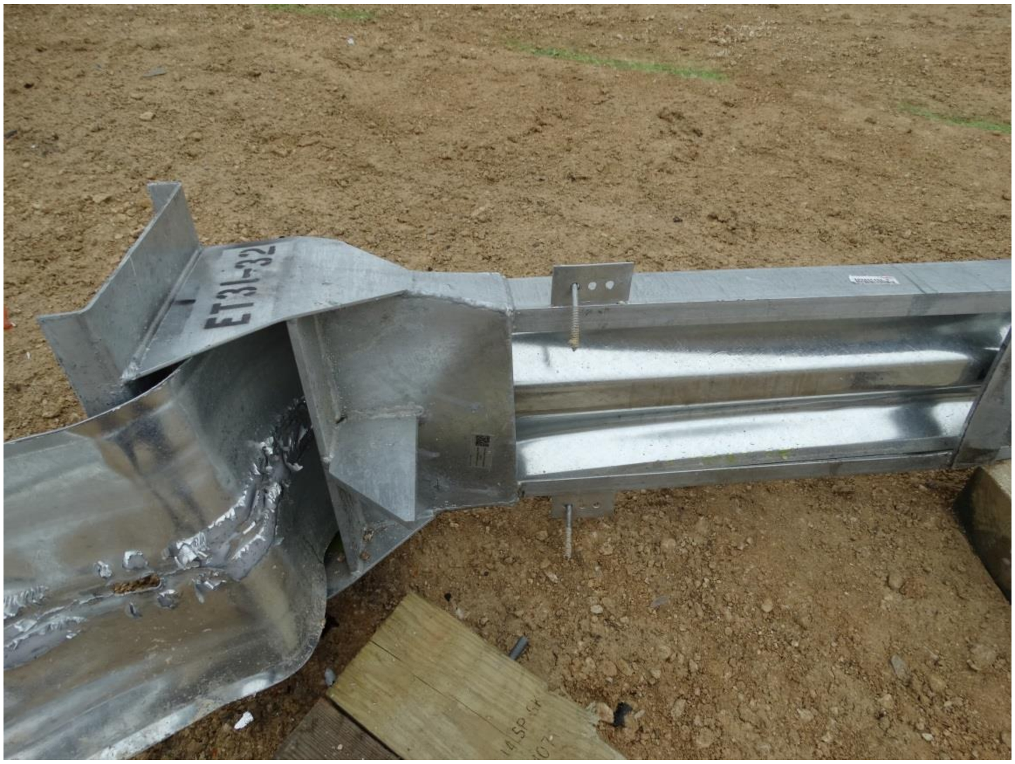


Figure 3.30: Post Test – Non-Traffic Side of Extruder Head

Figure 3.31: Post Test – Gated Guardrail Viewed from Downstream

Figure 3.32: Post Test – Debris Field on Non-Traffic Side (Anchor Cable Indicated)

Figure 3.33: Post Test Location of Debris and Anchor Cable

Figure 3.34: Post Test – Debris on Traffic Side

Figure 3.35: Post Test – Final Vehicle Location past Post 17

Figure 3.36: Post Test Verification of Extruder Head 8

Vehicle Damage

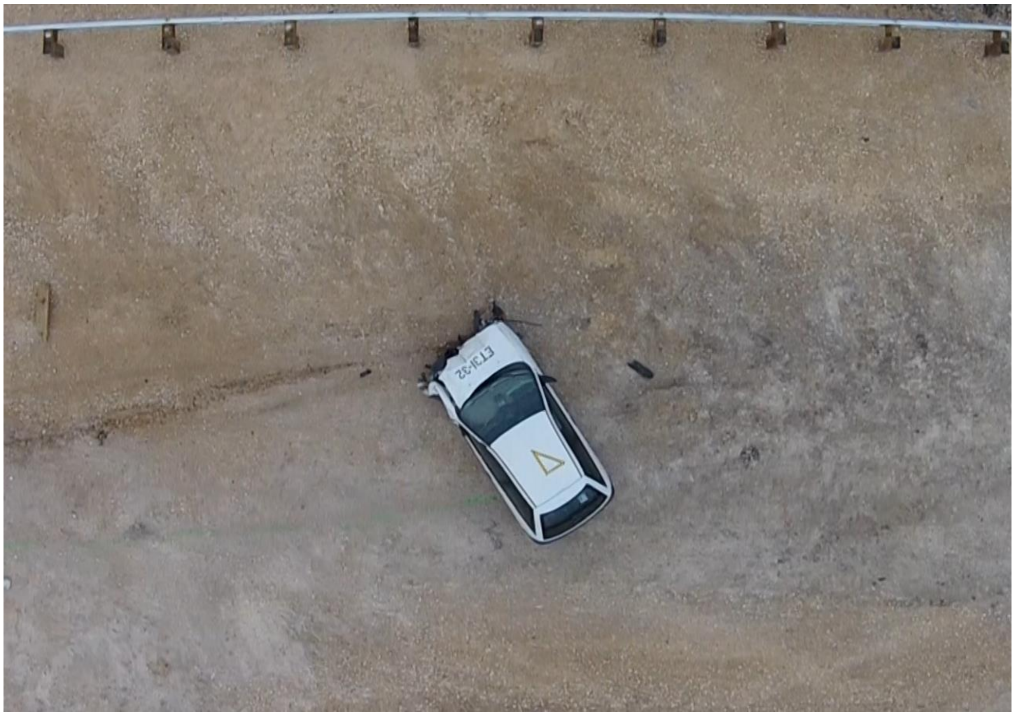


Figure 3.37: Vehicle Post-Test Location Past Post 17 (Wide Angle View)

Figure 3.38: Test Vehicle Path of Right Front Tire

Figure 3.39: Post Test Vehicle – Front View

Figure 3.40: Post Test Vehicle – Front View Close-up

Figure 3.41: Post Test Vehicle – Left Side

Figure 3.42: Post Test Vehicle – Right Side

Figure 3.43: Post Test Vehicle – Tear in Door Skin (see Figure 3.3)

Figure 3.44: Post Test Vehicle – Door Panel Intact behind Exterior Tear

Figure 3.45: Post-Test – Occupant Compartment

Figure 3.46: Post-Test – Driver Side Floorboard

Figure 3.47: Post-Test – Passenger Side Floorboard

4 ASSESSMENT OF TEST RESULTS

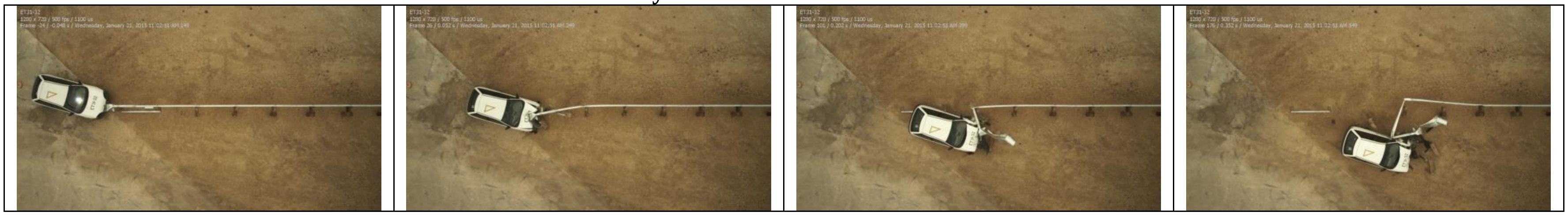
A comparison of the test results of Test ET31-32 against the evaluation criteria set forth in NCHRP Report 350 for Test 3-32 is provided in Table 4.1. A summary of the test results is provided in Table 4.2.

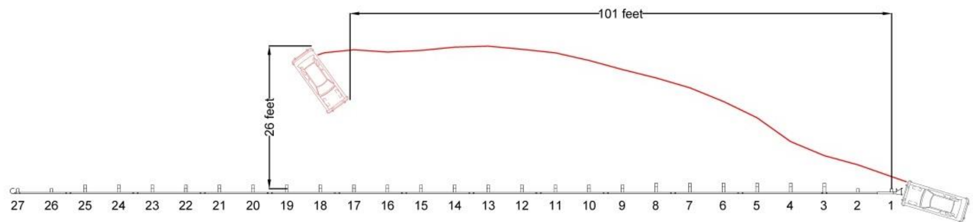
Table 4.1: Summary of Test Evaluation Results (NCHRP Report 350 Evaluation Criteria) for Test ET31-32

Evaluation Factor	Evaluation Criteria	Crash Test Result	Result
Structural Adequacy	C. Acceptable test article performance may be by redirection, controlled penetration, or controlled stopping of the vehicle.	Vehicle was decelerated in a controlled manner and gated through the system in a controlled fashion.	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.	No penetration or potential penetration of the occupant compartment or undue hazard presented by test article debris. See photos for post-test location of debris.	Pass
	F. The vehicle should remain upright during and after collision although moderate roll, pitching and yawing are acceptable.	Vehicle remained stable and upright during and after the collision.	Pass
	H. Occupant Impact Velocities (OIV) limits: Preferred = 9 m/s Maximum = 12 m/s	Occupant impact velocities: Longitudinal: 7.9 m/s Lateral: -1.3 m/s	Pass
	I. Occupant Ridedown Acceleration (ORA) limits: Preferred = 15 g Maximum = 20 g	Occupant Ridedown Accelerations: Longitudinal: -6.4 g Lateral: 6.3 g	Pass
Vehicle Trajectory	K. After collision it is preferable that the vehicle's trajectory not intrude into adjacent traffic lanes.	See photos; vehicle path post-impact was on non-traffic side of the guardrail.	See Note[1]
	N. Vehicle trajectory behind the test article is acceptable.	See photos; vehicle path post-impact was on non-traffic side of the guardrail.	Pass

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

Table 4.2: Summary of Test Results and Conditions for Test ET31-32





General Information		**Impact Conditions**		**Extruder Head Position from Start**	
Test Agency	Southwest Research Institute	Speed (km/hr)	98.5	Longitudinal	9.0 m (29.4 ft)
Test Number	ET31-32	Angle (degrees)	15.2	Lateral	2.1 m (6.9 ft)
Test Date	January 21, 2015	**Exit Conditions**		**Total System Deformation (Closest Point)**	
Test Category	3-32	Speed (km/hr)	54.3	Longitudinal	6.2 m (20.5 ft)
Test Article		Angle (degrees)	17.0	**Post Impact Vehicular Behavior**	
Type	End Terminal			Max Vehicle Rotation (degrees)	
Terminal Length	16.2 m (53’-1½”)	**Occupant Risk Values**		Max. Roll	7.1 @ 0.6444 sec.
Installation Length	49.5 m (162’-6”)	Impact Velocity (m/s)		Max. Pitch	6.3 @ 3.9684 sec.
Nom. Barrier Height	78.7 cm (31 in.)	x-direction	7.9	Max. Yaw	-138.3 @ 3.9375 sec.
Type of Primary Barrier	W-beam guardrail	y-direction	-1.3	Max 50ms Moving Average Accelerations (g)	
Soil	Stable, Dry - “Standard” Soil	Ridedown Accelerations (g)		x-direction	-11.2 @ 0.2362-0.2862 sec.
Test Vehicle		x-direction	-6.4	y-direction	3.5 @ 0.3748-0.4248 sec.
Type	Small car	y-direction	6.3	z-direction	-4.2 @ 0.2566-0.3066 sec.
Designation	820C	**Target Conditions**			
Model	1996 Chev./Geo Metro	Nominal Speed	100 km/hr (62.1 mph)		
Curb Mass (kg)	817.4 as received	Nominal Angle	15°		
Ballast Mass (kg)	0	**Tolerances**			
Test Inertial Mass (kg)	817.4	Nominal Speed	±4 km/hr		
Dummy Mass (kg)	75	Nominal Angle	±1.5˚		
Gross Static Mass (kg)	1967				

5 CONCLUSIONS

The performance of the ET Plus during Test ET31-32 against Structural Adequacy, Occupant Risk, and Vehicle Trajectory criteria specified in NCHRP Report 350 was as-follows:

Structural Adequacy

- The vehicle was decelerated in a controlled manner and gated through the system in a controlled fashion.

Occupant Risk

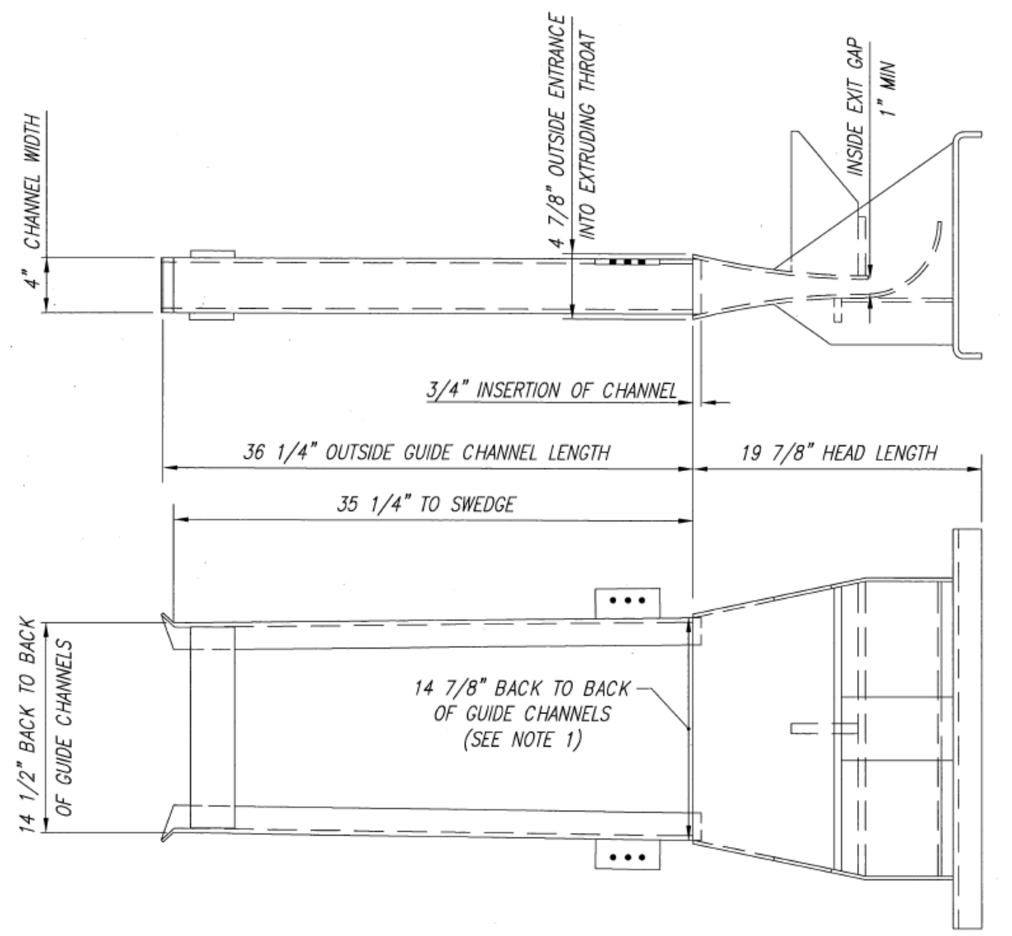
- There was no penetration of the vehicle by the test article, and no deformation of the occupant compartment resulting from the test.
- There was no undue hazard presented by test article debris outside of the immediate impact zone; the only debris thrown from the installation included pieces of posts and blockouts, the majority of which fell to the non-traffic side of the guardrail.
- The vehicle remained upright during and following the impact.
- The test article provided for controlled deceleration with impact velocity and ridedown acceleration values within allowable limits.

Vehicle Trajectory

- The vehicle was decelerated in a controlled manner, gated through the system in a controlled fashion, and came to a stop on the non-traffic side of the installation.

Based on the information provided in this report, the ET Plus End Terminal with 4-inch wide guide channel installed with a rail height of 31” as tested meets the Test Level 3, Test 3-32 criteria for NCHRP Report 350.

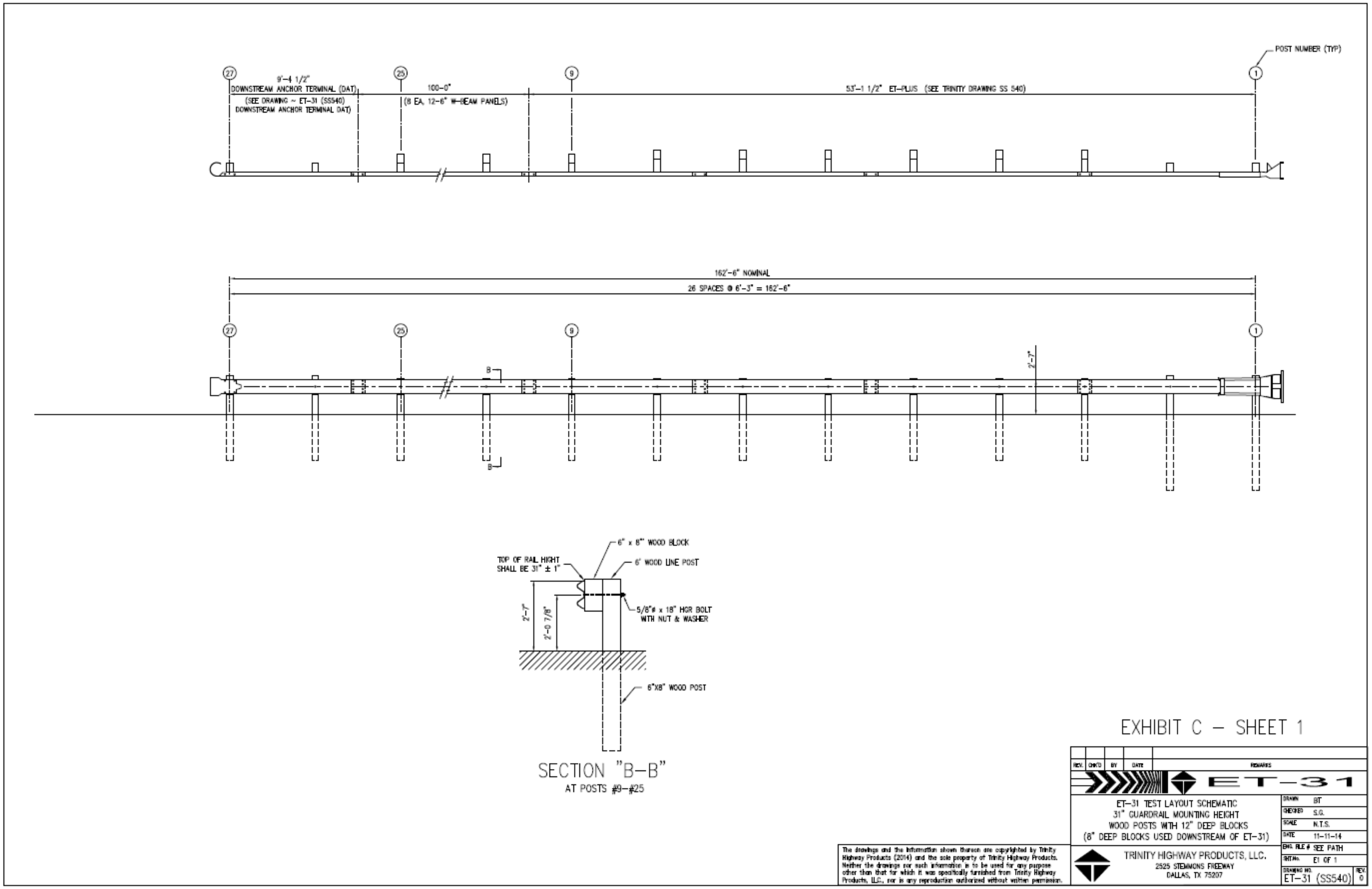
Appendix A: Test Article Drawings

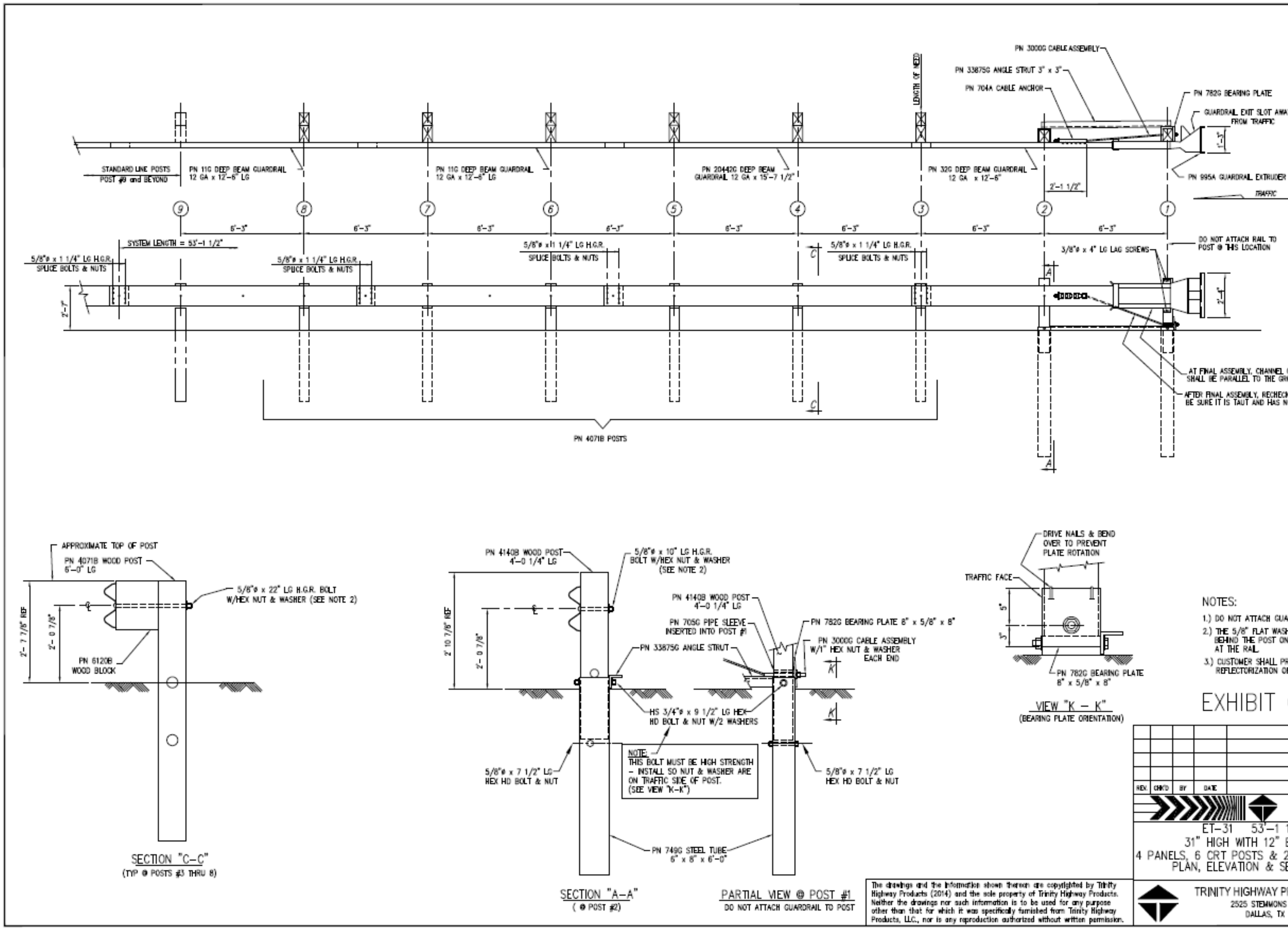


ET PLUS EXTRUDER HEAD (PN 995 REV 13)

NOTE 1: 14 7/8" DIMENSION BACK TO BACK OF GUIDE CHANNELS IS MEASURED AT SUB–ASSEMBLY BEFORE WELDING TO CHUTE. ACTUAL CHUTE VERTICAL OPENING DIMENSION IS 15".

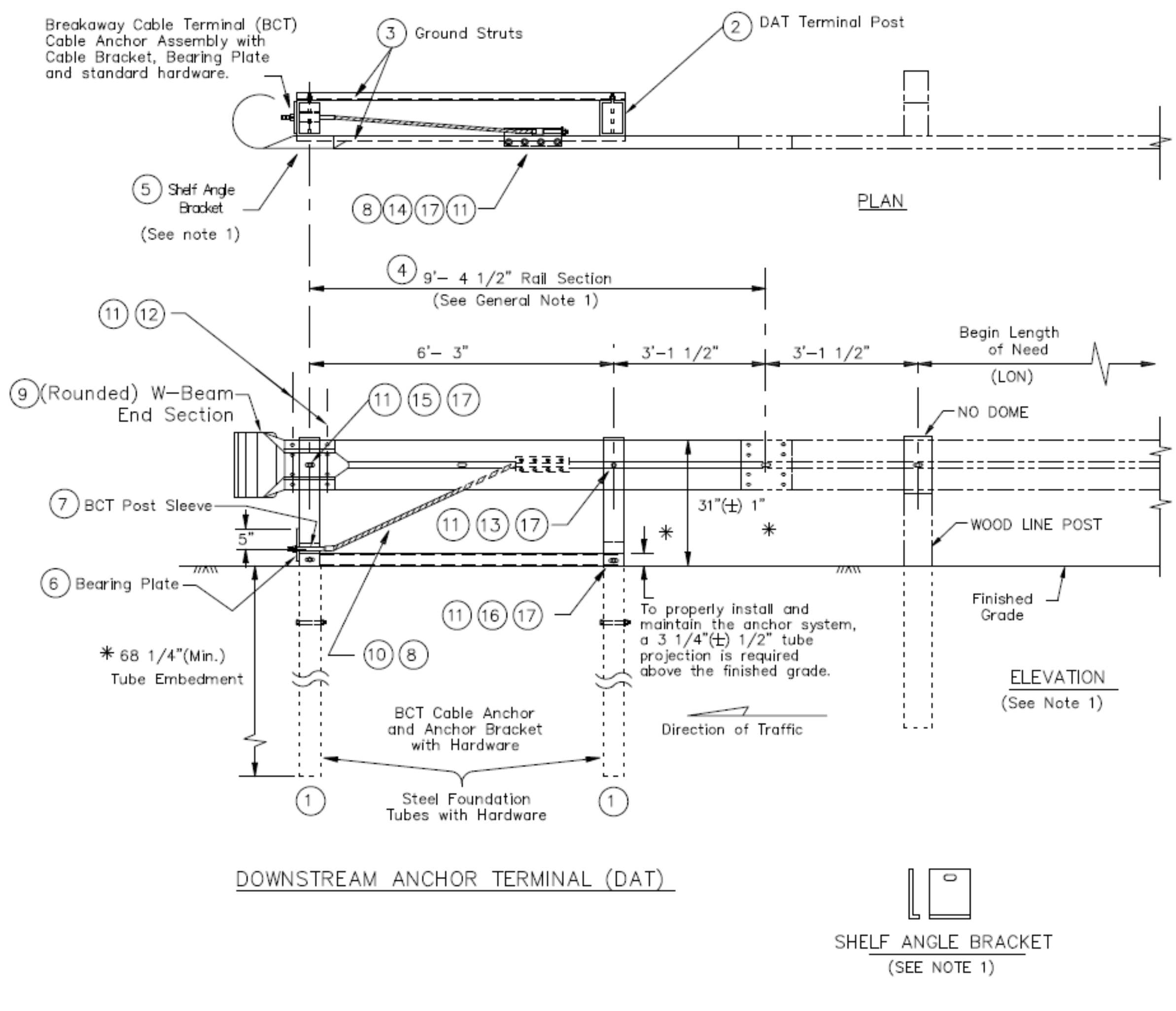
TRINITY HIGHWAY PRODUCTS, LLC.
2525 STEMMONS FREEWAY
DALLAS, TX 75207


POST NUMBER (TYP)
9'-4 1/2"
DOWNSTREAM ANCHOR TERMINAL (DAT)
(SEE DRAWING ~ ET-31 (SS540)
DOWNSTREAM ANCHOR TERMINAL DAT)
100'-0"
(8 EA. 12-6" W-BEAM PANELS)
53'-1 1/2" ET-PLUS (SEE TRINITY DRAWING SS 540)
162'-6" NOMINAL
26 SPACES @ 6'-3" = 162'-6"
6" x 8" WOOD BLOCK
TOP OF RAIL HIGHT SHALL BE 31" ± 1"
6' WOOD LINE POST
5/8"ø x 18" HGR BOLT WITH NUT & WASHER
6"X8" WOOD POST
SECTION "B-B"
AT POSTS #9-#25
EXHIBIT C – SHEET 1
REV. CHK'D BY DATE REMARKS
ET-31
ET-31 TEST LAYOUT SCHEMATIC
31" GUARDRAIL MOUNTING HEIGHT
WOOD POSTS WITH 12" DEEP BLOCKS
(8" DEEP BLOCKS USED DOWNSTREAM OF ET-31)
DRAWN BT
CHECKED S.G.
SCALE N.T.S.
DATE 11-11-14
ENG. FILE # SEE PATH
SHT.No. E1 OF 1
DRAWING NO. ET-31 (SS540)
REV. 0
TRINITY HIGHWAY PRODUCTS, LLC.
2525 STEMMONS FREEWAY
DALLAS, TX 75207
The drawings and the information shown thereon are copyrighted by Trinity Highway Products (2014) and the sole property of Trinity Highway Products. Neither the drawings nor such information is to be used for any purpose other than that for which it was specifically furnished from Trinity Highway Products, LLC., nor is any reproduction authorized without written permission.



BILL OF MATERIAL

PN	QTY	DESCRIPTION
11G	2	12/12'6/3'-1 1/2"/S
32G	1	12/12'6/6'3/S ANC (GUARDRAIL)
704A	1	CABLE ANCHOR BRACKET
705G	1	2" x 5 1/2" PIPE
749G	2	6'0 TUBE SLEEVE
782G	1	5/8" x 8" x 8" BEARING PLATE
995A	1	ET-PLUS EXTRUDER
3000G	1	CABLE 3/4 x 6'6
3300G	7	5/8" WASHER
3340G	41	5/8" HEX NUT
3360G	32	5/8"ø x 1 1/4" SPLICE BOLT
3478G	2	5/8"ø x 7 1/2" HEX HD BOLT
3500G	1	5/8"ø x 10" POST BOLT
3620G	6	5/8"ø x 22" POST BOLT
3700G	4	3/4" WASHER
3704G	2	3/4" HEX NUT
3900G	2	1" WASHER
3910G	2	1" HEX NUT
4071B	6	WD 6'0 POST 6 x 8
4140B	2	WD 4'-0 1/4" POST 5 1/2 x 7 1/2
4228G	2	3/8"ø x 4" LAG SCREW
5148G	2	3/4"ø x 9 1/2" HEX HD BOLT
6120B	6	WD BLOCK 1'-2" x 6 x 12 DR
20442G	1	12/15'-7.5/3'-1.5:206'-3"/S
33875G	1	ANGLE STRUT



PN	#	(DAT) PARTS LIST	QTY
724	1	Steel Foundation Tube	2
4140	2	DAT Terminal Post	2
19481	3	Channel Strut	2
20207	4	Terminal Rail Element	1
9713	5	Shelf Angle Bracket	1
782	6	BCT Bearing Plate	1
705	7	BCT Post Sleeve	1
700	8	Guardrail Anchor Bracket	1
907	9	(Rounded)W–Beam End Section	1
3000	10	BCT Cable Anchor	1
	11	Recessed Nut, Guardrail	20
	12	1 1/4" Button Head Bolt	4
	13	10" Button Head Bolt	2
	14	5/8" x 2" Hex Head Bolt	8
	15	5/8" x 8" Hex Head Bolt	4
	16	5/8" x 10" Hex Head Bolt	2
	17	5/8" Flat Washer	18

GENERAL NOTES

1. The rail section at the end post is supported by the Shelf Angle Bracket. The rail element is not attached to the end post.

EXHIBIT C – SHEET 3

METAL BEAM GUARD FENCE
ET–31 (SS540) 2014 TESTING
DOWNSTREAM ANCHOR TERMINAL (DAT)
REF: TxDOT, GF31DAT14.DGN

Appendix B: SwRI Data Sheets for Test ET31-32

EXHIBIT D-1: Installation Checklist

Test Number: ET31-32 Test Date: 1/21/2015

*Record the following impact head dimensions:

head stamp "8" 1/5/2015 OH

Dimension	*Pre-Test Measurements
Exit Gap (middle - inside)	1.2855" ✓
Entrance Gap (middle - outside)	4.6880" ✓
Guide Chute Exit Height (outside)	15 1/16" ✓
Guide Chute Entrance Height (outside)	14 9/16" ✓
Channel Width (outside)	4.0240" ✓
Channel Insertion into Extruder	0.3110" 0.4395" 0.4035" 0.5130"
Outside Guide Channel Length	36 3/8" ✓
Outside Guide Channel Length – Chute to start of swedge	35 3/8" ✓
Head length	56 5/8" ✓

a. Guardrail height as measured from the ground to the top of the guardrail at mid-span for the first eight spans:
   a. Between post 1 and 2: 30 7/8 inches Between post 5 and 6: 30 7/8 inches
   b. Between post 2 and 3: 30 3/4 inches Between post 6 and 7: 31 inches
   c. Between post 3 and 4: 31 1/8 inches Between post 7 and 8: 31 1/4 inches
   d. Between post 4 and 5: 31 1/2 inches Between post 8 and 9: 31 1/4 inches
   e. (ET27 series: all heights to be greater than or equal to 27-3/4" and less than 28-3/4")
   f. (ET31 series: all heights to be greater than 30-1/2" and less than 31-1/2")

b. Distance from the ground to the bottom of the impact face: 9 3/4 inches.

c. Distance from the ground to the top of the impact face: 37 3/4 inches.

d. Soil in the area around impact area and runout area is smooth and flat YES NO (circle one).

e. Backfill around the posts has been re-compacted: YES NO (circle one).

f. Distance from the ground to the top of the first foundation tube: 2 3/4 inches (Must be 4 inches or less).

g. Distance from the ground to the top of the second foundation tube: 2 1/2 inches (Must be 4 inches or less).

h. Bolts at the top of the foundation tubes at posts one and two are not overtightened and the walls of the steel tube are not collapsed or deformed. YES NO (circle one).

i. The ET-PLUS extruder head is pushed as far as it will go on the guardrail panel. The guardrail extends into the extruder 8 1/2 inches.

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EA 1/21 CAE 1/21/15

1/21/15 MSG 1/21/15

j. The two bolts (top and bottom) holding the extruder head to post one are snug and the extruder channel is approximately parallel to the finished grade (i.e., level): YES NO (circle one).
k. The cable anchor bracket is locked into place by pulling the bracket toward the impact end of the unit: YES NO (circle one). Make sure the hooks/lugs are well seated into the square holes on the guardrail.
l. The hex nuts on the cable ends are tightened such that the cable is taut: YES NO (circle one). The cable is taut when it does not deflect more than 1 inch when hand pressure is applied perpendicular to the mid-span of the cable.
m. The bearing plate is placed on the impact side of post 1 where the cable extends through the post: YES NO (circle one).
n. The cable bearing plate is oriented with the long dimensions turned up (from top of plate to center of cable hole is 5"): YES NO (circle one).
o. Wood blockouts have been toe-nailed to the posts: YES NO (circle one).
p. The CRT post top hole is located with the center of the hole approximately at the ground line (± 2"): YES NO (circle one).
q. The guardrail panels are lapped correctly: YES NO (circle one).

Completed by: Oliver Yanin 1/30/2015

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DATE: 12-19-14 TEST NO: ET31-32 VIN NO.: 2CMIR2262T6768124 MAKE: CHevy

MODEL: Metro YEAR: 1996 ODOMETER: 168758 TIRE SIZE:

TIRE INFLATION PRESSURE:

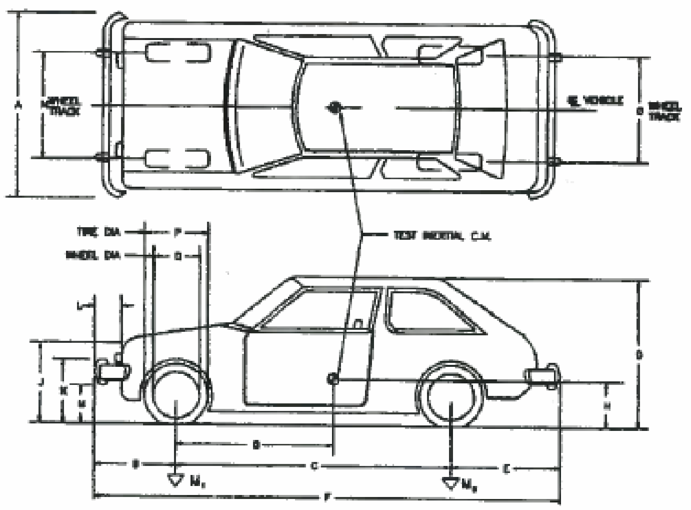
MASS DISTRIBUTION (kg) LF 556 RF 539 LR 347 RR 359

Total weight: 1802

DESCRIBE ANY DAMAGE TO VEHICLE PRIOR TO TEST:

SmALL DenT FRONT LeFT SiDe oF HooD

C/G = 11.0"
spindle height = 10 5/8"



ENGINE TYPE: GAS

ENGINE CID: 1.0 L

TRANSMISSION TYPE:

— AUTO

✓ MANUAL

OPTIONAL EQUIPMENT:

DUMMY DATA:

TYPE:

MASS: 165

SEAT POSITION: PASS

GEOMETRY – (cm)

A 59"	D 56"	G 36.44"	K 20 1/2"	N ~~49~~ 54"
B 32"	E 23"	H 21 5/8"	L 4 3/8"	O 52 1/2"
C 93"	F 148"	J 26"	M 16 1/2"	P 22"

O 14 1/4"

MASS – (kg)	CURB	TEST INERTIAL	GROSS STATIC
M_1			
M_2			
M_T			

EDR FRom FRONT spinDLe 42 1/2" FRomGround 16 1/4"

Figure 4.1. 700C and 820C parameters.

DH 1/20/2015

WHiTe

CG = 11.0"

Appendix C: Laboratory Statement

SOUTHWEST RESEARCH INSTITUTE®

6220 CULEBRA ROAD 78238-5166 • P.O. DRAWER 28510 78228-0510 • SAN ANTONIO, TEXAS, USA • (210) 684-5111 • WWW.SWRI.ORG

Refer to: 18.20887
January 15, 2015

TRINITY HIGHWAY PRODUCTS LLC
2525 Stemmons Freeway
Dallas, Texas 75207

Subject: Proposal and Fixed-Price Contract for Services No. 18-73314
SwRI® Project No. 18.20887

To Whom It May Concern:

Southwest Research Institute hereby attests to the following:

- SwRI is listed on FHWA's roster of laboratories suitable for performing NCHRP Report 350 and MASH crash tests.
- SwRI is currently ISO 17025 accredited by A2LA to perform NCHRP Report 350 and MASH crash tests (Testing Laboratory Certificate 1110.02).
- SwRI has not previously conducted crash testing of the ET-Plus End Terminal system.
- SwRI does not own intellectual property and does not receive royalty-related revenue associated with any of the roadside safety hardware involved in this test program or any guardrail terminal products competing with the ET-Plus End Terminal system.
- SwRI is financially independent from Trinity Highway Products and the Texas Transportation Institute (TTI) at Texas A&M University.

I, R. B. Kalmbach, Executive Director of Contracts, certify on behalf of Southwest Research Institute that the above representations are current, accurate and complete as of the date of this letter.

Should you have any questions, please contact Ms. Mary Lepel at 210/522-3026, by facsimile at 210/522-3559, or email mary.lepel@swri.org.

Sincerely,

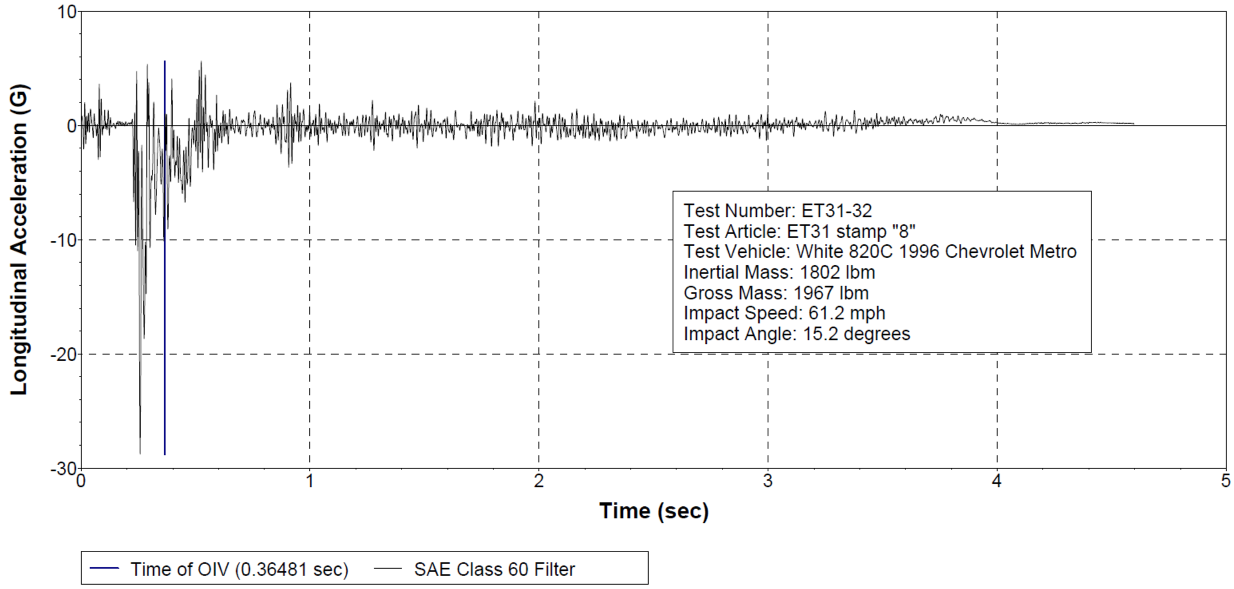
R. B. Kalmbach
Executive Director, Contracts

RBK/MKL/jms
cc: J. Ferren, SwRI (via email)

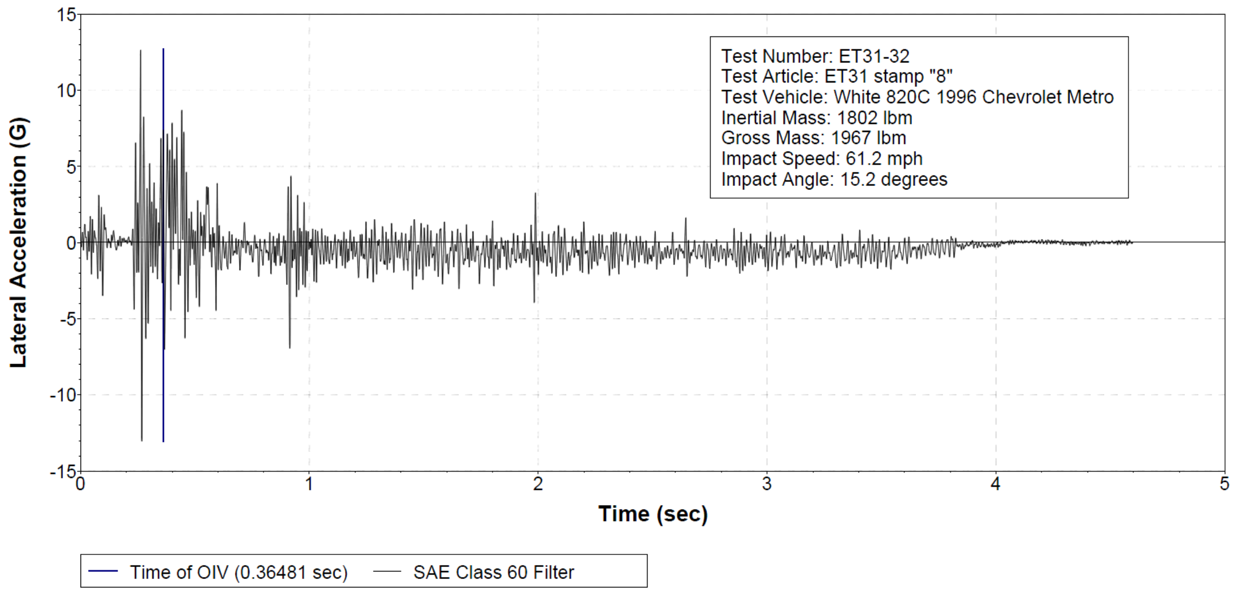
Benefiting government, industry and the public through innovative science and technology

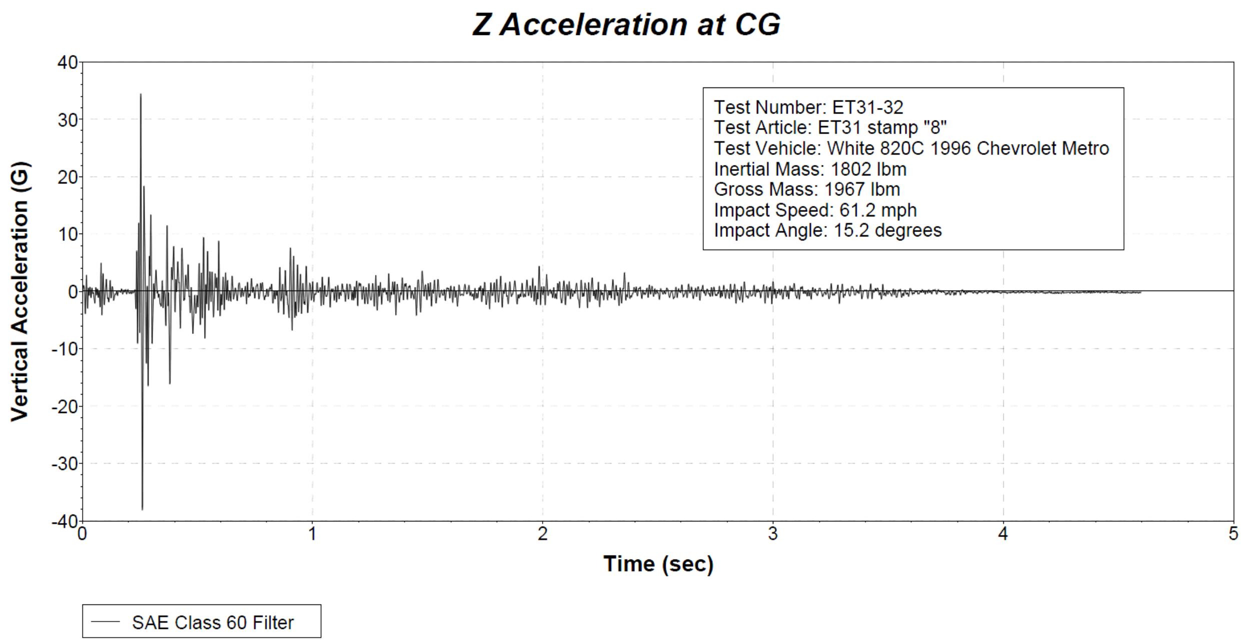
Appendix D: Test Data Plots

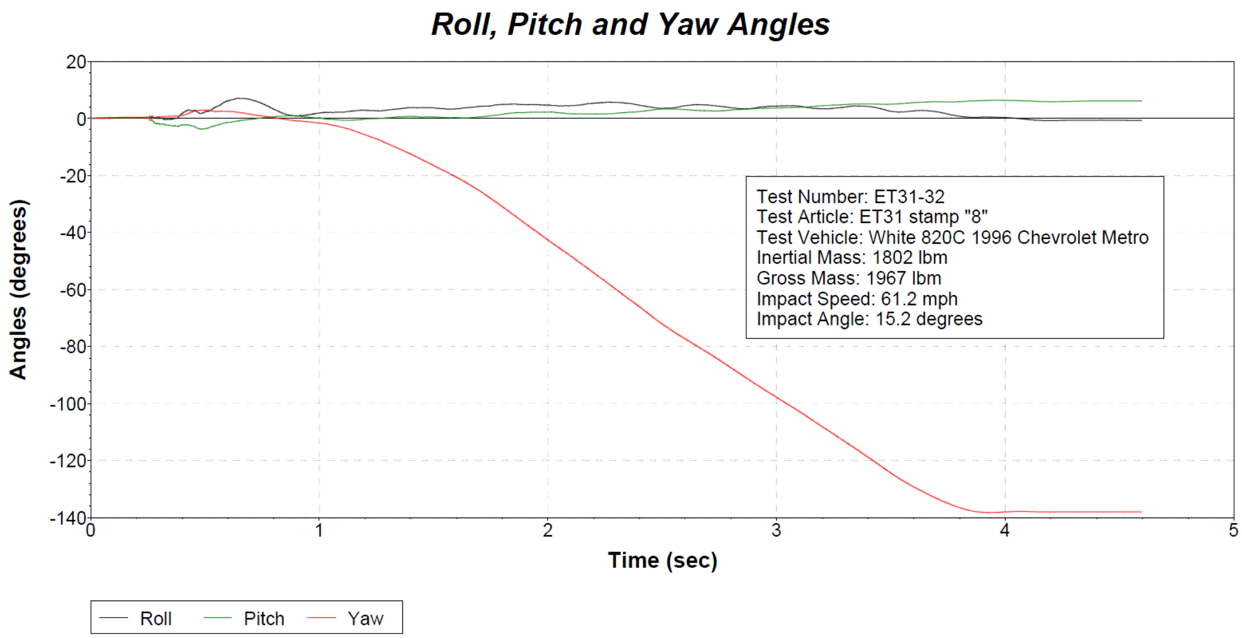
X Acceleration at CG

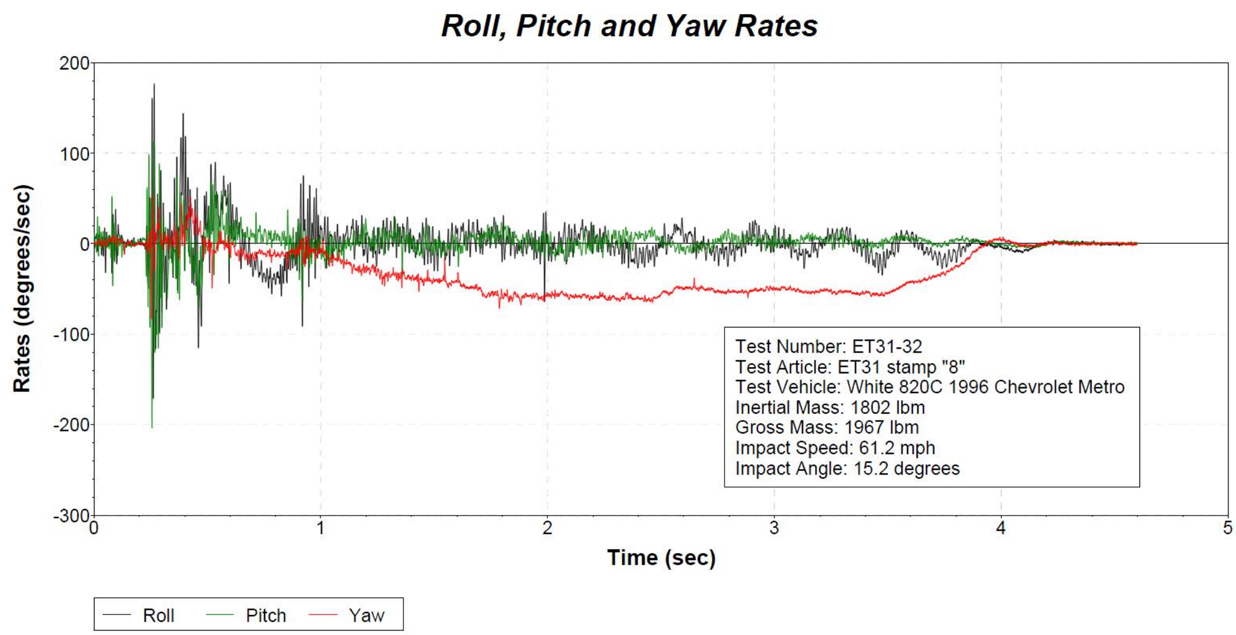


Y Acceleration at CG




Z Acceleration at CG
Test Number: ET31-32
Test Article: ET31 stamp "8"
Test Vehicle: White 820C 1996 Chevrolet Metro
Inertial Mass: 1802 lbm
Gross Mass: 1967 lbm
Impact Speed: 61.2 mph
Impact Angle: 15.2 degrees
Vertical Acceleration (G)
40
30
20
10
0
-10
-20
-30
-40
0
1
2
3
4
5
Time (sec)
SAE Class 60 Filter


Roll, Pitch and Yaw Angles
Angles (degrees)
Time (sec)
Test Number: ET31-32
Test Article: ET31 stamp "8"
Test Vehicle: White 820C 1996 Chevrolet Metro
Inertial Mass: 1802 lbm
Gross Mass: 1967 lbm
Impact Speed: 61.2 mph
Impact Angle: 15.2 degrees
Roll
Pitch
Yaw


Roll, Pitch and Yaw Rates
Rates (degrees/sec)
Time (sec)
Test Number: ET31-32
Test Article: ET31 stamp "8"
Test Vehicle: White 820C 1996 Chevrolet Metro
Inertial Mass: 1802 lbm
Gross Mass: 1967 lbm
Impact Speed: 61.2 mph
Impact Angle: 15.2 degrees
Roll
Pitch
Yaw

Appendix E: Soil Test Data

LABORATORY COMPACTION CHARACTERISTICS OF SOIL REPORT

Report Number: 90141414.0001
Service Date: 12/03/14
Report Date: 12/10/14

Terracon
6911 Blanco Road
San Antonio, TX 78216-6164
210-641-2112 Reg No: F-3272

Client
Southwest Research Institute
Attn: Jenny Ferren
6220 Culebra Road
San Antonio, TX 78228

Project
Southwest Research Institute-Moisture Testing
6220 Culebra Rd
San Antonio, TX

Project Number 90141414

Material Information
Source of Material: Project Site
Proposed Use: Fill

Sample Information
Sample Date: 12/03/14
Sampled By: Benjamin Butler
Sample Location: Project Site

Sample Description: Crushed Limestone

Laboratory Test Data
Test Procedure: ASTM D698
Test Method: Method C
Sample Preparation: Wet
Rammer Type: Mechanical

	Result	Specifications
Liquid Limit:	22	
Plastic Limit:	13	
Plasticity Index:	9	
In-Place Moisture (%):		

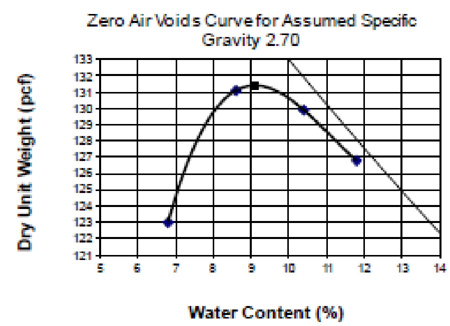
USCS:

Oversized Particles (%): 14.5
Moisture (%): 2.8
Sieve for Oversize Fraction: 3/4

Assumed Bulk Specific Gravity of Oversized Particles: 2.7

Corrected for Oversized Particles (ASTM D4718)
Maximum Dry Unit Weight (pcf): 131.4
Optimum Water Content (%): 9.1

Uncorrected Values
Maximum Dry Unit Weight (pcf): 126.6
Optimum Water Content (%): 10.2



Comments:

Services: Obtain a sample of treated subgrade at the project site and return it to the laboratory. Prepare and test the sample for moisture-density relationship and plasticity index.

Terracon Rep.: Benjamin Butler
Reported To:
Contractor:
Report Distribution:

(1) Southwest Research Institute, jenny.ferren@swri.org
(1) Terracon Consultants, Inc., dejacobs@terracon.com

Reviewed By: Daniel E. Jacobs

Daniel E. Jacobs
Senior Project Manager

Test Methods: ASTM

The tests were performed in general accordance with applicable ASTM, AASHTO, or DOT test methods. This report is exclusively for the use of the client indicated above and shall not be reproduced except in full without the written consent of our company. Test results transmitted herein are only applicable to the actual samples tested at the location(s) referenced and are not necessarily indicative of the properties of other apparently similar or identical materials.

CR0006, 10-16-13, Rev.7 Page 1 of 1

LABORATORY COMPACTION CHARACTERISTICS OF SOIL REPORT

Report Number: 90141414.0001
Service Date: 12/03/14
Report Date: 12/10/14

Terracon
6911 Blanco Road
San Antonio, TX 78216-6164
210-641-2112 Reg No: F-3272

Client
Southwest Research Institute
Attn: Jenny Ferren
6220 Culebra Road
San Antonio, TX 78228

Project
Southwest Research Institute-Moisture Testing
6220 Culebra Rd
San Antonio, TX

Project Number: 90141414

SIEVE ANALYSIS

Sieve Size	**% Retained**	**TXDOT Item 247.2 Type A Grade 2 Specifications % Retained**
1 ¾	0	0-10
7/8	11	---
3/8	35	---
#4	50	45-75
#40	75	60-85
#200	84	----

Remarks: The indicated laboratory tests were performed in general accordance with applicable ASTM standards unless otherwise noted. All test results meet the reference specification requirements unless noted by an asterisk *.

Services: Obtain a sample of treated subgrade at the project site and return it to the laboratory. Prepare and test the sample for moisture-density relationship and plasticity index.
Terracon Rep.: Benjamin Butler
Reported To:
Contractor:
Report Distribution:
(1) Southwest Research Institute, jenny.ferren@swri.org
(1) Terracon Consultants, Inc., dejacobs@terracon.com

Reviewed By: Daniel E. Jacobs

Daniel E. Jacobs
Senior Project Manager

CT0001, 9-28-10, Rev.8
Page 1 of 1

FIELD DENSITY TEST REPORT

Report Number: 90141414.0013
Service Date: 01/21/15
Report Date: 01/22/15
Task:

Terracon
6911 Blanco Road
San Antonio, TX 78216-6164
210-641-2112 Reg No: F-3272

Client

Southwest Research Institute
Attn: Jenny Ferren
6220 Culebra Road
San Antonio, TX 78228

Project

Southwest Research Institute-Moisture Testing
6220 Culebra Rd
San Antonio, TX

Project Number: 90141414

Material Information

Mat. No.	Proctor Ref. No.	Classification and Description	Laboratory Test Method	Lab Test Data: Optimum Water Content (%)	Lab Test Data: Max. Lab Density (pcf)	Project Requirements: Water Content (%)	Project Requirements: Compaction (%)
1	90141414.0001	Crushed Limestone	ASTM D698	9.1	131.4	10% Max	N/A

Field Test Data

Test No.	Test Location	Lift / Elev.	Mat. No.	Probe Depth (in)	Wet Density (pcf)	Water Content (pcf)	Water Content (%)	Dry Density (pcf)	Percent Compaction (%)
	ET 31-32								
1	North of Post #1	1	1	12	139.2	8.7	6.7	130.5	99.3
2	South of Post #2	1	1	12	133.1	8.8	7.1	124.3	94.6
3	West of Post #3	1	1	12	142.6	10.7	8.1	131.9	100+

Datum: **Serial No:**

Comments: **Test and/or retest results on this report meet project requirements as noted above.**

Services: Perform in-place density and moisture content tests to determine degree of compaction and material moisture condition.

Terracon Rep.: Esquivel, James
Reported To:
Contractor:
Report Distribution:
(1) Southwest Research Institute, jenny.ferren@swri.org
(1) Terracon Consultants, Inc., dejacobs@terracon.com

Reviewed By: Daniel E. Jacobs
Daniel E. Jacobs
Senior Project Manager

Test Methods: *, ASTM D6938

The tests were performed in general accordance with applicable ASTM, AASHTO, or DOT test methods. This report is exclusively for the use of the client indicated above and shall not be reproduced except in full without the written consent of our company. Test results transmitted herein are only applicable to the actual samples tested at the location(s) referenced and are not necessarily indicative of the properties of other apparently similar or identical materials.

CR0007, 11-16-12, Rev.7

Page 1 of 1

NCHRP Report 350 Test Report

Full-Scale Crash Evaluation of the ET Plus® End Terminal with 4-inch Wide Guide Channel Installed with a Rail Height of 31 Inches

Test Level 3, Test 3-30
Test Identification: ET31-30

SwRI® Project No. 18.20887

SwRI Document Number: 18.20887.05.100.FR4
Issue 1

Prepared for:
Trinity Highway Products
2525 Stemmons Freeway
Dallas, TX 75207

February 17, 2015

Authored by:

Jenny Ferren, Manager
Mechanical Engineering Division

Reviewed and Approved by:

Timothy A. Fey, P.E., Director
Mechanical Engineering Division

Southwest Research Institute®
6220 Culebra Road • Post Office Drawer 28510
San Antonio, Texas 78228-0510

ACCREDITED
TESTING CERT.#1110.02

Below is a table documenting the various changes recorded in this report. Each issuance of the report is clearly marked with the revision number and date of issue.

Table 0.1: Revision Table

ISSUE	EXPLANATION	PAGE NUMBERS	DATE EFFECTIVE
1	Original report	All	February 17, 2015

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

1 INTRODUCTION

The purpose of Crash Test ET31-30 was to evaluate the performance of the Trinity Highway Products ET Plus End Terminal with 4-inch wide guide channel installed with a rail height of 31”. To test the performance of this terminal, Test 3-30 was conducted according to National Cooperative Highway Research Program (NCHRP), Report 350. The total system installation length for the test was nominally 49.5 m (162’-6”), including the 16.2 m (53’-1½”) ET Plus terminal length.

Test 3-30 is intended primarily to evaluate occupant risk and vehicle trajectory criteria. The test consists of an 820 kg (1808 lb) small passenger car approaching parallel to the roadway (0 degree angle) and impacting the end terminal at 100 km/hr (62.1 mph). The vehicle impacts the end terminal to the left or right of the vehicle’s centerline, with the offset being equal to a quarter of the vehicle’s width.

Crash Test ET31-30 was conducted on January 27, 2015, at the Crash Test Site at Southwest Research Institute (SwRI) by SwRI personnel. This report presents information on the test parameters, a discussion of the test, and an assessment of the test results based on the criteria set forth in NCHRP Report 350.

2 TEST PARAMETERS

Test Facility

The full-scale crash testing was performed by Southwest Research Institute (SwRI), on the campus located at the following address:

Southwest Research Institute
6220 Culebra Road
San Antonio, Texas 78238

SwRI is ISO/IEC 17025 accredited by A2LA (American Association for Laboratory Accreditation) to perform this testing under Testing Laboratory Certificate #1110.02.

Test Article – Design and Construction

The full-scale crash test was performed on the ET Plus End Terminal which included the ET Plus extruder head with 4-inch wide guide channel and W-Beam guardrail installed with a rail height of 78.7 cm (31 in.). The ET Plus End Terminal installation tested uses standard AASHTO M180 Type 2, 12-gauge W-Beam guardrail panels mounted with the top of the rail 78.7 cm (31 in.) above the ground, two wooden breakaway posts in foundation sleeves without soil plates at Posts 1 and 2, and CRT posts at Posts 3 through 8. The end terminal included 15.2 cm x 30.5 cm (6" x 12") wood blockouts at Posts 3 through 8.

During installation, holes approximately 61 cm (2 ft) in diameter were drilled into the soil and then backfilled around the posts using "standard soil" as defined by NCHRP Report 350, Section 2.2.1.1. The base material was compacted in 15.2 cm (6 in) lifts, and was added until the surface was flush with the surrounding soil.

The guardrail line posts are 15.2 cm x 20.3 cm (6" x 8") wood posts with 15.2 cm x 20.3 cm (6" x 8") wood blockouts. The blockouts are toenailed, and the guardrail panels are mounted to the posts using 1.6 cm (5/8 in) diameter post bolts beginning with Post 2; the bolt for Post 2 is 25.4 cm (10 in) long, the bolts for Posts 3 through 8 are 55.9 cm (22 in) long, and all other post bolts are 45.7 cm (18 in) long. The post spacing is 1.9 m (6'-3"), and each splice joint used eight (8) 1.6 cm (5/8 in) diameter x 3.2 cm (1-¼ in) splice bolts and nuts; the splice bolts have a nominal total length of 4.1 cm (1-5/8 in) including the bolt head. The installation uses 1.9 cm (3/4 in) diameter x 25.4 cm (10 in) bolts through the soil tube, post, and strut at Post 1 and Post 2. An anchor cable is also installed at Post 1. The installation has a guardrail splice at Post 3. Subsequent guardrail splices are mid-span between Posts 5 and 6, and every 3.8 m (12'-6") afterward to the end of the system.

The total system installation length for the test was nominally 49.5 m (162'-6"), including the 16.2 m (53'-1½") ET Plus terminal length, 30.5 m (100 ft) of guardrail, and a 2.9 m (9'-4½") long downstream anchor terminal. Detailed drawings of the test article provided by Trinity Highway Products are provided in Appendix A.

The ET Plus end terminal extruder head was one of eight production samples CalTrans (California DOT) pulled from their inventory for testing at SwRI. The heads were inspected by CalTrans, FHWA, and Trinity Highway Products personnel at the CalTrans yard, and were stamped with identifiers "Kit #1" through "Kit #8". SwRI arranged for shipment of the heads to the test site in San Antonio, and the heads remained in controlled storage until they were installed for testing. The dimensions of the specific ET Plus end terminal extruder head used for Test ET31-30 are provided in Table 2.1 below; dimensions measured with a tape measure are listed in fractional inches, and dimensions measured with a digital caliper are listed as decimals. Copies of the datasheets reviewed by representatives from the FHWA, US DOT and various state Departments of Transportation (DOT) prior to testing are located in Appendix B.

The performance goal for the ET Plus is to achieve controlled vehicle deceleration in compliance with NCHRP Report 350 criteria for post-impact vehicle trajectory and occupant risk. Figure 2.1 through Figure 2.20 present photographs of the guardrail installation.

Table 2.1: Key ET Plus Head Dimensions

Extruder Head Stamp ID	5	
Exit Gap	2.67 cm	1.0495"
Entrance Gap	12.18 cm	4.7955"
Guide Chute Exit Height	38.1 cm	15"
Guide Chute Entrance Height	37.0 cm	14-9/16"
Channel Width (see Figure 2.2)	10.27 cm	4.0450"

Figure 2.1: ET Plus Head Sample Identification Number

Figure 2.2: Measurement of Channel Width of Head

Figure 2.3: Test Installation for ET Plus Test ET31-30

Figure 2.4: ET Plus End Terminal

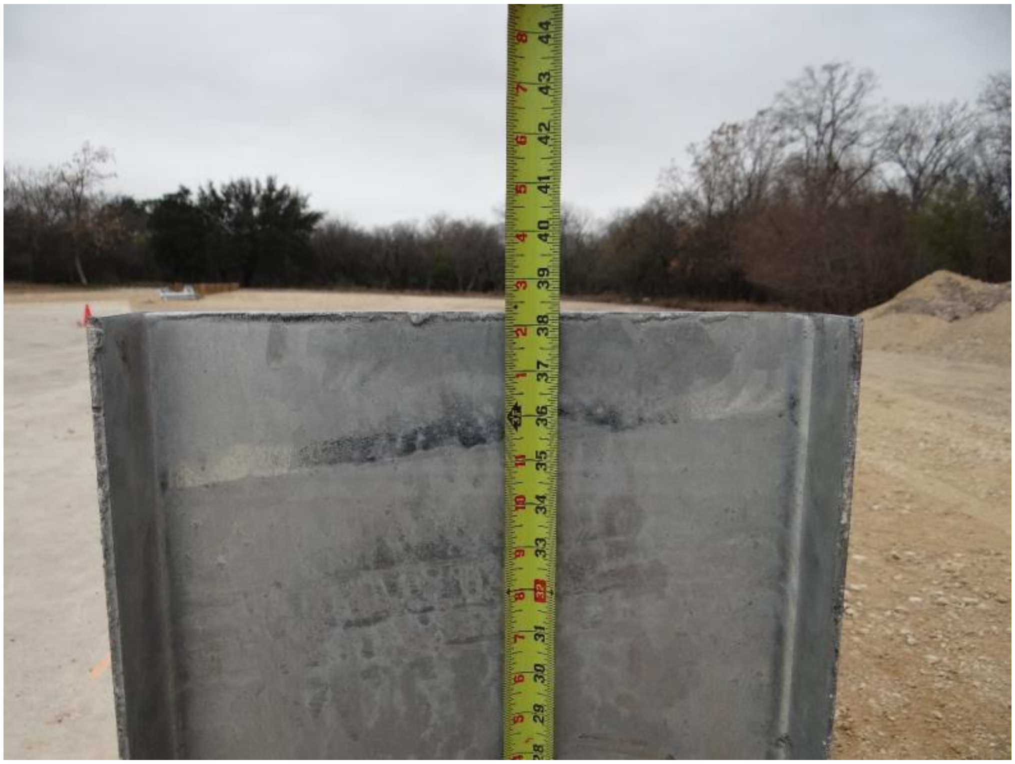


Figure 2.5: ET Plus Head Height Above Ground – Top

Figure 2.6: ET Plus Head Height Above Ground – Bottom

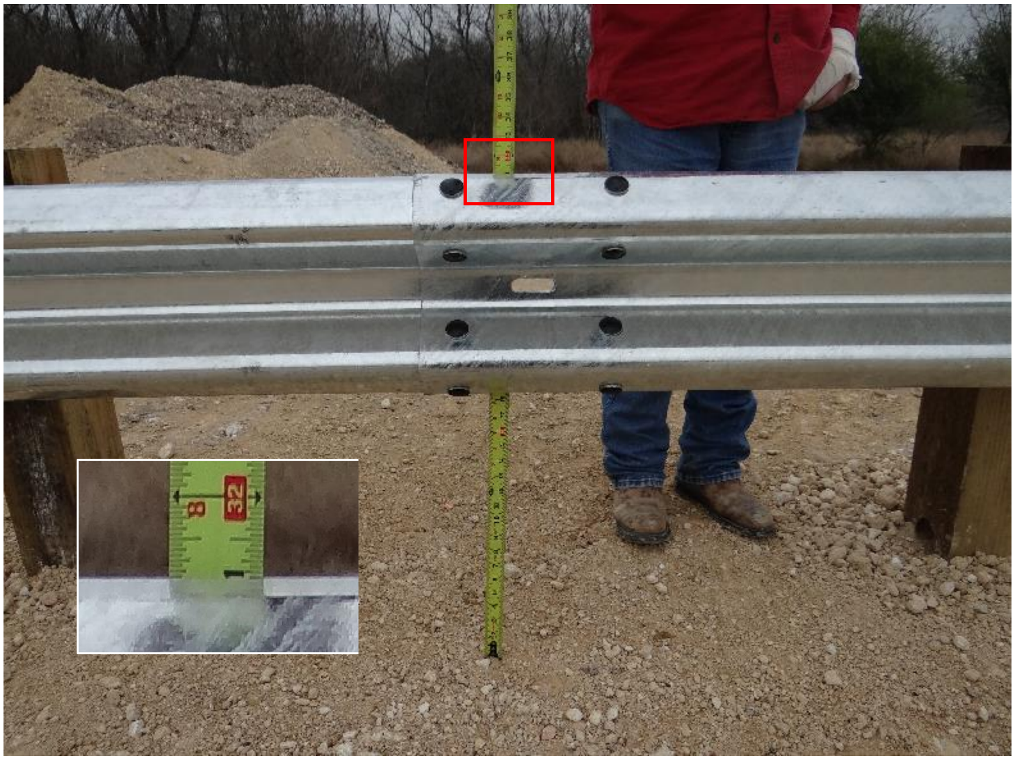


Figure 2.7: Measurement of Guardrail Installation Height

Figure 2.8: ET Plus Head and Anchor Cable Assembly

Figure 2.9: End Terminal Cable Anchor at Upstream End – Post 1

Figure 2.10: End Terminal Cable Anchor at Downstream End

Figure 2.11: First Guardrail Panel Splice Joint – Traffic Side (Splice Bolts Painted for Visibility in Video)

Figure 2.12: First Guardrail Panel Splice Joint – Non-Traffic Side (Nuts Painted for Visibility in Video)

Figure 2.13: Second Guardrail Panel Splice Joint Mid-Span between Posts 5 & 6 – Traffic Side (Splice Bolts Painted for Visibility in Video)

Figure 2.14: Second Guardrail Panel Splice Joint Mid-Span between Posts 5 & 6 – Non-Traffic Side (Nuts Painted for Visibility in Video)

Figure 2.15: ET Plus Head and Post 1 – Traffic Side

Figure 2.16: ET Plus Head and Post 1 – Non-Traffic Side

Figure 2.17: ET Plus Head with Posts 1 & 2 and Strut

Figure 2.18: ET Plus Head Looking Upstream at Post 1 (see Appendix B for Dimensions)

Figure 2.19: Downstream Anchor Terminal at Posts 26 and 27 – Traffic Side

Figure 2.20: Downstream Anchor Terminal at Posts 26 and 27 – Non-Traffic Side

Test Vehicle

The test vehicle was a 1998 Geo Metro, shown in Figure 2.21; the vehicle data sheet is provided in Appendix B. Figure 2.22 shows the relationship between the height of the vehicle bumper and the end terminal. Figure 2.23 shows the test vehicle positioned at the impact point of the end terminal, and Figure 2.24 shows an overhead view of the test vehicle positioned at the intended crash angle of 0° and an offset equal to a quarter of the vehicle width.

A 75 kg (165 lbs) anthropometric dummy was utilized for this test, and was placed in the driver's seat as shown in Figure 2.25 to contribute to the vehicle's post-impact instability as specified in NCHRP Report 350. No additional ballast mass was used.

The test inertial mass of the vehicle was 808 kg (1,782 lbs) as reflected in Table 4.2. Note that the test inertial mass does not include the weight of the anthropometric dummy.

Figure 2.21: Test Vehicle for Test ET31-30

Figure 2.22: Test Vehicle Bumper Height

Figure 2.23: Test Vehicle Impact Trajectory

Figure 2.24: Test Vehicle Impact Trajectory – Overhead View

Figure 2.25: Test Dummy Positioned in Driver's Seat

Test Vehicle Guidance

The test vehicle was towed into the end terminal using a tow vehicle and a series of pulleys and sheaves. A steel cable was attached to a quick-release pin under the front of the vehicle and was passed around a sheave and secured to the rear of a tow vehicle. The tow vehicle was equipped with an adjustable ignition restrictor that attenuated the tow vehicle's engine RPM when a pre-set speed was attained. The test vehicle was guided by means of a taught steel cable attached to a sliding shoe which was attached to the front spindle of the test vehicle shown in Figure 2.26. Just prior to impact, the sliding shoe and tow cable were stripped from the vehicle allowing the test vehicle to free wheel into the end terminal.

Figure 2.26: Test Vehicle Steering Guidance Assembly

Test Vehicle Data Acquisition

The data acquisition consisted of recording the acceleration and angular velocities of the test vehicle. The measurement of these two parameters allows SwRI engineers to perform an occupant risk evaluation. The device used to record the vehicle acceleration and angular velocities was a six (6) degree-of-freedom Instrumented Sensor Technology Electronic Data Recorder, henceforth referred to as the EDR-4.

The EDR-4 recorder unit is a compact package used for stand-alone recording of shock and vibration, and is able to record six channels of data. The three acceleration channels were recorded from a built-in triaxial accelerometer used to record the test vehicle's accelerations in three orthogonal directions (x, y, and z). The three angular velocity channels were recorded from built-in rate gyro transducers used to record the test vehicle's angular velocities in three orthogonal directions (roll, pitch, and yaw).

The data acquisition package was rigidly attached to the test vehicle. A metal bracket was welded onto the test vehicle's body. This bracket was attached inside the passenger compartment of the vehicle, as close as possible to the vehicle's center of gravity, without significantly modifying the vehicle's interior components (i.e., center console, bench seats). The data acquisition package was then bolted to the metal bracket as shown in Figure 2.27 and Figure 2.28. Because of the configuration of the EDR-4 as manufactured, the orientation of the data acquisition package within the vehicle matches the general axis designation given in Figure 4.6 of NCHRP Report 350, but the signs for the Y and Z axes had to be reversed during post-test processing to comply with the NCHRP and TRAP sign convention.

Figure 2.27: EDR Mounted in Test Vehicle for Test ET31-30

Figure 2.28: Close-up of EDR Orientation as Mounted in Vehicle

The sign convention used for data processing is as follows:

Table 2.2: Sign Convention for Vehicle Motion

X:	Positive in the normal forward motion direction
Y:	Positive toward the right
Z:	Positive vertically downward
ROLL:	Positive using right hand rule about +X direction
PITCH:	Positive using right hand rule about +Y direction
YAW:	Positive using right hand rule about +Z direction

The EDR-4 data recorder unit was configured with a sample rate of 2944 samples per second (per channel), and with a low pass filter setting of 300 Hz. After the data had been downloaded from the data acquisition package, the data was processed using Test Risk Assessment Program (TRAP) Version 2.3.11, (Texas A&M Transportation Institute and Capsher Technology, Inc.). The TRAP program was designed to determine the effectiveness of a roadside safety feature by analyzing data from a vehicle crash test of the feature and calculating standardized occupant risk factors. TRAP calculates occupant risk factors in accordance with the NCHRP Report 350 guidelines.

Test Vehicle Onboard Cameras

Two digital cameras were mounted to a rail such that one camera was behind the driver's seat, and one camera was behind the passenger's seat but aimed at the driver location. A photograph of the camera locations is provided in Figure 2.29.

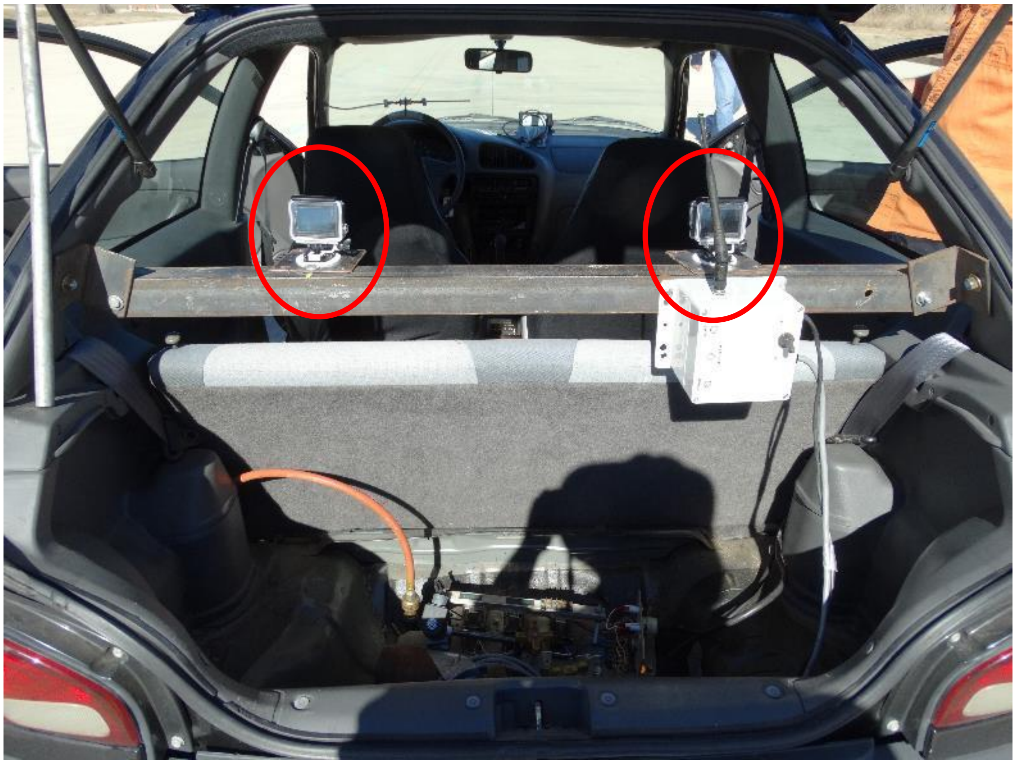


Figure 2.29: Onboard Cameras

Soil Conditions

The soil complied with the NCHRP Report 350 "Standard Soil" as described in the *Test Article – Design and Construction* section of this report. The day of testing, soil moisture content was measured by a certified environmental engineering firm. The maximum moisture content measured was 8.0% at a location near Post 6. There was no rainfall between when the moisture reading was taken and when the testing was conducted. Detailed results of the soil testing and moisture content evaluation are provided in Appendix E.

Calibrated Test Equipment

Test equipment used to perform the tests and acquire data during this testing program is listed in the table below.

Table 2.3: Equipment Used During Testing

Description	Manufacturer	Model	Asset No.	Due Date[1]
Data Recorder	IST	EDR-4-6DOF-200	S/N 40048	2/5/15
Wheel Scales	Longacre	72634	015238	11/5/15
Measuring Tape	Stanley	33-725	015324	11/7/15
Caliper	Starrett	721	020504	3/18/15
Speed Trap DAQ	NI	USB-6008	S/N 14D4376	8/27/15

[1]Unless otherwise specified, all equipment is calibrated or verified on an annual basis.

Test Observers

Representatives from the following organizations were among those present at the SwRI Crash Test Site and observed Test ET31-30 on January 27, 2015:

- Federal Highway Administration (FHWA)
- AASHTO
- Virginia DOT
- Texas DOT

Observers from FHWA and AASHTO were permitted to visually inspect and measure the ET Plus installation before and after the test. All other observers were allowed to visually inspect the ET Plus installation before and after the test. All observers were allowed to visually inspect the vehicle following the test.

3 TEST CONDITIONS AND RESULTS

Test Description

The purpose of Test ET31-30 was to evaluate the performance of Trinity Highway Products ET Plus End Terminal with 4-inch wide guide channel installed with a rail height of 31”. To test the performance of this terminal, Test 3-30 was conducted according to NCHRP Report 350. The test installation length for the test was 49.5 m (162’-6”), and the terminal length was 16.2 m (53’-1½”).

Test 3-30 is intended primarily to evaluate occupant risk and vehicle trajectory criteria. The test consists of an 820 kg (1808 lb) small passenger car approaching parallel to the roadway (0 degree angle) and impacting the end terminal at 100 km/hr (62.1 mph). The vehicle impacts the end terminal to the left or right of the vehicle’s centerline, with the offset being equal to a quarter of the vehicle’s width. NCHRP Report 350 states that the vehicle should be offset to the most critical side that will result in the greatest occupant risk during and following the impact, and that a surrogate passenger should be positioned in either the driver's seat or the passenger's seat, whichever position contributes most to the vehicle's post-impact instability. For Test ET31-30, the vehicle was offset towards the traffic side, which maximizes the off-center forces caused by the vehicle striking off-set downstream posts; this creates a worst-case vehicle yawing condition to the traffic side of the system. To further contribute to the vehicle’s post-impact instability, the restrained anthropometric dummy was positioned in the driver’s seat. The test configuration is shown in Figure 3.1, which is from Figure 3.2 of NCHRP Report 350.

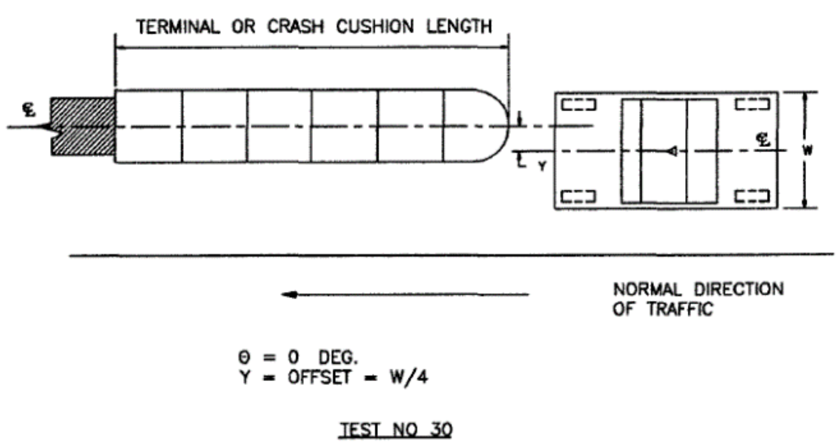


Figure 3.1: Impact Configuration *[from Figure 3.2 of NCHRP Report 350]*

The weather on the day of the test was mostly sunny, with temperatures ranging from 5-26°C (41-79°F). The temperature at the time of the test was approximately 21°C (70°F). The soil was dry as discussed in the *Soil Conditions* section of this report.

Impact Description/Vehicle Behavior

Figure 3.2 is an overhead photograph showing the post-test condition and location of the test article and test vehicle. Figure 3.3 through Figure 3.7 show that the test vehicle impacted the end terminal at a nominal 0° angle. The impact velocity of the test as measured by SwRI's speed trap system and verified by high-speed film analysis was determined to be 102.8 km/hr (63.9 mph). As a result of the test, the ET Plus extruder head moved 7.2 m (23.5 ft) longitudinally (downstream) and 1.3 m (4.4 ft) laterally as measured from its as-installed position. The total system deformation (i.e. longitudinal distance to closest point) measured after the impact was 6.46 m (21.2 ft) from the initial point of contact.

After the impact event, the ET Plus extruder head stroked along the guardrail, extruding approximately 3.9 m (13 ft) of guardrail. After the guide channel entrance end of the head had stroked past Post 2, the vehicle began a lateral clockwise spin towards the traffic side of the installation due to the quarter-offset impact and asymmetrical mass of the dummy positioned in the driver seat. As the vehicle traversed downstream, the ET Plus continued to stroke along the guardrail; when the guide channel entrance of the head had stroked past Post 3 and was approximately 0.7 m (2.3 ft) upstream of Post 4, the W beam began to bend at Post 4 causing the extruder head to rotate in a counter-clockwise direction. The vehicle continued to spin clockwise as it slid in the downstream direction; when the vehicle and extruder head had each rotated approximately 90 degrees from their original orientation and were parallel to one another and facing to the non-traffic side of the installation, the bend of the W-beam was aligned near the front hinge edge of the driver side door. The vehicle continued to slide downstream as it spun, impacting the bend in the W beam near the front of the driver's door in-line with the steering wheel; the vehicle continued to rotate an additional 135 degrees before coming to a stop with a total rotation of 225 degrees from its original trajectory. When the W beam impacted the driver door, the door skin and interior door panel folded inward at a point approximately 45.7 cm (18 in) aft of the front hinge edge of the door skin and contacted the side of the steering wheel. During the impact the W beam did not penetrate the outer door skin, and the door skin did not penetrate the interior door panel. The door skin and panel partially rebounded after the impact. The maximum post-test occupant compartment deformation was measured to be approximately 17.1 cm (6.75 in) at the closest point of the interior door panel (located approximately 2.2 cm (0.85 in) below the center of gravity and approximately 5.1 cm (2 in) aft of the instrument panel, roughly even with the height of the front edge of the seat); this equated to a reduction in the width of the occupant compartment of 14% and an Occupant Compartment Deformation Index[1] (OCDI) rating of LF0000200. Based on the location and magnitude of the deformation and the fact that there was no vehicle penetration, there was no indication of serious or life-threatening injury due to the occupant compartment reduction. Photographs of the occupant compartment including the seat and floorboard area are provided in the following section of this report; photographs were recorded with the surrogate dummy in place as well as after it had been removed through the passenger side door to facilitate post-test inspection. After the vehicle came to rest, the perpendicular distance between the original guardrail installation and the front left wheel was 1.71 m (67.3 in), and the distance to the rear wheel was 0.36 m (14.2 in). The vehicle was not operable after the test.

[1] The OCDI rating was computed in accordance with NCHRP Report 350, Appendix E.

The ET Plus extruder head directly contacted and sheared-off Posts 1 through 3 during the extrusion, and sheared Post 4 at the end of the stroke. The head of the post bolt at Post 3 was sheared off. Towards the end of the vehicle spin, the rear bumper of the vehicle impacted the guardrail at Post 5; the post and blockout appeared undamaged but slightly separated, and there was indication in the soil of slight post movement towards the non-traffic side. The guardrail was detached from the post bolts at Posts 5, 6, and 7. All posts and blockouts downstream of Post 5 appeared undamaged, and no appreciable movement of the downstream terminal anchor was observed. Additionally, the anchor cable at Post 1 broke free of the installation and came to rest on the non-traffic side even with Post 10. The extruded portion of the guardrail came to rest parallel to the installation on the non-traffic side. The only debris thrown from the installation as a result of the impact included vehicle parts and pieces of posts and blockouts from the first four posts; the majority of the post debris fell to the non-traffic side of the guardrail. There was no significant deformation of the 4” guide channels as a result of the impact, and they remained attached to the impact head.

The test vehicle experienced a maximum 50 millisecond moving average acceleration of -10.2g in the longitudinal direction, 6.7g in the lateral direction, and -2.2g in the vertical direction. The impact velocities and ridedown accelerations were below the preferred limits and well below the maximum limits listed in NCHRP Report 350.

- Occupant impact velocities were 8.2 m/s in the longitudinal direction, and 0.4 m/s in the lateral direction.
- Occupant ridedown accelerations were -11.8g in the longitudinal direction, and 8.7g in the lateral direction.

The following sections provide photographs of the post-impact condition of the test article as well as the vehicle. Table 4.2 presents a summary of the onboard data, and plots of the accelerometer and angular velocity transducers are provided in Appendix D.

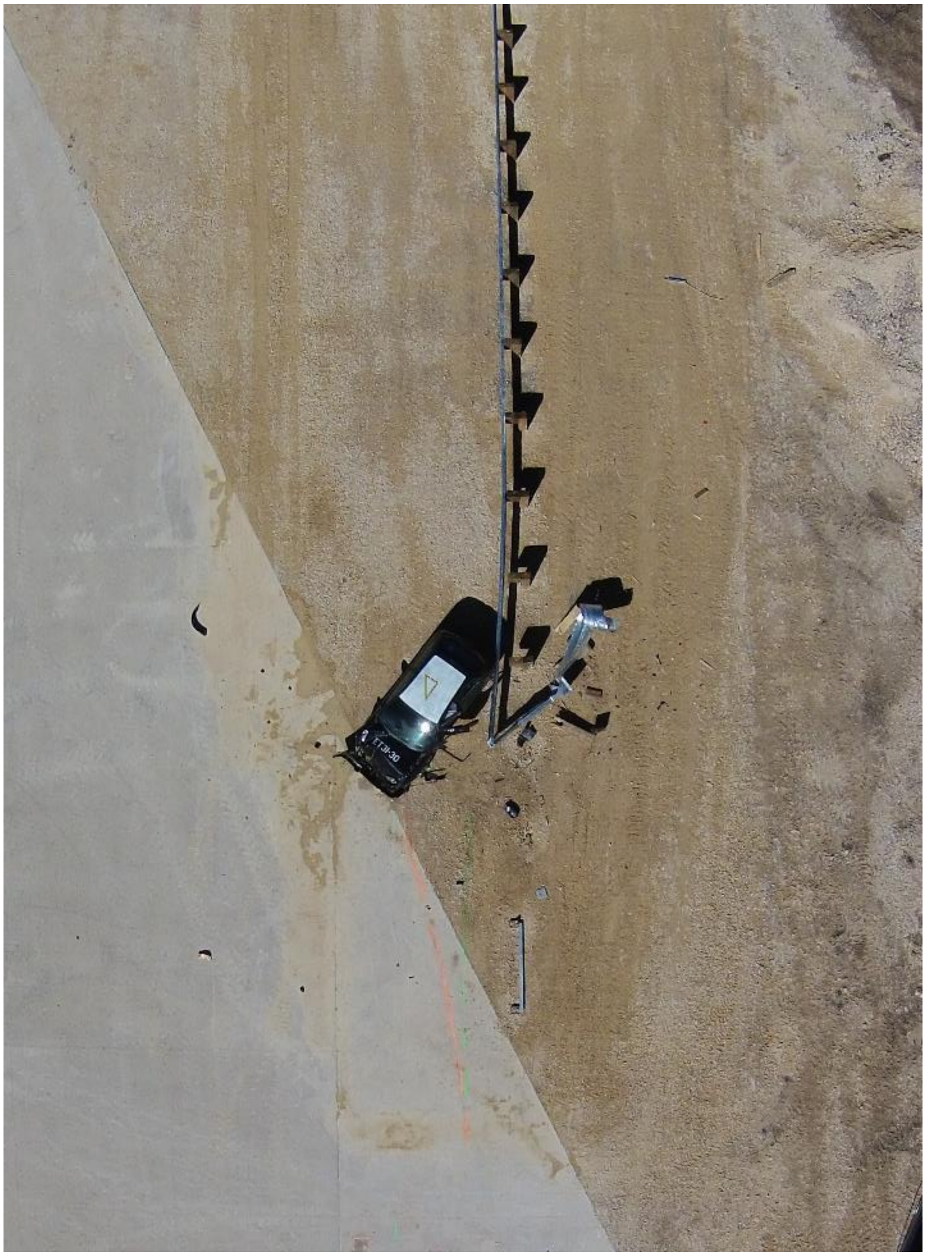


Figure 3.2: Post-Impact Condition of the Test Article and Vehicle

Impact Severity

NCHRP Report 350 states that the recommended impact severity for Test Level 3, Test 3-30 is 316.4 kJ, with a suggested tolerance of -24.8/+25.8 kJ. The actual impact severity of test ET31-30 was 329.9 kJ, a deviation of +13.5 kJ from the nominal impact severity recommended in NCHRP Report 350. *Note that for Test 3-30, Sin θ is set to 1 in accordance with Section 3.3.1 of Report 350.*

Impact Severity $= \frac{1}{2} \cdot M \cdot (V \cdot \sin\theta)^2$

$= \frac{1}{2} \cdot M \cdot V^2$

$= 0.5 \cdot (808.3\ \text{kg}) \cdot (28.57\ \text{m/s})^2$

$= 329.9\ \text{kJ}$

The equivalent impact speed of an 820 kg vehicle impacting the end terminal at 0 degrees would be 102.1 km/hr (63.5 mph).


Time = 0.000 seconds (Impact)


Time = 0.050 seconds


Time = 0.100 seconds


Time = 0.150 seconds


Time = 0.200 seconds


Time = 0.250 seconds


Time = 0.300 seconds


Time = 0.350 seconds


Time = 0.400 seconds

Figure 3.3: Sequential Photographs, as Viewed from Overhead, T=0.000 to 0.400 seconds

Time = 0.450 seconds

Time = 0.500 seconds

Time = 0.550 seconds

Time = 0.600 seconds

Time = 0.650 seconds

Time = 0.700 seconds

Time = 0.750 seconds

Time = 0.800 seconds

Time = 0.850 seconds

Figure 3.4: Sequential Photographs, as Viewed from Overhead, T=0.450 to 0.850 seconds


Time = 0.000 seconds (Impact)


Time = 0.050 seconds


Time = 0.100 seconds


Time = 0.150 seconds


Time = 0.200 seconds


Time = 0.250 seconds


Time = 0.300 seconds


Time = 0.350 seconds


Time = 0.400 seconds

Figure 3.5: Sequential Photographs, as Viewed from Downstream, T=0.000 to 0.400 seconds


Time = 0.450 seconds


Time = 0.500 seconds


Time = 0.550 seconds


Time = 0.600 seconds


Time = 0.650 seconds


Time = 0.700 seconds


Time = 0.750 seconds


Time = 0.800 seconds


Time = 0.850 seconds

Figure 3.6: Sequential Photographs, as Viewed from Downstream, T=0.450 to 0.850 seconds


Time = 0.000 seconds (Impact)


Time = 0.050 seconds


Time = 0.100 seconds


Time = 0.150 seconds


Time = 0.200 seconds


Time = 0.250 seconds


Time = 0.300 seconds


Time = 0.350 seconds


Time = 0.400 seconds

Figure 3.7: Sequential Photographs, as Viewed from Non Traffic Side of the End Terminal, T=0.000 to 0.400 seconds


Time = 0.450 seconds


Time = 0.500 seconds


Time = 0.550 seconds


Time = 0.600 seconds


Time = 0.650 seconds


Time = 0.700 seconds


Time = 0.750 seconds


Time = 0.800 seconds


Time = 0.850 seconds

Figure 3.8: Sequential Photographs, as Viewed from Non Traffic Side of the End Terminal, T=0.450 to 0.850 seconds

End Terminal Damage

Figure 3.9: Post Test – Downstream Traffic Side View of Extruder Head

Figure 3.10: Post Test – Upstream Non-Traffic Side View of Extruder Head

Figure 3.11: Post Test – Traffic Side View of Extruder Head

Figure 3.12: Post Test – End View of Impact Plate

Figure 3.13: Post Test – Non-Traffic Side View of Extruder Head

Figure 3.14: Post Test – Extruded Guardrail

Figure 3.15: Post Test – Foundation Sleeves at Posts 1 and 2

Figure 3.16: Post Test – Foundation Sleeve at Post 1

Figure 3.17: Post Test – Foundation Sleeve at Post 2

Figure 3.18: Post Test – Non-Traffic View of Post 3 (Left) and Post 4 (Right)

Figure 3.19: Post Test – Final Location of Post 3 (Left) and Post 4 (Right)

Figure 3.20: Post Test – Traffic View of Post 5

Figure 3.21: Post Test – Traffic View of Post 5 Blockout

Figure 3.22: Post Test – Non-Traffic View of Post 5

Figure 3.23: Post Test – Traffic View of Post 6

Figure 3.24: Post Test – Non-Traffic View of Post 6

Figure 3.25: Post Test – Side View of Post 7

Figure 3.26: Post Test – Traffic View of Post 7

Figure 3.27: Post Test – Side View of Post 8

Figure 3.28: Post Test – Second Splice

Figure 3.29: Post Test – Traffic Side View of Folded W Beam at Post 4

Figure 3.30: Post Test – Non-Traffic Side View of Folded W Beam at Post 4

Figure 3.31: Post Test – Upstream View of Guide Channel Entrance

Figure 3.32: Post Test – Traffic Side View of Guide Channels

Figure 3.33: Post Test – Traffic Side View of Extruder Head

Figure 3.34: Post Test – Upstream Traffic View of Extruder Throat

Figure 3.35: Post Test – Traffic Side View of Extruder Head

Figure 3.36: Post Test – Non-Traffic Side View of Extruder Head

Figure 3.37: Post Test – Non-Traffic Side View of Extruder Head

Figure 3.38: Post Test – Upstream Non-Traffic View of Extruder Throat

Figure 3.39: Post Test – Upstream Non-Traffic View of Extruder Throat, Close-up

Figure 3.40: Post Test – Upstream View of Gated Extruder Head

Figure 3.41: Post Test – Non-Traffic Side View of Guide Channels

Figure 3.42: Post Test – Non-Traffic Side Vide of Guide Channel Entrance

Figure 3.43: Post Test – Traffic Side View of Gated End Terminal

Figure 3.44: Post Test – Traffic Side View of Gated End Terminal

Figure 3.45: Post Test – Traffic Side View of Gated End Terminal

Figure 3.46: Post Test – Traffic Side View of Gated End Terminal

Figure 3.47: Post Test Location of Anchor Cable on Non-Traffic Side Even with Post 10

Figure 3.48: Post Test – Terminal Anchor Bolt End Near Sheared Post 4

Figure 3.49: Post Test – Sheared Post Bolt from Post 3

Figure 3.50: Post Test – Debris Field on Non-Traffic Side

Figure 3.51: Post Test – Debris Field on Non-Traffic Side

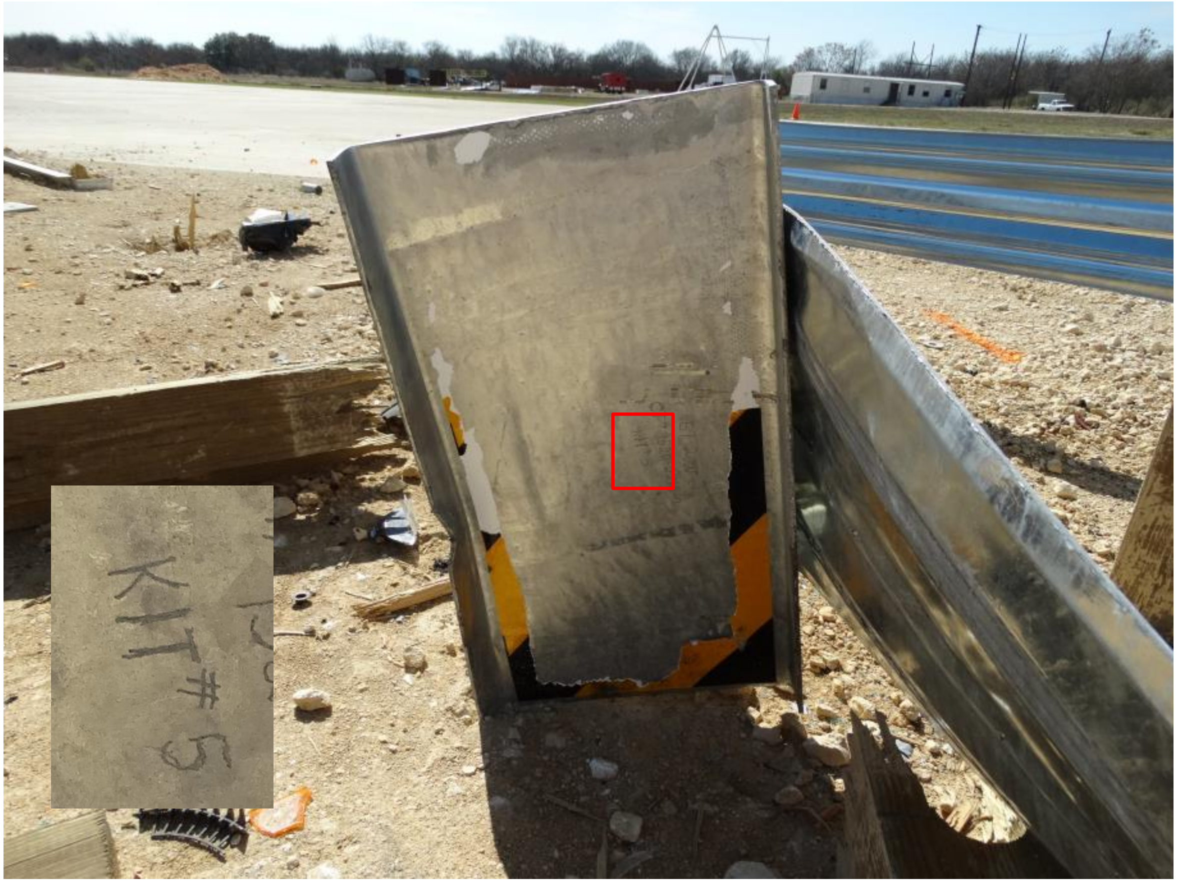


Figure 3.52: Post Test Verification of Extruder Head 5

Vehicle Damage

Figure 3.53: Vehicle Post Test Location (Front Left Tire Path in Green Paint)

Figure 3.54: Vehicle Post Test Location

Figure 3.55: Post Test Vehicle – Overhead View

Figure 3.56: Post Test Vehicle – Front View

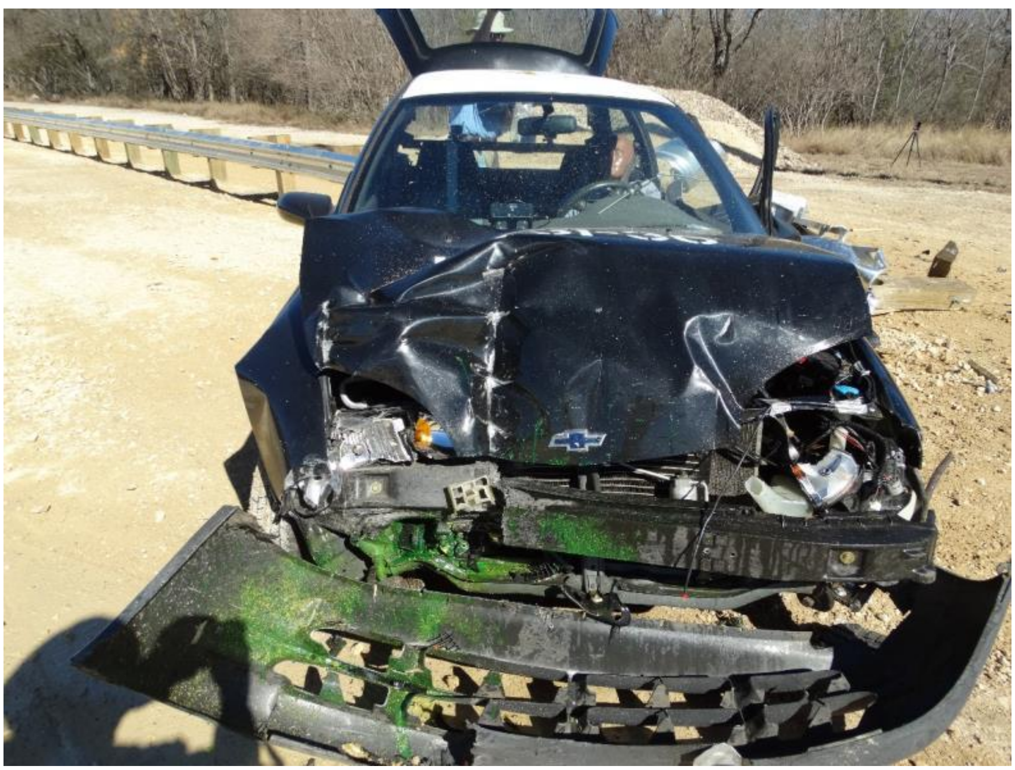


Figure 3.57: Post Test Vehicle – Front View Close-up

Figure 3.58: Post Test Vehicle – Front Hood

Figure 3.59: Post Test Vehicle – Right Side

Figure 3.60: Post Test Vehicle – Right Side, Close-up

Figure 3.61: Post Test Vehicle – Upstream View

Figure 3.62: Post Test Vehicle – Downstream View

Figure 3.63: Post Test Vehicle – Left Side

Figure 3.64: Post Test Vehicle – Left Side

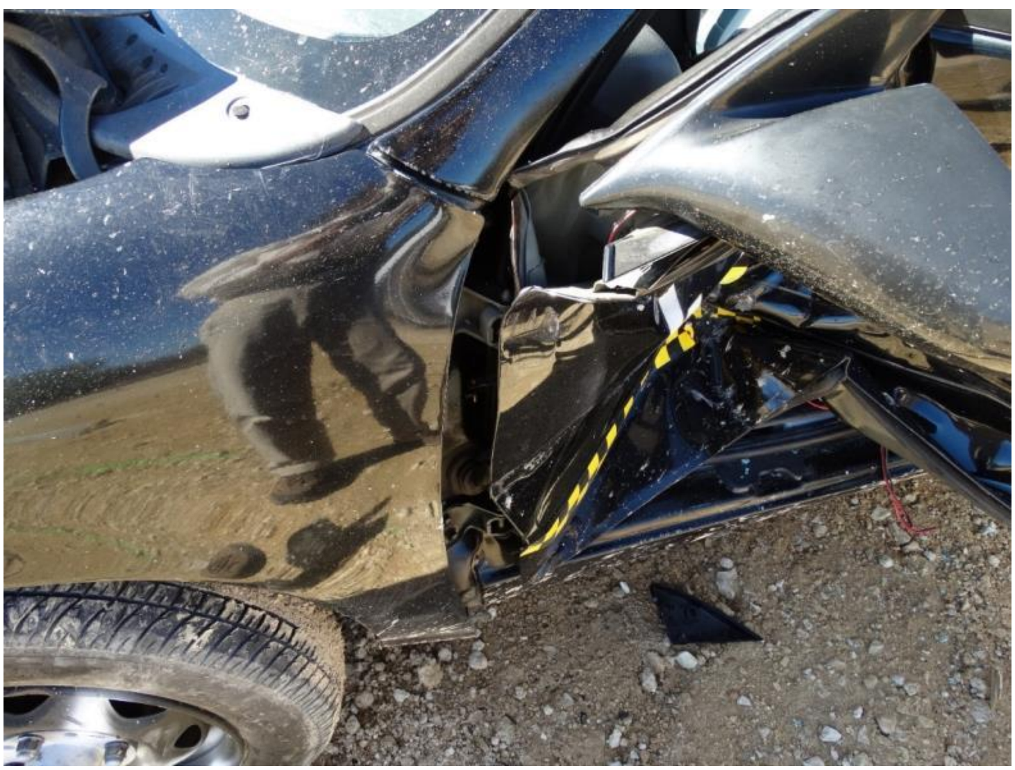


Figure 3.65: Post Test Vehicle – Left Side Door

Figure 3.66: Post Test Vehicle – Left Side Door

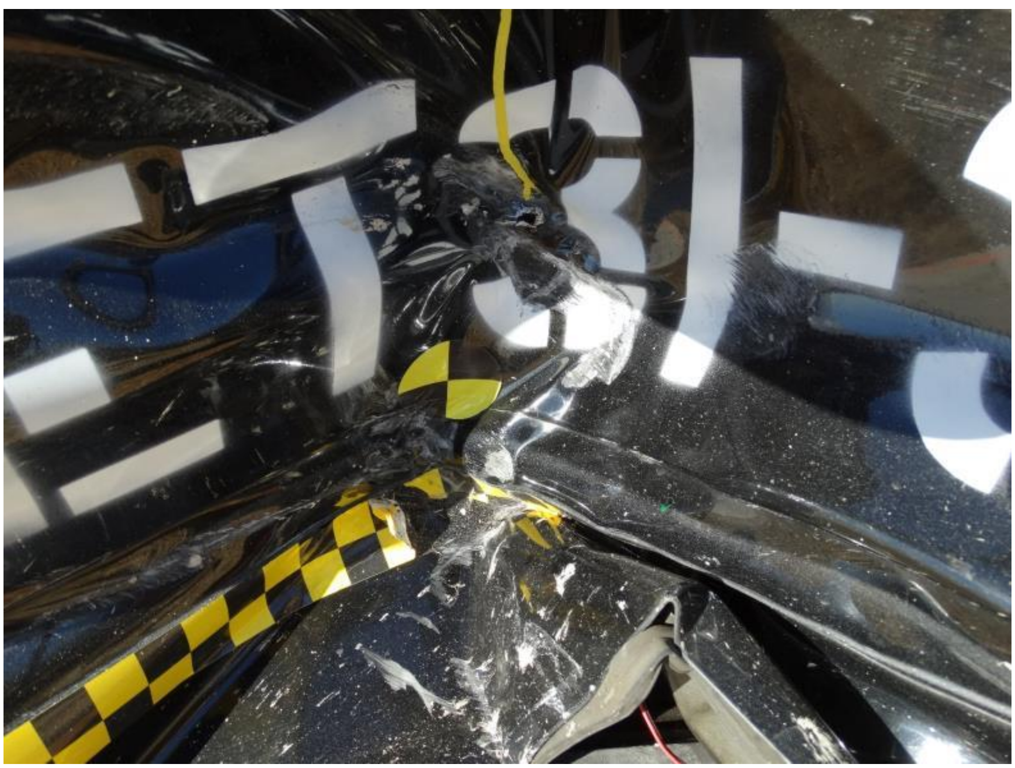


Figure 3.67: Post Test Vehicle – Left Side Door, Close-up

Figure 3.68: Post Test Vehicle – Left Side Door

Figure 3.69: Post Test Vehicle – Left Side Door and Door Panel

Figure 3.70: Post Test Vehicle – Left Side Door Panel

Figure 3.71: Post Test Vehicle – Left Side Door Panel, Interior

Figure 3.72: Post Test Vehicle – Left Side Door Panel , Interior

Figure 3.73: Post Test Vehicle – Left Side Door Panel, Interior

Figure 3.74: Post Test Vehicle – Left Side Door Panel, Interior

Figure 3.75: Post Test Vehicle – Occupant Compartment

Figure 3.76: Post Test Vehicle – Occupant Compartment

Figure 3.77: Post-Test – Driver Side Floorboard

Figure 3.78: Post-Test – Driver Side Floorboard, Close-up

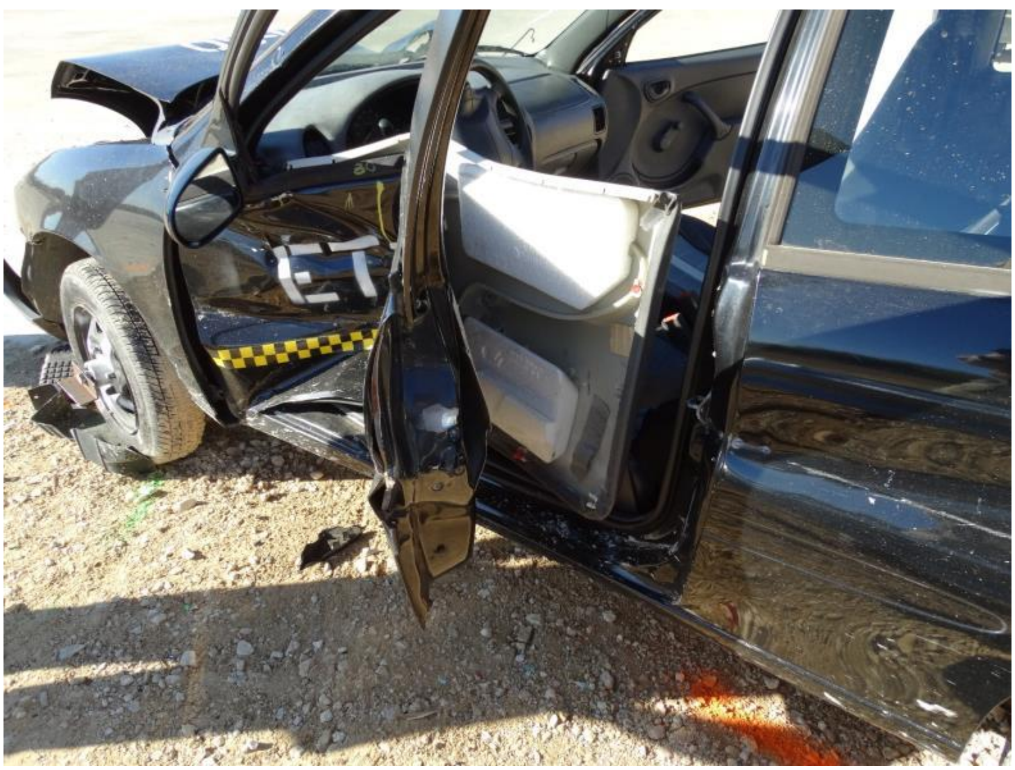


Figure 3.79: Dummy Removed – Left Side Door

Figure 3.80: Dummy Removed – Left Side Door, Top View

Figure 3.81: Measuring Interior Deformation

Figure 3.82: Location of Maximum Interior Deformation

Figure 3.83: Dummy Removed – Driver Side Occupant Compartment

Figure 3.84: Dummy Removed – Driver Side Floorboard

Figure 3.85: Dummy Removed – Driver Side Floorboard, Close-up

Figure 3.86: Post-Test – Passenger Side Floorboard

Figure 3.87: Post-Test – Passenger Side Floorboard, Close-up

4 ASSESSMENT OF TEST RESULTS

A comparison of the test results of Test ET31-30 against the evaluation criteria set forth in NCHRP Report 350 for Test 3-30 is provided in Table 4.1. A summary of the test results is provided in Table 4.2.

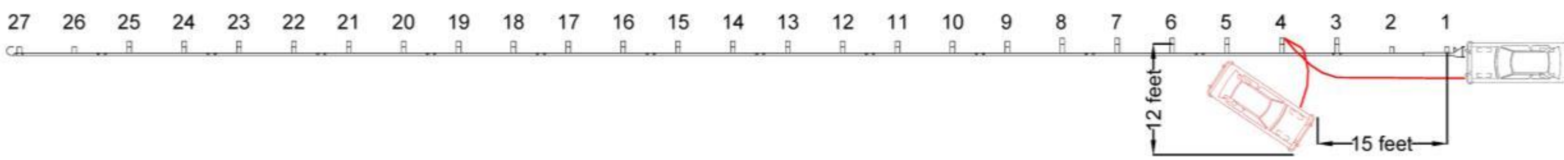
Table 4.1: Summary of Test Evaluation Results (NCHRP Report 350 Evaluation Criteria) for Test ET31-30

Evaluation Factor	Evaluation Criteria	Crash Test Result	Result
Structural Adequacy	C. Acceptable test article performance may be by redirection, controlled penetration, or controlled stopping of the vehicle.	Vehicle was decelerated 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.	The test article and debris did not penetrate occupant compartment or present undue hazard to traffic, pedestrians, or personnel. No indication of serious life-threatening injury due to occupant compartment reduction. OCDI rating of LF0000200. See photos for post-test location of debris.	Pass
	F. The vehicle should remain upright during and after collision although moderate roll, pitching and yawing are acceptable.	Vehicle remained stable and upright during and after the collision.	Pass
	H. Occupant Impact Velocities (OIV) limits: Preferred = 9 m/s Maximum = 12 m/s	Occupant impact velocities: Longitudinal: 8.2 m/s Lateral: 0.4 m/s	Pass
	I. Occupant Ridedown Acceleration (ORA) limits: Preferred = 15 g Maximum = 20 g	Occupant Ridedown Accelerations: Longitudinal: -11.8g Lateral: 8.7g	Pass
Vehicle Trajectory	K. After collision it is preferable that the vehicle's trajectory not intrude into adjacent traffic lanes.	See photos; vehicle path post-impact was on traffic side of the guardrail.	See Note[1,2]
	N. Vehicle trajectory behind the test article is acceptable.	See photos; vehicle path post-impact was on traffic side of the guardrail.	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.

Table 4.2: Summary of Test Results and Conditions for Test ET31-30



General Information		**Impact Conditions**		**Extruder Head Position from Start**	
Test Agency	Southwest Research Institute	Speed (km/hr)	102.8	Longitudinal	7.2 m (23.5 ft)
Test Number	ET31-30	Angle (degrees)	0.2	Lateral	1.3 m (4.4 ft)
Test Date	January 27, 2015	**Exit Conditions**		**Total System Deformation (Closest Point)**	
Test Category	3-30	Speed (km/hr)	N/A	Longitudinal	6.46 m (21.2 ft)
Test Article		Angle (degrees)	N/A	**Post Impact Vehicular Behavior**	
Type	End Terminal	**OCDI**	LF0000200	Max Vehicle Rotation (degrees)	
Terminal Length	16.2 m (53'-1½")	**Occupant Risk Values**		Max. Roll	5.5 @ 1.5496 sec.
Installation Length	49.5 m (162'-6")	Impact Velocity (m/s)		Max. Pitch	4.5 @ 0.7843 sec.
Nom. Barrier Height	78.7 cm (31 in.)	x-direction	8.2	Max. Yaw	219.1 @ 2.6298 sec.
Type of Primary Barrier	W-beam guardrail	y-direction	0.4	Max 50ms Moving Average Accelerations (g)	
Soil	Stable, Dry - "Standard" Soil	Ridedown Accelerations (g)		x-direction	-10.2 @ 0.2104-0.2604 sec.
Test Vehicle		x-direction	-11.8	y-direction	6.7 @ 0.6798-0.7298 sec.
Type	Small car	y-direction	8.7	z-direction	-2.2 @ 0.2471-0.2971 sec.
Designation	820C	**Target Conditions**			
Model	1998 Geo Metro	Nominal Speed	100 km/hr (62.1 mph)		
Curb Mass (kg)	808 as received	Nominal Angle	0°		
Ballast Mass (kg)	0	**Tolerances**			
Test Inertial Mass (kg)	808	Nominal Speed	±4 km/hr		
Dummy Mass (kg)	75	Nominal Angle	±1.5˚		
Gross Static Mass (kg)	883				

5 CONCLUSIONS

The performance of the ET Plus during Test ET31-30 against Structural Adequacy, Occupant Risk, and Vehicle Trajectory criteria specified in NCHRP Report 350 was as-follows:

Structural Adequacy

- The vehicle was decelerated in a controlled manner.

Occupant Risk

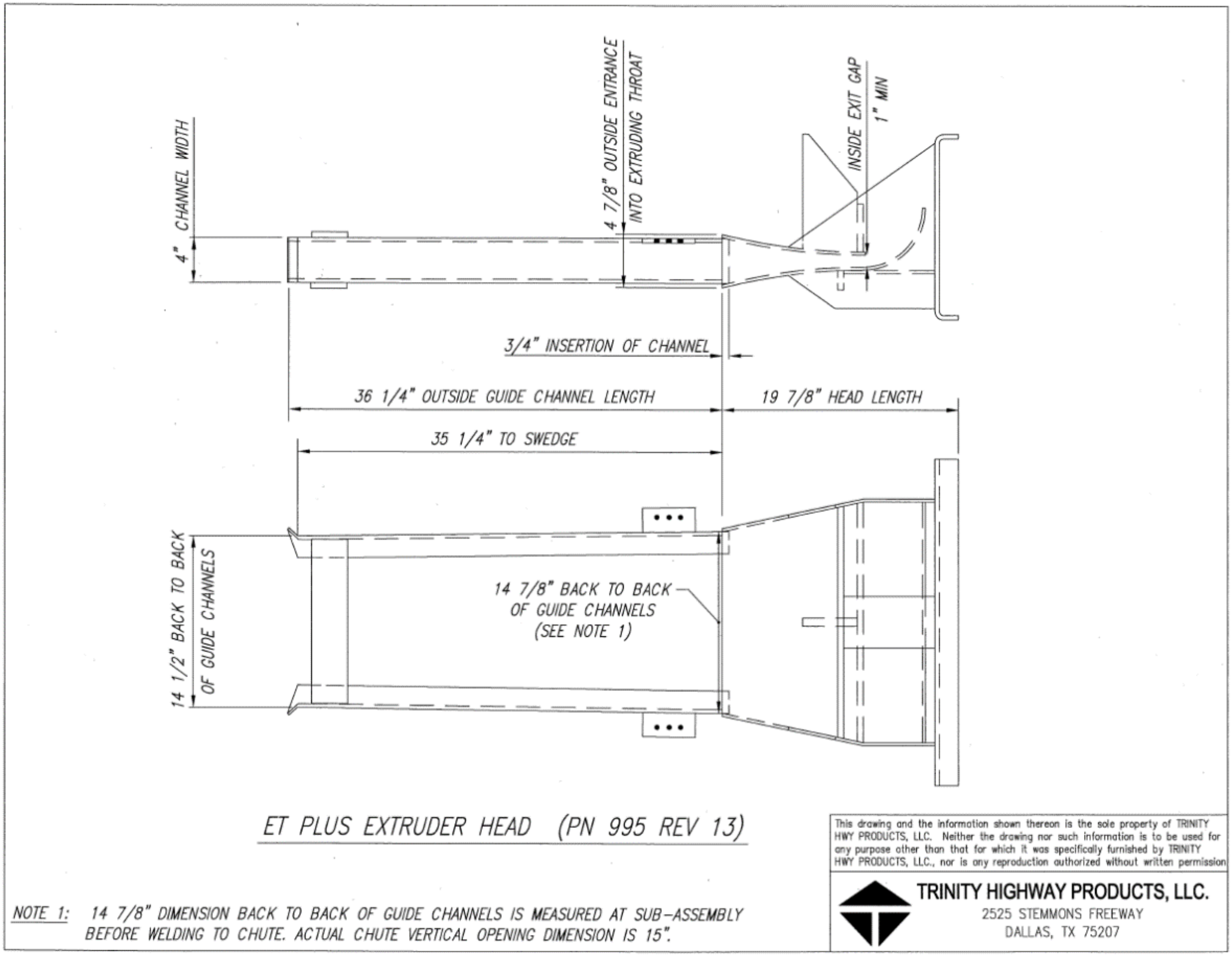
- The test article and debris did not penetrate the occupant compartment or present undue hazard to traffic, pedestrians, or personnel. No indication of serious or life-threatening injury due to occupant compartment reduction. OCDI rating of LF0000200.
- There was no undue hazard presented by test article debris outside of the immediate impact zone; the only debris thrown from the installation included pieces of the vehicle, posts and blockouts, the majority of which fell to the non-traffic side of the guardrail.
- The vehicle remained upright during and following the impact.
- The test article provided for controlled deceleration with impact velocity and ridedown acceleration values within allowable limits.

Vehicle Trajectory

- The vehicle was decelerated in a controlled manner and came to a stop on the traffic side of the installation.
- The vehicle was offset towards the traffic side of the installation as described in the Test Description section of this report; while this configuration was selected to maximize occupant risk as directed in NCHRP Report 350, it is widely recognized that vehicle trajectory and final resting position of the vehicle in Test 3-30 are prone to be in the adjacent travel lane.

Based on the information provided in this report, the ET Plus End Terminal with 4-inch wide guide channel installed with a rail height of 31” meets the Test Level 3, Test 3-30 criteria for NCHRP Report 350.

Appendix A: Test Article Drawings


4" CHANNEL WIDTH
4 7/8" OUTSIDE ENTRANCE INTO EXTRUDING THROAT
INSIDE EXIT GAP 1" MIN
3/4" INSERTION OF CHANNEL
36 1/4" OUTSIDE GUIDE CHANNEL LENGTH
19 7/8" HEAD LENGTH
35 1/4" TO SWEDGE
14 1/2" BACK TO BACK OF GUIDE CHANNELS
14 7/8" BACK TO BACK OF GUIDE CHANNELS (SEE NOTE 1)
ET PLUS EXTRUDER HEAD (PN 995 REV 13)
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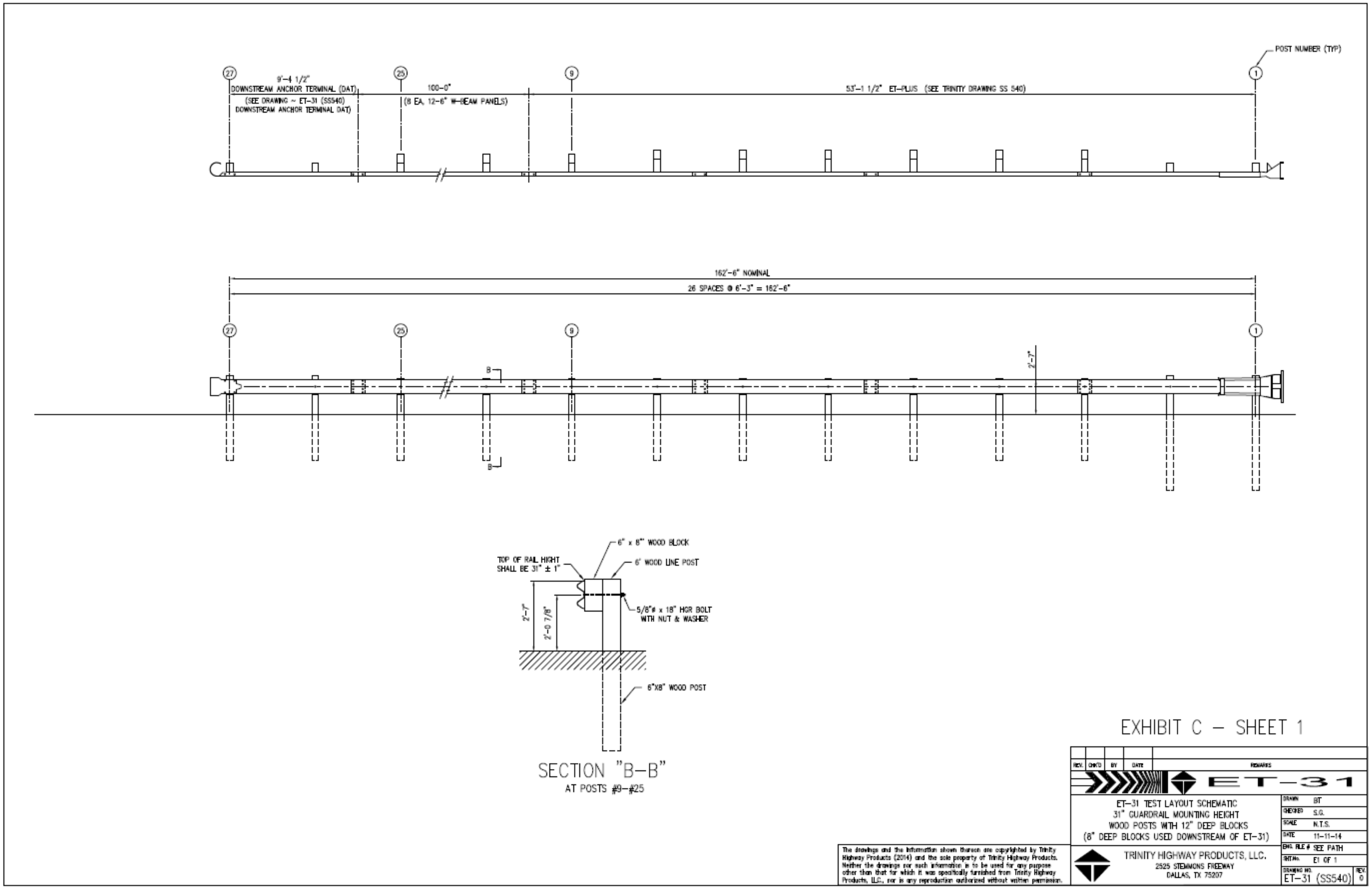
DALLAS, TX 75207
NOTE 1: 14 7/8" DIMENSION BACK TO BACK OF GUIDE CHANNELS IS MEASURED AT SUB-ASSEMBLY BEFORE WELDING TO CHUTE. ACTUAL CHUTE VERTICAL OPENING DIMENSION IS 15".


POST NUMBER (TYP)
9'-4 1/2"
DOWNSTREAM ANCHOR TERMINAL (DAT)
(SEE DRAWING ~ ET-31 (SS540)
DOWNSTREAM ANCHOR TERMINAL DAT)
100'-0"
(8 EA. 12'-6" W-BEAM PANELS)
53'-1 1/2" ET-PLUS (SEE TRINITY DRAWING SS 540)
162'-6" NOMINAL
26 SPACES @ 6'-3" = 162'-6"
2'-7"
6" x 8" WOOD BLOCK
TOP OF RAIL HIGHT SHALL BE 31" ± 1"
6' WOOD LINE POST
5/8"ø x 18" HGR BOLT WITH NUT & WASHER
2'-7"
2'-0 7/8"
6"X8" WOOD POST
SECTION "B-B"
AT POSTS #9-#25
EXHIBIT C – SHEET 1
REV. CHK'D BY DATE REMARKS
ET-31
ET-31 TEST LAYOUT SCHEMATIC
31" GUARDRAIL MOUNTING HEIGHT
WOOD POSTS WITH 12" DEEP BLOCKS
(8" DEEP BLOCKS USED DOWNSTREAM OF ET-31)
DRAWN BT
CHECKED S.G.
SCALE N.T.S.
DATE 11-11-14
ENG. FILE # SEE PATH
SHT.No. E1 OF 1
DRAWING NO. ET-31 (SS540)
REV. 0
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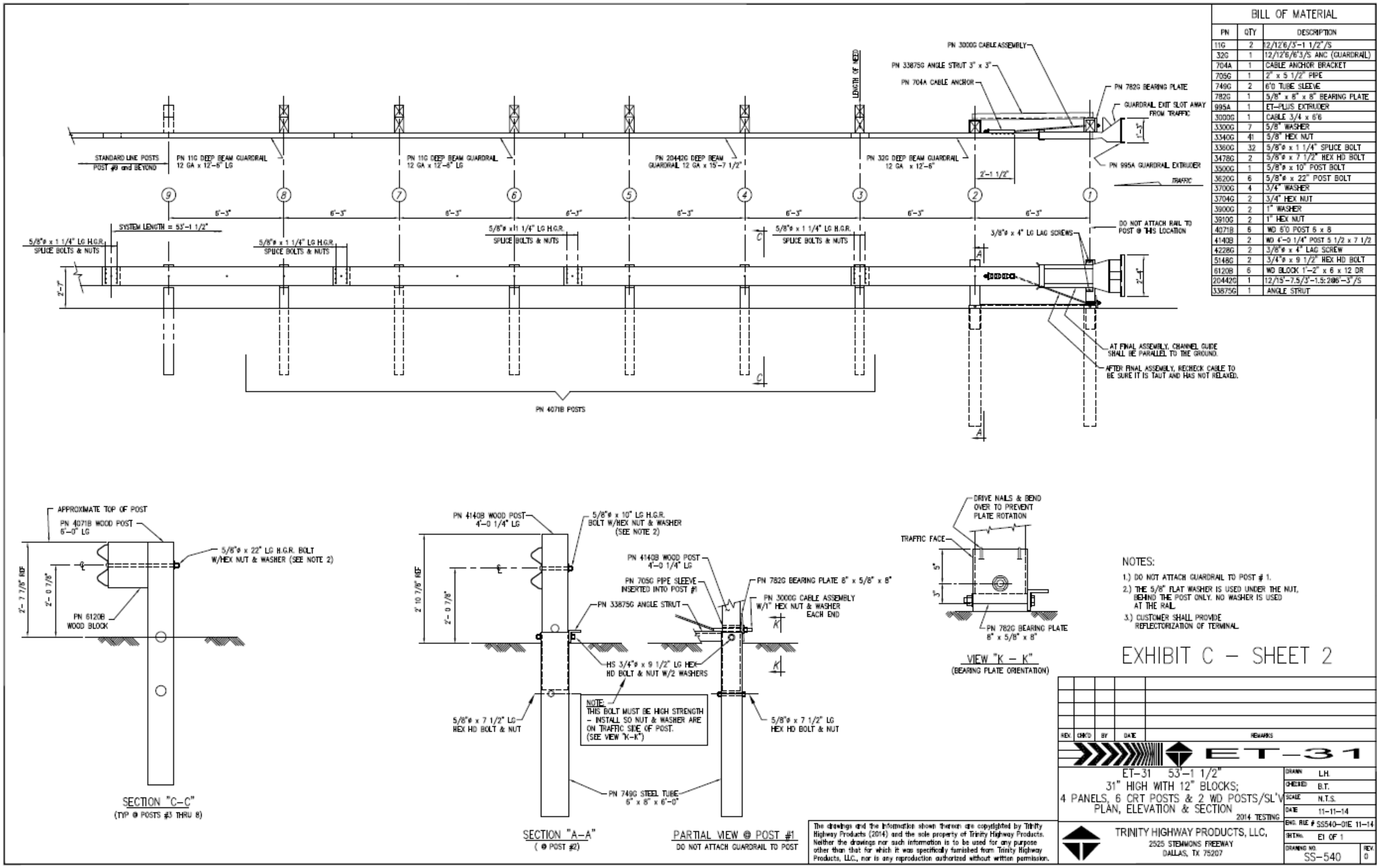
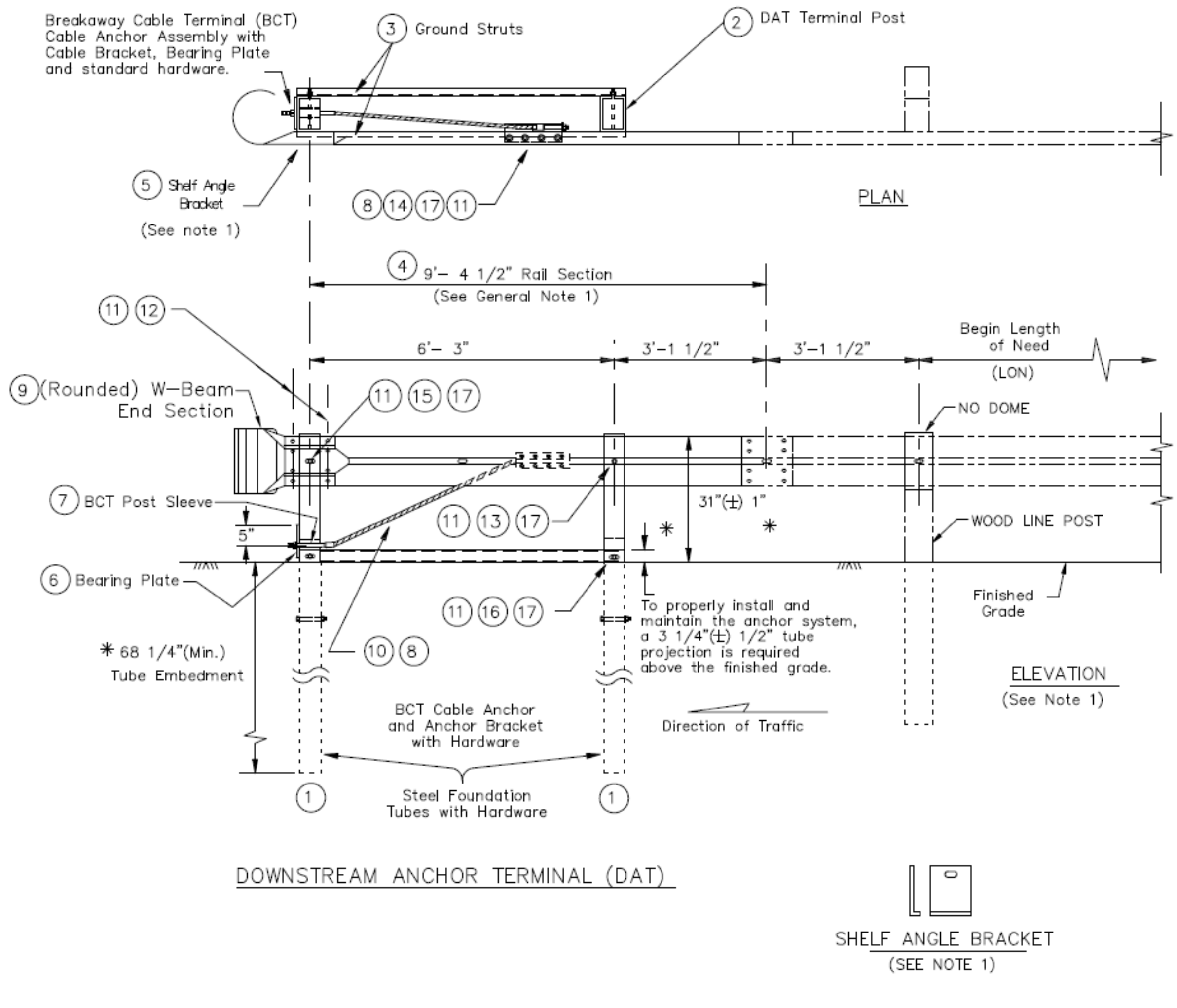
DALLAS, TX 75207



BILL OF MATERIAL

PN	QTY	DESCRIPTION
11G	2	12/12'6/3'-1 1/2"/S
32G	1	12/12'6/6'3/S ANC (GUARDRAIL)
704A	1	CABLE ANCHOR BRACKET
705G	1	2" x 5 1/2" PIPE
749G	2	6'0 TUBE SLEEVE
782G	1	5/8" x 8" x 8" BEARING PLATE
995A	1	ET-PLUS EXTRUDER
3000G	1	CABLE 3/4 x 6'6
3300G	7	5/8" WASHER
3340G	41	5/8" HEX NUT
3360G	32	5/8"ø x 1 1/4" SPLICE BOLT
3478G	2	5/8"ø x 7 1/2" HEX HD BOLT
3500G	1	5/8"ø x 10" POST BOLT
3620G	6	5/8"ø x 22" POST BOLT
3700G	4	3/4" WASHER
3704G	2	3/4" HEX NUT
3900G	2	1" WASHER
3910G	2	1" HEX NUT
4071B	6	WD 6'0 POST 6 x 8
4140B	2	WD 4'-0 1/4" POST 5 1/2 x 7 1/2
4228G	2	3/8"ø x 4" LAG SCREW
5148G	2	3/4"ø x 9 1/2" HEX HD BOLT
6120B	6	WD BLOCK 1'-2" x 6 x 12 DR
20442G	1	12/15'-7.5/3'-1.5:206'-3"/S
33875G	1	ANGLE STRUT



PN	#	(DAT) PARTS LIST	QTY
724	1	Steel Foundation Tube	2
4140	2	DAT Terminal Post	2
19481	3	Channel Strut	2
20207	4	Terminal Rail Element	1
9713	5	Shelf Angle Bracket	1
782	6	BCT Bearing Plate	1
705	7	BCT Post Sleeve	1
700	8	Guardrail Anchor Bracket	1
907	9	(Rounded)W–Beam End Section	1
3000	10	BCT Cable Anchor	1
	11	Recessed Nut, Guardrail	20
	12	1 1/4" Button Head Bolt	4
	13	10" Button Head Bolt	2
	14	5/8" x 2" Hex Head Bolt	8
	15	5/8" x 8" Hex Head Bolt	4
	16	5/8" x 10" Hex Head Bolt	2
	17	5/8" Flat Washer	18

GENERAL NOTES

1. The rail section at the end post is supported by the Shelf Angle Bracket. The rail element is not attached to the end post.

EXHIBIT C – SHEET 3

METAL BEAM GUARD FENCE
ET–31 (SS540) 2014 TESTING
DOWNSTREAM ANCHOR TERMINAL (DAT)

REF: TxDOT, GF31DAT14.DGN

Appendix B: SwRI Data Sheets for Test ET31-30

EXHIBIT D-1: Installation Checklist

Test Number: ET31-30 Test Date: ~~1/23/2015~~ delayed to 1/27/2015

*Record the following impact head dimensions:

OK

head stamp "5" 1/5/2015

Dimension	*Pre-Test Measurements
Exit Gap (middle - inside)	1.0495"
Entrance Gap (middle - outside)	4.7955"
Guide Chute Exit Height (outside)	15"
Guide Chute Entrance Height (outside)	14 9/16"
Channel Width (outside)	4.0450"
Channel Insertion into Extruder	0.1865" 0.4100" 0.4995" 0.6320"
Outside Guide Channel Length	36 1/8"
Outside Guide Channel Length – Chute to start of swedge	35 1/8"
Head length	56 3/8"

a. Guardrail height as measured from the ground to the top of the guardrail at mid-span for the first eight spans:
   a. Between post 1 and 2: 30 3/4 inches
   b. Between post 2 and 3: 30 7/8 inches
   c. Between post 3 and 4: 31 inches
   d. Between post 4 and 5: 31 1/4 inches
   Between post 5 and 6: 31 1/4 inches
   Between post 6 and 7: 30 3/4 inches
   Between post 7 and 8: 31 inches
   Between post 8 and 9: 31 inches
   e. (ET27 series: all heights to be greater than or equal to 27-3/4" and less than 28-3/4")
   f. (ET31 series: all heights to be greater than 30-1/2" and less than 31-1/2")
b. Distance from the ground to the bottom of the impact face: 10 3/8 inches.
c. Distance from the ground to the top of the impact face: 38 1/4 inches.
d. Soil in the area around impact area and runout area is smooth and flat: YES NO (circle one).
e. Backfill around the posts has been re-compacted: YES NO (circle one).
f. Distance from the ground to the top of the first foundation tube: 2 5/8 inches (Must be 4 inches or less).
g. Distance from the ground to the top of the second foundation tube: 2 1/4 inches (Must be 4 inches or less).
h. Bolts at the top of the foundation tubes at posts one and two are not overtightened and the walls of the steel tube are not collapsed or deformed: YES NO (circle one).
i. The ET-PLUS extruder head is pushed as far as it will go on the guardrail panel. The guardrail extends into the extruder 2 1/4 inches.

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JAM 1/27/15

j. The two bolts (top and bottom) holding the extruder head to post one are snug and the extruder channel is approximately parallel to the finished grade (i.e., level): YES NO (circle one).
k. The cable anchor bracket is locked into place by pulling the bracket toward the impact end of the unit: YES NO (circle one). Make sure the hooks/lugs are well seated into the square holes on the guardrail.
l. The hex nuts on the cable ends are tightened such that the cable is taut: YES NO (circle one). The cable is taut when it does not deflect more than 1 inch when hand pressure is applied perpendicular to the mid-span of the cable.
m. The bearing plate is placed on the impact side of post 1 where the cable extends through the post: YES NO (circle one).
n. The cable bearing plate is oriented with the long dimensions turned up (from top of plate to center of cable hole is 5"): YES NO (circle one).
o. Wood blockouts have been toe-nailed to the posts: YES NO (circle one).
p. The CRT post top hole is located with the center of the hole approximately at the ground line (± 2"): YES NO (circle one).
q. The guardrail panels are lapped correctly: YES NO (circle one).

Completed by: Oliver Karam 1/21/2015

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42

2C1MR2261W6703950

DATE: 12/19/14 TEST NO.: ET31-30 VIN NO.: ↑ MAKE: ~~CHEVY~~ GEO

MODEL: GEO METRO YEAR: 1998 ODOMETER: 139695 TIRE SIZE: 155/80 13

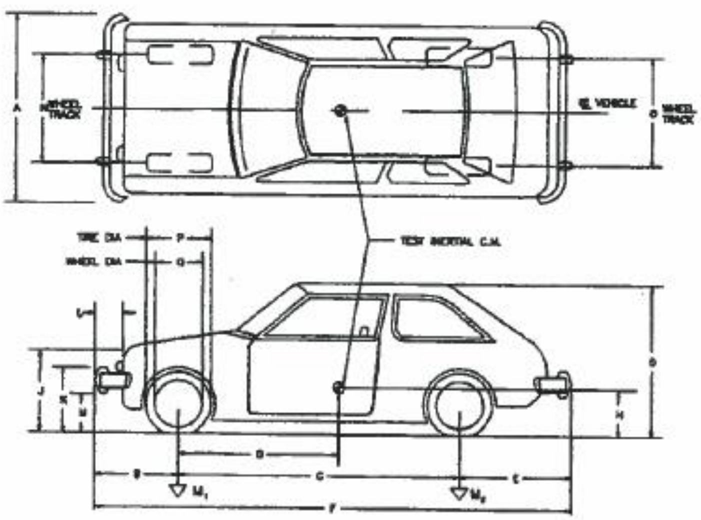
TIRE INFLATION PRESSURE: ______

MASS DISTRIBUTION (kg) LF 550 RF 560 LR 339 RR 333

TOTAL 1782

DESCRIBE ANY DAMAGE TO VEHICLE PRIOR TO TEST:

NONE



ENGINE TYPE: GAS

ENGINE CID: 1.0L

TRANSMISSION TYPE:

— AUTO

✓ MANUAL

OPTIONAL EQUIPMENT:

DUMMY DATA:

TYPE: ______

MASS: 165

SEAT POSITION: driver

CG 11.6" above the spindle

GEOMETRY – (cm)

A 60½"	D 56"	G 35.07"	K 21"	N 54""	Q 14¼"
B 32"	E 23½"	H 22.35"	L 4"	O 52¾	
C 93"	F 148½"	J 26"	M 17"	P 22⅛"	

MASS – (kg)	CURB	TEST INERTIAL	GROSS STATIC
M_1			
M_2			
M_T			

EDR Behind FRONT Axel 4 3/4" FROM GROUND 17"

Figure 4.1. 700C and 820C parameters.

OK 1/26/2015

Appendix C: Laboratory Statement

SOUTHWEST RESEARCH INSTITUTE®

6220 CULEBRA ROAD 78238-5166 • P.O. DRAWER 28510 78228-0510 • SAN ANTONIO, TEXAS, USA • (210) 684-5111 • WWW.SWRI.ORG

Refer to: 18.20887
January 15, 2015

TRINITY HIGHWAY PRODUCTS LLC
2525 Stemmons Freeway
Dallas, Texas 75207

Subject: Proposal and Fixed-Price Contract for Services No. 18-73314
SwRI® Project No. 18.20887

To Whom It May Concern:

Southwest Research Institute hereby attests to the following:

- SwRI is listed on FHWA's roster of laboratories suitable for performing NCHRP Report 350 and MASH crash tests.
- SwRI is currently ISO 17025 accredited by A2LA to perform NCHRP Report 350 and MASH crash tests (Testing Laboratory Certificate 1110.02).
- SwRI has not previously conducted crash testing of the ET-Plus End Terminal system.
- SwRI does not own intellectual property and does not receive royalty-related revenue associated with any of the roadside safety hardware involved in this test program or any guardrail terminal products competing with the ET-Plus End Terminal system.
- SwRI is financially independent from Trinity Highway Products and the Texas Transportation Institute (TTI) at Texas A&M University.

I, R. B. Kalmbach, Executive Director of Contracts, certify on behalf of Southwest Research Institute that the above representations are current, accurate and complete as of the date of this letter.

Should you have any questions, please contact Ms. Mary Lepel at 210/522-3026, by facsimile at 210/522-3559, or email mary.lepel@swri.org.

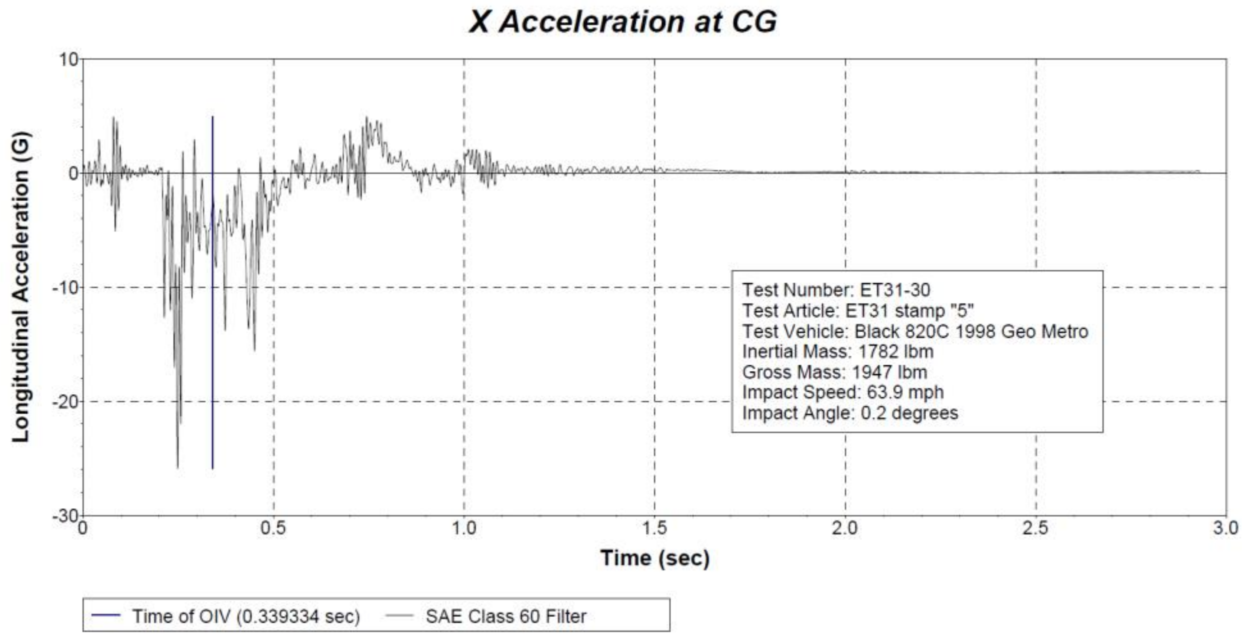
Sincerely,

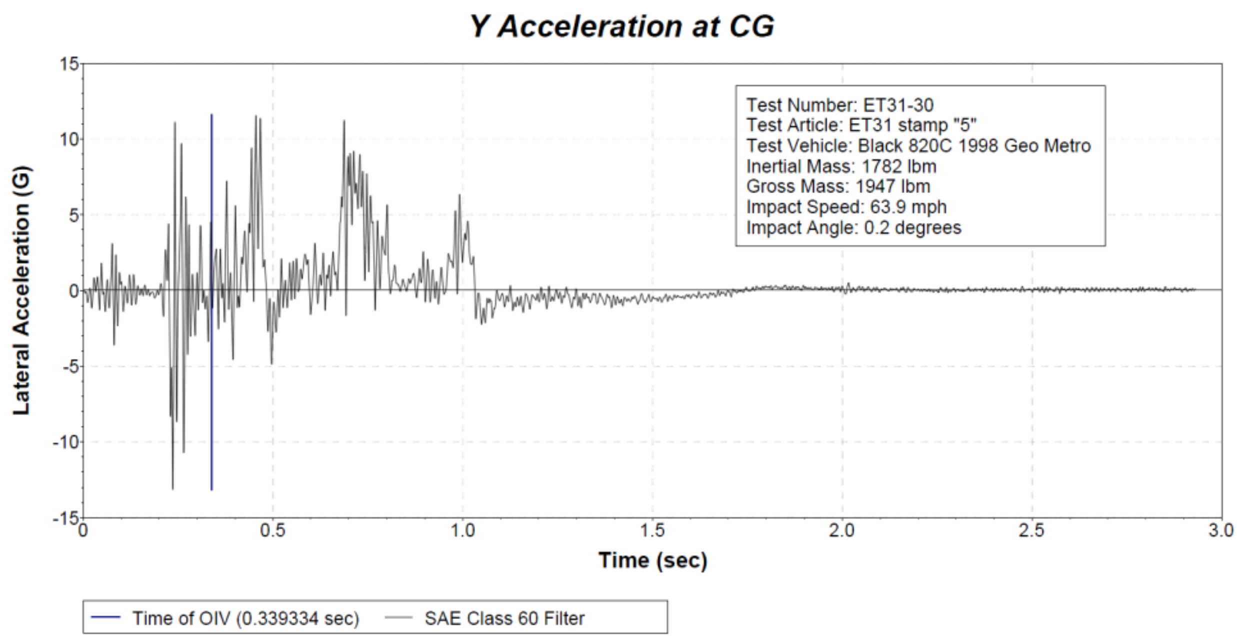
R. B. Kalmbach
Executive Director, Contracts

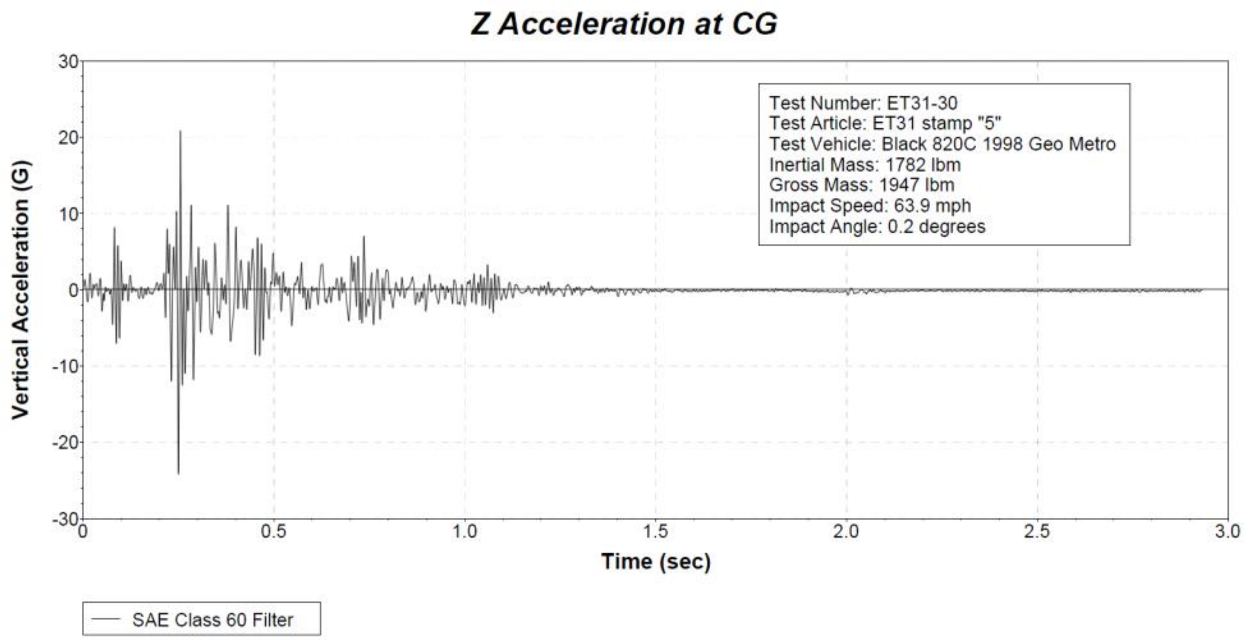
RBK/MKL/jms
cc: J. Ferren, SwRI (via email)

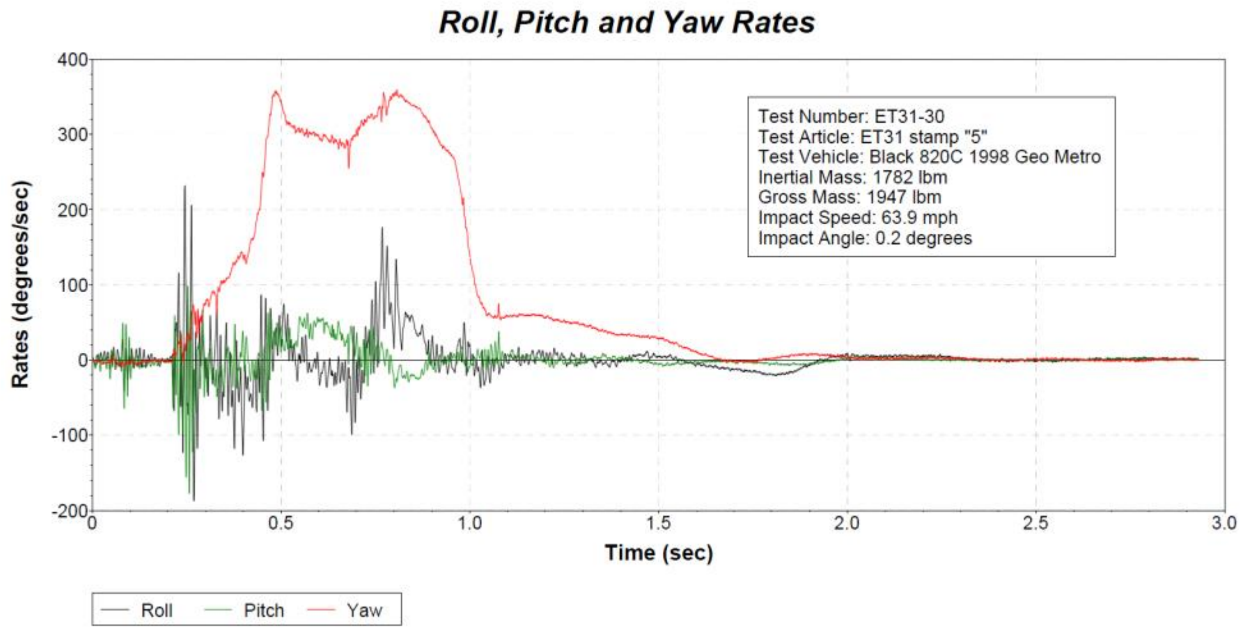
Benefiting government, industry and the public through innovative science and technology

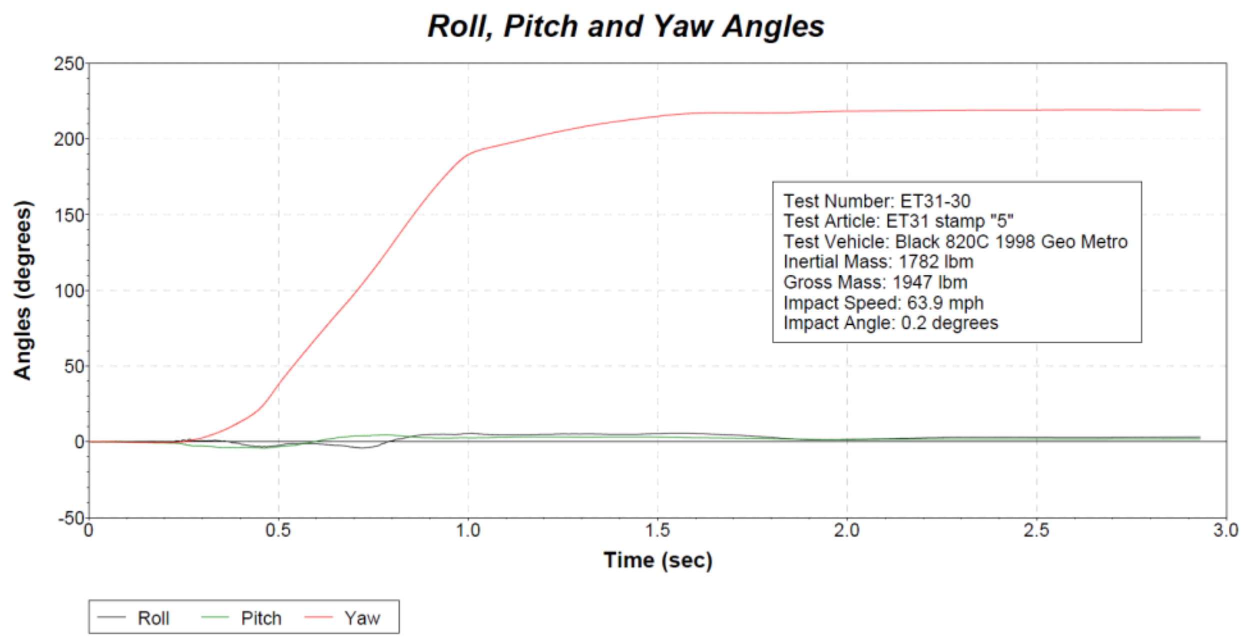
Appendix D: Test Data Plots


X Acceleration at CG
Longitudinal Acceleration (G)
Time (sec)
Test Number: ET31-30
Test Article: ET31 stamp "5"
Test Vehicle: Black 820C 1998 Geo Metro
Inertial Mass: 1782 lbm
Gross Mass: 1947 lbm
Impact Speed: 63.9 mph
Impact Angle: 0.2 degrees
Time of OIV (0.339334 sec)
SAE Class 60 Filter


Y Acceleration at CG
Lateral Acceleration (G)
Time (sec)
Test Number: ET31-30
Test Article: ET31 stamp "5"
Test Vehicle: Black 820C 1998 Geo Metro
Inertial Mass: 1782 lbm
Gross Mass: 1947 lbm
Impact Speed: 63.9 mph
Impact Angle: 0.2 degrees
Time of OIV (0.339334 sec)
SAE Class 60 Filter


Z Acceleration at CG
Test Number: ET31-30
Test Article: ET31 stamp "5"
Test Vehicle: Black 820C 1998 Geo Metro
Inertial Mass: 1782 lbm
Gross Mass: 1947 lbm
Impact Speed: 63.9 mph
Impact Angle: 0.2 degrees
Vertical Acceleration (G)
30
20
10
0
-10
-20
-30
0
0.5
1.0
1.5
2.0
2.5
3.0
Time (sec)
SAE Class 60 Filter


Roll, Pitch and Yaw Rates
Rates (degrees/sec)
400
300
200
100
0
-100
-200
0
0.5
1.0
1.5
2.0
2.5
3.0
Time (sec)
Test Number: ET31-30
Test Article: ET31 stamp "5"
Test Vehicle: Black 820C 1998 Geo Metro
Inertial Mass: 1782 lbm
Gross Mass: 1947 lbm
Impact Speed: 63.9 mph
Impact Angle: 0.2 degrees
Roll
Pitch
Yaw


Roll, Pitch and Yaw Angles
Angles (degrees)
250
200
150
100
50
0
-50
0
0.5
1.0
1.5
2.0
2.5
3.0
Time (sec)
Test Number: ET31-30
Test Article: ET31 stamp "5"
Test Vehicle: Black 820C 1998 Geo Metro
Inertial Mass: 1782 lbm
Gross Mass: 1947 lbm
Impact Speed: 63.9 mph
Impact Angle: 0.2 degrees
Roll
Pitch
Yaw

Appendix E: Soil Test Data

LABORATORY COMPACTION CHARACTERISTICS OF SOIL REPORT

Report Number: 90141414.0001
Service Date: 12/03/14
Report Date: 12/10/14

6911 Blanco Road
San Antonio, TX 78216-6164
210-641-2112 Reg No: F-3272

Client

Southwest Research Institute
Attn: Jenny Ferren
6220 Culebra Road
San Antonio, TX 78228

Project

Southwest Research Institute-Moisture Testing
6220 Culebra Rd
San Antonio, TX

Project Number 90141414

Material Information

Source of Material: Project Site
Proposed Use: Fill

Sample Information

Sample Date: 12/03/14
Sampled By: Benjamin Butler
Sample Location: Project Site

Sample Description: Crushed Limestone

Laboratory Test Data

Test Procedure: ASTM D698
Test Method: Method C
Sample Preparation: Wet
Rammer Type: Mechanical

	Result	Specifications
Liquid Limit:	22	
Plastic Limit:	13	
Plasticity Index:	9	
In-Place Moisture (%):		

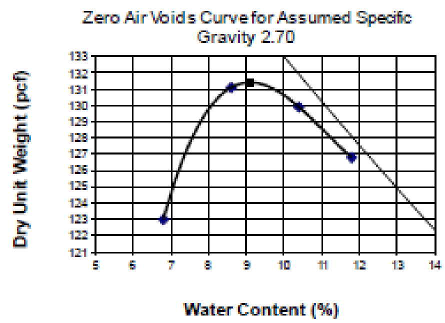
USCS:

Oversized Particles (%): 14.5
Moisture (%): 2.8
Sieve for Oversize Fraction: 3/4

Assumed Bulk Specific Gravity of Oversized Particles: 2.7

Corrected for Oversized Particles (ASTM D4718)
Maximum Dry Unit Weight (pcf): 131.4
Optimum Water Content (%): 9.1

Uncorrected Values
Maximum Dry Unit Weight (pcf): 126.6
Optimum Water Content (%): 10.2



Comments:

Services: Obtain a sample of treated subgrade at the project site and return it to the laboratory. Prepare and test the sample for moisture-density relationship and plasticity index.

Terracon Rep.: Benjamin Butler
Reported To:
Contractor:
Report Distribution:

(1) Southwest Research Institute, jenny.ferren@swri.org

(1) Terracon Consultants, Inc., dejacobs@terracon.com

Reviewed By:

Daniel E. Jacobs
Senior Project Manager

Test Methods: ASTM

The tests were performed in general accordance with applicable ASTM, AASHTO, or DOT test methods. This report is exclusively for the use of the client indicated above and shall not be reproduced except in full without the written consent of our company. Test results transmitted herein are only applicable to the actual samples tested at the location(s) referenced and are not necessarily indicative of the properties of other apparently similar or identical materials.

CR0006, 10-16-13, Rev.7 Page 1 of 1

LABORATORY COMPACTION CHARACTERISTICS OF SOIL REPORT

Report Number: 90141414.0001
Service Date: 12/03/14
Report Date: 12/10/14

Terracon
6911 Blanco Road
San Antonio, TX 78216-6164
210-641-2112 Reg No: F-3272

Client
Southwest Research Institute
Attn: Jenny Ferren
6220 Culebra Road
San Antonio, TX 78228

Project
Southwest Research Institute-Moisture Testing
6220 Culebra Rd
San Antonio, TX

Project Number: 90141414

SIEVE ANALYSIS

Sieve Size	% Retained	TXDOT Item 247.2 Type A Grade 2 Specifications % Retained
1 ¾	0	0-10
7/8	11	---
3/8	35	---
#4	50	45-75
#40	75	60-85
#200	84	----

Remarks: The indicated laboratory tests were performed in general accordance with applicable ASTM standards unless otherwise noted. All test results meet the reference specification requirements unless noted by an asterisk *.

Services: Obtain a sample of treated subgrade at the project site and return it to the laboratory. Prepare and test the sample for moisture-density relationship and plasticity index.
Terracon Rep.: Benjamin Butler
Reported To:
Contractor:
Report Distribution:
(1) Southwest Research Institute, jenny.ferren@swri.org
(1) Terracon Consultants, Inc., dejacobs@terracon.com

Reviewed By: Daniel E. Jacobs
Daniel E. Jacobs
Senior Project Manager

CT0001, 9-28-10, Rev.8
Page 1 of 1

FIELD DENSITY TEST REPORT

Report Number: 90141414.0016
Service Date: 01/27/15
Report Date: 01/27/15
Task:

Terracon
6911 Blanco Road
San Antonio, TX 78216-6164
210-641-2112 Reg No: F-3272

Client

Southwest Research Institute
Attn: Jenny Ferren
6220 Culebra Road
San Antonio, TX 78228

Project

Southwest Research Institute-Moisture Testing
6220 Culebra Rd
San Antonio, TX

Project Number: 90141414

Material Information

Mat. No.	Proctor Ref. No.	Classification and Description	Laboratory Test Method	Lab Test Data: Optimum Water Content (%)	Lab Test Data: Max. Lab Density (pcf)	Project Requirements: Water Content (%)	Project Requirements: Compaction (%)
1	90141414.0001	Crushed Limestone	ASTM D698	9.1	131.4	10% Max	N/A

Field Test Data

Test No.	Test Location	Lift / Elev.	Mat. No.	Probe Depth (in)	Wet Density (pcf)	Water Content (pcf)	Water Content (%)	Dry Density (pcf)	Percent Compaction (%)
	ET 31-30								
1	NE Corner of Post #2	1	1	12	142.4	8.1	6.0	134.3	100+
2	NE Corner of Post #4	1	1	12	144.4	9.2	6.8	135.2	100+
3	NE Corner of Post #6	1	1	12	137.9	10.2	8.0	127.7	97.2

Datum: **Serial No:**

Comments: **Test and/or retest results on this report meet project requirements as noted above.**

Services: Perform in-place density and moisture content tests to determine degree of compaction and material moisture condition.
Terracon Rep.: Esquivel, James
Reported To:
Contractor:
Report Distribution:
(1) Southwest Research Institute, jenny.ferren@swri.org
(1) Terracon Consultants, Inc., dejacobs@terracon.com

Reviewed By: Daniel E. Jacobs
Daniel E. Jacobs
Senior Project Manager

Test Methods: *, ASTM D6938

The tests were performed in general accordance with applicable ASTM, AASHTO, or DOT test methods. This report is exclusively for the use of the client indicated above and shall not be reproduced except in full without the written consent of our company. Test results transmitted herein are only applicable to the actual samples tested at the location(s) referenced and are not necessarily indicative of the properties of other apparently similar or identical materials.

CR0007, 11-16-12, Rev.7

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