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 27¾ Inches

Test Level 3, Test 3-33, 3-31, 3-32, and 3-30

Tests: ET27-33, ET27-31, ET27-32 and ET27-30

SwRI® Project No. 18.20887

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Issue 1

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

January 23, 2015

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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 27¾ 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
ET27-33	Test 3-33	12/10/2014	2000P	15°
ET27-31	Test 3-31	12/16/2014		0°
ET27-32	Test 3-32	12/17/2014	820C	15°
ET27-30	Test 3-30	1/6/2015		0°

A summary of the performance of the ET Plus End Terminal during the four tests performed in the ET27 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 27¾ 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 ET27 Test Series

Evaluation Factor	Evaluation Criteria	Test Results			
		ET27-33	ET27-31	ET27-32	ET27-30
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.

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 27¾ Inches

Test Level 3, Test 3-33
Test Identification: ET27-33

SwRI® Project No. 18.20887

SwRI Document Number: 18.20887.03.100.FR1
Issue 1

Prepared for:
Trinity Highway Products
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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	1/23/2015

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

1 INTRODUCTION

The purpose of Crash Test ET27-33 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 27¾”. 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 47.6 m (156’-3”), including the 15.2 m (50 ft) 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 vehicle 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 ET27-33 was conducted on December 10, 2014, 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 27¾". The ET Plus End Terminal installation tested uses standard AASHTO M180 Type 2, 12-gauge, 12'-6" W beam guardrail panels mounted with the top of the rail 27¾ inches 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.

During installation, holes approximately 2' 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 cm (6 in) lifts, and was added until the surface was flush with the surrounding soil.

The guardrail line posts are 6" x 8" wood posts with 6" x 8" wood blockouts. The blockouts are toenailed, and the guardrail panels are mounted to the posts using 5/8"ϕ post bolts beginning with Post 2; the bolt for Post 2 is 10" long, and all other post bolts are 18" long. The post spacing is 6'-3", and each splice joint used eight (8) 5/8"ϕ x 1-1/4" splice bolts and nuts; the splice bolts have a nominal total length of 1-5/8" including the bolt head. The installation uses 3/4"ϕ x 10" 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 guardrail splices at each odd-numbered post starting with Post 3.

The total system installation length for the test was nominally 156'-3" (47.6 m), including the 50 ft (15.2 m) ET Plus terminal length, 81'-3" (24.8 m) of guardrail, and a 25' (7.6 m) downstream terminal anchor section that included a turndown guardrail anchor spliced at Post 22 and mounted to a concrete footing. 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 ET27-33 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 2.1 through Figure 2.18 present photographs of the guardrail installation.

Table 2.1: Key ET Plus Head Dimensions

Extruder Head Stamp ID	1
Exit Gap	1.3260”
Entrance Gap	4.7790”
Guide Chute Exit Height	15”
Guide Chute Entrance Height	14-1/2”
Channel Width (see Figure 2.2)	4.0325”

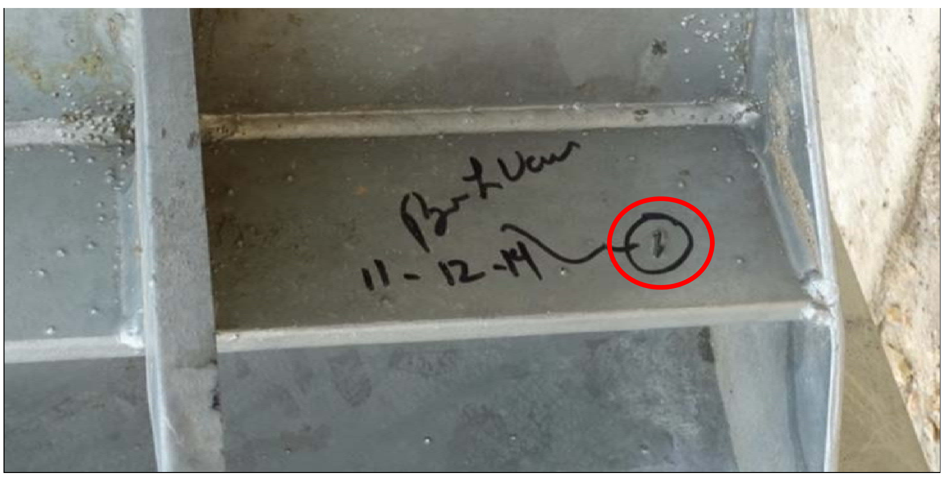


Figure 2.1: ET Plus Head Sample Identification Number

Figure 2.2: Measurement of Channel Width of Head

Figure 2.3: Test Installation for ET Plus Test ET27-33

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

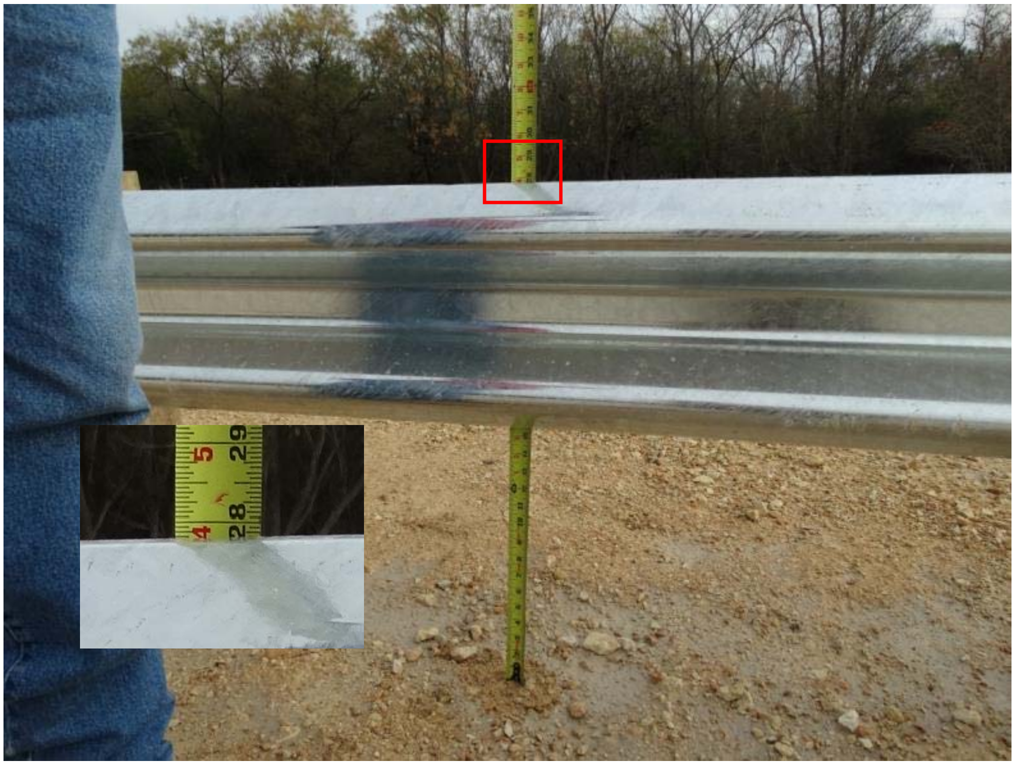


Figure 2.7: Measurement of Guardrail Installation Height

Figure 2.8: ET Plus Head and Anchor Cable Assembly

Figure 2.9: End Terminal Anchor Cable Mount – Post 1

Figure 2.10: End Terminal Cable Anchor

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: ET Plus Head and Post 1 – Traffic Side

Figure 2.14: ET Plus Head and Post 1 – Close-up

Figure 2.15: End Terminal Head with Posts 1 & 2 and Strut

Figure 2.16: ET Plus Head Extruder Exit (see Appendix B for Dimensions)

Figure 2.17: Post 22 Immediately Preceding Downstream Turndown Anchor

Figure 2.18: Downstream Turndown Anchor

Test Vehicle

The test vehicle was a 1995 Chevrolet C2500 pickup truck, shown in Figure 2.19; the vehicle data sheet is provided in Appendix B. Figure 2.20 and Figure 2.21 show the relationship between the height of the vehicle bumper and the end terminal. Figure 2.22 shows the test vehicle positioned at the impact point of the end terminal, and Figure 2.23 shows an overhead view of the test vehicle positioned at the intended crash angle of 15° and at the vehicle's centerline. Figure 2.24 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 1974 kg (4,352 lbs) as reflected in Table 4.2.

Figure 2.19: Test Vehicle for Test ET27-33

Figure 2.20: Test Vehicle Bumper Height

Figure 2.21: Test Vehicle Bumper Relative to ET Plus Head

Figure 2.22: Test Vehicle Impact Trajectory

Figure 2.23: Test Vehicle Impact Trajectory – Overhead View

Figure 2.24: 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 2.25. 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 2.25: 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 2.26 and 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 2.26: EDR Mounted in Test Vehicle for Test ET27-33

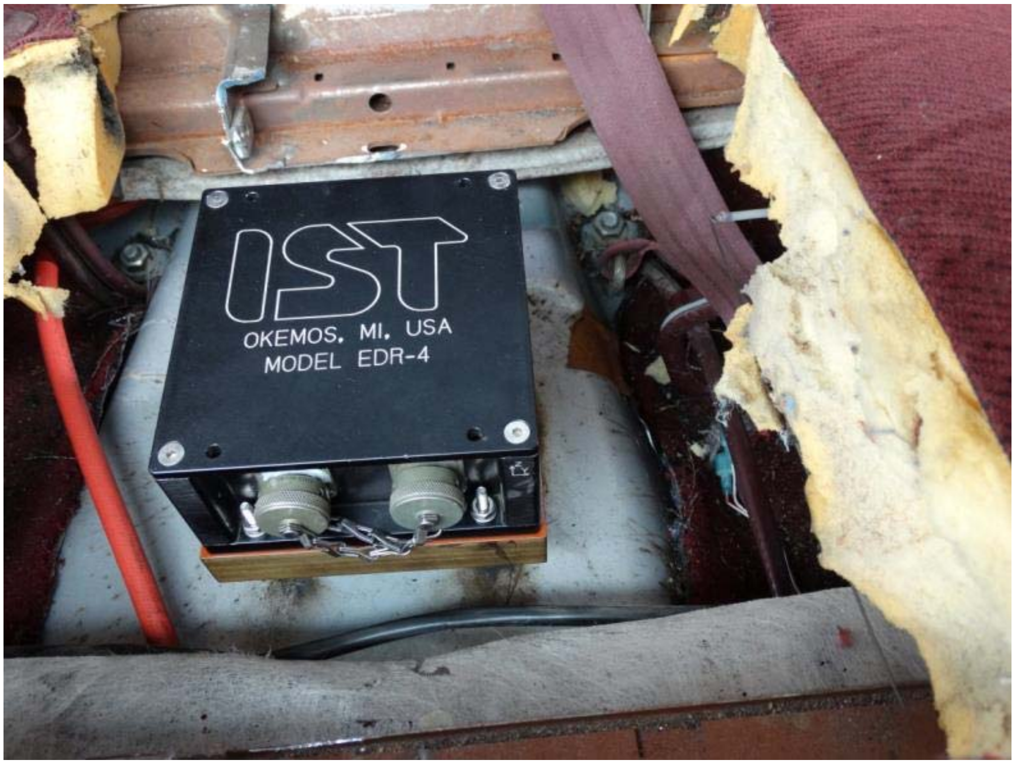


Figure 2.27: Close-up of EDR Mounted in Vehicle

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.

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 7.7% measured 10' from the installation. 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 ET27-33 on December 10, 2014:

- Federal Highway Administration (FHWA)
- US DOT
- CalTrans (California DOT)
- Florida DOT
- Virginia DOT
- Texas DOT (AASHTO Representative)

Observers from FHWA, US DOT 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 system the following day.

3 TEST CONDITIONS AND RESULTS

Test Description

The purpose of Test ET27-33 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 27¾". 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 156'-3" (47.6 m), and the terminal length was 15.2 m (50 ft).

Test 3-33 is intended primarily to evaluate occupant risk and vehicle trajectory criteria. The test consists of a 2000 kg vehicle 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.

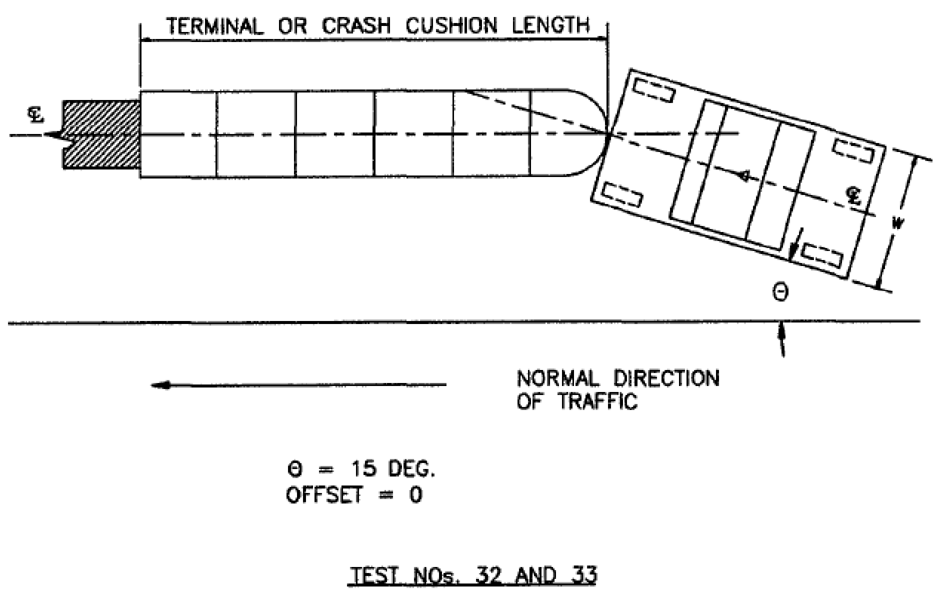


Figure 3.1: Impact Configuration *[from Figure 3.2 of NCHRP Report 350]*

The weather on the day of the test was mostly sunny, with temperatures ranging from 51-68°F. The temperature at the time of the test was approximately 68°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 103.3 km/hr (64.2 mph). As a result of the test, the ET Plus extruder head moved 5.8 m (19.1 ft) longitudinally (downstream) and 0.4 m (1.5 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 4.23 m (13.9 ft) from the initial point of contact.

Immediately prior to the initial impact event, the steel rod used to support the steering cable mechanism on the test vehicle was knocked-off the vehicle as-designed. As the rod spun through the air, it impacted the test vehicle and created a tear in the door skin at the lower rear area of the passenger side door; this damage was unrelated to the test article and will not be used to judge performance of the ET Plus.

After the initial impact event, the ET Plus extruder head stroked along the guardrail, extruding approximately 3 feet 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 2. As the vehicle continued its angled trajectory, the channel guide portion of the ET Plus extruder head was pushed further downstream on the W beam over the fold that had formed at Post 2. 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 ET Plus extruder head, the corner of the folded W beam scraped the driver’s side just past the front wheel well creating a tear approximately 9” long in the quarter panel and door surface; there was no intrusion or potential for intrusion of the test article into the occupant compartment based on the position of the guardrail relative to the vehicle trajectory when the damage occurred.

During the impact event, the ET Plus extruder head directly contacted and sheared-off Posts 1 and 2. At the end of the ET Plus extruder head rotation, the head impacted Post 3, shearing it at the ground and dislodging the first splice from the post. The impact pulled the guardrail panel off of Post 4, but the second splice remained attached at Post 5. Though Posts 4 and 5 appeared undamaged, there was slight movement between the post and blockout at Posts 4 and 5 due to relative longitudinal motion of the guardrail panel. All posts and blockouts downstream of Post 5 appeared undamaged, and no appreciable movement of the downstream turndown anchor was observed. Additionally, the anchor cable at Post 1 broke free of the installation and came to rest tangent to Post 7. There was no penetration of the vehicle by the test article, and there was no deformation of the occupant compartment resulting from the test. Debris thrown from the installation as a result of the impact included pieces of posts and blockouts from the first three 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 along the non-traffic side of the guardrail, the test vehicle brakes were remotely actuated in accordance with normal laboratory practice. The vehicle torqued slightly to the left when the brakes were applied, and then hit a small soil berm causing the vehicle to hop and rendering the brakes ineffective. The vehicle continued outside of the cleared runout area, finally coming to rest after impacting a tree 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 -6.1g in the longitudinal direction, 2.3g in the lateral direction, and -2.7g 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 risk impact velocities were 4.5 m/s in the longitudinal direction, and -1.5 m/s in the lateral direction.
- Occupant risk ridedown accelerations were -7.6g in the longitudinal direction, and 4.6g 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 3-33 is 771.7 kJ, with a suggested tolerance of -60.4/+62.9 kJ. The actual impact severity of test ET27-33 was 813.0 kJ, a deviation of +41.3 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 $= \frac{1}{2} \cdot M \cdot (V \cdot \sin\theta)^2$

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

$$= 0.5 \cdot (1974 \text{ kg}) \cdot (28.7 \text{ m/s})^2$$

$$= 813.0 \text{ kJ}$$

The equivalent impact speed of a 2000 kg vehicle impacting the end terminal at 15 degrees would be 102.6 km/hr (63.8 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 Traffic Side of the End Terminal

End Terminal Damage

Figure 3.6: Post Test – Overhead View

Figure 3.7: Post Test – Overhead View Close-up

Figure 3.8: Post Test – Side View

Figure 3.9: Post Test – Right Vehicle Track (Orange Paint)

Figure 3.10: Post Test – Debris Field on Non-Traffic Side

Figure 3.11: Post Test – Foundation Sleeve at Post 1

Figure 3.12: Post Test – Foundation Sleeve at Post 2

Figure 3.13: Post Test – First Splice at Post 3 (Splice Bolts Painted for Visibility in Video)

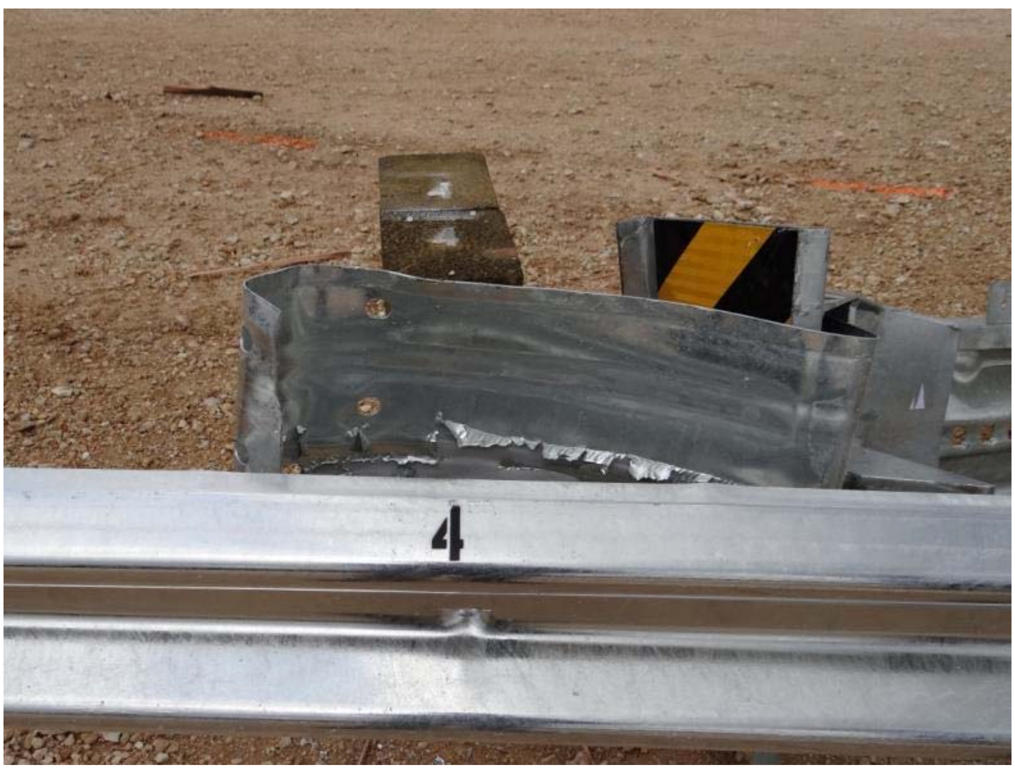


Figure 3.14: Post Test – Post 4

Figure 3.15: Post Test – View of Post 4 from Non-Traffic Side

Figure 3.16: Post Test – Side View of Post 4

Figure 3.17: Post-Test – Traffic Side View of Splice at Post 5

Figure 3.18: Post Test – Top View of Post 5

Figure 3.19: Post Test – Downstream View of Post 5

Figure 3.20: Post Test – Gated Guardrail

Figure 3.21: Post Test – Gated Guardrail Extruder Head

Figure 3.22: Post Test – First Splice at Post 3 from Non-Traffic Side

Figure 3.23: Post Test – Extruded W beam

Figure 3.24: Post Test – Overhead View

Figure 3.25: Post Test – Gating Past Extruder Head

Figure 3.26: Post Test – ET Plus Head Guide Chute Entrance

Figure 3.27: Post Test – Side View of Guide Chute Entrance

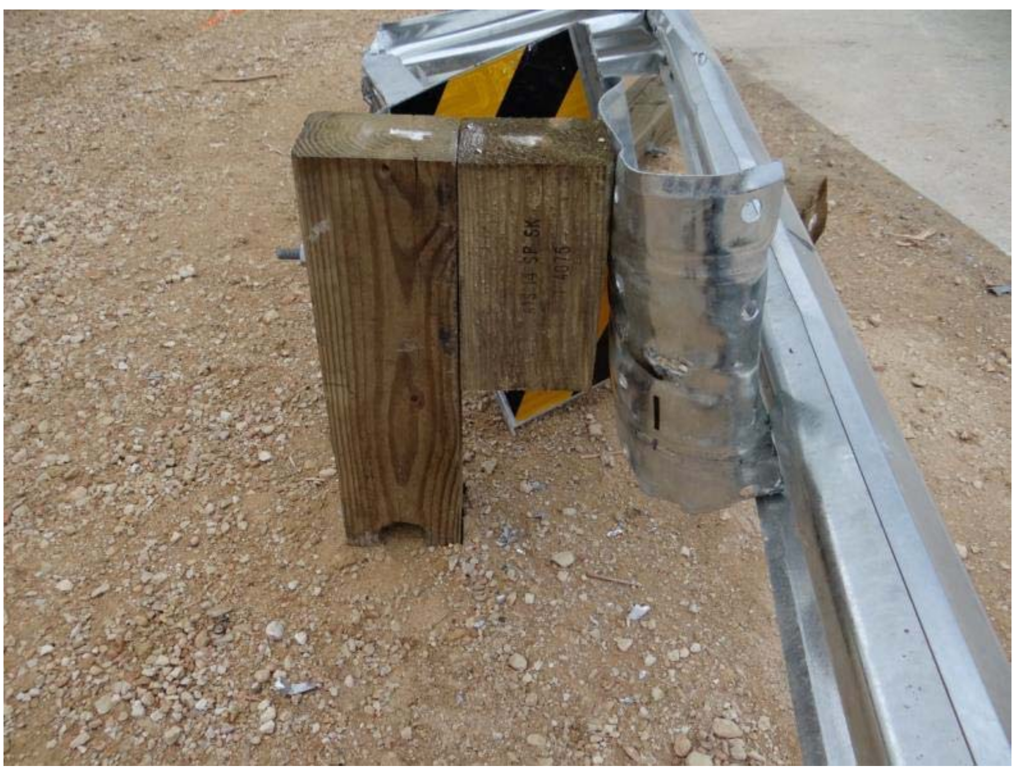


Figure 3.28: Post Test – Extruded Tail of W beam

Figure 3.29: Post Test – Extruded W beam at Exit Chute

Figure 3.30: Post Test – ET Plus Head Impact Plate

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

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

Figure 3.33: Post Test – ET Plus Head Guide Chute Entrance, Traffic Side

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

Figure 3.35: Post Test – ET Plus Head Guide Channel, Non-Traffic Side

Figure 3.36: Post Test – ET Plus Head Guide Chute Entrance, Non-Traffic Side

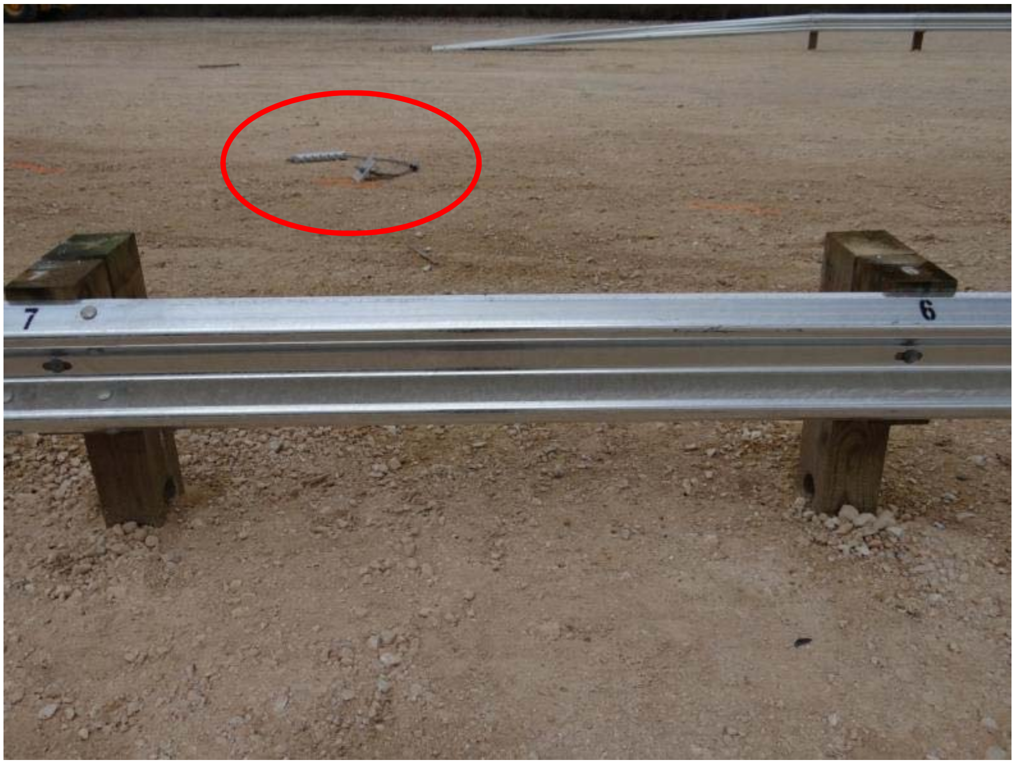


Figure 3.37: Post-Test Location of Anchor Cable

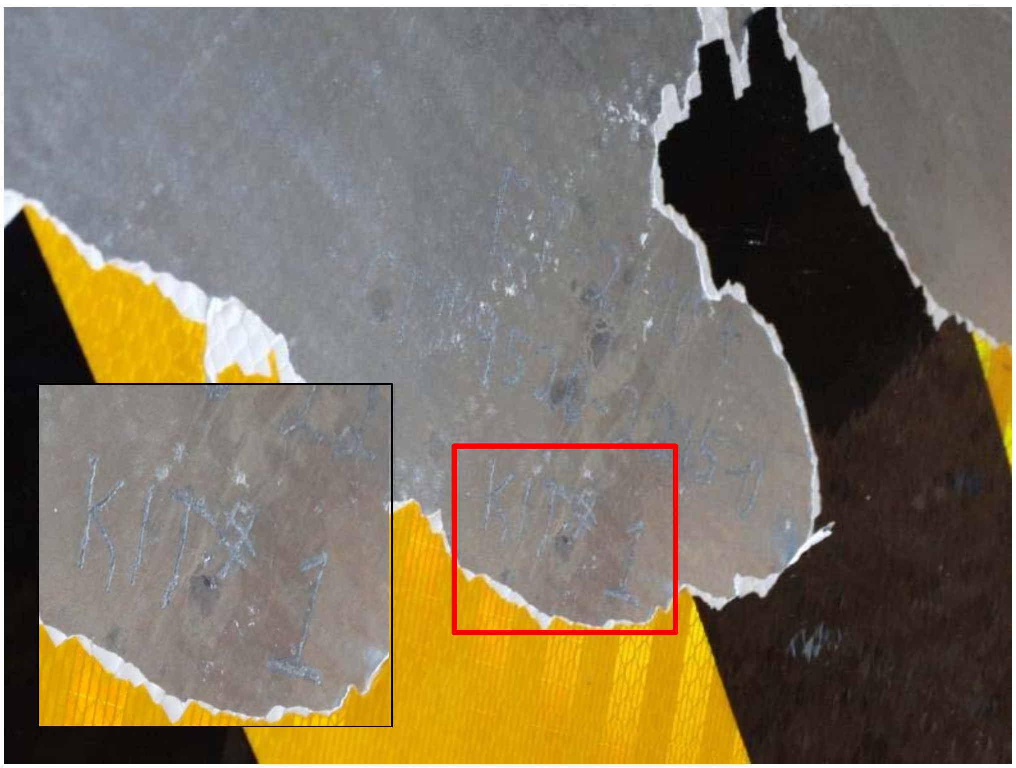


Figure 3.38: Post-Test Verification of Extruder Head 1

Vehicle Damage

Figure 3.39: Approximate Point Vehicle Brakes Applied Post-Impact

Figure 3.40: Post-Impact Path of Right Tire (Orange Paint)

Figure 3.41: Post-Test Location of Test Vehicle

Figure 3.42: Post-Impact Path of Test Vehicle

Figure 3.43: Test Vehicle Impacted Tree

Figure 3.44: Front End of Vehicle Following ET Plus Impact

Figure 3.45: Left Side of Vehicle Following ET Plus Impact

Figure 3.46: Left Side Damage (Note: Hood Damage/Bent Frame Due to Impact with Tree)

Figure 3.47: Left Side Damage – Close-up

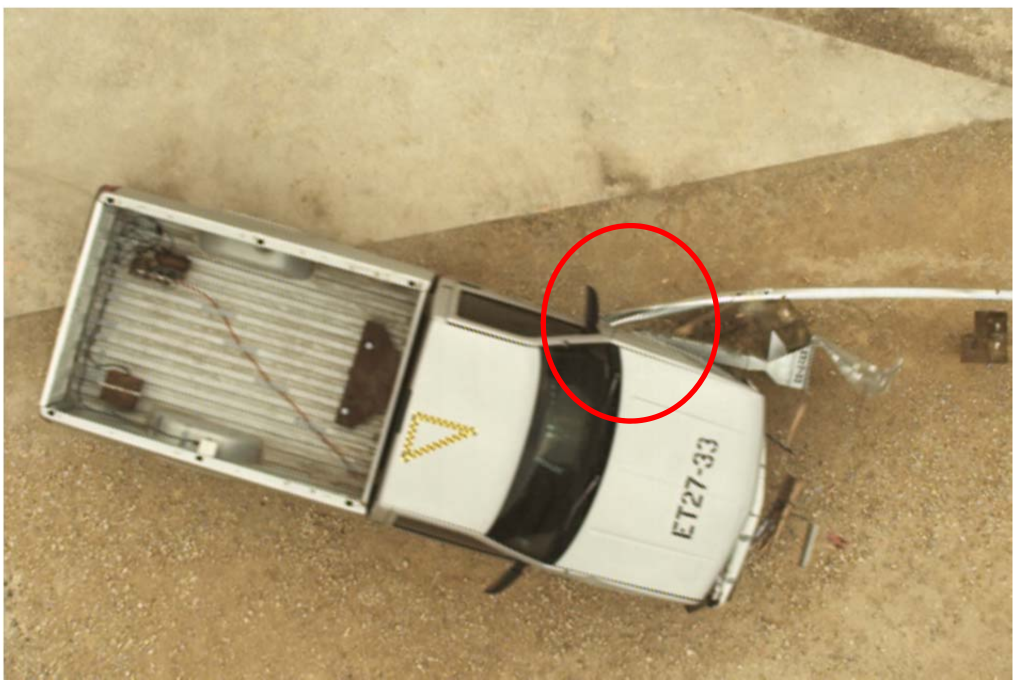


Figure 3.48: Left Side Damage Caused by W beam

Figure 3.49: Door Panel Intact Behind Tear in Door Skin

Figure 3.50: Right Side of Vehicle Following ET Plus Impact

Figure 3.51: Damage to Passenger Door Caused by Steering Cable Rod

Figure 3.52: Steering Cable Support Rod Creating Damage to Passenger Door Prior to Impact Event

Figure 3.53: Post-Test – Occupant Compartment

Figure 3.54: Post-Test – Driver Side Floorboard

Figure 3.55: Post-Test – Passenger Side Floorboard

4 ASSESSMENT OF TEST RESULTS

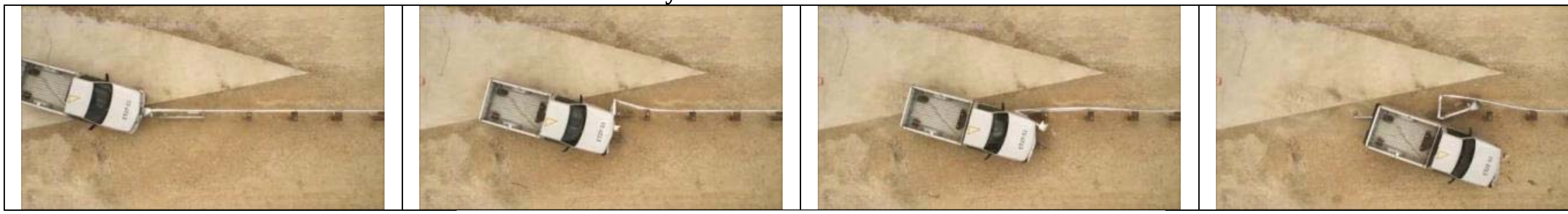
A comparison of the test results of Test ET27-33 against the evaluation criteria set forth in NCHRP Report 350 for Test 3-33 is provided in Table 4.1. A summary of the test results is provided in Table 4.2.

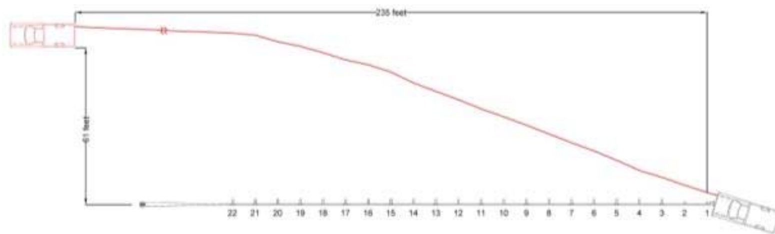
Table 4.1: Summary of Test Evaluation Results (NCHRP Report 350 Evaluation Criteria) for Test ET27-33

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: 4.5 m/s Lateral: -1.5 m/s	Pass
	I. Occupant Ridedown Acceleration (ORA) limits: Preferred = 15 g Maximum = 20 g	Occupant Ridedown Accelerations: Longitudinal: -7.6 g Lateral: 4.6 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 ET27-33





General Information			**Impact Conditions**			**Extruder Head Position from Start**	
Test Agency	Southwest Research Institute		Speed (km/hr)	103.3		Longitudinal	5.8 m (19.1 ft)
Test Number	ET27-33		Angle (degrees)	14.9		Lateral	0.4 m (1.5 ft)
Test Date	12/10/2015		**Exit Conditions**			**Total System Deformation (Closest Point)**	
Test Category	3-33		Speed (km/hr)	81.0		Longitudinal	4.23 m (13.9 ft)
Test Article			Angle (degrees)	20.7		**Post Impact Vehicular Behavior**	
Type	End Terminal					Max Vehicle Rotation (degrees)	
Terminal Length	15.24 m (50 ft)		**Occupant Risk Values**			Max. Roll	3.4 @ 0.3757 sec.
Installation Length	47.6 m (156.25 ft)		Impact Velocity (m/s)			Max. Pitch	-3.6 @ 0.8227 sec.
Nom. Barrier Height	705 mm (27.75 in)		x-direction	4.5		Max. Yaw	8.4 @ 0.7948 sec.
Type of Primary Barrier	W beam guardrail		y-direction	-1.5		Max 50ms Moving Average Accelerations (g)	
Soil	Stable, Dry - “Standard” Soil		Ridedown Accelerations (g)			x-direction	-6.1 @ 0.2250-0.2750 sec.
Test Vehicle			x-direction	-7.6		y-direction	2.3 @ 0.3571-0.4071 sec.
Type	¾ ton pickup truck		y-direction	4.6		z-direction	-2.7 @ 0.2967-0.3467 sec.
Designation	2000P		**Target Conditions**				
Model	1995 GMC C2500		Nominal Speed	100 km/hr (62.1 mph)			
Curb Mass (kg)	1874 as-received		Nominal Angle	0°			
Ballast Mass (kg)	100		**Tolerances**				
Test Inertial Mass (kg)	1974		Nominal Speed	±4 km/hr			
Dummy Mass (kg)	0		Nominal Angle	±1.5˚			
Gross Static Mass (kg)	1974						

5 CONCLUSIONS

The performance of the ET Plus during Test ET27-33 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

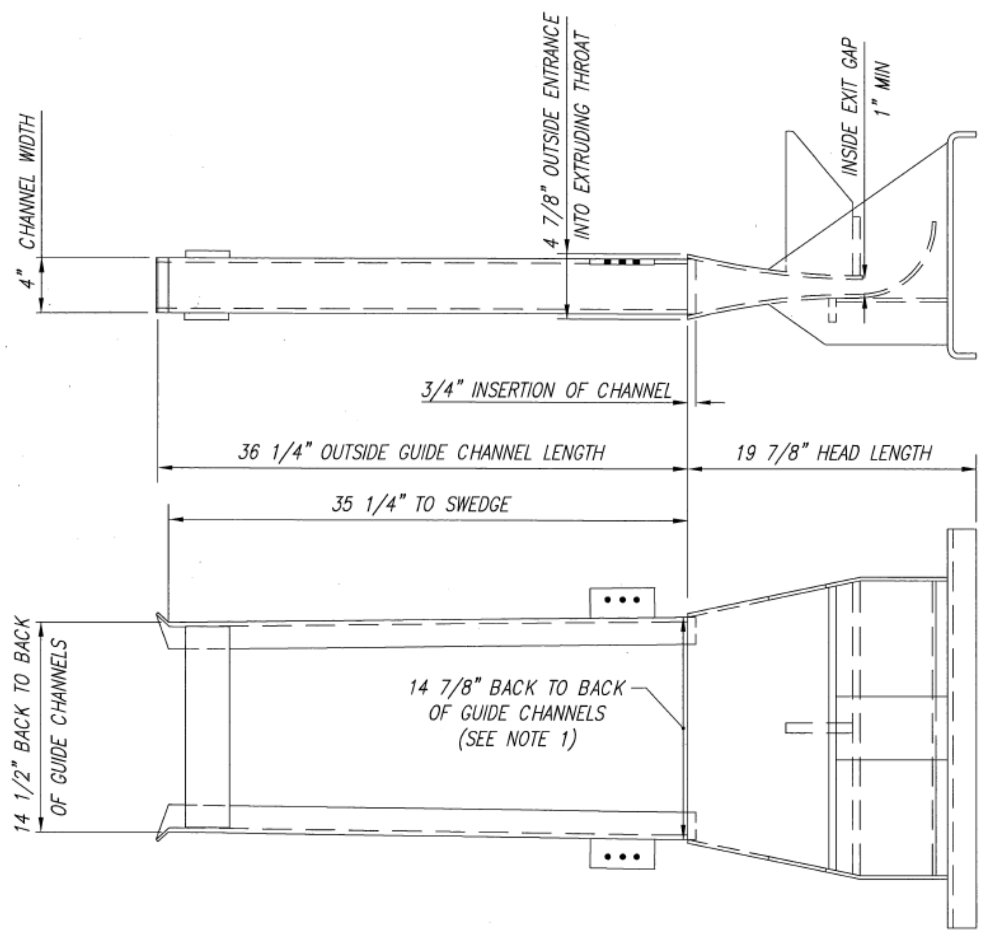
- There was no penetration of the vehicle by the test article, and no deformation of the occupant compartment resulting from the test.
- There was no undue hazard presented by test article debris outside of the immediate impact zone; the only debris thrown from the installation included pieces of posts 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 27¾" meets the Test Level 3, Test 3-33 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".

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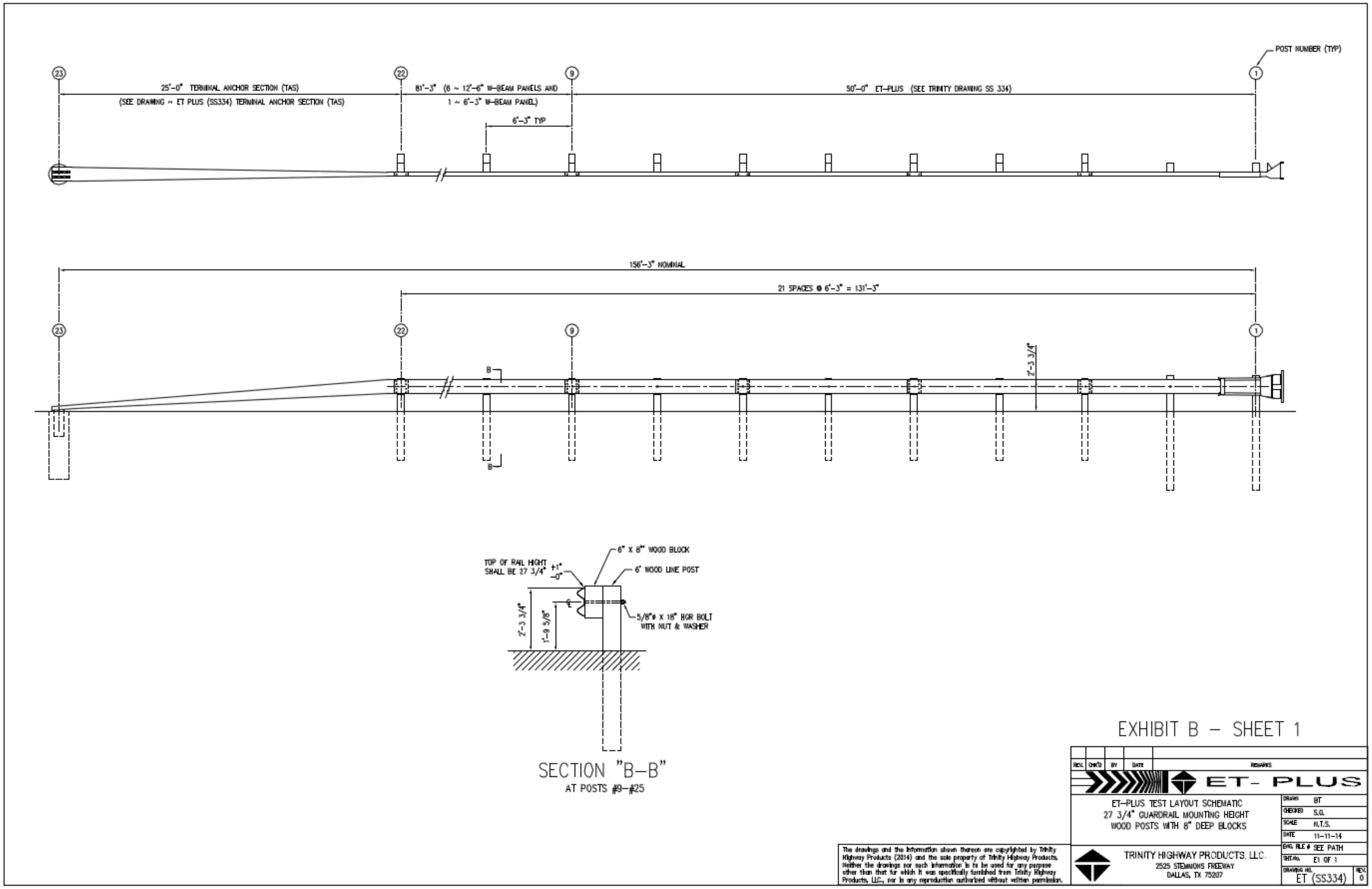
2525 STEMMONS FREEWAY
DALLAS, TX 75207


POST NUMBER (TYP)
25'-0" TERMINAL ANCHOR SECTION (TAS)
(SEE DRAWING ~ ET PLUS (SS334) TERMINAL ANCHOR SECTION (TAS)
81'-3" (6 ~ 12'-6" W-BEAM PANELS AND
1 ~ 6'-3" W-BEAM PANEL)
6'-3" TYP
50'-0" ET-PLUS (SEE TRINITY DRAWING SS 334)
156'-3" NOMINAL
21 SPACES @ 6'-3" = 131'-3"
2'-3 3/4"
6" X 8" WOOD BLOCK
TOP OF RAIL HIGHT SHALL BE 27 3/4" +1" -0"
6" WOOD LINE POST
5/8"ø X 18" HGR BOLT WITH NUT & WASHER
2'-3 3/4"
1'-9 5/8"
SECTION "B-B"
AT POSTS #9-#25
EXHIBIT B – SHEET 1
REV. CHK'D BY DATE REMARKS
ET- PLUS
ET-PLUS TEST LAYOUT SCHEMATIC
27 3/4" GUARDRAIL MOUNTING HEIGHT
WOOD POSTS WITH 8" DEEP BLOCKS
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 (SS334)
REV. 0
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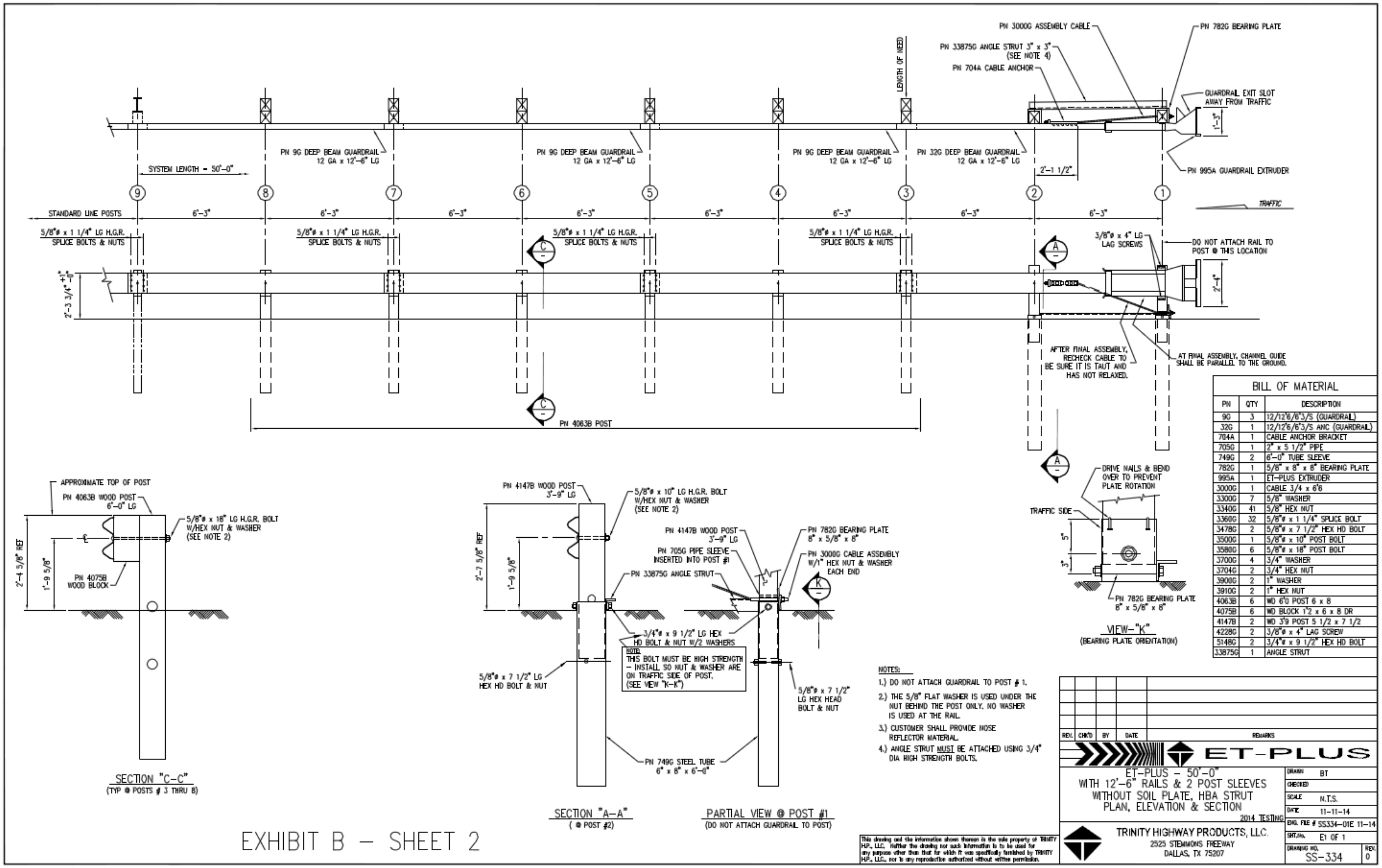

BILL OF MATERIAL

PN	QTY	DESCRIPTION
9G	3	12/12'6/6'3/S (GUARDRAIL)
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
3580G	6	5/8"ø x 18" POST BOLT
3700G	4	3/4" WASHER
3704G	2	3/4" HEX NUT
3900G	2	1" WASHER
3910G	2	1" HEX NUT
4063B	6	WD 6'0 POST 6 x 8
4075B	6	WD BLOCK 1'2 x 6 x 8 DR
4147B	2	WD 3'9 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
33875G	1	ANGLE STRUT

NOTES:

1.) DO NOT ATTACH GUARDRAIL TO POST # 1.

2.) THE 5/8" FLAT WASHER IS USED UNDER THE NUT BEHIND THE POST ONLY. NO WASHER IS USED AT THE RAIL.

3.) CUSTOMER SHALL PROVIDE NOSE REFLECTOR MATERIAL.

4.) ANGLE STRUT MUST BE ATTACHED USING 3/4" DIA HIGH STRENGTH BOLTS.

REV.	CHK'D	BY	DATE	REMARKS

ET-PLUS

ET-PLUS – 50'-0"
WITH 12'-6" RAILS & 2 POST SLEEVES
WITHOUT SOIL PLATE, HBA STRUT
PLAN, ELEVATION & SECTION
2014 TESTING

DRAWN	BT
CHECKED	
SCALE	N.T.S.
DATE	11-11-14
ENG. FILE #	SS334-01E 11-14
SHT./No.	E1 OF 1
DRAWING NO.	SS-334
REV.	0

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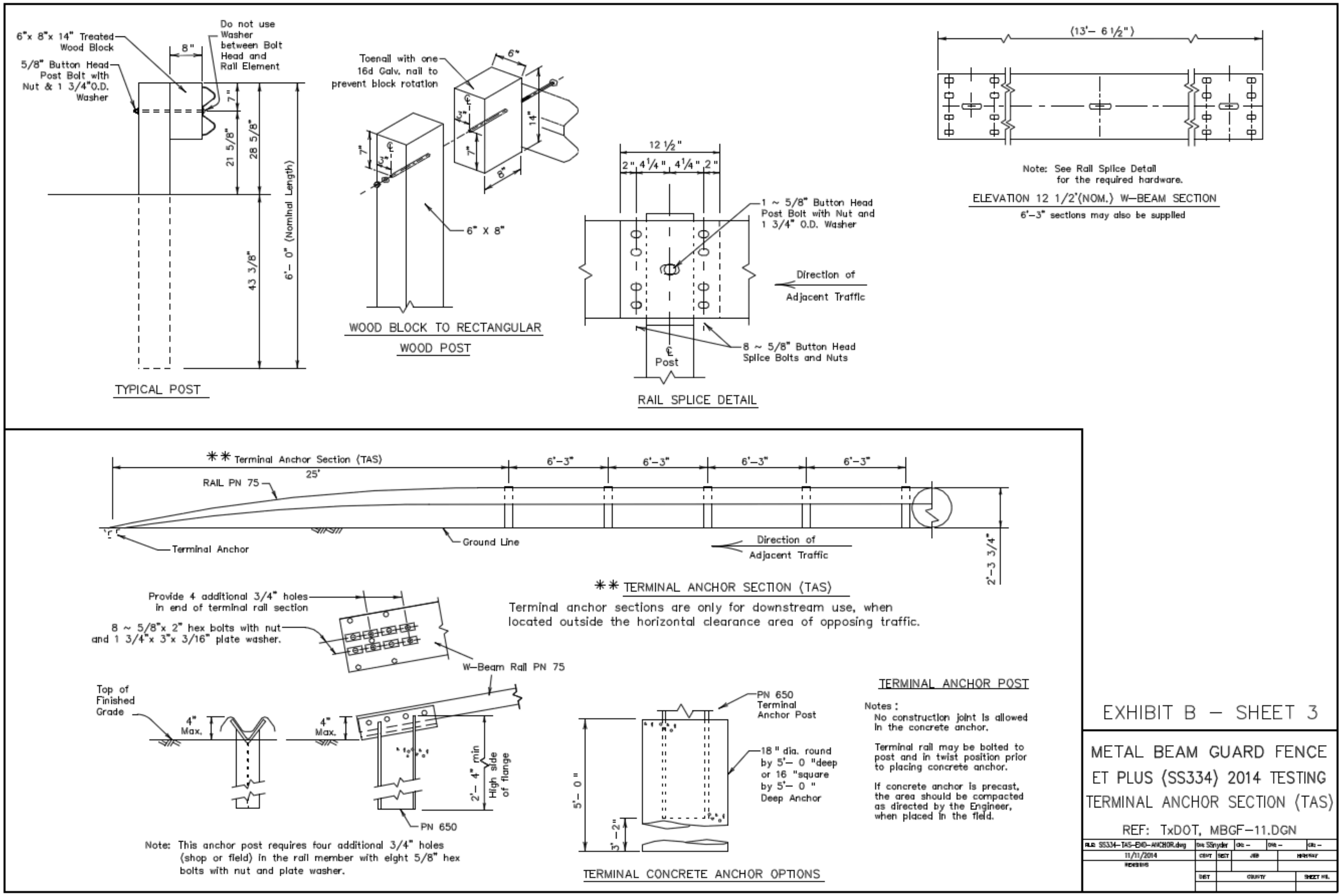

6"x 8"x 14" Treated Wood Block
5/8" Button Head Post Bolt with Nut & 1 3/4"O.D. Washer
Do not use Washer between Bolt Head and Rail Element
TYPICAL POST
Toenail with one 16d Galv. nail to prevent block rotation
WOOD BLOCK TO RECTANGULAR WOOD POST
1 ~ 5/8" Button Head Post Bolt with Nut and 1 3/4" O.D. Washer
Direction of Adjacent Traffic
8 ~ 5/8" Button Head Splice Bolts and Nuts
RAIL SPLICE DETAIL
Note: See Rail Splice Detail for the required hardware.
ELEVATION 12 1/2'(NOM.) W—BEAM SECTION
6'-3" sections may also be supplied
** Terminal Anchor Section (TAS)
RAIL PN 75
Terminal Anchor
Ground Line
Direction of Adjacent Traffic
** TERMINAL ANCHOR SECTION (TAS)
Terminal anchor sections are only for downstream use, when located outside the horizontal clearance area of opposing traffic.
Provide 4 additional 3/4" holes in end of terminal rail section
8 ~ 5/8"x 2" hex bolts with nut and 1 3/4"x 3"x 3/16" plate washer.
W—Beam Rail PN 75
Top of Finished Grade
PN 650
Note: This anchor post requires four additional 3/4" holes (shop or field) in the rail member with eight 5/8" hex bolts with nut and plate washer.
PN 650 Terminal Anchor Post
18" dia. round by 5'— 0 "deep or 16 "square by 5'— 0 " Deep Anchor
TERMINAL CONCRETE ANCHOR OPTIONS
TERMINAL ANCHOR POST
Notes:
No construction joint is allowed in the concrete anchor.
Terminal rail may be bolted to post and in twist position prior to placing concrete anchor.
If concrete anchor is precast, the area should be compacted as directed by the Engineer, when placed in the field.
EXHIBIT B — SHEET 3
METAL BEAM GUARD FENCE
ET PLUS (SS334) 2014 TESTING
TERMINAL ANCHOR SECTION (TAS)
REF: TxDOT, MBGF—11.DGN

Appendix B: SwRI Data Sheets for Test ET27-33

EXHIBIT D-1: Installation Checklist

Test Number: ET27-33 Test Date: 12/10/2014

*Record the following impact head dimensions:

OK head stamp "1" 12/4/2014

Dimension	*Pre-Test Measurements	
Exit Gap (middle - inside)	1.3260" ✓	
Entrance Gap (middle - outside)	4.7790"	
Guide Chute Exit Height (outside)	15" ✓	BOTH SIDES
Guide Chute Entrance Height (outside)	14.5" ✓	BOTH SIDES
Channel Width (outside)	4.0325" ✓	
Channel Insertion into Extruder	0.6035" 0.5015" 0.2315" ✓ 0.3875" ✓	
Outside Guide Channel Length	36.5" ✓	37" TO INSIDE
Outside Guide Channel Length – Chute to start of swedge	35" ✓	
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: 27 7/8 inches ✓ Between post 5 and 6: 27 7/8 inches
   b. Between post 2 and 3: 27 3/4 inches Between post 6 and 7: 27 7/8 inches
   c. Between post 3 and 4: 27 3/4 inches Between post 7 and 8: 28 inches
   d. Between post 4 and 5: 27 7/8 inches Between post 8 and 9: 28 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: 7 inches. ✓
c. Distance from the ground to the top of the impact face: 35 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 1/2 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 2 3/4 inches.

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12/10/14 @ E.A. @ RDA ~~AM~~

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 Hami[illegible] 12/10/2014

43

DATE: 12-2-14 TEST NO.: ET-27-33 VIN NO.: 1GTFC24K9 52556220 MAKE: GMC

MODEL: C2500 YEAR: 1995 ODOMETER: 216,389 GVW: 7200 LBS

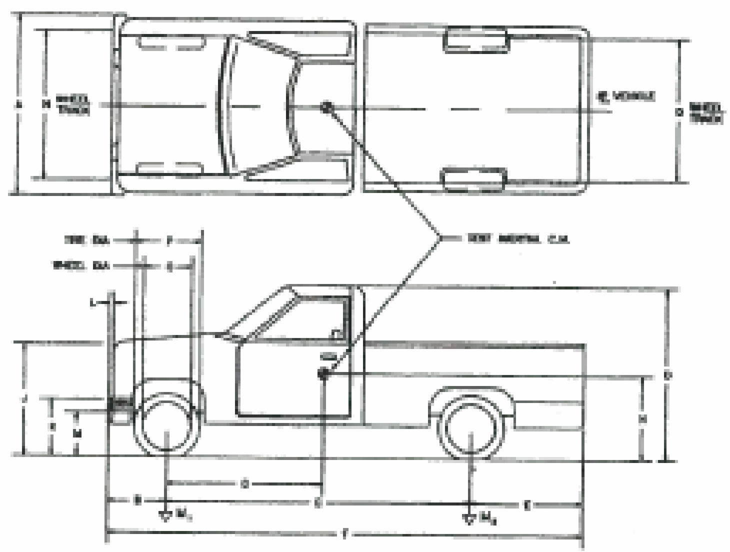
TIRE SIZE: 245/75 R16 TIRE INFLATION PRESSURE: 35 PSI TREAD TYPE: ____

MASS DISTRIBUTION (kg) LF 1286 RF 1270 LR 903 RR 893

TOTAL 4352 INCLUDED 221 LBS BALLAST

DESCRIBE ANY DAMAGE TO VEHICLE PRIOR TO TEST:

DENT RIGHT REAR NEAR TAIGATE



ENGINE TYPE: GAS

ENGINE CID: 5.7 L

TRANSMISSION TYPE:

✓ AUTO

— MANUAL

OPTIONAL EQUIPMENT:

DUMMY DATA:

TYPE: ____

MASS: ____

SEAT POSITION: ____

GEOMETRY – (cm)

A 75"	D 65"	G 54.42	K 26"	N 69"	Q 17.5"
B 35"	E 52"	H 26"	L 3.5"	O 70.5"	
C 131.875"	F 218.875	J 42.5	M 16.5"	P 29.5	

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

C.G. 11.6 ABOVE FRONT SPINDLE CL

EDR 54½" BACK 29½" FROM GROUND

Figure 4.2. 2000P parameters.

OK 12/10/2014

SILVER

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.

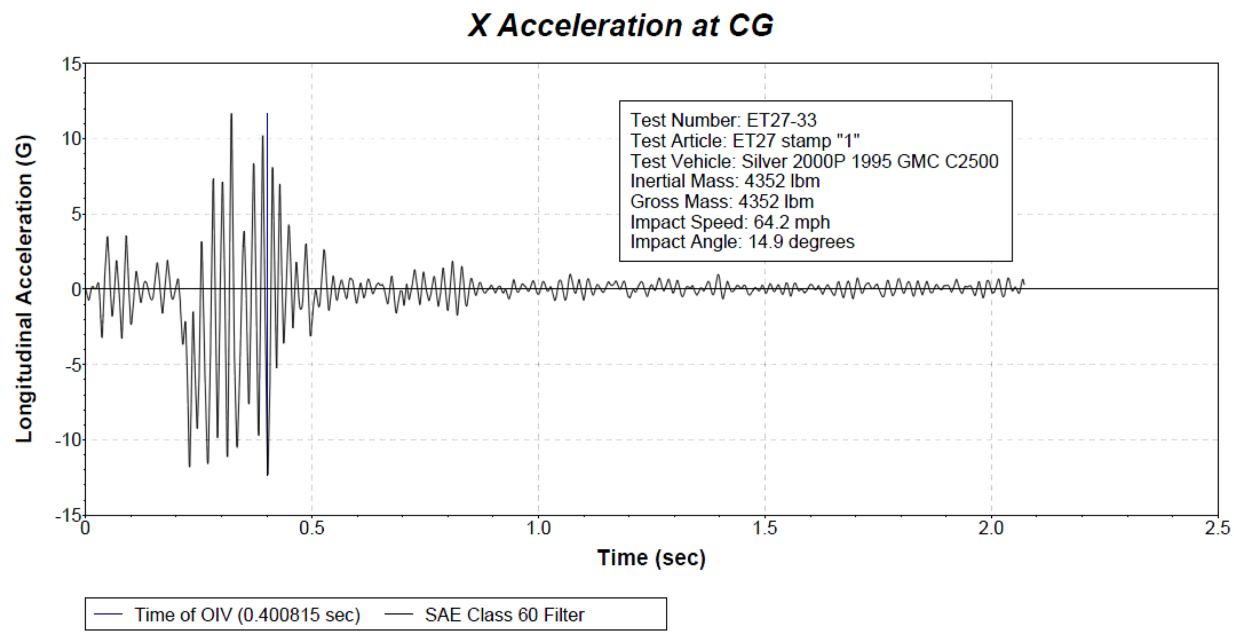
Sincerely,

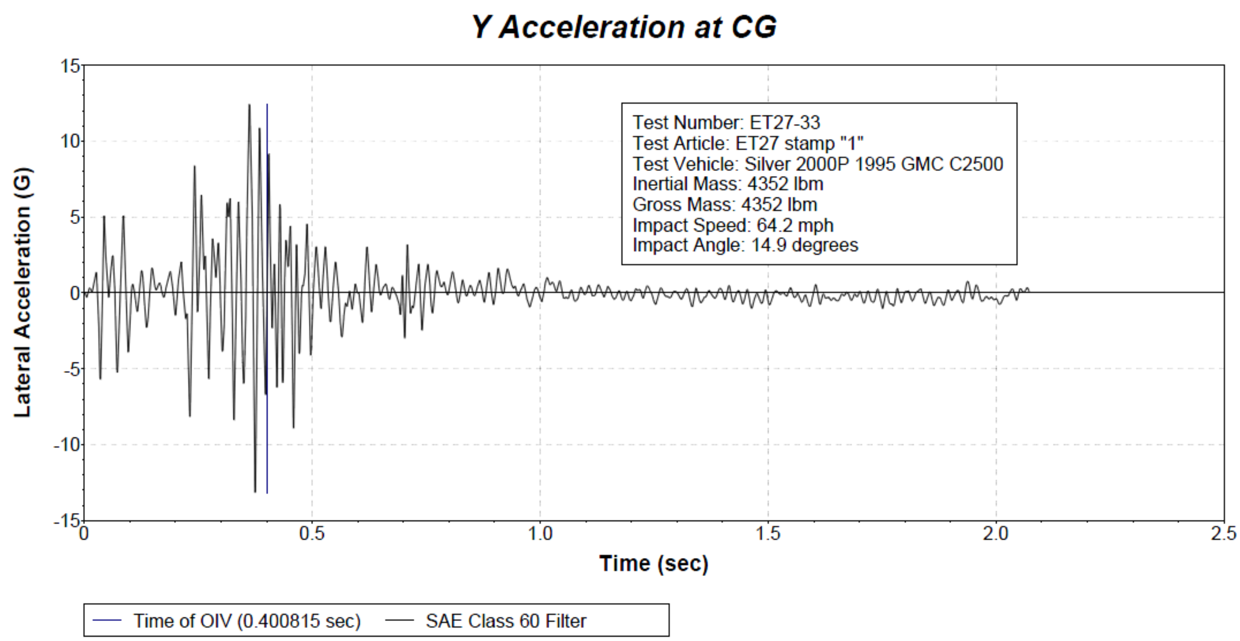
R. B. Kalmbach
Executive Director, Contracts

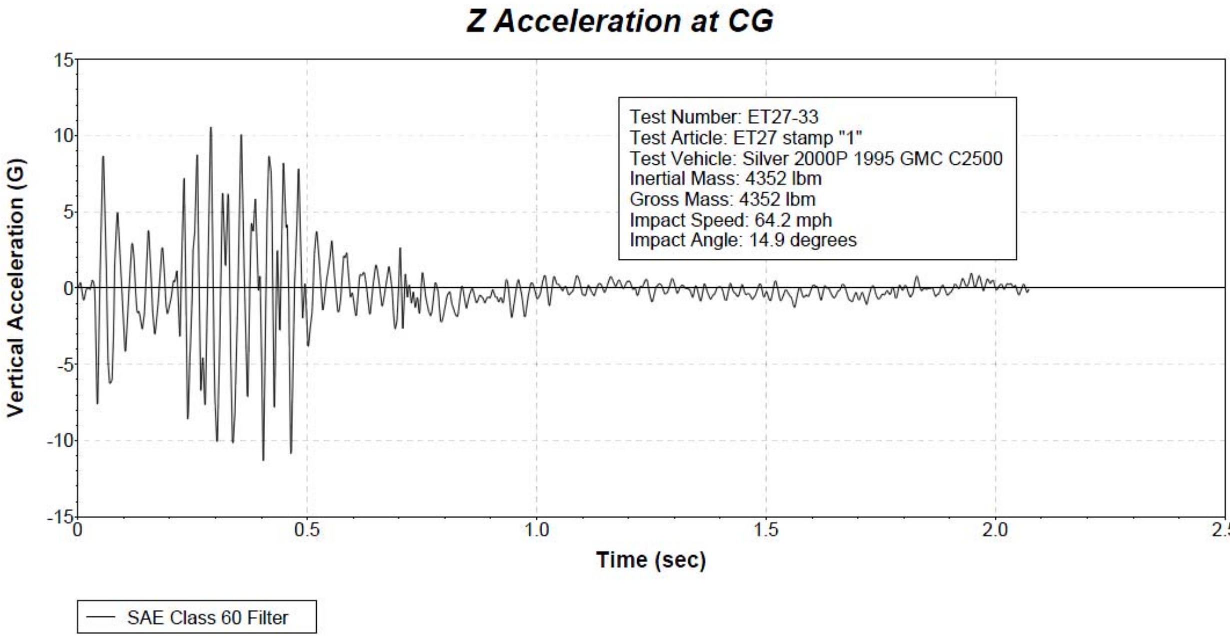
RBK/MKL/jms
cc: J. Ferren, SwRI (via email)

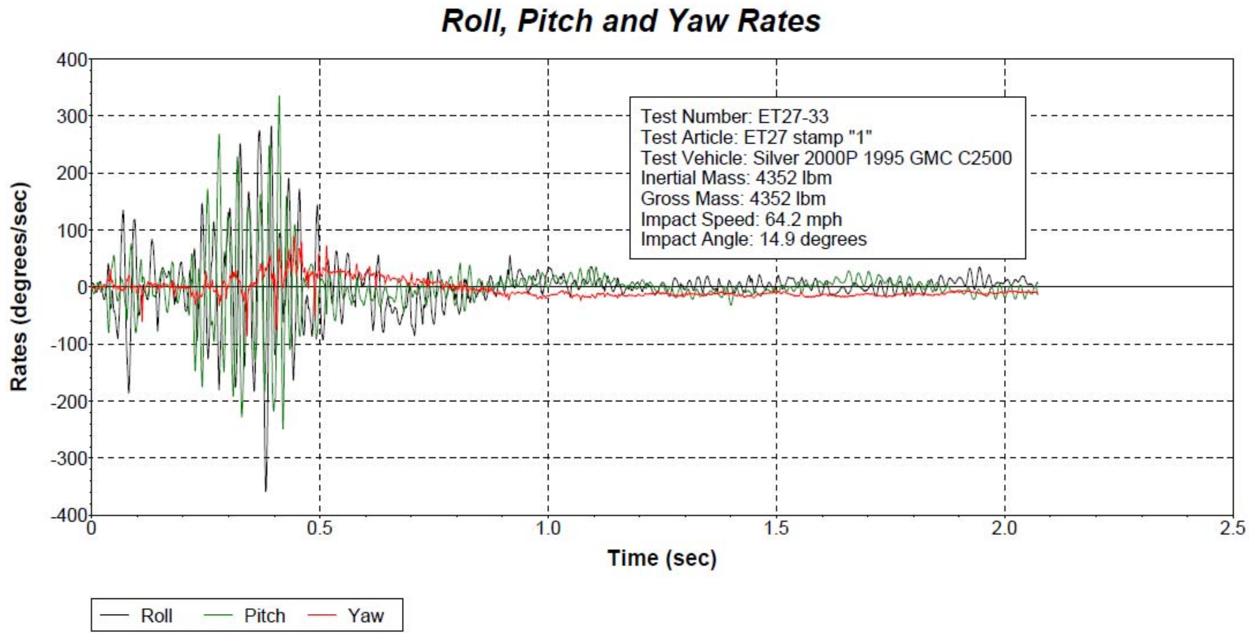
Benefiting government, industry and the public through innovative science and technology

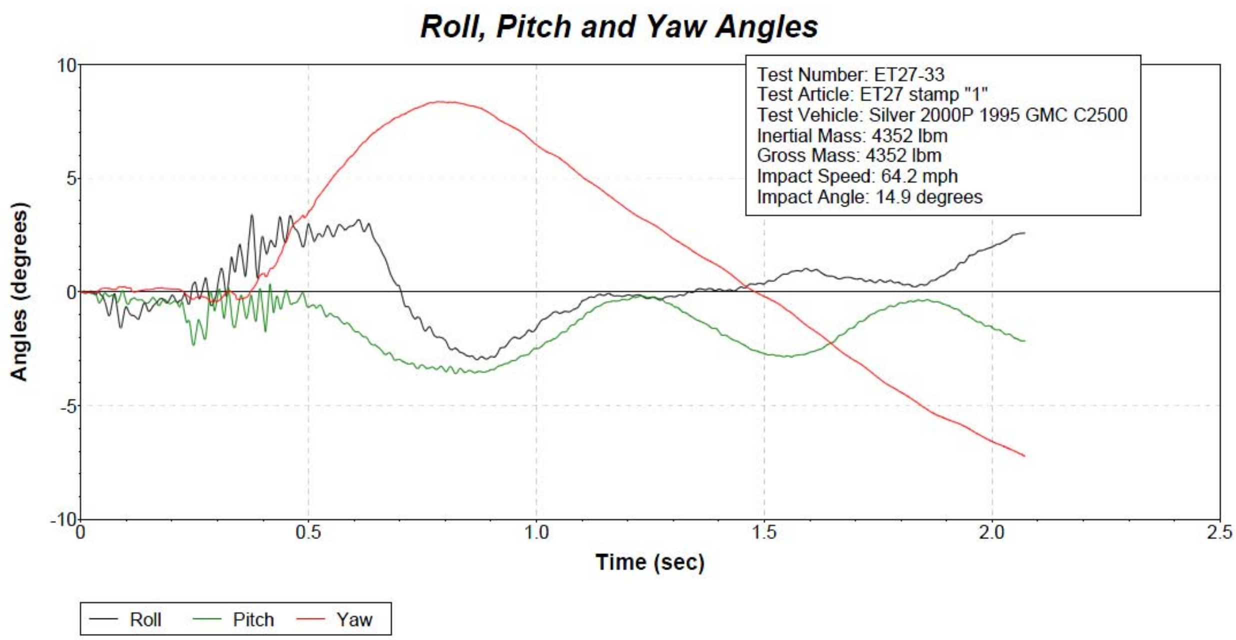
Appendix D: Test Data Plots


X Acceleration at CG
Test Number: ET27-33
Test Article: ET27 stamp "1"
Test Vehicle: Silver 2000P 1995 GMC C2500
Inertial Mass: 4352 lbm
Gross Mass: 4352 lbm
Impact Speed: 64.2 mph
Impact Angle: 14.9 degrees
Longitudinal Acceleration (G)
Time (sec)
Time of OIV (0.400815 sec)
SAE Class 60 Filter


Y Acceleration at CG
Test Number: ET27-33
Test Article: ET27 stamp "1"
Test Vehicle: Silver 2000P 1995 GMC C2500
Inertial Mass: 4352 lbm
Gross Mass: 4352 lbm
Impact Speed: 64.2 mph
Impact Angle: 14.9 degrees
Lateral Acceleration (G)
Time (sec)
Time of OIV (0.400815 sec)
SAE Class 60 Filter


Z Acceleration at CG
Test Number: ET27-33
Test Article: ET27 stamp "1"
Test Vehicle: Silver 2000P 1995 GMC C2500
Inertial Mass: 4352 lbm
Gross Mass: 4352 lbm
Impact Speed: 64.2 mph
Impact Angle: 14.9 degrees
Vertical Acceleration (G)
Time (sec)
15
10
5
0
-5
-10
-15
0
0.5
1.0
1.5
2.0
2.5
SAE Class 60 Filter


Roll, Pitch and Yaw Rates
Test Number: ET27-33
Test Article: ET27 stamp "1"
Test Vehicle: Silver 2000P 1995 GMC C2500
Inertial Mass: 4352 lbm
Gross Mass: 4352 lbm
Impact Speed: 64.2 mph
Impact Angle: 14.9 degrees
Rates (degrees/sec)
Time (sec)
Roll
Pitch
Yaw


Roll, Pitch and Yaw Angles
Test Number: ET27-33
Test Article: ET27 stamp "1"
Test Vehicle: Silver 2000P 1995 GMC C2500
Inertial Mass: 4352 lbm
Gross Mass: 4352 lbm
Impact Speed: 64.2 mph
Impact Angle: 14.9 degrees
Angles (degrees)
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:

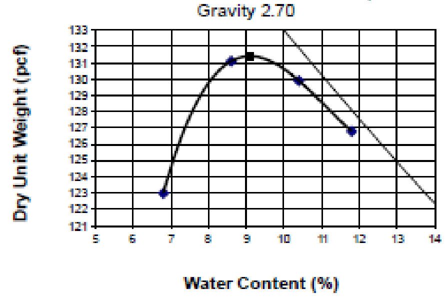
Oversized Particles (%): 14.5
Moisture (%): 2.8
Sieve for Oversize Fraction: 3/4

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**

Zero Air Voids Curve for Assumed Specific Gravity 2.70



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: 90141414.0002
Service Date: 12/10/14
Report Date: 12/15/14
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 (%)
	Test Rail #1								
1	10' Off Rail	Final	1	6	139.1	9.9	7.7	129.2	98.3

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.: Nathan J. Gunn
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 27¾ Inches

Test Level 3, Test 3-31
Test Identification: ET27-31

SwRI® Project No. 18.20887

SwRI Document Number: 18.20887.03.100.FR2
Issue 1

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

January 23, 2015

Authored by:

Jenny Ferren, Manager
Mechanical Engineering Division

Reviewed and Approved by:

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

The results of this test report apply only to the specific samples tested. If the manufacturer extends the test results to apply to other samples of the same model, or from the same lot or batch, the manufacturer should ensure the additional samples are manufactured using identical electrical and mechanical components. This test report shall not be reproduced, except in full, without written approval of Southwest Research Institute.

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	1/23/2015

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

1 INTRODUCTION

The purpose of Crash Test ET27-31 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 27¾”. 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 47.6 m (156’-3”), including the 15.2 m (50 ft) 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 vehicle 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 ET27-31 was conducted on December 16, 2014, 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 27¾". The ET Plus End Terminal installation tested uses standard AASHTO M180 Type 2, 12-gauge, 12'-6" W-Beam guardrail panels mounted with the top of the rail 27¾ inches 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.

During installation, holes approximately 2' 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 cm (6 in) lifts, and was added until the surface was flush with the surrounding soil.

The guardrail line posts are 6" x 8" wood posts with 6" x 8" wood blockouts. The blockouts are toenailed, and the guardrail panels are mounted to the posts using 5/8"ϕ post bolts beginning with Post 2; the bolt for Post 2 is 10" long, and all other post bolts are 18" long. The post spacing is 6'-3", and each splice joint used eight (8) 5/8"ϕ x 1-1/4" splice bolts and nuts; the splice bolts have a nominal total length of 1-5/8" including the bolt head. The installation uses 3/4"ϕ x 10" 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 guardrail splices at each odd-numbered post starting with Post 3.

The total system installation length for the test was nominally 156'-3" (47.6 m), including the 50 ft (15.2 m) ET Plus terminal length, 81'-3" (24.8 m) of guardrail, and a 25' (7.6 m) downstream terminal anchor section that included a turndown guardrail anchor spliced at Post 22 and mounted to a concrete footing. 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 ET27-31 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	2
Exit Gap	1.0890”
Entrance Gap	4.8090”
Guide Chute Exit Height	14-15/16”
Guide Chute Entrance Height	14-1/2”
Channel Width (see Figure 2.2)	4.0350”

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 ET27-31

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 Anchor Cable Mount – Post 1

Figure 2.10: End Terminal Cable Anchor

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

Figure 2.14: Second Guardrail Panel Splice Joint – 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 and Post 1 – Back Side

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

Figure 2.18: ET Plus Head Extruder Exit (see Appendix B for Dimensions)

Figure 2.19: Post 22 Immediately Preceding Downstream Turndown Anchor

Figure 2.20: Downstream Turndown Anchor

Test Vehicle

The test vehicle was a 1994 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 1998 kg (4,404 lbs) as reflected in Table 4.2.

Figure 2.21: Test Vehicle for Test ET27-31

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.

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 ET27-31

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.

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 7.3% behind both Post 2 and Post 4. 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 ET27-31 on December 16, 2014:

- Federal Highway Administration (FHWA)
- Virginia DOT
- Ohio 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 and the test vehicle following the test.

3 TEST CONDITIONS AND RESULTS

Test Description

The purpose of Test ET27-31 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 27¾". 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 156'-3" (47.6 m), and the terminal length was 15.2 m (50 ft).

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 vehicle 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.

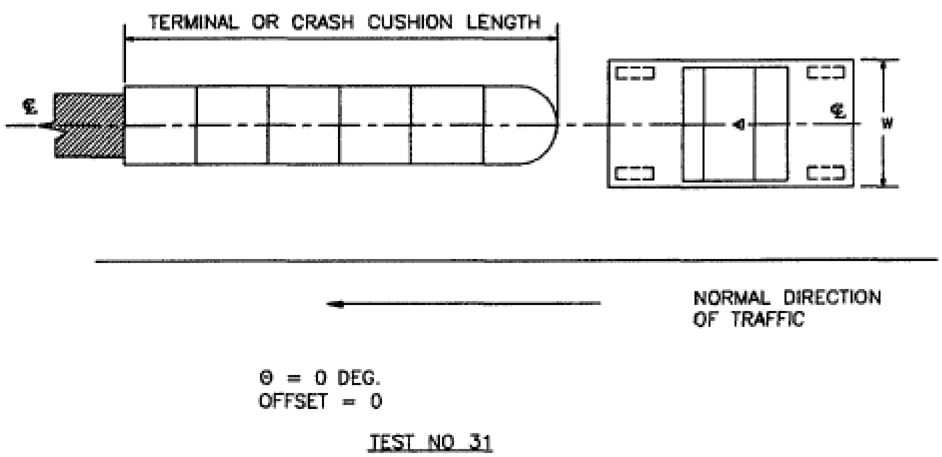


Figure 3.1: Impact Configuration *[from Figure 3.2 of NCHRP Report 350]*

The weather on the day of the test was mostly sunny, with temperatures ranging from 46-65°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 97.5 km/hr (60.6 mph). As a result of the test, the ET Plus extruder head moved 11.4 m (37.4 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.

After the impact event, the ET Plus extruder head stroked along the guardrail, extruding approximately 37.4 feet of guardrail including the first splice at Post 3 and the second splice at Post 5. The vehicle slowed and came to a stop when the channel entrance end of the head was at Post 7. 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 6, and damaged Posts 7 and 8 at the end of the stroke. After the vehicle came to rest, Post 1 was on the ground behind the vehicle, Posts 2 and 3 were on the ground under the bed of the pickup, and Posts 4, 5 and 6 were stacked under the front axle of the pickup, which lifted the vehicle slightly; the front tires were nearly 2 inches off the ground after the vehicle came to rest. Post 7 appeared to be undamaged, but the blockout was twisted and slightly damaged due to impact with the tail end of the extruder head. Posts 8 and 9 exhibited minor cracking following the test, and the Post 8 blockout was twisted due to the relative motion of the attached guardrail panel. All posts and blockouts downstream of Post 9 appeared undamaged, and no appreciable movement of the downstream turndown anchor was observed. Additionally, the anchor cable at Post 1 broke free of the installation and came to rest near Post 8. 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 10 and 11. 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 four posts; the majority of the debris fell to the non-traffic side of the guardrail, and the only debris landing on the traffic side was a small piece of Post 3 that landed near Post 13. 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 -7.2g in the longitudinal direction, 1.2g in the lateral direction, and 4.0g 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 risk impact velocities were 7.1 m/s in the longitudinal direction, and -0.3 m/s in the lateral direction.
- Occupant risk ridedown accelerations were -9.2g in the longitudinal direction, and 5.0g 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.

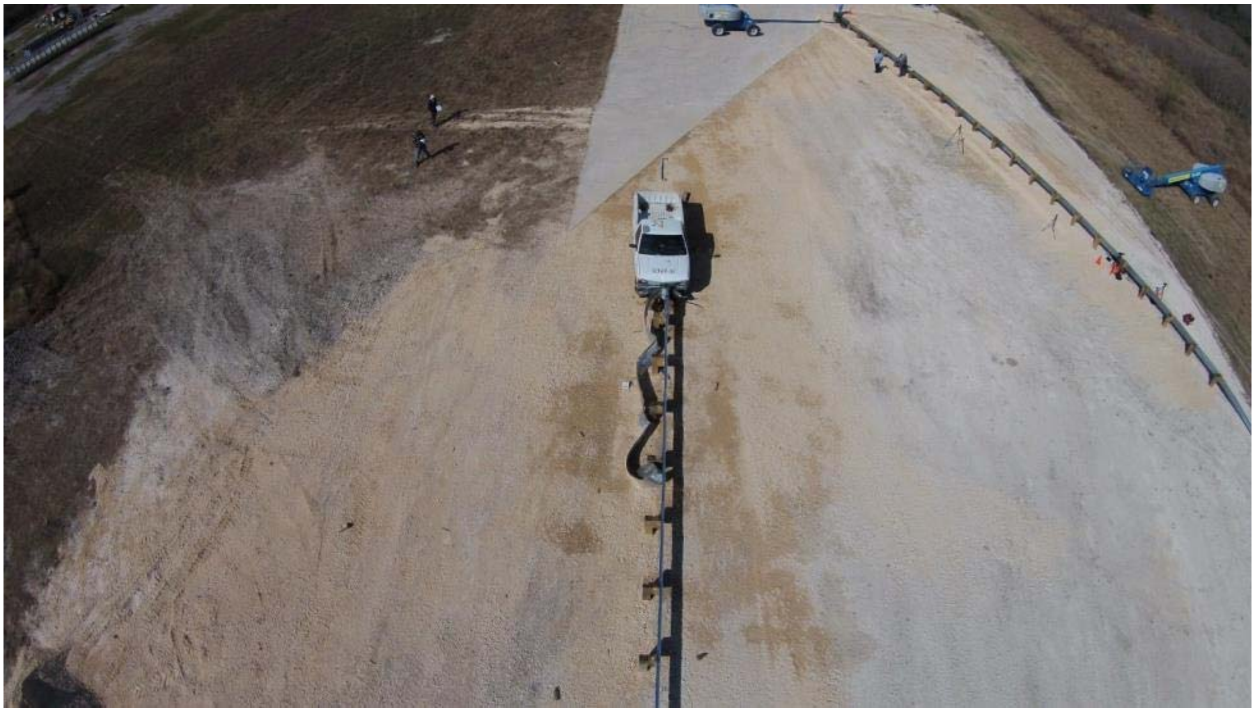


Figure 3.2: Post-Impact Condition of the Test Article and Vehicle

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 ET27-31 was 733.7 kJ, a deviation of -38.0 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.*

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

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

$= 0.5 \cdot (1998 \text{ kg}) \cdot (27.1 \text{ m/s})^2$

$= 733.7 \text{ kJ}$

The equivalent impact speed of a 2000 kg vehicle impacting the end terminal at 0 degrees would be 97.5 km/hr (60.6 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

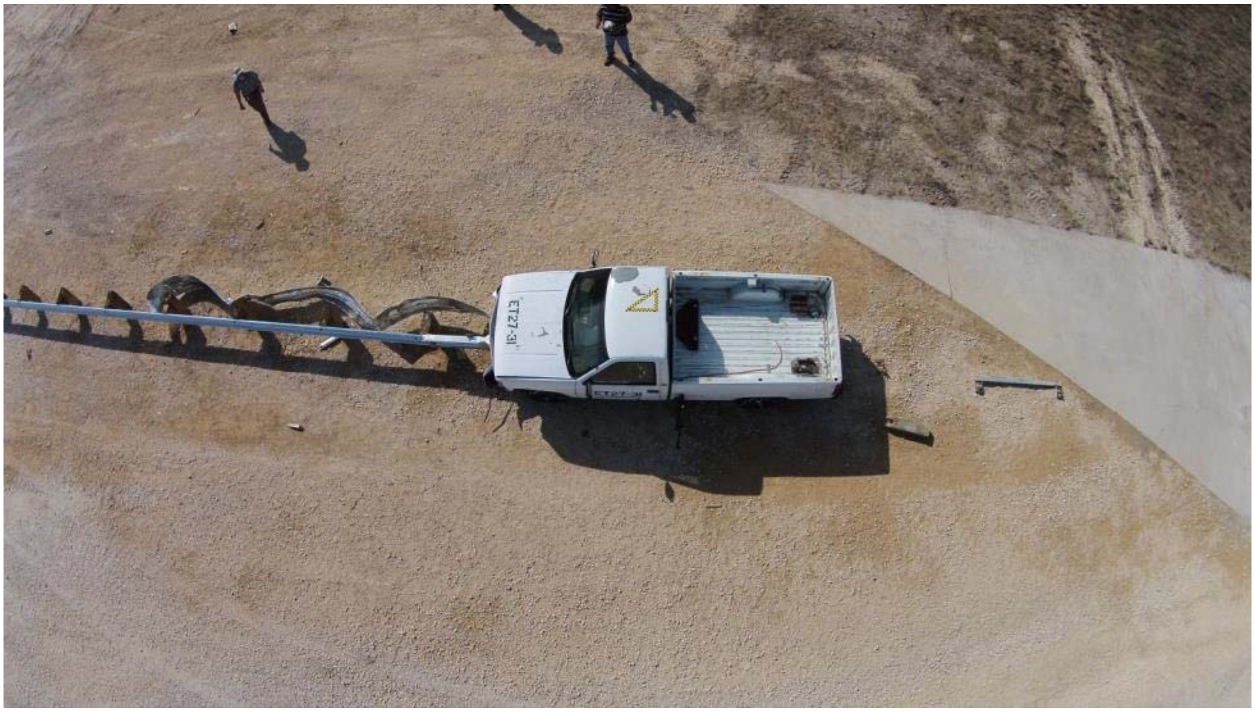


Figure 3.6: Post-Impact Condition of the Test Article and Vehicle

Figure 3.7: Post-Impact Condition of the Test Article and Vehicle

Figure 3.8: Post Test – Post 1 and 2 Foundation Sleeves and Strut

Figure 3.9: Post Test – Post 1 Foundation Sleeve

Figure 3.10: Post Test – Post 2 Foundation Sleeve

Figure 3.11: Post Test – Post 1

Figure 3.12: Post Test – Posts 2 and 3 Under Vehicle, Close-up

Figure 3.13: Post Test – Posts 4, 5 and 6 Stacked Under Vehicle

Figure 3.14: Post Test – Post 8 Cracked, Blockout Twisted

Figure 3.15: Post Test – Post 9 Cracked

Figure 3.16: Post Test – Back Side of Extruder Head

Figure 3.17: Post Test – Side View

Figure 3.18: Post Test – Extruder Head at Post 7, Blockout Twisted

Figure 3.19: Post Test – Extruder Head at Post 7 (Splice Bolts Painted for Visibility in Video)

Figure 3.20: Post Test – Extruder Head at Post 7, Top View

Figure 3.21: Post Test – Extruded Guardrail

Figure 3.22: Post Test – Post 8 Blockout Twisted

Figure 3.23: Post Test Location of Anchor Cable

Figure 3.24: Post Test – Extruded Guardrail

Figure 3.25: Post Test – Extruded Guardrail Coil

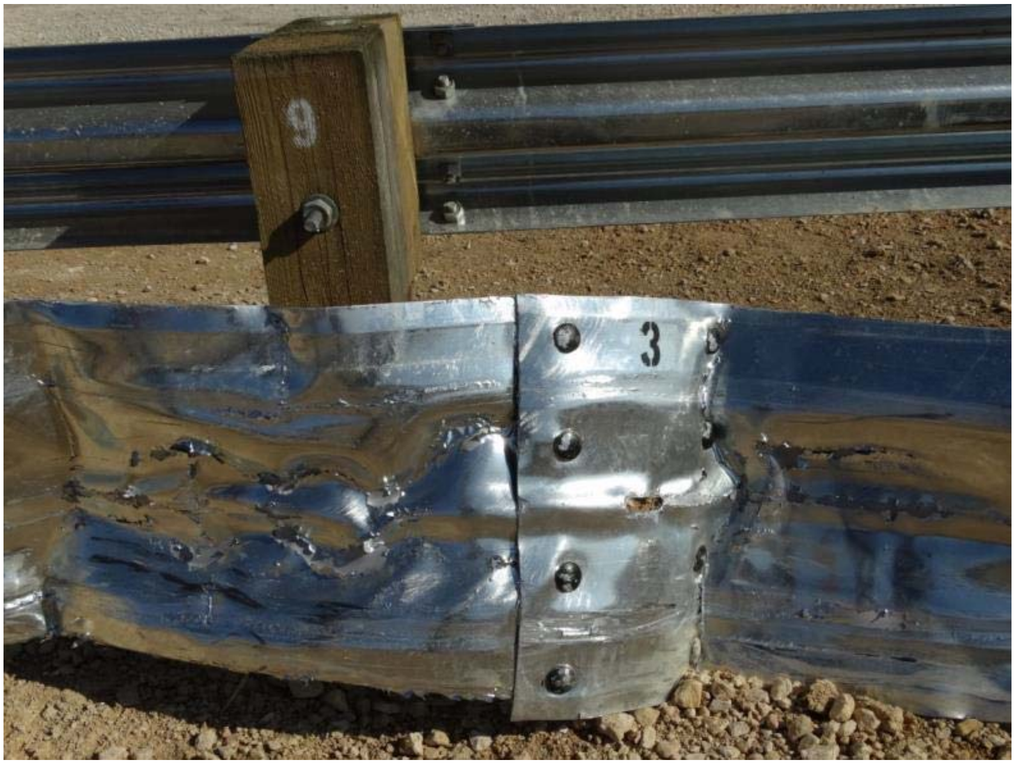


Figure 3.26: Post Test – Extruded Guardrail Splice from Post 3, Splice Bolts

Figure 3.27: Post Test – Extruded Guardrail Splice from Post 3, Splice Nuts

Figure 3.28: Post Test – Extruded Guardrail Splice from Post 5, Splice Bolts

Figure 3.29: Post Test – Extruded Guardrail Splice from Post 5, Splice Nuts

Figure 3.30: Post Test – Line Posts 7 and 8

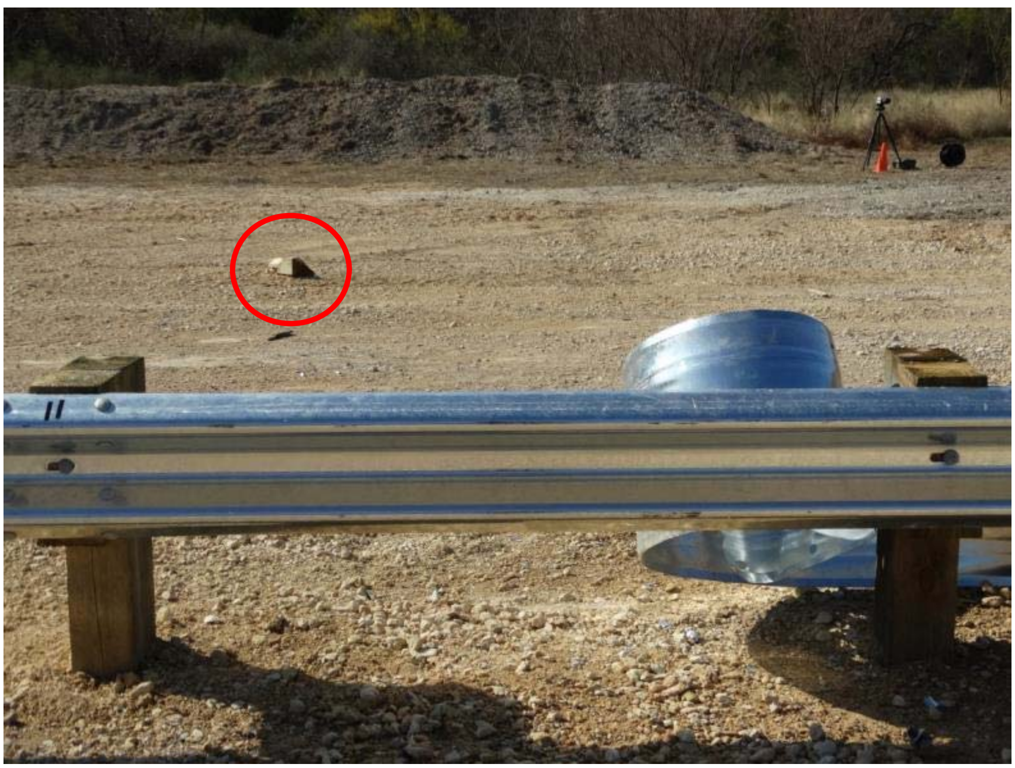


Figure 3.31: Post Test – Line Posts 10 & 11 and Debris

Figure 3.32: Post Test – Line Post 13 and Traffic-Side Debris

Figure 3.33: Post-Impact Test Article after Vehicle Removed

Figure 3.34: Post-Impact Test Article after Vehicle Removed – Traffic Side View

Figure 3.35: Post-Impact Test Article after Vehicle Removed – Rear View

Figure 3.36: Post-Impact Test Article after Vehicle Removed – Non-Traffic Side View

Figure 3.37: Post-Impact Test Article after Vehicle Removed –Guide Channel Entrance

Figure 3.38: Post Test Verification of Extruder Head 2

Vehicle Damage

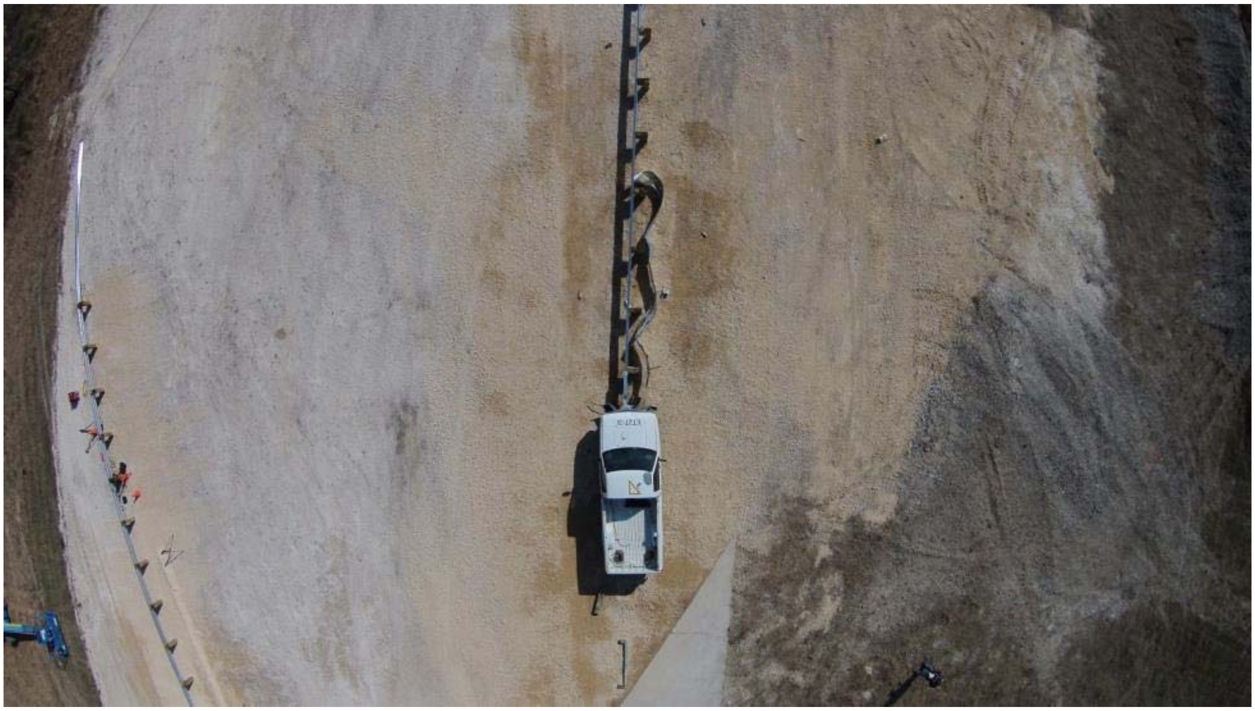


Figure 3.39: Test Vehicle Post-Test Location

Figure 3.40: Post Test Vehicle – Overhead View

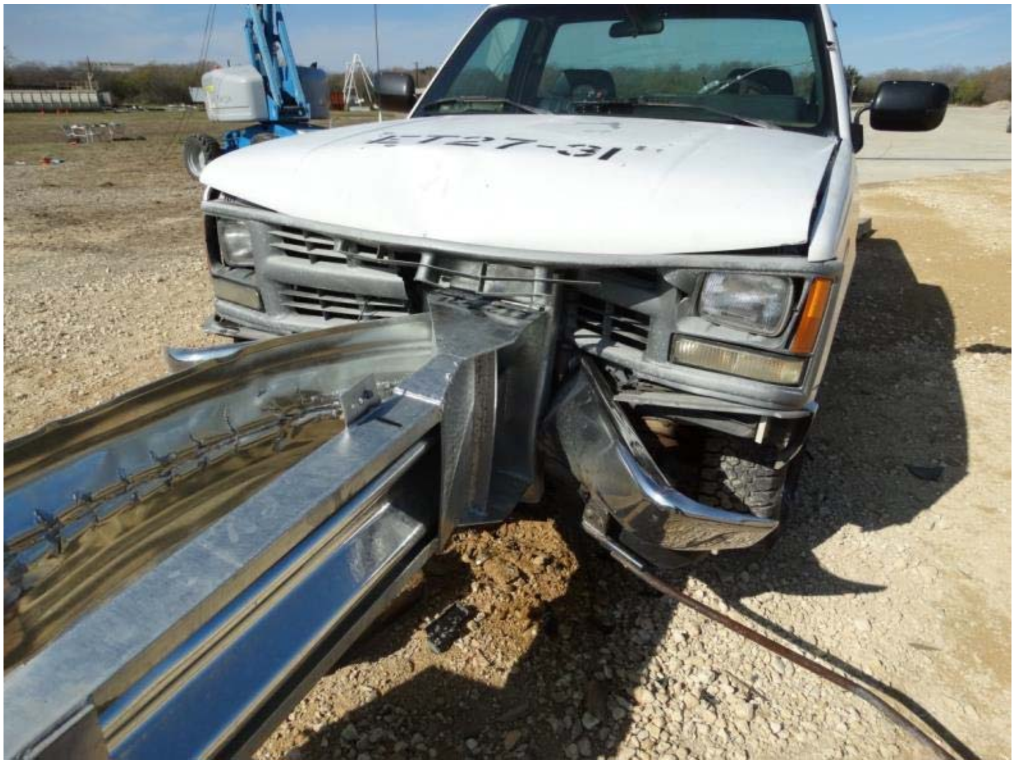


Figure 3.41: Post Test Vehicle – Front View

Figure 3.42: Damaged Test Vehicle – Front View Close-up

Figure 3.43: Post Test Vehicle – Left Side

Figure 3.44: Post Test Vehicle – Right Side

Figure 3.45: Post Test Vehicle – Front Hood

Figure 3.46: Post Test Vehicle – Accumulated Posts Located Under the Vehicle

Figure 3.47: Post Test Vehicle – Accumulated Posts Located Under the Vehicle

Figure 3.48: Post Test Vehicle – Accumulated Posts Lifted Vehicle

Figure 3.49: Post Test Vehicle – Front View after Removal from Guardrail

Figure 3.50: Post Test Vehicle – Left Side after Removal from Guardrail

Figure 3.51: Post Test Vehicle – Right Side after Removal from Guardrail

Figure 3.52: Post Test Vehicle – Occupant Compartment

Figure 3.53: Post Test Vehicle – Driver Side Floorboard

Figure 3.54: Post Test Vehicle – Passenger Side Floorboard

4 ASSESSMENT OF TEST RESULTS

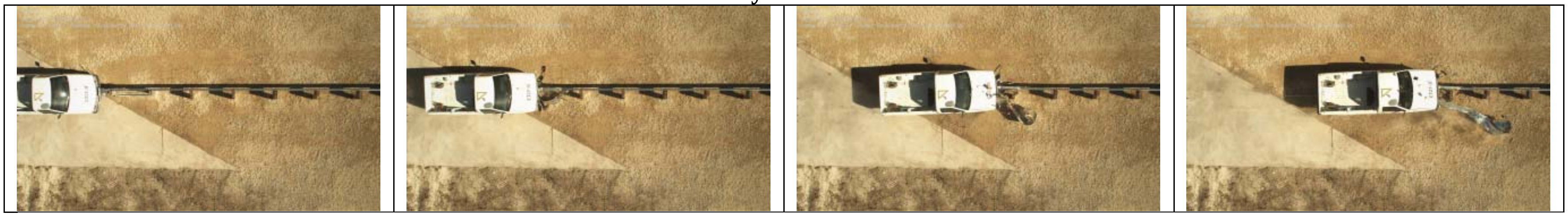
A comparison of the test results of Test ET27-31 against the evaluation criteria set forth in NCHRP Report 350 for Test 3-31 is provided in Table 4.1. A summary of the test results is provided in Table 4.2.

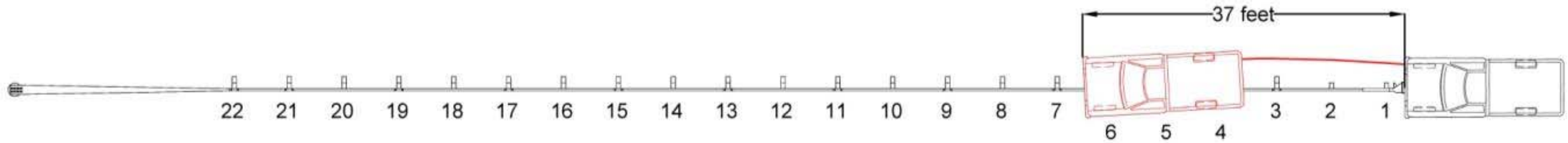
Table 4.1: Summary of Test Evaluation Results (NCHRP Report 350 Evaluation Criteria) for Test ET27-31

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: 7.1 m/s Lateral: -0.3 m/s	Pass
	I. Occupant Ridedown Acceleration (ORA) limits: Preferred = 15 g Maximum = 20 g	Occupant Ridedown Accelerations: Longitudinal: -9.2 g Lateral: 5.0 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		**Impact Conditions**		**Extruder Head Position from Start**	
Test Agency	Southwest Research Institute	Speed (km/hr)	97.5	Longitudinal	11.4 m (37.4 ft)
Test Number	ET27-31	Angle (degrees)	0.1	Lateral	~0 m
Test Date	12/16/2015	**Exit Conditions**		**Total System Deformation (Closest Point)**	
Test Category	3-31	Speed (km/hr)	N/A	Longitudinal	11.4 m (37.4 ft)
Test Article		Angle (degrees)	N/A	**Post Impact Vehicular Behavior**	
Type	End Terminal			Max Vehicle Rotation (degrees)	
Terminal Length	15.24 m (50 ft)	**Occupant Risk Values**		Max. Roll	-6.0 @ 1.2014 sec.
Installation Length	47.6 m (156.25 ft)	Impact Velocity (m/s)		Max. Pitch	-3.1 @ 0.7099 sec.
Nom. Barrier Height	705 mm (27.75 in)	x-direction	7.1	Max. Yaw	-2.8 @ 1.4195 sec.
Type of Primary Barrier	W-beam guardrail	y-direction	-0.3	Max 50ms Moving Average Accelerations (g)	
Soil	Stable, Dry - “Standard” Soil	Ridedown Accelerations (g)		x-direction	-7.2 @ 0.4346-0.4846 sec.
Test Vehicle		x-direction	-9.2	y-direction	1.2 @ 0.7131-0.7631 sec.
Type	Pickup truck	y-direction	5.0	z-direction	4.0 @ 0.9784-1.0284 sec.
Designation	2000P	**Target Conditions**			
Model	1994 Chevrolet C2500	Nominal Speed	100 km/hr (62.1 mph)		
Curb Mass (kg)	1898 as received	Nominal Angle	0°		
Ballast Mass (kg)	100	**Tolerances**			
Test Inertial Mass (kg)	1998	Nominal Speed	±4 km/hr		
Dummy Mass (kg)	N/A	Nominal Angle	±1.5°		
Gross Static Mass (kg)	1998				

5 CONCLUSIONS

The performance of the ET Plus during Test ET27-31 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

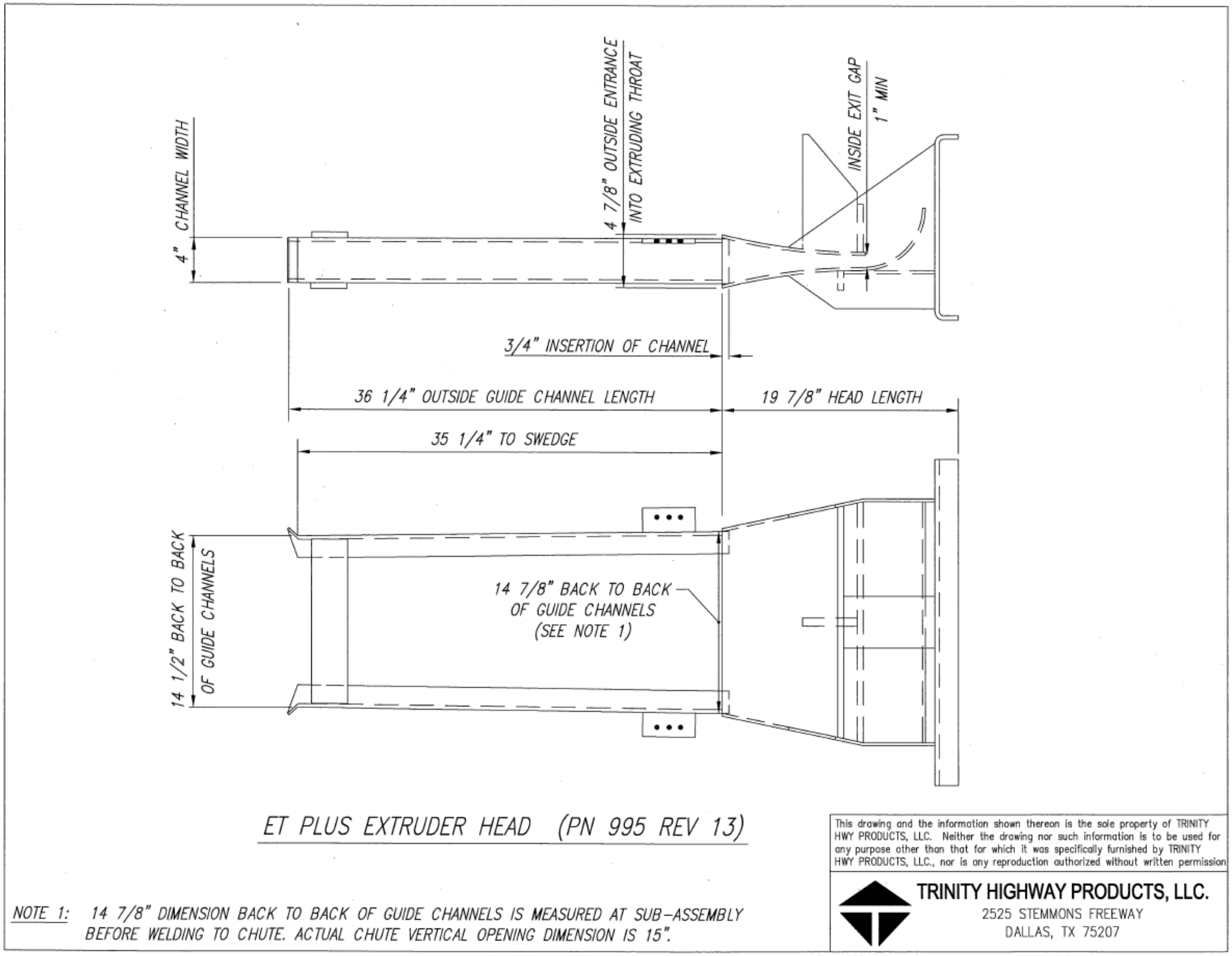
- There was no penetration of the vehicle by the test article, and no deformation of the occupant compartment resulting from the test.
- There was no undue hazard presented by test article debris outside of the immediate impact zone; the only debris thrown from the installation included pieces of posts 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.

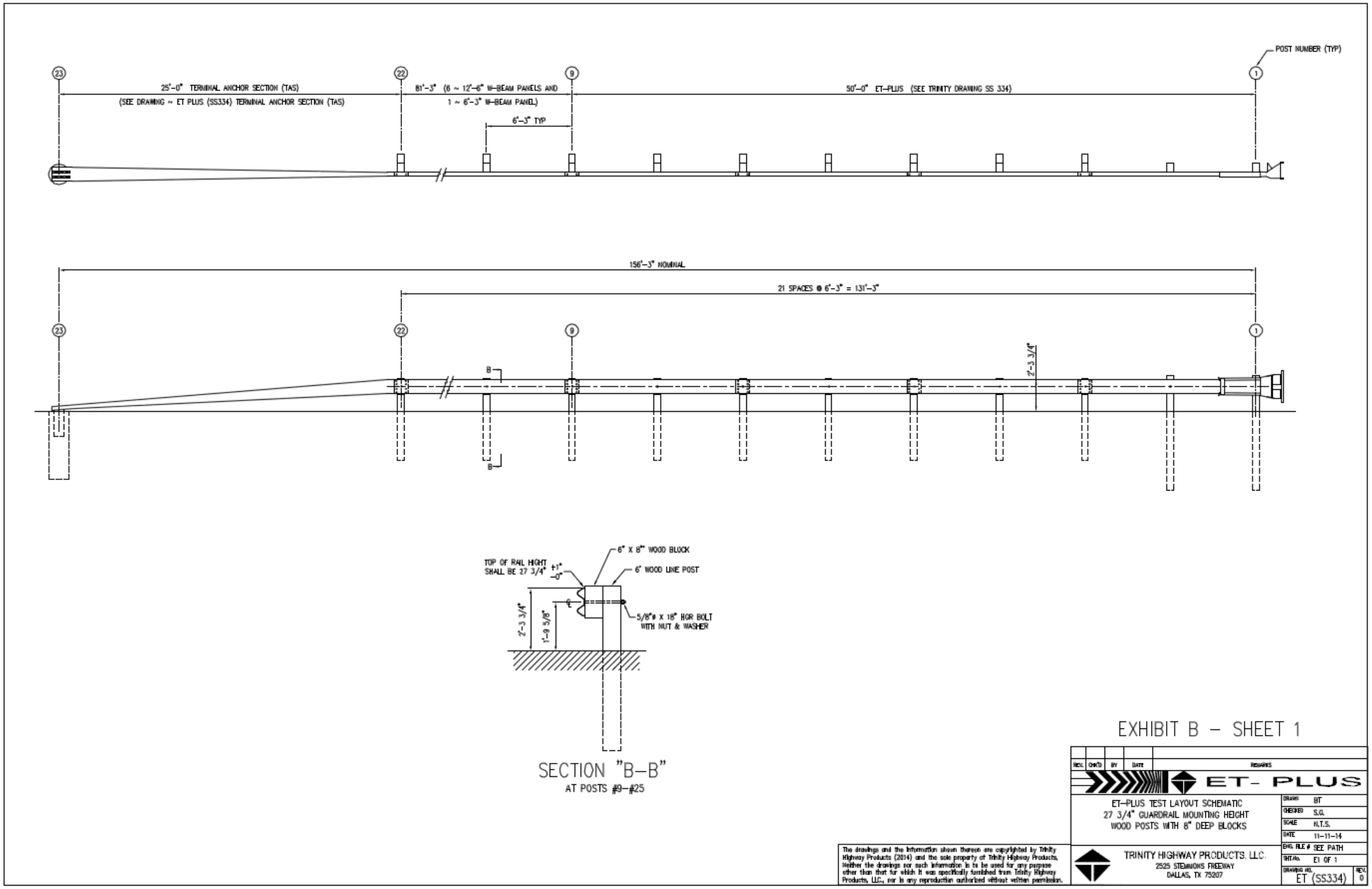
Vehicle Trajectory

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

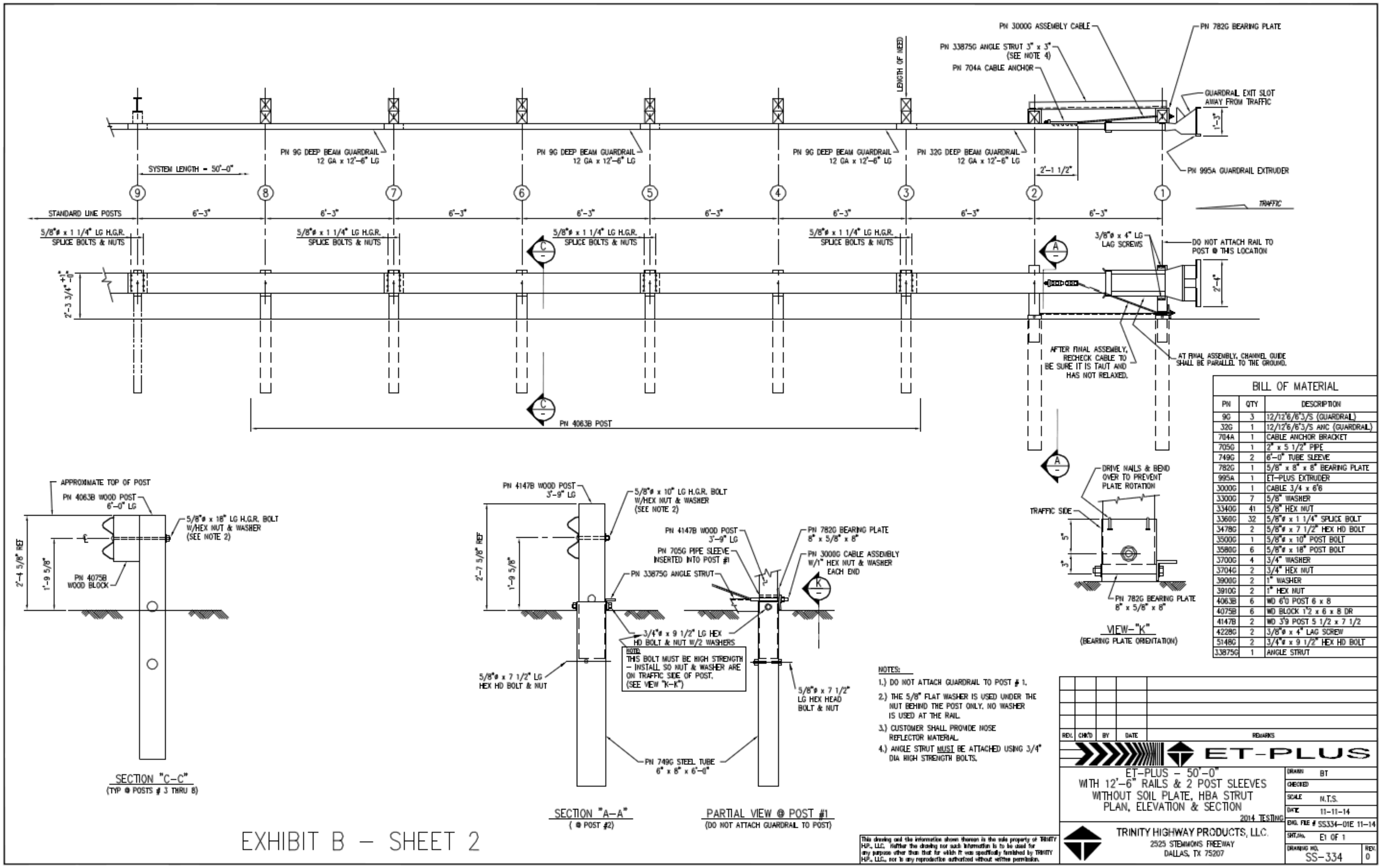
Based on the information provided in this report, the ET Plus End Terminal with 4-inch wide guide channel installed with a rail height of 27¾" meets the Test Level 3, Test 3-31 criteria for NCHRP Report 350.

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)
This drawing and the information shown thereon is the sole property of TRINITY HWY PRODUCTS, LLC. Neither the drawing nor such information is to be used for any purpose other than that for which it was specifically furnished by TRINITY HWY PRODUCTS, LLC., nor is any reproduction authorized without written permission
TRINITY HIGHWAY PRODUCTS, LLC.
2525 STEMMONS FREEWAY
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".



ET27-31
Appendix A – Test Article Drawings



BILL OF MATERIAL

PN	QTY	DESCRIPTION
9G	3	12/12'6/6'3/S (GUARDRAIL)
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
3580G	6	5/8"ø x 18" POST BOLT
3700G	4	3/4" WASHER
3704G	2	3/4" HEX NUT
3900G	2	1" WASHER
3910G	2	1" HEX NUT
4063B	6	WD 6'0 POST 6 x 8
4075B	6	WD BLOCK 1'2 x 6 x 8 DR
4147B	2	WD 3'9 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
33875G	1	ANGLE STRUT

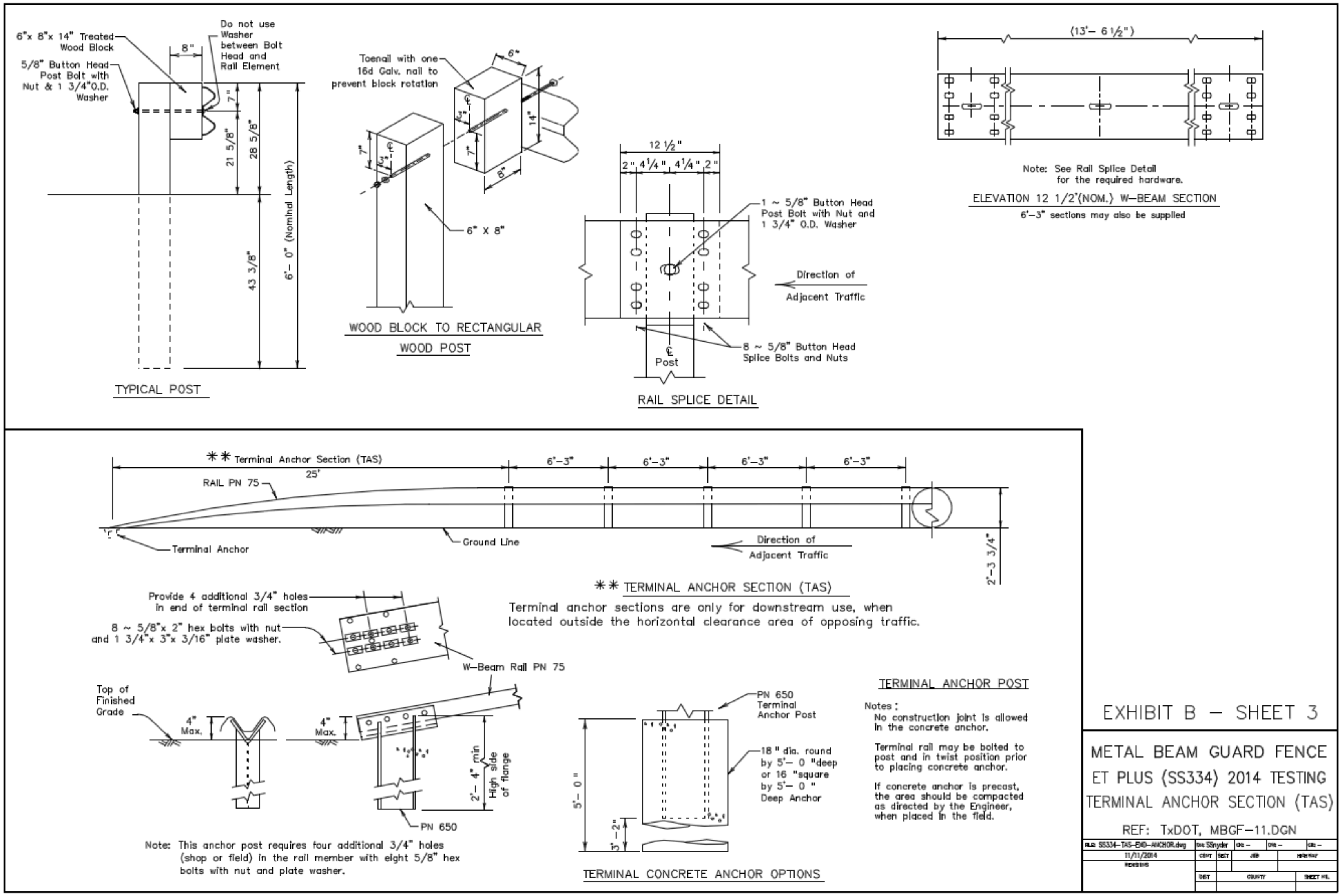
NOTES:

1.) DO NOT ATTACH GUARDRAIL TO POST # 1.

2.) THE 5/8" FLAT WASHER IS USED UNDER THE NUT BEHIND THE POST ONLY. NO WASHER IS USED AT THE RAIL.

3.) CUSTOMER SHALL PROVIDE NOSE REFLECTOR MATERIAL.

4.) ANGLE STRUT MUST BE ATTACHED USING 3/4" DIA HIGH STRENGTH BOLTS.



TYPICAL POST
6"x 8"x 14" Treated Wood Block
5/8" Button Head Post Bolt with Nut & 1 3/4"O.D. Washer
Do not use Washer between Bolt Head and Rail Element
WOOD BLOCK TO RECTANGULAR WOOD POST
Toenail with one 16d Galv. nail to prevent block rotation
RAIL SPLICE DETAIL
1 ~ 5/8" Button Head Post Bolt with Nut and 1 3/4" O.D. Washer
Direction of Adjacent Traffic
8 ~ 5/8" Button Head Splice Bolts and Nuts
Note: See Rail Splice Detail for the required hardware.
ELEVATION 12 1/2"(NOM.) W-BEAM SECTION
6'-3" sections may also be supplied
** Terminal Anchor Section (TAS)
RAIL PN 75
Terminal Anchor
Ground Line
** TERMINAL ANCHOR SECTION (TAS)
Terminal anchor sections are only for downstream use, when located outside the horizontal clearance area of opposing traffic.
Provide 4 additional 3/4" holes in end of terminal rail section
8 ~ 5/8"x 2" hex bolts with nut and 1 3/4"x 3"x 3/16" plate washer.
W-Beam Rail PN 75
Top of Finished Grade
PN 650
Note: This anchor post requires four additional 3/4" holes (shop or field) in the rail member with eight 5/8" hex bolts with nut and plate washer.
PN 650 Terminal Anchor Post
18" dia. round by 5'- 0" deep or 16" square by 5'- 0" Deep Anchor
TERMINAL CONCRETE ANCHOR OPTIONS
TERMINAL ANCHOR POST
Notes:
No construction joint is allowed in the concrete anchor.
Terminal rail may be bolted to post and in twist position prior to placing concrete anchor.
If concrete anchor is precast, the area should be compacted as directed by the Engineer, when placed in the field.
EXHIBIT B – SHEET 3
METAL BEAM GUARD FENCE
ET PLUS (SS334) 2014 TESTING
TERMINAL ANCHOR SECTION (TAS)
REF: TxDOT, MBGF-11.DGN

Appendix B: SwRI Data Sheets for Test ET27-31

EXHIBIT D-1: Installation Checklist

Test Number: ET 27-31 Test Date: 12/12/2014

*Record the following impact head dimensions:

head stamp "2" 12/4/2014 OH

Dimension	*Pre-Test Measurements
Exit Gap (middle - inside)	1.0890" ✓
Entrance Gap (middle - outside)	4.8090"
Guide Chute Exit Height (outside)	14 15/16" ✓
Guide Chute Entrance Height (outside)	14.5" ✓
Channel Width (outside)	4.0350" ✓
Channel Insertion into Extruder	0.4750" 0.4910" 0.4925" 0.6230"
Outside Guide Channel Length	36.5" ✓
Outside Guide Channel Length – Chute to start of swedge	35" ✓
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: 27 3/4 inches
   b. Between post 2 and 3: 28 inches
   c. Between post 3 and 4: 27 7/8 inches
   d. Between post 4 and 5: 27 3/4 inches
   Between post 5 and 6: 27 3/4 inches
   Between post 6 and 7: 28 inches
   Between post 7 and 8: 28 inches
   Between post 8 and 9: 28 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: 6 7/8 inches. ✓
c. Distance from the ground to the top of the impact face: 34 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 7/8 inches (Must be 4 inches or less).
g. Distance from the ground to the top of the second foundation tube: 3 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.

HIGHLY CONFIDENTIAL AM 12/12/14 RRA 12/12/14

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 12/12/2014

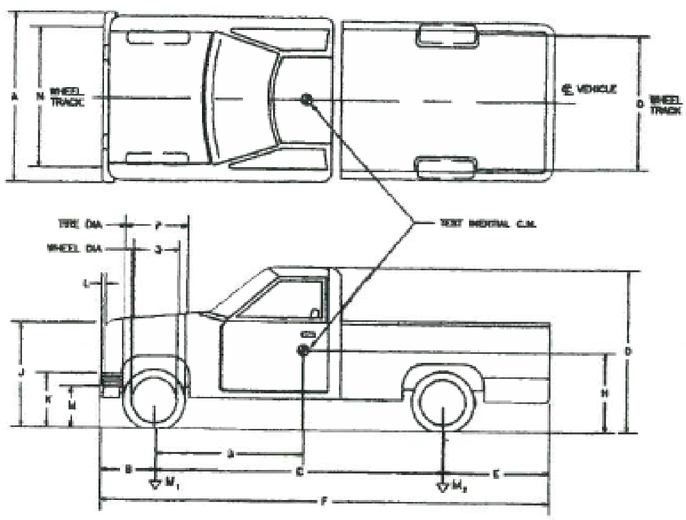
WHITE 1GCFC24K4RZ251587

DATE: 12/8/14 TEST NO.: ET27-31 VIN NO.: ______ MAKE: Chevy
MODEL: C2500 YEAR: 1994 ODOMETER: 206060 GVW: 7200
TIRE SIZE: 245/75 R16 TIRE INFLATION PRESSURE: 35 TREAD TYPE: ______

MASS DISTRIBUTION (kg) LF 1223 RF 1241 LR 957 RR 983
TOTAL - 4404 ⟵ INCLUDING 220lbs BALLAST

DESCRIBE ANY DAMAGE TO VEHICLE PRIOR TO TEST:

BROKEN TAILGATE HANDLE



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

DUMMY DATA:
TYPE: ______
MASS: ______
SEAT POSITION: ______

CG - 11.4" ABOVE FRONT SPINDLE CENTERLI

GEOMETRY – (cm)

A 76.5"	D 70.75"	G 57.9"	K 23.75"	N 72"	Q 17.4"
B 33.5"	E 51.5"	H 25.8"	L 3.4"	O 63.5"	
C 131.5"	F 216.5"	J 41"	M 15.75"	P 30.5"	

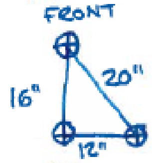
MASS – (kg)	CURB	TEST INERTIAL	GROSS STATIC
M_1			
M_2			
M_T			

EDR FROM FRONT SPINDLE 57.9", FROM GROUND 29"

Figure 4.2. 2000P parameters.

OH 12/11/2014

TOP TRIANGLE
FRONT



REAR

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.

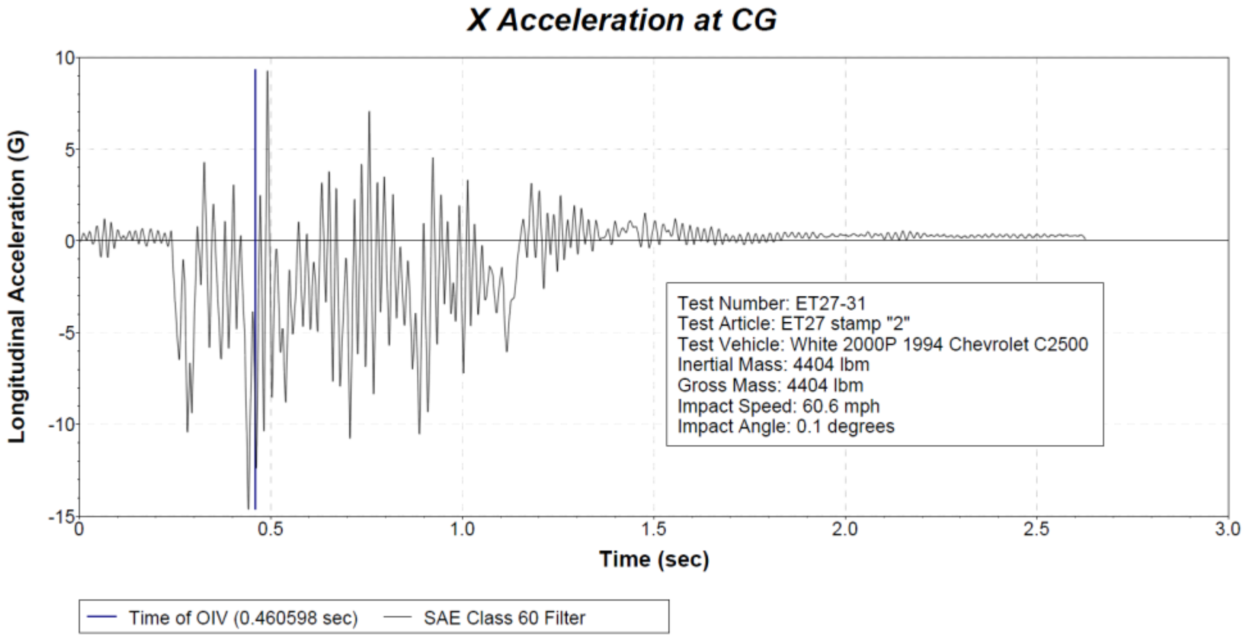
Sincerely,

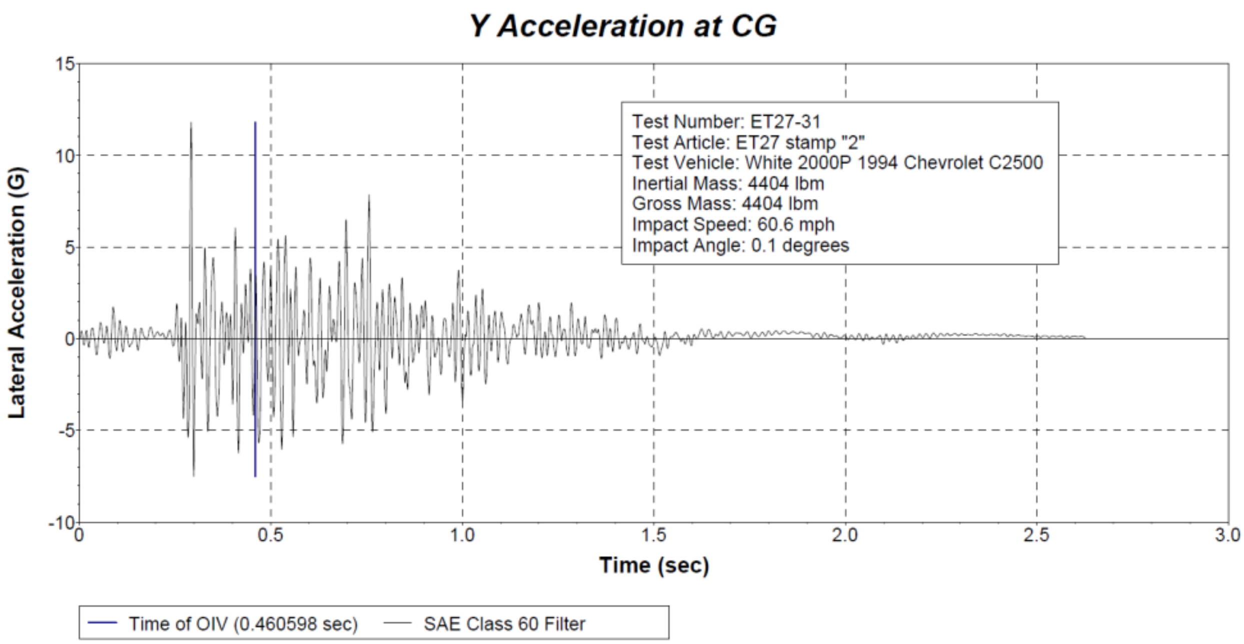
R. B. Kalmbach
Executive Director, Contracts

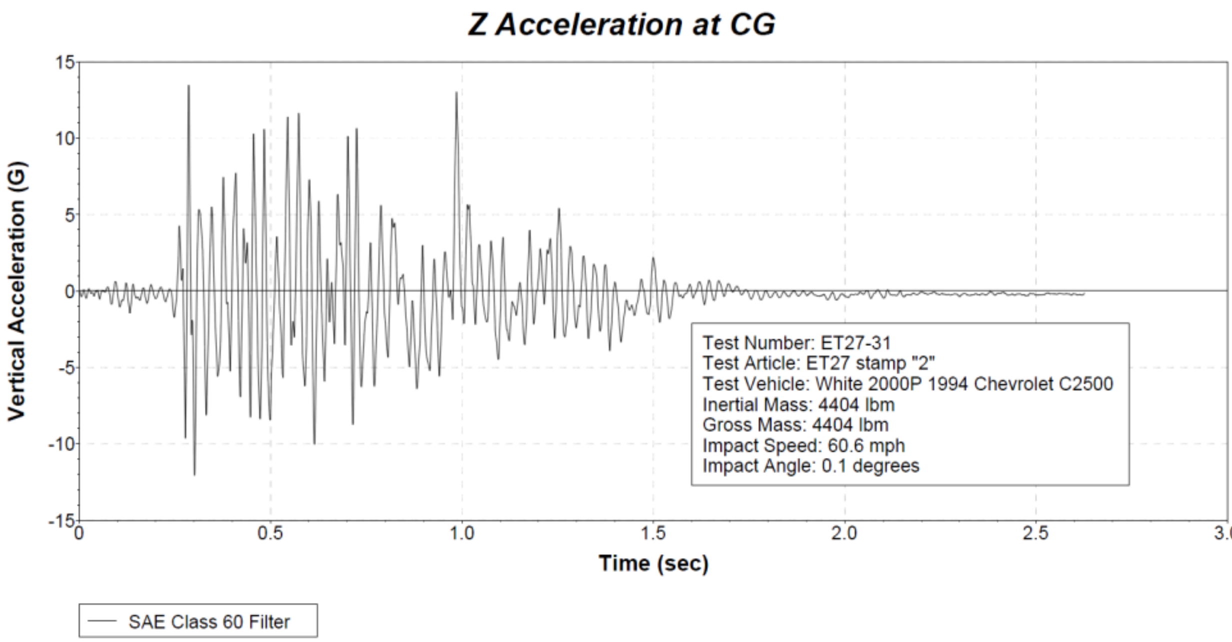
RBK/MKL/jms
cc: J. Ferren, SwRI (via email)

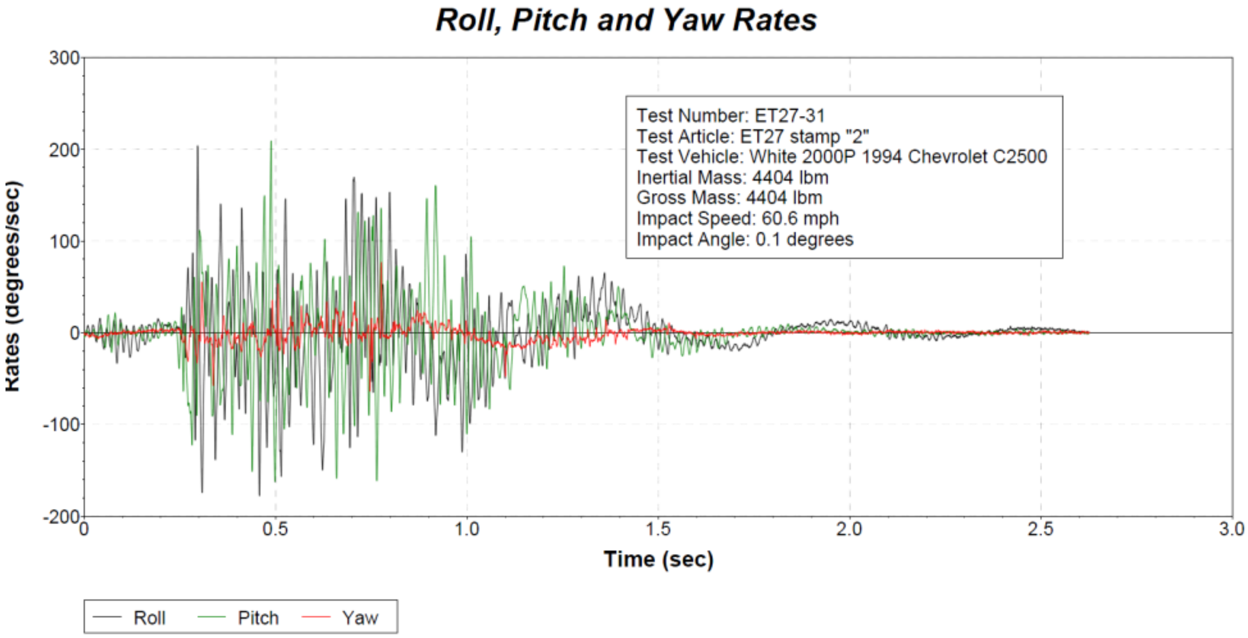
Benefiting government, industry and the public through innovative science and technology

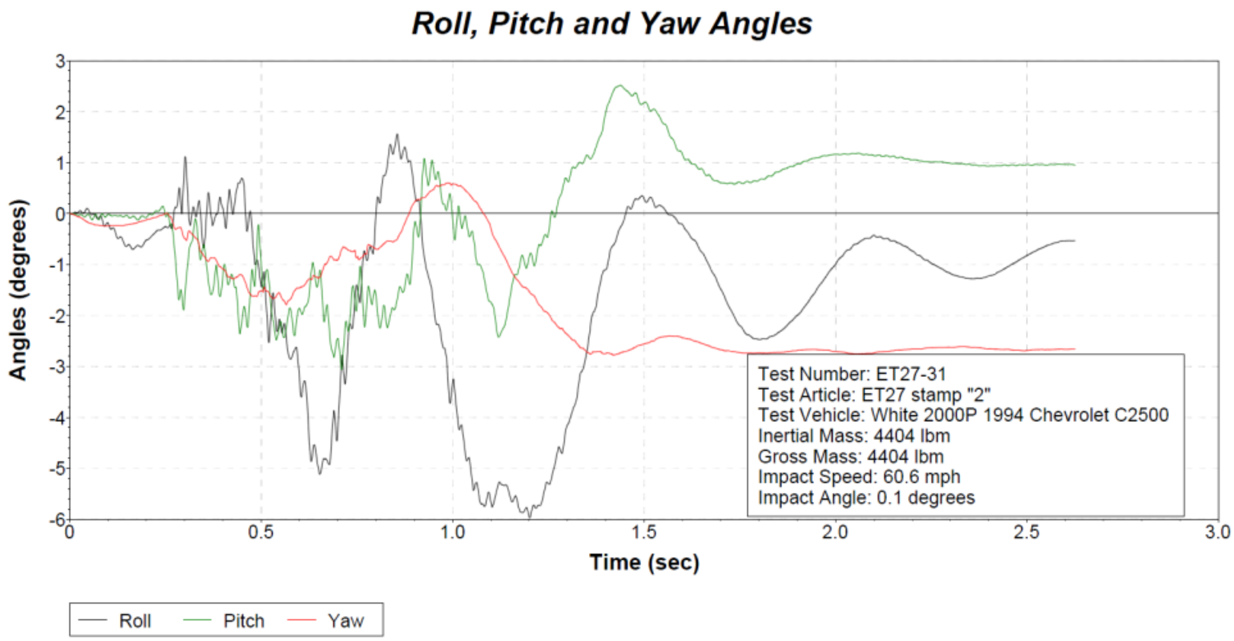
Appendix D: Test Data Plots


X Acceleration at CG
Longitudinal Acceleration (G)
Time (sec)
Test Number: ET27-31
Test Article: ET27 stamp "2"
Test Vehicle: White 2000P 1994 Chevrolet C2500
Inertial Mass: 4404 lbm
Gross Mass: 4404 lbm
Impact Speed: 60.6 mph
Impact Angle: 0.1 degrees
Time of OIV (0.460598 sec)
SAE Class 60 Filter


Y Acceleration at CG
Lateral Acceleration (G)
Time (sec)
Test Number: ET27-31
Test Article: ET27 stamp "2"
Test Vehicle: White 2000P 1994 Chevrolet C2500
Inertial Mass: 4404 lbm
Gross Mass: 4404 lbm
Impact Speed: 60.6 mph
Impact Angle: 0.1 degrees
Time of OIV (0.460598 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: ET27-31
Test Article: ET27 stamp "2"
Test Vehicle: White 2000P 1994 Chevrolet C2500
Inertial Mass: 4404 lbm
Gross Mass: 4404 lbm
Impact Speed: 60.6 mph
Impact Angle: 0.1 degrees
SAE Class 60 Filter


Roll, Pitch and Yaw Rates
Test Number: ET27-31
Test Article: ET27 stamp "2"
Test Vehicle: White 2000P 1994 Chevrolet C2500
Inertial Mass: 4404 lbm
Gross Mass: 4404 lbm
Impact Speed: 60.6 mph
Impact Angle: 0.1 degrees
Rates (degrees/sec)
Time (sec)
Roll
Pitch
Yaw


Roll, Pitch and Yaw Angles
Test Number: ET27-31
Test Article: ET27 stamp "2"
Test Vehicle: White 2000P 1994 Chevrolet C2500
Inertial Mass: 4404 lbm
Gross Mass: 4404 lbm
Impact Speed: 60.6 mph
Impact Angle: 0.1 degrees
Angles (degrees)
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 (%):		

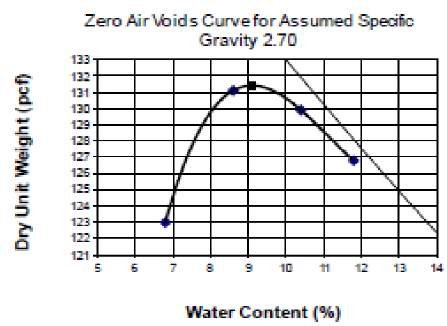
USCS:

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: 90141414.0006
Service Date: 12/16/14
Report Date: 12/18/14
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 (%)
	Test Rail #2								
1	10' off Rail	Final	1	12	133.4	8.1	6.5	125.3	95.4
2	Post #2	Final	1	12	135.2	9.2	7.3	126.0	95.9
3	Post #4	Final	1	12	136.8	9.3	7.3	127.5	97.0
4	Post #6	Final	1	12	133.8	7.9	6.3	125.9	95.8

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.: Nathan J. Gunn
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 27¾ Inches

Test Level 3, Test 3-32
Test Identification: ET27-32

SwRI® Project No. 18.20887

SwRI Document Number: 18.20887.03.100.FR3
Issue 1

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

January 23, 2015

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Mechanical Engineering Division

The results of this test report apply only to the specific samples tested. If the manufacturer extends the test results to apply to other samples of the same model, or from the same lot or batch, the manufacturer should ensure the additional samples are manufactured using identical electrical and mechanical components. This test report shall not be reproduced, except in full, without written approval of Southwest Research Institute.

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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	1/23/2015

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

1 INTRODUCTION

The purpose of Crash Test ET27-32 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 27¾". 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 47.6 m (156'-3"), including the 15.2 m (50 ft) 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 vehicle 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 ET27-32 was conducted on December 17, 2014, 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 27¾". The ET Plus End Terminal installation tested uses standard AASHTO M180 Type 2, 12-gauge, 12'-6" W-Beam guardrail panels mounted with the top of the rail 27¾ inches 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.

During installation, holes approximately 2' 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 cm (6 in) lifts, and was added until the surface was flush with the surrounding soil.

The guardrail line posts are 6" x 8" wood posts with 6" x 8" wood blockouts. The blockouts are toenailed, and the guardrail panels are mounted to the posts using 5/8"ϕ post bolts beginning with Post 2; the bolt for Post 2 is 10" long, and all other post bolts are 18" long. The post spacing is 6'-3", and each splice joint used eight (8) 5/8"ϕ x 1-1/4" splice bolts and nuts; the splice bolts have a nominal total length of 1-5/8" including the bolt head. The installation uses 3/4"ϕ x 10" 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 guardrail splices at each odd-numbered post starting with Post 3.

The total system installation length for the test was nominally 156'-3" (47.6 m), including the 50 ft (15.2 m) ET Plus terminal length, 81'-3" (24.8 m) of guardrail, and a 25' (7.6 m) downstream terminal anchor section that included a turndown guardrail anchor spliced at Post 22 and mounted to a concrete footing. 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 ET27-32 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 2.18 present photographs of the guardrail installation.

Table 2.1: Key ET Plus Head Dimensions

Extruder Head Stamp ID	4
Exit Gap	1.0475”
Entrance Gap	4.7690”
Guide Chute Exit Height	14-15/16”
Guide Chute Entrance Height	14-1/2”
Channel Width (see Figure 2.2)	4.0275”

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 ET27-32

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

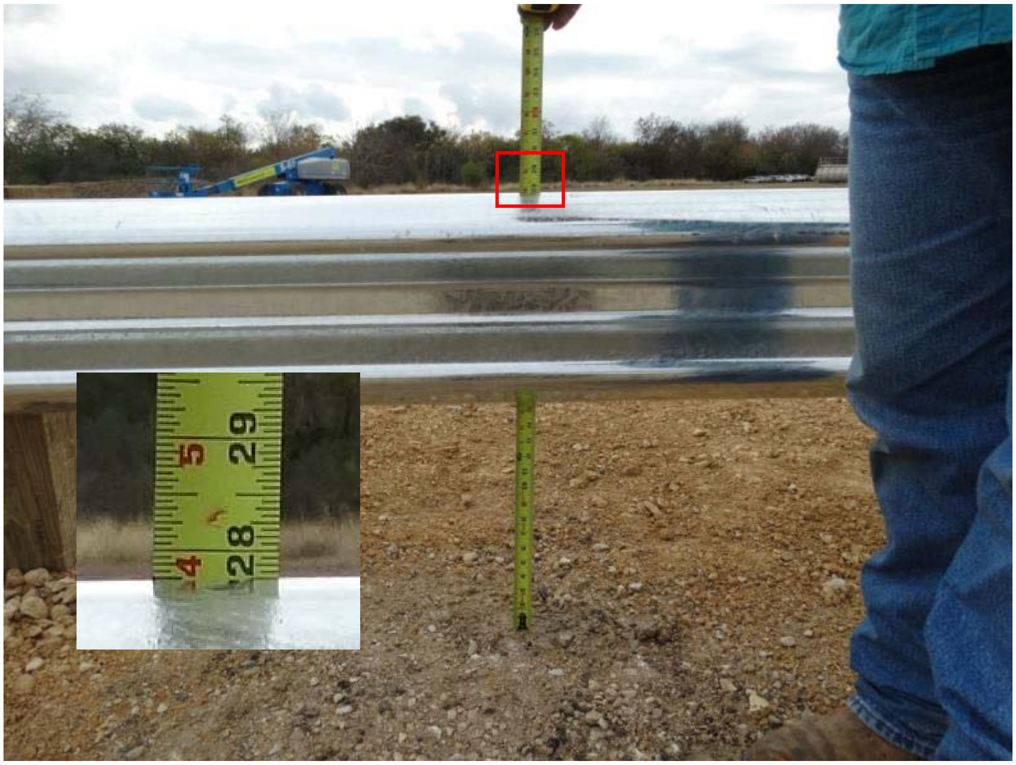


Figure 2.7: Measurement of Guardrail Installation Height

Figure 2.8: ET Plus Head and Anchor Cable Assembly

Figure 2.9: End Terminal Anchor Cable Mount – Post 1

Figure 2.10: End Terminal Cable Anchor

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: ET Plus Head and Post 1 – Traffic Side

Figure 2.14: ET Plus Head and Post 1 – Non-Traffic Side

Figure 2.15: End Terminal Head with Posts 1 & 2 and Strut

Figure 2.16: ET Plus Head Extruder Exit (see Appendix B for Dimensions)

Figure 2.17: Post 22 Immediately Preceding Downstream Turndown Anchor

Figure 2.18: Downstream Turndown Anchor

Test Vehicle

The test vehicle was a 1997 Geo Metro, shown in Figure 2.19; the vehicle data sheet is provided in Appendix B. Figure 2.20 shows the relationship between the height of the vehicle bumper and the end terminal. Figure 2.21 shows the test vehicle positioned at the impact point of the end terminal, and Figure 2.22 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 as shown in Figure 2.23 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 842 kg (1,856 lbs) as reflected in Table 4.2. Note that the test inertial mass does not include the weight of the anthropometric dummy.

Figure 2.19: Test Vehicle for Test ET27-32

Figure 2.20: Test Vehicle Bumper Height

Figure 2.21: Test Vehicle Impact Trajectory

Figure 2.22: Test Vehicle Impact Trajectory – Overhead View

Figure 2.23: 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 2.24. 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 2.24: 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 2.25. 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 2.25: EDR Mounted in Test Vehicle for Test ET27-32

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, and one camera was behind the passenger but aimed at the driver location. A photograph of the camera locations is provided in Figure 2.26.

Figure 2.26: Onboard Camera – Behind Driver

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 7.1% at a location behind Post 4. There was minimal rainfall in the form of drizzle between when the moisture reading was taken and when the testing was conducted, mostly in the 20 minutes immediately preceding the test. 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 ET27-32 on December 17, 2014:

- Federal Highway Administration (FHWA)
- Virginia DOT
- Ohio 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 and the test vehicle following the test.

3 TEST CONDITIONS AND RESULTS

Test Description

The purpose of Test ET27-32 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 27¾". 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 156'-3" (47.6 m), and the terminal length was 15.2 m (50 ft).

Test 3-32 is intended primarily to evaluate occupant risk and vehicle trajectory criteria. The test consists of an 820 kg vehicle 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.

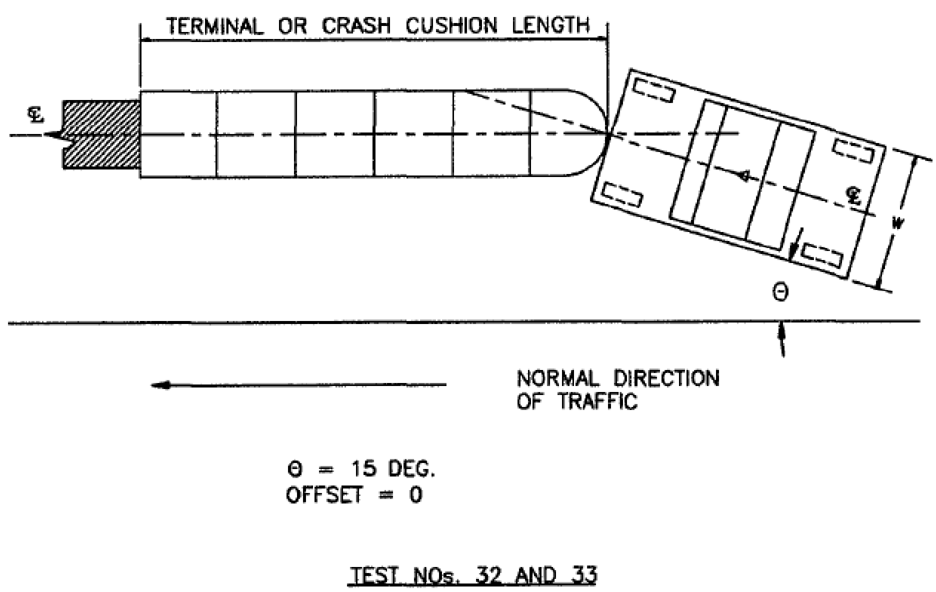


Figure 3.1: Impact Configuration *[from Figure 3.2 of NCHRP Report 350]*

The weather on the day of the test was mostly cloudy with some drizzle, with temperatures ranging from 48-59°F. The temperature at the time of the test was approximately 51°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 98.3 km/hr (61.1 mph). As a result of the test, the ET Plus extruder head moved 5.3 m (17.3 ft) longitudinally (downstream) and 1.1 m (3.5 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 3.7 m (12.3 ft) from the initial point of contact.

After the initial impact event, the ET Plus extruder head stroked along the guardrail, extruding approximately 3 feet 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 2. As the vehicle continued its angled trajectory, the channel guide portion of the ET Plus extruder head was pushed further downstream on the W beam over the fold that had formed at Post 2. 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 guide channel entrance scraped the driver’s side door creating a tear approximately 9” 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, and damaged Post 3 at the end of the stroke. The splice at Post 3 remained intact and connected to the post. Although Post 4 appeared undamaged, there was twisting of the Post 4 blockout due to relative longitudinal motion of the guardrail panel. All posts and blockouts downstream of Post 4 appeared undamaged, and no appreciable movement of the downstream turndown anchor was observed. Additionally, the anchor cable at Post 1 broke free of the installation and came to rest near Post 4. 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 and blockouts from the first two 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 45 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 2 feet. The vehicle was not operable after the test.

The test vehicle experienced a maximum 50 millisecond moving average acceleration of -11.0g in the longitudinal direction, 3.5g in the lateral direction, and -4.9g 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 risk impact velocities were 8.5 m/s in the longitudinal direction, and -1.5 m/s in the lateral direction.
- Occupant risk ridedown accelerations were -4.1g in the longitudinal direction, and 3.3g 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 Condition 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 ET27-32 was 313.8 kJ, a deviation of -2.6 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 $= \frac{1}{2} \cdot M \cdot (V \cdot \sin\theta)^2$

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

$= 0.5 \cdot (842\ \text{kg}) \cdot (27.3\ \text{m/s})^2$

$= 313.8\ \text{kJ}$

The equivalent impact speed of an 820 kg vehicle impacting the end terminal at 15 degrees would be 99.6 km/hr (61.9 mph).


Time = 0.000 seconds (Impact)


Time = 0.050 seconds


Time = 0.100 seconds


Time = 0.150 seconds


Time = 0.200 seconds

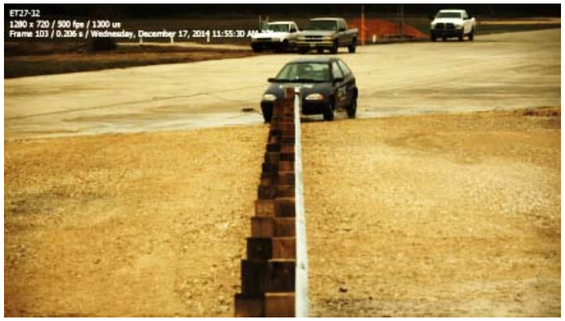

Time = 0.250 seconds


Time = 0.300 seconds


Time = 0.350 seconds


Time = 0.400 seconds

Figure 3.3: Sequential Photographs, as Viewed from Overhead



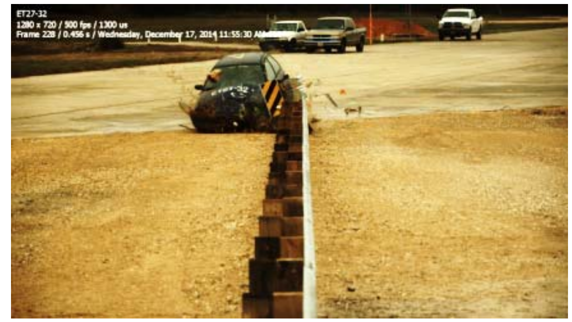
Time = 0.000 seconds (Impact)

Time = 0.050 seconds

Time = 0.100 seconds

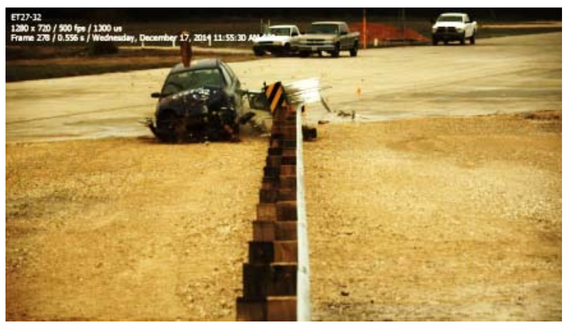
Time = 0.150 seconds

Time = 0.200 seconds

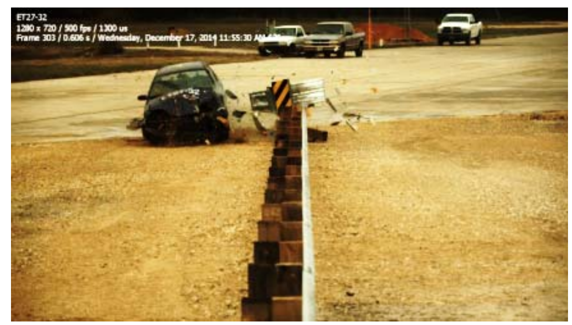


Time = 0.250 seconds

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 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 – Left Vehicle Track

Figure 3.8: Post Test – Foundation Sleeve at Post 1

Figure 3.9: Post Test – Foundation Sleeve at Post 2

Figure 3.10: Post Test – Post 3

Figure 3.11: Post Test – Post 4

Figure 3.12: Post Test – Post 5

Figure 3.13: Post Test – Gated Guardrail, View from Traffic Side

Figure 3.14: Post Test – Gated Guardrail

Figure 3.15: Post Test – Gated Guardrail

Figure 3.16: Post Test – Extruded Tail of W-Beam

Figure 3.17: Post Test – Extruded Guardrail Tail

Figure 3.18: Post Test – Extruded Guardrail

Figure 3.19: Post Test – Gating Between Posts 2 and 3

Figure 3.20: Post Test – Non-Traffic Side of Extruder Head

Figure 3.21: Post Test – Top View of Extruder Head

Figure 3.22: Post Test – Gated Guardrail

Figure 3.23: Post Test – Debris Field on Non-Traffic Side

Figure 3.24: Post Test – Debris on Traffic Side

Figure 3.25: Post Test – Final Vehicle Location past Post 17

Figure 3.26: Post Test Location of Anchor Cable at Post 4

Figure 3.27: Post Test Terminal Extruder Head Impact Plate

Figure 3.28: Post Test – Non-Traffic Side of Extruder Head

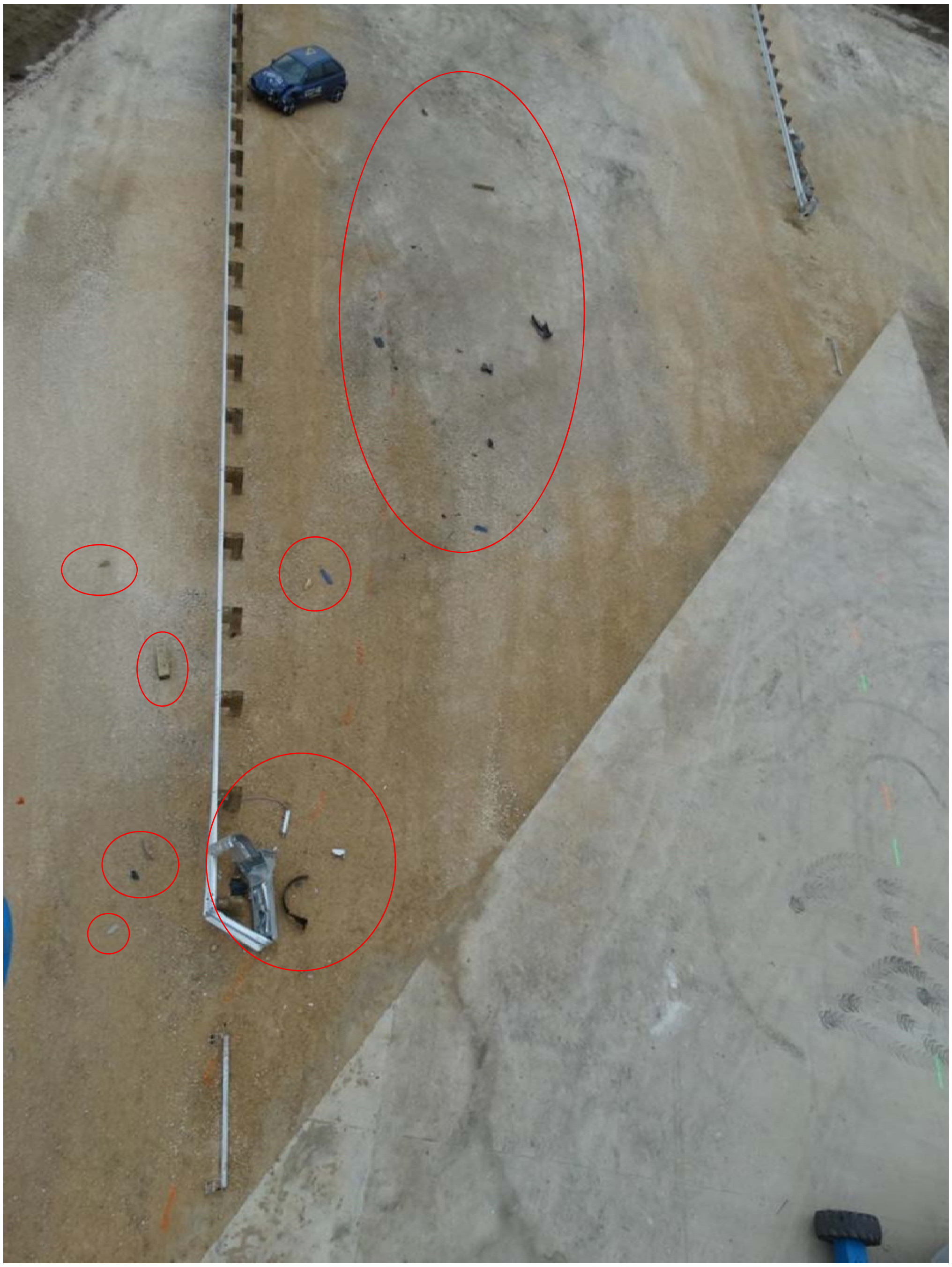


Figure 3.29: Post-Impact Debris Field

Figure 3.30: Post Test Verification of Extruder Head 4

Vehicle Damage

Figure 3.31: Vehicle Post-Test Location

Figure 3.32: Test Vehicle Path of Left Front Tire

Figure 3.33: Damaged Test Vehicle – Front View

Figure 3.34: Damaged Test Vehicle – Front View Close-up

Figure 3.35: Damaged Test Vehicle – Left Side

Figure 3.36: Damaged Test Vehicle – Right Side

Figure 3.37: Guide Channel at Driver Side Door During Test

Figure 3.38: Damaged Test Vehicle – Tear in Door Skin

Figure 3.39: Damaged Test Vehicle – Door Panel Intact behind Exterior Tear

Figure 3.40: Post-Test – Occupant Compartment

Figure 3.41: Post-Test – Driver Side Floorboard

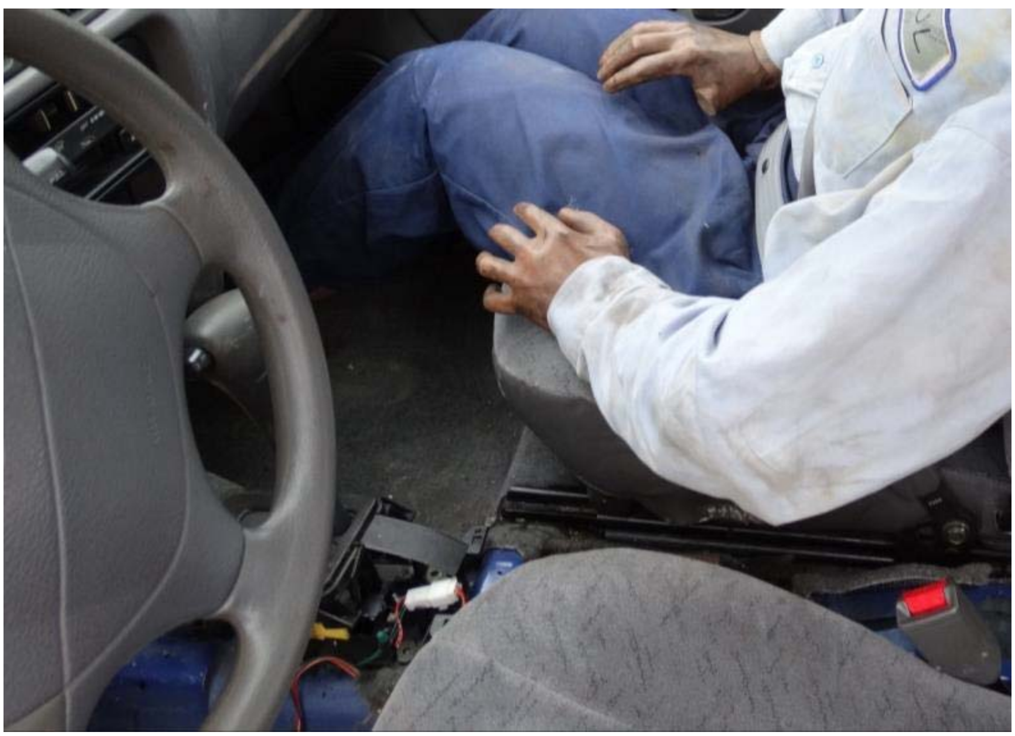


Figure 3.42: Post-Test – Passenger Side Floorboard

4 ASSESSMENT OF TEST RESULTS

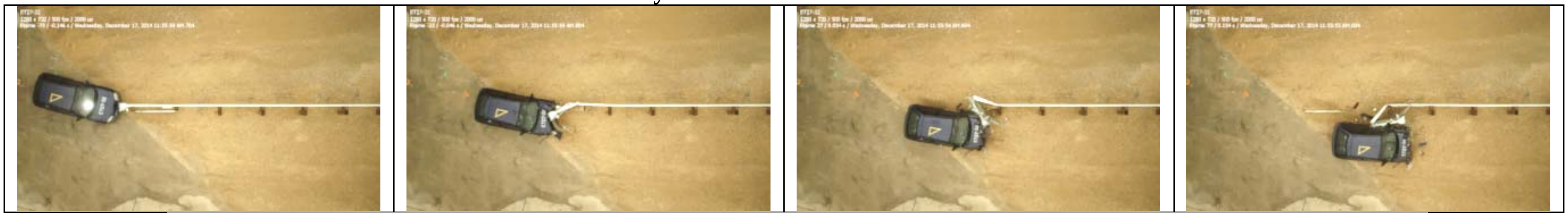
A comparison of the test results of Test ET27-32 against the evaluation criteria set forth in NCHRP Report 350 for Test 3-32 is provided in Table 4.1. A summary of the test results is provided in Table 4.2.

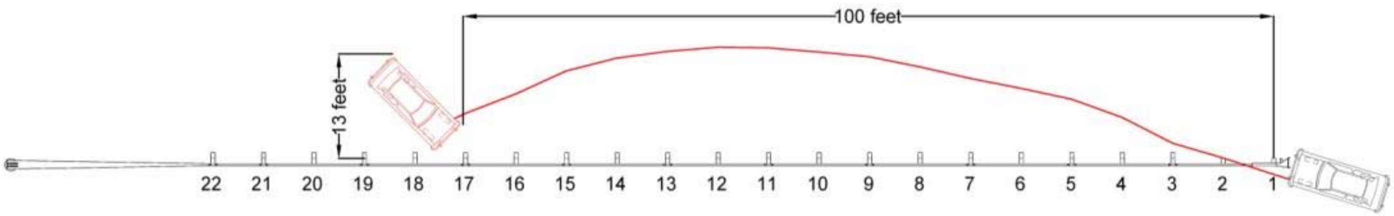
Table 4.1: Summary of Test Evaluation Results (NCHRP Report 350 Evaluation Criteria) for Test ET27-32

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: 8.5 m/s Lateral: -1.5 m/s	Pass
	I. Occupant Ridedown Acceleration (ORA) limits: Preferred = 15 g Maximum = 20 g	Occupant Ridedown Accelerations: Longitudinal: -4.1 g Lateral: 3.3 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 ET27-32





General Information		**Impact Conditions**		**Extruder Head Position from Start**	
Test Agency	Southwest Research Institute	Speed (km/hr)	98.3	Longitudinal	5.3 m (17.3 ft)
Test Number	ET27-32	Angle (degrees)	15.2	Lateral	1.1 m (3.5 ft)
Test Date	12/17/2014	**Exit Conditions**		**Total System Deformation (Closest Point)**	
Test Category	3-32	Speed (km/hr)	58.3	Longitudinal	3.7 m (12.3 ft)
Test Article		Angle (degrees)	0.6	**Post Impact Vehicular Behavior**	
Type	End Terminal			Max Vehicle Rotation (degrees)	
Terminal Length	15.24 m (50 ft)	**Occupant Risk Values**		Max. Roll	9.6 @ 0.7174 sec.
Installation Length	47.6 m (156.25 ft)	Impact Velocity (m/s)		Max. Pitch	-5.8 @ 0.4457 sec.
Nom. Barrier Height	705 mm (27.75 in)	x-direction	8.5	Max. Yaw	-147.4 @ 3.6382 sec.
Type of Primary Barrier	W-beam guardrail	y-direction	-1.5	Max 50ms Moving Average Accelerations (g)	
Soil	Stable, Dry - “Standard” Soil	Ridedown Accelerations (g)		x-direction	-11.0 @ 0.2461-0.2961 sec.
Test Vehicle		x-direction	-4.1	y-direction	3.5 @ 0.3018-0.3518 sec.
Type	Small car	y-direction	3.3	z-direction	-4.9 @ 0.2705-0.3205 sec.
Designation	820C	**Target Conditions**			
Model	1997 Geo Metro	Nominal Speed	100 km/hr (62.1 mph)		
Curb Mass (kg)	842 as received	Nominal Angle	15°		
Ballast Mass (kg)	0	**Tolerances**			
Test Inertial Mass (kg)	842	Nominal Speed	±4 km/hr		
Dummy Mass (kg)	75	Nominal Angle	±1.5˚		
Gross Static Mass (kg)	917				

5 CONCLUSIONS

The performance of the ET Plus during Test ET27-32 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

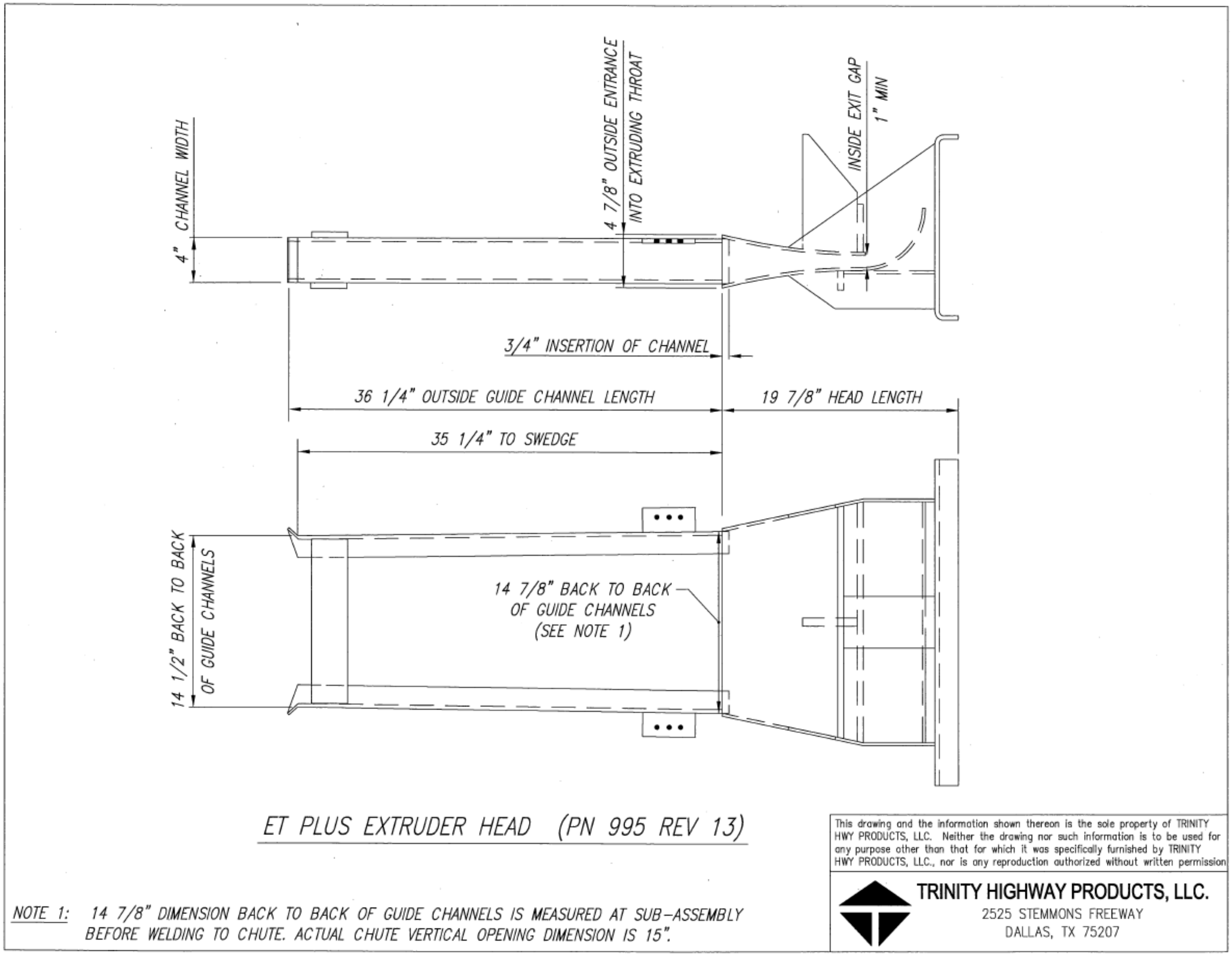
- There was no penetration of the vehicle by the test article, and no deformation of the occupant compartment resulting from the test.
- There was no undue hazard presented by test article debris outside of the immediate impact zone; the only debris thrown from the installation included pieces of posts 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 27¾" meets the Test Level 3, Test 3-32 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)
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".
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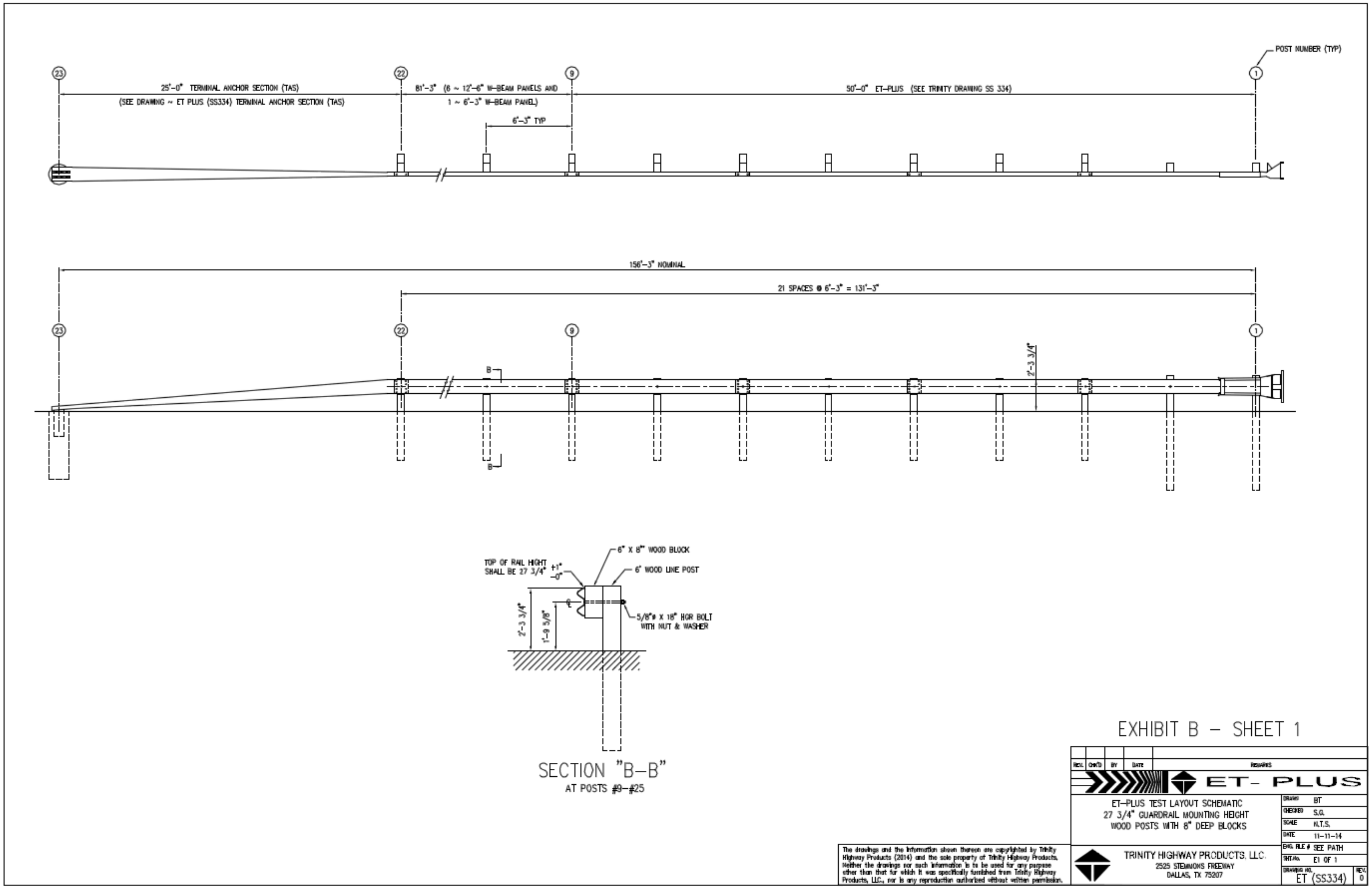
TRINITY HIGHWAY PRODUCTS, LLC.
2525 STEMMONS FREEWAY
DALLAS, TX 75207


POST NUMBER (TYP)
25'-0" TERMINAL ANCHOR SECTION (TAS)
(SEE DRAWING ~ ET PLUS (SS334) TERMINAL ANCHOR SECTION (TAS)
81'-3" (6 ~ 12'-6" W-BEAM PANELS AND
1 ~ 6'-3" W-BEAM PANEL)
6'-3" TYP
50'-0" ET-PLUS (SEE TRINITY DRAWING SS 334)
156'-3" NOMINAL
21 SPACES @ 6'-3" = 131'-3"
2'-3 3/4"
6" X 8" WOOD BLOCK
TOP OF RAIL HIGHT SHALL BE 27 3/4" +1" -0"
6" WOOD LINE POST
5/8"ø X 18" HGR BOLT WITH NUT & WASHER
2'-3 3/4"
1'-9 5/8"
SECTION "B-B"
AT POSTS #9-#25
EXHIBIT B – SHEET 1
ET- PLUS
ET-PLUS TEST LAYOUT SCHEMATIC
27 3/4" GUARDRAIL MOUNTING HEIGHT
WOOD POSTS WITH 8" DEEP BLOCKS
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 (SS334)
0
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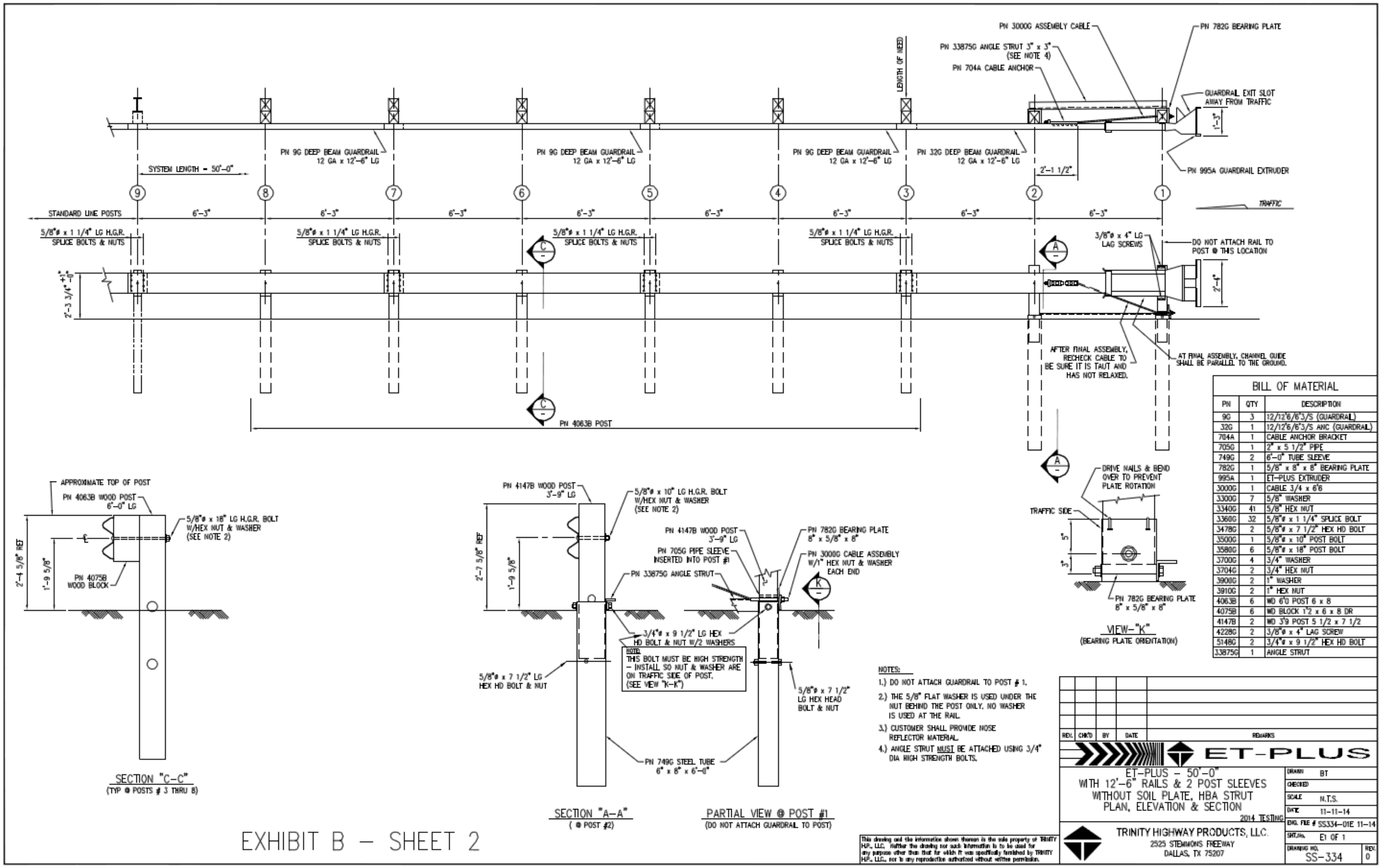
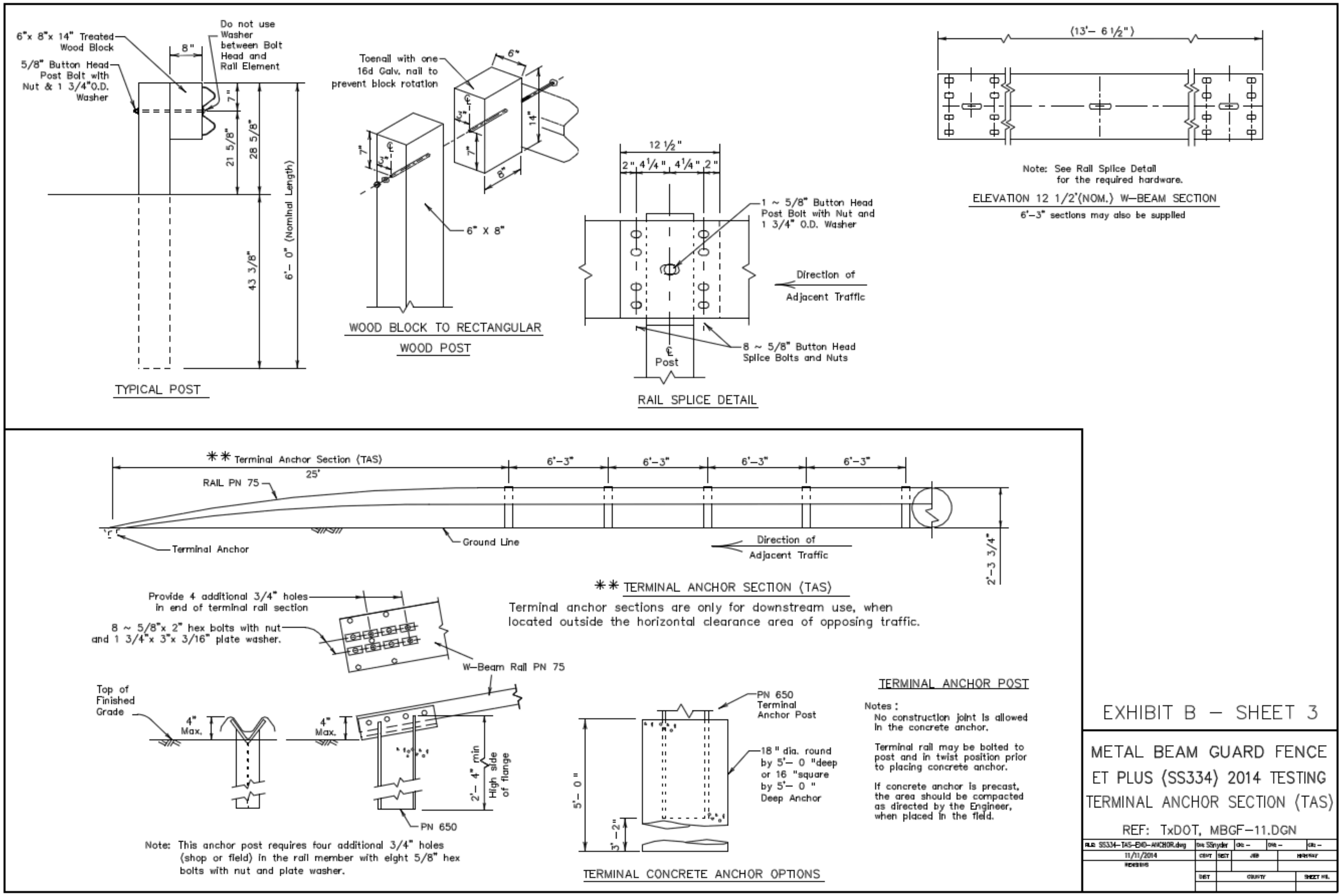

PN 3000G ASSEMBLY CABLE
PN 782G BEARING PLATE
PN 33875G ANGLE STRUT 3" x 3" (SEE NOTE 4)
PN 704A CABLE ANCHOR
LENGTH OF NEED
GUARDRAIL EXIT SLOT AWAY FROM TRAFFIC
PN 9G DEEP BEAM GUARDRAIL 12 GA x 12'-6" LG
PN 32G DEEP BEAM GUARDRAIL 12 GA x 12'-6" LG
SYSTEM LENGTH = 50'-0"
PN 995A GUARDRAIL EXTRUDER
TRAFFIC
STANDARD LINE POSTS
6'-3"
5/8"ø x 1 1/4" LG H.G.R. SPLICE BOLTS & NUTS
3/8"ø x 4" LG LAG SCREWS
DO NOT ATTACH RAIL TO POST @ THIS LOCATION
AFTER FINAL ASSEMBLY, RECHECK CABLE TO BE SURE IT IS TAUT AND HAS NOT RELAXED.
AT FINAL ASSEMBLY, CHANNEL GUIDE SHALL BE PARALLEL TO THE GROUND.
PN 4063B POST
BILL OF MATERIAL
PN | QTY | DESCRIPTION
9G | 3 | 12/12'6/6'3/S (GUARDRAIL)
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
3580G | 6 | 5/8"ø x 18" POST BOLT
3700G | 4 | 3/4" WASHER
3704G | 2 | 3/4" HEX NUT
3900G | 2 | 1" WASHER
3910G | 2 | 1" HEX NUT
4063B | 6 | WD 6'0 POST 6 x 8
4075B | 6 | WD BLOCK 1'2 x 6 x 8 DR
4147B | 2 | WD 3'9 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
33875G | 1 | ANGLE STRUT
APPROXIMATE TOP OF POST
PN 4063B WOOD POST 6'-0" LG
5/8"ø x 18" LG H.G.R. BOLT W/HEX NUT & WASHER (SEE NOTE 2)
PN 4075B WOOD BLOCK
SECTION "C-C" (TYP @ POSTS # 3 THRU 8)
PN 4147B WOOD POST 3'-9" LG
5/8"ø x 10" LG H.G.R. BOLT W/HEX NUT & WASHER (SEE NOTE 2)
PN 705G PIPE SLEEVE INSERTED INTO POST #1
PN 33875G ANGLE STRUT
PN 782G BEARING PLATE 8" x 5/8" x 8"
PN 3000G CABLE ASSEMBLY W/1" HEX NUT & WASHER EACH END
3/4"ø x 9 1/2" LG HEX HD BOLT & NUT W/2 WASHERS
NOTE: THIS BOLT MUST BE HIGH STRENGTH - INSTALL SO NUT & WASHER ARE ON TRAFFIC SIDE OF POST. (SEE VIEW "K-K")
5/8"ø x 7 1/2" LG HEX HD BOLT & NUT
5/8"ø x 7 1/2" LG HEX HEAD BOLT & NUT
PN 749G STEEL TUBE 6" x 8" x 6'-0"
SECTION "A-A" (@ POST #2)
PARTIAL VIEW @ POST #1 (DO NOT ATTACH GUARDRAIL TO POST)
DRIVE NAILS & BEND OVER TO PREVENT PLATE ROTATION
TRAFFIC SIDE
PN 782G BEARING PLATE 8" x 5/8" x 8"
VIEW-"K" (BEARING PLATE ORIENTATION)
NOTES:
1.) DO NOT ATTACH GUARDRAIL TO POST # 1.
2.) THE 5/8" FLAT WASHER IS USED UNDER THE NUT BEHIND THE POST ONLY. NO WASHER IS USED AT THE RAIL.
3.) CUSTOMER SHALL PROVIDE NOSE REFLECTOR MATERIAL.
4.) ANGLE STRUT MUST BE ATTACHED USING 3/4" DIA HIGH STRENGTH BOLTS.
REV. CHK'D BY DATE REMARKS
ET-PLUS
ET-PLUS - 50'-0" WITH 12'-6" RAILS & 2 POST SLEEVES WITHOUT SOIL PLATE, HBA STRUT PLAN, ELEVATION & SECTION
2014 TESTING
DRAWN BT
SCALE N.T.S.
DATE 11-11-14
DWG. FILE # SS334-01E 11-14
SHT. E1 OF 1
DRAWING NO. SS-334 REV. 0
TRINITY HIGHWAY PRODUCTS, LLC. 2525 STEMMONS FREEWAY DALLAS, TX 75207
EXHIBIT B - SHEET 2


6"x 8"x 14" Treated Wood Block
5/8" Button Head Post Bolt with Nut & 1 3/4"O.D. Washer
Do not use Washer between Bolt Head and Rail Element
TYPICAL POST
Toenail with one 16d Galv. nail to prevent block rotation
6" X 8"
WOOD BLOCK TO RECTANGULAR WOOD POST
1 ~ 5/8" Button Head Post Bolt with Nut and 1 3/4" O.D. Washer
Direction of Adjacent Traffic
8 ~ 5/8" Button Head Splice Bolts and Nuts
RAIL SPLICE DETAIL
Note: See Rail Splice Detail for the required hardware.
ELEVATION 12 1/2"(NOM.) W-BEAM SECTION
6'-3" sections may also be supplied
** Terminal Anchor Section (TAS)
RAIL PN 75
Terminal Anchor
Ground Line
Direction of Adjacent Traffic
** TERMINAL ANCHOR SECTION (TAS)
Terminal anchor sections are only for downstream use, when located outside the horizontal clearance area of opposing traffic.
Provide 4 additional 3/4" holes in end of terminal rail section
8 ~ 5/8"x 2" hex bolts with nut and 1 3/4"x 3"x 3/16" plate washer.
W-Beam Rail PN 75
Top of Finished Grade
PN 650
Note: This anchor post requires four additional 3/4" holes (shop or field) in the rail member with eight 5/8" hex bolts with nut and plate washer.
PN 650 Terminal Anchor Post
18" dia. round by 5'-0" deep or 16" square by 5'-0" Deep Anchor
TERMINAL CONCRETE ANCHOR OPTIONS
TERMINAL ANCHOR POST
Notes:
No construction joint is allowed in the concrete anchor.
Terminal rail may be bolted to post and in twist position prior to placing concrete anchor.
If concrete anchor is precast, the area should be compacted as directed by the Engineer, when placed in the field.
EXHIBIT B – SHEET 3
METAL BEAM GUARD FENCE
ET PLUS (SS334) 2014 TESTING
TERMINAL ANCHOR SECTION (TAS)
REF: TxDOT, MBGF-11.DGN

Appendix B: SwRI Data Sheets for Test ET27-32

EXHIBIT D-1: Installation Checklist

Test Number: ET27-32 Test Date: TBD

*Record the following impact head dimensions:

head Stamp "4" 12/4/2014 DH

Dimension	*Pre-Test Measurements
Exit Gap (middle - inside)	1.0475"
Entrance Gap (middle - outside)	4.7690"
Guide Chute Exit Height (outside)	14 15/16"
Guide Chute Entrance Height (outside)	14.5"
Channel Width (outside)	4.0275"
Channel Insertion into Extruder	0.4195" 0.5230" 0.5210" 0.4665"
Outside Guide Channel Length	36 9/16"
Outside Guide Channel Length – Chute to start of swedge	35"
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: 28 inches
   b. Between post 2 and 3: 27 3/4 inches
   c. Between post 3 and 4: 27 3/4 inches
   d. Between post 4 and 5: 27 3/4 inches
   Between post 5 and 6: 28 inches
   Between post 6 and 7: 27 7/8 inches
   Between post 7 and 8: 27 7/8 inches
   Between post 8 and 9: 28 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: 7 inches.
c. Distance from the ground to the top of the impact face: 34 7/8 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 3/4 inches (Must be 4 inches or less).
g. Distance from the ground to the top of the second foundation tube: 2 7/8 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.

HIGHLY CONFIDENTIAL

AM 12/12/14 RPA 12/12/14

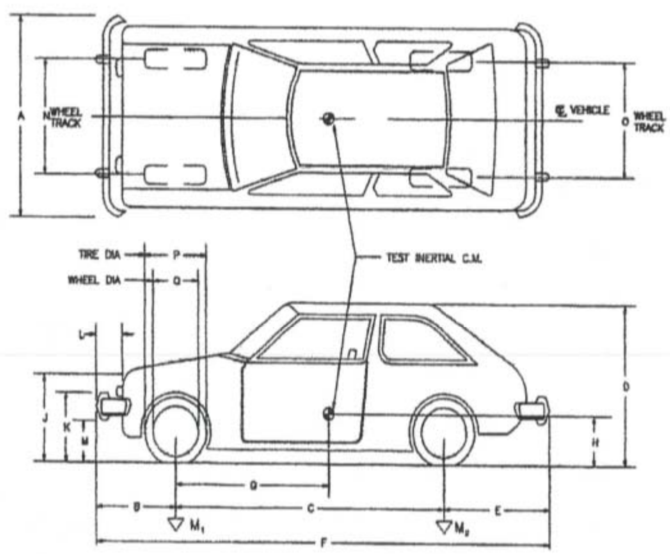
j. The two bolts (top and bottom) holding the extruder head to post one are snug and the extruder channel is approximately parallel to the finished grade (i.e., level) YES NO (circle one).
k. The cable anchor bracket is locked into place by pulling the bracket toward the impact end of the unit: YES NO (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 Hannin 12/12/2014

DATE: 12-6-14 TEST NO.: ET27-32 VIN NO.: 2C1MR2291V6750923 MAKE: GEO
MODEL: METRO YEAR: 1997 ODOMETER: 082692 TIRE SIZE: 155/80 R13
TIRE INFLATION PRESSURE: 44 PSI

MASS DISTRIBUTION (kg) LF ~~324~~ 618 RF 593 LR 329 RR 316
1866 total

DESCRIBE ANY DAMAGE TO VEHICLE PRIOR TO TEST:



ENGINE TYPE: GAS
ENGINE CID: 1.3 L.
TRANSMISSION TYPE:
✓ AUTO
— MANUAL
OPTIONAL EQUIPMENT:

DUMMY DATA:
TYPE:
MASS: 165
SEAT POSITION: Passenger

C/G ill. 1 Above Front Spindel Centerline

GEOMETRY — (cm)

A 61"	D 56.25"	G 32.4	K 20.5"	N 54"	O 14.375"
B 32"	E 22.25"	H 21.725	L 4.5"	O 53"	
C 93.25"	F 147.5"	J 28"	M 16.125"	P 22.5"	

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

EDR FROM FRONT SPINDEL 42.9" FROM GROUND 16.5"

Figure 4.1. 700C and 820C parameters.

OY 12/17/2016

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.

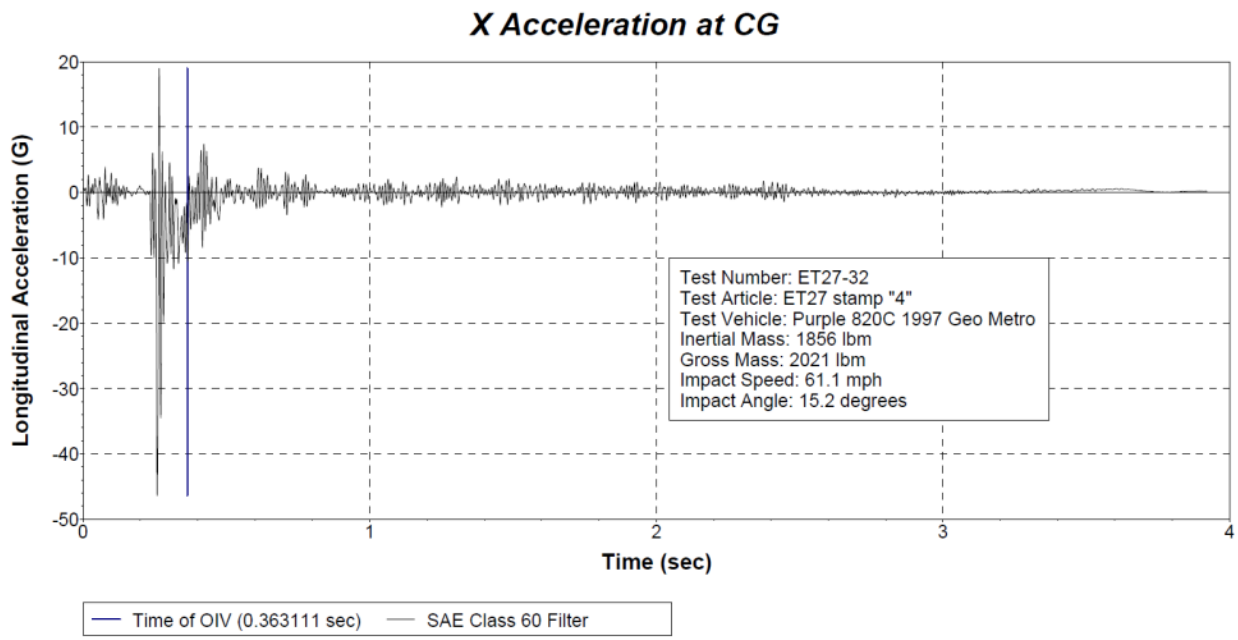
Sincerely,

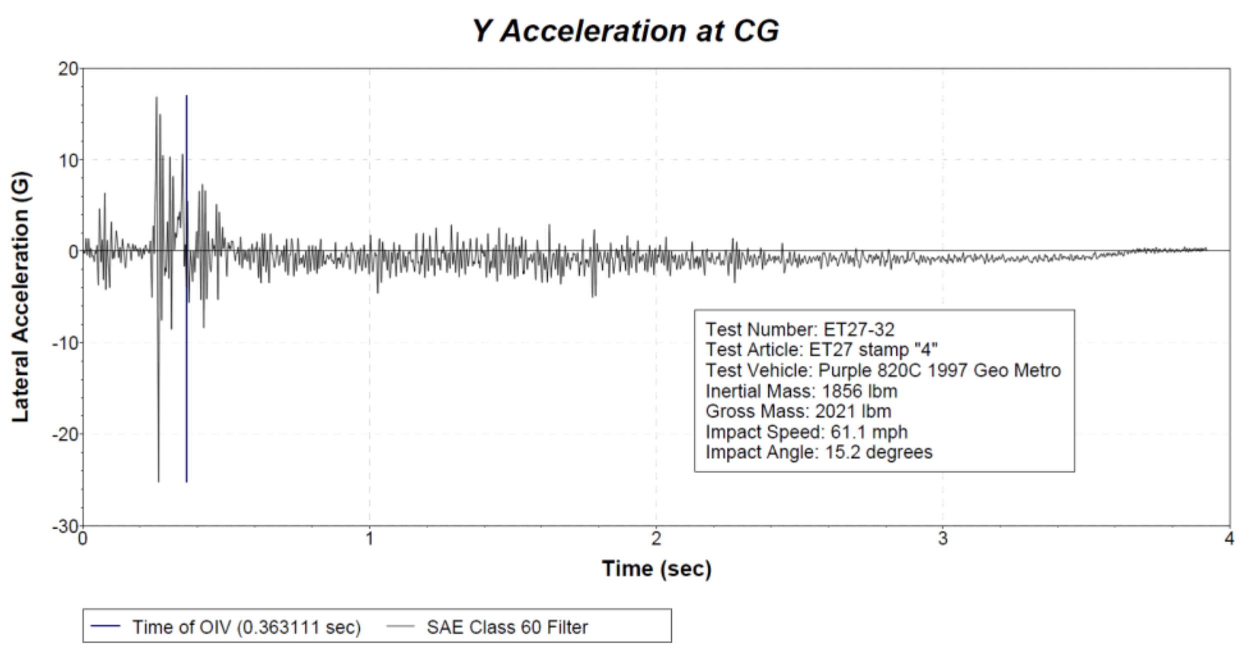
R. B. Kalmbach
Executive Director, Contracts

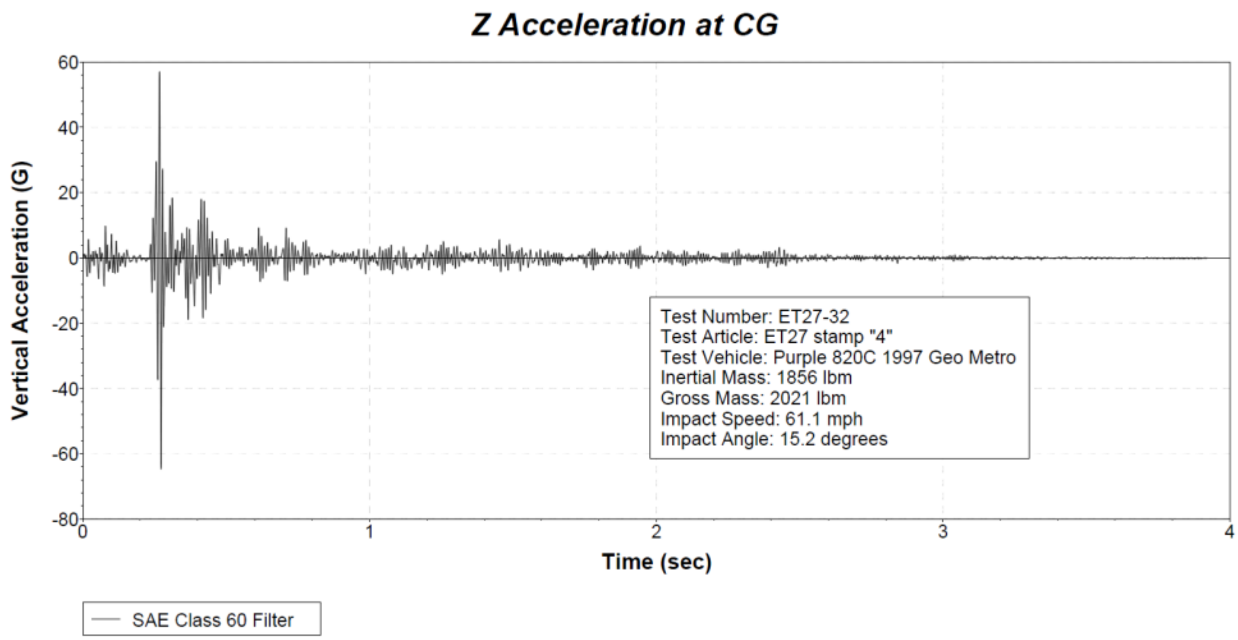
RBK/MKL/jms
cc: J. Ferren, SwRI (via email)

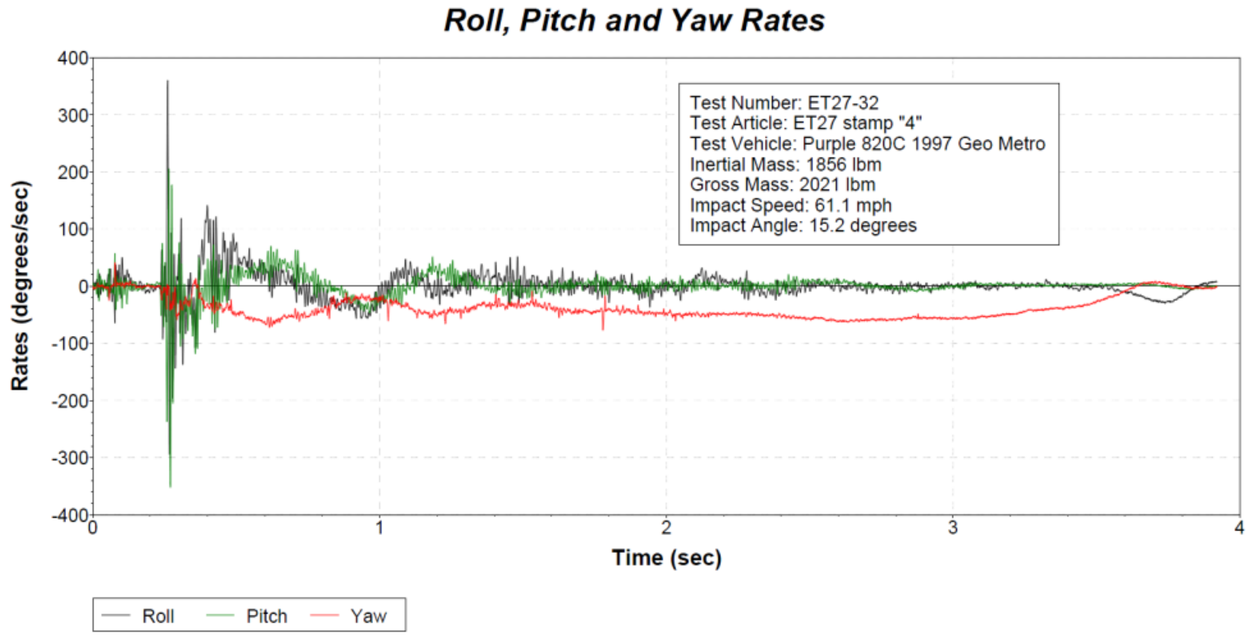
Benefiting government, industry and the public through innovative science and technology

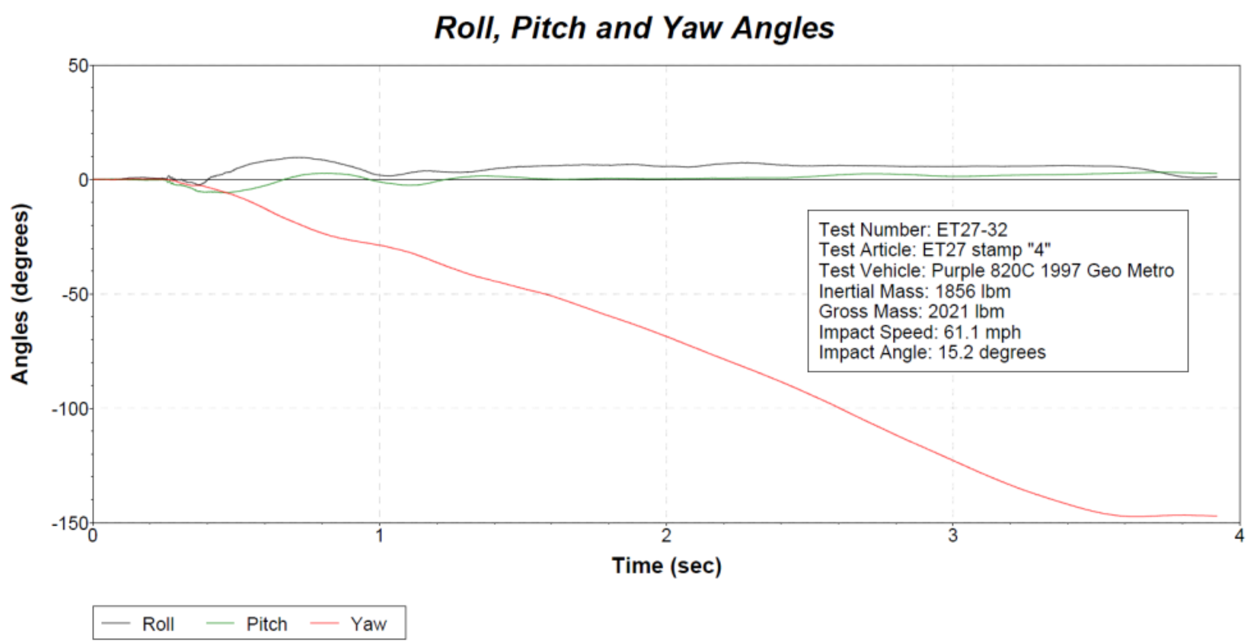
Appendix D: Test Data Plots


X Acceleration at CG
Longitudinal Acceleration (G)
20
10
0
-10
-20
-30
-40
-50
0
1
2
3
4
Time (sec)
Test Number: ET27-32
Test Article: ET27 stamp "4"
Test Vehicle: Purple 820C 1997 Geo Metro
Inertial Mass: 1856 lbm
Gross Mass: 2021 lbm
Impact Speed: 61.1 mph
Impact Angle: 15.2 degrees
Time of OIV (0.363111 sec)
SAE Class 60 Filter


Y Acceleration at CG
Lateral Acceleration (G)
20
10
0
-10
-20
-30
0
1
2
3
4
Time (sec)
Test Number: ET27-32
Test Article: ET27 stamp "4"
Test Vehicle: Purple 820C 1997 Geo Metro
Inertial Mass: 1856 lbm
Gross Mass: 2021 lbm
Impact Speed: 61.1 mph
Impact Angle: 15.2 degrees
Time of OIV (0.363111 sec)
SAE Class 60 Filter


Z Acceleration at CG
60
40
20
0
-20
-40
-60
-80
Vertical Acceleration (G)
0
1
2
3
4
Time (sec)
Test Number: ET27-32
Test Article: ET27 stamp "4"
Test Vehicle: Purple 820C 1997 Geo Metro
Inertial Mass: 1856 lbm
Gross Mass: 2021 lbm
Impact Speed: 61.1 mph
Impact Angle: 15.2 degrees
SAE Class 60 Filter


Roll, Pitch and Yaw Rates
Test Number: ET27-32
Test Article: ET27 stamp "4"
Test Vehicle: Purple 820C 1997 Geo Metro
Inertial Mass: 1856 lbm
Gross Mass: 2021 lbm
Impact Speed: 61.1 mph
Impact Angle: 15.2 degrees
Rates (degrees/sec)
400
300
200
100
0
-100
-200
-300
-400
0
1
2
3
4
Time (sec)
Roll
Pitch
Yaw


Roll, Pitch and Yaw Angles
Test Number: ET27-32
Test Article: ET27 stamp "4"
Test Vehicle: Purple 820C 1997 Geo Metro
Inertial Mass: 1856 lbm
Gross Mass: 2021 lbm
Impact Speed: 61.1 mph
Impact Angle: 15.2 degrees
Angles (degrees)
50
0
-50
-100
-150
0
1
2
3
4
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 (%):		

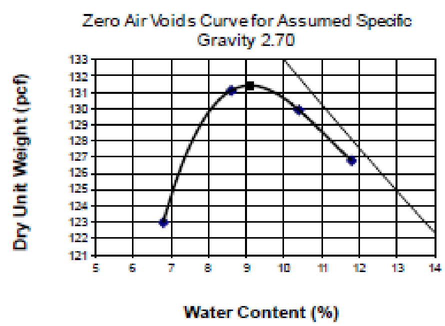
USCS:

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.

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: 90141414.0007
Service Date: 12/17/14
Report Date: 12/18/14
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 (%)
	Head #4								
1	Test Hole	1	1	6	139.0	8.0	6.1	131.0	99.7
2	Post #2	1	1	6	136.8	8.5	6.6	128.3	97.6
3	Post #3	1	1	6	130.6	8.2	6.7	122.4	93.2
4	Post #4	1	1	6	131.6	8.7	7.1	122.9	93.5

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.: Daniel Alanis
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.

Page 1 of 1

CR0007, 11-16-12, Rev.7

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 27¾ Inches

Test Level 3, Test 3-30
Test Identification: ET27-30

SwRI® Project No. 18.20887

SwRI Document Number: 18.20887.03.100.FR4
Issue 1

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

January 23, 2015

Authored by:

Jenny Ferren

Jenny Ferren, Manager
Mechanical Engineering Division

Reviewed and Approved by:

Timothy A. Fey

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

The results of this test report apply only to the specific samples tested. If the manufacturer extends the test results to apply to other samples of the same model, or from the same lot or batch, the manufacturer should ensure the additional samples are manufactured using identical electrical and mechanical components. This test report shall not be reproduced, except in full, without written approval of Southwest Research Institute.

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	1/23/2015

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

1 INTRODUCTION

The purpose of Crash Test ET27-30 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 27¾”. 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 47.6 m (156’-3”), including the 15.2 m (50 ft) 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 vehicle 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 ET27-30 was conducted on January 6, 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 27¾". The ET Plus End Terminal installation tested uses standard AASHTO M180 Type 2, 12-gauge, 12'-6" W-Beam guardrail panels mounted with the top of the rail 27¾ inches 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.

During installation, holes approximately 2' 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 cm (6 in) lifts, and was added until the surface was flush with the surrounding soil.

The guardrail line posts are 6" x 8" wood posts with 6" x 8" wood blockouts. The blockouts are toenailed, and the guardrail panels are mounted to the posts using 5/8"ϕ post bolts beginning with Post 2; the bolt for Post 2 is 10" long, and all other post bolts are 18" long. The post spacing is 6'-3", and each splice joint used eight (8) 5/8"ϕ x 1-1/4" splice bolts and nuts; the splice bolts have a nominal total length of 1-5/8" including the bolt head. The installation uses 3/4"ϕ x 10" 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 guardrail splices at each odd-numbered post starting with Post 3.

The total system installation length for the test was nominally 156'-3" (47.6 m), including the 50 ft (15.2 m) ET Plus terminal length, 81'-3" (24.8 m) of guardrail, and a 25' (7.6 m) downstream terminal anchor section that included a turndown guardrail anchor spliced at Post 22 and mounted to a concrete footing. 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 ET27-30 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 2.18 present photographs of the guardrail installation.

Table 2.1: Key ET Plus Head Dimensions

Extruder Head Stamp ID	3
Exit Gap	1.1395”
Entrance Gap	4.7590”
Guide Chute Exit Height	15-1/16”
Guide Chute Entrance Height	14-1/2”
Channel Width (see Figure 2.2)	4.0305”

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 ET27-30

Figure 2.4: ET Plus End Terminal

Figure 2.5: ET Plus Head Height Above Ground – Top

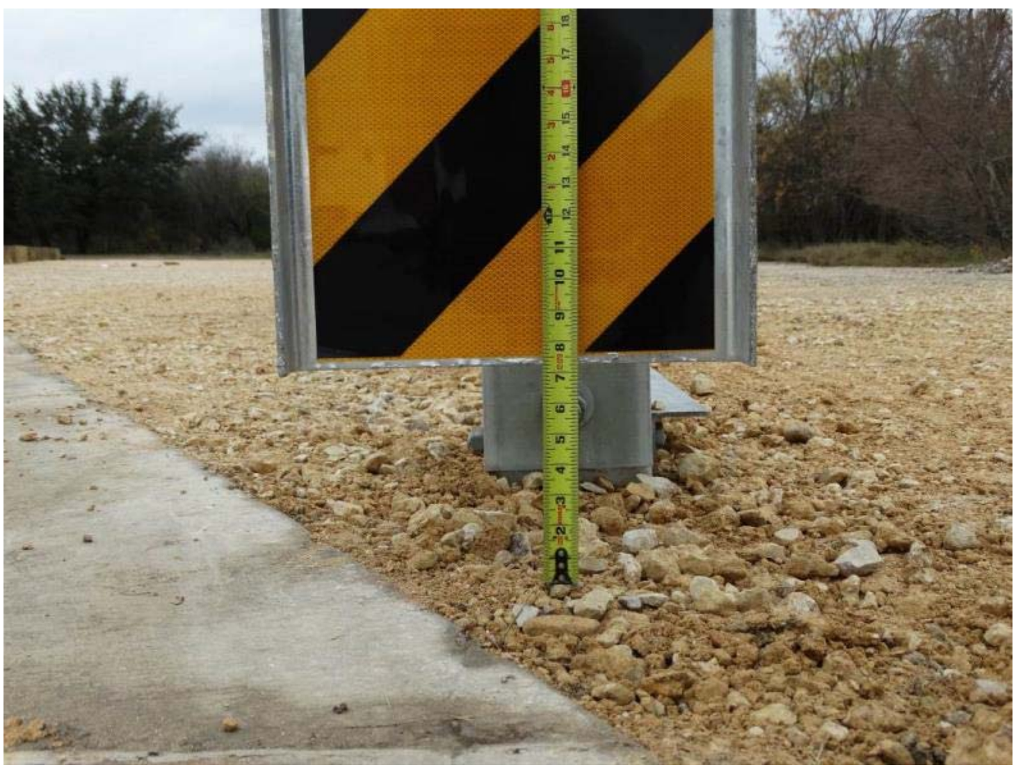


Figure 2.6: ET Plus Head Height Above Ground – Bottom

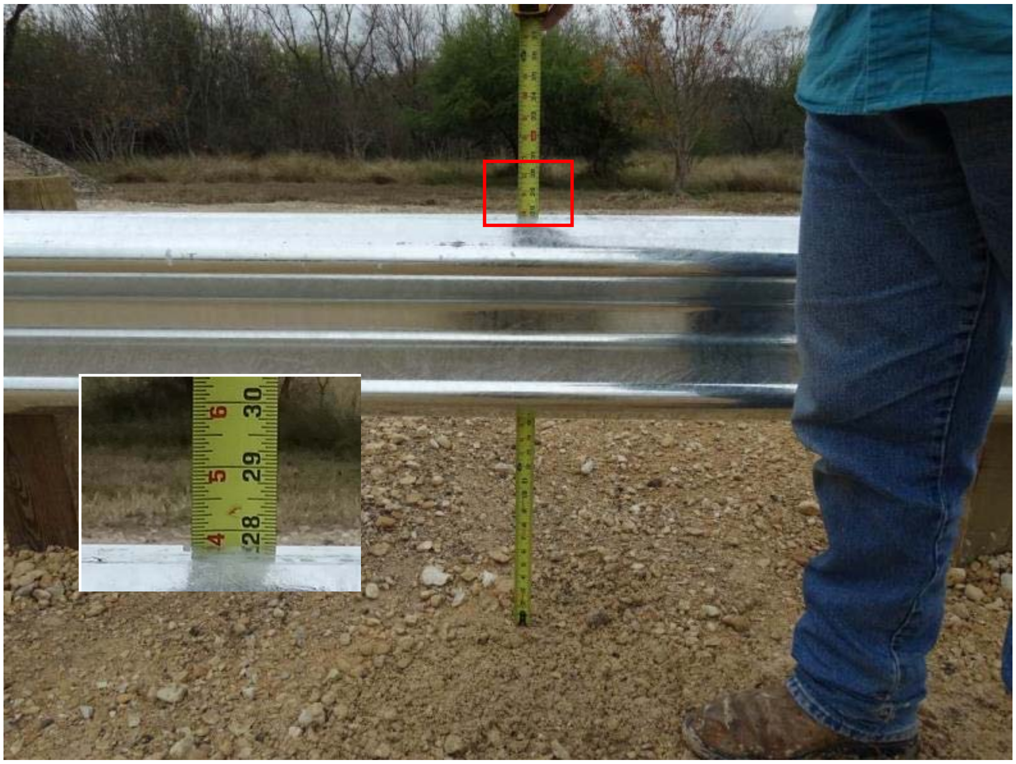


Figure 2.7: Measurement of Guardrail Installation Height

Figure 2.8: ET Plus Head and Anchor Cable Assembly

Figure 2.9: End Terminal Anchor Cable Mount – Post 1

Figure 2.10: End Terminal Cable Anchor

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

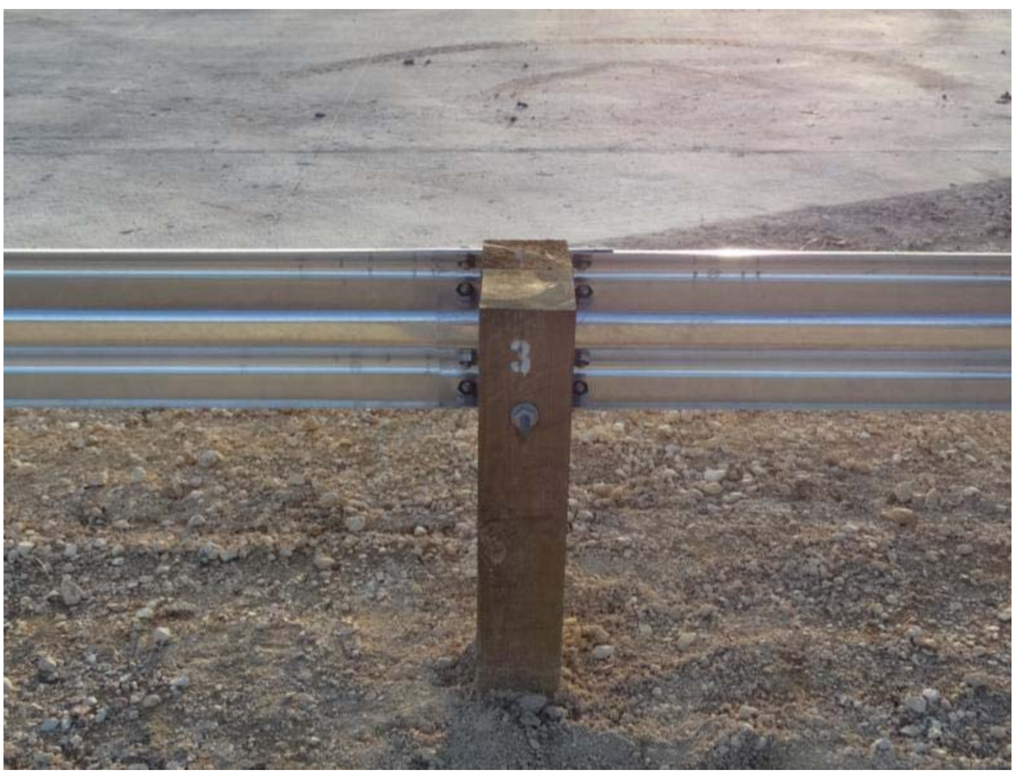


Figure 2.12: First Guardrail Panel Splice Joint – Non-Traffic Side

Figure 2.13: ET Plus Head and Post 1 – Traffic Side

Figure 2.14: ET Plus Head and Post 1 – Non-Traffic Side

Figure 2.15: End Terminal Head with Posts 1 & 2 and Strut

Figure 2.16: ET Plus Head Extruder Exit (see Appendix B for Dimensions)

Figure 2.17: Post 22 Immediately Preceding Downstream Turndown Anchor

Figure 2.18: Downstream Turndown Anchor

Test Vehicle

The test vehicle was a 1999 Geo Metro, shown in Figure 2.19; the vehicle data sheet is provided in Appendix B. Figure 2.20 shows the relationship between the height of the vehicle bumper and the end terminal. Figure 2.21 shows the test vehicle positioned at the impact point of the end terminal, and Figure 2.22 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 passenger seat as shown in Figure 2.23 to contribute to the vehicle's post-impact instability as specified in NCHRP Report 350. Ballast mass totaling 18.1 kg (40 lbs) was added to the vehicle, and was bolted to the passenger floorboard as shown in Figure 2.24.

The test inertial mass of the vehicle, including the added ballast weight, was 796 kg (1,755 lbs) as reflected in Table 4.2. Note that the test inertial mass does not include the weight of the anthropometric dummy.

Figure 2.19: Test Vehicle for Test ET27-30

Figure 2.20: Test Vehicle Bumper Height

Figure 2.21: Test Vehicle Impact Trajectory

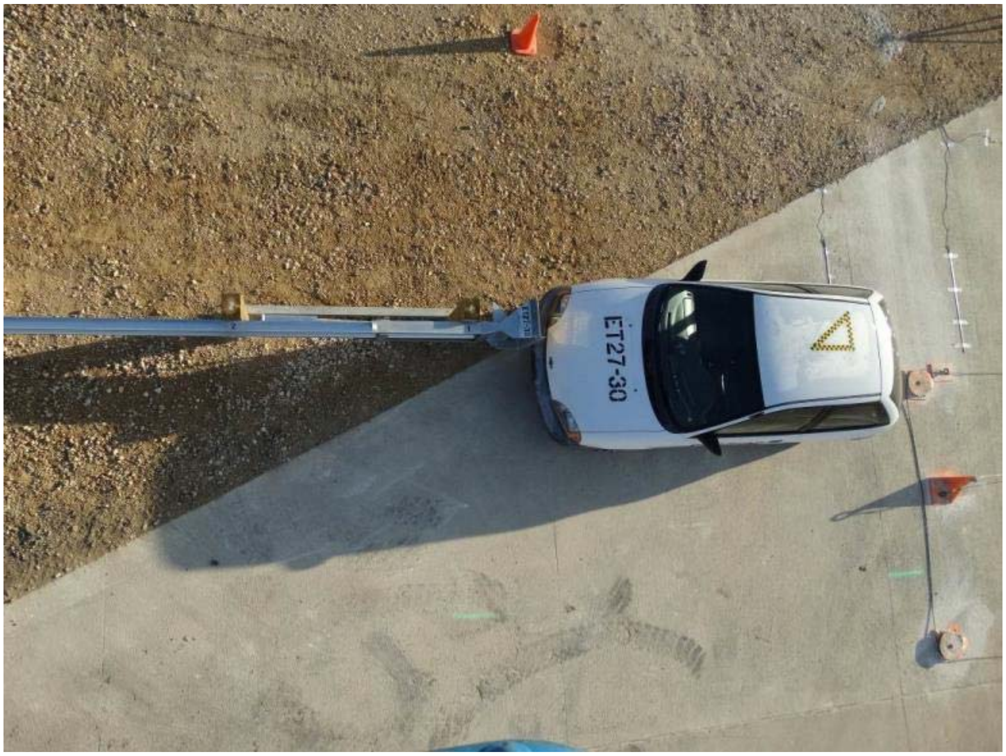


Figure 2.22: Test Vehicle Impact Trajectory – Overhead View

Figure 2.23: Test Dummy Positioned in Driver Seat

Figure 2.24: Ballast Mass

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 2.25. 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 2.25: 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 2.26 and 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 2.26: EDR Mounted in Test Vehicle for Test ET27-30

Figure 2.27: 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.

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 prior to testing, soil moisture content was measured by a certified environmental engineering firm. The maximum moisture content measured was 6.9% at a location behind 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 ET27-30 on January 6, 2015:

- Federal Highway Administration (FHWA)
- New Hampshire DOT (AASHTO Representative)
- 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 and the test vehicle following the test.

3 TEST CONDITIONS AND RESULTS

Test Description

The purpose of Test ET27-30 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 27¾". 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 156'-3" (47.6 m), and the terminal length was 15.2 m (50 ft).

Test 3-30 is intended primarily to evaluate occupant risk and vehicle trajectory criteria. The test consists of an 820 kg vehicle 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 ET27-30, 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.

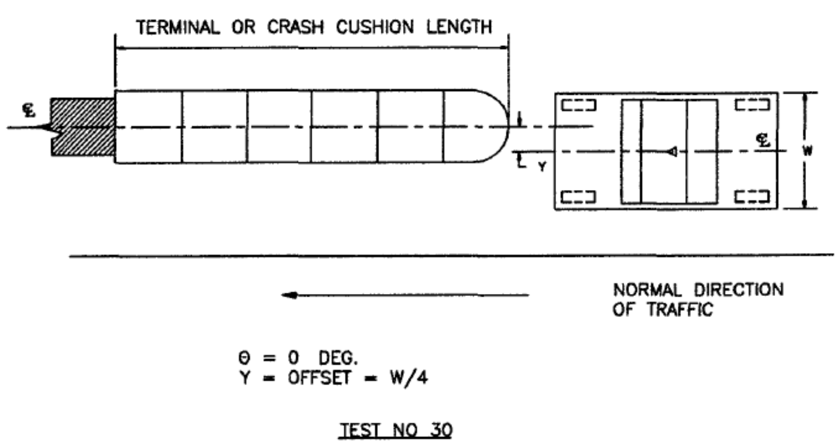


Figure 3.1: Impact Configuration *[from Figure 3.2 of NCHRP Report 350]*

The weather on the day of the test was mostly sunny, with temperatures ranging from 34-64°F. The temperature at the time of the test was approximately 52°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 102.5 km/hr (63.7 mph). As a result of the test, the ET Plus extruder head moved 5.5 m (18.0 ft) longitudinally (downstream) and 0.7 m (2.2 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 5.5 m (18.0 ft) from the initial point of contact.

After the impact event, the ET Plus extruder head stroked along the guardrail, extruding approximately 18 feet of guardrail including the first splice at Post 3. When the guide channel entrance end of the head was nearly to Post 4, the guardrail began to bend, and the vehicle began a lateral clockwise spin due to the quarter-offset impact and asymmetrical mass due to the dummy positioned in the driver seat. The front hood separated from the vehicle at the start of the spin and fell to the ground near where the ET Plus head stopped its stroke. The front bumper cover became disconnected on the driver side and swung around during the spin, but remained attached at the passenger side. Once the vehicle began to rotate, it spun nearly 180 degrees in a pivot about Post 4, and then reversed the spin slightly until it came to rest facing in the direction generally opposite of its pre-impact trajectory, and at an angle of approximately 45 degrees. After the vehicle came to rest, the perpendicular distance between the guardrail and the front left wheel was 119”, and the distance to the rear wheel was 175”. The vehicle was not operable after the test.

The ET Plus extruder head directly contacted and sheared-off Posts 1 through 3, and damaged Post 4 and the attached blockout at the end of the stroke. Although Post 5 appeared undamaged, there was twisting and cracking of the Post 5 blockout due to relative longitudinal motion of the guardrail panel. All posts and blockouts downstream of Post 5 appeared unaffected, and no appreciable movement of the downstream turndown anchor was observed. Additionally, the anchor cable at Post 1 broke free of the installation and came to rest near Post 4. The extruded portion of the guardrail came to rest parallel to the installation on the non-traffic side. 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 and blockouts from the first three 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 test vehicle experienced a maximum 50 millisecond moving average acceleration of -11.0g in the longitudinal direction, 2.6g in the lateral direction, and -2.7g 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 risk impact velocities were 7.5 m/s in the longitudinal direction, and 0.4 m/s in the lateral direction.
- Occupant risk ridedown accelerations were -14.0g in the longitudinal direction, and 6.8g 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

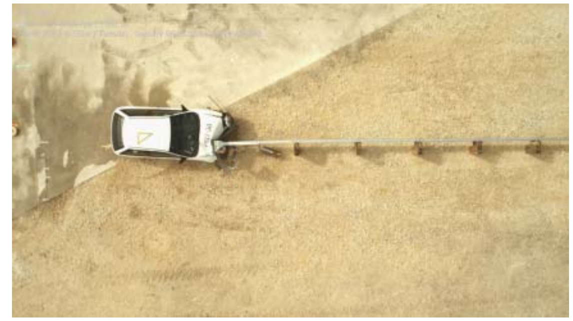
NCHRP Report 350 states that the recommended impact severity for Test Level 3, Test 3-30 is 316.4 kJ, with a suggested tolerance of -24.8/+25.8 kJ. The actual impact severity of test ET27-30 was 323.3 kJ, a deviation of +6.9 kJ from the nominal impact severity recommended in NCHRP Report 350. *Note that for Test 3-30, Sin θ is set to 1 in accordance with Section 3.3.1 of Report 350.*

$$
\begin{aligned}
\text{Impact Severity} \quad &= \tfrac{1}{2}\cdot M\cdot(V\cdot\sin\theta)^2 \\
&= \tfrac{1}{2}\cdot M\cdot V^2 \\
&= 0.5\cdot(796\ \text{kg})\cdot(28.5\ \text{m/s})^2 \\
&= 323.3\ \text{kJ}
\end{aligned}
$$

The equivalent impact speed of an 820 kg vehicle impacting the end terminal at 0 degrees would be 101.1 km/hr (62.8 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 Test – Side View of Extruder Head

Figure 3.7: Post Test – Foundation Sleeves at Posts 1 and 2

Figure 3.8: Post Test – Foundation Sleeve at Post 1

Figure 3.9: Post Test – Foundation Sleeve at Post 2

Figure 3.10: Post Test – Post 3 and Extruder Head

Figure 3.11: Post Test – End View of Extruder Head Impact Plate

Figure 3.12: Post Test – Upstream View of Extruder Head

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

Figure 3.14: Post Test – Side View of Extruder Head

Figure 3.15: Post Test – Downstream View

Figure 3.16: Post Test – Non-Traffic Side of Post 4

Figure 3.17: Post Test – Extruded Guardrail at Extruder Head

Figure 3.18: Post Test – Extruded Guardrail Splice

Figure 3.19: Post Test – Extruded Guardrail Splice

Figure 3.20: Post Test – Extruded Guardrail Splice

Figure 3.21: Post Test – Upstream View of Post 4

Figure 3.22: Post Test – Upstream of Posts 4, 5 and 6

Figure 3.23: Post Test – Extruded Guardrail Coil and Post Debris

Figure 3.24: Post Test – Traffic Side View of Extruder Head

Figure 3.25: Post Test Location of Anchor Cable

Figure 3.26: Post Test – Breakaway Posts 1 and 2

Figure 3.27: Extruder Head Post Test – Traffic Side

Figure 3.28: Extruder Head Post Test – Non-Traffic Side

Figure 3.28: Post Test Verification of Extruder Head 3

Vehicle Damage

Figure 3.29: Vehicle Post Test Location

Figure 3.30: Test Vehicle Path of Left Front Tire (Orange Paint)

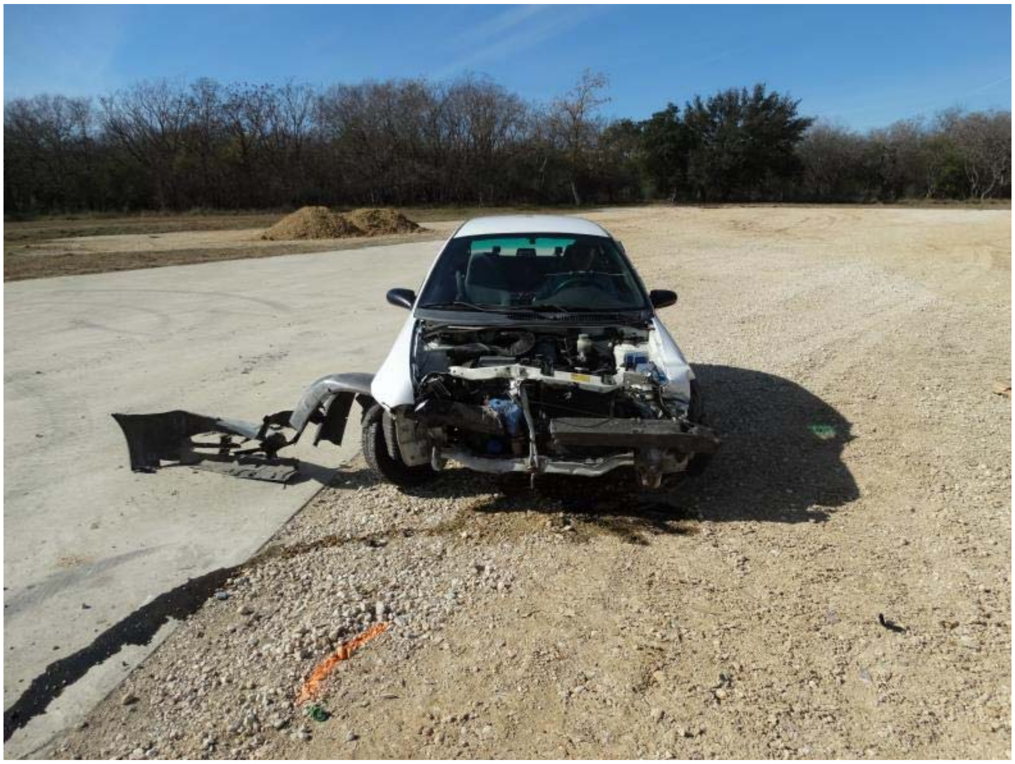


Figure 3.31: Damaged Test Vehicle – Front View

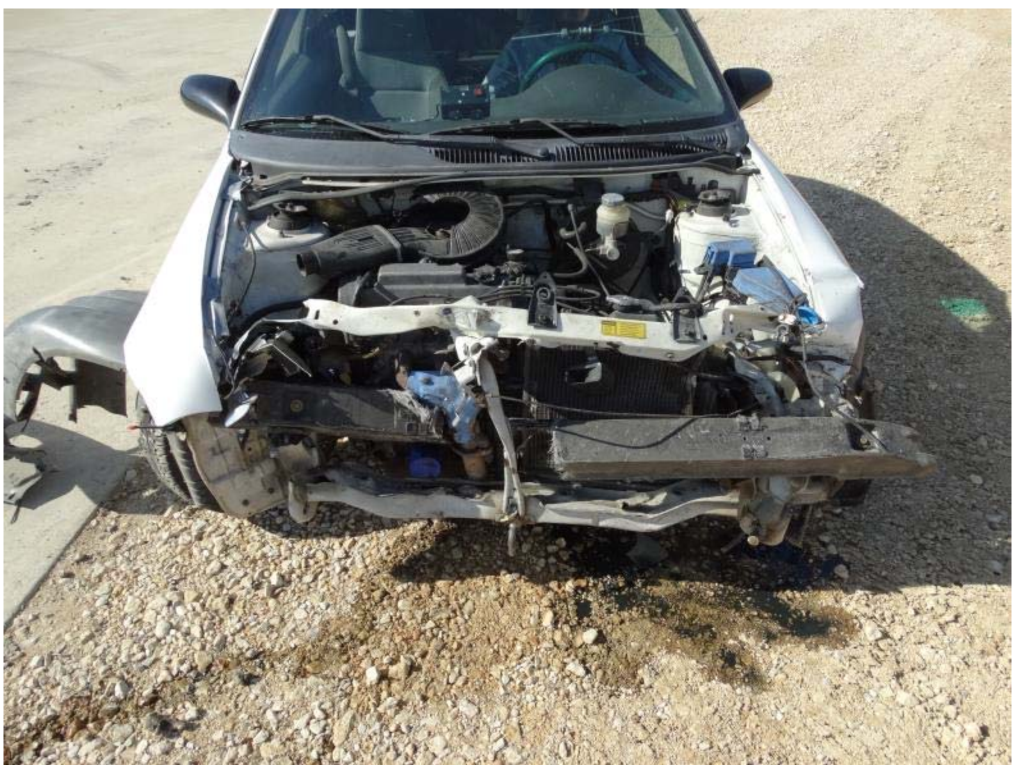


Figure 3.32: Damaged Test Vehicle – Front View Close-up

Figure 3.33: Damaged Test Vehicle – Left Side

Figure 3.34: Damaged Test Vehicle – Right Side

Figure 3.35: Damaged Test Vehicle – Front Hood

Figure 3.36: Post-Test – Occupant Compartment

Figure 3.37: Post-Test – Driver Side Floorboard

Figure 3.38: Post-Test – Passenger Side Floorboard

4 ASSESSMENT OF TEST RESULTS

A comparison of the test results of Test ET27-30 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.

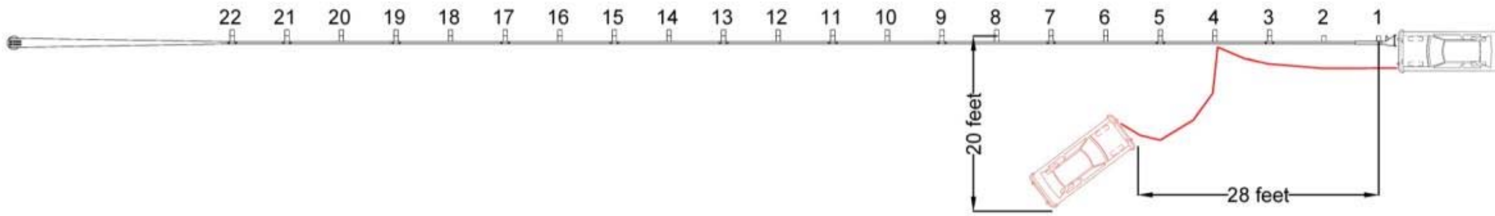
Table 4.1: Summary of Test Evaluation Results (NCHRP Report 350 Evaluation Criteria) for Test ET27-30

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.	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: 7.5 m/s Lateral: 0.4 m/s	Pass
	I. Occupant Ridedown Acceleration (ORA) limits: Preferred = 15 g Maximum = 20 g	Occupant Ridedown Accelerations: Longitudinal: -14.0 g Lateral: 6.8 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 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 ET27-30



General Information	
Test Agency	Southwest Research Institute
Test Number	ET27-30
Test Date	01/06/2015
Test Category	3-30
Test Article	
Type	End Terminal
Terminal Length	15.24 m (50 ft)
Installation Length	47.6 m (156.25 ft)
Nom. Barrier Height	705 mm (27.75 in)
Type of Primary Barrier	W-beam guardrail
Soil	Stable, Dry - “Standard” Soil
Test Vehicle	
Type	Small car
Designation	820C
Model	1999 Chevrolet Metro
Curb Mass (kg)	778 as received
Ballast Mass (kg)	18
Test Inertial Mass (kg)	796
Dummy Mass (kg)	75
Gross Static Mass (kg)	871

Impact Conditions	
Speed (km/hr)	102.5
Angle (degrees)	0.1
Exit Conditions	
Speed (km/hr)	N/A
Angle (degrees)	N/A
Occupant Risk Values	
Impact Velocity (m/s)	
x-direction	7.5
y-direction	0.4
Ridedown Accelerations (g)	
x-direction	-14.0
y-direction	6.8
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	5.5 m (18.0 ft)
Lateral	0.7 m (2.2 ft)
Total System Deformation (Closest Point)	
Longitudinal	5.5 m (18.0 ft)
Post Impact Vehicular Behavior	
Max Vehicle Rotation (degrees)	
Max. Roll	-5.4 @ 0.8519 sec.
Max. Pitch	-5.4 @ 0.6613 sec.
Max. Yaw	167.7 @ 1.8862 sec.
Max 50ms Moving Average Accelerations (g)	
x-direction	-11.0 @ 0.2155-0.2655 sec.
y-direction	2.6 @ 0.6489-0.6989 sec.
z-direction	-2.7 @ 0.2444-0.2944 sec.

5 CONCLUSIONS

The performance of the ET Plus during Test ET27-30 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

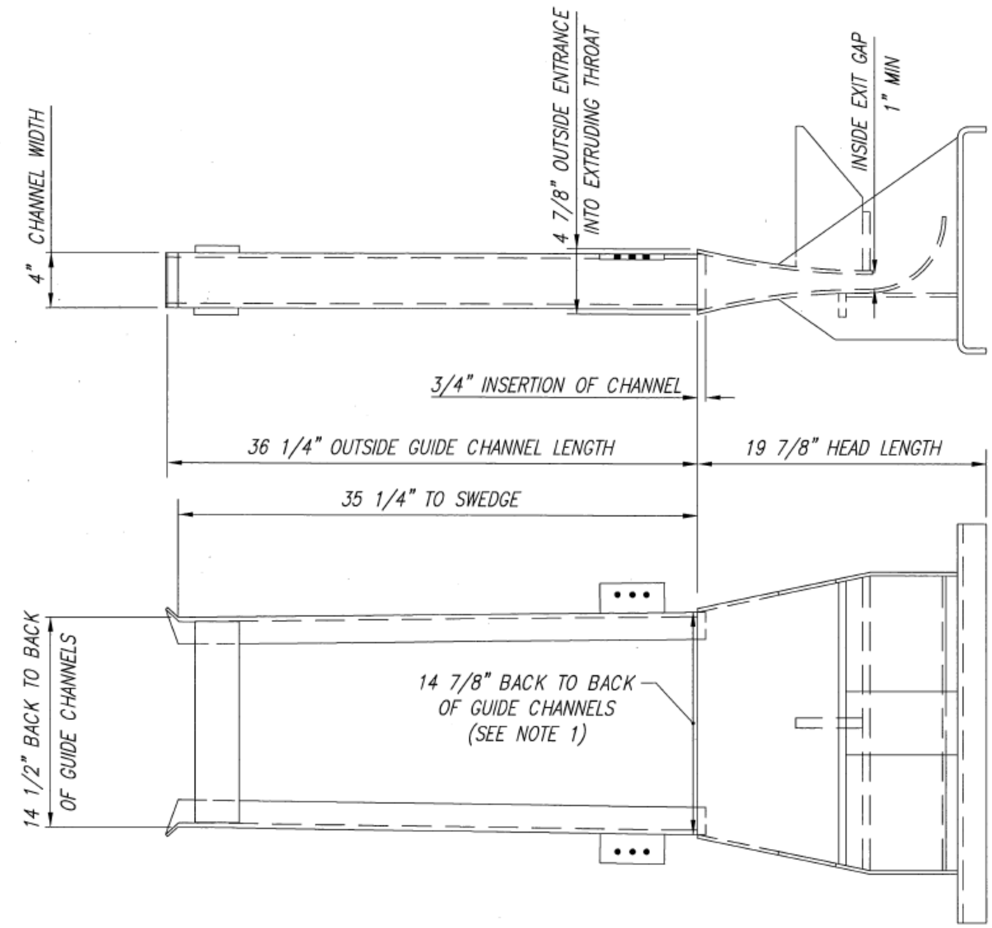
- There was no penetration of the vehicle by the test article, and no deformation of the occupant compartment resulting from the test.
- There was no undue hazard presented by test article debris outside of the immediate impact zone; the only debris thrown from the installation included pieces of posts 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 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 27¾” meets the Test Level 3, Test 3-30 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".

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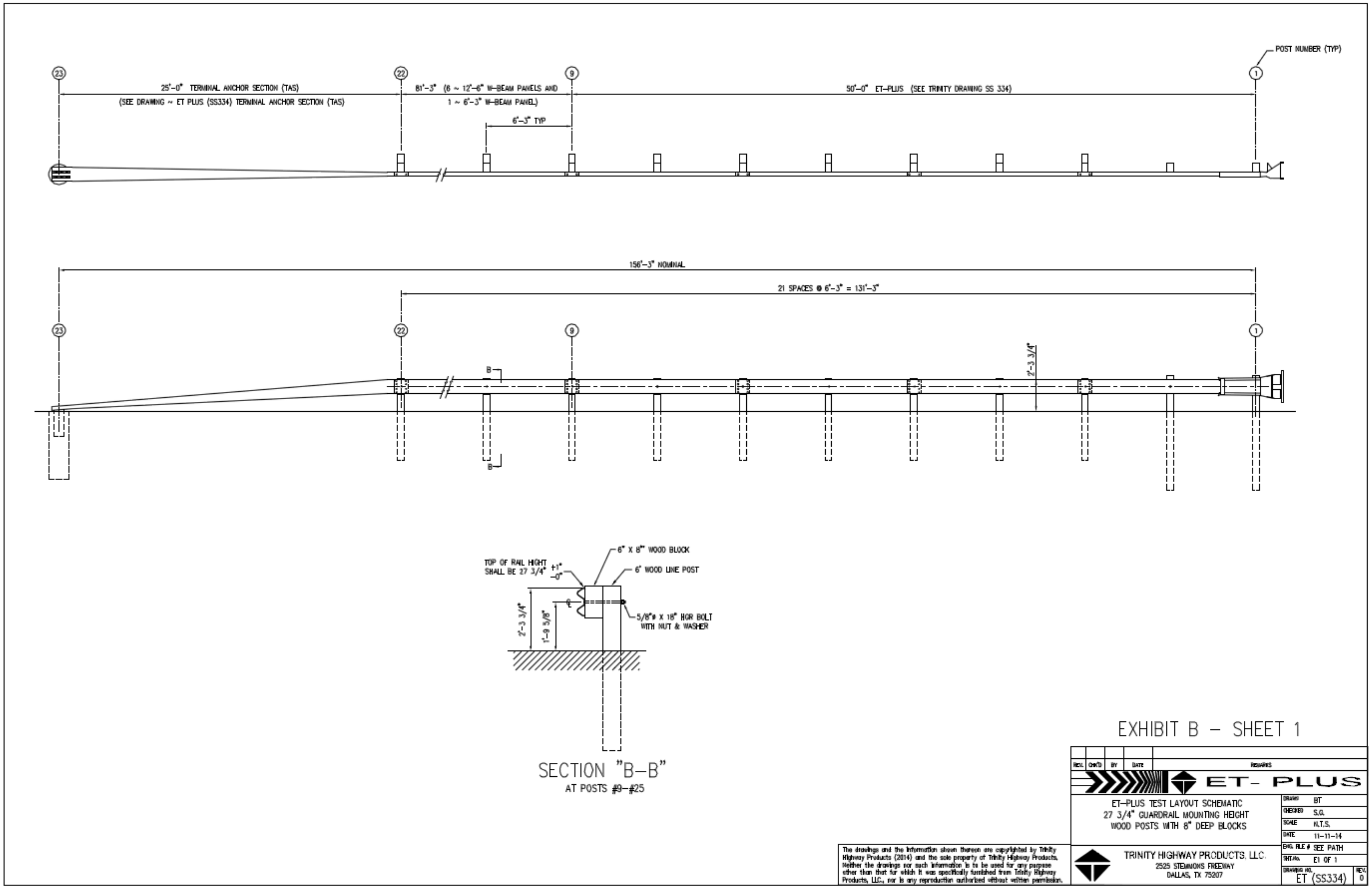
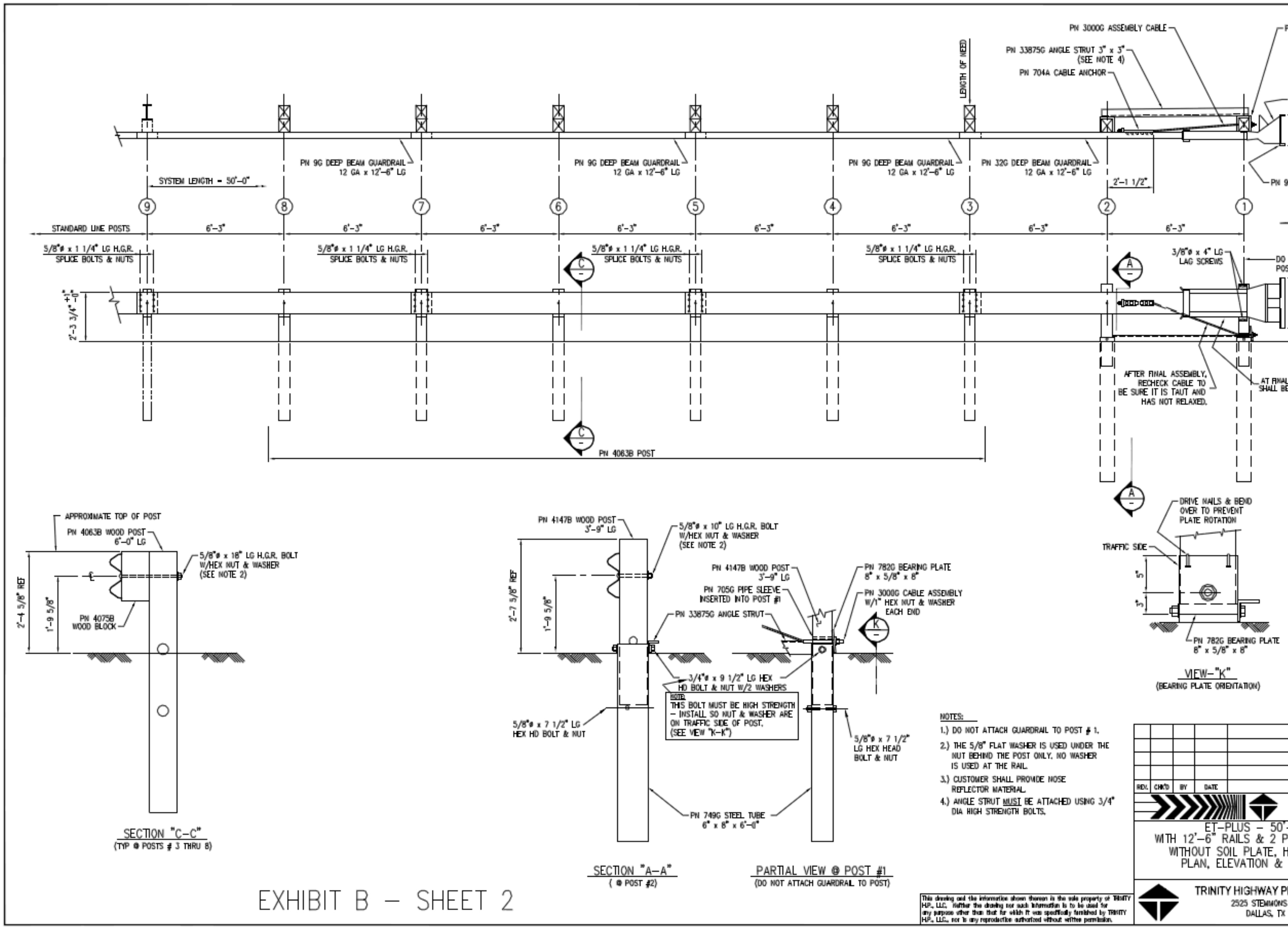
TRINITY HIGHWAY PRODUCTS, LLC.
2525 STEMMONS FREEWAY
DALLAS, TX 75207


POST NUMBER (TYP)
25'-0" TERMINAL ANCHOR SECTION (TAS)
(SEE DRAWING ~ ET PLUS (SS334) TERMINAL ANCHOR SECTION (TAS)
81'-3" (6 ~ 12'-6" W-BEAM PANELS AND
1 ~ 6'-3" W-BEAM PANEL)
6'-3" TYP
50'-0" ET-PLUS (SEE TRINITY DRAWING SS 334)
156'-3" NOMINAL
21 SPACES @ 6'-3" = 131'-3"
2'-3 3/4"
6" X 8" WOOD BLOCK
TOP OF RAIL HIGHT SHALL BE 27 3/4" +1" -0"
6" WOOD LINE POST
5/8"ø X 18" HGR BOLT WITH NUT & WASHER
1'-9 5/8"
SECTION "B-B"
AT POSTS #9-#25
EXHIBIT B – SHEET 1
ET-PLUS
ET-PLUS TEST LAYOUT SCHEMATIC
27 3/4" GUARDRAIL MOUNTING HEIGHT
WOOD POSTS WITH 8" DEEP BLOCKS
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 (SS334)
0



BILL OF MATERIAL

PN	QTY	DESCRIPTION
9G	3	12/12'6/6'3/S (GUARDRAIL)
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
3580G	6	5/8"ø x 18" POST BOLT
3700G	4	3/4" WASHER
3704G	2	3/4" HEX NUT
3900G	2	1" WASHER
3910G	2	1" HEX NUT
4063B	6	WD 6'0 POST 6 x 8
4075B	6	WD BLOCK 1'2 x 6 x 8 DR
4147B	2	WD 3'9 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
33875G	1	ANGLE STRUT

NOTES:

1.) DO NOT ATTACH GUARDRAIL TO POST # 1.

2.) THE 5/8" FLAT WASHER IS USED UNDER THE NUT BEHIND THE POST ONLY. NO WASHER IS USED AT THE RAIL.

3.) CUSTOMER SHALL PROVIDE NOSE REFLECTOR MATERIAL.

4.) ANGLE STRUT MUST BE ATTACHED USING 3/4" DIA HIGH STRENGTH BOLTS.

REV.	CHK'D	BY	DATE	REMARKS

ET-PLUS

ET-PLUS – 50'-0"
WITH 12'-6" RAILS & 2 POST SLEEVES
WITHOUT SOIL PLATE, HBA STRUT
PLAN, ELEVATION & SECTION
2014 TESTING

DRAWN	BT
CHECKED	
SCALE	N.T.S.
DATE	11-11-14
ENG. FILE #	SS334-01E 11-14
SHT./No.	E1 OF 1
DRAWING NO.	SS-334
REV.	0

TRINITY HIGHWAY PRODUCTS, LLC.
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DALLAS, TX 75207

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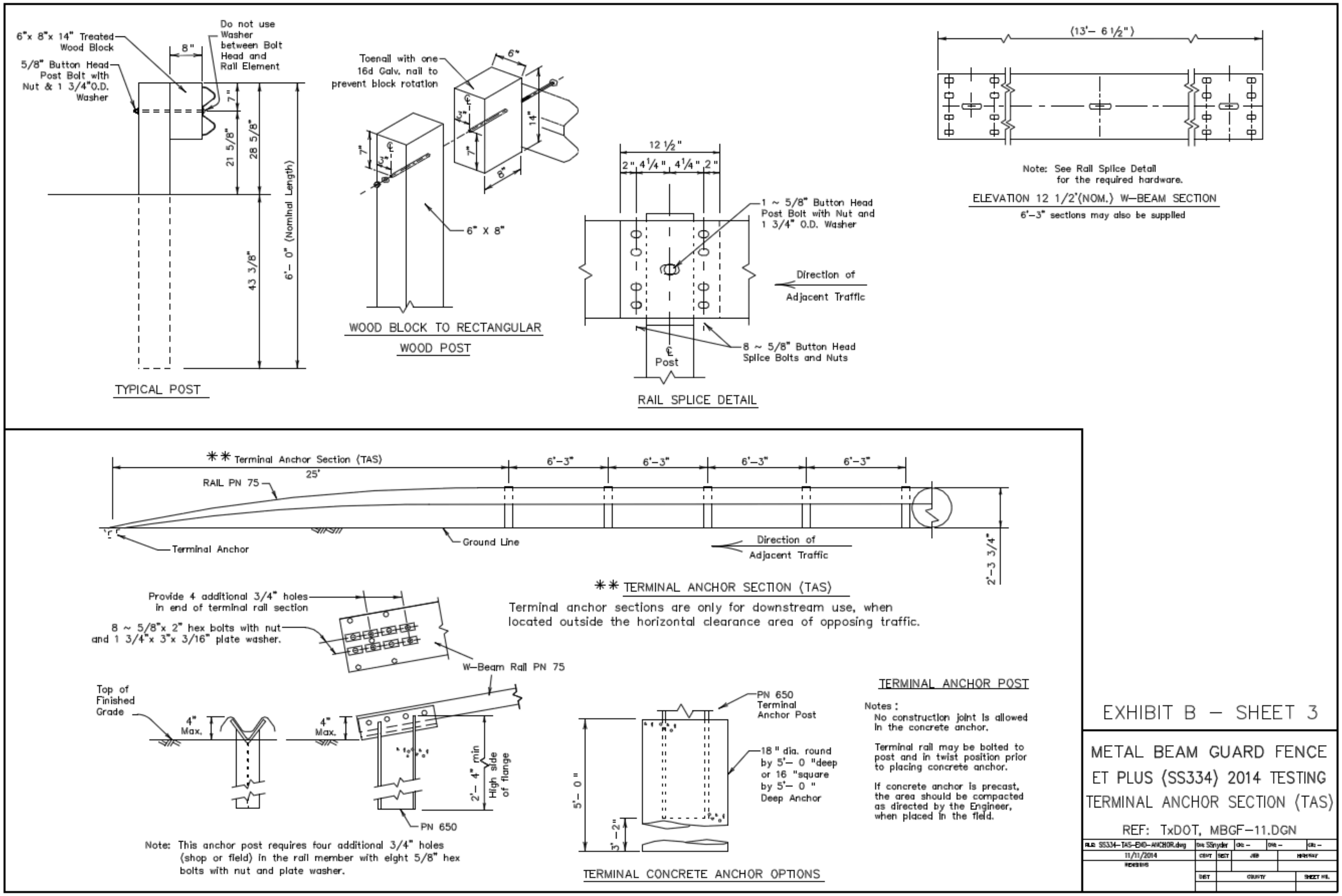
6"x 8"x 14" Treated Wood Block
5/8" Button Head Post Bolt with Nut & 1 3/4"O.D. Washer
Do not use Washer between Bolt Head and Rail Element
8"
7"
21 5/8"
28 5/8"
43 3/8"
6'- 0" (Nominal Length)
TYPICAL POST
Toenail with one 16d Galv. nail to prevent block rotation
6"
14"
7"
8"
6" X 8"
WOOD BLOCK TO RECTANGULAR WOOD POST
12 1/2"
2" 4 1/4" 4 1/4" 2"
1 ~ 5/8" Button Head Post Bolt with Nut and 1 3/4" O.D. Washer
Direction of Adjacent Traffic
8 ~ 5/8" Button Head Splice Bolts and Nuts
℄ Post
RAIL SPLICE DETAIL
(13'- 6 1/2")
Note: See Rail Splice Detail for the required hardware.
ELEVATION 12 1/2"(NOM.) W-BEAM SECTION
6'-3" sections may also be supplied
** Terminal Anchor Section (TAS)
25'
6'-3"
6'-3"
6'-3"
6'-3"
RAIL PN 75
Terminal Anchor
Ground Line
Direction of Adjacent Traffic
2'-3 3/4"
** TERMINAL ANCHOR SECTION (TAS)
Terminal anchor sections are only for downstream use, when located outside the horizontal clearance area of opposing traffic.
Provide 4 additional 3/4" holes in end of terminal rail section
8 ~ 5/8"x 2" hex bolts with nut and 1 3/4"x 3"x 3/16" plate washer.
W-Beam Rail PN 75
Top of Finished Grade
4" Max.
4" Max.
2'- 4" min
High side of flange
PN 650
Note: This anchor post requires four additional 3/4" holes (shop or field) in the rail member with eight 5/8" hex bolts with nut and plate washer.
PN 650 Terminal Anchor Post
18" dia. round by 5'- 0" deep or 16" square by 5'- 0" Deep Anchor
5'- 0"
3'- 2"
TERMINAL CONCRETE ANCHOR OPTIONS
TERMINAL ANCHOR POST
Notes :
No construction joint is allowed in the concrete anchor.
Terminal rail may be bolted to post and in twist position prior to placing concrete anchor.
If concrete anchor is precast, the area should be compacted as directed by the Engineer, when placed in the field.
EXHIBIT B – SHEET 3
METAL BEAM GUARD FENCE
ET PLUS (SS334) 2014 TESTING
TERMINAL ANCHOR SECTION (TAS)
REF: TxDOT, MBGF-11.DGN

Appendix B: SwRI Data Sheets for Test ET27-30

EXHIBIT D-1: Installation Checklist

Test Number: ET27-30 Test Date: TBD

*Record the following impact head dimensions:

head stamp "3" 12/4/2014 OK

Dimension	*Pre-Test Measurements
Exit Gap (middle - inside)	1.1395" ✓
Entrance Gap (middle - outside)	4.7590"
Guide Chute Exit Height (outside)	15 1/16" ✓
Guide Chute Entrance Height (outside)	14.5" ✓
Channel Width (outside)	4.0305" ✓
Channel Insertion into Extruder	0.4060" 0.4100" 0.5300" 0.3610"
Outside Guide Channel Length	36 5/8" ✓
Outside Guide Channel Length – Chute to start of swedge	35 1/8" ✓
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: 28 inches — Between post 5 and 6: 28 inches
   b. Between post 2 and 3: 28 3/4 inches — Between post 6 and 7: 27 3/4 inches
   c. Between post 3 and 4: 27 7/8 inches — Between post 7 and 8: 27 3/4 inches
   d. Between post 4 and 5: 28 inches — Between post 8 and 9: 28 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: 7 1/4 ✓ inches.
c. Distance from the ground to the top of the impact face: 35 1/8 ✓ 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 7/8 ✓ 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 1 1/4 inches.

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AM 12/12/14
RDA 12/12/14

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 12/11/2014

42

2CLMR2268X6717183

DATE: 12/4/14 TEST NO.: ET27-30 VIN NO.: ↑ MAKE: GEO

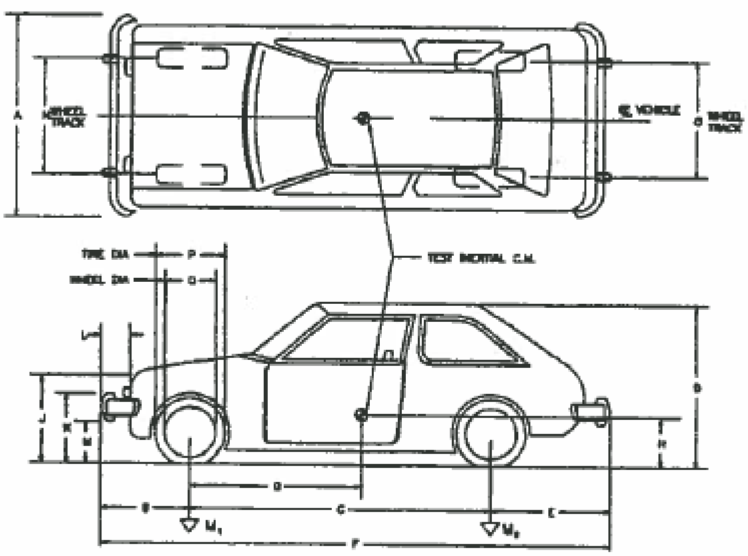
MODEL: Metro YEAR: 1999 ODOMETER: 199089 TIRE SIZE: 155/80/R13

TIRE INFLATION PRESSURE: ______

MASS DISTRIBUTION (kg) LF 530 RF 522 LR 336 RR 327

(w/Ballast)

DESCRIBE ANY DAMAGE TO VEHICLE PRIOR TO TEST: 40 lb Ballast Total ~~1715~~ 1755 OH 1/23/2015



ENGINE TYPE: Gas

ENGINE CID: 1.0L

TRANSMISSION TYPE:

— AUTO

X MANUAL

OPTIONAL EQUIPMENT:

DUMMY DATA:

TYPE: ______

MASS: 165

SEAT POSITION: Driver

GEOMETRY – (cm)

A 61"	D 55"	G 35.58"	K 22"	N 54.25"	Q 14
B 31"	E 24"	H 19.5"	L 4"	O 53.5"	
C 93"	F 148"	J 27"	M 10"	P 22"	

C/G = 11.5"

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

EDR mounted From Front spindel 43" From Ground 16 1/4"

Figure 4.1. 700C and 820C parameters.

OH 1/5/2015

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.

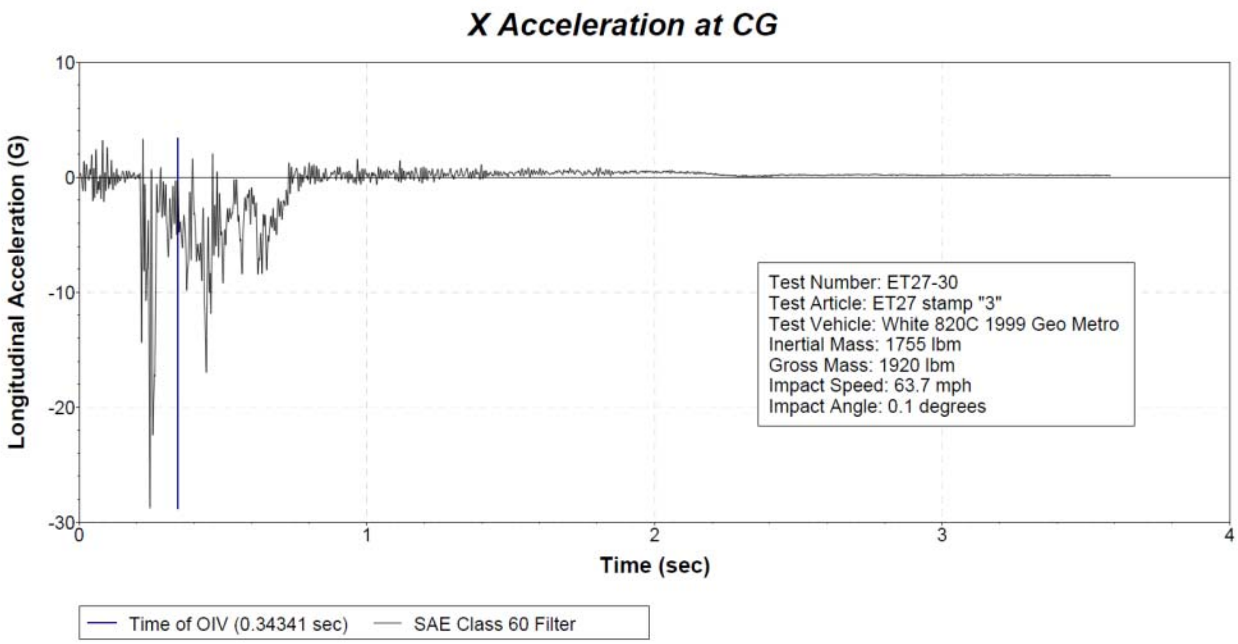
Sincerely,

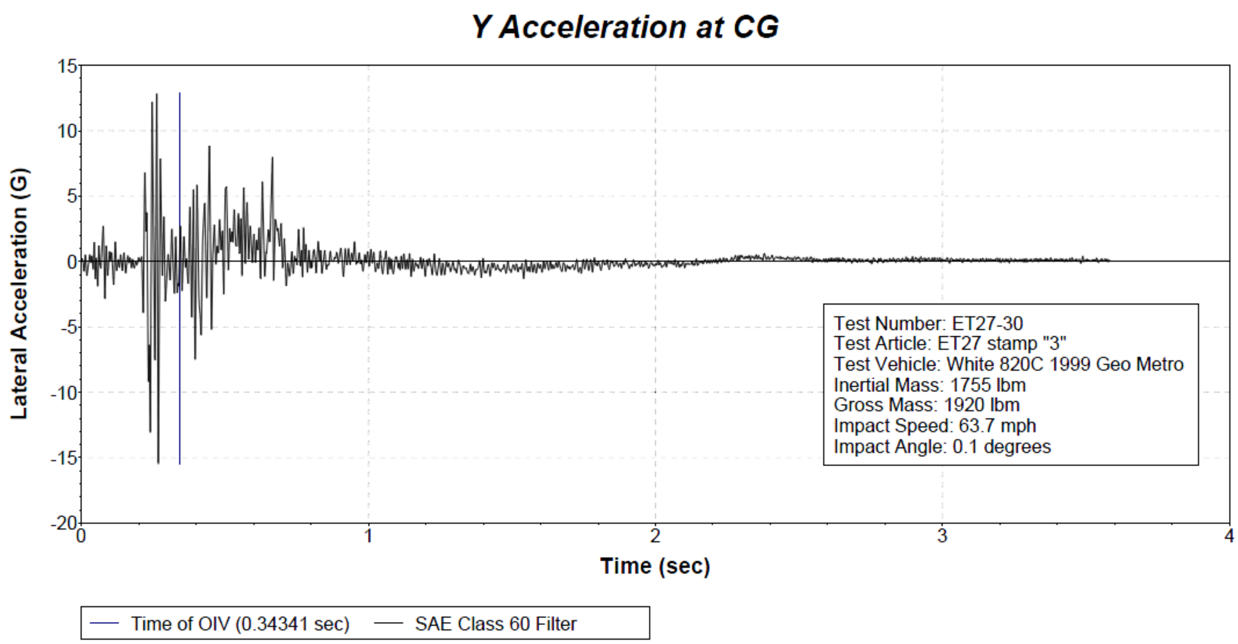
R. B. Kalmbach
Executive Director, Contracts

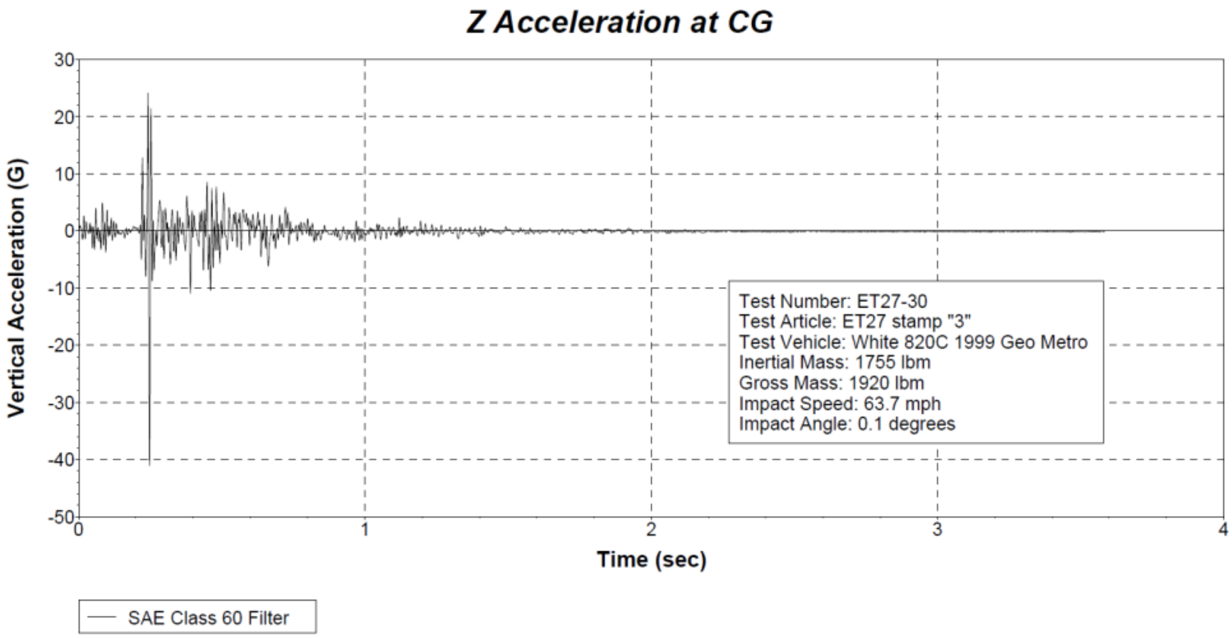
RBK/MKL/jms
cc: J. Ferren, SwRI (via email)

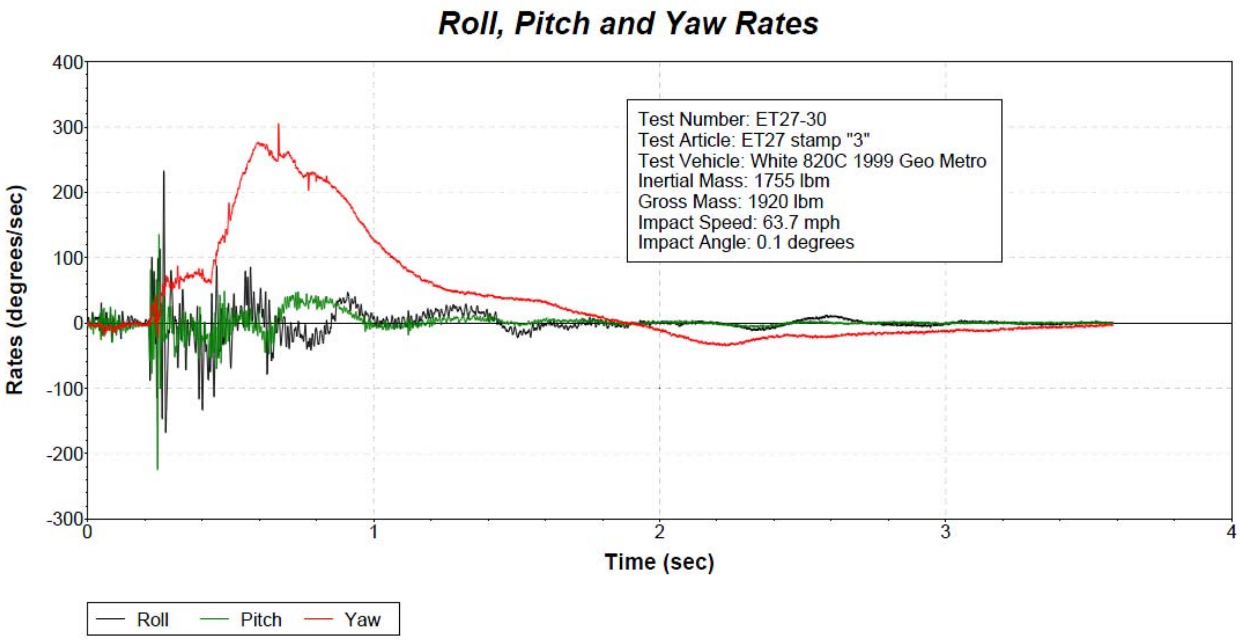
Benefiting government, industry and the public through innovative science and technology

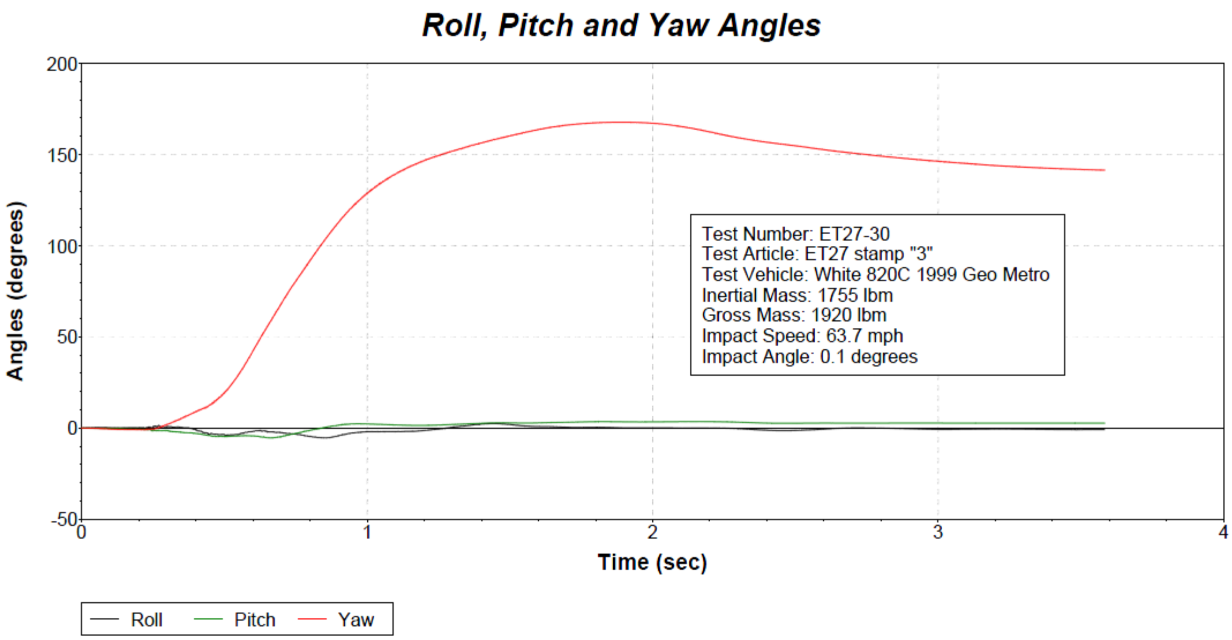
Appendix D: Test Data Plots


X Acceleration at CG
Longitudinal Acceleration (G)
10
0
-10
-20
-30
0
1
2
3
4
Time (sec)
Test Number: ET27-30
Test Article: ET27 stamp "3"
Test Vehicle: White 820C 1999 Geo Metro
Inertial Mass: 1755 lbm
Gross Mass: 1920 lbm
Impact Speed: 63.7 mph
Impact Angle: 0.1 degrees
Time of OIV (0.34341 sec)
SAE Class 60 Filter


Y Acceleration at CG
Lateral Acceleration (G)
15
10
5
0
-5
-10
-15
-20
0
1
2
3
4
Time (sec)
Test Number: ET27-30
Test Article: ET27 stamp "3"
Test Vehicle: White 820C 1999 Geo Metro
Inertial Mass: 1755 lbm
Gross Mass: 1920 lbm
Impact Speed: 63.7 mph
Impact Angle: 0.1 degrees
Time of OIV (0.34341 sec)
SAE Class 60 Filter


Z Acceleration at CG
Vertical Acceleration (G)
30
20
10
0
-10
-20
-30
-40
-50
0
1
2
3
4
Time (sec)
Test Number: ET27-30
Test Article: ET27 stamp "3"
Test Vehicle: White 820C 1999 Geo Metro
Inertial Mass: 1755 lbm
Gross Mass: 1920 lbm
Impact Speed: 63.7 mph
Impact Angle: 0.1 degrees
SAE Class 60 Filter


Roll, Pitch and Yaw Rates
Test Number: ET27-30
Test Article: ET27 stamp "3"
Test Vehicle: White 820C 1999 Geo Metro
Inertial Mass: 1755 lbm
Gross Mass: 1920 lbm
Impact Speed: 63.7 mph
Impact Angle: 0.1 degrees
Rates (degrees/sec)
400
300
200
100
0
-100
-200
-300
0
1
2
3
4
Time (sec)
Roll
Pitch
Yaw


Roll, Pitch and Yaw Angles
Test Number: ET27-30
Test Article: ET27 stamp "3"
Test Vehicle: White 820C 1999 Geo Metro
Inertial Mass: 1755 lbm
Gross Mass: 1920 lbm
Impact Speed: 63.7 mph
Impact Angle: 0.1 degrees
Angles (degrees)
200
150
100
50
0
-50
0
1
2
3
4
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 (%):		

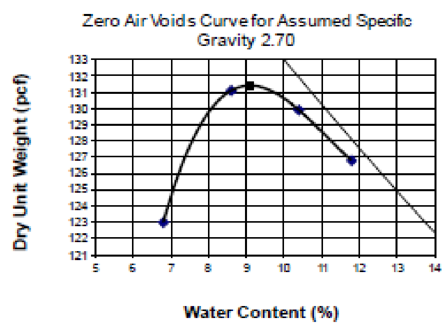
USCS:

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: 90141414.0008
Service Date: 01/05/15
Report Date: 01/06/15
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 (%)
	Site ET27-30								
1	9'9" to the Right of Post #1	1/ Final	1	12	141.3	9.0	6.8	132.3	100+
2	Behind Post #2	1/ Final	1	12	142.6	9.2	6.9	133.4	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