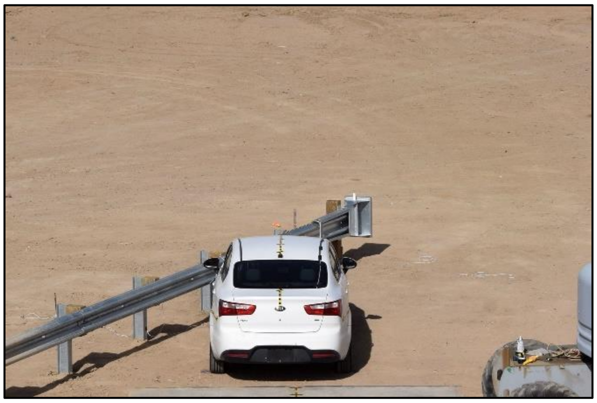
Test Report For:

SPIG Industries, LLC

SGET End Terminal



TESTED TO:

Manual for Assessing Safety Hardware (MASH 2016)

Test 3-37b

PREPARED FOR:

SPIG Industries, LLC

14675 Industrial Park Road

Bristol, Virginia 24202

TEST REPORT NUMBER:

TR-P38033-01-NC

REPORT DATE:

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April 10, 2018

KARCO Engineering, LLC. TL-371
Automotive Safety and Testing Facility
9270 Holly Road, Adelanto, CA 92301
Tel: (760) 246-1672 Fax: (760) 246-8112
www.KARCO.com

Tested By:	______________________
	Mr. Robert L. Ramirez Project Engineer
Report By:	______________________
	Mr. Balbino A. Beltran Program Manager
Reviewed By:	______________________
	Mr. Andrew J. Espindola Quality Assurance Manager
Approved By:	______________________
	Mr. Michael L. Dunlap Director of Operations
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15. Supplementary Notes

16. Abstract

One (1) Test Level 3, Test 37 (3-37) was performed on the subject SPIG Industries, LLC SGET end terminal. The terminal was impacted by a 2012 Kia Rio 4-door sedan. Testing was conducted by KARCO Engineering, LLC. in Adelanto, CA on April 10, 2018.

The test vehicle impacted the SGET end terminal at a velocity of 62.30 mph (100.26 km/h) and an impact angle of 25.2°. The post 3 location was selected as the critical impact point for this test. The first 12.5 ft. (3.8 m) of the system was damaged as a result of the impact. The vehicle gated through the system in a stable manner.

The majority of the vehicle damage was concentrated at the front end. The driver side of the vehicle was also was also subject to dents and deformation. The occupant compartment was not penetrated and the deformation limits were not exceeded.

The SPIG Industries, LLC SGET met all the requirements for MASH 2016 Test 3-37b.

17. Key Words SPIG Industries, LLC SGET Terminal MASH 2016 3-37b	**18. Distribution Statement**

19. Security Classification of this report	20. Security Classification of this page	21. No. of Pages	22. Price
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Table of Contents

List of Tables

List of Figures

Quantity	Typical Application	Std Units	Metric Unit	Multiply By
Mass	Vehicle Weight	lb	kg	0.4536
Linear Velocity	Impact Velocity	miles/hr	km/hr	1.609344
Length or Distance	Measurements	in	mm	25.4
Volume	Fuel Systems	gal	liter	3.785
Volume	Small Fluids	oz	mL	29.574
Pressure	Tire Pressures	lbf/in^2	kPa	6.895
Temperature	General Use	^{o}F	^{o}C	=(Tf -32)/1.8
Force	Dynamic Forces	lbf	N	4.448
Moment	Torque	lbf-ft	N•m	1.355

1. Introduction

1.1 Problem Statement

The purpose of this report is to detail the safety performance of the SPIG Industries, LLC Spig Gating End Terminal (SGET) when evaluated to the criteria set forth by the *Manual for Assessing Safety Hardware* (MASH 2016).

1.2 Objective

The primary objective of this project was to evaluate the safety performance of the SGET when subjected to full-scale crash testing according to MASH 2016 Test Level 3, Test 37 (3-37b) for redirective terminals.

1.3 Scope

This project consists of full-scale dynamic crash testing of the SGET. The system was subject to MASH 2016 Test 3-37b. For post-and-beam terminals with a breakaway cable system, MASH 2016 recommends that the 1100C vehicle be used as it will generally be the critical vehicle for this test. Test 3-37 is a reverse direction impact with the test vehicle impacting the system at a nominal angle of 25° at the critical impact point (CIP). The CIP chosen for this test was at post 3 to increase the vehicle's potential to snag on the terminal's anchor assembly.

2. System Details

2.1 Test Article

The SPIG Gating End Terminal (SGET) is an energy absorbing guardrail end treatment designed to reduce the severity of end on impacts with W-beam guardrail. When impacted the SGET feeds the rail through the impact head and exits to the non-traffic side of the system. The SGET system was composed of one (1) impact head, one (1) post 1 assembly, one (1) cable anchor system, one (1) specialty panel, and seven (7) yielding posts. The posts were spaced 75.0 in. (1.9 m) on centers with the rail splices located at the posts. The total terminal length was 50.0 ft. (15.2 m). The system was attached to 56.3 ft. (17.2 m) of standard guardrail with splices placed midspan. The system can be installed with a top rail height of 31 in. ± 1 inch. The as-tested system was installed with a rail height of 32.0 in. (813 mm) to increase the risk of vehicle underride. The system was tested with an RFID chip attached to the impact head.

The impact head rests over the specialty panel and mounts to the first post with two (2) 3.0 in. (76 mm) long lag bolts and washers. The impact head was 64.0 in. (1.6 m) long and had a rear chute width of 5.0 in. (127 mm). The front face of the impact head was 24.0 in. (610 mm) tall and 17.0 in. (432 mm) wide. Welded 9.0 in. (229 mm) behind the front face of the impact head was a 0.625 in. (16 mm) thick steel post breaker plate. The chute was composed of 0.25 in. (6 mm) C-channel. The downstream end of the impact head tapers to an overall height of 13.5 in. (343 mm). There were two (2) 0.5 in. (13 mm) thick straps welded at the downstream end of the impact head.

Post 1 was a wooden post inserted into a steel foundation tube and once assembled was 8.9 ft. (2.7 m) long. The wooden post and foundation tube were connected with a 10.0 in. (254 mm) long 0.625 in. hex head bolt. The steel foundation tube was 6.0 in (152 mm) by 8.0 in. (203 mm) and 6.0 ft. (1.8 m) long. The wooden portion of post 1 was a 5.5 in. (140 mm) by 7.5 in. (188 mm) and was 4.2 ft. (1.3 m) long. The wooden portion had two (2) 0.75 in. (19 mm) holes drilled 13.0 in. (330 mm) down from the top to mount the strike plate and block. The strike plate and block were installed on the leading side of post 1 with one (1) 14.0 in. long 0.625 in. guardrail bolt, washer and guardrail nut. The rail does not attach to post 1 and there is no blockout.

The cable anchor assembly was secured to post 1 with a bearing plate and to the specialty panel with a guardrail grabber. The cable was routed through a 2.5 in (64 mm) hole located at the base of post 1. The bearing plate was 0.625 in (16 mm) thick and had two (2) 0.5 in. (13 mm) holes at the top used to secure the plate to post 1 with two (2) lag bolts. The downstream end of the cable assembly was the guardrail grabber. The grabber was 17.0 in. (432 mm) long and had six (6) teeth that lock into the specialty panel. Between the specialty panel and the grabber there was a 17.0 in. (432mm) long reinforcement panel. The reinforcement panel was held onto the rail with six (6) 1.25in long 1/2 in. bolts, twelve (12) washers, six (6) lock washers and six (6) nuts. The specialty panel was a standard 12 Ga w-beam section measuring 12.5 ft. (3.8 m) long and had six (6) rectangular slots cut for the guardrail grabber. The other three (3) panels in the terminal section were standard 12 Ga 12.5 ft. (3.8m) MGS guardrail panels.

Posts 2 through 8 were 6.0 ft. (1.8 m) long yielding posts. The yielding posts had two (2) 0.5 in. (13 mm) holes drilled through both of its flanges 31.0 in. (787 mm) from the top of the post. There was a 3.0 in. (76 mm) by 3.0 in. (76 mm) by 80.0 in. (2032 mm) long strut channel that was connected between post 1 and 2. The upstream end was mounted at the connection point of the foundation tube and wooden post. The downstream end of the strut was connected to post 2 with two (2) 2.0 in. long 1.5 in. bolts, four (4) washers, two (2) lock washers and two (2) nuts. Post 2 attached to the specialty panel with a standard 1.25 in. long 0.625 in. guardrail bolt and nut with no blockout. Posts 3 through 8 used 8.0 in. (203 mm) deep notched wooden blockouts and 10.0 in. long 0.625 in. guardrail bolts.

After the terminal there was one (1) 9.4 ft. (2.9 m) panel to transition the splices to the midspan location. After the transition panel there were seventeen (17) W6x8.5 galvanized steel posts, seventeen (17) 8.0 in. (203 mm) deep notched wooden blocks and six (6) 12.5 ft. (3.8 m) MGS panels. The rails were spliced together with 1.25 in. long 5/8 in. guardrail splice bolts and nuts. The rails were held to the posts using 10.0 in. long 5/8 in. guardrail bolts and nuts. A second 9.4 ft. (2.9 m) transition panel was used before the downstream anchor and the installation was terminated with an SFT type anchor.

Photographs of the as-tested unit and installation are available in Appendix A of this report. The manufacturer’s drawings are available in Appendix D. A complete set of manufacturer drawings are available in KARCO CD-R 2018-4896.

3. Test Requirements and Evaluation Criteria

3.1 Test Requirements

The SGET system described in this report was classified as a redirective terminal. MASH 2016 recommends a series of up to nine (9) full scale crash tests to evaluate redirective terminals. However, Test 3-36 is intended for a system that had a rigid backup structure and is not applicable for this system. Test 3-38 is intended for a staging device and is not applicable for this system. Therefore Test 3-36 and 3-38 were not conducted.

Table 1 MASH 2016 TL-3 Test Matrix for Redirective Terminals

<table>
<tr><th rowspan="2"></th><th>Test Designation</th><th colspan="3">Impact Conditions</th><th rowspan="2">Evaluation Criteria</th></tr>
<tr><th>MASH Test No.</th><th>Vehicle</th><th>Nominal Speed (mph)</th><th>Nominal Angle (deg)</th></tr>
<tr><td rowspan="10">Test Level 3</td><td>3-30</td><td>1100C</td><td>62</td><td>0</td><td>C,D,F,H,I,N</td></tr>
<tr><td>3-31</td><td>2270P</td><td>62</td><td>0</td><td>C,D,F,H,I,N</td></tr>
<tr><td>3-32</td><td>1100C</td><td>62</td><td>5-15</td><td>C,D,F,H,I,N</td></tr>
<tr><td>3-33</td><td>2270P</td><td>62</td><td>5-15</td><td>C,D,F,H,I,N</td></tr>
<tr><td>3-34</td><td>1100C</td><td>62</td><td>15</td><td>C,D,F,H,I,N</td></tr>
<tr><td>3-35</td><td>2270P</td><td>62</td><td>25</td><td>A,D,F,H,I</td></tr>
<tr><td>3-36</td><td>2700P</td><td>62</td><td>25</td><td>A,D,F,H,I</td></tr>
<tr><td>3-37a</td><td>2700P</td><td rowspan="2">62</td><td rowspan="2">25</td><td rowspan="2">C,D,F,H,I,N</td></tr>
<tr><td>3-37b</td><td>1100C</td></tr>
<tr><td>3-38</td><td>1500A</td><td>62</td><td>0</td><td>C,D,F,H,I,N</td></tr>
</table>

3.2 Evaluation Criteria

Evaluation criteria for full-scale vehicle crash testing are based on three criteria: (1) Structural Adequacy, (2) Occupant Risk, and (3) Post-Impact Vehicular Response. Criteria for structural adequacy evaluate the article's ability to allow redirection, controlled penetration, or controlled stopping of the vehicle. Occupant risk evaluates the degree of hazard to occupants in the impacting vehicle. Post-impact vehicular response is a measure of the potential of the vehicle to result in a secondary collision with other vehicles or fixed objects.

Post-Impact Head Deceleration (PHD), Theoretical Head Impact Velocity (THIV), and Acceleration Severity Index (ASI) occupant risk values have also been calculated for the evaluation of the crash tests.

Table 2 MASH 2016 Evaluation Criteria for Terminals and Crash Cushions

<table>
<tr><th>Evaluation Factors</th><th colspan="4">Evaluation Criteria</th></tr>
<tr><td>Structural Adequacy</td><td>C</td><td colspan="3">Acceptable test article performance may be by redirection, controlled penetration, or controlled stopping of the vehicle.</td></tr>
<tr><td rowspan="10">Occupant Risk</td><td>D.</td><td colspan="3">Detached elements, fragments, or other debris from the test article should not penetrate or show potential for penetrating the occupant compartment or present undue hazard to other traffic, pedestrian, or personnel in a work zone.</td></tr>
<tr><td>F.</td><td colspan="3">The vehicle should remain upright during and after collision. The maximum roll and pitch angles are not to exceed 75 degrees</td></tr>
<tr><td rowspan="4">H.</td><td colspan="3">Occupant impact velocities (OIV) should satisfy the following</td></tr>
<tr><td colspan="3">Occupant Impact Velocity Limits, ft/s (m/s)</td></tr>
<tr><td>Component</td><td>Preferred</td><td>Maximum</td></tr>
<tr><td>Longitudinal and Lateral</td><td>30 ft/s
(9.1 m/s)</td><td>40 ft/s
(12.2 m/s)</td></tr>
<tr><td rowspan="4">I.</td><td colspan="3">The occupant ridedown acceleration should satisfy the following limits</td></tr>
<tr><td colspan="3">Occupant Ridedown Acceleration Limits (G)</td></tr>
<tr><td>Component</td><td>Preferred</td><td>Maximum</td></tr>
<tr><td>Longitudinal and Lateral</td><td>15.0 G</td><td>20.49 G</td></tr>
<tr><td>Post-Impact Vehicular Response</td><td>N.</td><td colspan="3">Vehicle trajectory behind the test article is acceptable.</td></tr>
</table>

3.3 Soil Strength Requirements

In accordance to Appendix B of MASH 2016, the soil strength must be verified before any full-scale crash testing can be conducted on soil-based installations. Two instrumented W6x16 posts are installed near the impact area of the installation. The posts are pulled prior to full-scale testing to ensure the soil meets 90% of the established baseline.

4. Test Conditions

4.1 Test Facility

This test series was conducted at KARCO Engineering's test facility in Adelanto, California.

4.2 Vehicle Tow and Guidance System

The tow road is a continuous level surface constructed of reinforced concrete and measures 700.0 ft. (213.4 m) in length, 14.0 ft. (4.3 m) wide, and 6.0 in. (152 mm) thick. A steel rail is embedded in the road to provide vehicle guidance. Vehicle tow propulsion is provided by a 1 ton truck using a 1-to-2 pulley system. The test vehicle is towed into the test article by a nylon rope clamped to a 0.375 in. (10 mm) steel cable. The clamp is released from the cable on contact with a cable release mechanism positioned to allow the test vehicle to proceed under its own momentum for a maximum of 25.0 ft. (7.6 m) before impacting the test article.

4.3 Test Vehicles

For test 3-37b, an 1100C test vehicle was used. The vehicle was a 2012 Kia Rio 4-door sedan with a front mounted engine, manual transmission, and front wheel drive. The 1100C test vehicle had a curb, test inertial, and gross static weight of 2,495.6 lbs (1,132.0 kg), 2,398.6 lbs (1,088.0 kg), and 2,563.9 lbs (1,163.0 kg) respectively. An Anthropomorphic Test Device (ATD) was placed on the driver seat for this test.

The vehicles hood height and average track width were out of tolerance as specified in MASH. MASH recommends that the hood height be between 20.0 in. (508 mm) and 28.0 in. (711 mm). The recorded hood height was 29.5 in. (750 mm). MASH also recommends that the average track width be between 54.0 in. (1,372 mm) and 58.0 in. (1,473 mm). The test vehicle's track width was recorded as 60.0 in. (1,525 mm).

Despite the hood height dimensions falling out of the MASH tolerance, KARCO utilized the test vehicle because it was determined that the dimension would not have a significant effect on the performance of the system for this test. For Test 3-37b, the impact head engages the front quarter panel of the vehicle. The hood of the vehicle is not contacted until the vehicle is fully engaged with the article. The hood and grill are constructed of sheet metal and plastic with little structural integrity. These components crush during impact and do not significantly affect the vehicle dynamics during the impact event.

Regarding the vehicle's wheel track, a vehicle's track width has the potential to affect the vehicle's trajectory and stability. Being that the total average track width was exceeded by 2.0 in. (51 mm), which approximately translates to only 1.0 in. (25 mm) per wheel, the out of tolerance wheel track was deemed as insignificant. The vehicle's CG was not changed by the out of tolerance wheel track, as it remained the same if the track width was within tolerance. The wider wheel track could potentially make the vehicle less susceptible to roll based on the wider stance, though as the maximum roll angle seen in the test was 7.7° it can be concluded that stability in the roll axis was not a concern for this test since it was significantly lower than the 75° limit specified in MASH.

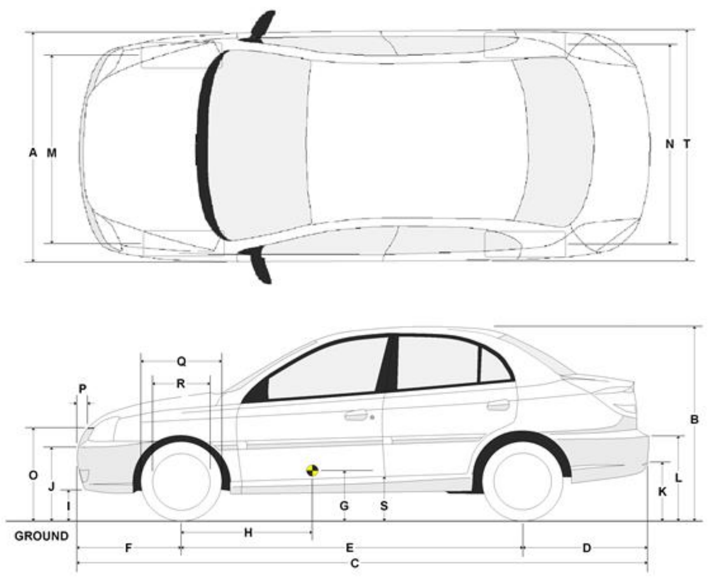
In summary the out of tolerance average wheel track and hood height were deemed to have an insignificant effect on the outcome of the test. Test vehicle information can be found in Figure 1.

Test Date……… 04/10/18 Project No…...... P38033-01 Year…………… 2012

Make…………..... Kia Model………….... Rio Color………….. White

Tire Size………. P185/65R15 Vehicle Vin #..... KNADM4A30D6201614

Tire Inflation…... 32 psi Odometer……… 118,070 mi



GVWR Rating

Total…………………… 3,595 lbs

Front…………………… 2,028 lbs

Rear…………………… 1,852 lbs

Engine Type…………… Inline 4

Engine Size……………. 1.6 L

Transmission Type……. Manual

Dummy Type………….. 50^{th} Male

Dummy Mass………….. 165 lb

Seat Position………… Driver Seat

Previous Vehicle Damage…. None

No.	Inches	mm	No.	Inches	mm	No.	Inches	mm	No.	Inches	mm
A	67.3	1710	F	31.5	800	K	19.8	502	P	1.4	35
B	57.3	1455	G	26.9	683	L	26.3	667	Q	24.0	610
C	170.8	4338	H	41.4	1051	M	60.0	1525	R	16.3	415
D	38.3	973	I	15.7	400	N	60.0	1525	S	11.3	288
E	101.2	2570	J	20.6	523	O	31.5	800	T	67.3	1710

TEST VEHICLE MASS

	As Received (lbs)			Test Inertial (lbs)			Gross Static (lbs)		
	Front	Rear	Total	Front	Rear	Total	Front	Rear	Total
Left	745.1	506.0	1251.1	694.4	503.7	1198.1	769.4	584.2	1353.6
Right	751.8	492.7	1244.5	723.1	477.3	1200.4	736.3	474.0	1210.3
Ratio (%)	60.0	40.0	100.0	59.1	40.9	100.0	58.7	41.3	100.0
Total	1496.9	998.7	2495.6	1417.5	981.0	2398.6	1505.7	1058.2	2563.9

	As Received (kg)			Test Inertial (kg)			Gross Static (kg)		
	Front	Rear	Total	Front	Rear	Total	Front	Rear	Total
Left	338.0	229.5	567.5	315.0	228.5	543.5	349.0	265.0	614.0
Right	341.0	223.5	564.5	328.0	216.5	544.5	334.0	215.0	549.0
Ratio (%)	60.0	40.0	100.0	59.1	40.9	100.0	58.7	41.3	100.0
Total	679.0	453.0	1132.0	643.0	445.0	1088.0	683.0	480.0	1163.0

Figure 1 Test 3-37b Vehicle Information

4.4 Data Acquisition Systems

All data acquisition for this test of the terminal was performed in accordance with the MASH 2016 requirements.

4.4.1 Test Vehicle Instrumentation

The test vehicle was instrumented with one (1) tri-axial accelerometer and one (1) tri-axial angular rate sensor. The set of accelerometers and angular rate sensors were mounted within 2.0 in. (50 mm) of the test vehicle's center of gravity in the x-y plane. The accelerometers measured longitudinal (x), lateral (y), and vertical (z) acceleration. The angular rate sensors measured roll (moment x), pitch (moment y) and yaw (moment z).

Table 3 Vehicle Instrumentation List for Test 3-37b

Ch.	Location	Axis	Ident. No.	Description	MFR	Model	Units
1	Vehicle CG	X	P51708	Accel, Half Bridge	Endevco	7264-2K	g
2	Vehicle CG	Y	P51700	Accel, Half Bridge	Endevco	7264-2K	g
3	Vehicle CG	Z	P51696	Accel, Half Bridge	Endevco	7264-2K	g
4	Vehicle CG	Yaw	ARS8537	Rate Gyro	DTS	ARS-18K	Deg/s
5	Vehicle CG	Pitch	ARS8532	Rate Gyro	DTS	ARS-18K	Deg/s
6	Vehicle CG	Roll	ARS8486	Rate Gyro	DTS	ARS-18K	Deg/s

4.4.2 Calibration

All instrumentation used in this test has been calibrated through standards traceable to NIST and is maintained in a calibrated condition.

4.4.3 Photographic Documentation

Photographic documentation of this test series included a minimum of two (2) real-time video cameras at 30 frames per second (fps), and six (6) high-speed color digital video cameras at 1,000 fps. All high-speed cameras were activated by a pressure-sensitive tape switch which was positioned on the test article to indicate the instant of contact (time zero). A digital still camera was used for documenting the pre- and post-test condition of the test article and the test vehicle.

Table 4 High Speed Camera Information Test 3-37b

View No.	Location	Identification No.	Manufacturer	Type
1	Driver Overall View	7959	Phantom	V9
2	Passenger Overall View	6657	Phantom	V10
3	Inline Track View	8187	Phantom	V10
4	Inline Article View	6936	Phantom	V10
5	Overhead Close-up	6710	Phantom	V5
6	Oblique View	8520	Phantom	V9

4.4.4 Measurement Uncertainty

Measurement uncertainties have been determined for pertinent values affecting the results of this test. KARCO maintains these uncertainty budgets, which are available upon request, but are not included in this report. In certain cases the nature of the test method may preclude rigorous and statistically valid calculation of uncertainty of measurement. In these cases KARCO attempts to identify the components of uncertainty and make a reasonable estimation. Reasonable estimation is based on knowledge of the performance of the method and on the measurement scope and makes use of, for example, previous experience and validation data.

5.Crash Test Results

5.1 Static Soil Test

Prior to full scale crash test P38033-01, a static soil test was conducted to ensure the soil condition was acceptable for full-scale crash testing. The static test results at 5.0 in. (127 mm), 10.0 in. (254 mm) and 15.0 in. (381 mm) were above 90% of the baseline established during soil certification. Static test results can be found in Appendix C of this test report.

5.2 Weather conditions

Test No. P38033-01 was conducted on April 10, 2018 at approximately 12:04 P.M.

Table 5 Weather Conditions Test 3-37

Temperature	83 °F
Wind Speed	2 mph
Humidity	9%
Wind Direction	South East

Information for reference only

5.3 MASH 2016 Test 3-37

As recommended in MASH 2016 a full-scale impact test was conducted to evaluate the impact performance of the Spig Industries, LLC SGET end terminal to MASH Test 3-37b on April 10, 2018. The test article was positioned at a nominal angle of 25° to the direction of travel of the test vehicle, with the vehicle aligned to impact the CIP. The test was conducted using a commercially available 2012 Kia Rio 4-door sedan with a test inertial mass of 2,398.6 lbs (1,088.0 kg).

5.4 Test Description

The test vehicle impacted the system at a velocity of 62.30 mph (100.26 km/h) and an angle of 25.2°. The vehicle was set to impact the center of the post 3 location, the actual first point of contact with the system was 7.1 in. (181 mm) downstream of the intended point.

On impact the first W-beam panel began to be deflected towards the field side. As the vehicle proceeded forward it further engaged the system deforming the W-beam around the front left corner of the vehicle and as a result the left front wheel of the vehicle underrode the W-beam.

The vehicle contacted post 2 at 0.060 s. On impact the forced was forced down by the vehicle and subsequently twisted due to the rail deflection. As the post twisted and folded at the base its flanges were forced into the W-beam, this contact started a tear in the W-beam at approximately 0.095 s which caused the rail to ultimately rupture at 0.113 s.

After the W-beam ruptured redirection stopped and the vehicle continued forward. As the vehicle moved forward it impacted post 1 and the impact head. Post 1 shattered at approximately 0.162 s. After the post was shattered the impact head was no longer attached to any part of the terminal. It was forced off the system and flung towards the traffic side at approximately 0.267 s when it was separated from the vehicle.

The vehicle exited the system at approximately 0.312 s, non-tracking at a exit angle of 18.5° and a heading angle of 28.4°. The exit velocity was 33.20 mph (53.43 km/h). After the brakes were applied the vehicle came to rest 70.1 ft. (21.4 m) downstream and 44.8 ft. (13.7 m) left from its initial point of contact with the system measured from the vehicle's center of gravity.

5.5 Test Article Damage

The system was damaged for the first 12.5 ft. (3.8 m), post 1 through post 3. The first W-beam tore at the end of the reinforcement plate. The piece of W-beam that remained attached to the rest of the terminal was deformed. The remaining damage to the system consisted of post damage. Even though the impact head and cable anchor assembly separated from the terminal, it was not subject to any damage.

- Post 1 – Wooden post was broken at soil tube connection point
- Post 2 – Folded down at base
- Post 3 – Slight shift downstream
- Post 4 – Slight shift downstream

5.6 Test Vehicle Damage

The majority of the vehicle damage occurred at the front end. The bumper fascia, bumper beam, quarter panels, and hood were all damaged due to the impact. The bumper fascia separated from the vehicle and the bumper beam deformed and detached from the driver side crush can. The quarter panels and hood were also subject to deformation. Both headlights were broken and separated from the vehicle.

Within the engine compartment the radiator, radiator support, and driver side crush rail were damaged. The engine shifted slightly rearward. The front driver side tire was flattened as a result of the impact. The occupant compartment was not penetrated and the deformation limits were not exceeded.

Table 6 Maximum Occupant Compartment Deformation by Location

Location	Maximum Deformation	MASH Allowable Deformation
Roof	0.0 in.	4.0 in. (102 mm)
Windshield	0.0 in.	3.0 in. (76 mm)
Window	0.0 in.	0.0 in
Wheel / foot well and toe pan	0.4 in. (10 mm)	9.0 in. (229 mm)
Side front panel (forward of A-pillar	0.0 in.	12.0 in. (305 mm)
Front side door area (above seat)	0.0 in.	9.0 in. (229 mm)
Front side door area (below seat	0.0 in.	12.0 in. (305 mm)
Floor pan and transmission tunnel	0.2 in. (5 mm)	12.0 in. (305 mm)

5.7 Structural Adequacy

Acceptable test article performance may be by redirection, controlled penetration, or controlled stopping of the vehicle. The terminal allowed the vehicle to penetrate the system.

5.8 Occupant Risk

Under occupant risk, the test articles are evaluated by four (4) criteria. The first criterion evaluates the potential hazard of detached elements, fragments, or other debris from the test article to penetrate the test vehicle’s occupant compartment or present undue hazard to other traffic, pedestrians, or personnel in a work zone. The second criterion is that the vehicle remains upright. The third criterion is that the roll angle of the vehicle does not exceed 75° throughout the test. The final criteria are based on the calculated Occupant Impact Velocities (OIV) and occupant ridedown accelerations. The maximum allowable limit for Occupant Impact Velocity Limit in both the longitudinal and lateral directions is 40.0 ft/s (12.2 m/s). The maximum allowable ridedown acceleration in both the longitudinal and lateral directions is 20.49 g. Both criteria are calculated from the acceleration data collected during the test.

The maximum extent of the debris field was 148.6 ft. (45.3 m) downstream and 23.9 ft. (7.3 m) to the left side (field side) measured from the first point of contact with the system. The debris consisted of the impact head, posts, and broken guardrail.

Table 7 Summary of Occupant Risk Factors

Test Parameter	Axis	Units	Max	Time (ms)	Min	Time (ms)
Vehicle Impact Velocity	X	ft/s	91.2			
Occupant Impact Velocity	X	ft/s	32.2	148.4		
Occupant Impact Velocity	Y	ft/s	9.2	148.4		
Ridedown Acceleration	X	g	3.2	203.8	-10.0	172.4
Ridedown Acceleration	Y	g	4.5	161.2	-9.8	174.1
THIV		ft/s	34.1	147.4		
PHD		g	13.0	174.1		
ASI			1.03	106.3		
Roll	X	deg.	7.7	112.9	-2.9	440.8
Pitch	Y	deg.	4.6	697.8	-2.4	174.7
Yaw	Z	deg.	41.1	999.9	-3.8	108.7

5.9 Discussion and Summary of Results

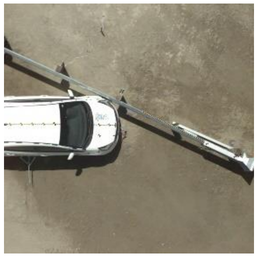
The SPIG Industries, LLC SGET end terminal met all the requirements for MASH 2016 Test 3-37b. The system allowed the vehicle to penetrate without causing substantial vehicle instability. None of the intrusion limits were exceeded, there was no penetration into the occupant compartment, and all the occupant risk factors were within the allowable limits. The SGET end terminal's performance to MASH 2016 test 3-37b, was deemed as acceptable.

Table 8 Evaluation Criteria Summary

<table>
<tr><th>Evaluation Factor</th><th colspan="2">Evaluation Criteria</th><th>Result</th></tr>
<tr><td>Structural Adequacy</td><td>C</td><td>Acceptable test article performance may be redirection, controlled penetration, or controlled stopping of the vehicle.</td><td>PASS</td></tr>
<tr><td rowspan="4">Occupant Risk</td><td>D</td><td>Detached elements, fragments, or other debris from the test article should not penetrate or show potential for penetrating the occupant compartment, or present undue hazard to other traffic, pedestrians, or personnel in a work zone.</td><td>PASS</td></tr>
<tr><td>F</td><td>The vehicle should remain upright during and after the collision. The maximum roll and pitch angles are not to exceed 75°.</td><td>PASS</td></tr>
<tr><td>H</td><td>Occupant impact velocities (OIV) should satisfy the following limits:<table><tr><th>Component</th><th>Preferred</th><th>Maximum</th></tr><tr><td>Longitudinal and Lateral</td><td>30 ft/s (9.1 m/s)</td><td>40 ft/s (12.2 m/s)</td></tr></table></td><td>PASS</td></tr>
<tr><td>I</td><td>The occupant ridedown acceleration should satisfy the following limits:<table><tr><th>Component</th><th>Preferred</th><th>Maximum</th></tr><tr><td>Longitudinal and Lateral</td><td>15.0 g</td><td>20.49 g</td></tr></table></td><td>PASS</td></tr>
<tr><td>Vehicle Trajectory</td><td>N</td><td>Vehicle trajectory behind the test article is acceptable.</td><td>PASS</td></tr>
</table>

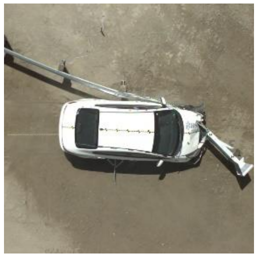
OVERALL TEST ASSESSMENT	PASS

MASH 2016 Test 3-37b Summary

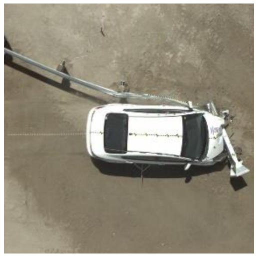


0.000 s

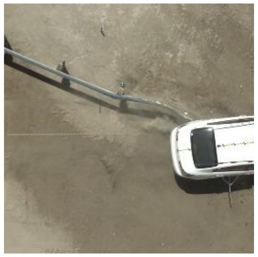
0.060 s



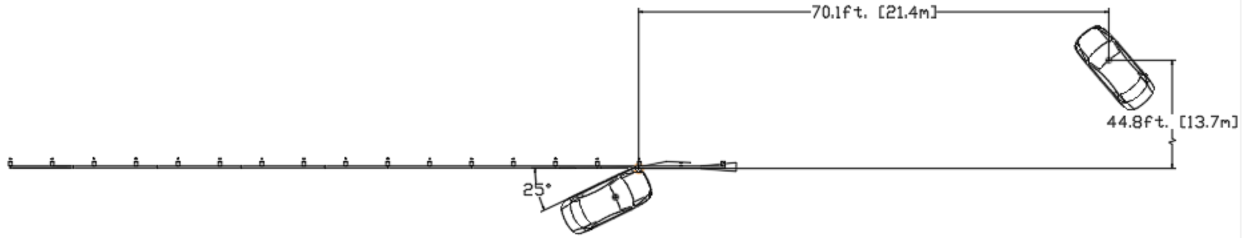
0.100 s



0.140 s



0.400 s



GENERAL INFORMATION	
Test Agency……………….	KARCO Engineering, LLC.
KARCO Test No…………	P38033-01
Test Designation…………	3-37
Test Date…………………	04/10/18
TEST ARTICLE	
Name / Model……………..	SGET
Type……………………….	End Terminal
Installation Length………..	106.3 ft. (32.4 m)
Terminal Length………….	50.0 ft. (15.2 m)
Road Surface…………….	Medium to Fine Silty Soil
TEST VEHICLE	
Type / Designation……….	1100C
Year, Make, and Model….	2012 Kia Rio
Curb Mass………………..	2,495.6 lbs (1,132.0 kg)
Test Inertial Mass………..	2,398.6 lbs (1,088.0 kg)
Gross Static Mass……….	2,563.9 lbs (1,163.0 kg)

Impact Conditions	
Impact Velocity……………	62.30 mph (100.26 km/h)
Impact Angle…………………	25.2°
Location / Orientation………	Post 3
Impact Severity………………	56.4 kip-ft (76.5 kJ)
Exit Conditions	
Exit Velocity…………………	33.20 mph (53.43 km/h)
Exit Angle……………………	18.5°
Final Vehicle Position………	70.1 ft. (21.4 m) dw
	44.8 ft. (13.7 m) left
Exit Box Criteria Met………	N/A
Vehicle Snagging……………	None
Vehicle Pocketing………….	None
Vehicle Stability…………….	Satisfactory
Maximum Roll Angle……….	7.7 °
Maximum Pitch Angle………	4.6 °
Maximum Yaw Angle……….	41.1 °

Occupant Risk	
Longitudinal OIV……………	32.2 ft/s (9.8 m/s)
Lateral OIV………………….	9.2 ft/s (2.8 m/s)
Longitudinal RA…………….	-10.0 g
Lateral RA…………………..	-9.8 g
THIV…………………………	34.1 ft/s (10.4 m/s)
PHD………………………….	13.0 g
ASI…………………………..	1.03
Test Article Deflections	
Static…………………………	0.9 ft. (0.3 m)
Dynamic……………………..	2.3 ft. (0.7 m)
Working Width………………	2.3 ft. (0.7 m)
Debris Field…………………	148.6 ft. (45.3 m) dw
	23.9 ft. (7.3 m) Field Side
Vehicle Damage	
Vehicle Damage Scale…….	01-LFQ-5
CDC………………………….	01LFEW4
Maximum Intrusion…………	0.4 in. (10 mm)

Figure 2 Summary of Test 3-37b

Appendix A

Photographs

LIST OF PHOTOGRAPHS

LIST OF PHOTOGRAPHS … (CONTINUED)

FIGURE 1. Test Setup

FIGURE 2. Test Setup, Close-Up

FIGURE 3. Test Setup

FIGURE 4. Test Setup, Close-Up

FIGURE 5. Test Setup

FIGURE 6. Test Setup, Close-Up

FIGURE 7. Test Setup

FIGURE 8. Test Setup, Close-Up

FIGURE 9. Test Setup

FIGURE 10. Test Setup, Close-Up

FIGURE 11. Pre-Test

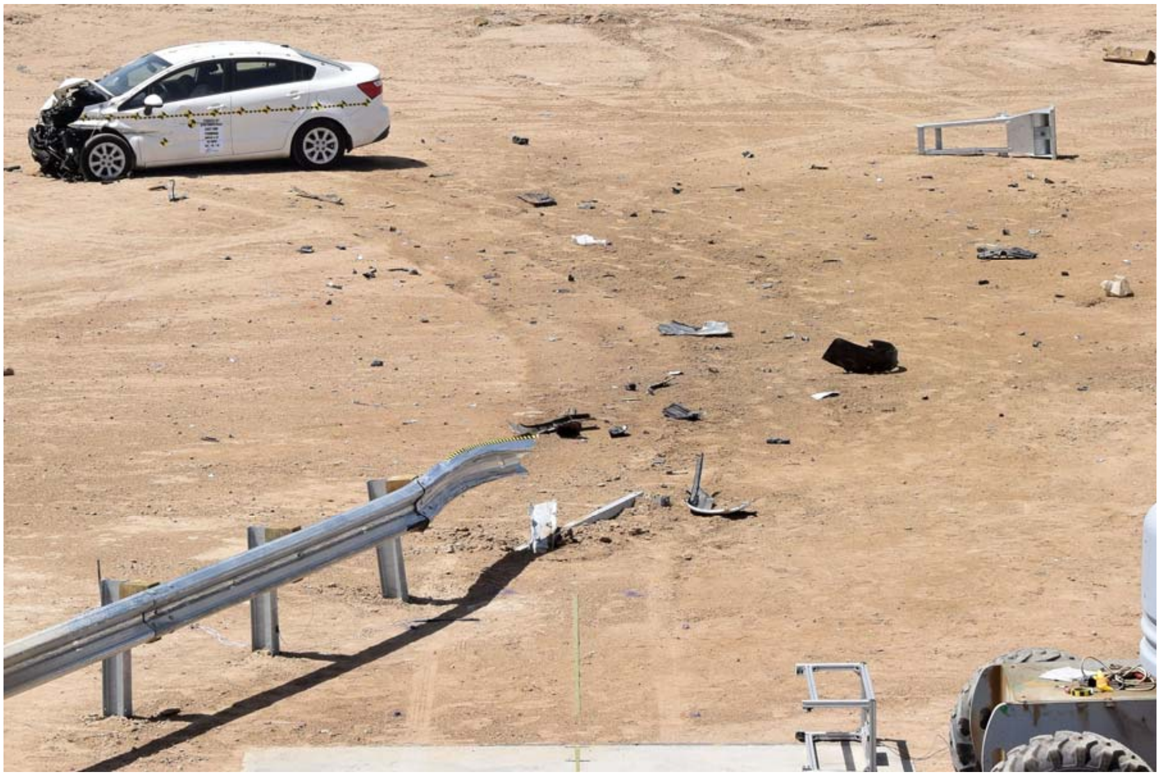


FIGURE 12. Post-Test

FIGURE 13. Post-Test

FIGURE 14. Post-Test

FIGURE 15. Pre-Test Front View of Test Article

FIGURE 16. Post-Test Front View of Test Article

FIGURE 17. Pre-Test Right Front ¾ View of Test Article

FIGURE 18. Post-Test Right Front ¾ View of Test Article

FIGURE 19. Pre-Test Right View of Test Article

FIGURE 20. Post-Test Right View of Test Article

FIGURE 21. Pre-Test Right Rear ¾ View of Test Article

FIGURE 22. Post-Test Right Rear ¾ View of Test Article

FIGURE 23. Pre-Test Rear View of Test Article

FIGURE 24. Post-Test Rear View of Test Article

FIGURE 25. Pre-Test Left Rear ¾ View of Test Article

FIGURE 26. Post-Test Left Rear ¾ View of Test Article

FIGURE 27. Pre-Test Left View of Test Article

FIGURE 28. Post-Test Left View of Test Article

FIGURE 29. Pre-Test Left Front ¾ View of Test Article

FIGURE 30. Post-Test Left Front ¾ View of Test Article

FIGURE 31. Test Article Damage

FIGURE 32. Test Article Damage

FIGURE 33. Test Article Damage

FIGURE 34. Test Article Damage

FIGURE 35. Test Article Damage

FIGURE 36. Test Article Damage

FIGURE 37. Pre-Test Left View of Test Vehicle

FIGURE 38. Post-Test Left View of Test Vehicle

FIGURE 39. Pre-Test Left Front ¾ View of Test Vehicle

FIGURE 40. Post-Test Left Front ¾ View of Test Vehicle

FIGURE 41. Pre-Test Front View of Test Vehicle

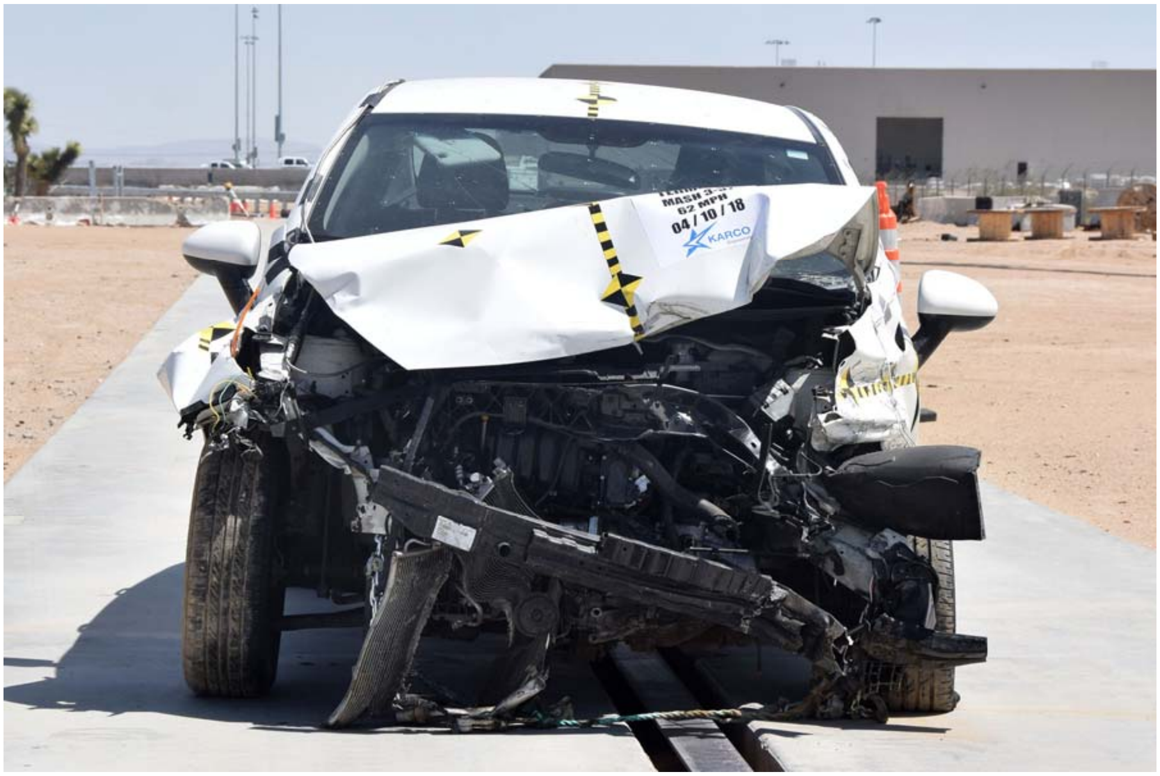


FIGURE 42. Post-Test Front View of Test Vehicle

FIGURE 43. Pre-Test Right Front ¾ View of Test Vehicle

FIGURE 44. Post-Test Right Front ¾ View of Test Vehicle

FIGURE 45. Pre-Test Right View of Test Vehicle

FIGURE 46. Post-Test Right View of Test Vehicle

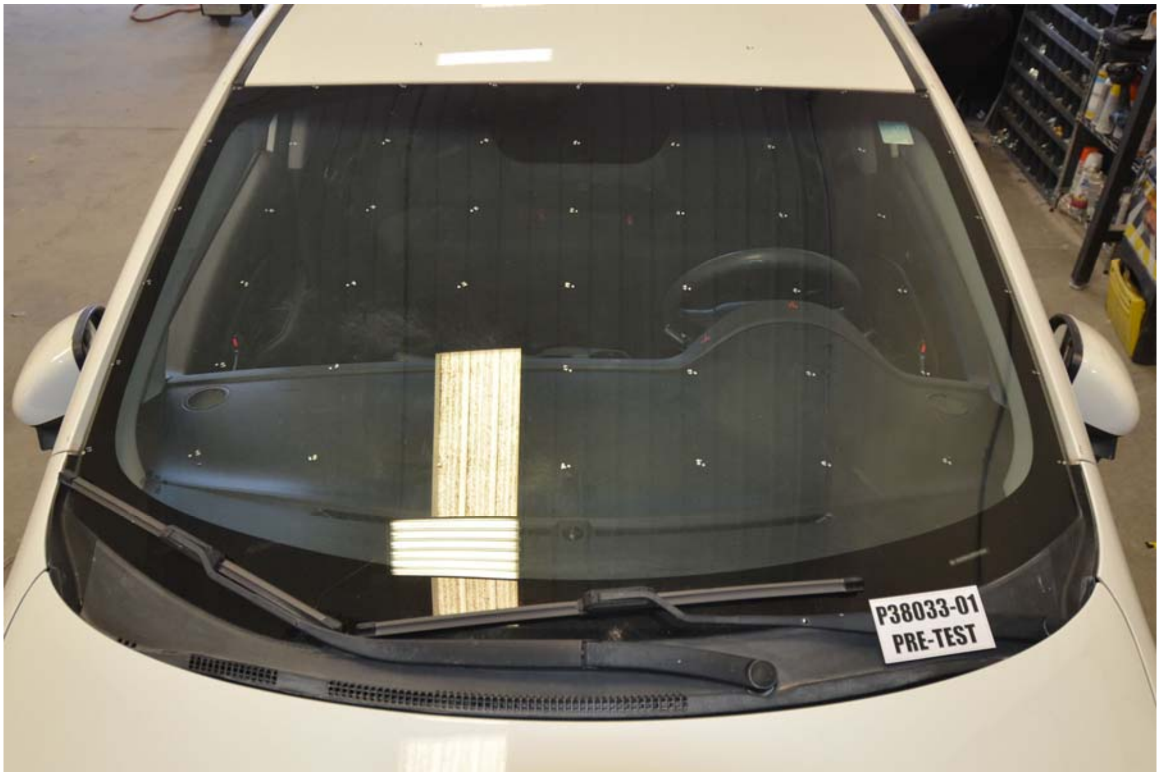


FIGURE 47. Pre-Test Windshield

FIGURE 48. Post-Test Windshield

FIGURE 49. Pre-Test Driver Side Occupant Compartment

FIGURE 50. Post-Test Driver Side Occupant Compartment

FIGURE 51. Pre-Test Driver Side Floorpan

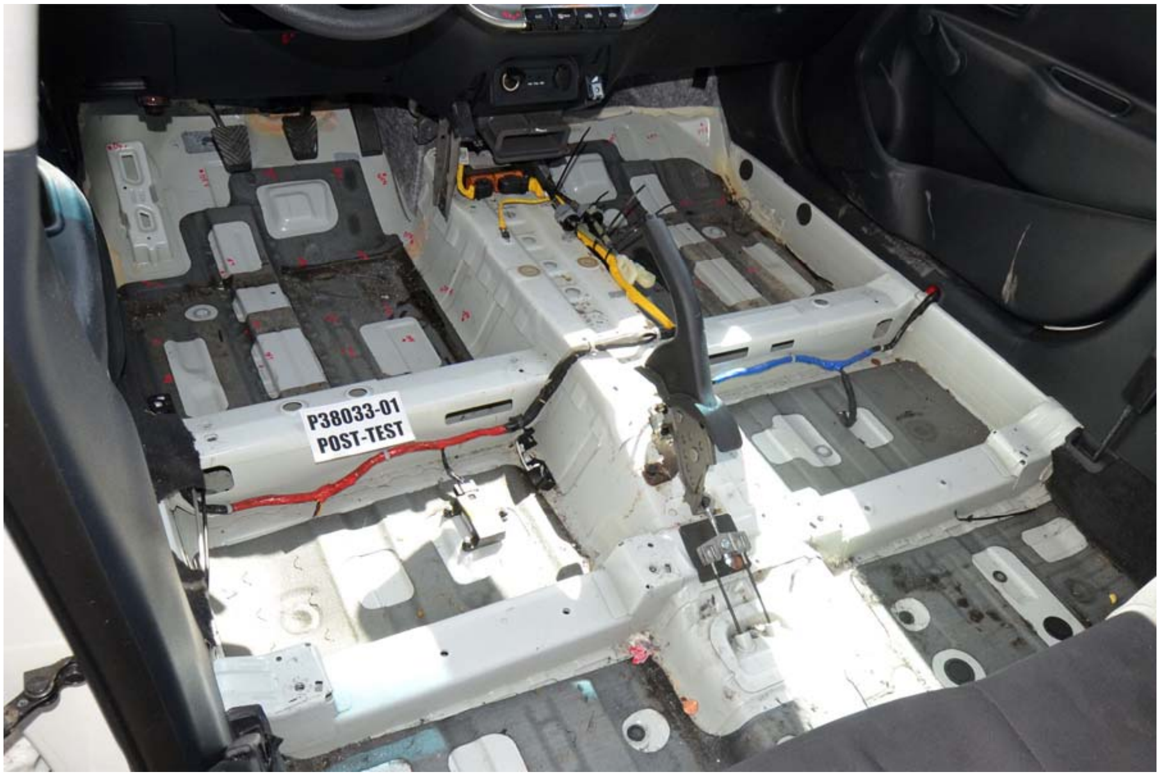


FIGURE 52. Post-Test Driver Side Floorpan

FIGURE 53. Pre-Test Passenger Side Occupant Compartment

FIGURE 54. Post-Test Passenger Side Occupant Compartment

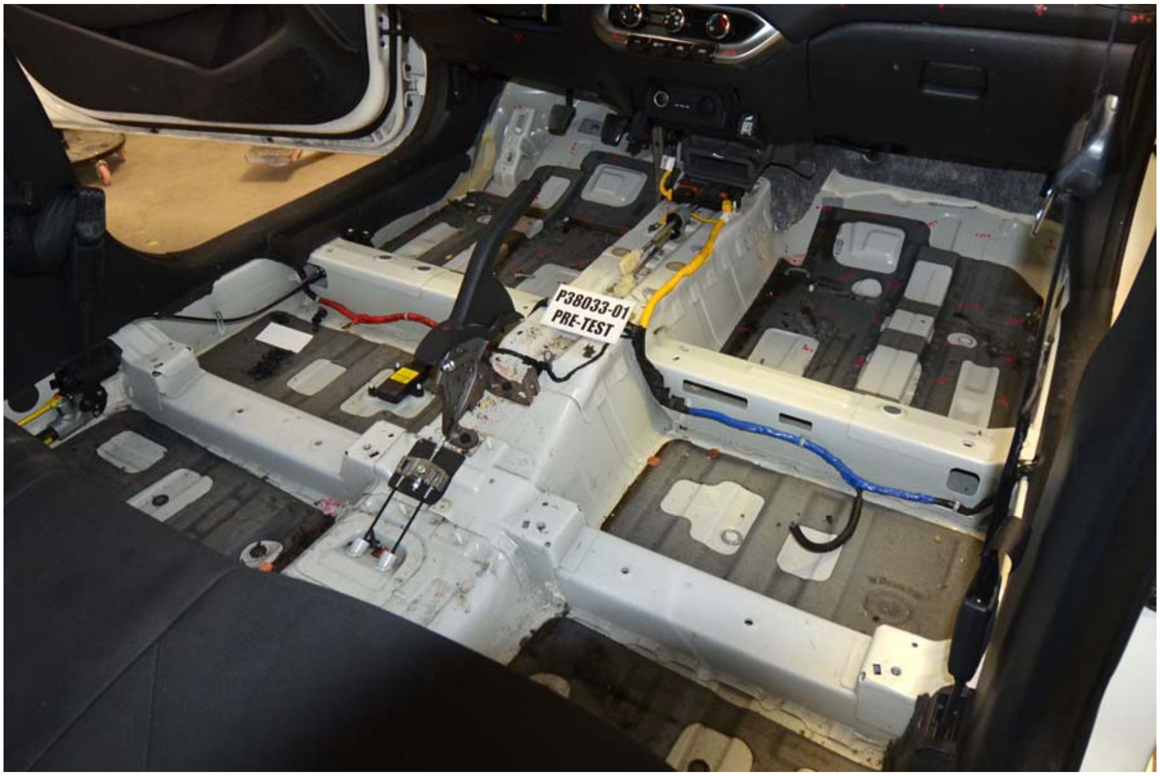


FIGURE 55. Pre-Test Passenger Side Floorpan

FIGURE 56. Post-Test Passenger Side Floorpan

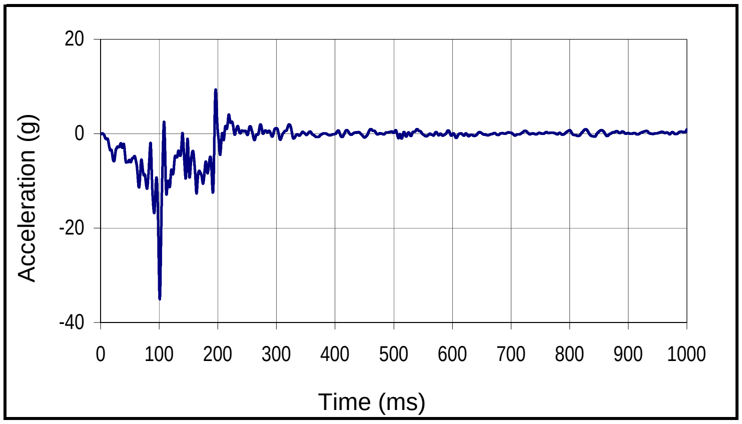
FIGURE 57. Test Vehicle Manufacturer's Label

Appendix B

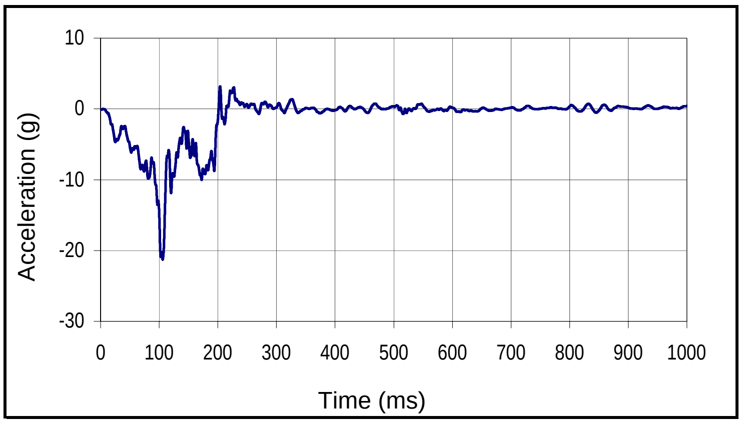
Data Plots

LIST OF DATA PLOTS

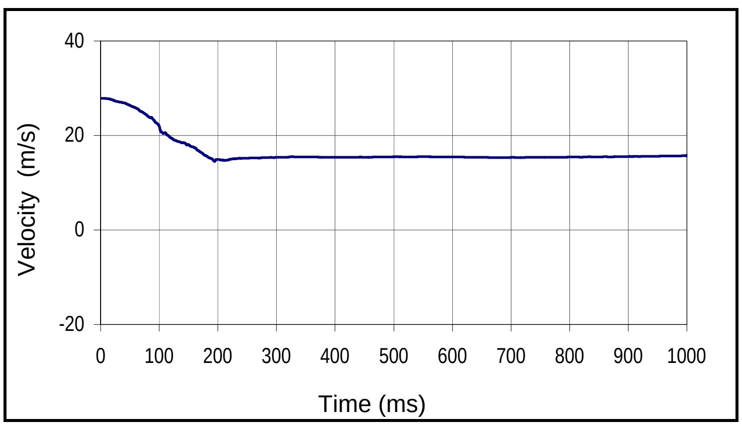
Test Article:	SPIG Industries SGET End Terminal	Project No:	P38033-01
Test Program:	MASH 3-37b	Test Date.:	04/10/18



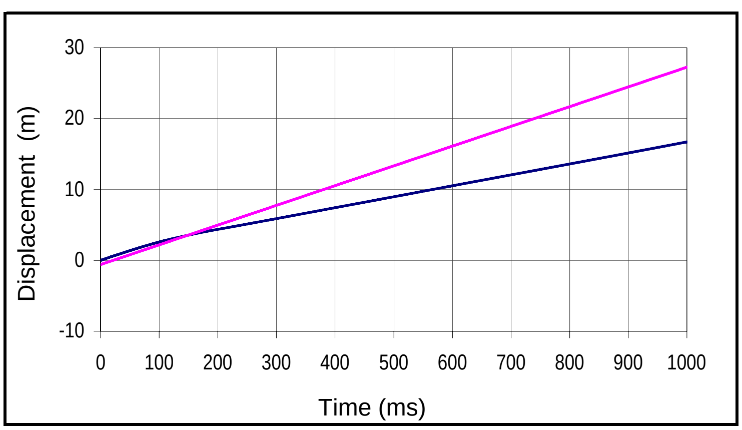
Curve Description			
Test Vehicle CG X			
Plot No.		SAE Class	Units
001		60	g
Max	Time	Min	Time
9.4	196.3	-35.0	101.0



Curve Description			
Test Vehicle CG X Moving Average			
Plot No.		SAE Class	Units
002		180	g
Max	Time	Min	Time
3.2	203.8	-21.3	105.9



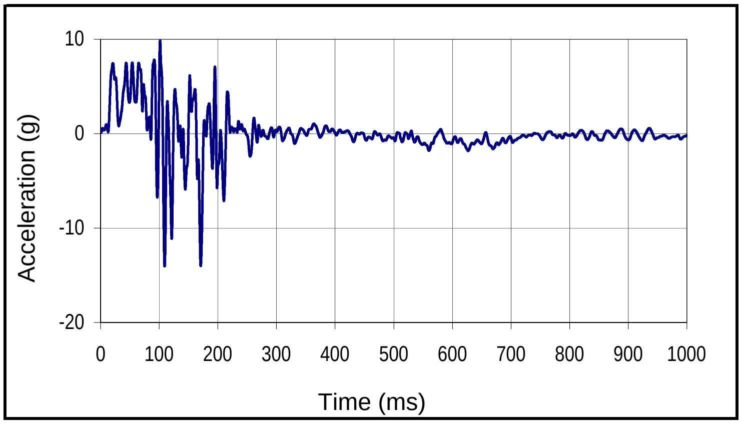
Curve Description			
Test Vehicle CG X Velocity			
Plot No.		SAE Class	Units
003		180	m/s
Max	Time	Min	Time
27.8	4.2	14.5	194.3



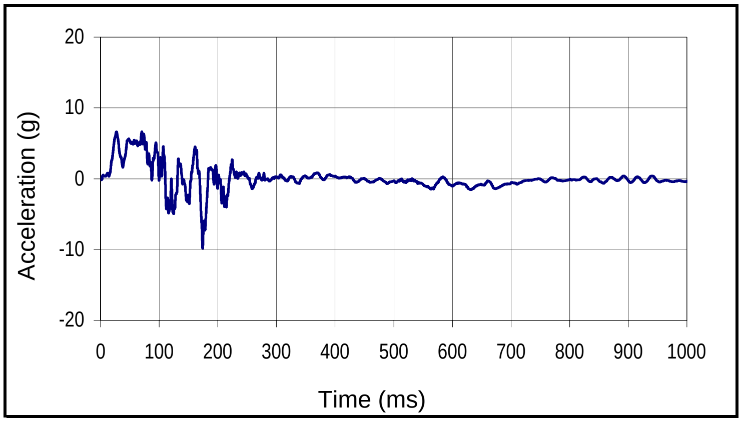
Curve Description			
Test Vehicle CG X Displacement			
Plot No.		SAE Class	Units
004		180	m
Max	Time	Min	Time
16.7	999.9	0.0	0.0

Vehicle CG X Displacement
Occupant X Displacement

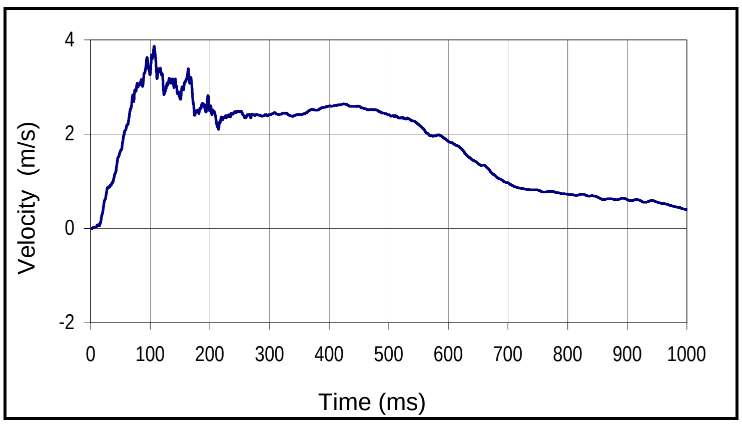
Test Article:	SPIG Industries SGET End Terminal	Project No:	P38033-01
Test Program:	MASH 3-37b	Test Date.:	04/10/18



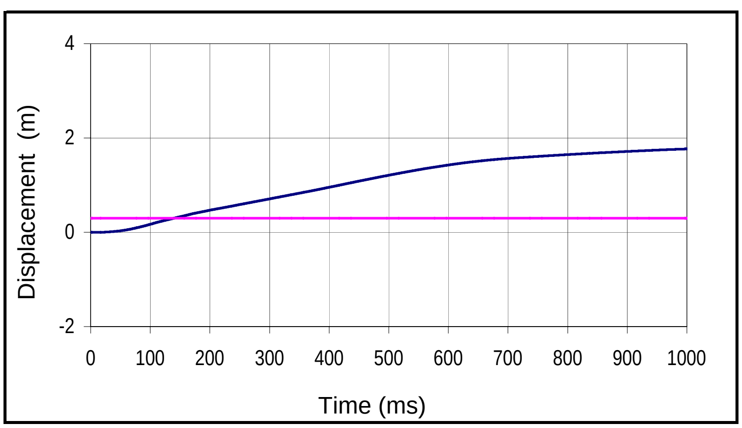
Curve Description			
Test Vehicle CG Y			
Plot No.		SAE Class	Units
005		60	g
Max	Time	Min	Time
9.8	101.5	-14.0	109.3



Curve Description			
Test Vehicle CG Y Moving Average			
Plot No.		SAE Class	Units
006		180	g
Max	Time	Min	Time
6.6	27.0	-9.8	174.1



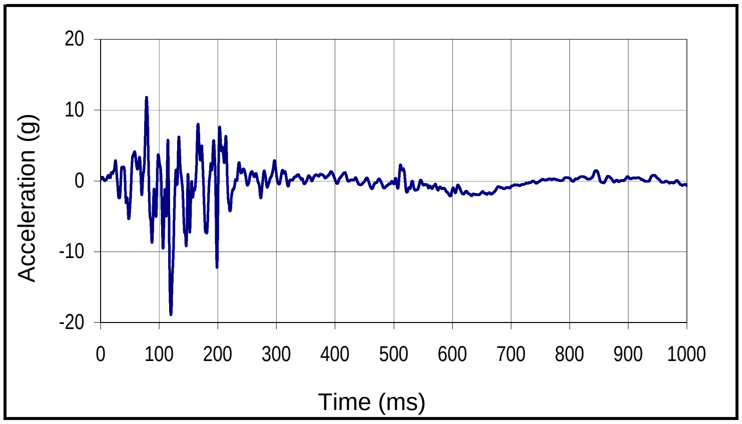
Curve Description			
Test Vehicle CG Y Velocity			
Plot No.		SAE Class	Units
007		180	m/s
Max	Time	Min	Time
3.9	106.7	0.0	1.4



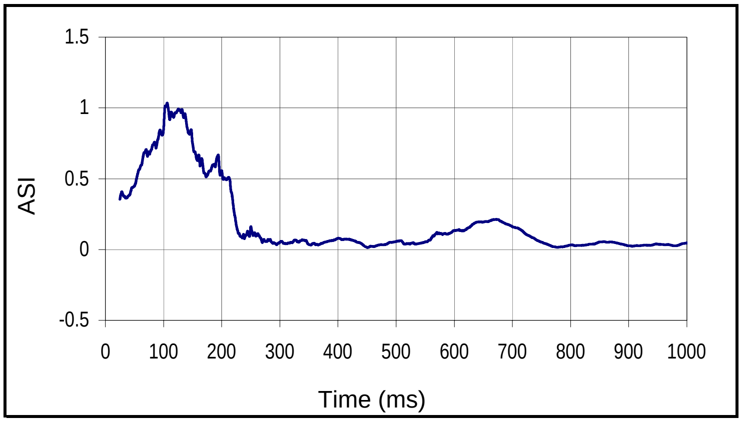
Curve Description			
Test Vehicle CG Y Displacement			
Plot No.		SAE Class	Units
008		180	m
Max	Time	Min	Time
1.8	999.9	0.0	1.5

Vehicle CG Y Displacement
Occupant Y Displacement

Test Article:	SPIG Industries SGET End Terminal	Project No:	P38033-01
Test Program:	MASH 3-37b	Test Date.:	04/10/18

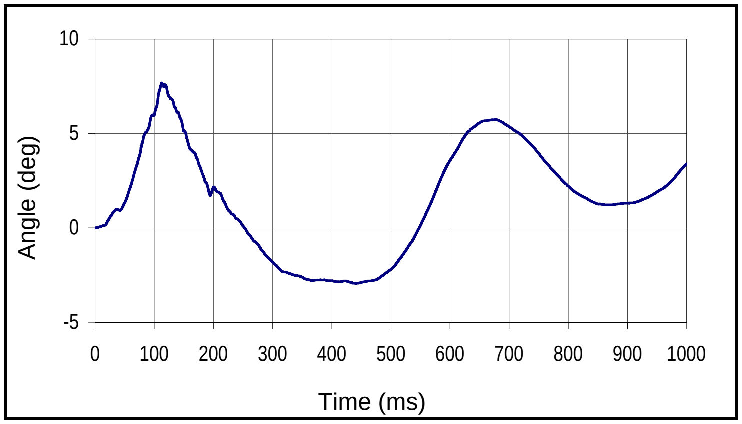


Curve Description			
Test Vehicle CG Z			
Plot No.		SAE Class	Units
009		60	g
Max	Time	Min	Time
11.8	78.4	-18.9	120.0

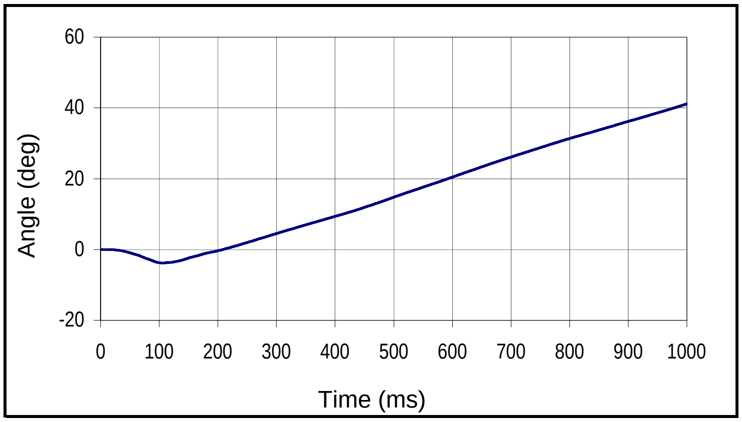


Curve Description			
Test Vehicle Accident Severity Index			
Plot No.		SAE Class	Units
010		180	ASI
Max	Time	Min	Time
1.0	106.3	0.0	450.7

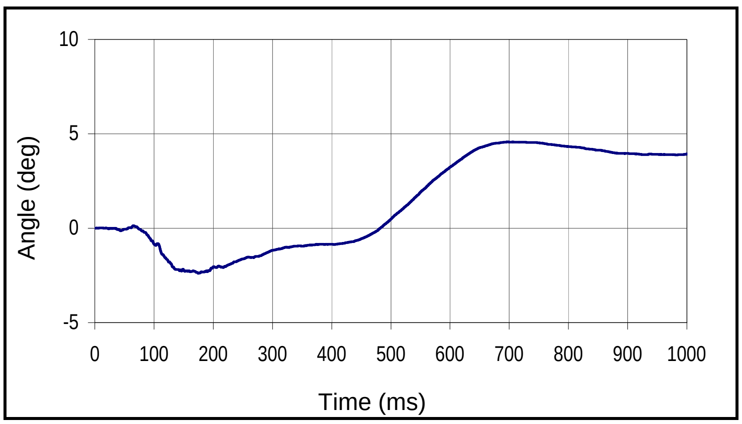
Test Article:	SPIG Industries SGET End Terminal	Project No:	P38033-01
Test Program:	MASH 3-37b	Test Date.:	04/10/18



Curve Description			
Test Vehicle Roll Angle			
Plot No.		SAE Class	Units
011		180	deg
Max	Time	Min	Time
7.7	112.9	-2.9	440.8



Curve Description			
Test Vehicle Yaw Angle			
Plot No.		SAE Class	Units
012		180	deg
Max	Time	Min	Time
41.1	999.9	-3.8	108.7



Curve Description			
Test Vehicle Pitch Angle			
Plot No.		SAE Class	Units
013		180	deg
Max	Time	Min	Time
4.6	697.8	-2.4	174.7

Appendix C

Soil Strength Information

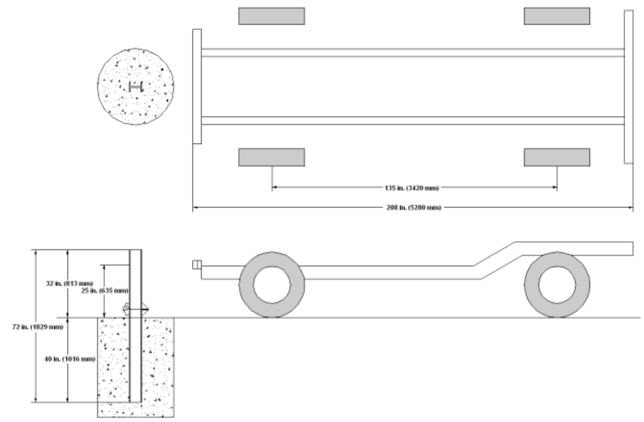
LIST OF FIGURES

DYNAMIC SOIL STRENGTH DATA

Test Article:	SPIG Industries SGET End Terminal	Project No.	P38033-01
Test Program:	MASH 3-37b	Test Date:	04/10/18

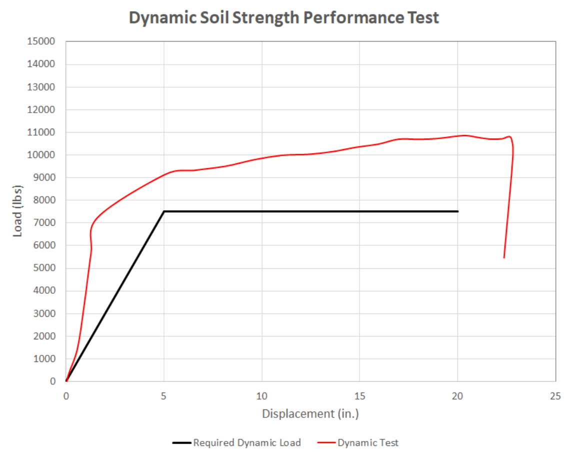
DYNAMIC SOIL STRENGTH TEST DATA

Dynamic Test Setup



Dynamic Test/Installation Details

Post-Test Photo of Post



Comparison of Load vs. Displacement

Certification Date	02/06/17
Test Facility and Site Location	KARCO, Track 4
In Situ Soil Description (ASTM D 2487)	Medium to fine silty sand
Description of Fill Placement Procedure	8.0 in. (203 mm) lifts compacted with pneumatic tamper
Bogie Weight	2,044.8 lbs (927.5 kg)
Impact Velocity	20.74 mph (33.38 km/h)

Figure 1: Dynamic Soil Strength Data

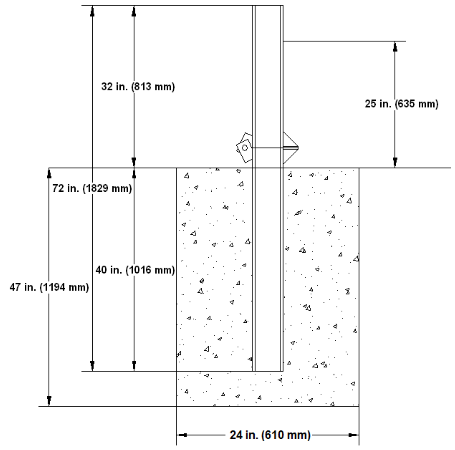
STATIC SOIL STRENGTH DATA

Test Article: SPIG Industries SGET End Terminal   Project No. P38033-01

Test Program: MASH 3-37b   Test Date: 04/10/18

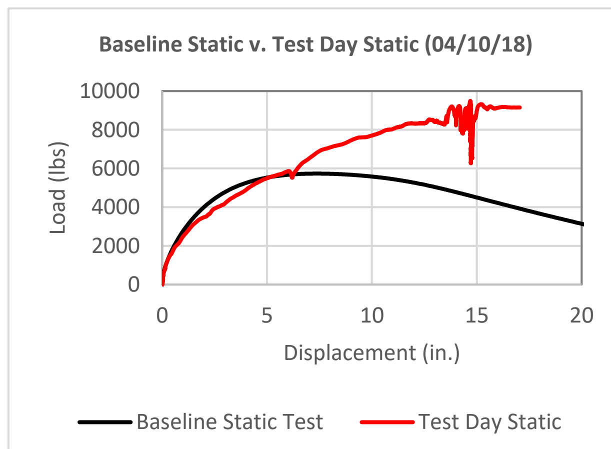
STATIC SOIL VERIFICATION TEST DATA

Static Load Test Setup



Static Test/Installation Details

Post-Test Photo of Post



Comparison of Load vs. Displacement

Date	04/10/18
Test Facility and Site Location	KARCO, Track 4
In Situ Soil Description (ASTM D 2487)	Medium to fine silty sand
Description of Fill Placement Procedure	8.0 in. (203 mm) lifts compacted with pneumatic tamper

Figure 2: Static Soil Strength Data

SOIL SIEVE ANALYSIS

Test Article:	SPIG Industries SGET End Terminal	Project No.	P38033-01
Test Program:	MASH 3-37b	Test Date:	04/10/18

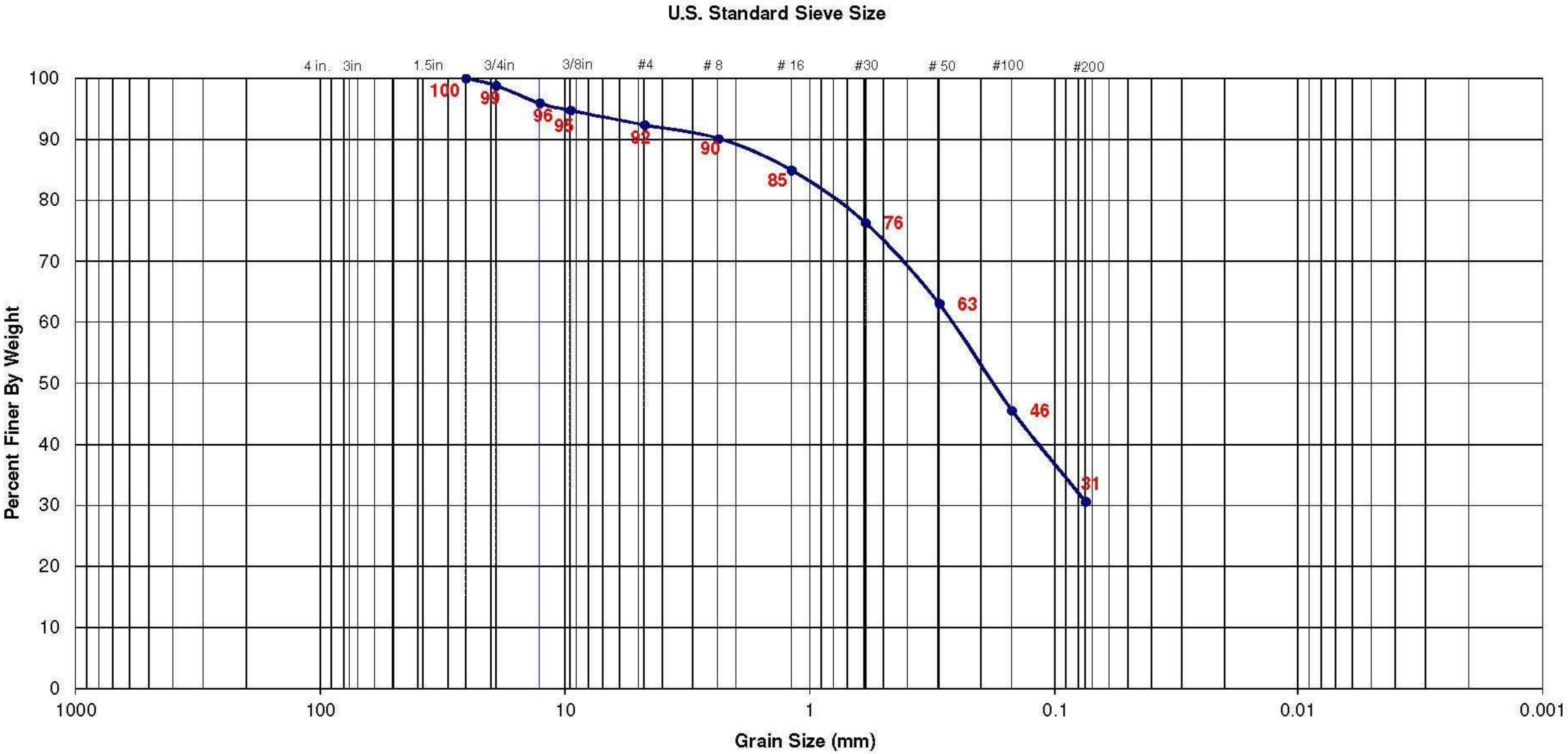
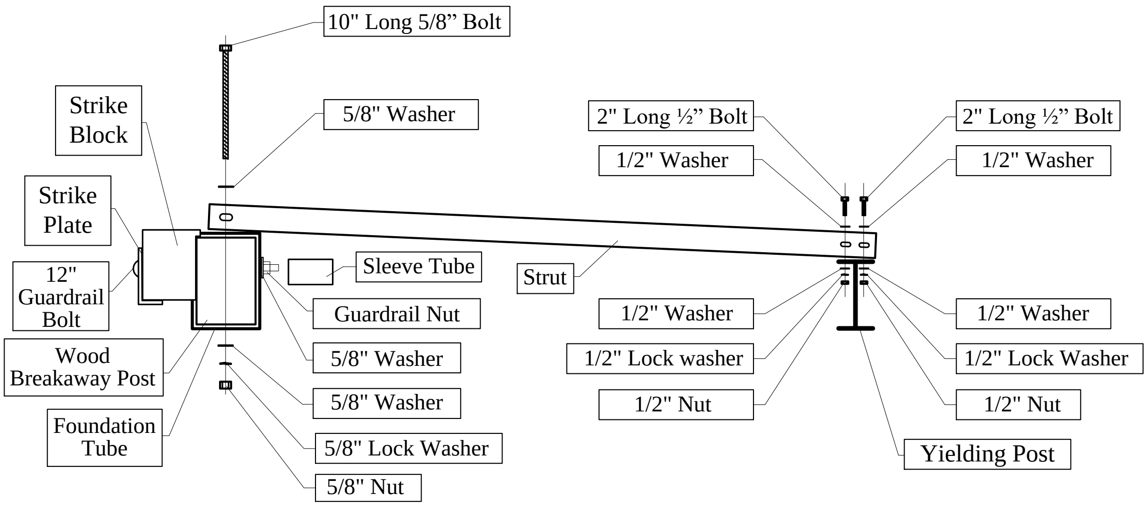


Figure 3: Soil Sieve Analysis

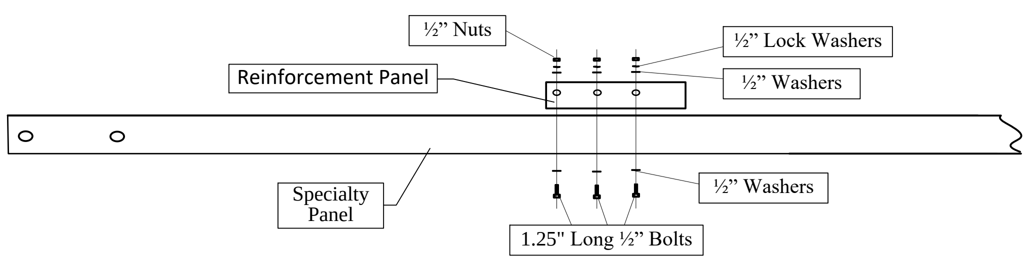
Appendix D

Manufacturer Documents

LIST OF FIGURES

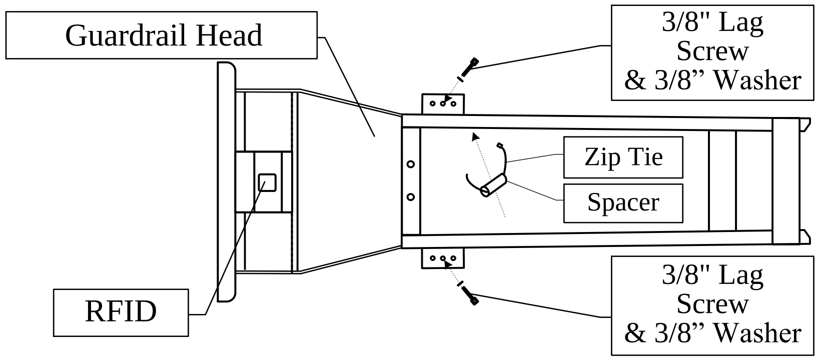


POST PARTS	QTY
12” Guardrail Bolt – 5/8 X 12 307A HDG	1
Strike Plate	1
Strike Block	1
Guardrail Nut – 5/8-11 Nut A563 HDG	1
Wood Breakaway Post – 5-1/2 X 7-1/2 X 50 BCT	1
Foundation Tube – 6” X 8” X 6’ Rectangular Tube	1
10” long 5/8” Bolt – 5/8-11 X 10 A325 HDG	1
5/8” Nut – 5/9-11 A563 Hex Nut Galvanized	1
5/8” Washer – 5/8 F436(A325) HDG Flatwasher	3
5/8” Lock Washer Galvanized	1
2” long 1/2” Bolt – 1/2-13 X 2 A325 HDG	2
1/2” Washer – 1/2 F436(A325) HDG Flatwasher	4
1/2” Nut – 1/2-13 A563 Hex Nut Galvanized	2
1/2” Lock Washer Galvanized	2
Yielding Post – Modified W6 X 8.5 Guardrail Post	7
Strut – 3” X 3” X 80” Angle	1
Sleeve Tube – 2-3/8 OD X 4-1/4	1

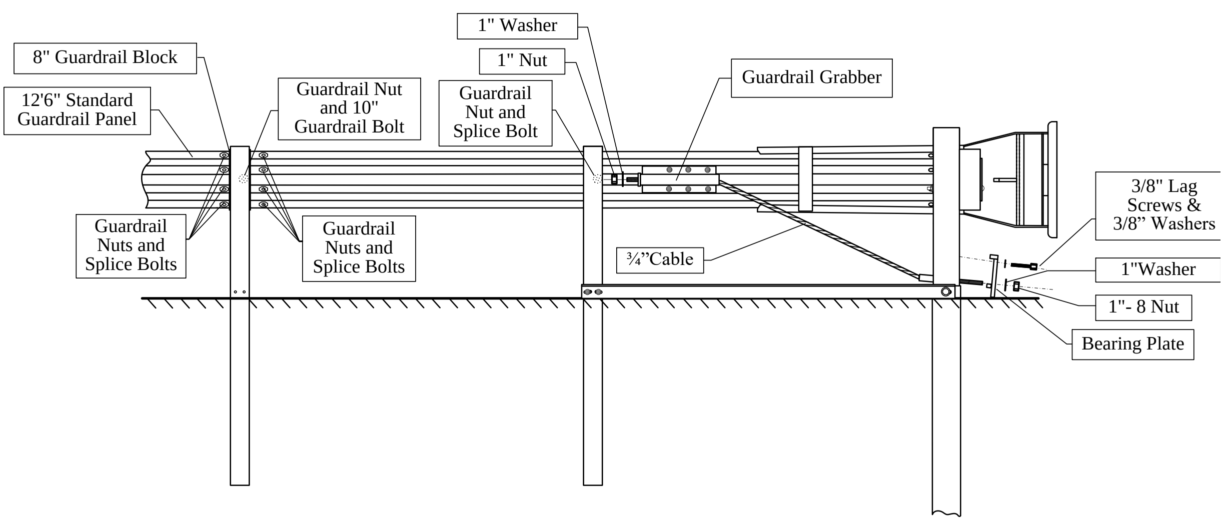


SPECIALTY PANEL PARTS	QTY
Specialty Panel	1
1.25” Long 1/2” Bolt – 1/2-13 X 1-1/4 A325 HDG	6
1/2” Washer – 1/2 F436(A325) HDG Flatwasher	12
1/2” Nut – 1/2-13 A563 Hex Nut Galvanized	6
1/2” Lock Washer Galvanized	6
Reinforcement Plate	1

Figure 1: SGET System Parts



GUARDRAIL HEAD PARTS	QTY
Guardrail Head	1
3/8" Lag Screw – 3/8 X 3 GR5 HDG Hex Lag Screw	2
3/8" Washer Galvanized F844	2
Spacer – 4" Long X 1-1/2 SCH-40 PVC PIPE	1
Zip Tie – 18"-24" Long Rated at 175-200 lbs.	1
RFID chip rated MIL-STD-810F (e.g. Omni-ID EX0750)	1



RAIL AND CABLE PARTS	QTY
¾" Cable – 81" Long BCT Cable	1
1" Nut – 1- 8 Hex Nut UNC Galvanized A563DH	2
1" Washer Galvanized F436	2
Guardrail Splice Bolt – 5/8 X 1-1/4 307A HDG	25
10" Guardrail Bolt – 5/8 X 10 307A HDG	6
Guardrail Nut– 5/8-11 Nut A563 HDG	31
8" Guardrail Block	6
12' 6" Standard Guardrail Panel – W-Beam M-180	3
Bearing Plate	1
3/8" Lag Screw – 3/8 X 3 GR5 HDG Hex Lag Screw	2
3/8" Washer Galvanized F844	2
Guardrail Grabber	1

Figure 2: SGET System Parts

Appendix E

Sequential Photographs

		
0.000 s	0.100 s	0.180 s
		
0.340 s	0.750 s	1.300 s

		
0.000 s	0.100 s	0.180s
		
0.350 s	0.600 s	0.950 s

Appendix F

References

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FINAL PAGE OF REPORT