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GROUND RETRACTABLE AUTOMOBILE BARRIER
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The Ground Retractable Automobile Barrier (GRAB-400) system is an active vehicle barrier that has met the demanding ASTM M40 test criteria established by the Department of Defense. The system provides ultimate security in protecting facilities from outside threats. In numerous real world impacts, the GRAB system has effectively stopped vehicles weighing up to 15,000 pounds traveling at speeds reaching 40 mph. The GRAB system has been the barrier of choice for government agencies, military, petrochemical industry, and a wide variety of corporate companies and civil clients.

SPECIFICATION

- ASTM M40 crash certified
- 12’ to 60’ tested - received P2 rating
- 12’ tested - received P1 rating
- Unlike other barrier choices, the GRAB- 400 provides a cost-effective means of securing a single 12’ road way
- 18” shallow mount foundation
- Ability to reset and be back in operation within minutes of impact
- Short stopping distance
- Flexible design suitable for access
- All electric operation
- Reusable system: interchangeable parts for quick and easy replacement
- No hazardous materials
- Traffic control devices integrated
- into barrier design
- Low maintenance requirements
- All weather operation
- Custom covers available to match facility design standards
- Cost efficient: replaces multiple barriers with one GRAB system

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Texas Transportation Institute
Proving Ground

Report No.: 400001-USR21
Report Date: January 2011

ASTM F2656-07 TEST M40 OF THE 12 FT GRAB-400

by

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Contract No. P2011039
Test No. 400001-USR21
Test Date: November 11, 2010

Sponsored by
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Technical Report Documentation Page

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16. Abstract

The objective of this test is to determine if the 12 ft GRAB-400 is capable of arresting a 15,000 lb truck traveling at 40 mi/h according to Condition Designation M40 of *ASTM F2656-07*. This condition designation requires the 12 ft GRAB-400 to withstand kinetic energy of 802 ft-kip.

This report presents the construction details of the 12 ft GRAB-400, details of the impact vehicle used in the test, details of the test performed, and the assessment of the test results.

ASTM F2656-07 provides a range of vehicle test designations and penetration levels that allow agencies to select perimeter security devices that satisfy their specific facility needs. The amount of vehicle penetration of the security device at the required impact velocity determines the dynamic penetration rating for each condition designation. The leading edge of the cargo bed penetrated 1.1 ft beyond the inside edge of the 12 ft GRAB-400. According to *ASTM F2656-07*, the 12 ft GRAB-400 meets Condition Designation/Penetration Rating M40/P1, which allows penetration of ≤3.3 ft when impacted by the medium duty truck at 40 mi/h.

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SI* (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
		AREA		
in^2	square inches	645.2	square millimeters	mm^2
ft^2	square feet	0.093	square meters	m^2
yd^2	square yard	0.836	square meters	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	square kilometers	km^2
		VOLUME		
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.028	cubic meters	m^3
yd^3	cubic yards	0.765	cubic meters	m^3
		NOTE: volumes greater than 1000 L shall be shown in m^3		
		MASS		
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams (or "metric ton")	Mg (or "t")
		TEMPERATURE (exact degrees)		
°F	Fahrenheit	5 (F-32)/9 or (F-32)/1.8	Celsius	°C
		ILLUMINATION		
fc	foot-candles	10.76	lux	lx
fl	foot-Lamberts	3.426	candela/m^2	cd/m^2
		FORCE and PRESSURE or STRESS		
lbf	poundforce	4.45	newtons	N
lbf/in^2	poundforce per square inch	6.89	kilopascals	kPa

APPROXIMATE CONVERSIONS FROM SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
		AREA		
mm^2	square millimeters	0.0016	square inches	in^2
m^2	square meters	10.764	square feet	ft^2
m^2	square meters	1.195	square yards	yd^2
ha	hectares	2.47	acres	ac
km^2	square kilometers	0.386	square miles	mi^2
		VOLUME		
mL	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m^3	cubic meters	35.314	cubic feet	ft^3
m^3	cubic meters	1.307	cubic yards	yd^3
		MASS		
g	grams	0.035	ounces	oz
kg	kilograms	2.202	pounds	lb
Mg (or "t")	megagrams (or "metric ton")	1.103	short tons (2000 lb)	T
		TEMPERATURE (exact degrees)		
°C	Celsius	1.8C+32	Fahrenheit	°F
		ILLUMINATION		
lx	lux	0.0929	foot-candles	fc
cd/m^2	candela/m^2	0.2919	foot-Lamberts	fl
		FORCE and PRESSURE or STRESS		
N	newtons	0.225	poundforce	lbf
kPa	kilopascals	0.145	poundforce per square inch	lbf/in^2

*SI is the symbol for the International System of Units. Appropriate rounding should be made to comply with Section 4 of ASTM E380. (Revised March 2003)

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INTRODUCTION

PROBLEM

In an effort to assess the performance of anti-terrorist protection barriers, the United States Department of State, Bureau of Diplomatic Security, Physical Security Division, Office of Physical Security Programs (PSP) developed guidelines to evaluate the performance of perimeter security devices. According to this standard, performance of an anti-terrorist protection security device (barrier/gate) is evaluated and assessed according to its effectiveness in arresting attacking vehicles, and not necessarily for economics, aesthetics, operational cycle time, special maintenance needs, or climate and environment effects. The 12 ft GRAB-400 barrier system evaluated herein was designed by Universal Safety Response. The intended function of this design is to provide perimeter security capable of arresting an attacking vehicle.

BACKGROUND

In August 2007, the American Standards for Testing Materials (ASTM) International developed and published *ASTM Designation: F2656-07, Standard Test Method for Vehicle Crash Testing of Perimeter Barriers*. The procedures set out in *ATSM F2656-07* are intended to ensure that perimeter security devices provide a specified level of vehicle impact resistance as recommended by the U. S. Department of State, Bureau of Diplomatic Security, Physical Security Division, Office of Physical Security Programs. The *ATSM F2656-07* test method provides a range of vehicle impact conditions, test designations, and penetration levels that allow agencies to select perimeter security devices that satisfy their specific facility needs. This new test method was formally adopted by U. S. Department of State, Bureau of Diplomatic Security, Physical Security Division, Office of Physical Security Programs, in February 2009 as the official standard for testing of perimeter security devices.

The test reported herein was performed and evaluated in accordance with *ATSM F2656-07, Standard Test Method for Vehicle Crash Testing of Perimeter Barriers*.

OBJECTIVES/SCOPE OF RESEARCH

The objective of this test is to determine if the 12 ft GRAB-400 is capable of arresting a 15,000 lb truck traveling at 40 mi/h according to Condition Designation M40 of *ASTM F2656-07*. This condition designation requires the 12 ft GRAB-400 to withstand kinetic energy of 802 ft-kip.

This report presents the construction details of the 12 ft GRAB-400, details of the impact vehicle used in the test, details of the test performed, and the assessment of the test results.

TECHNICAL DISCUSSION

TEST PARAMETERS

Test Facility

The full-scale crash test reported herein was performed at Texas Transportation Institute (TTI) Proving Ground. TTI Proving Ground is an International Standards Organization (ISO) 17025 accredited laboratory with American Association for Laboratory Accreditation (A2LA) Mechanical Testing certificate 2821.01. The full-scale crash test was performed according to TTI Proving Ground quality procedures developed for ISO 17025 accreditation and according to the *ASTM F2656* guidelines and standards.

The test facilities at the TTI's Proving Ground consist of a 2000-acre complex of research and training facilities situated 10 miles northwest of the main campus of Texas A&M University. The site, formerly an Air Force base, has large expanses of concrete runways and parking aprons well suited for experimental research and testing in the areas of vehicle performance and handling, vehicle-roadway interaction, durability and efficacy of highway pavements, and evaluation of roadside safety hardware and perimeter security device. The site selected for placing of the 12 ft GRAB-400 was along the edge of a wide out-of-service apron. The apron consists of an unreinforced jointed concrete pavement in 12.5 ft × 15 ft blocks nominally 8-12 inches deep. The apron is over 50 years old and the joints have some displacement, but are otherwise flat and level.

Test Article – Design and Construction

Universal Safety Response, Inc. (USR) GRAB-400 12 ft active vehicle barrier is a deployable gate/net system. The vehicle barrier tested herein consists of a net, anchor stanchions and proprietary lift arm mechanism. The width of the net for this test was 12 ft. The net was anchored on each end by a separate anchor stanchion and foundation. The net has upper and lower horizontal 1-½-inch diameter wire ropes with closed swage end connections. Vertical ¾-inch diameter wire ropes are attached to the main horizontal wire ropes and the middle horizontal ¾-inch diameter wire rope.

The net is deployed by an electric motor attached to a secondary post system located on each end of the net. The posts in the lifting arm assembly were HSS10×6×⅜. The net is attached to these secondary posts by a 5/16-inch shear pin and turnbuckle assembly that allow for tensioning of the net between deployment posts. Details of the net system are shown in figure 1.

Swage fittings connect the net to the stanchion anchors at each end. A 2¼-inch × 11-inch pin connecting the swage fittings to the stanchion anchors. The pin is fabricated from ASTM 416 stainless steel material. A ¼-inch thick plastic washer was used between the swage fitting and the stanchion anchors. A ¾-inch thick plastic washer was used to separate the two swage fittings. Details of the pipe sleeves are provided in figure 1.

A steel anchor stanchion assembly was used to anchor the stanchion sleeves to a concrete foundation. For this test, the distance between the stanchion centerlines was approximately 18 ft 6 inches. The steel anchor stanchion assembly consisted of a W8×67 structural steel section welded to a TS20×8×½ structural steel tube. The W-section was manufactured from ASTM A992 steel material. The structural tube was manufactured from ASTM A500 Grade B material. The TS20×8×½ steel tube was 90 inches long. Four square holes were machined into the steel tube; the tube was filled with concrete while pouring the foundation. The W-section was 25 inches long and welded perpendicular to the tube section such that 14½ inches were above the top of the tube section. The top 8.3 inches of the W-section's web was removed to receive a stanchion pin. A ½-inch plate was welded across the top of the w-section. The flanges of the W-section were reinforced by welding a 6¾-inch diameter by ¾-inch thick steel plate. A 2.3-inch diameter hole was drilled through the W-section and reinforcing plates to receive the stanchion pin. All steel plates were manufactured from ASTM A36 material. Details of the steel anchor stanchion assembly are provided in figure 1.

Each anchor stanchion assembly was anchored to an irregularly shaped concrete foundation, as shown in figure 1. The concrete foundation was 18 inches deep. Reinforcement in the foundation consisted of #5 reinforcing steel at 1 ft typical spacing in two mats of reinforcing steel (top and bottom) with the exception of the longitudinal reinforcing immediately beneath the steel anchor stanchion. Addition assemblies of prebent #5 reinforcing bars, 6 inches on center, were used around the steel anchor stanchions. These bars helped to anchor the steel anchor stanchion in the concrete foundation. All reinforcing steel was ASTM A615 Grade 60 material. Considering the deployed state of the net from the impact of the vehicle, the foundations and steel anchor stanchion assemblies were oriented 15 degrees from the direction of travel of the vehicle. The compressive strength of the foundation concrete was specified to be 4000psi, and on the day the test was performed it was 4587 psi.

An 18-inch concrete apron was constructed between the anchor stanchion's concrete foundations. The concrete apron was approximately 27 ft 6 inches long by 6 ft 9¾ inches wide and provides a 12-ft barrier lane width between the net lift arms for vehicular travel. In addition, the concrete apron was used as a foundation for the lift arm assemblies. Embedded in the apron is a 24-inch wide net pad that protects the net from vehicle travel when in the non active position. The concrete apron was poured integrally with the anchor stanchion foundations. Reinforcing steel was used to connect the two foundation systems. Reinforcement in the apron consisted of #5 reinforcing steel spaced at 12 inches on center, each way. One single mat of reinforcing steel was used to construct the apron. All reinforcing steel was ASTM A615 Grade 60 material. The compressive strength of the apron concrete was specified to be 4000 psi, and on the day the test was performed it was 4587 psi. Details of the system are provided in figure 1, and photographs of the completed installation are shown in figure 2.

The information pertaining to and used to develop this test article description were provided by USR. The test article was constructed and installed on site by a USR-approved contractor.

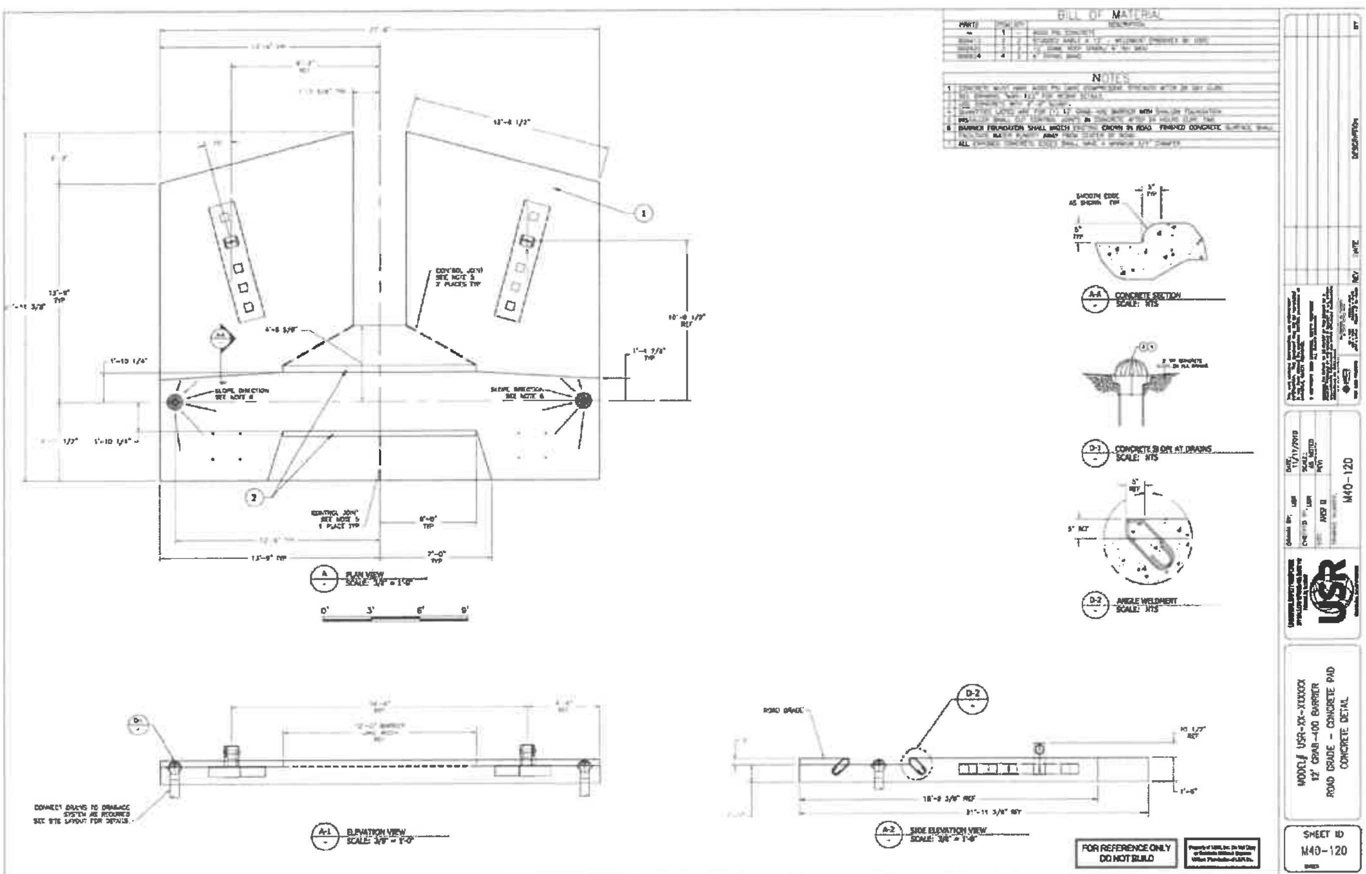


Figure 1. Details of the 12 ft GRAB-400.

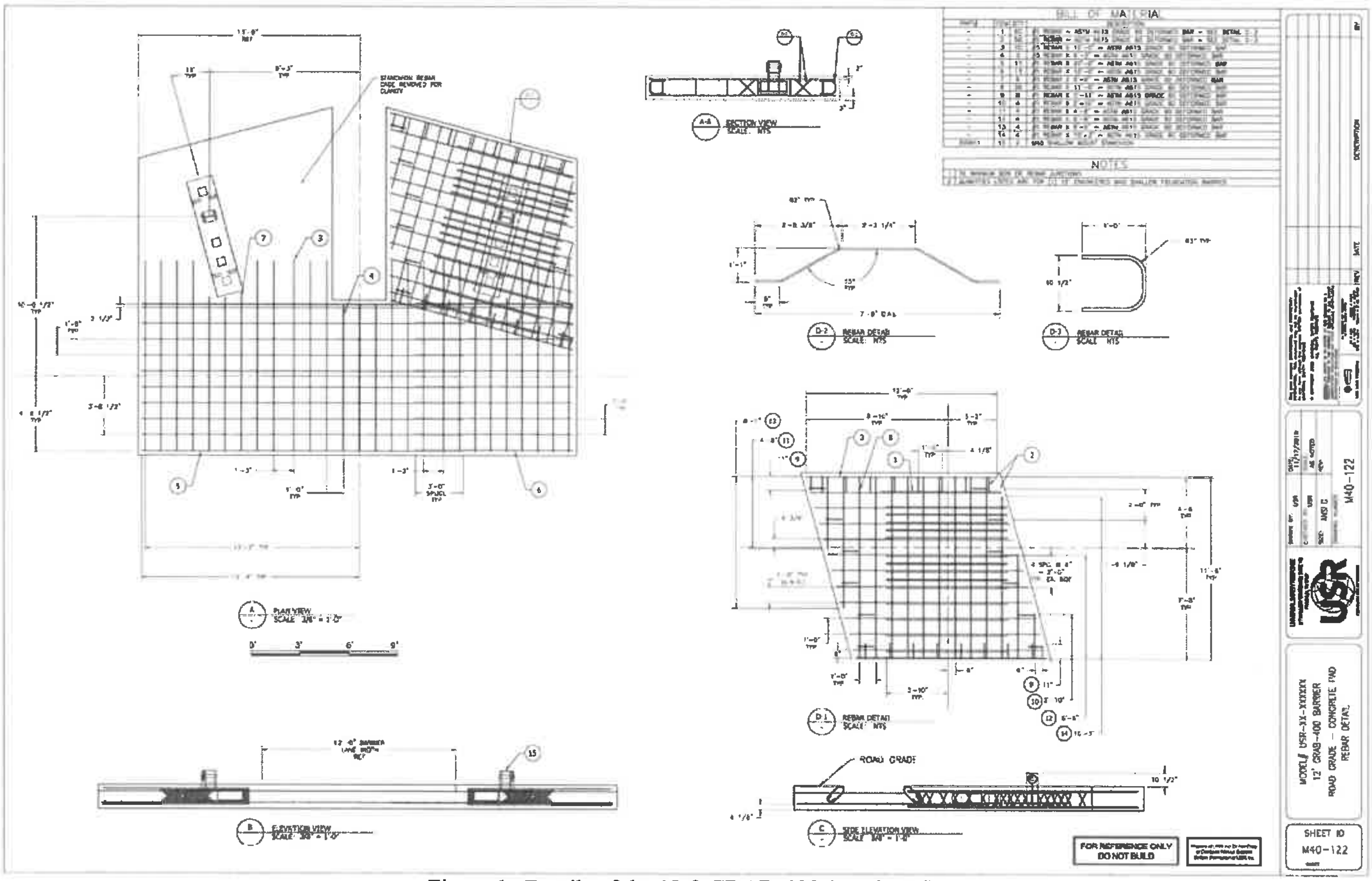


Figure 1. Details of the 12 ft GRAB-400 (continued).

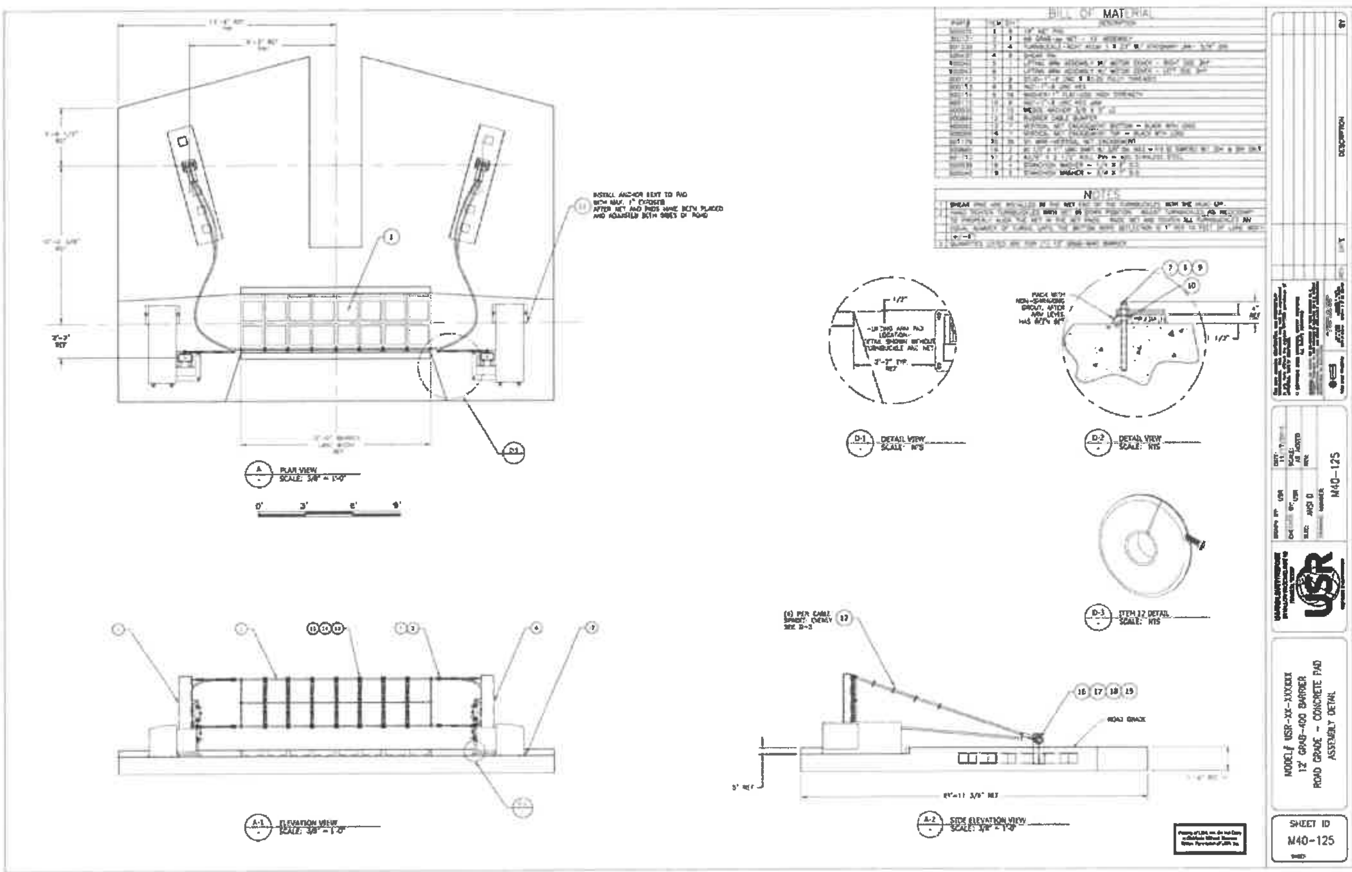


Figure 1. Details of the 12 ft GRAB-400 (continued).

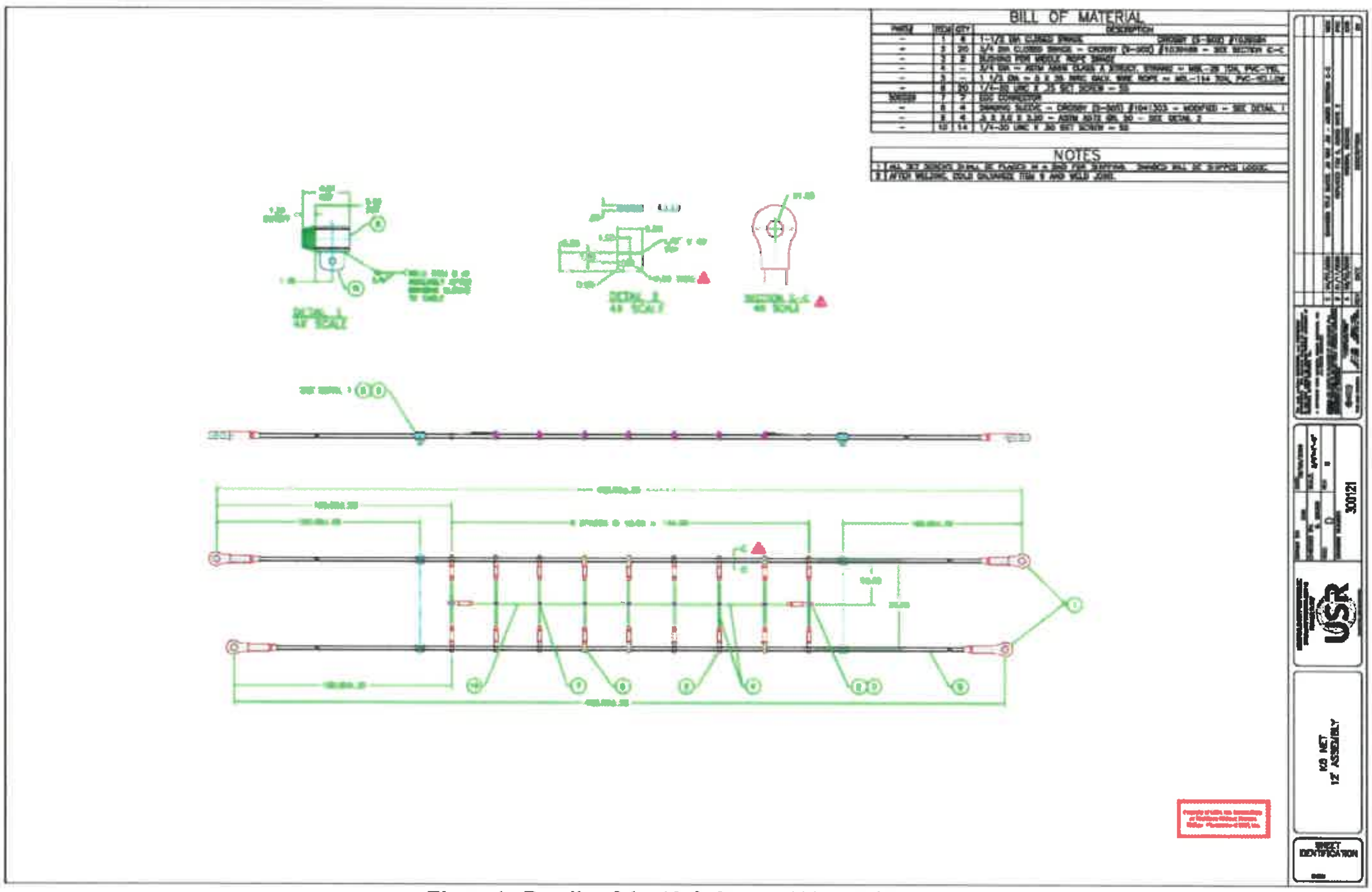


Figure 1. Details of the 12 ft GRAB-400 (continued).

Figure 2. 12 ft GRAB-400 prior to testing.

Test Conditions and Evaluation Criteria

The test reported herein was performed in accordance with *ASTM F2656-07*. Appendix A presents a brief description of the procedures followed for this test.

According to *ASTM F2656-07,* the 12 ft GRAB-400 can be rated according to one of three designated condition levels as shown in Table 1. The levels of kinetic energy that a security device shall withstand at each condition level are also shown in Table 1. The test conditions are intended to ensure that perimeter barriers and gates will provide a specified level of vehicle impact resistance. Actual vehicle weight and speed must be within a permissible range to receive the specific condition designation. The condition designations, which are defined by test vehicle type and impact speed, are shown in the last column of table 1 as taken from *ASTM F2656-07.*

Table 1. Impact Condition Designations according to *ASTM F2656-07.*

Test Vehicle/Minimum Test Inertial Mass, kg(lbm)	Nominal Minimum Test Velocity km/h(mph)	Permissible Speed Range, km/h (mph)	Kinetic Energy, KJ (ft-kips)	Condition Designation
Small passenger car (C) 1100 (2430)	65 (40) 80 (50) 100 (60)	60.1-75.0 (38.0-46.9) 75.1-90.0 (47.0-56.9) 90.1-above (57.0-above)	179 (131) 271 (205) 424 (295)	C40 C50 C60
Pickup truck (P) 2300 (5070)	65 (40) 80 (50) 100 (60)	60.1-75.0 (38.0-46.9) 75.1-90.0 (47.0-56.9) 90.1-above (57.0-above)	375 (273) 568 (426) 887 (613)	PU40 PU50 PU60
Medium-duty truck (M) 6800(15000)	50 (30) 65 (40) 80 (50)	45.0-60.0 (28.0-37.9) 60.1-75.0 (38.0-46.9) 75.1-above (47.0-above)	656 (451) 1110 (802) 1680 (1250)	M30 M40 M50
Heavy goods vehicle (H) 29500(65000)	50 (30) 65 (40) 80 (50)	45.0-60.0 (28.0-37.9) 60.1-75.0 (38.0-46.9) 75.1-above (47.0-above)	2850 (1950) 4810 (3470) 7280 (5430)	H30 H40 H50

The test vehicle specified was a medium duty truck with diesel engine, tested at a vehicle gross weight of 15,000 lb ±200 lb. According to Condition Designation M40 of *ASTM F2656-07*, which involves the medium duty truck impacting at 40 mi/h, the 12 ft GRAB-400 is required to withstand kinetic energy of 802 ft-kip.

The amount of vehicle penetration of the security device at the required impact velocity determines the dynamic penetration rating for each condition designation. Test vehicle dynamic penetration is referenced to each vehicle as follows: The base of the "A" pillar for the small passenger car (C); the front leading lower edge of the pickup truck bed (P); the leading lower edge of the cargo bed on the medium duty truck (M); and the leading lower vertical edge of the cargo bed on the heavy goods vehicle (H). Penetration ratings according to *ASTM F2656-07* are shown in table 2.

Table 2. Penetration Ratings according to *ASTM F2656-07*.

Penetration Designation	***Dynamic Penetration Rating***
P1	*≤ 1 m (3.3 ft)*
P2	*1.01 m to 7 m (3.31 to 23.0 ft)*
P3	*7.01 m to 30 m (23.1 to 98.4 ft)*
P4	*30 m (98 ft) or greater*

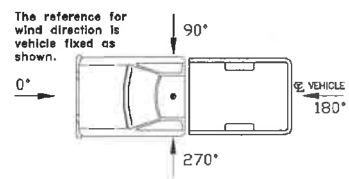
CRASH TEST 400001-USR21 (*ASTM F2656-07* M40)

Test Vehicle

The 2000 International 4700 single-unit, flatbed truck, shown in figures 3 and 4, was used for the crash test. Test inertia weight of the vehicle was 15,050 lb. The height to the lower edge of the vehicle front bumper was 20.0 inches, and the height to the upper edge of the front bumper was 31.0 inches. Figure 10 in appendix B gives additional dimensions and information on the vehicle. The vehicle was directed into the installation using the cable reverse tow and guidance system, and was released to be free-wheeling and unrestrained just prior to impact.

Soil and Weather Conditions

The crash test was performed the morning of November 11, 2010. A total of 0.32 inch of rainfall was recorded nine days prior to the test. Moisture content of the crushed limestone base material in which the test article was installed was 6.1 percent. Weather conditions at the time of testing were: Wind Speed: 10 mi/h; Wind Direction: 161 degrees with respect to the vehicle (vehicle was traveling in a northerly direction); Temperature: 73°F); Relative Humidity: 82 percent.



Impact Description

The 2000 International 4700 single-unit, flatbed truck, traveling at an impact speed of 39.3 mi/h, impacted the 12 ft GRAB-400 at an impact angle of 89.6 degrees. The centerline of the vehicle was aligned with the centerline of the 12 ft GRAB-400. At 0.020 s, the net detached from the left upper arm of the GRAB-400 system, and at 0.022 s, the net detached from the right upper arm of the GRAB-400 system. The net detached from the right lower arm of the GRAB-400 system at 0.029 s, and the net began to wrap around the right front tire at 0.047 s. At 0.058 s, the right front tire steered inward, and at 0.063 s, the net detached from the left lower arm. The net began to wrap around the left front tire at 0.076 s, and the right front tire was pulled off the ground surface at 0.089 s. At 0.090 s, the net was pulled downward off the hood and the hood detached from the vehicle, and at 0.116 s, the right front wheel touched the ground surface again. The left front tire aired out at 0.120 s, and the rear wheels became airborne at 0.121 s. At 0.133 s, the net was at maximum deflection of 4.9 ft. Maximum penetration of the front of the cargo bed was 1.1 ft beyond the "inside" edge of the net. Forward motion of the test vehicle stopped at 0.620 s. At 0.932 s, the rear tires touched ground and the vehicle came to rest with the front of the cargo bed 1.0 ft beyond the "inside" edge of the net. Appendix C, figures 11 and 12, show sequential photographs of the test period.

Figure 3. Vehicle/installation geometrics for test 400001-USR21.

Figure 4. Vehicle before test 400001-USR21.

Damage to Test Article

Damage to the 12 ft GRAB-400 is shown in figure 5 and 6. The top cable on the left side failed at 96 inches from the connector, and the right side failed at 64 inches from the connector. Isolated strands of the center cable sheared, and the fourth vertical cable from the right side pulled out of the bottom swage.

Vehicle Damage

Damage to the 2000 International 4700 single-unit, flatbed truck is shown in figure 7. The right and left front frame rails, front U-bolts and springs and left rear U-bolts and springs were damaged. The front bumper, hood, radiator, radiator support, fan, water pump, right and left front tires and wheel rims, right and left fuel tanks and windshield were also damaged. Estimated maximum crush to the exterior of the vehicle was 14 inches. Photographs of the interior of the vehicle are shown in figure 8.

Occupant Risk Factors

Data from the accelerometer, located at the vehicle center of gravity, were digitized for evaluation of occupant risk for informational purposes only. In the longitudinal direction, the occupant impact velocity was 44.9 ft/s at 0.146 s, the highest 0.010-s occupant ridedown acceleration was 15.2 Gs from 0.174 to 0.184 s, and the maximum 0.050-s average acceleration was -24.8 Gs between 0.080 and 0.130 s. In the lateral direction, the occupant impact velocity was 1.3 ft/s at 0.146 s, the highest 0.010-s occupant ridedown acceleration was 3.8 Gs from 0.147 to 0.157 s, and the maximum 0.050-s average was 1.5 Gs between 0.930 and 0.980 s. These data and other pertinent information from the test are summarized in figure 9. Vehicle accelerations versus time traces are presented in appendix D, figures 13 through 17.

Figure 5. Vehicle position after test 400001-USR21.

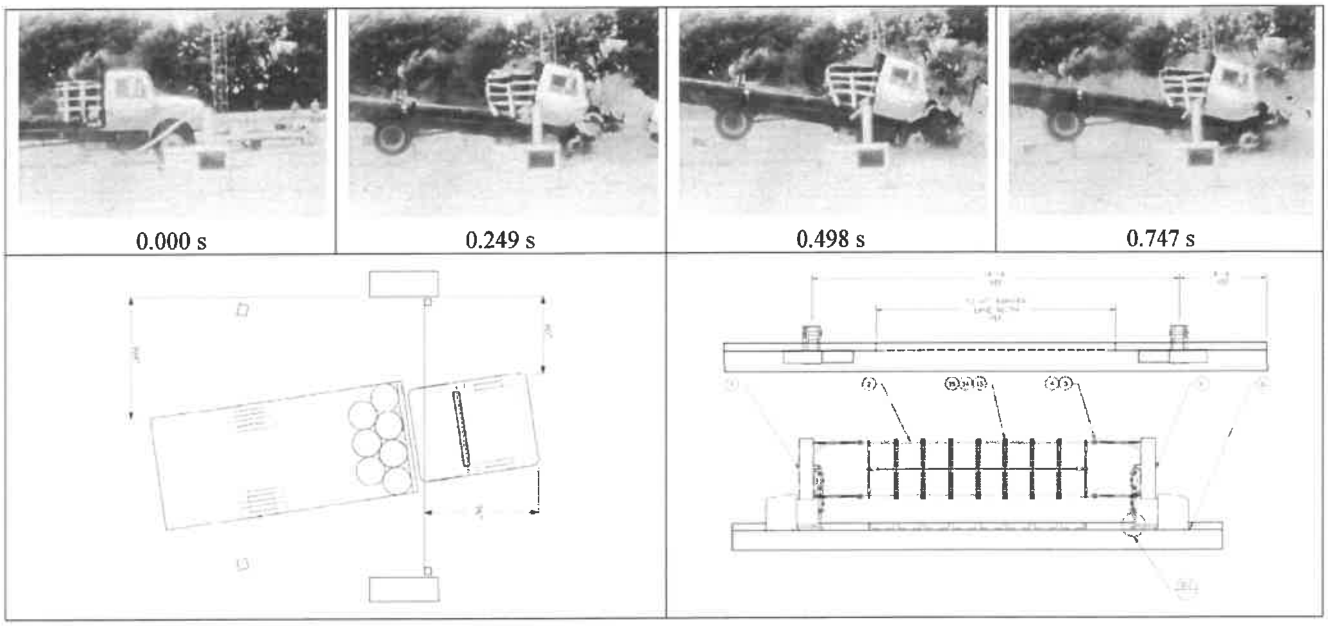
Figure 6. Installation after test 400001-USR21.

Figure 7. Vehicle after test 400001-USR21.

Before Test

After Test

Figure 8. Interior of vehicle for test 400001-USR21.



General Information

Test Agency	Texas Transportation Institute (TTI)
Test Standard Test No.	ASTM F2656-07 M40
Test No.	400001-USR21
Date	2010-11-11

Test Article

Type	Security Barrier
Name	12 ft GRAB-400
Installation Length	27.5 ft
Material or Key Elements	Net, anchor stanchions and proprietary lift arm mechanism

Soil/Foundation Type	Concrete Foundation in Crushed Limestone, Dry 6.1%

Test Vehicle

Type	Medium Duty Truck
Designation	M40
Model	2000 International 4700
Mass	
Curb	14,010 lb
Test Inertial	15,050 lb

Impact Conditions

Speed	39.3 mi/h
Angle	89.6 degrees

Exit Conditions

Speed	Stopped
Angle	85 degrees

Occupant Risk Values

Impact Velocity	
Longitudinal	44.9 ft/s
Lateral	1.3 ft/s
Ridedown Accelerations	
Longitudinal	15.2 Gs
Lateral	3.8 Gs
Max. 0.050-s Average	
Longitudinal	-24.8 Gs
Lateral	1.5Gs
Vertical	-4.8 Gs

Penetration of Cargo Bed

Distance Beyond Inside Edge of Security Device	1.1 ft

Figure 9. Summary of results for *ASTM F2656-07* test M40 on 12 ft GRAB-400.

SUMMARY AND CONCLUSIONS

ASSESSMENT OF TEST RESULTS

The 2000 International 4700 single-unit, flatbed truck impacted the 12 ft GRAB-400 at 89.6 degrees, with the centerline of the vehicle aligned with the centerline of the 12 ft GRAB-400. The acceptable range for impact speed for this M40 test was 38.0-46.9 mi/h, and the actual impact speed was 39.3 mi/h. The 12 ft GRAB-400 brought the vehicle to a complete stop. The cargo remained onboard the vehicle; however, the hood of the vehicle was thrown beyond the inside edge of the 12 ft GRAB-400. The leading edge of the cargo bed penetrated 1.1 ft beyond the "inside" edge of the security device.

CONCLUSIONS

ASTM F2656-07 provides a range of vehicle test designations and penetration levels that allow agencies to select perimeter security devices that satisfy their specific facility needs. The amount of vehicle penetration of the security device at the required impact velocity determines the dynamic penetration rating for each condition designation. The leading edge of the cargo bed penetrated 1.1 ft beyond the inside edge of the 12 ft GRAB-400. According to *ASTM F2656-07*, the 12 ft GRAB-400 meets Condition Designation/Penetration Rating M40/P1, which allows penetration of ≤3.3 ft when impacted by the medium duty truck at 40 mi/h.

REFERENCES

1. "Standard Test Method for Vehicle Crash Testing of Perimeter Barriers," *ASTM Designation: F2656-07*, American Standards for Testing Materials International, West Conshohocken, PA, August 2007.

APPENDIX A. CRASH TEST PROCEDURES AND DATA ANALYSIS

The crash test and data analysis procedures were in accordance with guidelines presented in *ASTM F2656-07*. Brief descriptions of these procedures are presented as follows.

ELECTRONIC INSTRUMENTATION AND DATA PROCESSING

The test vehicle was instrumented with a triaxial accelerometer near the vehicle center of gravity (c.g.) to measure longitudinal, lateral, and vertical acceleration levels; and a backup triaxial accelerometer in the rear of the vehicle to measure longitudinal, lateral, and vertical acceleration levels. These accelerometers were ENDEVCO® Model 2262CA, piezoresistive accelerometers with a $\pm$100 g range.

The accelerometers are strain gage type with a linear millivolt output proportional to acceleration. Signal conditioners and amplifiers in the test vehicle increase the low-level signals to a $\pm$2.5 volt maximum level. The signal conditioners also provide the capability of an R-cal (resistive calibration) or shunt calibration for the accelerometers and a precision voltage calibration for the rate transducers. The electronic signals from the accelerometers are transmitted to a base station by means of an 8-channel, proportional-bandwidth, Inter-Range Instrumentation Group (IRIG), FM/FM telemetry link for digital recording. Calibration signals from the test vehicle are recorded before the test and immediately afterwards. A crystal-controlled time reference signal is simultaneously recorded with the data. Wooden dowels actuate pressure-sensitive switches on the bumper of the impacting vehicle prior to impact to indicate the elapsed time over a known distance to provide a measurement of impact velocity. The initial contact also produces an "event" mark on the data record to establish the instant of contact with the installation.

The multiplex of data channels, transmitted on one radio frequency, is received and demultiplexed onto TEAC® instrumentation data recorder. After the test, the data are played back from the TEAC® recorder and digitized. A proprietary software program (WinDigit) converts the analog data from each transducer into engineering units using the R-cal and pre-zero values at 10,000 samples per second, per channel. WinDigit also provides Society of Automotive Engineers (SAE) J211 class 180 phaseless digital filtering and vehicle impact velocity.

All accelerometers are calibrated annually according to SAE J211 *4.6.1* by means of an ENDEVCO® 2901, precision primary vibration standard. This device and its support instruments are returned to the factory annually for a National Institute of Standards Technology (NIST) traceable calibration. The subsystems of each data channel are also evaluated annually, using instruments with current NIST traceability, and the results are factored into the accuracy of the total data channel, per SAE J211. Calibrations and evaluations are made any time data are suspect. Acceleration data is measured with an expanded uncertainty of ±1.7% at a confidence fracture of 95% (k=2).

The Test Risk Assessment Program (TRAP) uses the data from WinDigit to compute occupant/compartment impact velocities, time of occupant/compartment impact after vehicle impact, and the highest 10-millisecond (ms) average ridedown acceleration. WinDigit calculates change in vehicle velocity at the end of a given impulse period. In addition, maximum average accelerations over 50-ms intervals in each of the three directions are computed. For reporting purposes, the data from the vehicle-mounted accelerometers are filtered with a 60-Hz digital filter, and acceleration versus time curves for the longitudinal, lateral, and vertical directions are plotted using TRAP.

PHOTOGRAPHIC INSTRUMENTATION AND DATA PROCESSING

Photographic coverage of the test included three high-speed cameras: one overhead with a field of view perpendicular to the ground and directly over the impact point; one placed behind the installation at an angle; and a third placed to have a field of view parallel to and aligned with the installation at the downstream end. A flashbulb activated by pressure-sensitive tape switches was positioned on the impacting vehicle to indicate the instant of contact with the installation and was visible from each camera. The films from these high-speed cameras were analyzed on a computer-linked motion analyzer to observe phenomena occurring during the collision and to obtain time-event, displacement, and angular data. A mini-DV and still cameras recorded and documented conditions of the test vehicle and installation before and after the test.

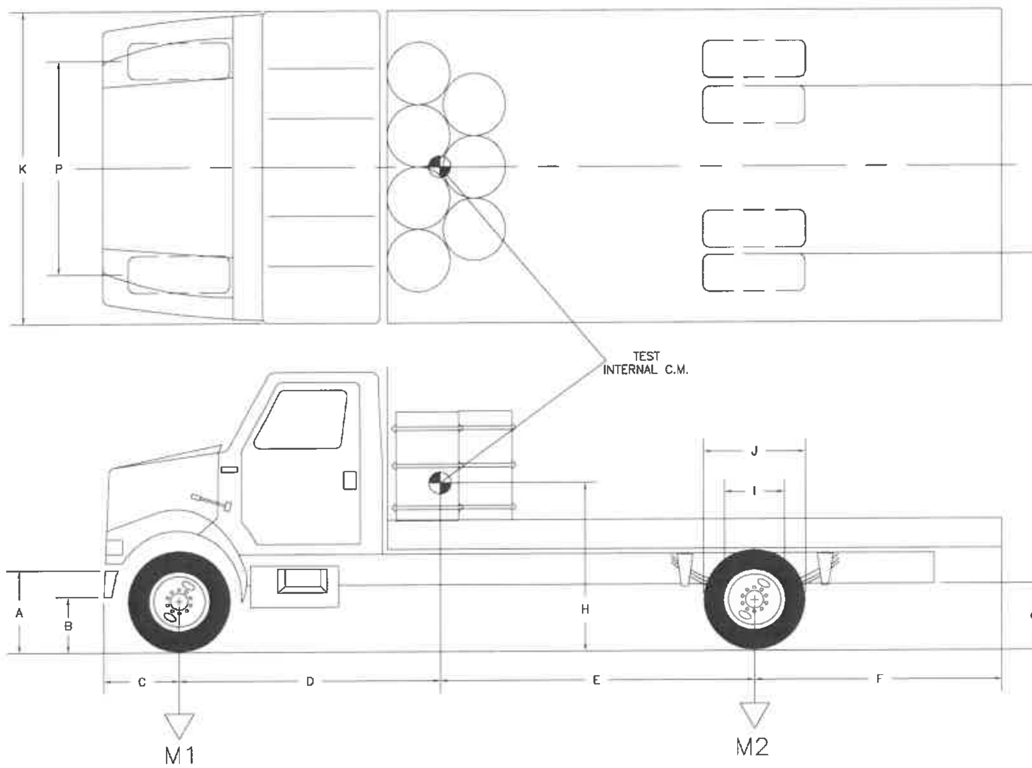
TEST VEHICLE PROPULSION AND GUIDANCE

The test vehicle was towed into the test installation using a steel cable guidance and reverse tow system. A steel cable for guiding the test vehicle was tensioned along the path, anchored at each end, and threaded through an attachment to the front wheel of the test vehicle. An additional steel cable was connected to the test vehicle, passed around a pulley near the impact point, through a pulley on the tow vehicle, and then anchored to the ground such that the tow vehicle moved away from the test site. A two-to-one speed ratio between the test and tow vehicle existed with this system. Just prior to impact with the installation, the test vehicle was released to be free-wheeling and unrestrained. The vehicle remained free-wheeling, i.e., no steering or braking inputs, until the vehicle cleared the immediate area of the test site.

APPENDIX B. TEST VEHICLE PROPERTIES AND INFORMATION

Vehicle Measurements for State Department Testing

DATE:	2010-11-11	TEST NO.:	400001-USR21	VIN NO.:	1HTSCABN9YH674369
YEAR:	2000	MAKE:	International	MODEL:	4700
TIRE SIZE:		ODOMETER:	18299		



GEOMETRY (inches)

A	31.0	B	20.0	C	30.5	D	107.4	E	98.6	F	112.0	G	29.25
H		I	23.5	J	39.5	K	96.0	L	80.5	N	73.0	D+E = 206	

Allowed Range for Wheelbase (D+E) = 208 ± 20 inches

MASS DISTRIBUTION (lb)

LF	3650	RF	3550	LR	4060	RR	3790

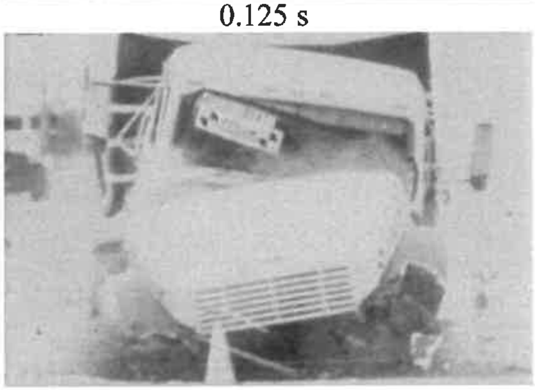
MASS (kg)	CURB	TEST INERTIAL	
M_1	3700	7200	
M_2	7310	7850	Allowed Range for Inertial Wt.= 15000 ± 309 lb
M_{Total}	14010	15050	

Figure 10. Vehicle properties for test 400001-USR21.

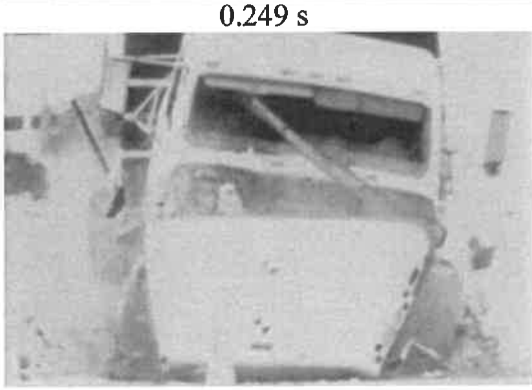
APPENDIX C. SEQUENTIAL PHOTOGRAPHS

0.000 s

0.125 s



0.249 s



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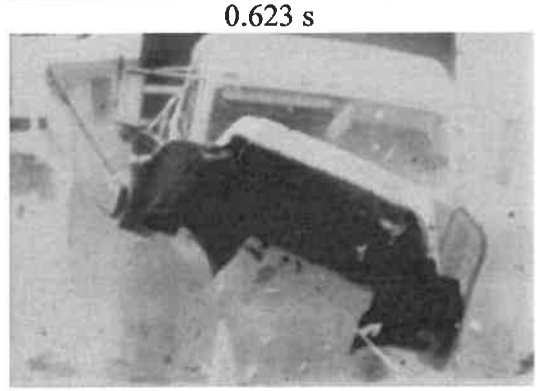
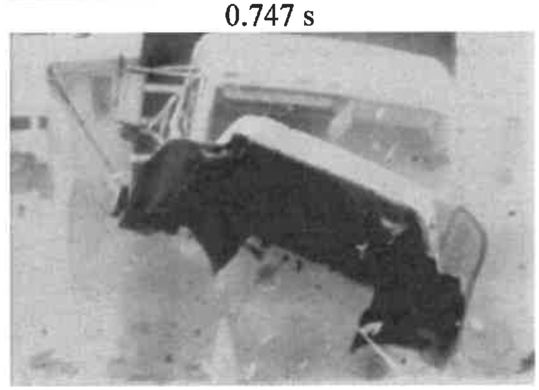
0.498 s

0.623 s



0.747 s



0.872 s

Figure 11. Sequential photographs for test 400001-USR21 (frontal view).

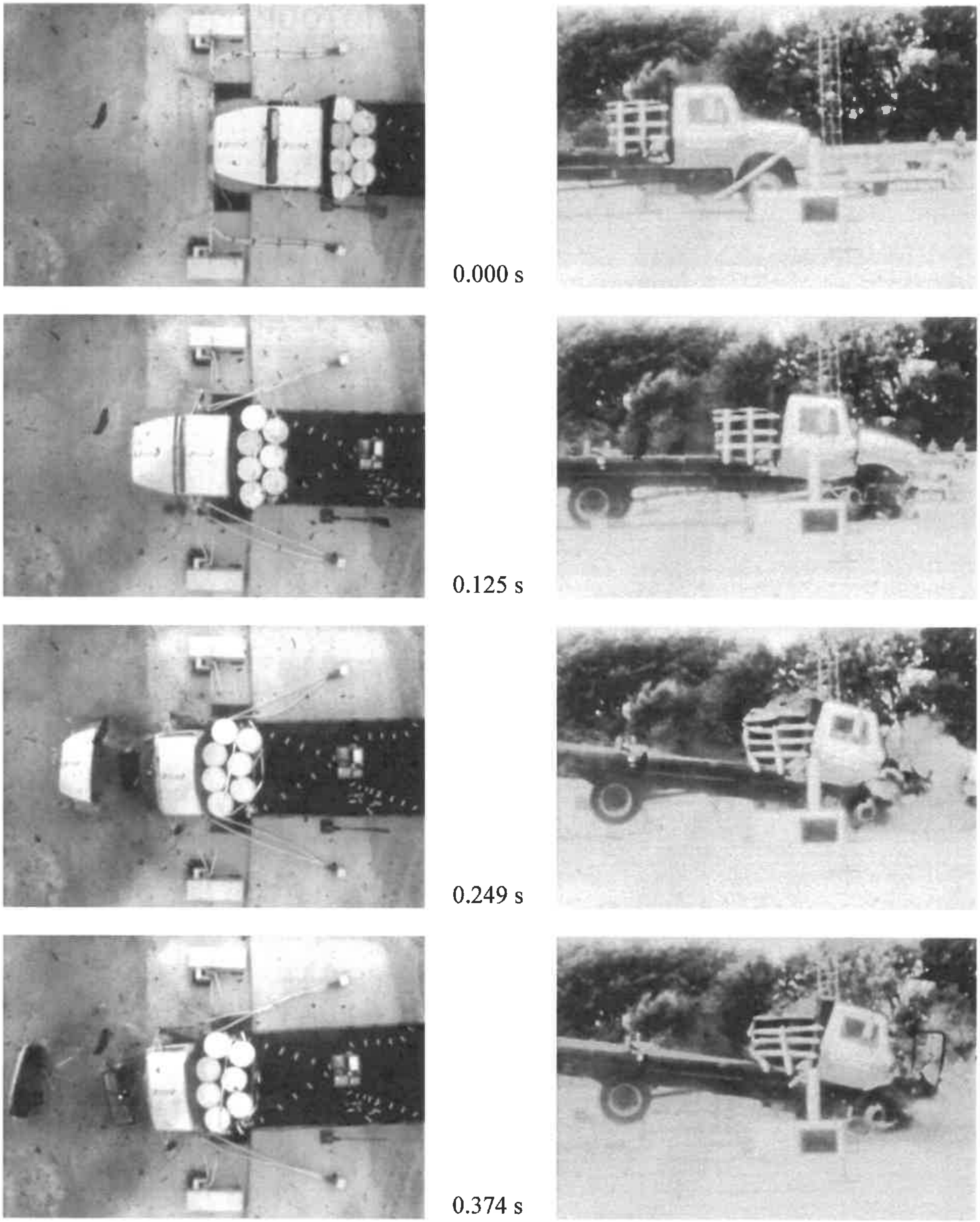


Figure 12. Sequential photographs for test 400001-USR21
(overhead and perpendicular views).

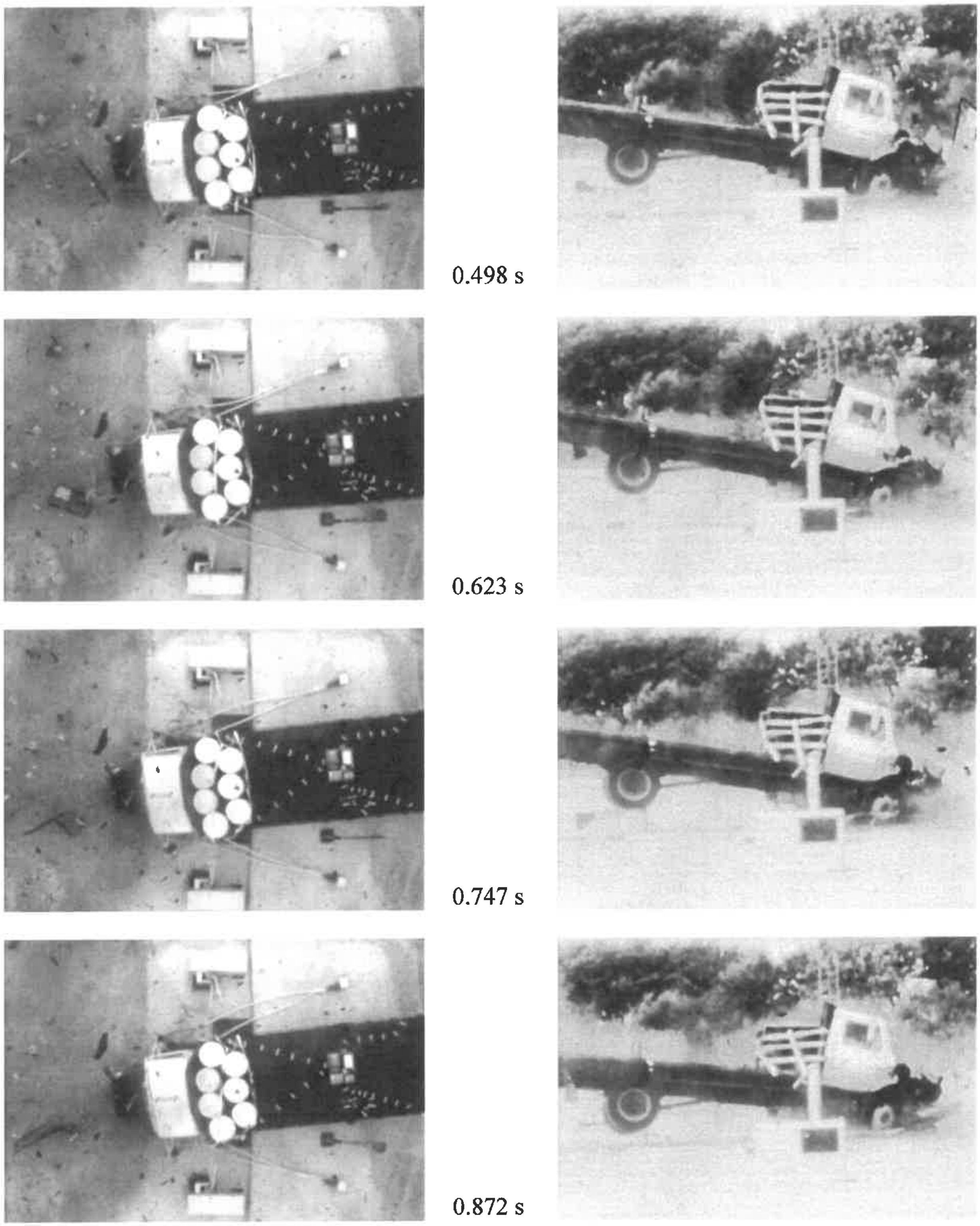


Figure 12. Sequential photographs for test 400001-USR21
(overhead and perpendicular views) (continued).

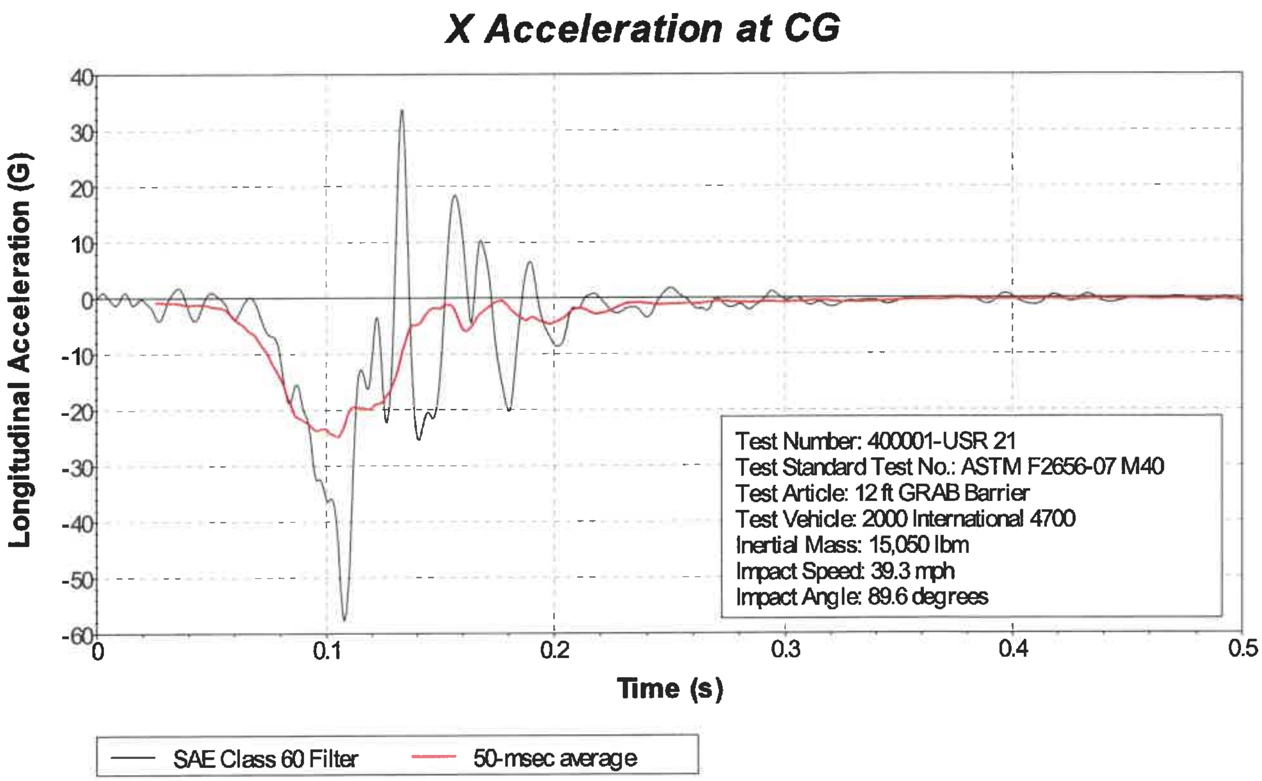


Figure 13. Vehicle longitudinal accelerometer trace for test 400001-USR21 (accelerometer located at center of gravity).

Accelerometer wires cut during test

Figure 14. Vehicle lateral accelerometer trace for test 400001-USR21 (accelerometer located at center of gravity).

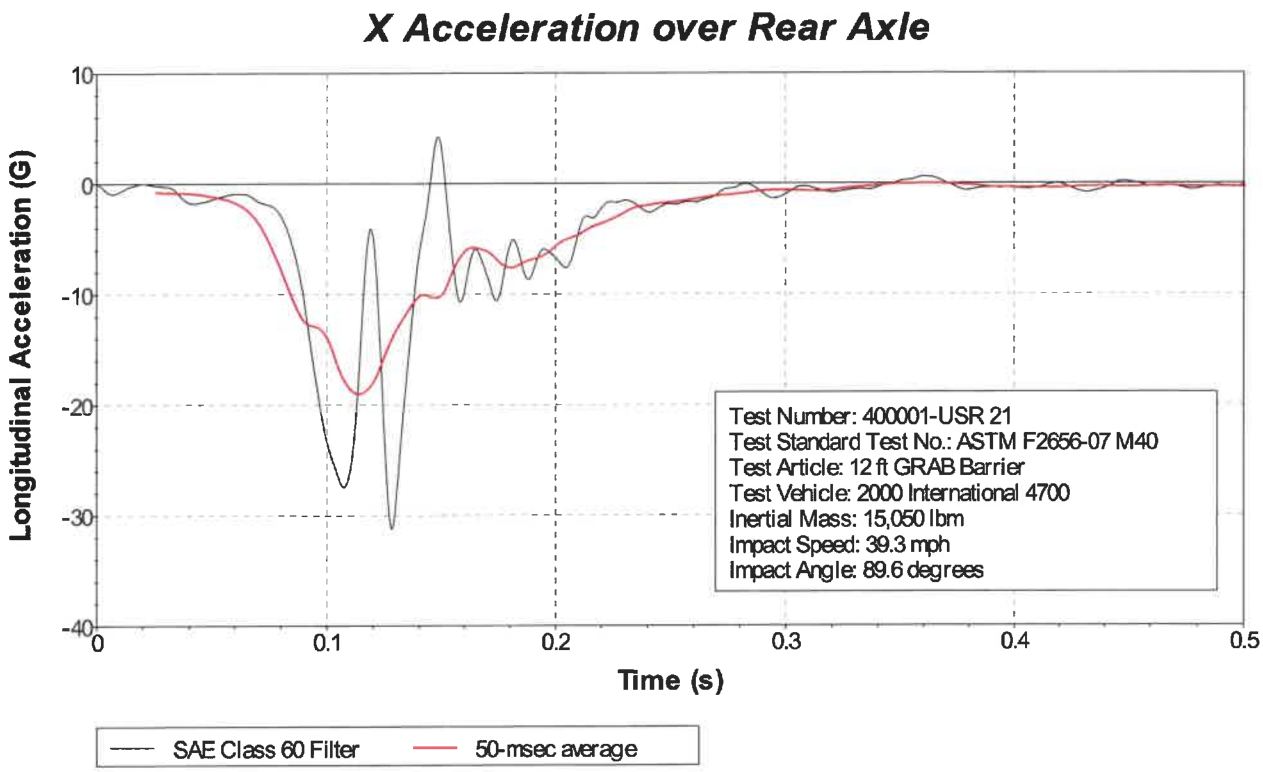


Figure 15. Vehicle longitudinal accelerometer trace for test 400001-USR21
(accelerometer located over rear axle).

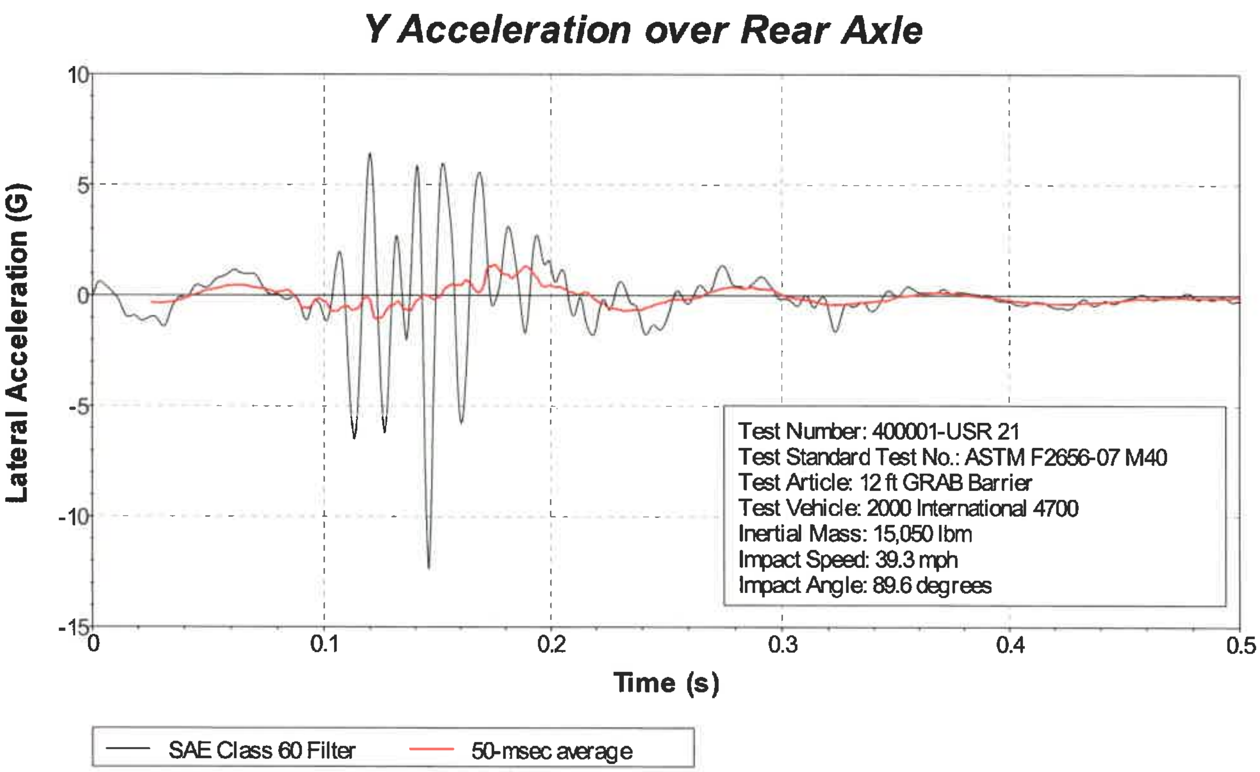


Figure 16. Vehicle lateral accelerometer trace for test 400001-USR21
(accelerometer located over rear axle).

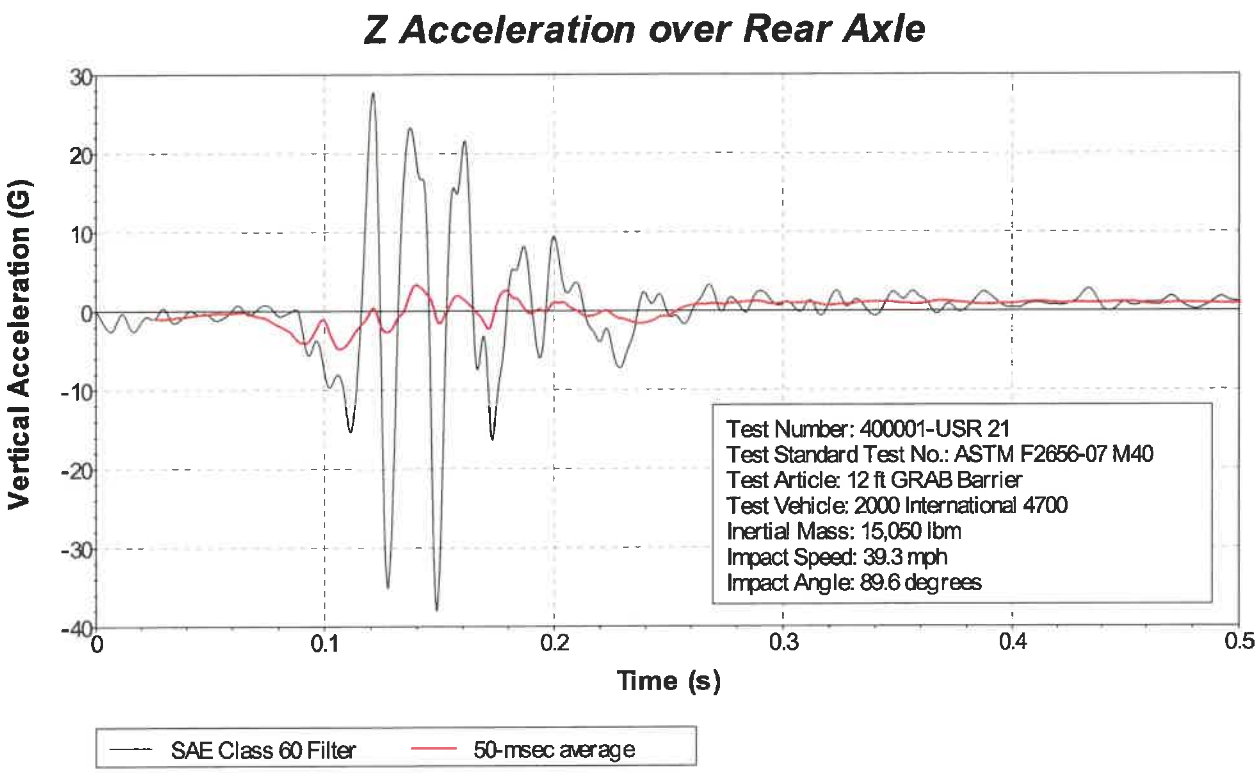


Figure 17. Vehicle vertical accelerometer trace for test 400001-USR21 (accelerometer located over rear axle).