Texas A&M Transportation Institute
Proving Ground

Test Report No.: 510602-SWS3
Test Report Date: August 2012

ASTM F2656-07 M50 TEST ON THE SMITH & WESSON 16-FT WEDGE SYSTEM

by

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Contract No.: P2012316
Test No.: 510602-SWS3
Test Date: 2012-06-19

Sponsored by
Smith & Wesson Security Solutions

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ISO 17025 Laboratory
Testing Certificate # 2821.01

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Technical Report Documentation Page

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16. Abstract

The objective of the test reported was to determine if the Smith & Wesson 16-ft wedge system was capable of arresting a 15,000 lb truck traveling at 47 mi/h or above according to Condition Designation M50 of *ASTM F2656-07*. This condition designation requires the Smith & Wesson 16-ft wedge system to withstand kinetic energy of 1,250,000 ft-lb. This report presents the construction details of the Smith & Wesson 16-ft wedge system, 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 did not penetrate beyond the inside edge of the 16-ft wedge system. According to ASTM F2656-07, the Smith & Wesson 16-ft wedge system meets Condition Designation/Penetration Rating M50/P1, which allows penetration of less than or equal to 3.2 ft when impacted by the medium duty truck at 47 mi/h or greater.

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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)		
^oF	Fahrenheit	5 (F-32)/9 or (F-32)/1.8	Celsius	^oC
		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)		
^oC	Celsius	1.8C+32	Fahrenheit	^oF
		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 16-ft wedge system evaluated herein was designed/manufactured by Smith & Wesson Security Solutions. 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 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 the test reported was to determine if the Smith & Wesson 16-ft wedge system was capable of arresting a 15,000 lb truck traveling at 47 mi/h or above according to Condition Designation M50 of *ASTM F2656-07*. This condition designation requires the Smith & Wesson 16-ft wedge system to withstand kinetic energy of 1,250,000 ft-lb.

This report presents the construction details of the Smith & Wesson 16-ft wedge system, 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 A&M 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 Texas A&M Transportation Institute'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 installation of the Smith & Wesson 16-ft wedge system was at the end of a wide out-of-service apron. The apron consists of an unreinforced jointed concrete pavement in 12.5 ft × 15 ft blocks nominally 6 inches deep. The apron is over 60 years old and the joints have some displacement, but are otherwise flat and level.

Test Article – Design and Construction

The Smith & Wesson Securities Solutions 16-ft wedge is a retractable steel plate wedge barrier system anchored within a shallow concrete foundation. In the deployed position, the leading edge of the barrier is approximately 37 inches in height. The wedge plate rotates about seven hinges in a steel frame cast within a shallow concrete foundation. In the deployed position, the wedge plate is at an angle of approximately 27 degrees to the roadway surface. The barrier is supported by two steel channel buttresses that brace the steel wedge plate to the concrete foundation. In the retracted position, the barrier is flush with the roadway travel surface to permit vehicular traffic over the barrier system. The barrier is 16 ft wide × 7.1 ft long and is anchored within a reinforced concrete foundation that measures 13.25 ft long × 18.08 ft wide × 1.5 ft thick. The wedge is deployed using two MOOG Type 5 electric actuators and assisted by seven coil springs (one coil spring located at each hinge point).

The Smith & Wesson Securities Solutions Barrier uses a ½-inch thick steel wedge plate reinforced by seven A500 Grade B TS 4-inch × 4-inch × ⅜-inch transverse stiffener tubes aligned with the hinge positions and wedge plate synthetic restraining straps. The wedge plate rests in the stored position on A-36 C4 × 7.25 channels.

In the front and back areas of the concrete foundation, six longitudinal #5 bars (three top bars and three bottom bars) were enclosed in #5 closed stirrups. Additional reinforcing steel bar details are presented in figure 1.

All reinforcing steel used in the concrete foundation was Grade 60 material. All concrete was specified to have a minimum compressive strength of 4000 psi. Concrete compressive strength on the day of the test (7 days of age) was 4645 psi. Moisture content and density of the crushed limestone base material surrounding the foundation was 4.9 percent and 99.7 percent, respectively. Fabrication details of the wedge are presented in figures 1 and 2. Photographs of the completed installation are shown in figure 3.

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 Smith & Wesson 16-ft wedge system can be rated according to one of three designated condition levels when tested with a medium-duty truck, 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*.

The test vehicle specified was a medium duty truck with diesel engine, tested at a vehicle gross weight of 15,000 lb ±309 lb. According to Condition Designation M50 of *ASTM F2656-07*, which involves the medium duty truck impacting at 47 mi/h or above, the Smith & Wesson 16-ft wedge system is required to withstand kinetic energy of 1,250,000 ft-lb.

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.

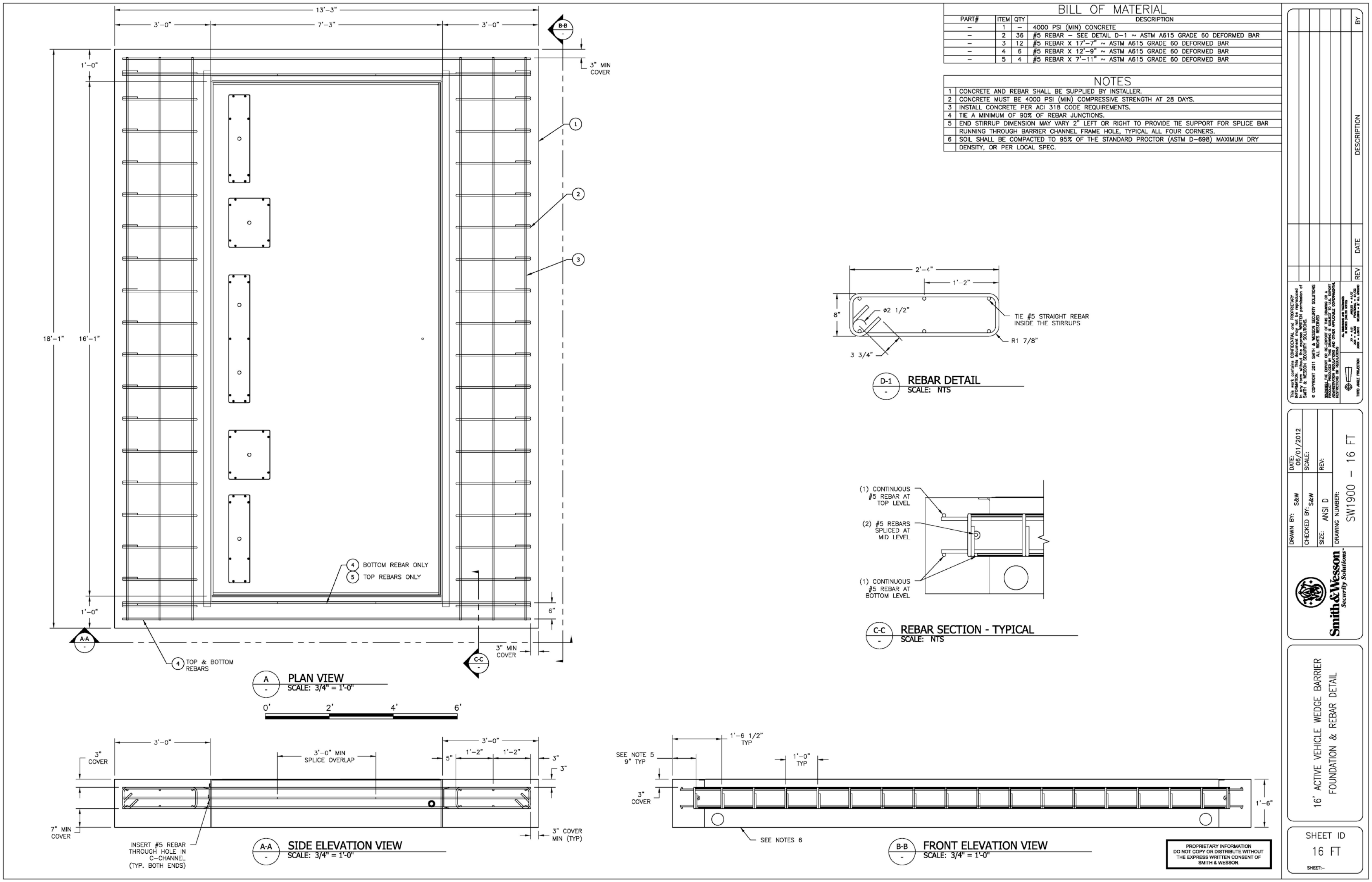
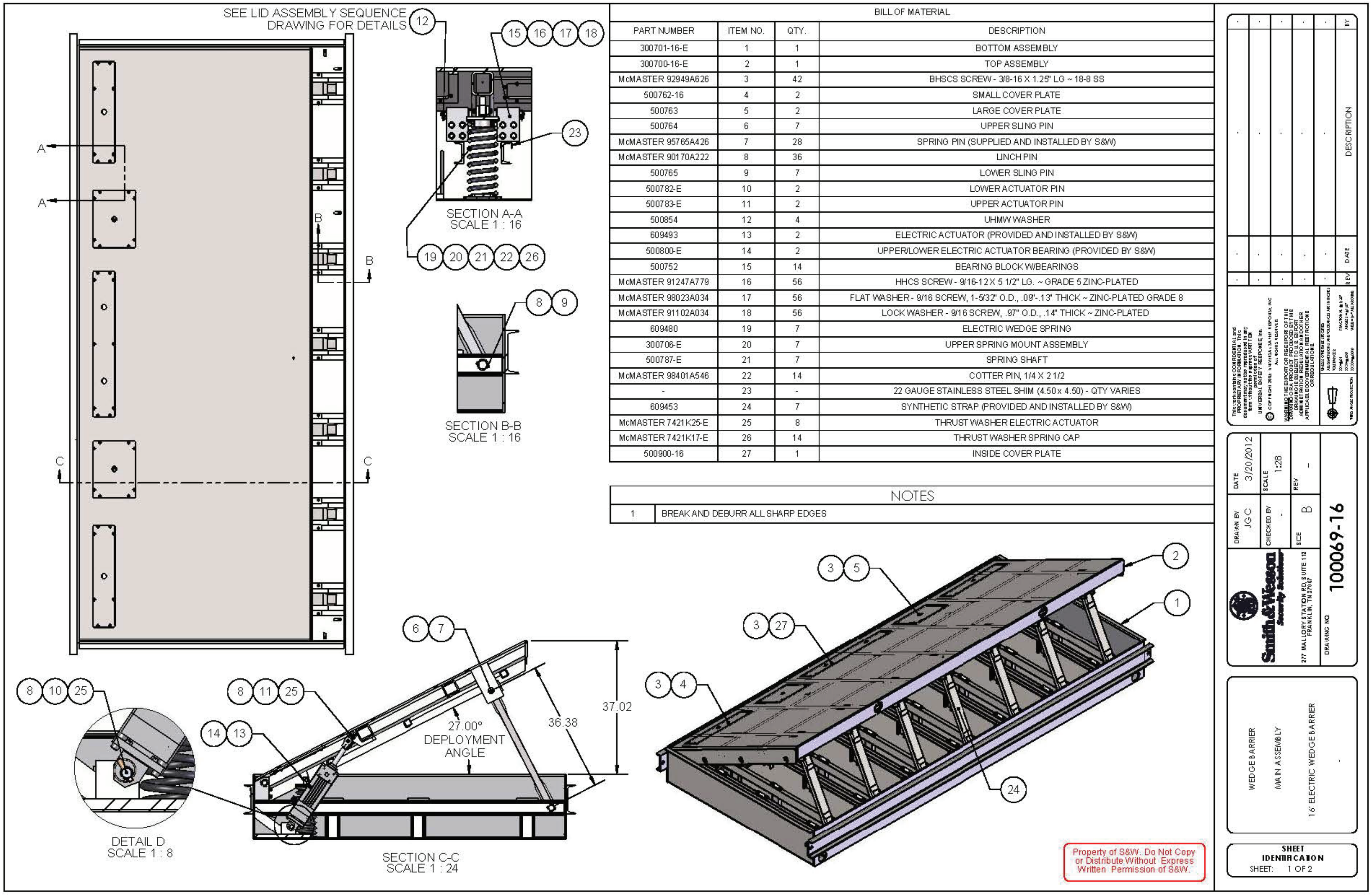


Figure 1. Foundation details for the Smith & Wesson 16-ft wedge system.



BILL OF MATERIAL

PART NUMBER	ITEM NO.	QTY.	DESCRIPTION
300701-16-E	1	1	BOTTOM ASSEMBLY
300700-16-E	2	1	TOP ASSEMBLY
McMASTER 92949A626	3	42	BHSCS SCREW - 3/8-16 X 1.25" LG ~ 18-8 SS
500762-16	4	2	SMALL COVER PLATE
500763	5	2	LARGE COVER PLATE
500764	6	7	UPPER SLING PIN
McMASTER 95765A426	7	28	SPRING PIN (SUPPLIED AND INSTALLED BY S&W)
McMASTER 90170A222	8	36	LINCH PIN
500765	9	7	LOWER SLING PIN
500782-E	10	2	LOWER ACTUATOR PIN
500783-E	11	2	UPPER ACTUATOR PIN
500854	12	4	UHMW WASHER
609493	13	2	ELECTRIC ACTUATOR (PROVIDED AND INSTALLED BY S&W)
500800-E	14	2	UPPER/LOWER ELECTRIC ACTUATOR BEARING (PROVIDED BY S&W)
500752	15	14	BEARING BLOCK W/BEARINGS
McMASTER 91247A779	16	56	HHCS SCREW - 9/16-12 X 5 1/2" LG. ~ GRADE 5 ZINC-PLATED
McMASTER 98023A034	17	56	FLAT WASHER - 9/16 SCREW, 1-5/32" O.D., .09"-.13" THICK ~ ZINC-PLATED GRADE 8
McMASTER 91102A034	18	56	LOCK WASHER - 9/16 SCREW, .97" O.D., .14" THICK ~ ZINC-PLATED
609480	19	7	ELECTRIC WEDGE SPRING
300706-E	20	7	UPPER SPRING MOUNT ASSEMBLY
500787-E	21	7	SPRING SHAFT
McMASTER 98401A546	22	14	COTTER PIN, 1/4 X 2 1/2
-	23	-	22 GAUGE STAINLESS STEEL SHIM (4.50 x 4.50) - QTY VARIES
609453	24	7	SYNTHETIC STRAP (PROVIDED AND INSTALLED BY S&W)
McMASTER 7421K25-E	25	8	THRUST WASHER ELECTRIC ACTUATOR
McMASTER 7421K17-E	26	14	THRUST WASHER SPRING CAP
500900-16	27	1	INSIDE COVER PLATE

Figure 2. Details of the Smith & Wesson 16-ft wedge system.

Figure 3. Smith & Wesson 16-ft wedge system prior to testing.

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*

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*

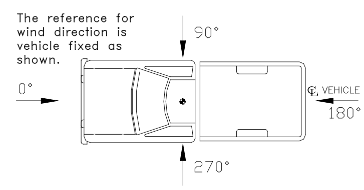
CRASH TEST 510602-SWS3 (*ASTM F2656-07* M50)

Test Vehicle

A 2000 International 4700 single-unit flatbed truck, shown in figures 4 and 5, was used for the crash test. Test inertia weight of the vehicle was 15,160 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. Table 3 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.

Weather Conditions

The crash test was performed the morning of June 19, 2012. Weather conditions at the time of testing were: Wind Speed: 8 mi/h; Wind Direction: 171 degrees with respect to the vehicle (vehicle was traveling in a northerly direction); Temperature: 84ºF); Relative Humidity: 76 percent.



Impact Description

The 2000 International 4700 single-unit flatbed truck, traveling at an impact speed of 50.2 mi/h, impacted the Smith & Wesson 16-ft wedge system at an impact angle of 90.0 degrees. The centerline of the vehicle was aligned with the centerline of the Smith & Wesson 16-ft wedge system. At 0.035 s after impact, the wedge and the foundation began to deflect toward the "protected" side, and at 0.040 s, a crack formed in the foundation on the impact side of the wedge. The foundation stopped moving at 0.088 s, and the truck stopped moving forward at 0.198 s. As the truck stopped, it did not penetrate the "protected" side of the wedge. The closest the leading edge of the truck bed reached was 8.5 ft on the impact side from the "protected" side of the wedge. The vehicle rebounded and came to rest 8.55 ft on the impact side. Appendix C, figures 12 and 13, show sequential photographs of the test period.

Damage to Test Article

Damage to the Smith & Wesson 16-ft wedge system is shown in figures 6 and 7. The concrete footing moved through the soil toward the "protected" side 2.5 inches on the left side and 1.25 inches on the right side. The concrete surface adjacent to the front of the metal frame of the wedge was cracked. The front plate on the top of the wedge was deformed, and there were tire marks and oil on the synthetic strap covering the hinge supports.

Figure 4. Vehicle/installation geometrics for test 510602-SWS3.

Figure 5. Vehicle before test 510602-SWS3.

Figure 6. Installation/vehicle after test 510602-SWS3.

Figure 7. Installation after test 510602-SWS3.

Vehicle Damage

Damage to the vehicle is shown in figure 8. The right and left frame rails, front spring mounts, motor and motor mounts, transmission and transmission mounts, firewall, drive shaft, steering box, rear U-bolts and rear springs and spring mounts were deformed. Also damaged were the front bumper, hood, radiator, water pump and fan, windshield, cab, left battery box, right and left fuel tanks, right and left doors and door glass, front seat, and the left front tire and wheel rim. Estimated exterior crush to the vehicle was approximately 36 inches. Photographs of the interior of the vehicle are shown in figure 9.

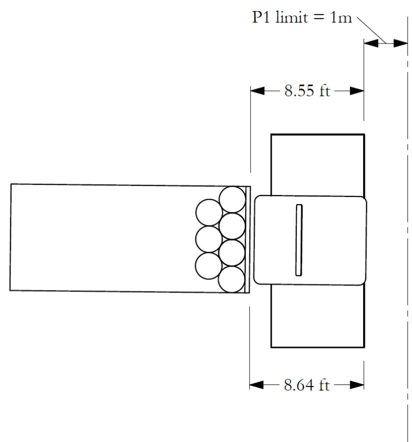
Occupant Risk Factors

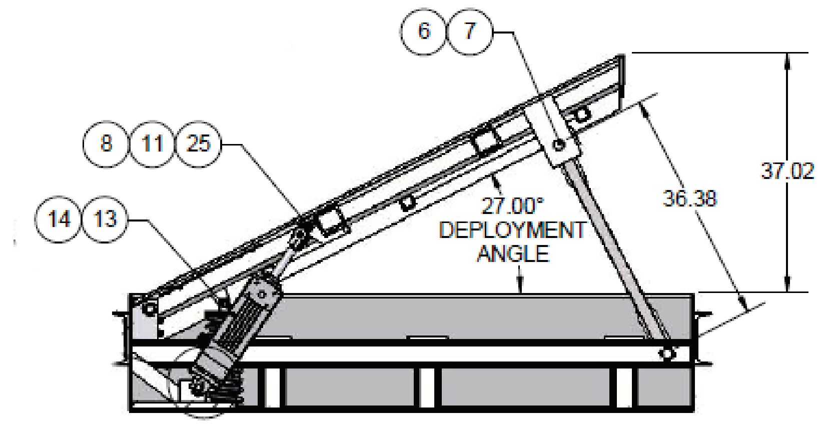
Data from the accelerometer, located at the vehicle center of gravity, were digitized for evaluation of occupant risk for informational purposes only. In the longitudinal direction, the occupant impact velocity was 57.4 ft/s at 0.077 s, the highest 0.010-s occupant ridedown acceleration was 41.8 Gs from 0.090 to 0.100 s, and the maximum 0.050-s average acceleration was -27.5 Gs between 0.018 and 0.068 s. In the lateral direction, no occupant impact impact occurred before 0.077 s, the highest 0.010-s occupant ridedown acceleration was 22.2 Gs from 0.137 to 0.147 s, and the maximum 0.050-s average was 6.8 Gs between 0.041 and 0.091 s. These data and other pertinent information from the test are summarized in figure 10. Vehicle accelerations versus time traces are presented in appendix D, figure 14 through 18.

A strain gage was also placed on the system. However, the conditions under which the strain gage was installed resulted in data of unknown benefit. The results are graphed in figure 11.

Figure 8. Vehicle after test 510602-SWS3.

Figure 9. Interior of vehicle for test 510602-SWS3.





General Information
- Test Agency .... Texas Transportation Institute (TTI)
- Test Standard Test No. .... ASTM F2656-07 M50
- Test No. 510602-SWS3
- Date 2012-06-19

Test Article
- Type .... Anti-Ram Wedge
- Name .... Smith & Wesson 16-ft wedge system
- Installation Length .... 13 ft-3 inches x 18 ft-1 inch
- Material or Key Elements ...... Retractable steel plate wedge anchored within a shallow concrete foundation

Soil/Foundation Type .... Crushed limestone base material

Test Vehicle
- Type .... Medium Duty Truck
- Designation M50
- Model .... 2000 International 4700
- Mass
  - Curb .... 12,030 lb
  - Test Inertial .... 15,160 lb

Impact Conditions
- Speed .... 50.2 mi/h
- Angle .... 90.0 degrees

Exit Conditions
- Speed .... Stopped
- Angle .... ~90 degrees

Occupant Risk Values
- Impact Velocity
  - Longitudinal .... 57.4 ft/s
  - Lateral .... No Contact
- Ridedown Accelerations
  - Longitudinal .... 41.8 Gs
  - Lateral .... 22.2 Gs
- Max. 0.050-s Average
  - Longitudinal .... -27.5 Gs
  - Lateral .... 6.8 Gs
- Distance Beyond Inside Edge of Security Device ... Did not penetrate
- Truck Disabled? .... Yes
- Rating M50/P1

Figure 10. Summary of results for *ASTM F2656-07* test M50 on the Smith & Wesson 16-ft wedge system.

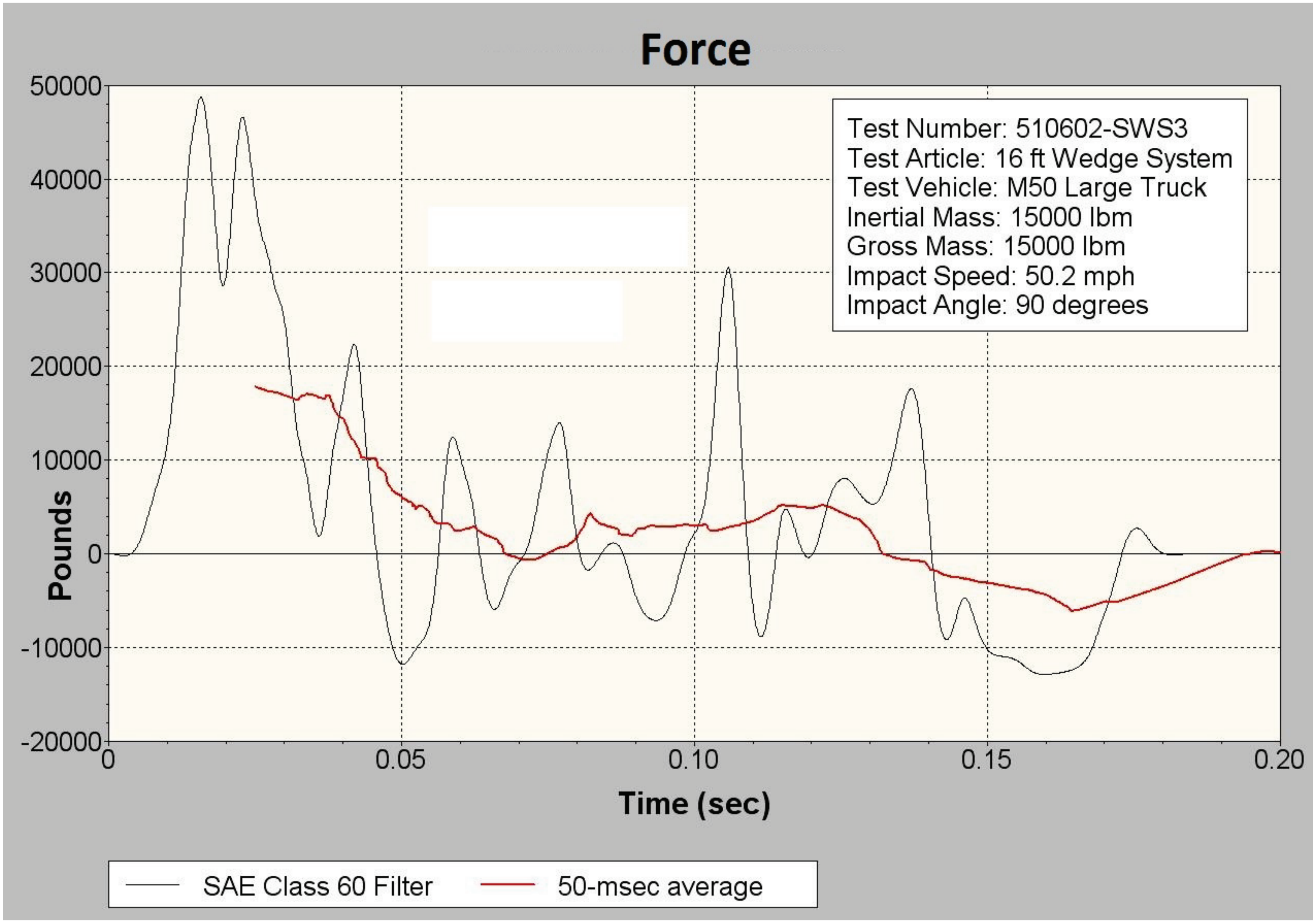


Figure 11. Strain gage data for test 510602-SWS3.

SUMMARY AND CONCLUSIONS

ASSESSMENT OF TEST RESULTS

On June 19, 2012, TTI Proving Ground performed ASTM F2656-07 M50 test on the 16-ft wedge system manufactured by Smith & Wesson Security Solutions. A 2000 International 4700 single-unit flatbed truck weighing 15,160 lb impacted the 16-ft wedge system at approximately 90.0 degrees, with the centerline of the vehicle aligned with the centerline of the 16-ft wedge system. The acceptable range for impact speed for this M50 test was 47.0 mi/h or above, and the actual impact speed was 50.2 mi/h. The 16-ft wedge system brought the vehicle to a stop. The cargo remained onboard the vehicle. The vehicle was disabled. The leading edge of the cargo bed did not penetrate beyond the inside edge of the 16-ft wedge system.

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 did not penetrate beyond the inside edge of the 16-ft wedge system. According to ASTM F2656-07, the Smith & Wesson 16-ft wedge system meets Condition Designation/Penetration Rating M50/P1, which allows penetration of less than or equal to 3.2 ft when impacted by the medium duty truck at 47 mi/h or greater.

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 ±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 ±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 factor 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.

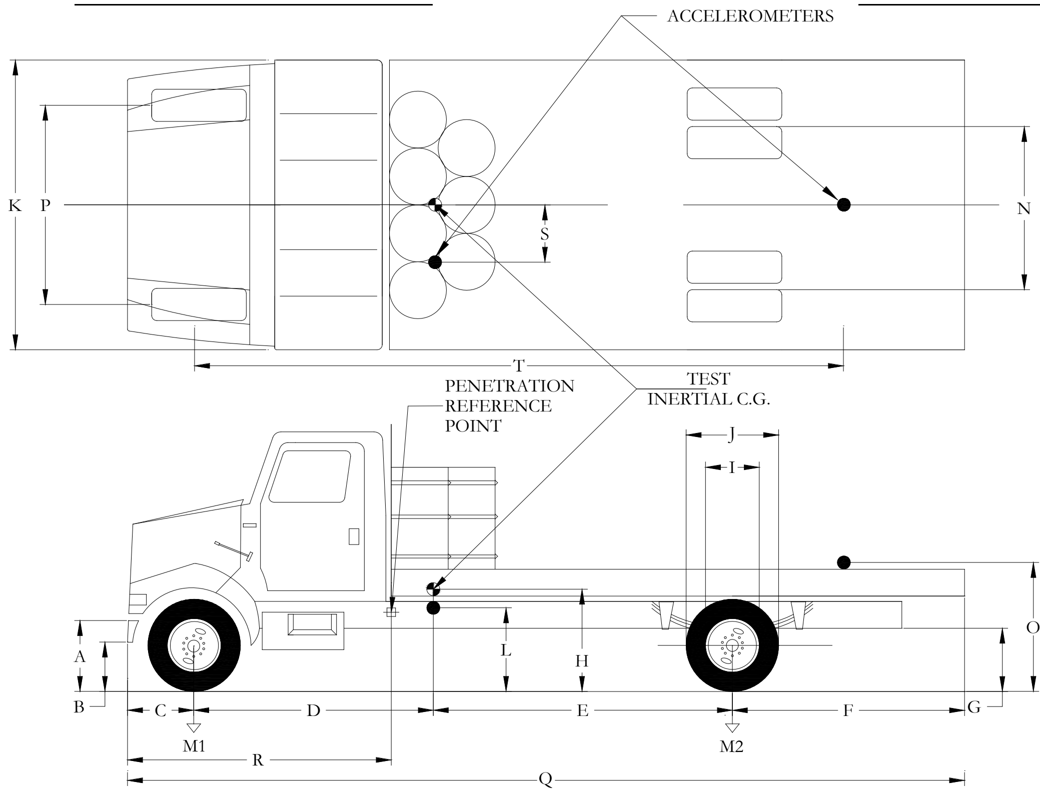
TEST VEHICLE PROPULSION AND GUIDANCE

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

Table 3. Vehicle properties for test 510602-SWS3.

DATE:	2012-06-19	TEST NO.:	510602-SWS3	VIN NO.:	1HTSCABN7Y674371
YEAR:	2000	MAKE:	International	MODEL:	4700
TIRE SIZE:	275/80R22.5			ODOMETER:	169032



GEOMETRY (inches)

A	31.00	B	30.00	C	30.50	D	97.91	E	108.03	F	81.00	G	30.50
H	39.90	I	23.50	J	39.50	K	96.00	L	31.50	N	73.00	O	54.00
P	80.50	Q	317.50	R	97.00	S	18.50	T	206.00			D+E =	205.94

Allowed Range for Wheelbase (D+E) = 208 ±20 inches;
Allowable Flatbed Length = 18 ft ±24 inches; Allowable U-bolt Spacing = 3 ft ±8 inches

MASS DISTRIBUTION (lb)

LF	4040	RF	3910	LR	3610	RR	3600

MASS (lb)	CURB	TEST INERTIAL	
M_1	6310	7950	
M_2	5720	7210	Allowed Range for Inertial Wt.= 15000 ± 309 lb
M_{Total}	12030	15160	

APPENDIX C. SEQUENTIAL PHOTOGRAPHS

0.000 s

0.045 s

0.090 s

0.135 s

0.180 s

0.225 s

0.270 s

0.315 s

Figure 12. Sequential photographs for test 510602-SWS3 (perpendicular view).

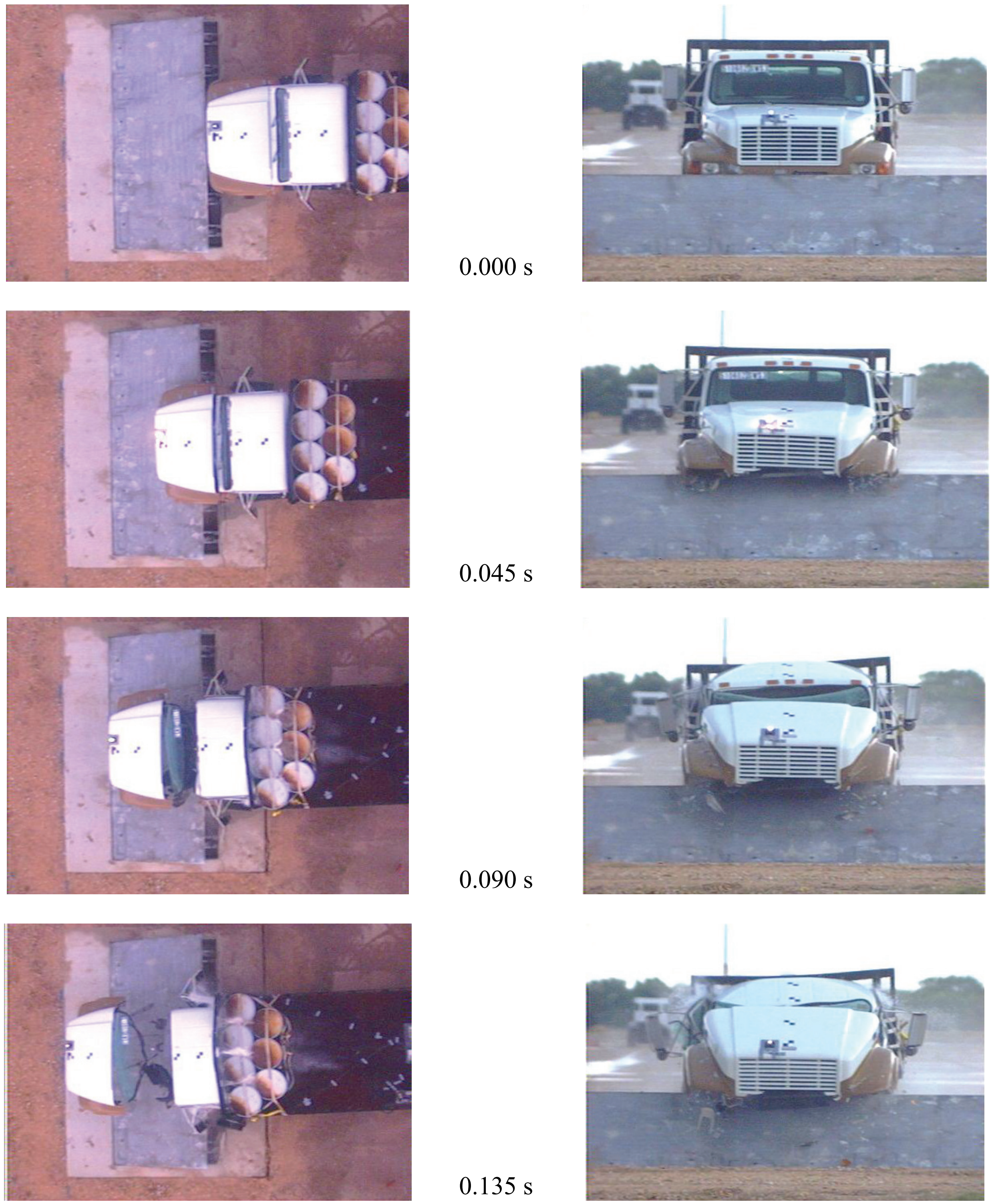


Figure 13. Sequential photographs for test 510602-SWS3
(overhead and frontal views).

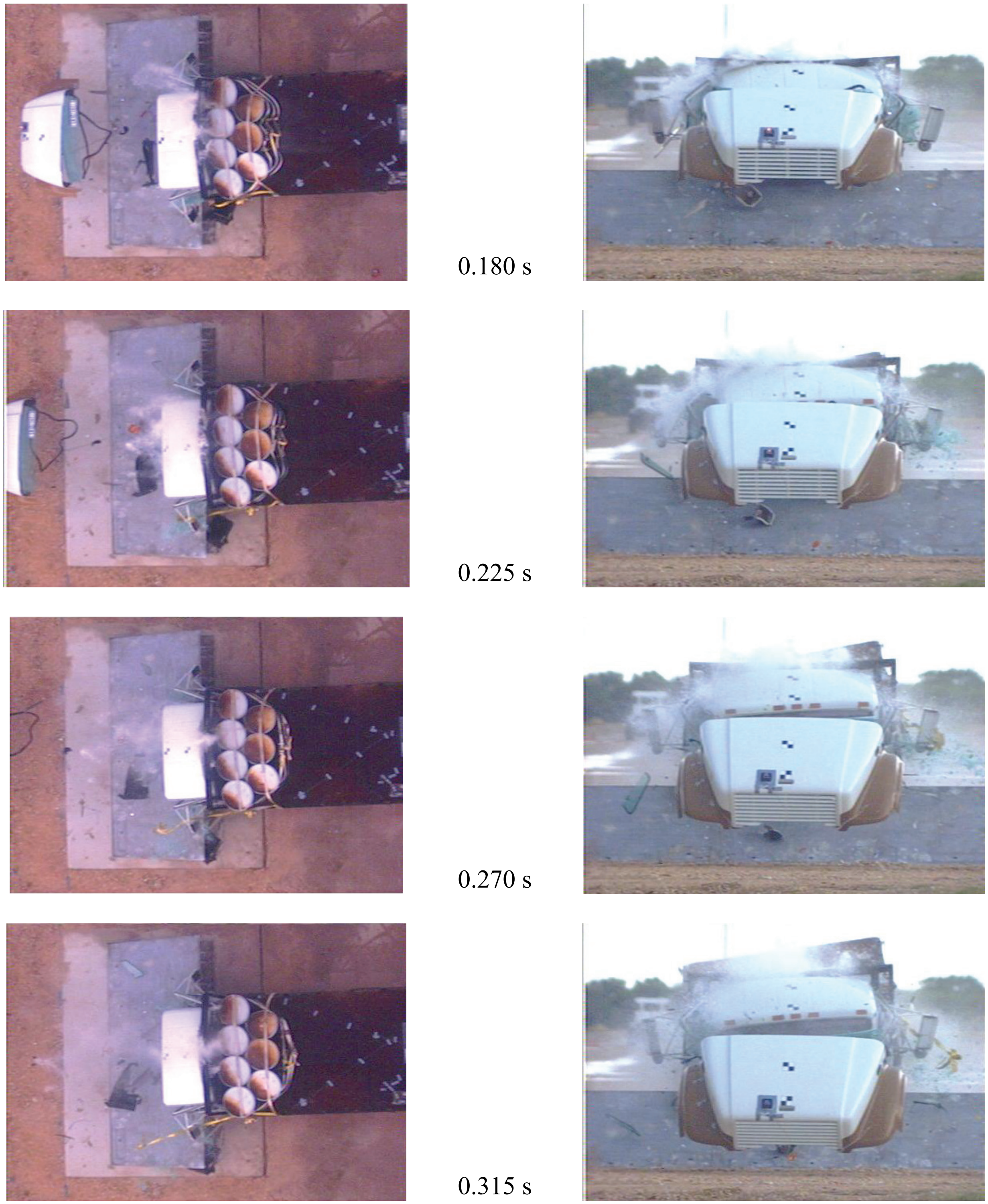


Figure 13. Sequential photographs for test 510602-SWS3
(overhead and frontal views) (continued).

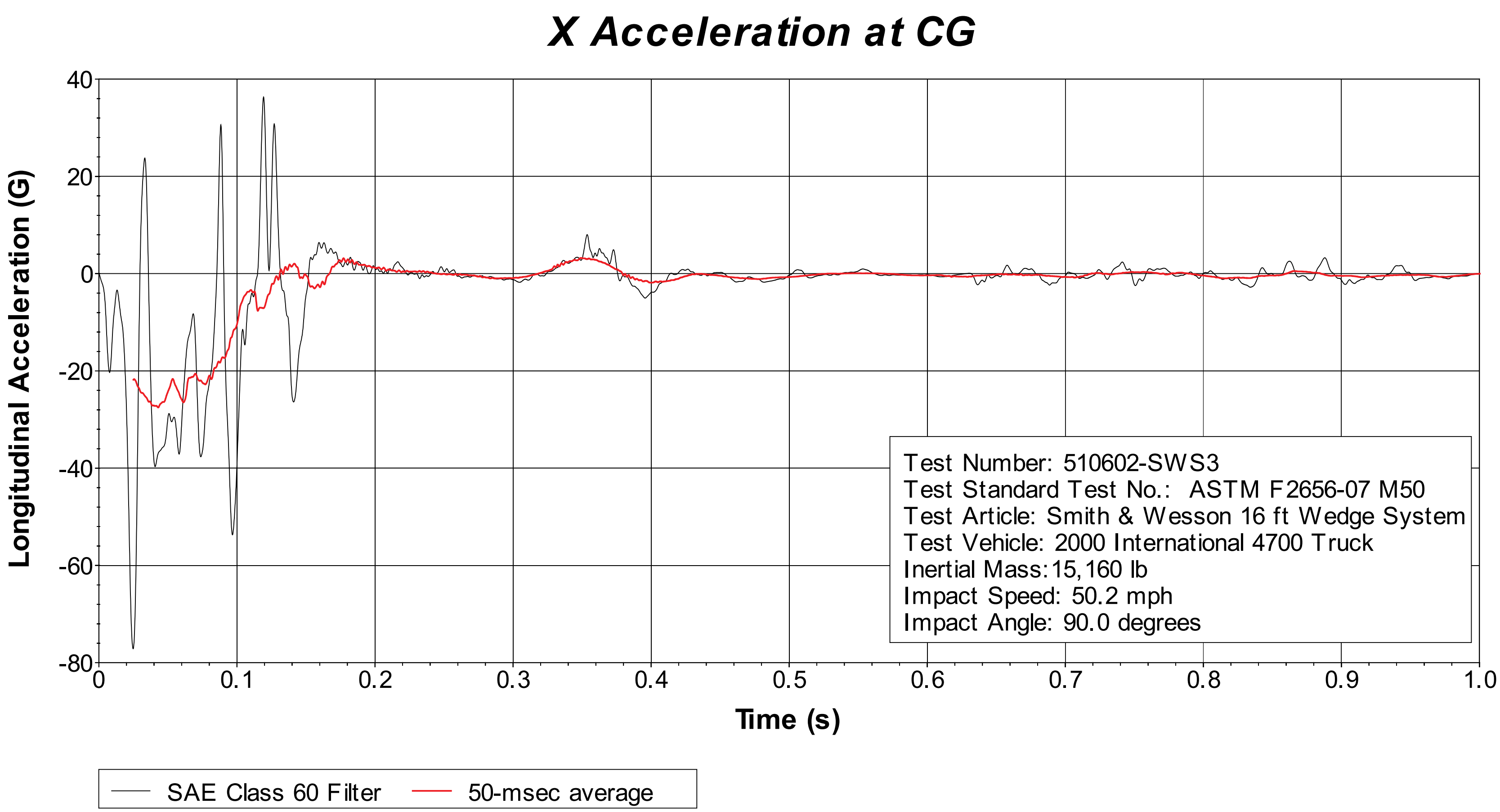


Figure 14. Vehicle longitudinal accelerometer trace for test 510602-SWS3 (accelerometer located at center of gravity).

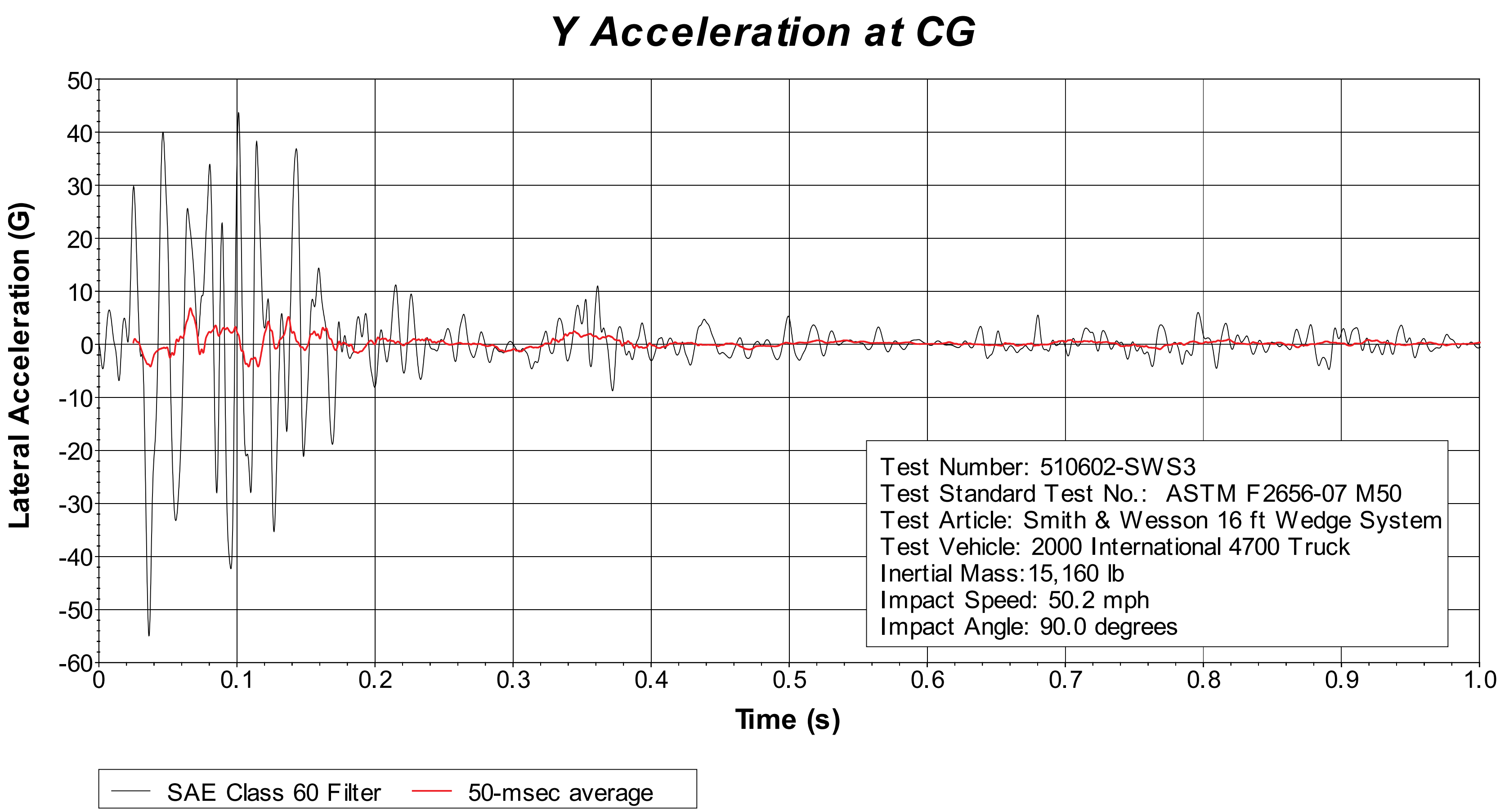


Figure 15. Vehicle lateral accelerometer trace for test 510602-SWS3
(accelerometer located at center of gravity).

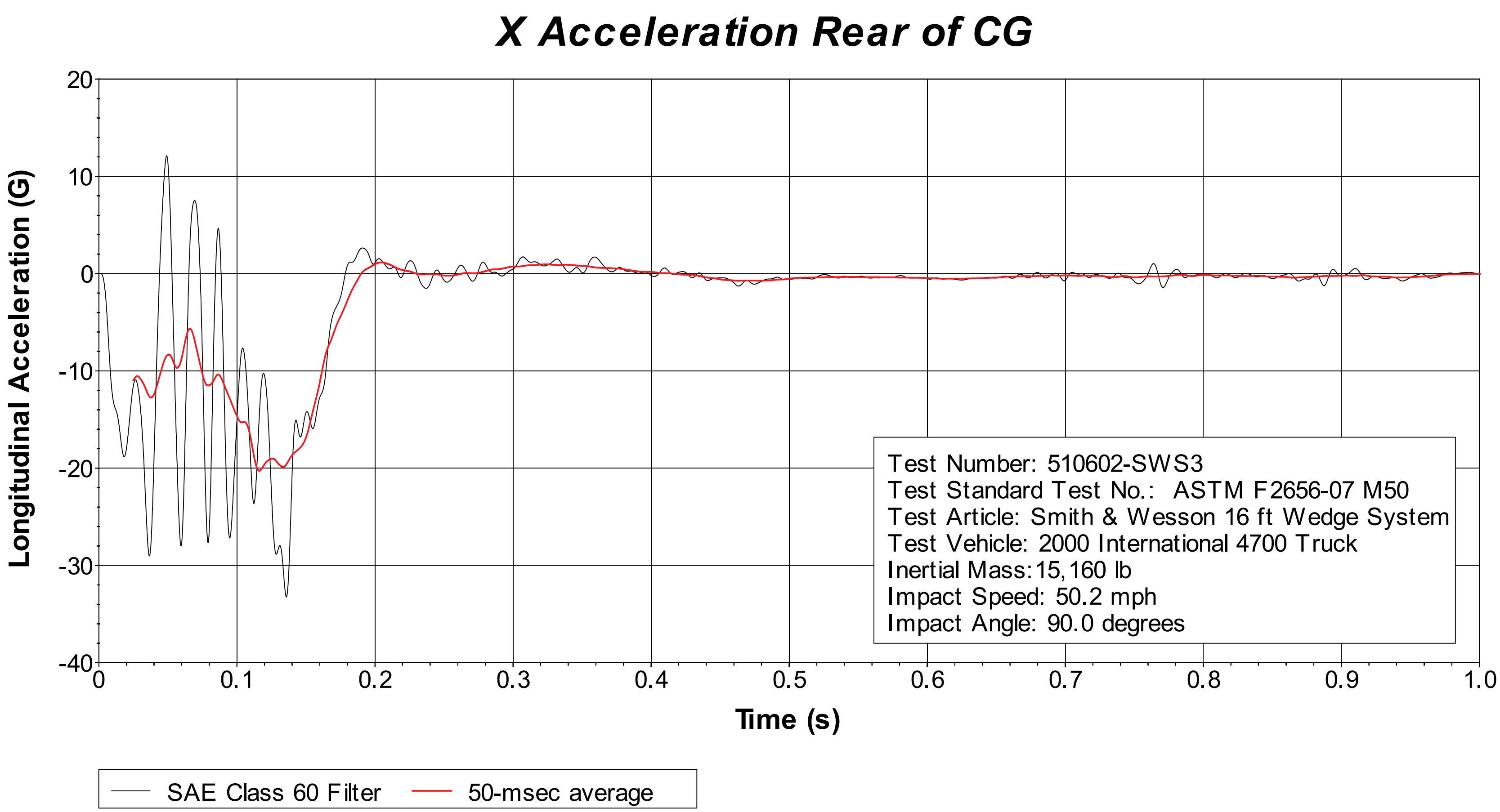


Figure 16. Vehicle longitudinal accelerometer trace for test 510602-SWS3 (accelerometer located rear of center of gravity).

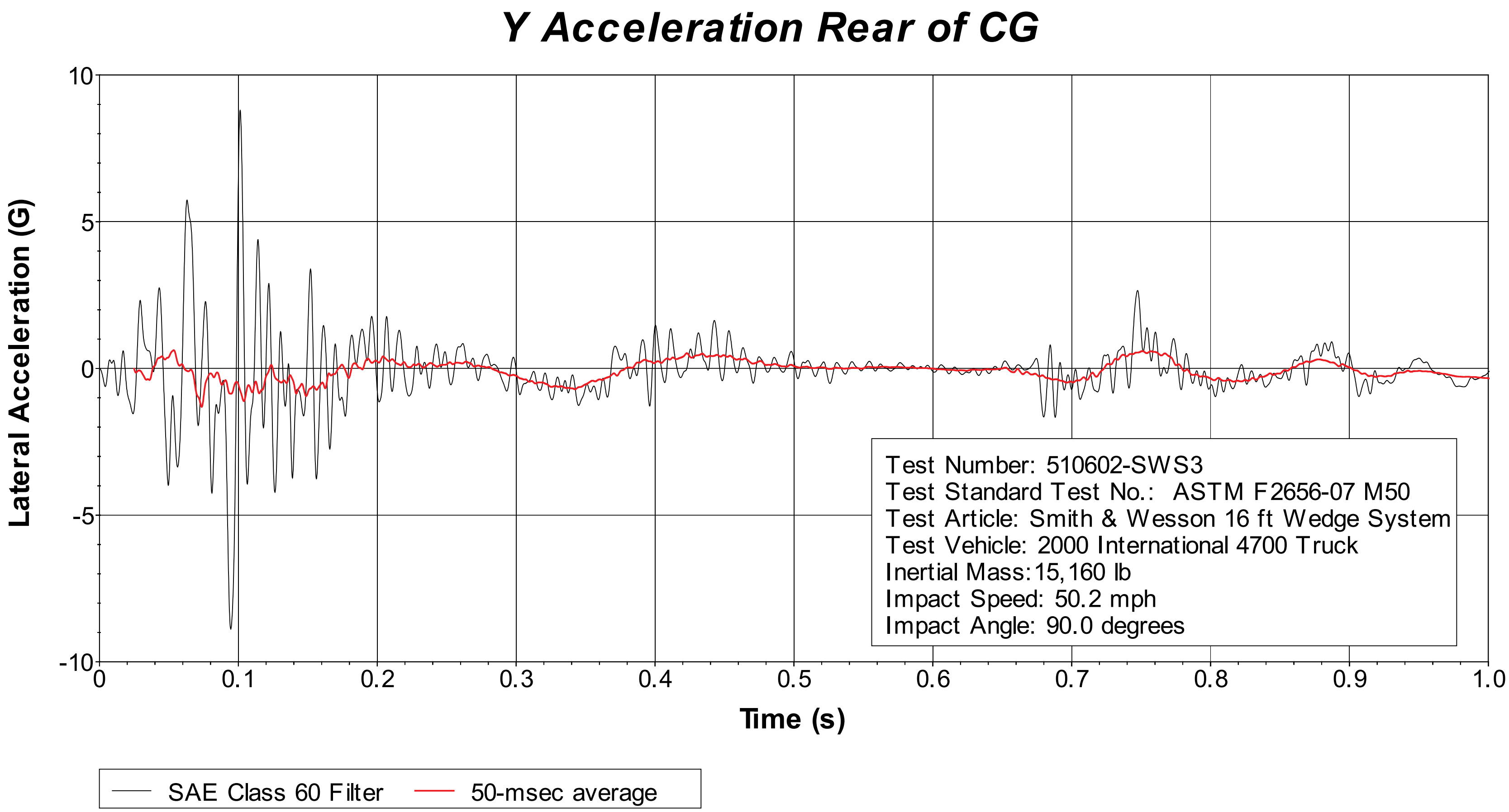


Figure 17. Vehicle lateral accelerometer trace for test 510602-SWS3 (accelerometer located rear of center of gravity).

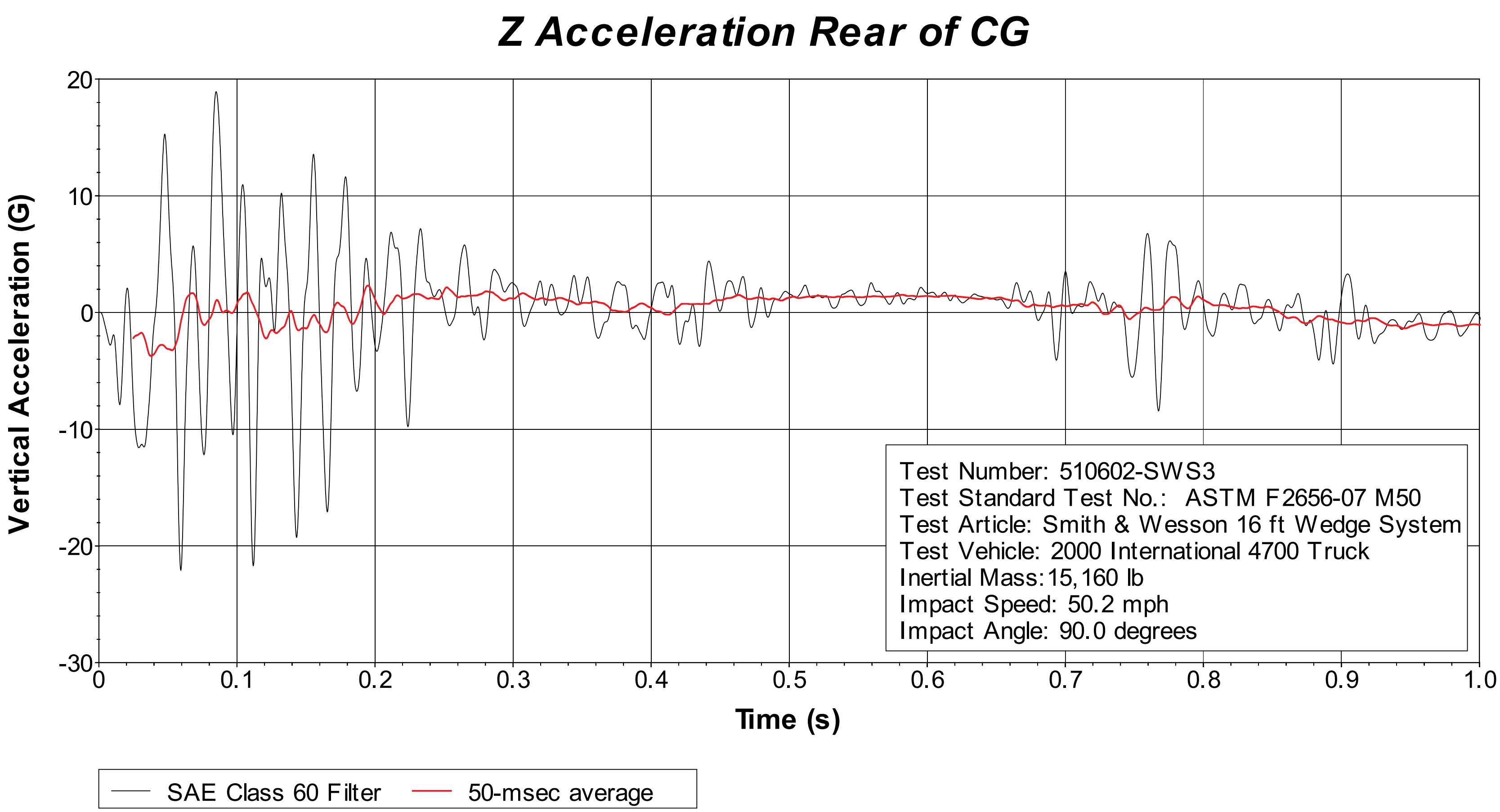


Figure 18. Vehicle vertical accelerometer trace for test 510602-SWS3
(accelerometer located rear of center of gravity).