ENCLOSURE 3

Texas Transportation Institute, "DOS K12 Crash Test and Evaluation of the HESCO C-3315 Flood Barrier," April 2005

Texas Transportation Institute

DOS K12 CRASH TEST AND EVALUATION OF THE HESCO C-3315 FLOOD BARRIER

by

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Contract No.: P2005003
Project/Test No.: 400001-HBL2
Test Date: 12-17-2004

Sponsored by
HESCO Bastion Ltd.

April 2005

TEXAS TRANSPORTATION INSTITUTE
THE TEXAS A&M UNIVERSITY SYSTEM
COLLEGE STATION, TEXAS 77843

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KEY WORDS

Anti-ram; perimeter; crash testing; barriers; gates; bollards; walls; fences; homeland security.

Technical Report Documentation Page

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle DOS K12 Crash Test and Evaluation of the HESCO C-3315 Flood Barrier		5. Report Date April 2005 6. Performing Organization Code
7. Author(s) Dean C. Alberson, Wanda L. Menges, and Rebecca R. Haug		8. Performing Organization Report No. 400001-HBL2
9. Performing Organization Name and Address Texas Transportation Institute The Texas A&M University System College Station, Texas 77843-3135		10. Work Unit No. (TRAIS) 11. Contract or Grant No. P2005003
12. Sponsoring Agency Name and Address HESCO Bastion Ltd. 47152 Conrad E. Anderson Drive Hammond, LA 70401		13. Type of Report and Period Covered Test Report: November 2004 – January 2005 14. Sponsoring Agency Code

15. Supplementary Notes

Research Study Title: Crash Testing HESCO Bastion Ltd Concertainers (HBLC) to U.S. State Department K-12

Name of Contacting Representative: Col. (ret) Jere Cook

16. Abstract

The objective of this test is to determine if the HESCO Bastion Ltd. C-3315 flood barrier is capable of arresting a 6810 kg (15,000 lb) truck traveling at 80 km/h (50 mi/h) with 1.0 m (3.3 ft) of vehicle partial penetration and/or deflection. This criterion is based on Condition Designation K12 as stated in *ST-STD-02.01, Revision A*. This condition designation requires the HESCO Bastion Ltd. C-3315 flood barrier to withstand kinetic energy of 1,695,000 J (1,250,000 ft-lb).

This report presents the construction details of the HESCO Bastion Ltd. C-3315 flood barrier, details of the vehicle used in the test, details of the test, and the assessment of the test results. Target impact speed was 75.0 km/h or above (47.0 to 56.9 mi/h), and the actual impact speed was 81.0 km/h (50.3 mi/h). The 1995 International 4700 single-unit flatbed truck impacted the barrier at 90 degrees, with the centerline of the vehicle aligned with the centerline of the barrier. The HESCO C-3315 barrier brought the vehicle to a complete stop with minimal penetration of the vehicle. The front of the cargo bed did not penetrate the inside edge of the barrier and came to rest 0.85 m (2.8 ft) from the inside edge of the barrier.

ST-STD-02.01, Revision A performance criteria limits penetration of the leading edge of the cargo bed to 1 m beyond the pre-impact, inside edge of the barrier. As stated above, the cargo bed did not penetrate the inside edge of the barrier. The actual impact speed was within the permissible range to receive the designated K12 condition level. According to the results of the full-scale crash test, the HESCO Bastion C-3315 flood barrier, as constructed in this test configuration, met the requirements for Condition Designation K12.

17. Key Words	18. Distribution Statement
anti-ram; perimeter; crash testing; barriers; gates; bollards; walls; fences; homeland security	Copyrighted. Not to be copied or reprinted without consent from HESCO Bastion Ltd.

19. Security Classif.(of this report)	20. Security Classif.(of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	42	

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(Next page is ii)

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 (DS/PSP/PSD) had developed guidelines to evaluate the performance of perimeter barriers/gates. The March 2003 standard, *SD-STD-02.01, Revision A – Test Method for Vehicle Crash Testing of Perimeter Barriers and Gates,* used to evaluate the performance of an anti-terrorist protection barrier.[1] According to these guidelines, performance of the anti-terrorist protection barrier 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 HESCO Bastion Ltd. C-3315 flood barrier evaluated herein was designed by HESCO Bastion Ltd. The intended function of this design is to provide road closure capable of arresting an attacking vehicle.

BACKGROUND

The procedures set out in *SD-STD-02.01, Revision A* were intended to ensure that perimeter barriers/gates provide a specified level of vehicle impact resistance as recommended by the DS/PSP/PSD. The assessment criteria are based on the capability of the barrier/gate to arrest the vehicle such that it does not penetrate or vault over the system. Three levels of performance are defined based on the amount of vehicular impact kinetic energy the barrier/gate is capable of arresting. *SD-STD-02.01, Revision A* also limits the penetration of the leading edge of the cargo bed to one meter (3.3 ft) beyond the pre-impact, inside edge of the barrier. If the barrier meets this requirement, a pass rating will be assigned at the appropriate speed designation.

OBJECTIVES/SCOPE OF RESEARCH

The objective of this test is to determine if the HESCO Bastion Ltd. C-3315 flood barrier is capable of arresting a 6810 kg (15,000 lb) truck traveling at 80 km/h (50 mi/h) with 1.0 m (3.3 ft) of vehicle partial penetration and/or deflection. This criterion is based on Condition Designation K12 as stated in ST-STD-02.01, Revision A. This condition designation requires the HESCO Bastion Ltd. C-3315 flood barrier to withstand kinetic energy of 1,695,000 J (1,250,000 ft-lb).

This report presents the construction details of the HESCO Bastion Ltd. C-3315 flood barrier, details of the vehicle used in the test, details of the test, and the assessment of the test results.

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TECHNICAL DISCUSSION

TEST PARAMETERS

Test Facility

The test facilities at the Texas Transportation Institute's Proving Ground consist of an 809-hectare (2000-acre) complex of research and training facilities situated 16 km (10 mi) 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 barriers/gates. The site selected for placing of the HESCO Bastion Ltd. C-3315 flood barrier was on a wide out-of-service apron. The apron consists of an unreinforced jointed concrete pavement in 3.8 m x 4.6 m (12.5 ft x 15 ft) blocks nominally 203-305 mm (8-12 in) deep. The apron is about 50 years old and the joints have some displacement, but are otherwise flat and level.

Test Article – Design and Construction

The total installation length of the HESCO Bastion Ltd. C-3315 flood barrier was 9.14 m (30.0 ft). Width at the base was 1.83 m (6.0 ft) and the height of the bottom tier was 0.91 m (3.0 ft). The top tier was identical to the bottom tier. Overall height of the test installation was 1.83 m (6.0 ft).

The HESCO Bastion Ltd. C-3315 flood barriers are constructed with welded wire sheets to form open top cubes that measured 0.91 m (3.0 ft) wide by 0.91 m (3.0 ft) tall. The welded wire was 4mm (0.158 in) diameter and was welded on a 76 mm x 76 mm (3.0 in x 3.0 in) grid. A series of 5 cubes came pre-assembled and lined with 2mm (0.8 in) non-woven polypropylene geotextile fabric. Corners of the HESCO Bastion Ltd. C-3315 flood barriers are formed with coiled 4 mm (0.158 in) wire. The coils are 32 mm (1.25 in) diameter with a coil pitch of 25 mm (1.0 in). Pre-assembled units are joined with adjacent units by overlapping wire coils and placing a 4mm (0.158 in) joining pin in the overlapped section of coils.

The HESCO Bastion Ltd. C-3315 flood barriers were filled with a reddish-tan silty, clayey sand, designated as select fill from the Kelly Burt pit. The density of the fill material was 1900 kg/cubic meter (118.5 lbs/cubic ft) and was manually tamped by HESCO installers. Details of the installation are shown in figures 1 and 2. Photographs of the completed installation are shown in figure 3.

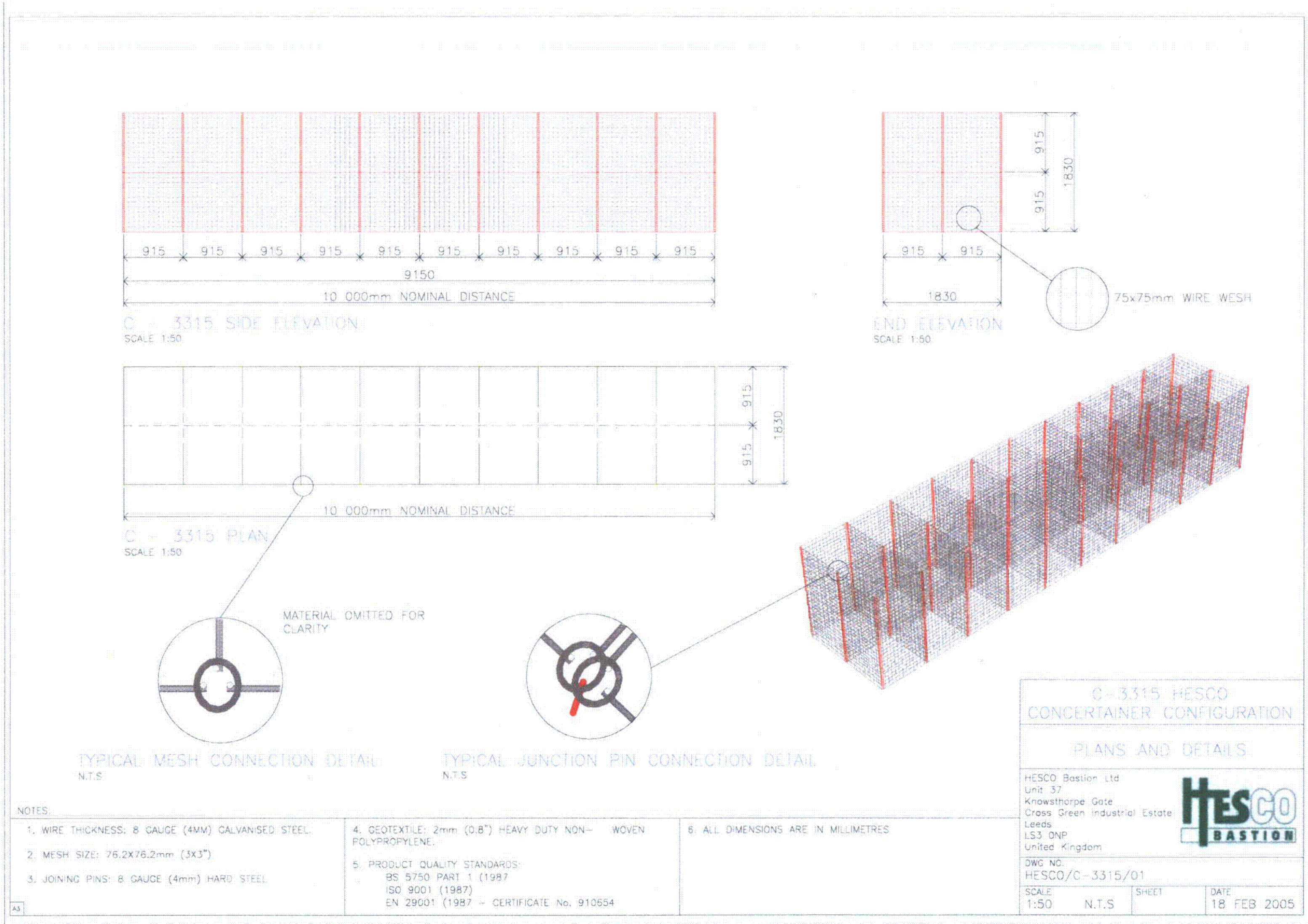

Figure 1. Details of HESCO C-3315 flood barrier.

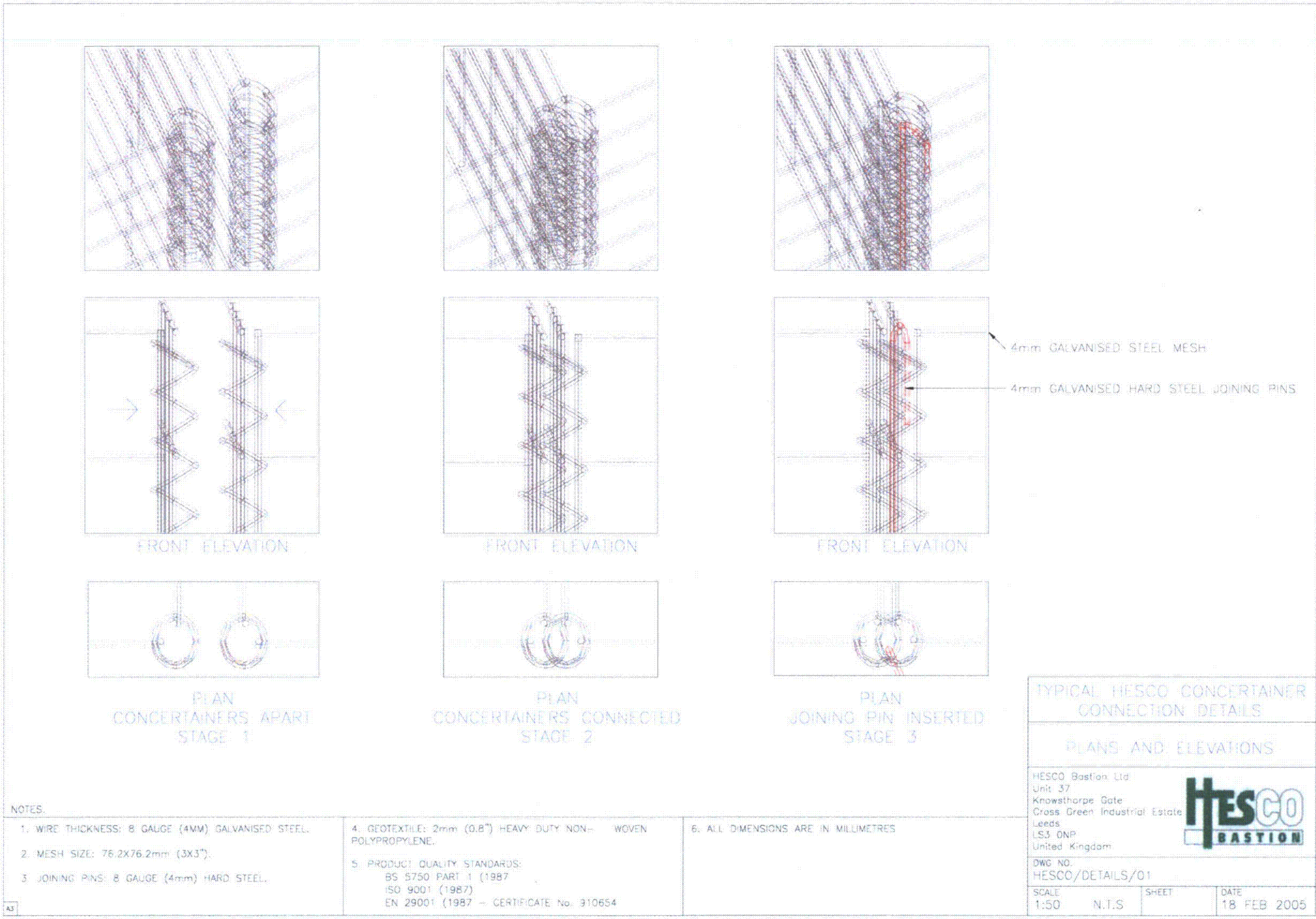

Figure 2. Connection details of HESCO C-3315 flood barrier.

Figure 3. HESCO C-3315 flood barrier prior to testing.

Test Conditions and Evaluation Criteria

According to *SD-STD-02.01, Revision A,* the test article can be rated according to one of three designated condition levels as shown in table 1. The test procedures are intended to ensure that perimeter barriers and gates will provide a specified level of vehicle impact resistance. Actual vehicle speed must be within a permissible range to receive the condition designation. *ST-STD-02.01, Revision A* performance criteria limits penetration of the leading edge of the cargo bed to 1 m beyond the pre-impact, inside edge of the barrier. If the barrier meets this requirement, a pass rating will be assigned at the appropriate speed designation as shown in table 1. The test vehicle specified is a medium duty truck with diesel engine, tested at a gross vehicle weight of 6,800 kg (15,000 lb) ±90 kg (200 lb).

Table 1. Impact condition designations.*

Nominal Impact Speed	***Permissible Impact Speed Range***	***Kinetic Energy***	***Designation***
80 kph *50 mph*	*75.0 kph-above* *47.0-56.9 mph*	*1,695,000 J* *1,250,000 ft-lb*	*K12*
65 kph *40 mph*	*60.1-75.0 kph* *38.0-46.9 mph*	*1,085,000 J* *800,000 ft-lb*	*K8*
50 kph *30 mph*	*45.0-60.0 kph* *28.0-37.9 mph*	*610,000 J* *450,000 ft-lb*	*K4*

* Table taken directly from *SD-STD-02.01, Revision A*, March 2003.

The crash test and data analysis procedures were in accordance with guidelines presented in *SD-STD-02.01, Revision A*. Appendix A presents brief descriptions of these procedures.

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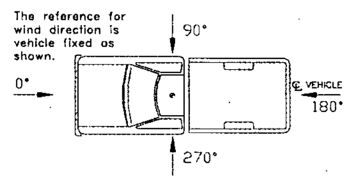
CRASH TEST 400001-HBL2 (*SD-STD-02.01* CONDITION DESIGNATION K12)

Test Vehicle

A 1995 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 6867 kg (15,140 lb). The height to the lower edge of the vehicle front bumper was 514 mm (20.25 inches), and the height to the upper edge of the front bumper was 800 mm (31.5 inches). Figure 11 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 morning of December 17, 2004. Weather conditions at the time of testing were: Wind Speed: 5 km/h (3 mi/h); Wind Direction: 0 degrees with respect to the vehicle (vehicle was traveling in a northerly direction); Temperature: 9°C (49°F); Relative Humidity: 78 percent.



Impact Description

The 1995 International 4700 single-unit flatbed truck, traveling at a speed of 81.0 km/h (50.3 mi/h), impacted the HESCO Bastion Ltd. C-3315 flood barrier at an impact angle of 90.8 degrees, with the centerline of the vehicle aligned with the centerline of the barrier. Shortly after impact, the hood of the vehicle separated from the vehicle near the cab. At 0.054 s, the head rack of the truck bed contacted the rear of the cab. The inside edge of the bottom row of box units began to move toward the inside of the barrier at 0.060 s, and the top row began to move toward inside of the barrier at 0.078 s. The strap on the front row of the box units separated at 0.560 s. At 0.800 s, the vehicle reached maximum penetration of the front of the truck bed of 1.1 m (3.7 ft) into the barrier (or 0.8 m (2.9 ft) from the impact side of the inside edge of the barrier). The vehicle subsequently backed up slightly and came to rest with the front of the cargo bed 0.85 m (2.8 ft) to the impact side of the inside edge of the barrier. The front of the cargo bed did not reach inside edge of the barrier. Appendix C, figures 12 and 13, show sequential photographs of the test period.

Figure 4. Vehicle/installation geometrics for test 400001-HBL2.

Figure 5. Vehicle before test 400001-HBL2.

Damage to Test Article

The wire mesh ruptured and the center rows were damaged. Three rows of box units on each side were intact The ends of the barrier were pulled inward, 150 mm (5.9 inches) on the right side and 140 mm (5.5 inches) on the left side. Soil was scattered over an area to the inside of the barrier, 12.2 m (40 ft) long and 9.1 m (30 ft) wide. Damage to the installation is shown in figures 6 and 7.

Vehicle Damage

Damage to the vehicle is shown in figure 8 and 9. The front of the cargo bed did not penetrate the inside edge of the barrier, and came to rest 0.85 m (2.8 ft) from the inside edge of the barrier.

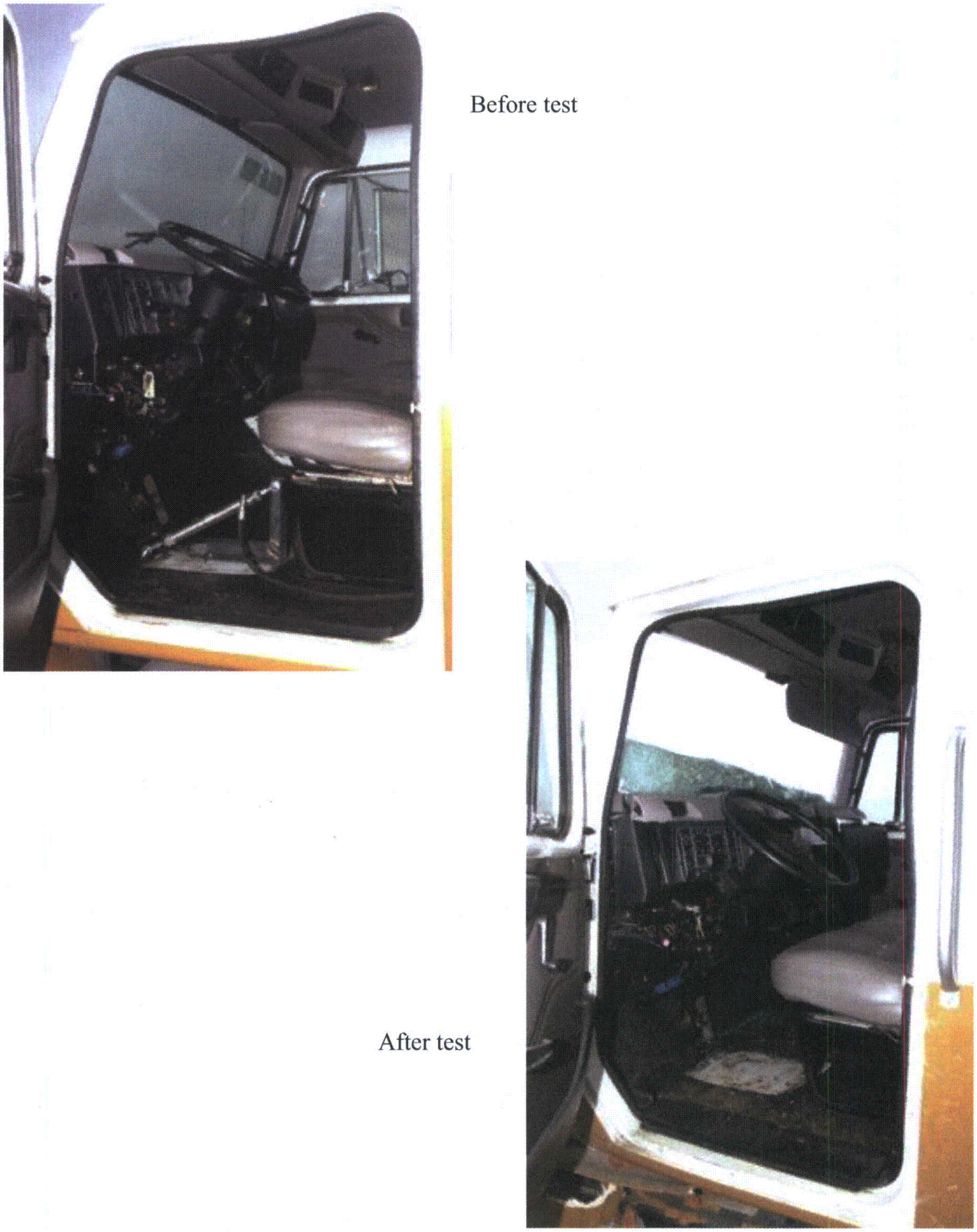
Occupant Risk Factors

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 11.9 m/s (39.0 ft/s) at 0.106 s, the highest 0.010-s occupant ridedown acceleration was -10.6 g's from 0.106 to 0.116 s, and the maximum 0.050-s average acceleration was -14.4 g's between 0.011 and 0.061 s. In the lateral direction, the occupant impact velocity was 0.4 m/s (1.3 ft/s) at 0.106 s, the highest 0.010-s occupant ridedown acceleration was 3.0 g's from 0.113 to 0.123 s, and the maximum 0.050-s average was -1.5 g's between 0.024 and 0.074 s. These data and other pertinent information from the test are summarized in figure 10. Vehicle angular displacements and accelerations versus time traces are presented in appendix D, figures 14 through 19.

Figure 6. Vehicle trajectory path after test 400001-HBL2.

Figure 7. Installation after test 400001-HBL2.

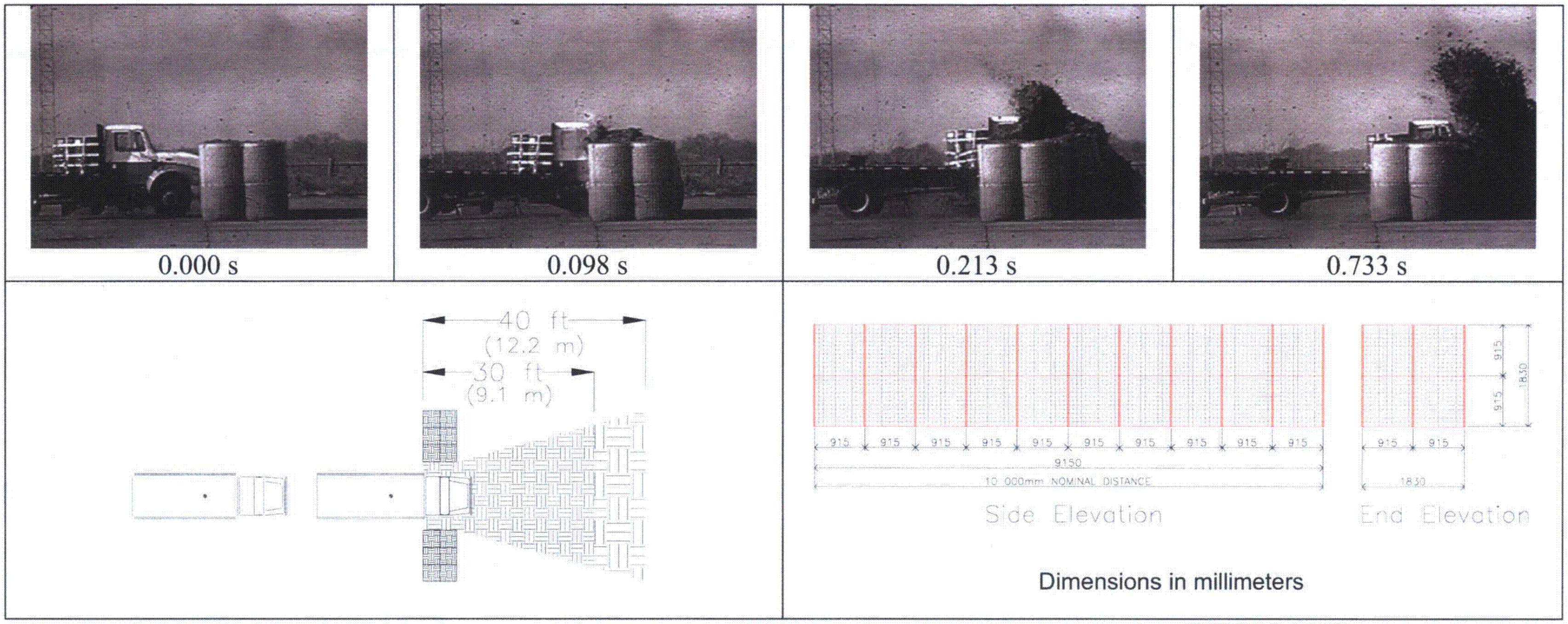
Figure 8. Vehicle after test 400001-HBL2.



Before test

After test

Figure 9. Interior of vehicle for test 400001-HBL2.



General Information

Test Agency	Texas Transportation Institute
Test No.	400001-HBL2
Date	12-17-2004

Test Article

Type	Anti-Ram Barrier
Name	HESCO C-3315 Flood Barrier
Installation Length (m)	4.6
Material or Key Elements	Wire Mesh Box Units with Lining and Filled with Soil

Soil/Foundation Type	Placed on Concrete Surface

Test Vehicle

Type	Production
Designation	K12
Model	1995 International 4700
Mass (kg)	
Curb	5951
Test Inertial	6867
Gross Static	6867

Impact Conditions

Speed (km/h)	81.0
Angle (deg)	90.8

Exit Conditions

Speed (km/h)	Stopped
Angle (deg)	90

Occupant Risk Values

Impact Velocity (m/s)	
Longitudinal	11.9
Lateral	0.4
Ridedown Accelerations (g's)	
Longitudinal	-10.6
Lateral	3.0
Max. 0.050-s Average (g's)	
Longitudinal	-14.4
Lateral	-1.5
Vertical	-2.4

Penetration of Cargo Bed (m)

Distance Beyond Inside Edge of Barrier (m)	-0.85 (did not reach inside edge of barrier)

Figure 10. Summary of results for test *SD-STD-2.01* test K12 on the HESCO C-3315 flood barrier.

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SUMMARY AND CONCLUSIONS

ASSESSMENT OF TEST RESULTS

Target impact speed was 75.0 km/h or above (47.0 to 56.9 mi/h), and the actual impact speed was 81.0 km/h (50.3 mi/h). The 1995 International 4700 single-unit flatbed truck impacted the barrier at 90 degrees, with the centerline of the vehicle aligned with the centerline of the barrier. The HESCO C-3315 barrier brought the vehicle to a complete stop with minimal penetration of the vehicle. The front of the cargo bed did not penetrate the inside edge of the barrier, and came to rest 0.85 m (2.8 ft) from the inside edge of the barrier.

CONCLUSIONS

ST-STD-02.01, Revision A performance criteria limits penetration of the leading edge of the cargo bed to 1 m beyond the pre-impact, inside edge of the barrier. As stated above, the cargo bed did not penetrate the inside edge of the barrier. The actual impact speed was within the permissible range to receive the designated K12 condition level. According to the results of the full-scale crash test, the HESCO Bastion C-3315 flood barrier, as constructed in this test configuration, met the requirements for Condition Designation K12.

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REFERENCES

1. "Test Method for Vehicle Crash Testing of Perimeter Barriers and Gates," *SD-STD-02.01, Revision A*, Physical Security Division, United States Department of State, Washington, D.C., March 2003.

2. H. E. Ross, Jr., D. L. Sicking, R. A. Zimmer and J. D. Michie, *Recommended Procedures for the Safety Performance Evaluation of Highway Features*, National Cooperative Highway Research Program Report 350, Transportation Research Board, National Research Council, Washington, D.C., 1993.

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APPENDIX A. CRASH TEST PROCEDURES AND DATA ANALYSIS

The crash test and data analysis procedures were in accordance with guidelines presented in *SD-STD-2.01, Revision A*. Brief descriptions of these procedures are presented as follows.

ELECTRONIC INSTRUMENTATION AND DATA PROCESSING

The test vehicle was instrumented with three solid-state angular rate transducers to measure roll, pitch, and yaw rates; a triaxial accelerometer near the vehicle center of gravity (c.g.) to measure longitudinal, lateral, and vertical acceleration levels; and a backup biaxial accelerometer in the rear of the vehicle to measure longitudinal and lateral 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. Angular rate transducers are solid state, gas flow units designed for high-"g" service. 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 and rate transducers are transmitted to a base station by means of a 15-channel, constant-bandwidth, Inter-Range Instrumentation Group (IRIG), FM/FM telemetry link for recording on magnetic tape and for display on a real-time strip chart. 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 by wooden dowels 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.

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.

TRAP uses the data from the yaw, pitch, and roll rate transducers to compute angular displacement in degrees at 0.0001-s intervals and then plots yaw, pitch, and roll versus time. These displacements are in reference to the vehicle-fixed coordinate system with the initial position and orientation of the vehicle-fixed coordinate systems being initial impact.

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 BetaCam, a VHS-format video camera and recorder, 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.

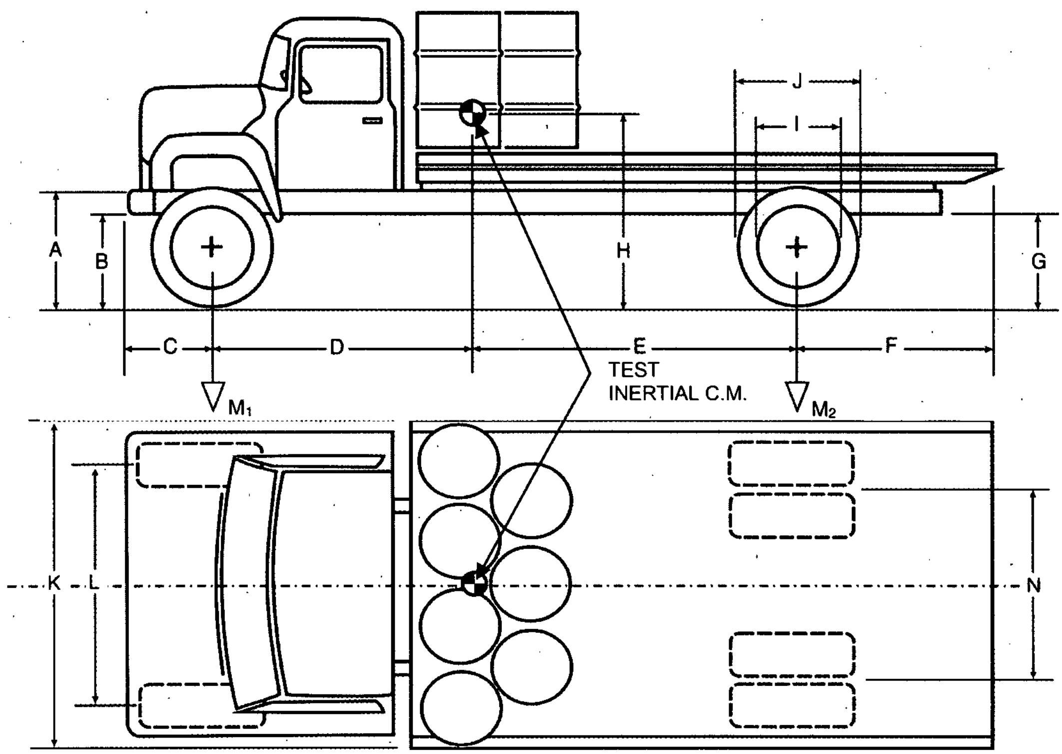
APPENDIX B. TEST VEHICLE PROPERTIES AND INFORMATION

SD-STD-2.01, Revision A, March 2003
Vehicle Measurements for State Department Testing

DATE: 12-17-2004 TEST NO.: 400001-HBL2 VIN NO.: 1HTSCABN2SH207933

YEAR: 1995 MAKE: International MODEL: 4700

TIRE SIZE: 275/80/R22.5 ODOMETER: 025522



GEOMETRY (cm)

A	800	B	514	C	775	D	2623	E	2534	F	2794	G	737
H		I	597	J	1003	K	2445	L	2045	N	1854		

MASS DISTRIBUTION (kg)

LF	1696	RF	1678	LR	1783	RR	1710

MASS (kg)	CURB	TEST INERTIAL
M_1	2889	3375
M_2	3062	3493
M_{Total}	5951	6868

Figure 11. Vehicle properties for test 400001-HBL2.

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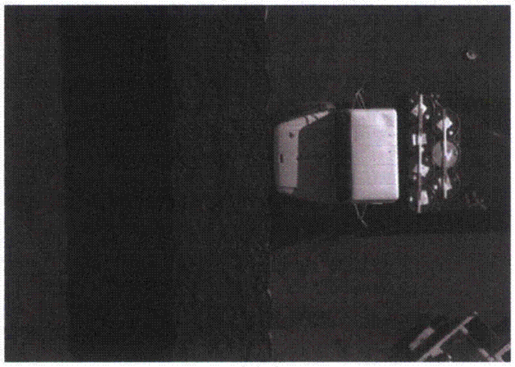
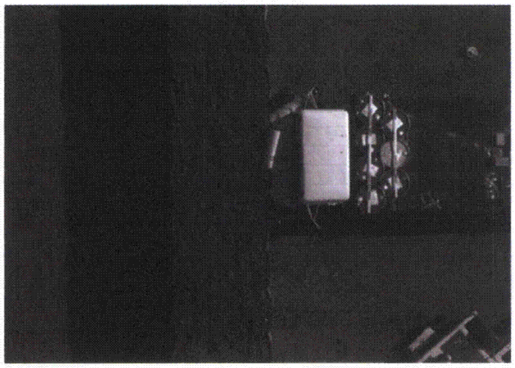
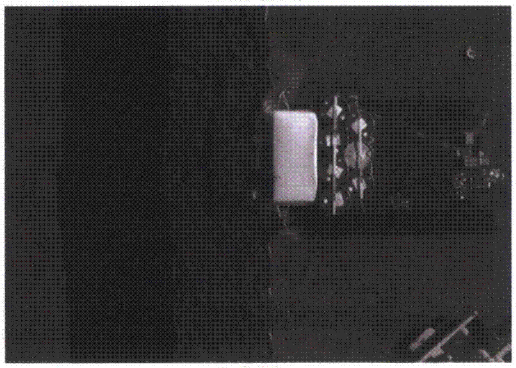
APPENDIX C. SEQUENTIAL PHOTOGRAPHS



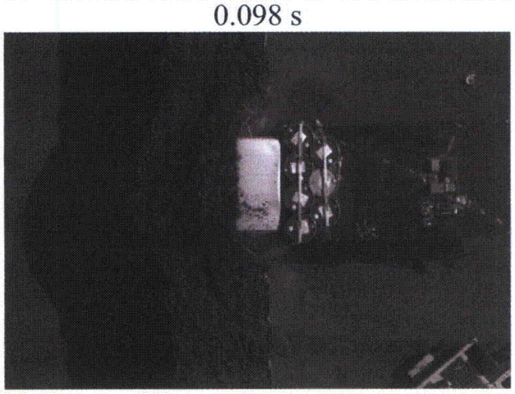
0.000 s



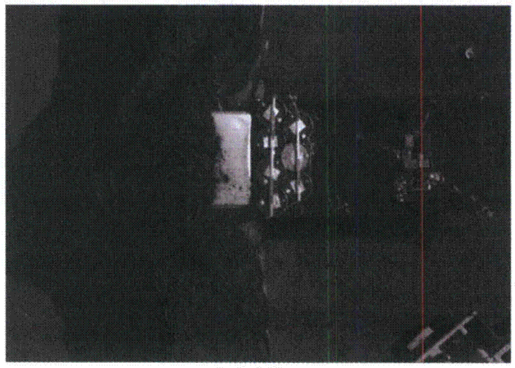
0.048 s



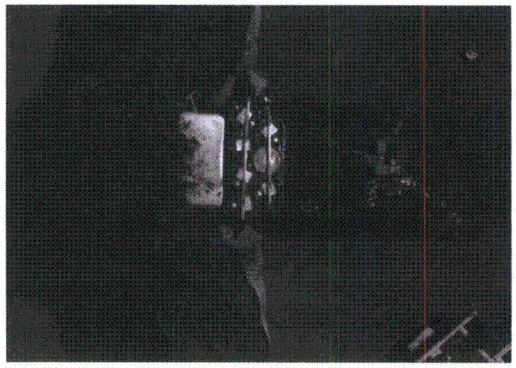
0.098 s



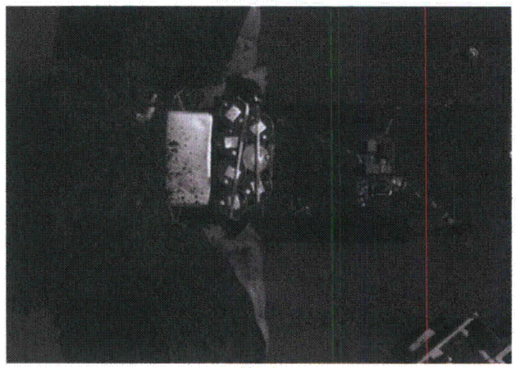
0.196 s



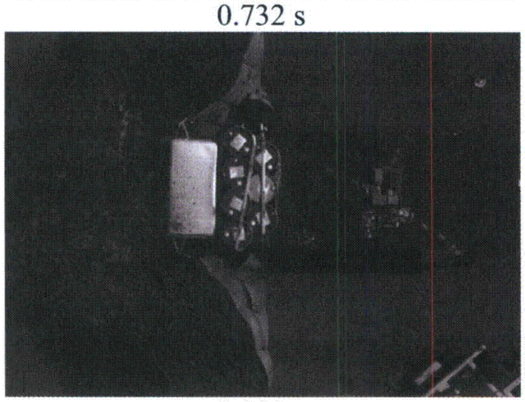
0.318 s



0.526 s



0.732 s



0.990 s

Figure 12. Sequential photographs for test 400001-HBL2 (overhead view).

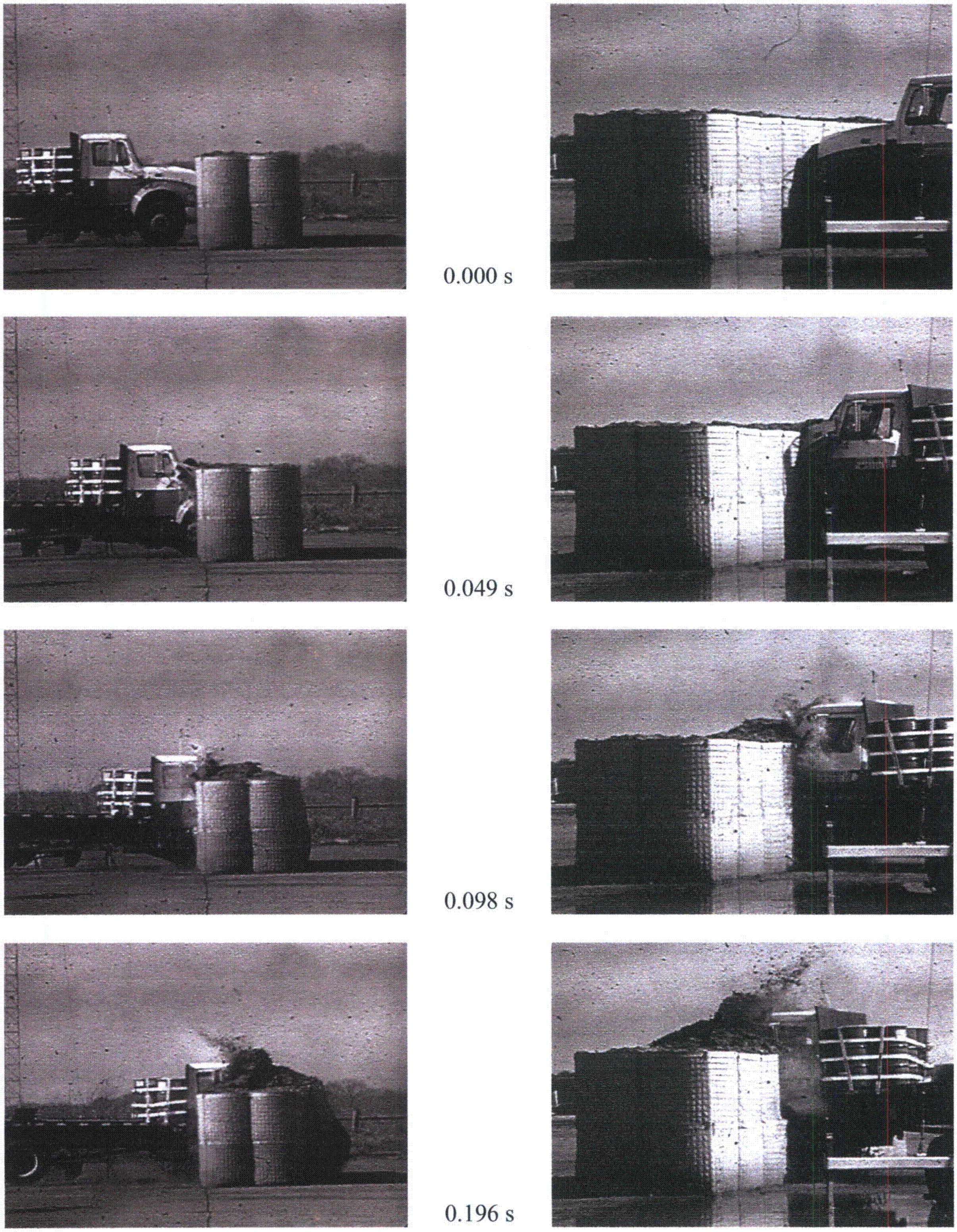


Figure 13. Sequential photographs for test 400001-HBL2
(perpendicular and oblique views).

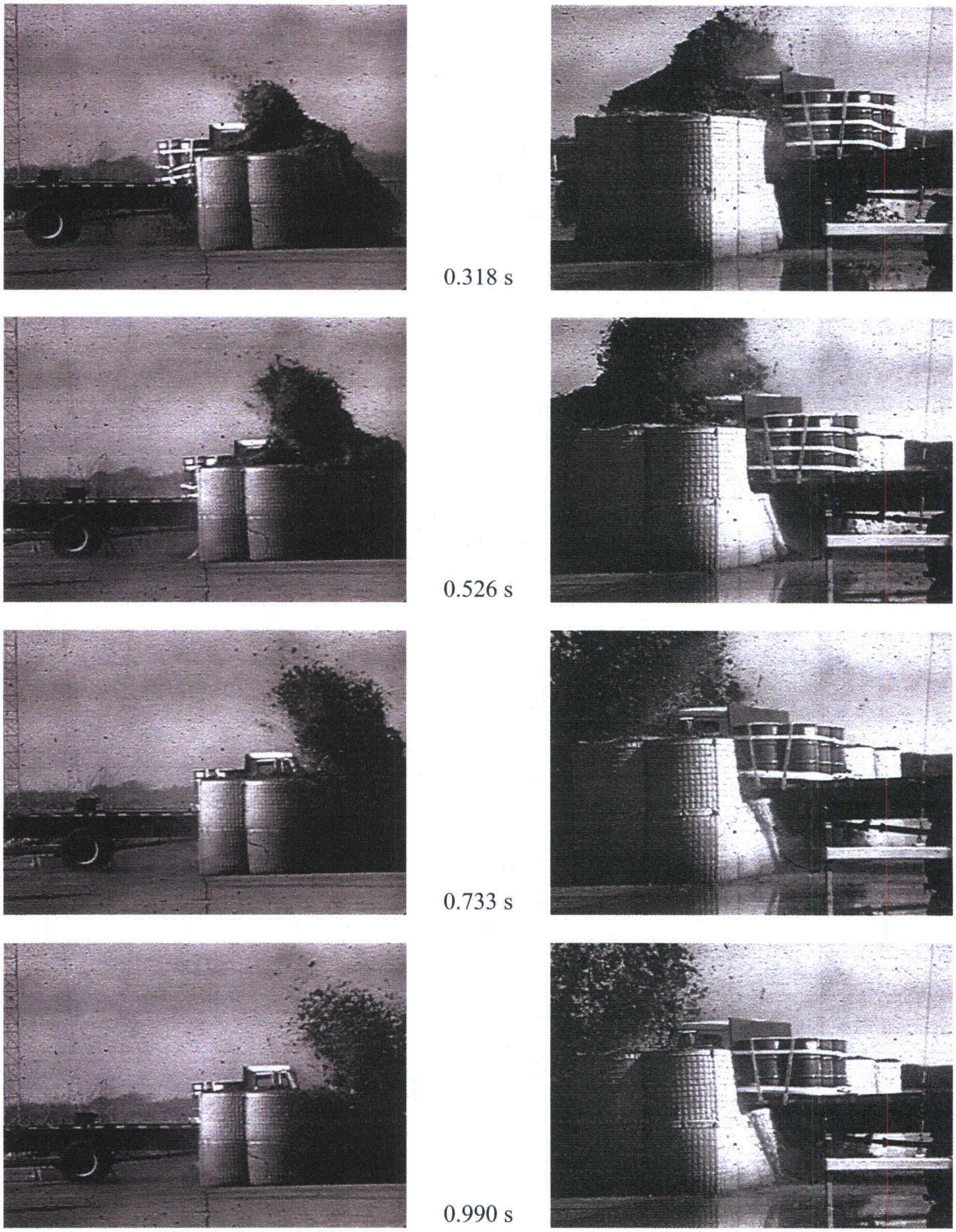


Figure 13. Sequential photographs for test 400001-HBL2 (perpendicular and oblique views) (continued).

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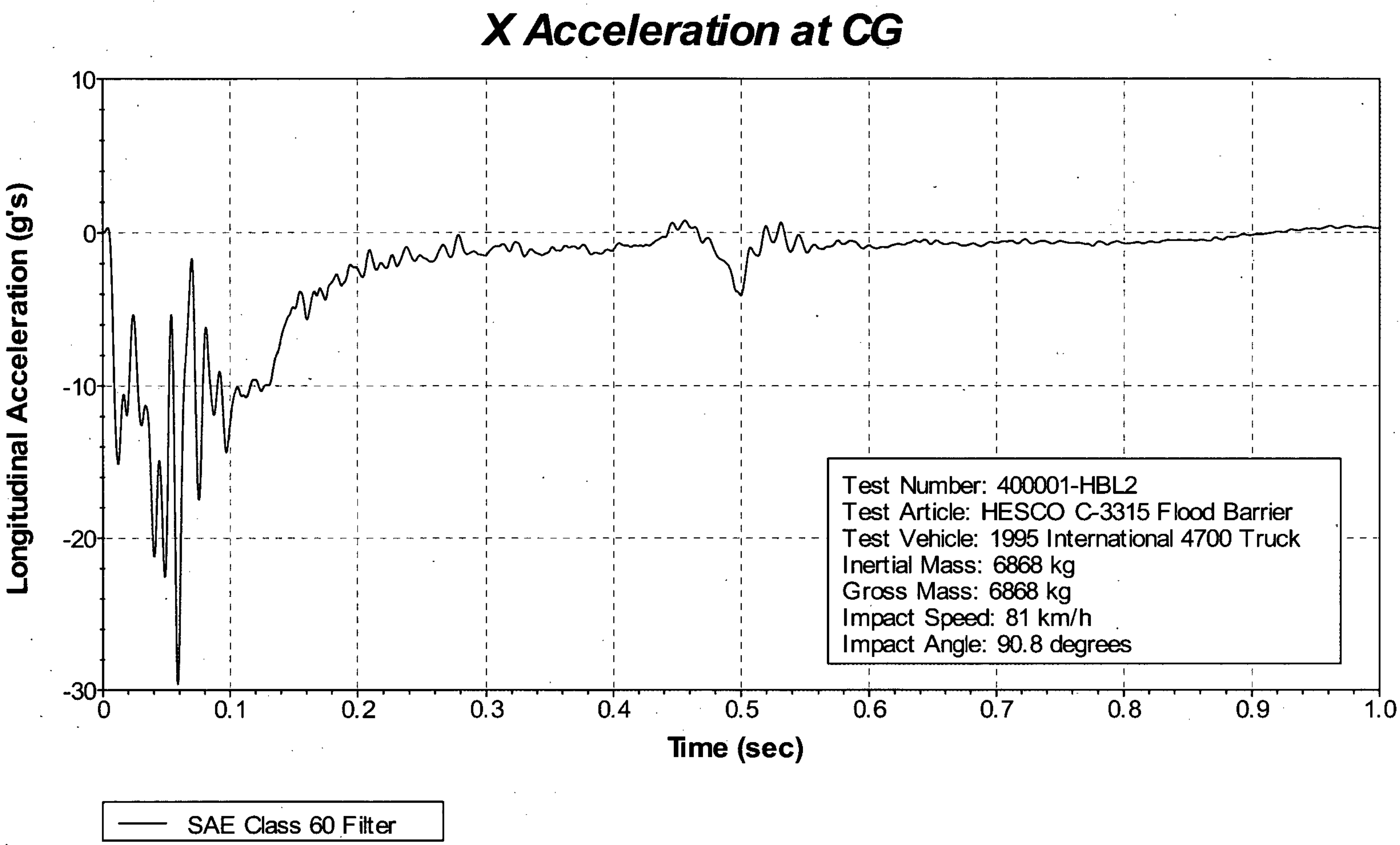

Figure 14. Vehicle longitudinal accelerometer trace for test 400001-HBL2
(accelerometer located at center of gravity).

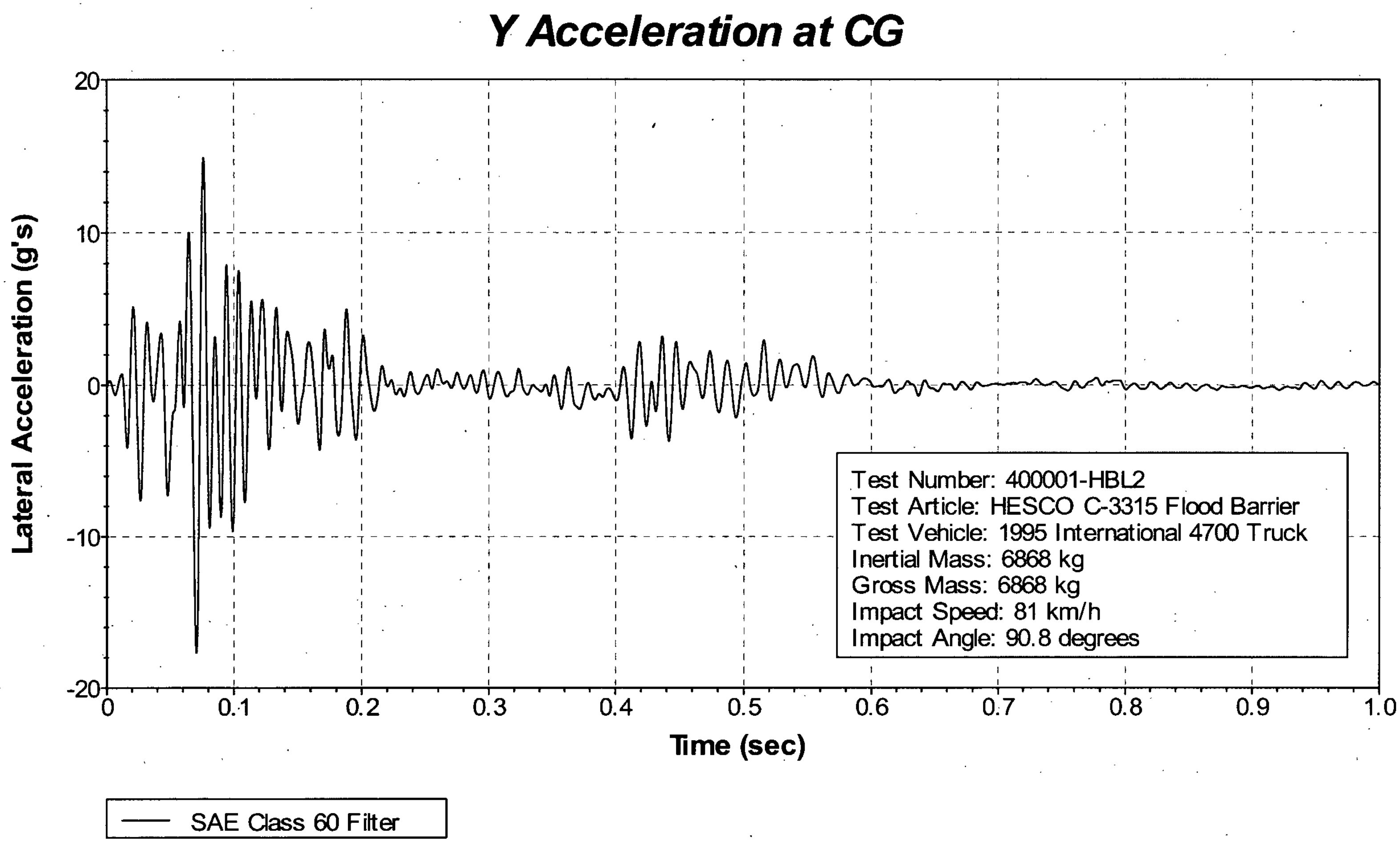

Figure 15. Vehicle lateral accelerometer trace for test 400001-HBL2 (accelerometer located at center of gravity).

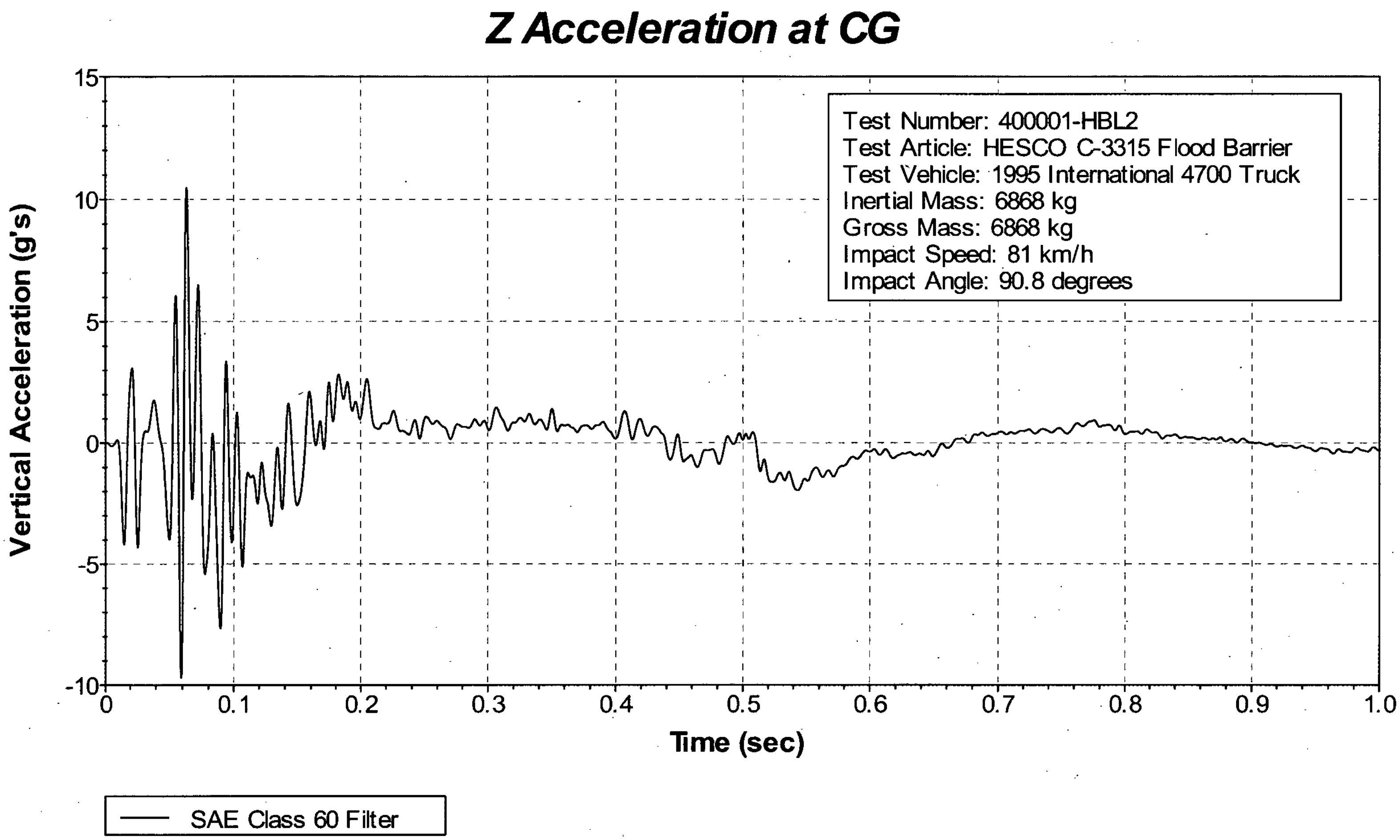

Figure 16. Vehicle vertical accelerometer trace for test 400001-HBL2
(accelerometer located at center of gravity).

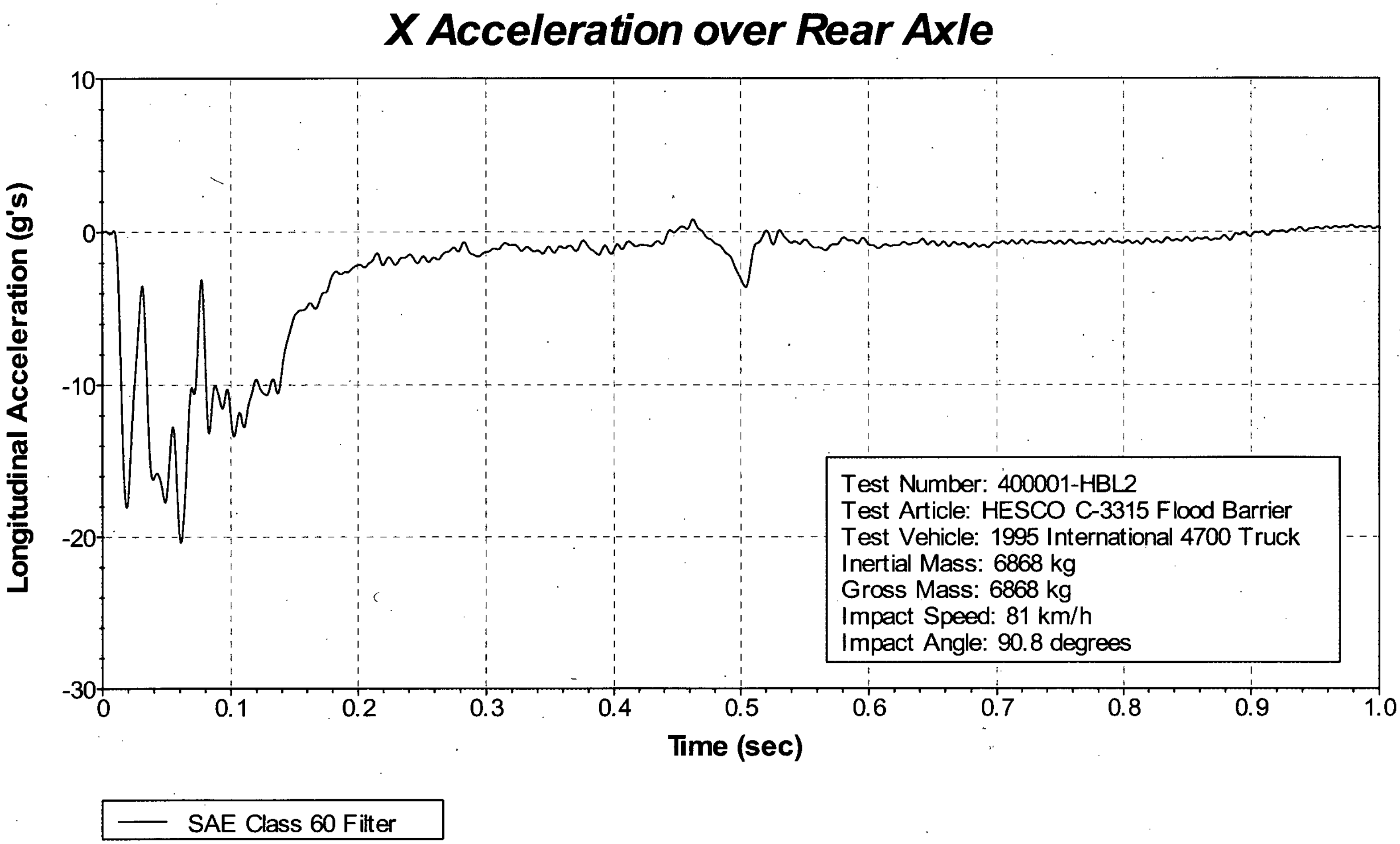

Figure 17. Vehicle longitudinal accelerometer trace for test 400001-HBL2 (accelerometer located over rear axle).

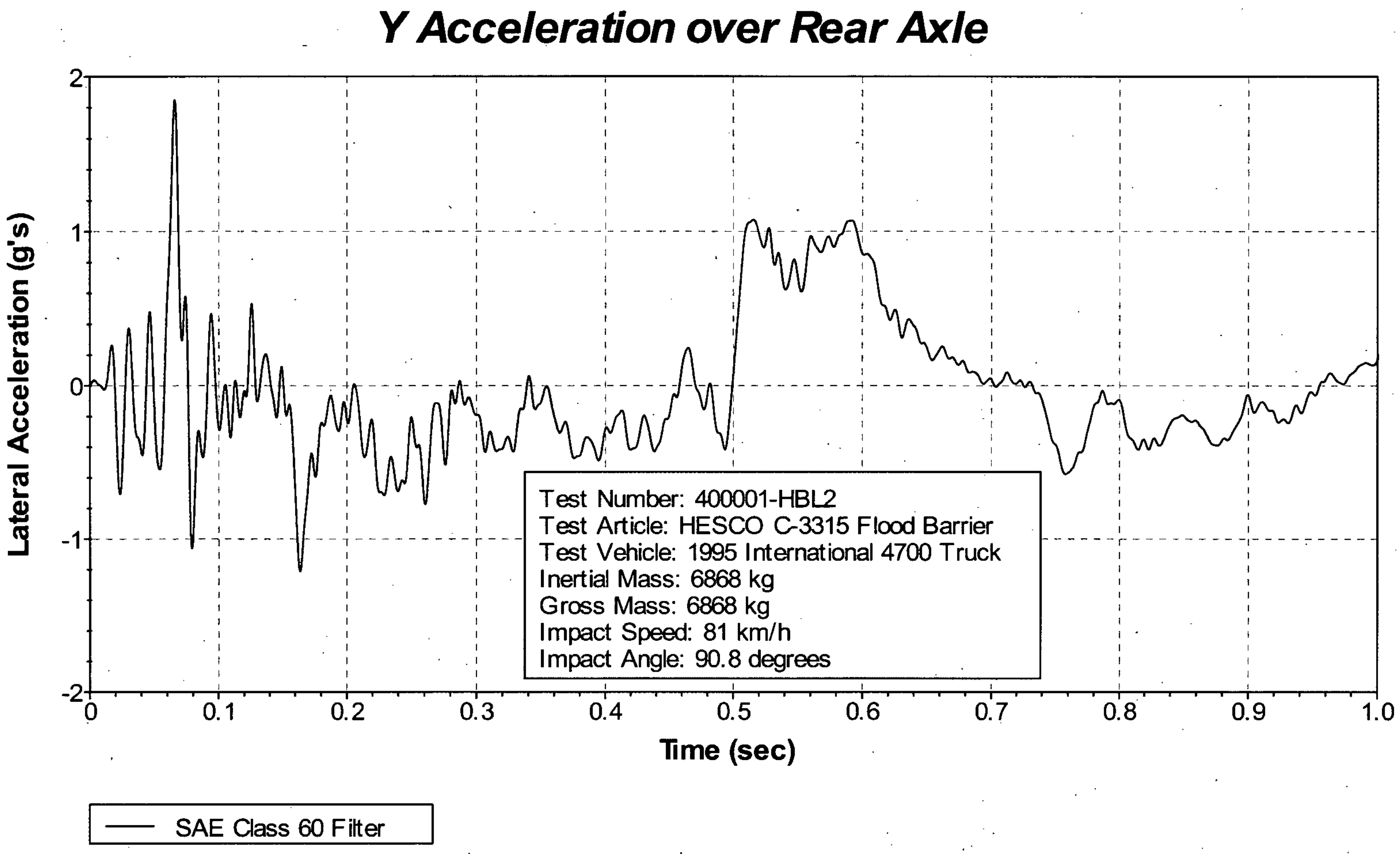

Figure 18. Vehicle lateral accelerometer trace for test 400001-HBL2 (accelerometer located over rear axle).

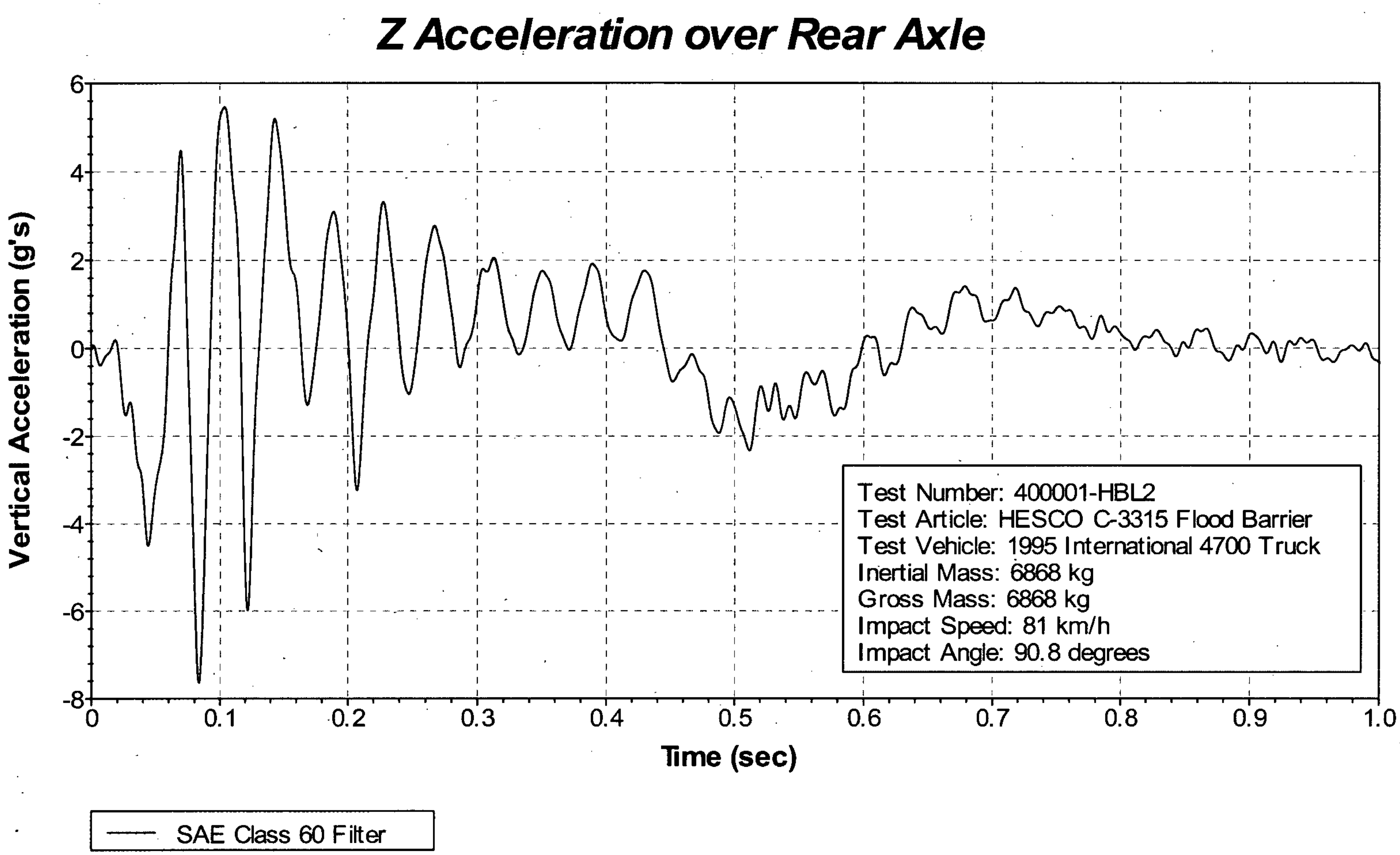

Figure 19. Vehicle vertical accelerometer trace for test 400001-HBL2 (accelerometer located over rear axle).