Texas Transportation Institute
PROVING GROUND

CRASH TESTING AND EVALUATION OF BEXAR CONCRETE WORKS F-SHAPE CONCRETE TRAFFIC BARRIER (CTB) WITH QUICK-BOLT CONNECTION

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THE TEXAS A&M UNIVERSITY SYSTEM
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KEY WORDS

Longitudinal barriers, precast concrete barriers, portable concrete barriers, PCB, crash testing, roadside safety

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16. Abstract

Portable concrete barriers are often used to provide positive protection for motorists and workers in a highway work zone. Most highway work zones are restricted in terms of available lateral space for accommodating traffic and the work activity. Consequently, it is desirable to minimize the deflection of work zone barriers in order to minimize the required buffer distance between the barrier and work activity area and, thereby, maximize the space and number of lanes available for traffic.

Under this project, the impact performance of a new connection for portable concrete traffic barriers developed by Bexar Concrete Works I, LTD was evaluated. The new Quick-Bolt connection involves two 7/8-inch diameter threaded rods that span across the barrier joint along the vertical centerline of the barrier. During movement and transport of the barrier segments, the connection rods are stored inside bolt retraction cavities precast into the barrier ends. After placement of the barriers, the connection rods are fed across the joint into the adjacent barrier segment through PVC pipe sleeves with the aid of hand holes. The rods are secured in place with nuts and washers on each end.

A barrier system comprised of 30-ft long segments of F-shape barrier attached with the Quick-Bolt connection was crash tested following the impact conditions of Test Designation 3-11 of the AASHTO *Manual for Assessing Safety Hardware (MASH08)*. This test involves a 5,000-lb pickup impacting the critical impact location along the length of the barrier at a nominal speed of 62 mi/h and a nominal angle of 25 degrees. The F-shape barrier with Quick-Bolt connection met all of the required performance evaluation criteria. The maximum dynamic deflection of the barrier was 31.0 inches.

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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)

TABLE OF CONTENTS

Section			Page
1.	INTRODUCTION		1
	1.1	BACKGROUND	1
	1.2	OBJECTIVES/SCOPE OF RESEARCH	1
2.	SYSTEM DETAILS		3
	2.1	TEST ARTICLE DESIGN AND CONSTRUCTION	3
	2.2	MATERIAL SPECIFICATIONS	3
	2.4	SOIL CONDITIONS	3
3.	TEST REQUIREMENTS AND EVALUATION CRITERIA		7
	3.1	CRASH TEST MATRIX	7
	3.2	EVALUATION CRITERIA	7
4.	TEST CONDITIONS		9
	4.1	TEST FACILITY	9
	4.2	VEHICLE TOW AND GUIDANCE SYSTEM	9
	4.3	DATA ACQUISITION SYSTEMS	9
	4.3.1	Vehicle Instrumentation and Data Processing	9
	4.3.2	Anthropomorphic Dummy Instrumentation	11
	4.3.3	Photographic Instrumentation and Data Processing	11
5.	CRASH TEST 400001-BCW1 (*MASH08* TEST NO. 3-11)		13
	5.1	TEST DESIGNATION AND ACTUAL IMPACT CONDITIONS	13
	5.2	TEST VEHICLE	13
	5.3	WEATHER CONDITIONS	13
	5.4	TEST DESCRIPTION	13
	5.5	TEST ARTICLE AND COMPONENT DAMAGE	16
	5.6	TEST VEHICLE DAMAGE	16
	5.7	OCCUPANT RISK VALUES	16
	5.8	ASSESSMENT OF TEST RESULTS	22
	5.8.1	Structural Adequacy	22
	5.8.2	Occupant Risk	22
	5.8.3	Vehicle Trajectory	23
6.	SUMMARY AND CONCLUSIONS		25
	6.1	SUMMARY OF RESUTLS	25
	6.2	CONCLUSIONS	25
REFERENCES			27
APPENDIX A.	DETAILS OF TEST ARTICLE		A-1
APPENDIX B.	CRASH TEST NO. 400001-BCW1		B-1
	B1.	VEHICLE PROPERTIES AND INFORMATION	B-1
	B2.	SEQUENTIAL PHOTOGRAPHS	B-5
	B3.	VECHICLE ANGULAR DISPLACEMENTS	B-8
	B4.	VEHICLE ACCELERATIONS	B-9

LIST OF FIGURES

Page

Figure 2.1. Details of the Bexar Concrete Works I, LTD F-shape CTB with Quick-bolt connection – sheet 1 of 2. 4
Figure 2.2. Details of the Bexar Concrete Works I, LTD F-shape CTB with Quick-bolt connection – sheet 2 of 2. 5
Figure 2.3. Bexar Concrete Works I, LTD F-shape CTB with Quick-bolt connection prior to testing. 6
Figure 5.1. Vehicle/installation geometrics for test 400001-BCW1. 14
Figure 5.2. Vehicle before test 400001-BCW1. 15
Figure 5.3. Vehicle trajectory path after test 400001-BCW1. 17
Figure 5.4. Installation after test 400001-BCW1. 18
Figure 5.5. Vehicle after test 400001-BCW1. 19
Figure 5.6. Interior of vehicle for test 400001-BCW1. 20
Figure 5.7. Summary of results for *NCHRP Report 350* test 3-11 on Bexar Concrete Works F-shape CTB with Quick-Bolt connection. 21
Figure B1. Vehicle properties for test 400001-BCW1. ..... B-1
Figure B3. Sequential photographs for test 400001-BCW1 (rear view). B-5
Figure B2. Sequential photographs for test 400001-BCW1 (overhead and frontal views). B-6
Figure B4. Vehicle angular displacements for test 400001-BCW1. ..... B-8
Figure B5. Vehicle longitudinal accelerometer trace for test 400001-BCW1 (accelerometer located at center of gravity). B-9
Figure B6. Vehicle lateral accelerometer trace for test 400001-BCW1 (accelerometer located at center of gravity). B-10
Figure B7. Vehicle vertical accelerometer trace for test 400001-BCW1 (accelerometer located at center of gravity). B-11

LIST OF TABLES

Page

Table 6.1. Performance evaluation summary for *MASH08* test 3-11 on the Bexar Concrete Works F-Shape CTB with Quick-Bolt Connection. 26
Table B1. Vehicle parametric measurements for test 400001-BCW1..... B-2
Table B2. Exterior crush measurements for test 400001-BCW1. ..... B-3
Table B3. Occupant compartment measurements for test 400001-BCW1..... B-4

1. INTRODUCTION

1.1 BACKGROUND

Portable concrete barriers are often used to provide positive protection for motorists and workers in a highway work zone. Most highway work zones are restricted in terms of available lateral space for accommodating traffic and the work activity. Consequently, it is desirable to minimize the deflection of work zone barriers in order to minimize the required buffer distance between the barrier and work activity area and, thereby, maximize the space and number of lanes available for traffic.

The impact performance of portable concrete barriers is typically assessed through full-scale vehicle crash testing. After its publication in 1993, *NCHRP Report 350*, "Recommended Procedures for the Safety Performance Evaluation of Highway Features" *(1)* was formally adopted by the Federal Highway Administration (FHWA) as a "Guide or Reference" document in the Federal Register, Volume 58, Number 135, dated July 16, 2993, which added paragraph (a)(13) to 23 CFR 625.5. FHWA subsequently mandated that only highway safety appurtenances that have successfully met the performance evaluation guidelines set forth in *NCHRP Report 350* may be used on new construction projects on the National Highway System (NHS).

Research to update *NCHRP Report 350* and take the next step in the continued advancement and evolution of roadside safety testing and evaluation was recently completed under NCHRP Project 22-14(02) *(2)*. The results of this research culminated in a new document know as the *Manual for Assessing Safety Hardware (MASH)* that will be published by the American Association of State Highway and Transportation Officials (AASHTO) and will supersede *NCHRP Report 350*. Changes incorporated into the new guideline include new design test vehicles, revised test matrices, and revised impact conditions.

1.2 OBJECTIVES/SCOPE OF RESEARCH

The objective of this project was to assess the performance of the Bexar Concrete Works I, LTD F-shape concrete traffic barrier (CTB) with Quick-bolt connection according to the safety-performance evaluation guidelines recommended in the soon to be published AASHTO *Manual for Assessing Safety Hardware* (*MASH*).

The specific test performed on the Bexar Concrete Works I, LTD F-shape CTB with Quick-bolt connection was *MASH* test designation 3-11. This test involves a 5000 lb, 1/2 ton, 4-door pickup impacting the critical impact point along the length of need of the barrier at a nominal impact speed and angle of 62 mi/h and 25 degrees, respectively. This report contains details of the barrier and Quick-Bolt connection, a description of the full-scale crash test, the results of the test, and an assessment of the test results.

2. SYSTEM DETAILS

2.1 TEST ARTICLE DESIGN AND CONSTRUCTION

The precast segments used in the construction of the test installation were 30 ft in length and had a standard F-shape profile. The barrier segments were 32 inches in height, 24 inches wide at the base, and 9-1/2 inches wide at the top.

Horizontal barrier reinforcement of the barrier segments consists of eight #5 bars placed symmetrically about the vertical centerline of the barrier at heights of approximately 3-1/2 inches, 8 5/8 inches, 1 ft-5 5/8 inches, and 2 ft-5 5/8 inches from the bottom of the barrier. Vertical barrier reinforcement consists of #4 bars spaced 12 inches on center. These vertical bars are bent to conform to the F-shape barrier profile. Within 5 ft of the barrier ends, the spacing of the vertical bars is reduced to provide additional strength for the connection. A U-shaped bar is tied to the bottom of the vertical bars to provide closed stirrups in this region.

Ten inch long sections of 1-1/2 inch diameter PVC pipe is horizontally cast into the end of the barrier segment along its centerline at heights of 1 ft-1 inch and 1 ft-10-1/2 inches from the bottom of the barrier. The PVC sleeve leads to a hand hole cast into the side of the barrier segment that provides access for feeding the threaded rod from one barrier into another and for securing the nuts and washers once the threaded rod is in place. A 3-inch diameter, 12-inches long bolt retraction cavity extends from the hand hole further into the center of the barrier. Two #5 “hairpin” shaped bars extend horizontally along the top and bottom of the PVC sleeve, hand hole, and bolt retraction cavity. Three #5 stirrups enclose these hairpin bars to provide further strength to the connection.

The barrier connection is made with two 7/8 inch diameter, 2 ft-1 inch long steel rods. A 3 inch x 3 inch x 3/8 inch plate washer and nut are used on each end of the threaded rod.

The completed test installation consisted of eight barrier segments connected together for a total length of approximately 240 ft. Details of the barrier and Quick-Bolt connection are shown in figures 2.1 and 2.2. Photographs of the completed test installation are shown in figure 2.3.

2.2 MATERIAL SPECIFICATIONS

The 28-day compressive strength of the concrete barriers is specified to be 3,600 psi. All reinforcing steel is grade 60. The barrier connection rods are fabricated from SAE Grade 5 or equivalent steel rod. The plate washers are fabricated from ASTM A-36 steel plate.

2.4 SOIL CONDITIONS

The barriers were placed on an existing concrete surface.

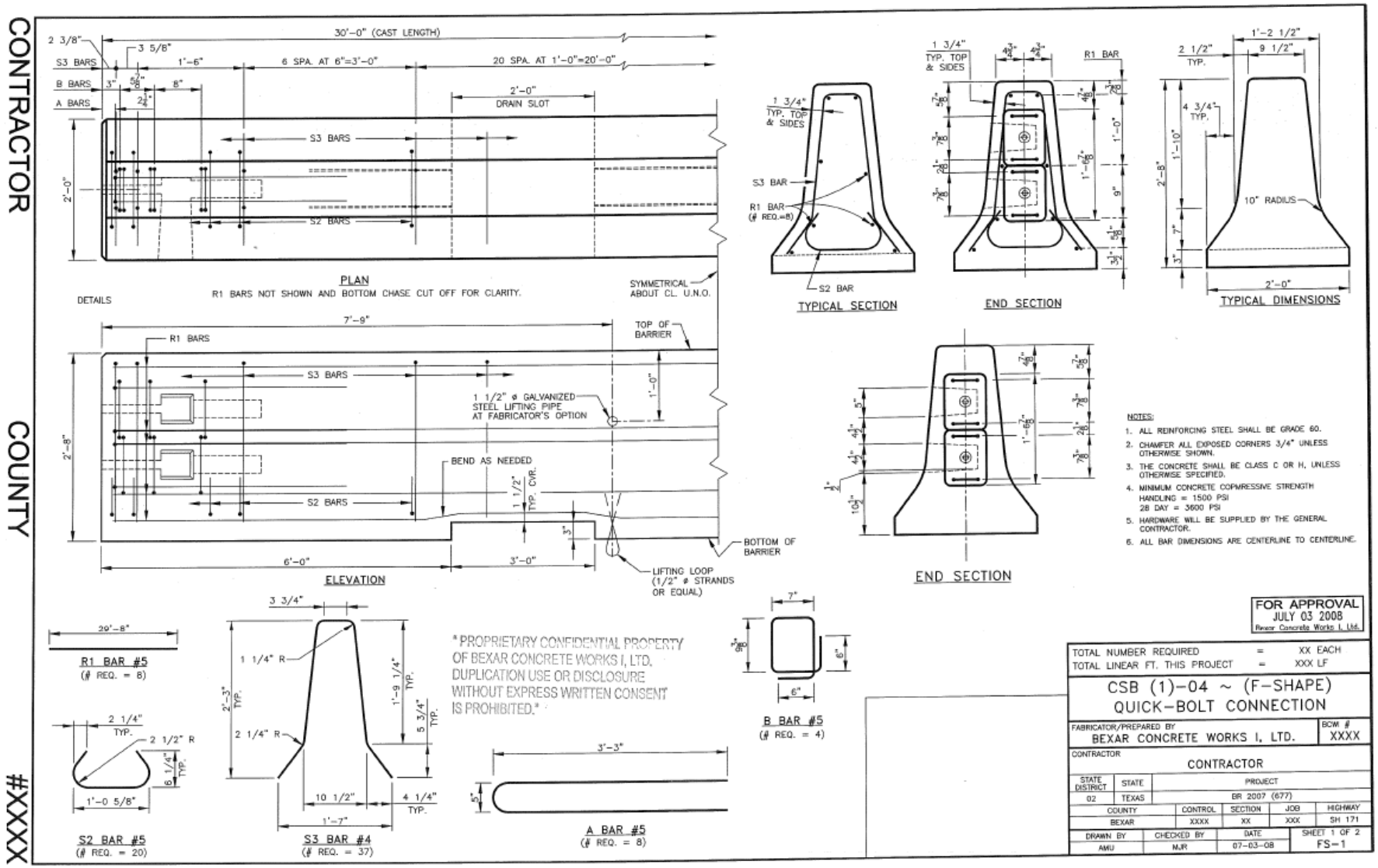


Figure 2.1. Details of the Bexar Concrete Works I, LTD F-shape CTB with Quick-bolt connection – sheet 1 of 2.

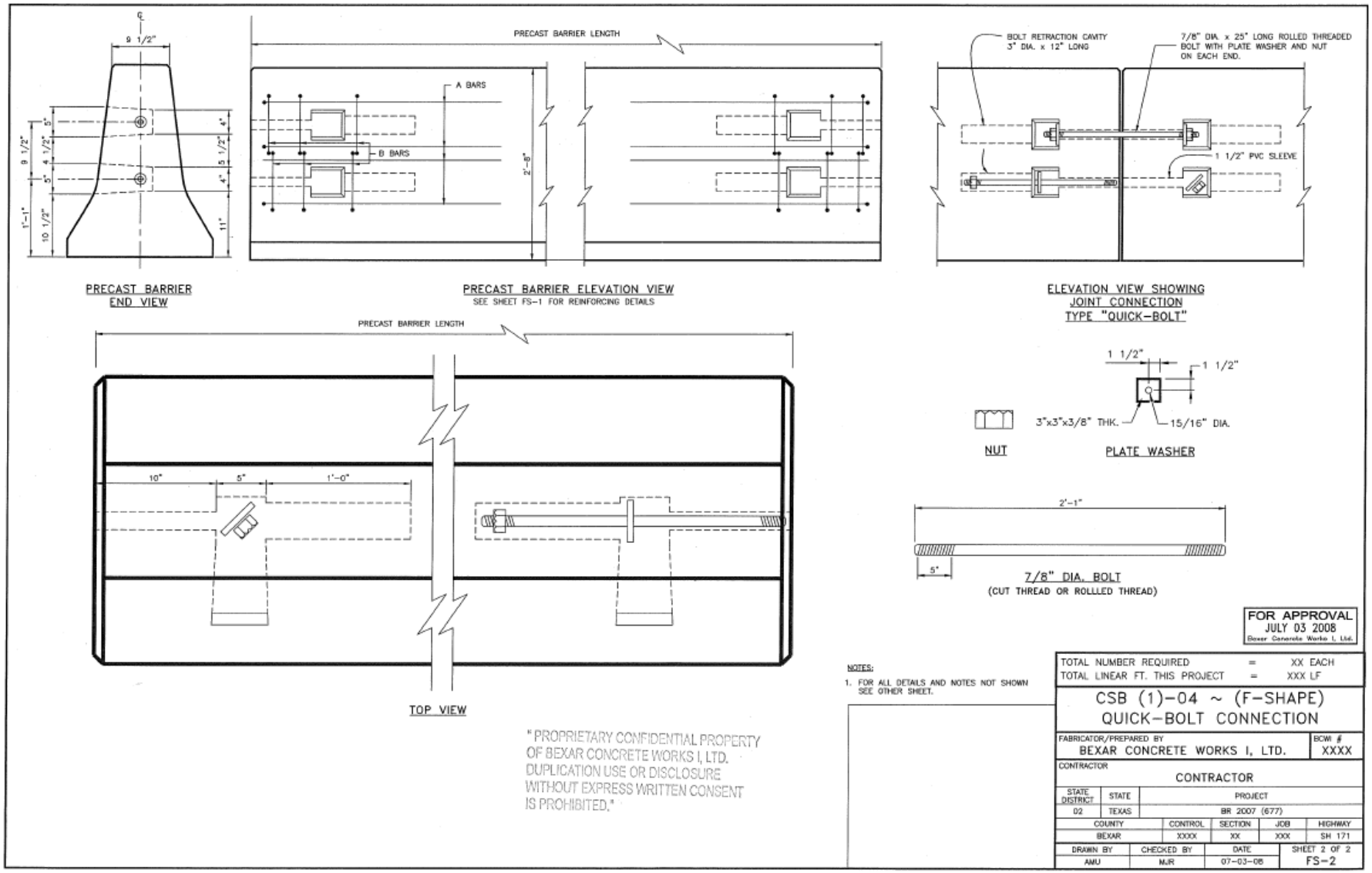


Figure 2.2. Details of the Bexar Concrete Works I, LTD F-shape CTB with Quick-bolt connection – sheet 2 of 2.

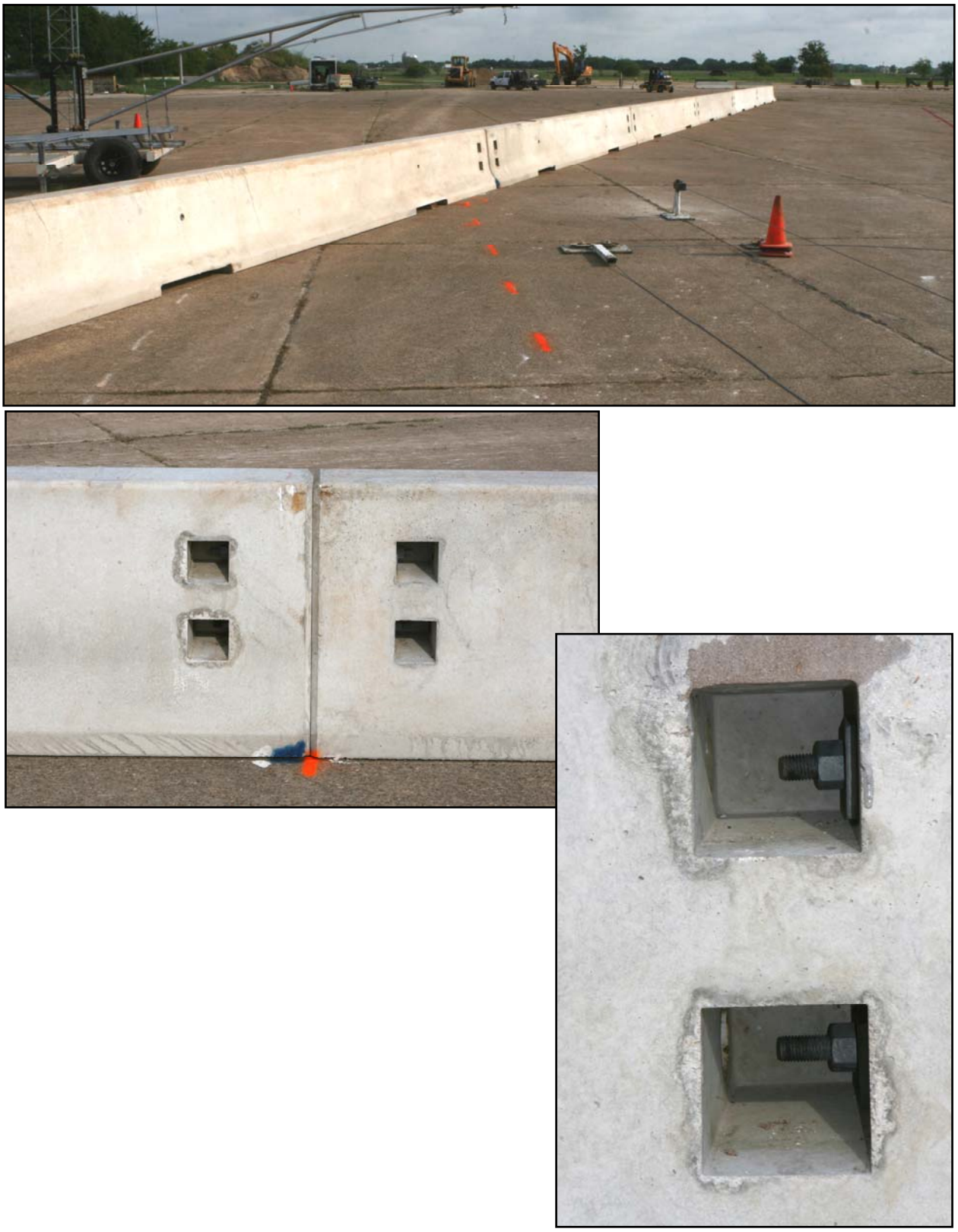


Figure 2.3. Bexar Concrete Works I, LTD F-shape CTB
with Quick-bolt connection prior to testing.

3. TEST REQUIREMENTS AND EVALUATION CRITERIA

3.1 CRASH TEST MATRIX

The test matrix recommended in *MASH* for evaluating the impact performance of longitudinal barriers to test level three (TL-3) consists of two tests as described below.

> ***MASH* test designation 3-10**: An 1100C (2420 lb/1100 kg) vehicle impacting the critical impact point (CIP) of the length of need (LON) of the barrier at a nominal impact speed and angle of 62 mi/h and 25 degrees, respectively. This test is intended to investigate a barrier's ability to successfully contain and redirect a small passenger vehicle.
>
> ***MASH* test designation 3-11**: A 2270P (5000 lb/2270 kg) vehicle impacting the critical impact point (CIP) of the length of need (LON) of the barrier at a nominal impact speed and angle of 62 mi/h and 25 degrees, respectively. This is a strength test intended to verify a barrier's performance for impacts involving light trucks and SUV's.

The crash test performed on the Bexar Concrete Works I, LTD F-shape CTB with Quick-Bolt connection was *MASH* test 3-11 with the 2270P vehicle. This is the critical test for evaluating the strength of a portable concrete barrier connection and for defining a barrier systems maximum deflection or working width.

The crash test and data analysis procedures followed for this project were in accordance with guidelines presented in *MASH*. Brief descriptions of these procedures are presented in Chapter 4.

3.2 EVALUATION CRITERIA

The crash test was evaluated in accordance with the criteria presented in *MASH*. The performance of the barrier is judged on the basis of three factors: structural adequacy, occupant risk, and post impact vehicle trajectory. Structural adequacy is judged upon the barrier's ability to contain and redirect the vehicle, or bring the vehicle to a controlled stop in a predictable manner. Occupant risk criteria evaluate the potential risk of injury to occupants in the impacting vehicle, and to some extent the hazard posed to other traffic, pedestrians, or workers in construction zones, if applicable. Post impact vehicle trajectory is evaluated to determine potential for secondary impact with other vehicles or fixed objects, creating further risk of injury to occupants of the impacting vehicle and/or risk of injury to occupants in other vehicles. The appropriate safety evaluation criteria from table 5.1 of *MASH* were used to evaluate the crash test reported herein, and are listed in further detail under Section 5.8 "Assessment of Test Results."

4. TEST CONDITIONS

4.1 TEST FACILITY

The test facilities at the Texas Transportation Institute's Proving Ground consist of a 2000 acre complex of research and training facilities situated 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 safety evaluation of roadside safety hardware. The site selected for the placement of the Bexar Concrete Works I, LTD F-shape CTB with Quick-bolt connection was on the surface of a wide out-of-service apron. The apron consists of unreinforced jointed concrete pavement in 12.5 ft x 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.

4.2 VEHICLE TOW AND GUIDANCE SYSTEM

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 of the vehicle, anchored at each end, and threaded through an attachment to the front wheel of the test vehicle. A steel tow 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 as it pulled the test vehicle toward the test installation. A two-to-one speed ratio existed between the test and tow vehicles. 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, at which time brakes on the vehicle were activated to bring it to a safe and controlled stop.

4.3 DATA ACQUISITION SYSTEMS

4.3.1 Vehicle 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

±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 and for display. 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 the (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-milliseconds (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.

4.3.2 Anthropomorphic Dummy Instrumentation

Use of a dummy in the 2270P vehicle is optional according to *MASH*. There was no dummy used in the test with the 2270P vehicle performed under this project.

4.3.3 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 camera and still cameras recorded and documented conditions of the test vehicle and installation before and after the test.

5. CRASH TEST 400001-BCW1 (*MASH08* TEST NO. 3-11)

5.1 TEST DESIGNATION AND ACTUAL IMPACT CONDITIONS

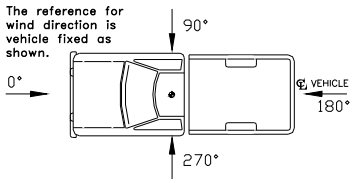
MASH08 test 3-11 involves a 2270P vehicle weighing 5000 lb ±100 lb impacting the barrier at an impact speed of 62.2 mi/h ±2.5 mi/h and an impact angle of 25 degrees ±1.5 degrees. The target impact point was 4.25 ft upstream of the joint between segments 3 and 4 of the Bexar Concrete Works I, LTD F-shape CTB with Quick-bolt connection. The 2002 Dodge Ram 1500 quad-cab pickup truck used in the test weighed 5012 lb and the actual impact speed and angle were 61.5 mi/h and 24.2 degrees, respectively. The actual impact point was 3.9 ft upstream of the joint between segments 3 and 4.

5.2 TEST VEHICLE

A 2002 Dodge Ram 1500 quad-cab pickup truck, shown in figures 5.1 and 5.2, was used for the crash test. Test inertia weight of the vehicle was 5012 lb, and its gross static weight was 5012 lb. The height to the lower edge of the vehicle front bumper was 13.75 inches, and the height to the upper edge of the front bumper was 26.0 inches. Additional dimensions and information on the vehicle are given in appendix B, figure B1 and table B1. The vehicle was directed into the installation using a cable reverse tow and guidance system, and was released to be free-wheeling and unrestrained just prior to impact.

5.3 WEATHER CONDITIONS

The crash test was performed the morning of August 22, 2008. Weather conditions at the time of testing were: Wind speed: 9 mi/h; wind direction: 180 degrees with respect to the vehicle (vehicle was traveling in a northwesterly direction); temperature: 85 ºF; relative humidity: 77 percent.



5.4 TEST DESCRIPTION

The 2002 Dodge Ram 1500 quad-cab pickup truck, traveling at an impact speed of 61.5 mi/h, impacted the CTB at an impact angle of 24.2 degrees at a point 3.9 ft upstream of the joint between segments 3 and 4. At approximately 0.024 s, the downstream end of segment 3 began to deflect toward the field side, and at 0.037 s, the upper left corner of the left front door began to gap open. The 2270P vehicle began to redirect at 0.047 s. At 0.184 s, the vehicle was traveling parallel with the barrier at a speed of 54.7 mi/h. The rear of the vehicle contacted the CTB at 0.211 s, at which time the vehicle also became airborne. At 0.586 s, the vehicle lost contact with the CTB, and exit angle was estimated to be 7.7 degrees. The vehicle was out of view of the camera and, therefore, an exit speed was not obtainable. Brakes on the vehicle were not applied, and the vehicle came to rest 170 ft downstream of impact and 159 ft toward traffic lanes. Sequential photographs of the test period are shown in appendix C, figures B2 and B3.

Figure 5.1. Vehicle/installation geometrics for test 400001-BCW1.

Figure 5.2. Vehicle before test 400001-BCW1.

5.5 TEST ARTICLE AND COMPONENT DAMAGE

Damage to the F-shape CTB with Quick-bolt connection is shown in figure 5.3 and 5.4. The upstream barrier (segment 1) was pulled downstream 0.2 inch, and there was minimal movement at the joint between segments 1 and 2. The barrier was pushed toward the field side 1.2 inches at the joint between segments 2 and 3. The gap between the segments at joint 3-4 opened 2.4 inches, and the barrier was pushed toward the field side 29.0 inches. The downstream toe of segment 3 had 10 inches of concrete spalling at the joint, and the upstream end of segment 4 was spalled in a region from the base of the barrier to 25 inches above ground and extending 27.0 inches along the toe of the barrier. The gap between segments 4 and 5 opened up 1.0 inch, the downstream end of segment 4 was pushed toward the field side 1.4 inches, and the upstream end of segment 5 was pushed toward the field side 2.2 inches. Segment 5 had 6 vertical hairline cracks covering 5 ft, beginning approximately 7 ft from the upstream end. The gap between segments 5 and 6 opened up 0.4 inch, the downstream end of segment 5 was pushed toward the field side 2.75 inches, and the upstream end of segment 6 was pushed toward the field side 2.0 inches. At the joint between segments 6 and 7, the barrier was pushed toward the field side 1.0 inch, and at the joint between segments 7 and 8, the barrier was pushed toward the field side 0.8 inch. No movement was noted on the downstream end of the barrier. Maximum permanent deformation of the barrier was 29.0 inches. Working width was 2.6 ft, and maximum dynamic deflection during the test was 31.0 inches.

5.6 TEST VEHICLE DAMAGE

The vehicle sustained damage to the entire left side, as shown in figure 5.5. The left upper A-arm, left frame rail, and rear axle were deformed. Also damaged were the front bumper, grill, hood, left front fender, left front tire and wheel rim, left front and rear doors, the left exterior bed, rear bumper, and tailgate. Maximum exterior crush to the vehicle was 19.7 inches at the left front corner at bumper height. Maximum occupant compartment deformation was 0.8 inch at hip height across the rear passenger compartment. Exterior vehicle crush and occupant compartment measurements are shown in appendix B, tables B2 and B3.

5.7 OCCUPANT RISK VALUES

Data from the accelerometer, located at the vehicle center of gravity, were digitized for evaluation of occupant risk. In the longitudinal direction, the occupant impact velocity was 14.1 ft/s at 0.097 s, the highest 0.010-s occupant ridedown acceleration was -5.2 Gs from 0.217 to 0.227 s, and the maximum 0.050-s average acceleration was -6.0 Gs between 0.025 and 0.075 s. In the lateral direction, the occupant impact velocity was 22.3 ft/s at 0.097 s, the highest 0.010-s occupant ridedown acceleration was 13.1 Gs from 0.224 to 0.234 s, and the maximum 0.050-s average was 11.7 Gs between 0.031 and 0.081 s. Theoretical Head Impact Velocity (THIV) was 28.4 km/h or 7.9 m/s at 0.095 s; Post-Impact Head Decelerations (PHD) was 13.1 Gs between 0.224 and 0.234 s; and Acceleration Severity Index (ASI) was 1.42 between 0.026 and 0.076 s. These data and other pertinent information from the test are summarized in figure xx. Vehicle angular displacements and accelerations versus time traces are presented in appendix B, figures B4 through B10.

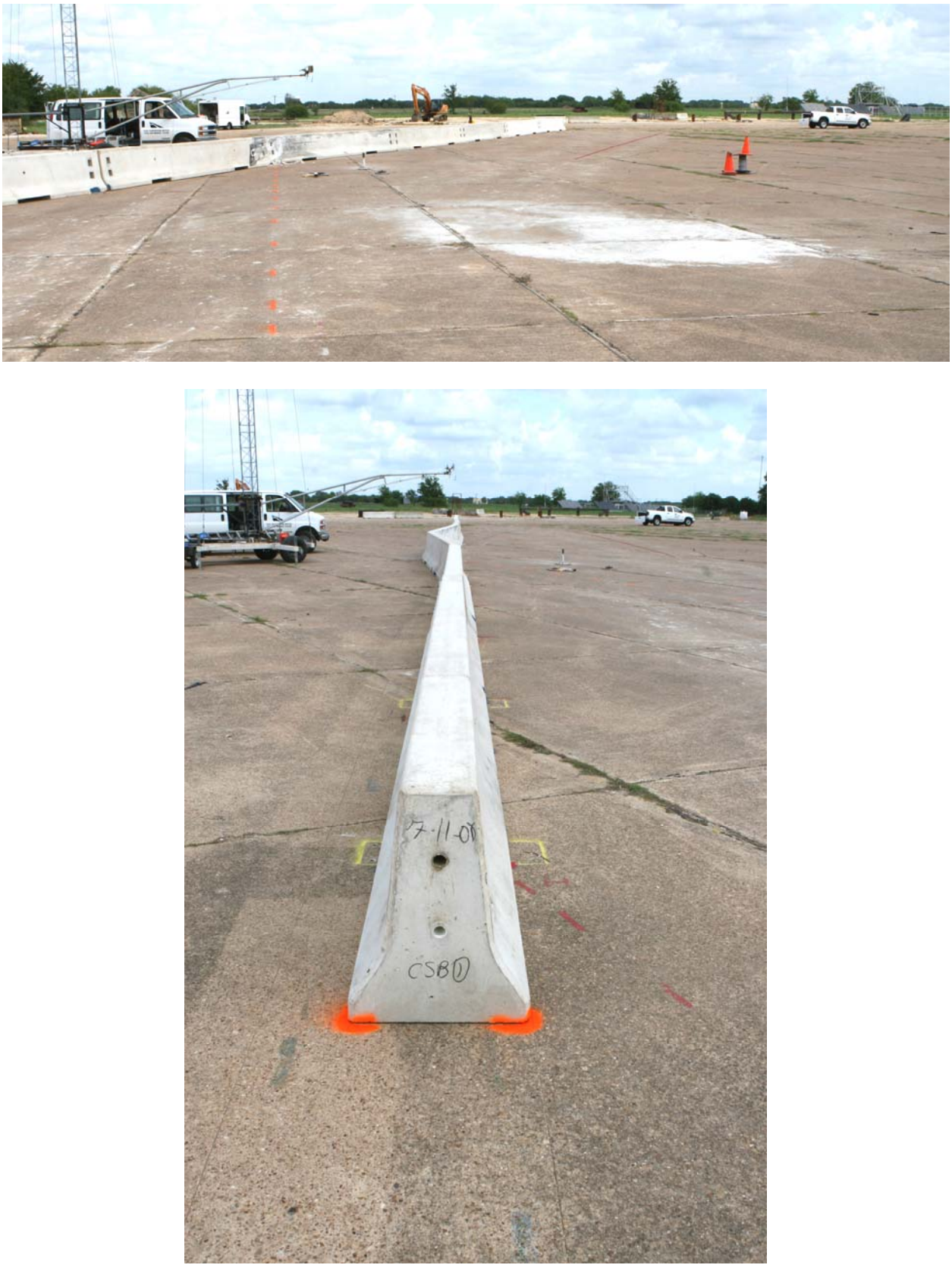


Figure 5.3. Vehicle trajectory path after test 400001-BCW1.

Figure 5.4. Installation after test 400001-BCW1.

Figure 5.5. Vehicle after test 400001-BCW1.

Before Test

After Test

Figure 5.6. Interior of vehicle for test 400001-BCW1.

General Information
- Test Agency ..... Texas Transportation Institute
- Test No. 400001-BCW1
- Date 2008-08-22

Test Article
- Type ..... Portable Concrete Barrier (PCB) with Quick-Bolt Connection
- Name ..... Bexar Concrete Works CTB
- Installation Length ..... 240 ft
- Material or Key Elements ..... F-Shaped Barrier
  - Length ..... 30 ft segments
  - Base Width ..... 24 inches
  - Height ..... 32 inches

Soil Type and Condition ..... Placed on concrete pavement, dry

Test Vehicle
- Type/Designation 2270P
- Make and Model ..... 2002 Dodge Ram 1500 Quad-Cab
- Curb ..... 4919 pounds
- Test Inertial ..... 5012 pounds
- Dummy ..... No dummy
- Gross Static ..... 5012 pounds

Impact Conditions
- Speed ..... 61.5 mi/h
- Angle ..... 24.2 degrees
- Location/Orientation ..... 3.9 ft upstream of joint 3-4

Exit Conditions
- Speed ..... Not obtainable
- Angle ..... 7.7 degrees

Occupant Risk Values
- Impact Velocity
  - Longitudinal ..... 14.4 ft/s
  - Lateral ..... 22.3 ft/s
- Ridedown Accelerations
  - Longitudinal ..... -5.2 Gs
  - Lateral ..... 13.1 Gs
- THIV ..... 28.4 km/h
- PHD ..... 13.1 Gs
- Max. 0.050-s Average
  - Longitudinal ..... -6.0 Gs
  - Lateral ..... 11.7 Gs
  - Vertical ..... -3.1 Gs

Post-Impact Trajectory
- Stopping Distance ..... 170 ft downstream
  159 ft toward traffic

Vehicle Behavior
- Max. Yaw Angle 41
- Max. Pitch Angle ..... -13
- Max. Roll Angle ..... -17
- Vehicle Snagging ..... None
- Vehicle Pocketing ..... None

Test Article Deflections
- Dynamic ..... 31.0 inches
- Permanent ..... 29.0 inches
- Working Width ..... 31.0 inches

Vehicle Damage
- VDS 11LFQ3
- CDC 11LFES3
- Max. Exterior Deformation ..... 19.7 inches
- Max. Occupant Compartment Deformation ..... 0.8 inch
- OCDI LF0001000

Figure 5.7. Summary of results for *NCHRP Report 350* test 3-11 on Bexar Concrete Works F-shape CTB with Quick-Bolt connection.

5.8 ASSESSMENT OF TEST RESULTS

An assessment of the test based on the applicable *MASH* safety evaluation criteria is presented below.

5.8.1 Structural Adequacy

A. *Test article should contain and redirect the vehicle or bring the vehicle to a controlled stop; the vehicle should not penetrate, underride, or override the installation although controlled lateral deflection of the test article is acceptable.*

Results: The Bexar Concrete Works F-shape CTB with Quick-Bolt connection contained and redirected the 2270P vehicle. The vehicle did not penetrate, underride, or override the barrier. Maximum dynamic deflection of the barrier was 31.0 inches. (PASS)

5.8.2 Occupant Risk

D. *Detached elements, fragments, or other debris from the test article should not penetrate or show potential for penetrating the occupant compartment, or present an undue hazard to other traffic, pedestrians, or personnel in a work zone. Deformation of, or intrusions into, the occupant compartment should not exceed limits set forth in Section 5.3 and Appendix E of MASH08. (roof ≤102 mm (4.0 inches); windshield = ≤76 mm (3.0 inches); side windows = no shattering by test article structural member; wheel/foot well/toe pan ≤229 mm (9.0 inches); forward of A-pillar ≤305 mm (12.0 inches); front side door area above seat ≤229 mm (9.0 inches); front side door below seat ≤305 mm (12.0 inches); floor pan/transmission tunnel area ≤305 mm (12.0 inches))*

Results: No detached elements, fragments, or other debris were present to penetrate or show potential to penetrate the occupant compartment, or to present undue hazard to others in the area. (PASS)
Maximum occupant compartment deformation was 0.8 inch at hip level in the rear occupant compartment. (PASS)

F. *The vehicle should remain upright during and after collision. The maximum roll and pitch angles are not to exceed 75 degrees.*

Results: The 2270P vehicle remained upright during and after the collision period. Maximum roll angle was -17 degrees, and maximum pitch angle was -13 degrees. (PASS)

H. *Occupant impact velocities should satisfy the following:*

Longitudinal and Lateral Occupant Impact Velocity

Preferred	*Maximum*
30 ft/s	*40 ft/s*

Results: Longitudinal occupant impact velocity was 14.1 ft/s, and lateral occupant impact velocity was 22.3 ft/s. (PASS)

I. Occupant ridedown accelerations should satisfy the following:

Longitudinal and Lateral Occupant Ridedown Accelerations

Preferred	*Maximum*
15.0 Gs	*20.49 Gs*

Results: Longitudinal occupant ridedown acceleration was -5.2 Gs, and lateral ridedown acceleration was 13.1 Gs. (PASS)

5.8.3 Vehicle Trajectory

For redirective devices, the vehicle shall exit the device within the exit box.

Result: The 2270P vehicle came to rest 170 ft downstream of impact and 159 ft toward traffic lanes. The vehicle exited the barrier "within" the exit box. (PASS)

6. SUMMARY AND CONCLUSIONS

6.1 SUMMARY OF RESUTLS

The Bexar Concrete Works F-shape CTB with Quick-Bolt connection contained and redirected the 2270P vehicle. The vehicle did not penetrate, underride, or override the barrier. Maximum dynamic deflection of the barrier was 31 inches. No detached elements, fragments, or other debris were present to penetrate or show potential to penetrate the occupant compartment, or to present undue hazard to others in the area. Maximum occupant compartment deformation was 0.8 inch at hip level in the rear occupant compartment. The 2270P vehicle remained upright during and after the collision period. Maximum roll angle was -17 degrees, and maximum pitch angle was -13 degrees. Occupant risk values were within the limits specified in *MASH*. The 2270P vehicle came to rest 170 ft downstream of impact and 159 ft toward traffic lanes.

6.2 CONCLUSIONS

As shown in table 6.1, all relevant *MASH08* performance evaluation criteria were satisfied. The F-shape concrete traffic barrier (CTB) with Quick-Bolt connection successfully contained and redirected the impacting 2270P vehicle in a stable manner with a maximum roll angle of -17 degrees. The occupant risk indices (i.e., occupant impact velocity and ridedown accelerations) were below preferred thresholds, and occupant compartment deformation was acceptable. The maximum permanent deflection of the barrier after the test was approximately 29.0 inches. The maximum dynamic deflection during the test was 31.0 inches.

Table 6.1. Performance evaluation summary for *MASH08* test 3-11
on the Bexar Concrete Works F-Shape CTB with Quick-Bolt Connection.

Test Agency: Texas Transportation Institute Test No.: 400001-BCW1 Test Date: 2008-08-22

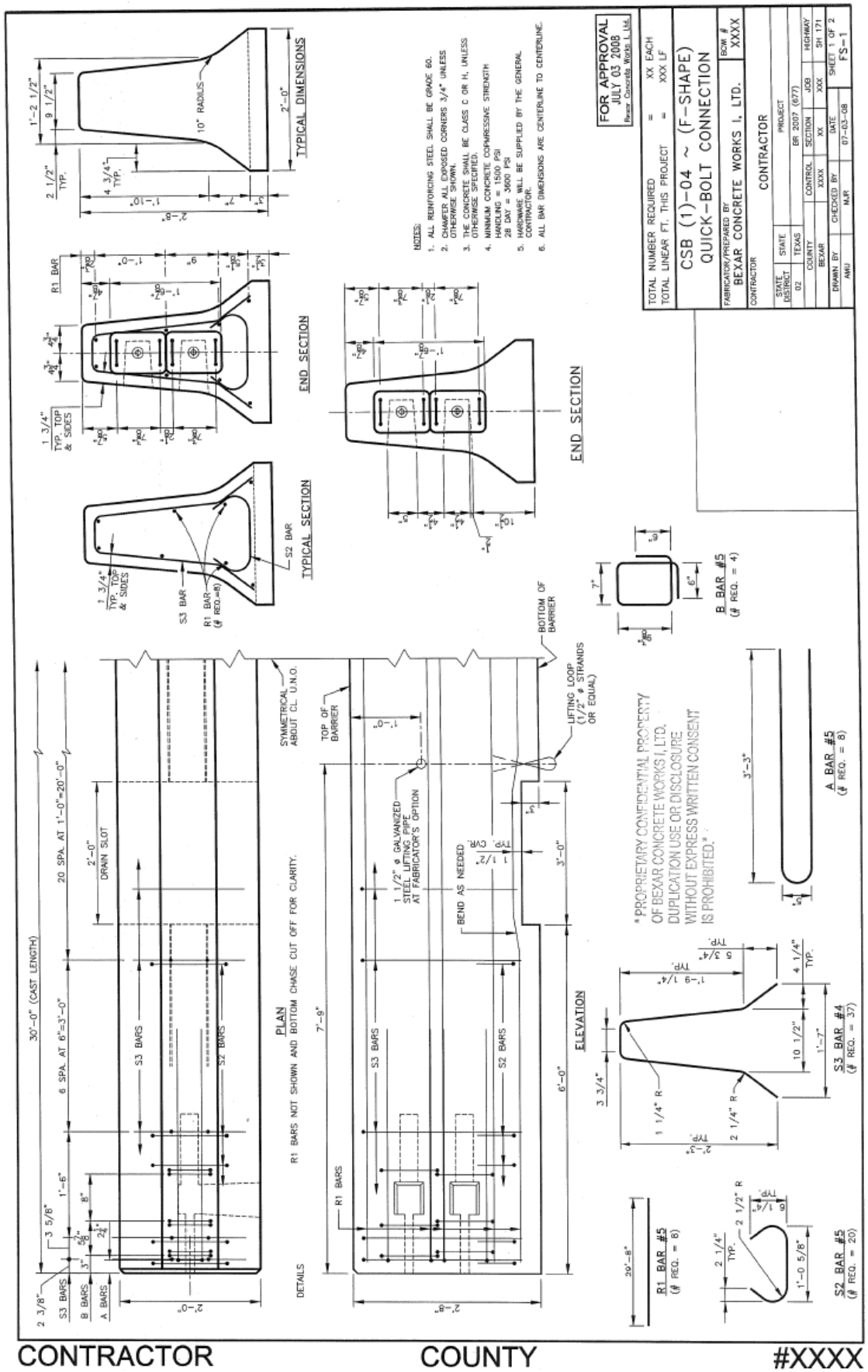
***MASH08* Test 3-11 Evaluation Criteria**	**Test Results**	**Assessment**
Structural Adequacy		
A. Test article should contain and redirect the vehicle or bring the vehicle to a controlled stop; the vehicle should not penetrate, underride, or override the installation although controlled lateral deflection of the test article is acceptable	The Bexar Concrete Works F-shape CTB with Quick-Bolt connection contained and redirected the 2270P vehicle. The vehicle did not penetrate, underride, or override the barrier. Maximum dynamic deflection of the barrier was 31 inches.	Pass
Occupant Risk		
D. Detached elements, fragments, or other debris from the test article should not penetrate or show potential for penetrating the occupant compartment, or present an undue hazard to other traffic, pedestrians, or personnel in a work zone.	No detached elements, fragments, or other debris were present to penetrate or show potential to penetrate the occupant compartment, or to present undue hazard to others in the area.	Pass
Deformations of, or intrusions into, the occupant compartment should not exceed limits set forth in Section 5.3 and Appendix E of MASH08.	Maximum occupant compartment deformation was 0.8 inch at hip level in the rear occupant compartment.	Pass
F. The vehicle should remain upright during and after collision. The maximum roll and pitch angles are not to exceed 75 degrees.	The 2270P vehicle remained upright during and after the collision. Maximum roll angle was -17 degrees, and maximum pitch angle was -13 degrees.	Pass
H. Longitudinal and lateral occupant impact velocities should fall below the preferred value of 30 ft/s, or at least below the maximum allowable value of 40 ft/s.	Longitudinal occupant impact velocity was 14.1 ft/s, and lateral occupant impact velocity was 22.3 ft/s.	Pass
I. Longitudinal and lateral occupant ridedown accelerations should fall below the preferred value of 15.0 Gs, or at least below the maximum allowable value of 20.49 Gs.	Longitudinal occupant ridedown acceleration was -5.2 Gs, and lateral ridedown acceleration was 13.1 Gs.	Pass
Vehicle Trajectory		
For redirective devices, the vehicle shall exit the barrier within the exit box.	The 2270P vehicle came to rest 170 ft downstream of impact and 159 ft toward traffic lanes. The vehicle exited the barrier within the exit box.	Pass

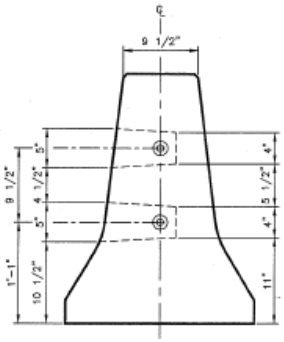
REFERENCES

1. Ross, Jr., H.E., Sicking, D.L., Zimmer, R.A. and Michie, J.D., "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.

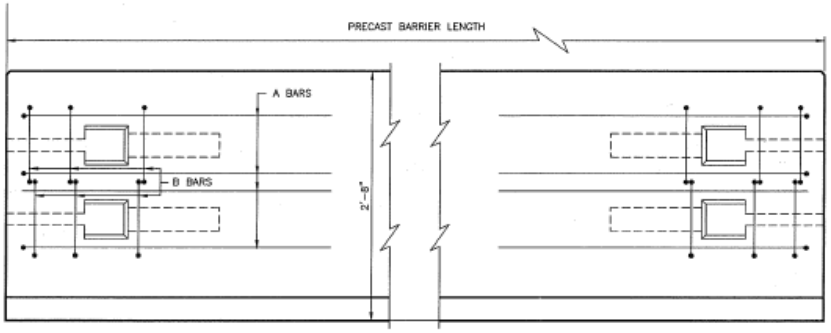
2. Sicking, D.L. and Mak, K.K., *Recommended Procedures for the Safety-Performance Evaluation of Roadside Features, Draft Final Report*, National Cooperative Highway Research Program Project No. 22-14(02), National Research Council, Washington, D.C., February 2007.

APPENDIX A. DETAILS OF TEST ARTICLE

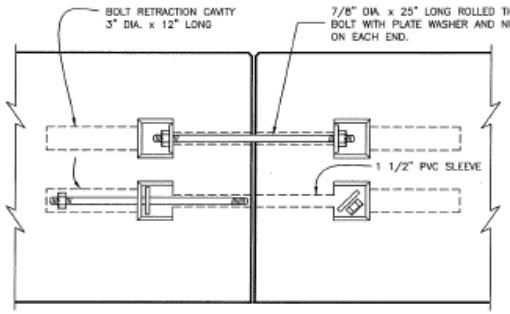




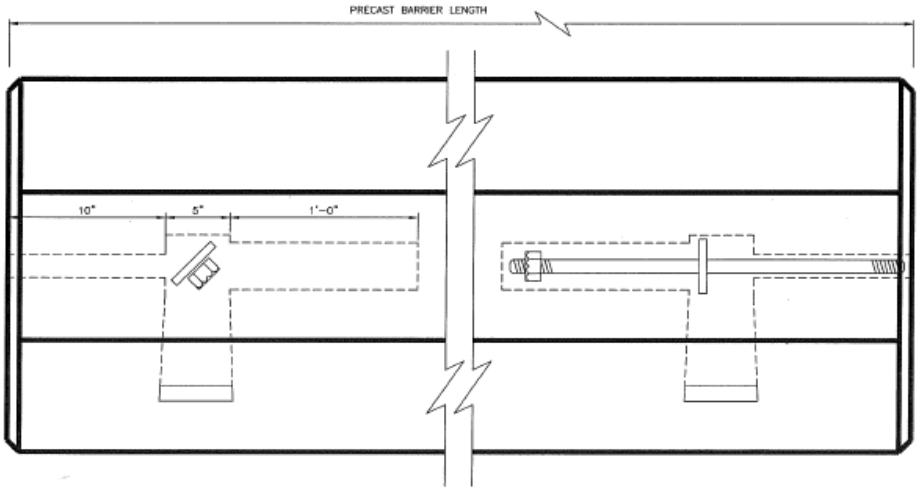
PRECAST BARRIER
END VIEW



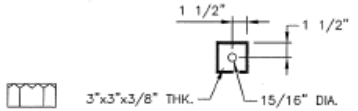
PRECAST BARRIER ELEVATION VIEW
SEE SHEET FS-1 FOR REINFORCING DETAILS



ELEVATION VIEW SHOWING
JOINT CONNECTION
TYPE "QUICK-BOLT"

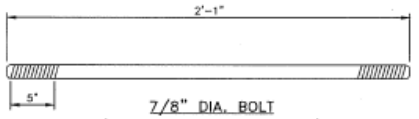


TOP VIEW



NUT

PLATE WASHER



7/8" DIA. BOLT
(CUT THREAD OR ROLLLED THREAD)

FOR APPROVAL
JULY 03 2008
Bexar Concrete Works I, Ltd.

NOTES:

1. FOR ALL DETAILS AND NOTES NOT SHOWN SEE OTHER SHEET.

"PROPRIETARY CONFIDENTIAL PROPERTY
OF BEXAR CONCRETE WORKS I, LTD.
DUPLICATION USE OR DISCLOSURE
WITHOUT EXPRESS WRITTEN CONSENT
IS PROHIBITED."

TOTAL NUMBER REQUIRED = XX EACH					
TOTAL LINEAR FT. THIS PROJECT = XXX LF					
CSB (1)-04 ~ (F-SHAPE) QUICK-BOLT CONNECTION					
FABRICATOR/PREPARED BY: BEXAR CONCRETE WORKS I, LTD.					BCWI #: XXXX
CONTRACTOR: CONTRACTOR					
STATE DISTRICT	STATE	PROJECT			
02	TEXAS	BR 2007 (677)			
COUNTY		CONTROL	SECTION	JOB	HIGHWAY
BEXAR		XXXX	XX	XXX	SH 171
DRAWN BY	CHECKED BY	DATE	SHEET 2 OF 2		
AMU	MJR	07-03-08	FS-2		

APPENDIX B. CRASH TEST NO. 400001-BCW1

B1. VEHICLE PROPERTIES AND INFORMATION

Date: 2008-08-22 Test No.: 400001-BCW1 VIN No.: 1D7HA18N125704789

Year: 2002 Make: Dodge Model: Ram 1500 Quad-Cab

Tire Size: 245/70/R17 Tire Inflation Pressure: 44 psi

Tread Type: Highway Odometer: 247120

Note any damage to the vehicle prior to test:

• Denotes accelerometer location.

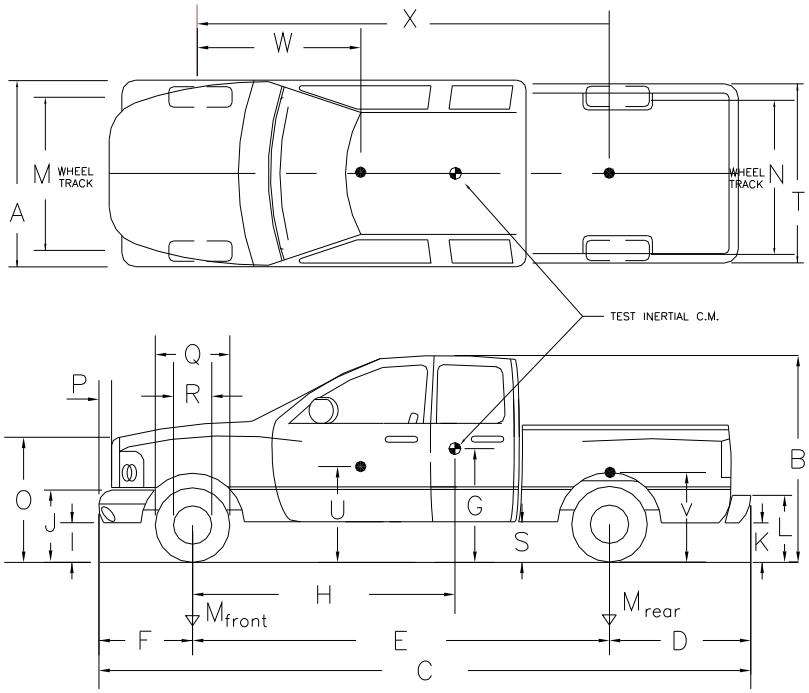
NOTES:

Engine Type: V-8
Engine CID: 4.7 liter

Transmission Type:
x Auto or ___ Manual
___ FWD x RWD ___ 4WD

Optional Equipment:

Dummy Data:
Type:
Mass:
Seat Position:



Geometry: inches

A	77	F	37	K	18	P	3.5	U	27.5
B	74	G	28.31	L	27.5	Q	30	V	33
C	224.5	H	62.82	M	68.25	R	18.25	W	59.5
D	47	I	13.75	N	67.25	S	15.38	X	140.5
E	140.25	J	26	O	44.5	T	75.5		

Wheel Center Ht Front	14.25	Wheel Well Clearance (FR)	6	Frame Ht (FR)	16
Wheel Center Ht Rear	14.5	Wheel Well Clearance (RR)	11.5	Frame Ht (RR)	25.25

GVWR Ratings:		**Mass:** lb	Curb	Test Inertial	Gross Static
Front	3650	M_{front}	2788	2777	
Back	3900	M_{rear}	2131	2241	
Total	6650	M_{Total}	4919	5012	

Mass Distribution:
lb LF: 1373 RF: 1398 LR: 1110 RR: 1131

Figure B1. Vehicle properties for test 400001-BCW1.

Table B1. Vehicle parametric measurements for test 400001-BCW1.

Date: 2008-03-04 Test No.: 400001-BCW1 VIN: 1D7HA18N125704789

Year: 2002 Make: Dodge Model: Ram 1500 Quad-Cab

Body Style: Quad-Cab Mileage: 247120

Engine: 4.7 liter V-8 Transmission: Automatic

Fuel Level: Empty Ballast: 264 lb front of bed / 100 lb center of bed

Tire Pressure: Front: 44 psi Rear: 44 psi Size: 245/70/R17

Measured Vehicle Weights: (lb)

LF: 1373	RF: 1398	Front Axle: 2771
LR: 1110	RR: 1131	Rear Axle: 2241
Left: 2483	Right: 2529	Total: 5012

Wheel Base: 140.5 in Track: F: 68.25 in R: 27.25 in

Center of Gravity, SAE J874 Suspension Method

X: 62.82 in Rear of Front Axle

Y: 0.31 in Right of Vehicle Centerline

Z: 28.31 in Above Ground

Hood Height 44.5 inches Front Bumper Height: 26 inches

Front Overhang: 37 inches Rear Bumper Height: 27.5 inches

Overall Length: 224.5 inches

Test Conductor: Zimmer/Dobrovolny

Table B2. Exterior crush measurements for test 400001-BCW1.

Date: 2008-08-22 Test No.: 400001-BCW1 VIN No.: 1D7HA18N125704789

Year: 2002 Make: Dodge Model: Ram 1500 Quad-Cab

VEHICLE CRUSH MEASUREMENT SHEET[1]

Complete When Applicable	
End Damage	Side Damage
Undeformed end width _____	Bowing: B1 _____ X1 _____
Corner shift: A1 _____	B2 _____ X2 _____
A2 _____	
End shift at frame (CDC)	Bowing constant
(check one)	$\frac{X1+X2}{2}$ = _____
< 4 inches _____	
≥ 4 inches _____	

Note: Measure C_1 to C_6 from Driver to Passenger side in Front or Rear impacts – Rear to Front in Side Impacts.

Specific Impact Number	Plane* of C-Measurements	Direct Damage		Field L**	C_1	C_2	C_3	C_4	C_5	C_6	±D
		Width** (CDC)	Max*** Crush								
1	Front plane at bumper ht	300	280	700	280	253	75	60	30	0	-350
2	Side plane at bumper ht	300	500	1300	10	65	N/A	N/A	400	500	+1900

[1]Table taken from National Accident Sampling System (NASS).

*Identify the plane at which the C-measurements are taken (e.g., at bumper, above bumper, at sill, above sill, at beltline, etc.) or label adjustments (e.g., free space).

Free space value is defined as the distance between the baseline and the original body contour taken at the individual C locations. This may include the following: bumper lead, bumper taper, side protrusion, side taper, etc. Record the value for each C-measurement and maximum crush.

**Measure and document on the vehicle diagram the beginning or end of the direct damage width and field L (e.g., side damage with respect to undamaged axle).

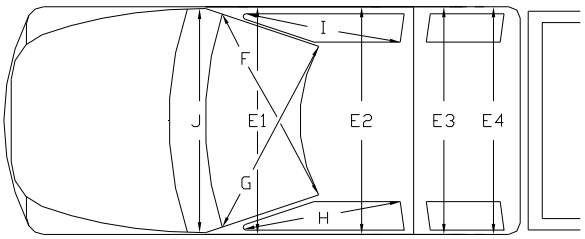
***Measure and document on the vehicle diagram the location of the maximum crush.

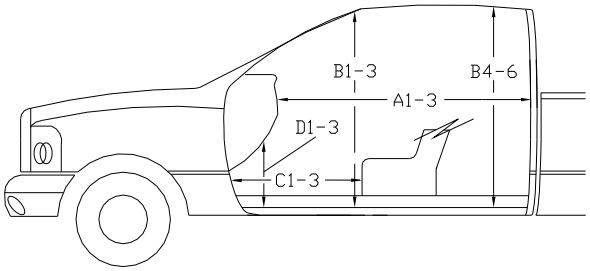
Note: Use as many lines/columns as necessary to describe each damage profile.

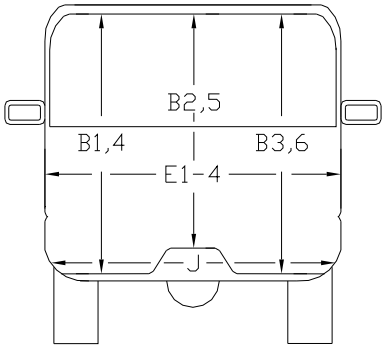
Table B3. Occupant compartment measurements for test 400001-BCW1.

Date: 2008-08-22 Test No.: 400001-BCW1 VIN No.: 1D7HA18N125704789

Year: 2002 Make: Dodge Model: Ram 1500 Quad-Cab



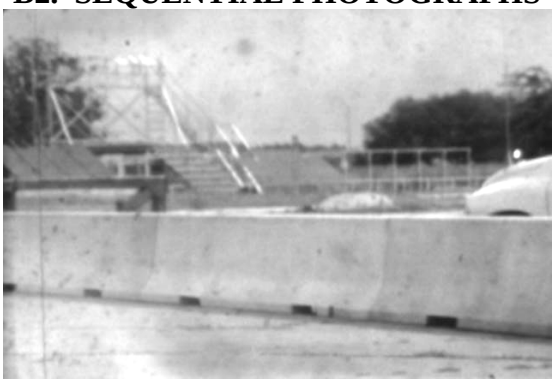




*Lateral area across the cab from driver's side kickpanel to passenger's side kickpanel.

OCCUPANT COMPARTMENT DEFORMATION MEASUREMENT	Before (mm)	After (mm)
A1	1640	1634
A2	1625	1625
A3	1660	1660
B1	1145	1145
B2	1003	1003
B3	1155	1155
B4	1256	1256
B5	1134	1134
B6	1255	1255
C1	755	755
C2	----	----
C3	725	725
D1	320	310
D2	63	63
D3	297	297
E1	1610	1600
E2	1635	1618
E3	1624	1605
E4	1629	1616
F	1525	1525
G	1525	1525
H	1000	1000
I	1000	1000
J*	1582	1580

B2. SEQUENTIAL PHOTOGRAPHS



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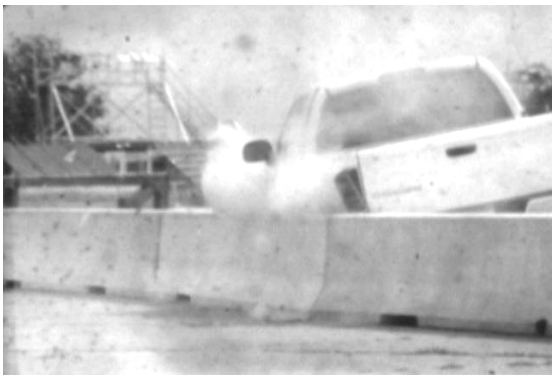

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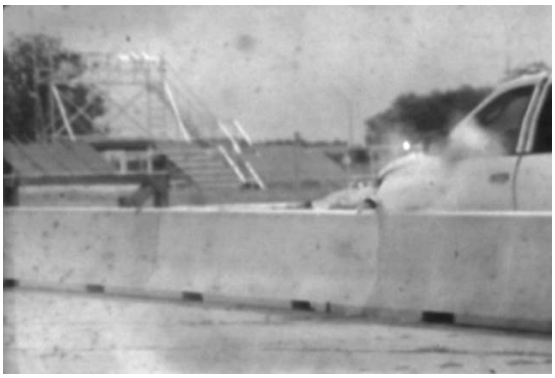

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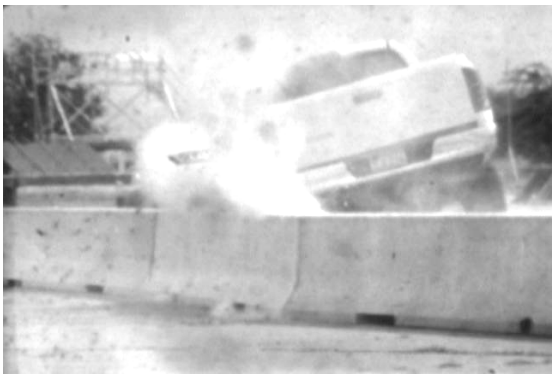

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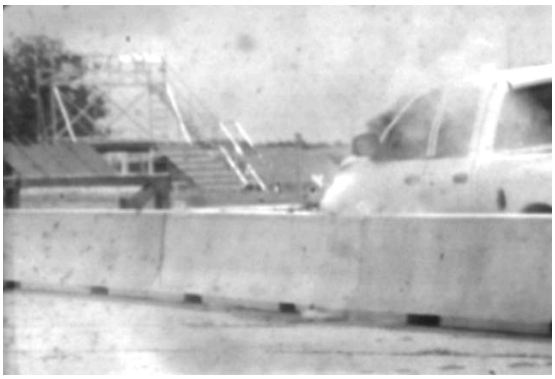

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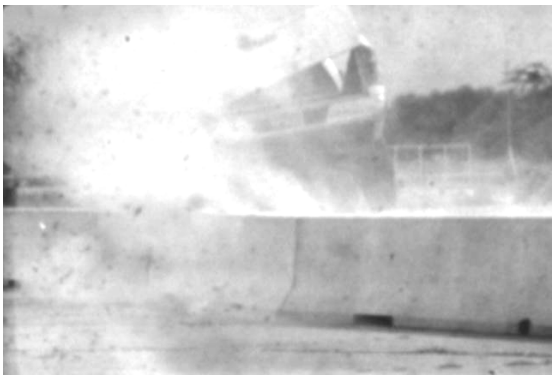
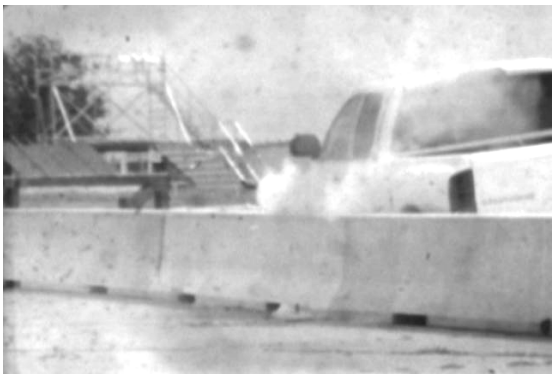
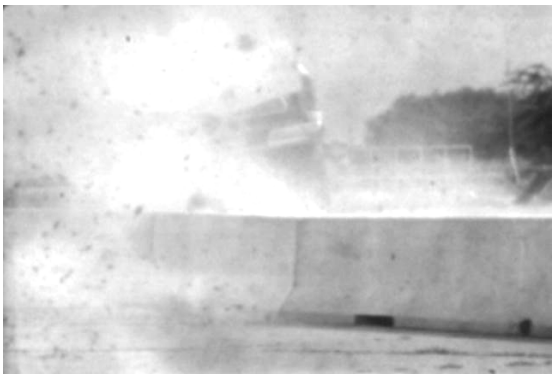


0.586 s



0.184 s



0.809 s

Figure B3. Sequential photographs for test 400001-BCW1 (rear view).

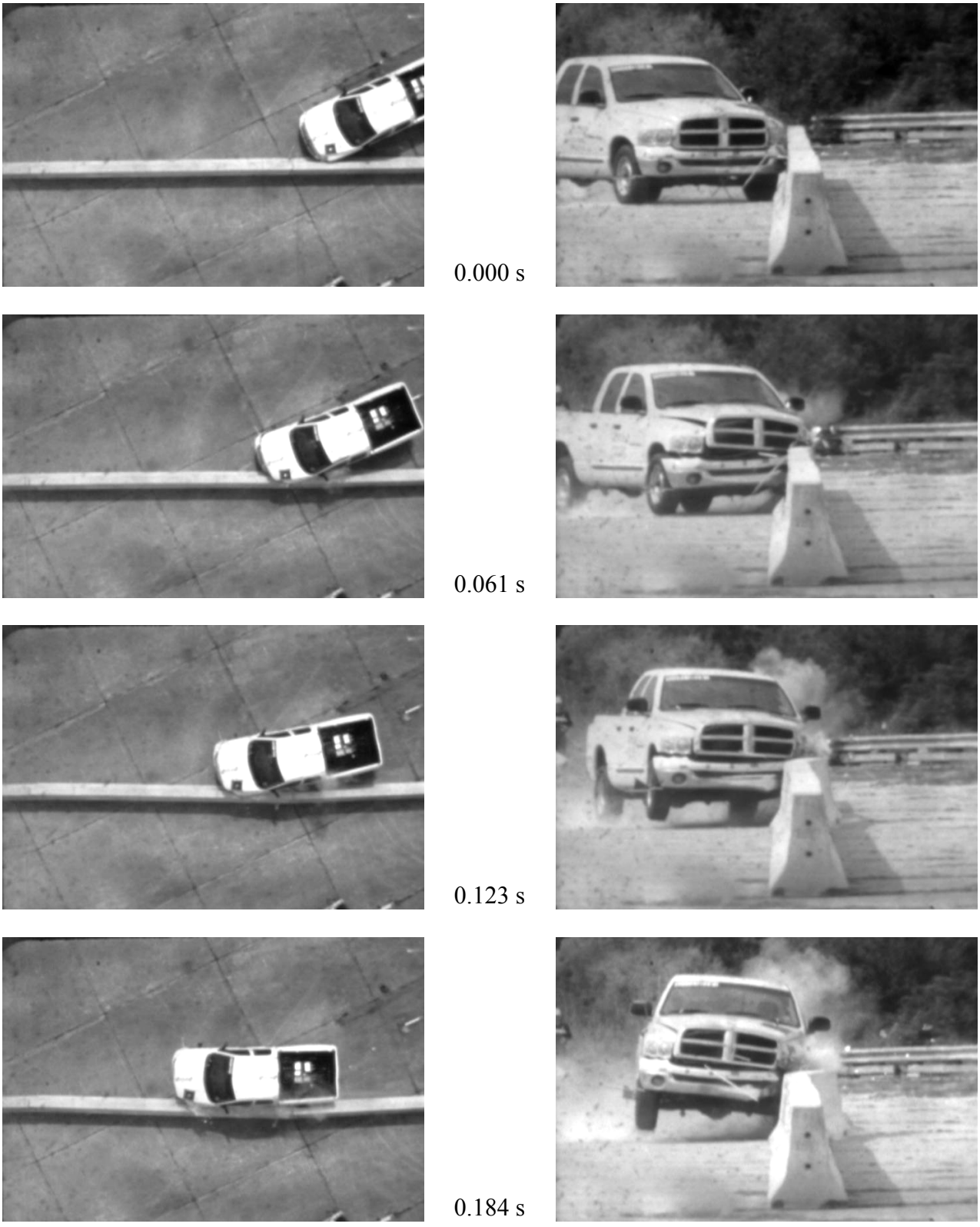
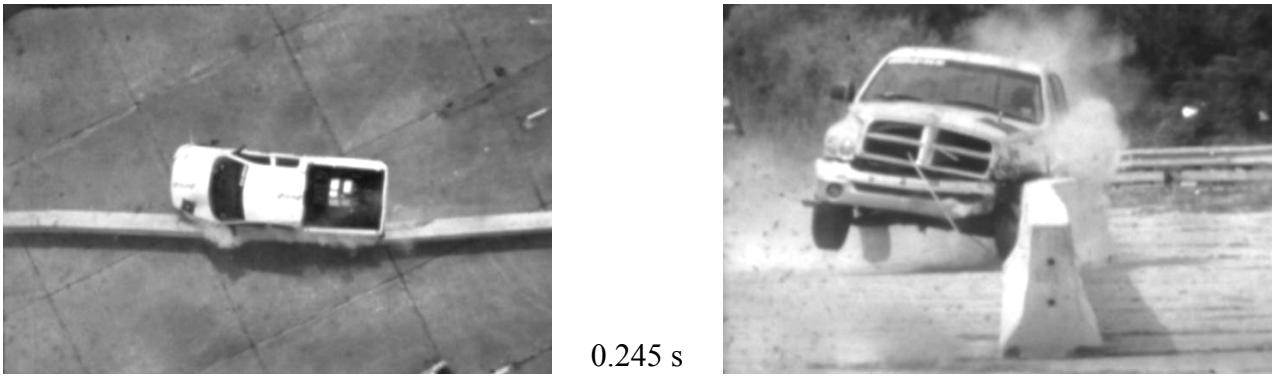
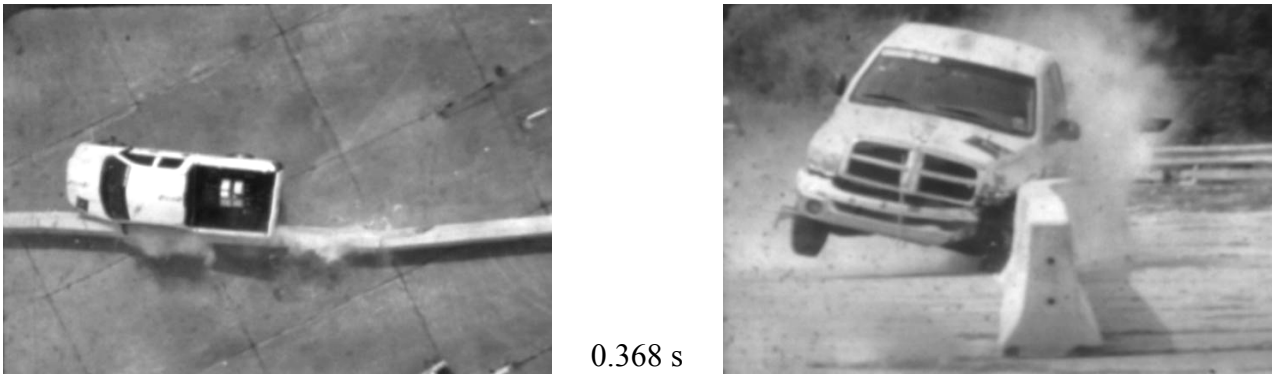


Figure B2. Sequential photographs for test 400001-BCW1
(overhead and frontal views).

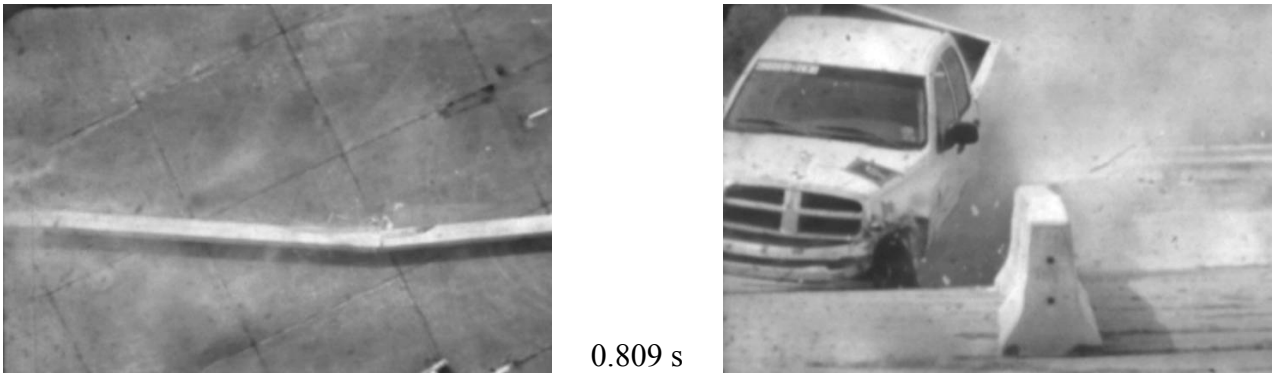


0.245 s



0.368 s

0.586 s



0.809 s

Figure B2. Sequential photographs for test 400001-BCW1
(overhead and frontal views) (continued).

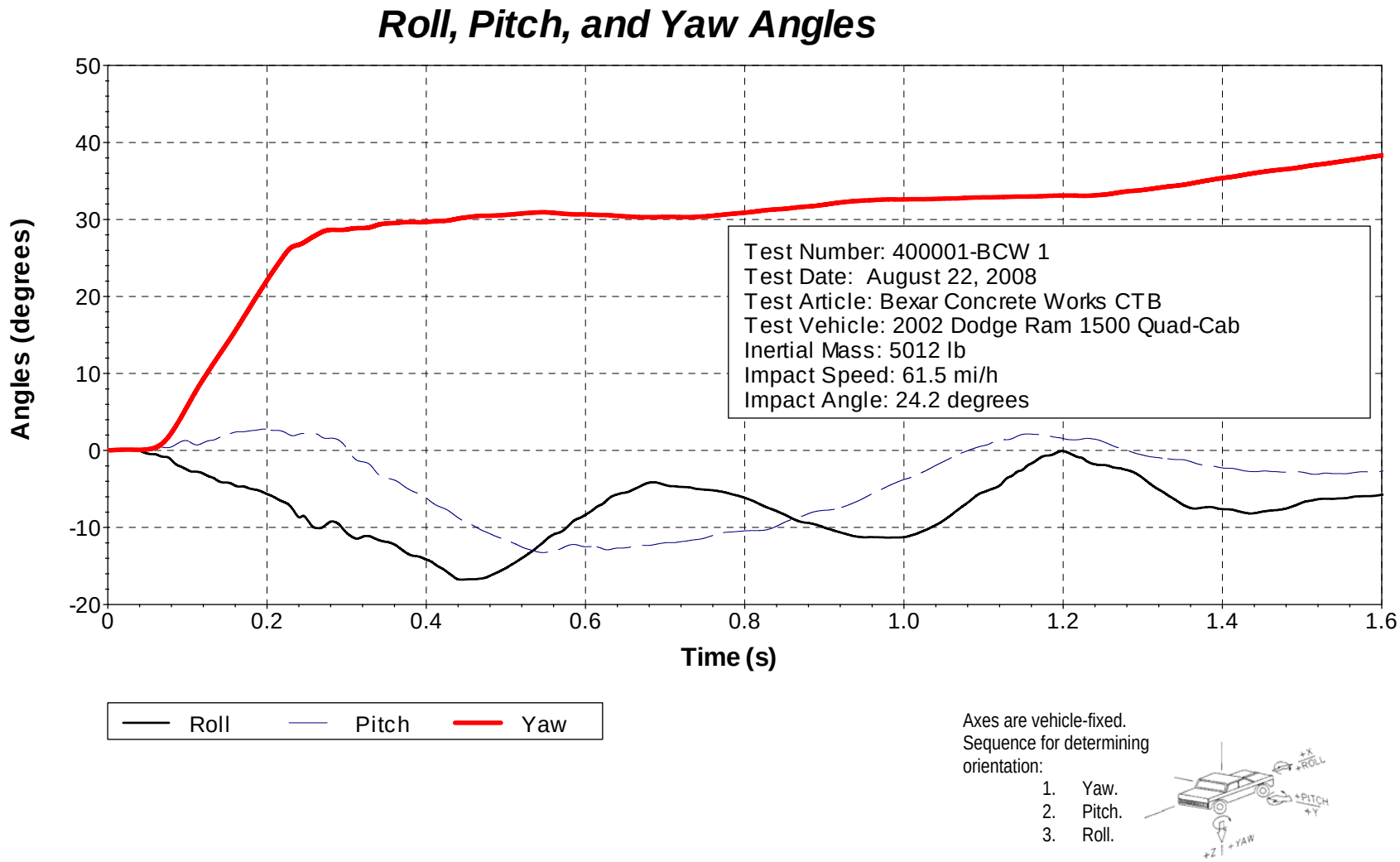


Figure B4. Vehicle angular displacements for test 400001-BCW1.

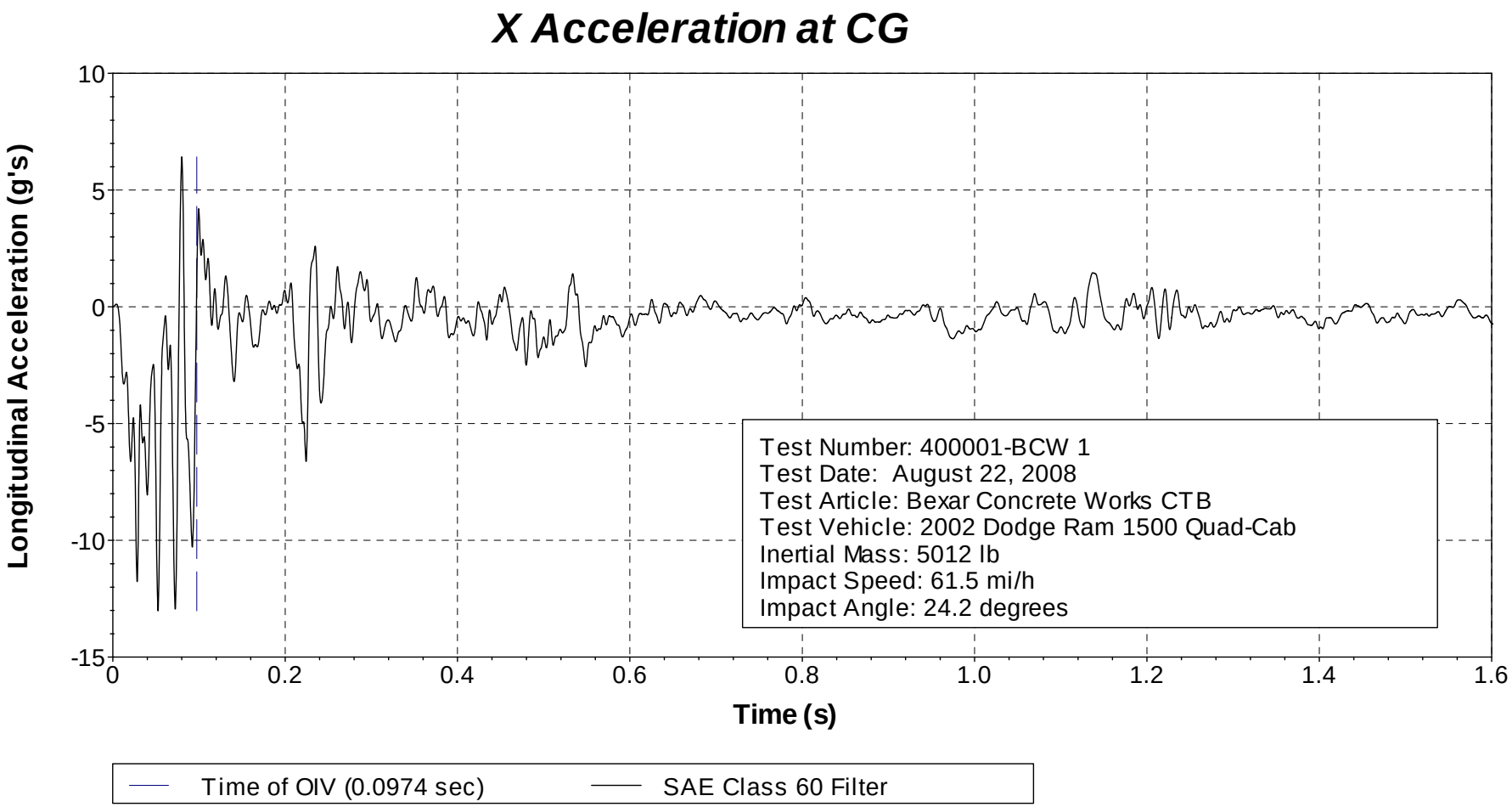


Figure B5. Vehicle longitudinal accelerometer trace for test 400001-BCW1
(accelerometer located at center of gravity).

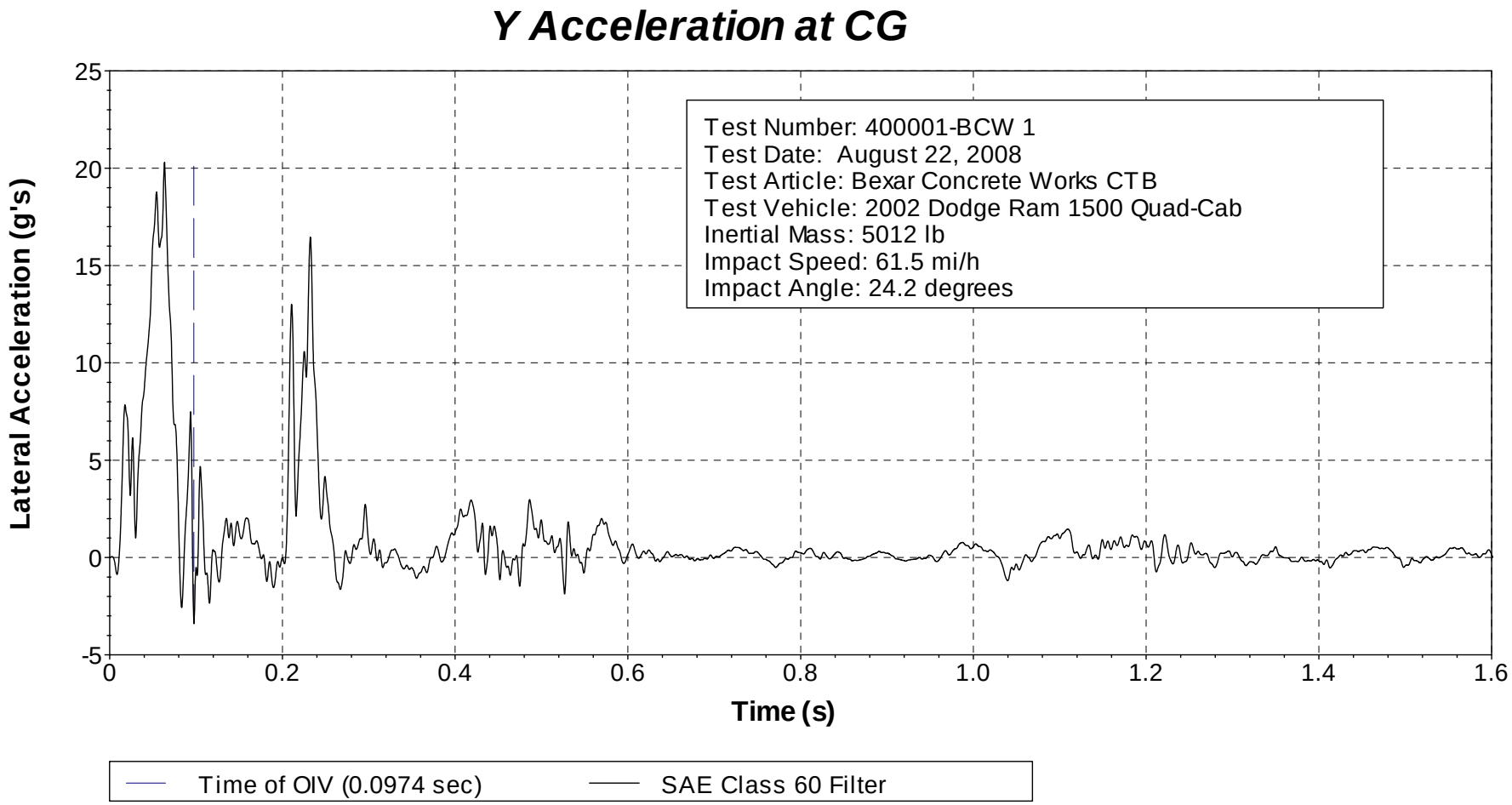


Figure B6. Vehicle lateral accelerometer trace for test 400001-BCW1
(accelerometer located at center of gravity).

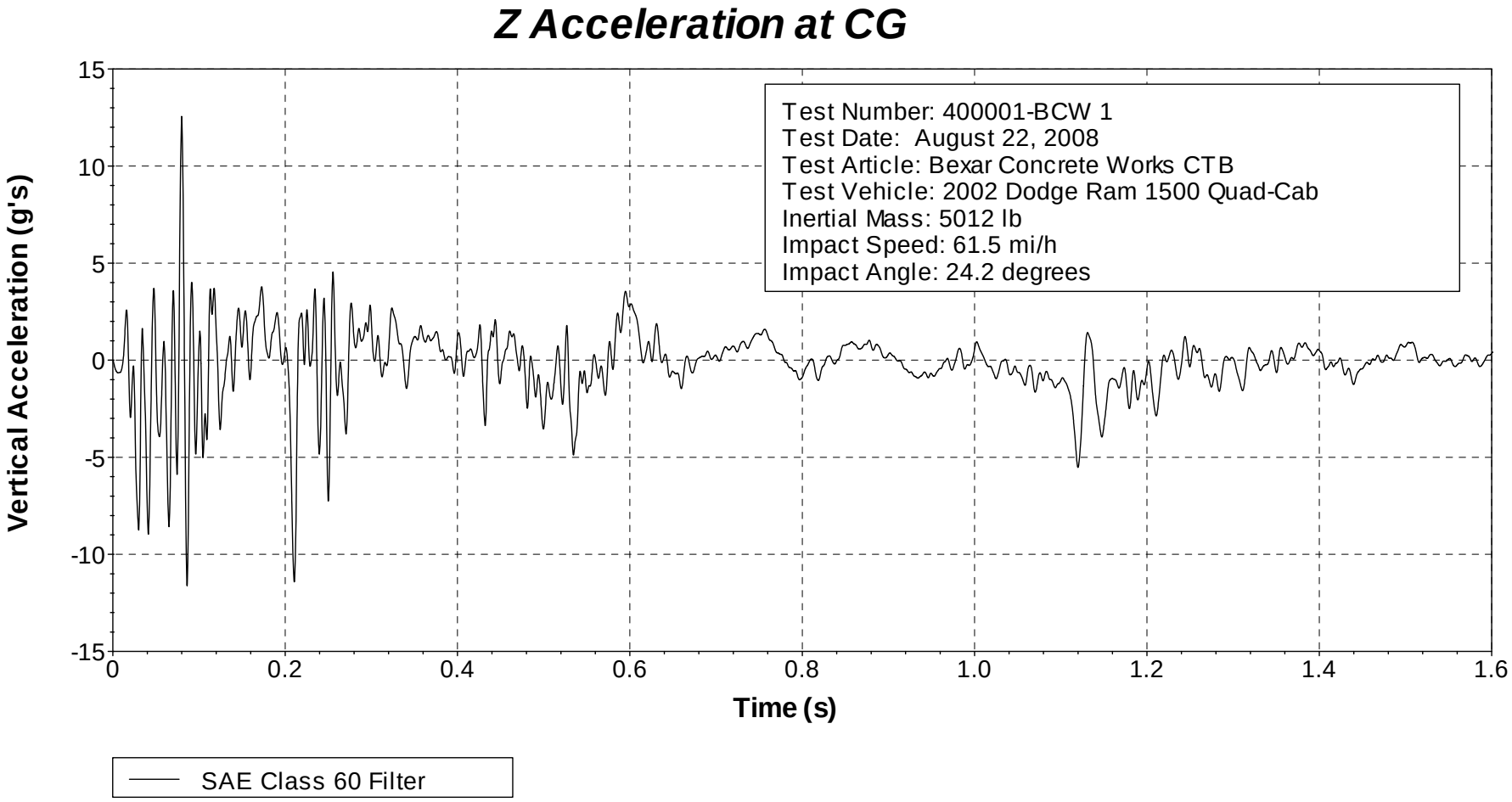


Figure B7. Vehicle vertical accelerometer trace for test 400001-BCW1
(accelerometer located at center of gravity).