EVALUATION OF BOX BEAM STIFFENING OF UNANCHORED TEMPORARY CONCRETE BARRIERS

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Albany, New York 12232

MwRSF Research Report No. TRP-03-202-08

March 14, 2008

Technical Report Documentation Page

1. Report No. TRP-03-202-08	2.	3. Recipient's Accession No.
4. Title and Subtitle Evaluation of Box Beam Stiffening of Unanchored Temporary Concrete Barriers		5. Report Date March 14, 2008
		6.
7. Author(s) Stolle, C.J., Polivka, K.A., Faller, R.K., Sicking, D.L., Bielenberg, R.W., Reid, J.D., Rohde, J.R., Allison, E.M., and Terpsma, R.J.		8. Performing Organization Report No. TRP-03-202-08
9. Performing Organization Name and Address Midwest Roadside Safety Facility (MwRSF) University of Nebraska-Lincoln 527 Nebraska Hall Lincoln, Nebraska 68588-0529		10. Project/Task/Work Unit No.
		11. Contract © or Grant (G) No.
12. Sponsoring Organization Name and Address New York State Department of Transportation 50 Wolf Road, 6th Floor Albany, New York 12232		13. Type of Report and Period Covered Final Report 2007-2008
		14. Sponsoring Agency Code C-06-17

15. Supplementary Notes

Prepared in cooperation with U.S. Department of Transportation, Federal Highway Administration

16. Abstract (Limit: 200 words)

Temporary concrete barrier (TCB) systems that are not pinned into the pavement can be displaced during an impact and can result in workers being crushed between the barrier and objects within the workspace. Alternatively, the barrier could be moved far enough to fall off of the paved surface and onto workers in an excavation, below a bridge, or onto traffic under the bridge. The process for drilling holes in a bridge deck to anchor temporary concrete barriers is time-consuming, costly, and may ultimately result in damage to the bridge. Thus, a means for reducing the deflection of the barrier system is necessary and without the use of anchoring the barrier sections to the underlying pavements with pins, rods, or bolts.

The primary objective of this study was to evaluate the potential for reducing barrier deflections through the use of box beam stiffening on New York State's TCBs. The secondary objective of the study was to evaluate stiffened and unstiffened versions of New York State's temporary concrete barrier system according to the Test Level 3 (TL-3) criteria set forth in the currently proposed Update to NCHRP Report No. 350. The research study included three full-scale vehicle crash tests with Dodge Quad Cab pickup trucks. The first system utilized 152-mm x 152-mm x 4.8-mm (6-in. x 6-in. x 0.1875-in.) box beam sections placed across three joints. The second system consisted of an unstiffened version of the temporary concrete barrier system. The final system utilized 152-mm x 203-mm x 6.4-mm (6-in. x 8-in. x 0.25-in.) box beam sections placed across six joints with the back side of the barriers placed 305 mm (12 in.) away from the bridge deck edge. Following the successful redirection of all three pickup trucks, the safety performance of the unstiffened and the two stiffened designs were determined to be acceptable according the TL-3 evaluation criteria specified in the currently proposed Update to NCHRP Report No. 350. Furthermore, the stiffened versions of the temporary concrete barrier system can be safely installed with a 305 mm (12 in.) gap between the bridge deck edge and the back side of the barriers.

17. Document Analysis/Descriptors Highway Safety, Roadside Appurtenances, Longitudinal Barriers, Temporary Barriers, Concrete Barriers, Box Beam Stiffener, Crash Test, Compliance Test, NCHRP 350 Update		18. Availability Statement No restrictions. Document available from: National Technical Information Services, Springfield, Virginia 22161	
19. Security Class (this report) Unclassified	20. Security Class (this page) Unclassified	21. No. of Pages 223	22. Price

DISCLAIMER STATEMENT

The contents of this report reflect the views of the authors who are responsible for the facts and accuracy of the data presented herein. The contents do not necessarily reflect the official views nor policies of the New York State Department of Transportation, the United States Department of Transportation, nor the Federal Highway Administration. This report does not constitute a standard, specification, regulation, product endorsement, nor an endorsement of manufacturers.

ACKNOWLEDGMENTS

The authors wish to acknowledge several sources that made a contribution to this project: (1) the New York State Department of Transportation for sponsoring the project; and (2) MwRSF personnel for constructing the barriers and conducting the crash tests.

A special thanks is also given to the following individuals who made a contribution to the completion of this research project.

<u>Midwest Roadside Safety Facility</u>

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<u>Federal Highway Administration</u>

Jim Growney, P.E., New York Division Office

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James Dunlap, President and Owner

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1 INTRODUCTION

1.1 Problem Statement

Temporary concrete barrier (TCB) systems that are not pinned into the pavement can be displaced during an impact. The displacement could result in workers being crushed between the barrier and objects within the workspace. Alternatively, the barrier could be moved laterally such as to fall off of the paved surface and onto workers in an excavation, below a bridge, or onto traffic under the bridge. While it is possible to drill holes into a bridge deck in order to anchor the TCB system, the process is time-consuming, costly, and ultimately may result in damage to the bridge. Thus, there is a need for a means of reducing the deflection of the TCB system that does not require an attachment to the pavement.

Previous crash testing of the New York State Department of Transportation (NYSDOT) TCB system, in both pinned and unpinned configurations, has shown acceptable performance. The previous crash testing had been conducted according to the National Cooperative Highway Research Program (NCHRP) Report No. 350 safety performance criteria (1). However, an unpinned, stiffened version of the TCB has not been crash tested. In order to stiffen the system, a proposed solution was to fasten box beam sections across barrier joints and to anchor both ends of the barrier system. Although the bolt heads used to fasten the box beams to the barrier sections may have a slight effect on the vehicle's response, they should not be a cause for concern. These box beam stiffening sections were believed to be capable of reducing lateral deflections and preventing separation of the barriers when deflected and suspended over the edge of a bridge deck.

1.2 Research Objective

The objective of this research project was to evaluate the safety performance of stiffened NYSDOT temporary concrete barrier systems and compare it to the performance observed for non-stiffened TCBs. As part of the testing program, Midwest Roadside Safety Facility (MwRSF) researchers suggested that the stiffened TCB be placed adjacent to the free edge of a bridge deck in order to evaluate a real-world scenario as well as to provide convincing evidence of the system's effectiveness. NYSDOT officials agreed to this modified test layout as part of the final crash test. NYSDOT officials were confident that the barrier systems would meet all impact safety standards. However, the NYSDOT desired that the temporary concrete barrier systems be evaluated according to the new Test Level 3 (TL-3) safety performance criteria set forth in the currently proposed Update to NCHRP Report No. 350 (2).

1.3 Scope

The research objective was achieved through the completion of several tasks. First, full-scale vehicle crash tests were performed on the box beam stiffened and unstiffened versions of the temporary concrete barrier system. The crash tests utilized ½ ton pickup trucks, each weighing approximately 2,270 kg (5,004 lbs) as recommended by the currently proposed Update to NCHRP Report No. 350 (2). The target impact conditions for the tests were an impact speed of 100.0 km/h (62.1 mph) and an impact angle of 25 degrees. Next, the test results were analyzed, evaluated, and documented. Finally, conclusions and recommendations were made that pertain to the safety performance of the box beam stiffened and unstiffened variations of the temporary concrete barrier system.

2 LITERATURE REVIEW

Previous testing on the NYSDOT TCB system was conducted by the Texas Transportation Institute (TTI) (3-4). Crash testing of the TCB system was evaluated according to the criteria provided in NCHRP Report No. 350 (1).

In 1999, TTI tested the unpinned version of the NYSDOT TCB (3). In test no. 473220-7, a 2,075-kg (4,575-lb) pickup truck impacted the ten barrier system 1.2 m (3 ft - 11 in.) upstream of the connection between barrier segment nos. 3 and 4 at a speed of 98.0 km/h (60.9 mph) and at an angle of 26.3 degrees. During the impact, three of the barrier joints failed, causing the barrier at the point of impact to overturn. Subsequently, the vehicle overrode the barrier and rolled over. Thus, the test was determined to be unacceptable according to the NCHRP Report No. 350 requirements, since the vehicle did not remain upright after collision with the system. The joint failure was subsequently attributed to substandard welding in the connection joints.

In 2001, TTI retested the properly fabricated unpinned NYSDOT TCB system (4). It should be noted that the end barrier sections were unpinned as well. During test no. 473220-14, a 2,076-kg (4,577-lb) pickup truck impacted the ten barrier system 1.38 m (4 ft - 6 in.) upstream of the joint between barrier segment nos. 3 and 4 at a speed of 100.8 km/h (62.6 mph) and at an angle of 25.6 degrees. During the impact, the vehicle was redirected smoothly, and the test was determined to be acceptable according to the NCHRP Report No. 350 requirements. The barrier system experienced 1,270 mm (50 in.) of dynamic deflection and 1,270 mm (50 in.) of permanent set deflection. During the test, the upstream end was pulled 148 mm (5.8 in.) longitudinally downstream, while the downstream end was displaced 5 mm (0.2 in.) longitudinally upstream, or toward the impact point. The noted lateral barrier deflections would be correlated to the unpinned section ends.

It was NYSDOT's concern over this large barrier deflection that caused the state agency to contract with MwRSF to conduct the barrier stiffening research covered by this report.

3 TEST REQUIREMENTS AND EVALUATION CRITERIA

3.1 Test Requirements

Historically, longitudinal barriers, such as temporary concrete barriers, have been required to satisfy impact safety standards in order to be accepted by the Federal Highway Administration (FHWA) for use on National Highway System (NHS) construction projects or as a replacement for existing designs not meeting current safety standards. In recent years, these safety standards have consisted of the guidelines and procedures published in NCHRP Report No. 350 (1). However, NCHRP Project 22-14(2) generated revised testing procedures and guidelines for use in the evaluation of roadside safety appurtenances and have been presented in the draft report entitled, *Recommended Procedures for the Safety Performance Evaluation of Highway Features* (2). Therefore, according to TL-3 of the currently proposed Update to NCHRP Report No. 350, longitudinal barrier systems must be subjected to two full-scale vehicle crash tests. The two full-scale crash tests are as follows:

1. Test Designation 3-10 consisting of an 1,100-kg (2,425-lb) passenger car impacting the barrier system at a nominal speed and angle of 100.0 km/h (62.1 mph) and 25 degrees, respectively.

2. Test Designation 3-11 consisting of a 2,270-kg (5,004-lb) pickup truck impacting the barrier system at a nominal speed and angle of 100.0 km/h (62.1 mph) and 25 degrees, respectively.

A rigid, F-shape bridge rail was successfully impacted by a small car weighing 893 kg (1,800 lbs) at 96.7 km/h (60.1 mph) and 21.4 degrees according to the American Association of State Highway and Transportation Officials (AASHTO) *Guide Specifications for Bridge Railings* (5-6). In the same manner, rigid New Jersey safety shape barriers struck by small cars have also been shown to meet safety performance standards (7-8). In addition, a New Jersey safety shape barrier was impacted by a passenger car weighing 1,170 kg (2,579 lbs) at 97.9 km/h (60.8 mph) and 26.1

degrees according to the TL-3 standards set forth in the currently proposed Update to NCHRP Report No. 350 (9). Furthermore, temporary New Jersey safety shape concrete median barriers have experienced only slight barrier deflections when impacted by small cars and behave similar to rigid barriers (10). As such, the 1,100-kg (2,425-lb) passenger car test was deemed unnecessary for this project. The test conditions for TL-3 longitudinal barriers are summarized in Table 1.

For this crash testing program, the NYSDOT's primary objective was to evaluate the potential for reducing barrier deflections through the use of box beam stiffening on an approved TCB design.

3.2 Evaluation Criteria

According to the currently proposed Update to NCHRP Report No. 350, the evaluation criteria for full-scale vehicle crash testing are based on three appraisal areas: (1) structural adequacy; (2) occupant risk; and (3) vehicle trajectory after collision. Criteria for structural adequacy are intended to evaluate the ability of the barrier to contain, redirect, or allow controlled vehicle penetration in a predictable manner. Occupant risk evaluates the degree of hazard to occupants in the impacting vehicle. Vehicle trajectory after collision is a measure of the potential for the post-impact trajectory of the vehicle to cause subsequent multi-vehicle accidents. This criterion also indicates the potential safety hazard for the occupants of other vehicles or the occupants of the impacting vehicle when subjected to secondary collisions with other fixed objects. These three evaluation criteria are summarized in Table 2 and defined in greater detail in the currently proposed Update to NCHRP Report No. 350 (2). The full-scale vehicle crash tests were conducted and reported in accordance with the procedures provided in the currently proposed Update to NCHRP Report No. 350.

In addition to the standard occupant risk measures, the Post-Impact Head Deceleration

(PHD) and Theoretical Head Impact Velocity (THIV) were also determined and reported on the test summary sheets. Additional discussion on PHD and THIV is provided in reference (2).

Table 1. Update to NCHRP Report No. 350 Test Level 3 Crash Test Conditions

Test Article	Test Designation	Test Vehicle	Impact Conditions			Evaluation Criteria[1]
			Speed		Angle (degrees)	
			(km/h)	(mph)		
Longitudinal Barrier	3-10	1100C	100	62.1	25	A,D,F,H,I,M
	3-11	2270P	100	62.1	25	A,D,F,H,I,M

[1] Evaluation criteria explained in Table 2.

Table 2. Update to NCHRP Report No. 350 Evaluation Criteria for Crash Tests

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.
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. Deformations of, or intrusions into, the occupant compartment should not exceed limits set forth in Section 5.3 and Appendix E of the currently proposed Update to NCRHP Report No. 350.
	F. The vehicle should remain upright during and after collision. The maximum roll and pitch angles are not to exceed 75 degrees.
	H. Longitudinal and lateral occupant impact velocities should fall below the preferred value of 9.1 m/s (30.0 ft/s), or at least below the maximum allowable value of 12.2 m/s (40.0 ft/s).
	I. Longitudinal and lateral occupant ridedown accelerations should fall below the preferred value of 15.0 g's, or at least below the maximum allowable value of 20.49 g's.
Vehicle Trajectory	M. After impact, the vehicle shall exit the barrier within the exit box.

4 TEST CONDITIONS

4.1 Test Facility

The testing facility is located at the Lincoln Air Park on the northwest side of the Lincoln Municipal Airport and is approximately 8.0 km (5 mi.) northwest of the University of Nebraska-Lincoln.

4.2 Vehicle Tow and Guidance System

A reverse cable tow system with a 1:2 mechanical advantage was used to propel the test vehicle. The distance traveled and the speed of the tow vehicle were one-half that of the test vehicle. The test vehicle was released from the tow cable before impact with the barrier system. A digital speedometer on the tow vehicle increases the accuracy of the test vehicle impact speed.

A vehicle guidance system developed by Hinch (11) was used to steer the test vehicle. A guide-flag, attached to the front-left wheel and the guide cable, was sheared off before impact with the barrier system. The 9.5-mm (0.375-in.) diameter guide cable was tensioned to approximately 15.6 kN (3,500 lbf), and supported laterally and vertically every 30.48 m (100 ft) by hinged stanchions. The hinged stanchions stood upright while holding up the guide cable, but as the vehicle was towed down the line, the guide-flag struck and knocked each stanchion to the ground. For tests NYTCB-1, NYTCB-2, and NYTCB-3, the vehicle guidance system was 335 m (1,100 ft) long.

4.3 Test Vehicles

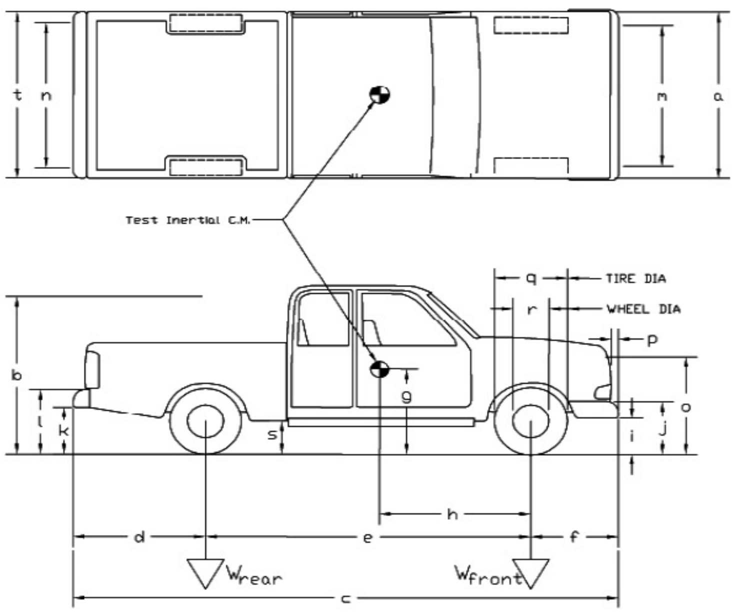
For test NYTCB-1, a 2002 Dodge Ram 1500 Quad Cab pickup truck was used as the test vehicle. The test inertial and gross static weights were 2,275 kg (5,016 lbs). The test vehicle is shown in Figure 1, and vehicle dimensions are shown in Figure 2.

For test NYTCB-2, a 2002 Dodge Ram 1500 Quad Cab pickup truck was used as the test

Figure 1. Test Vehicle, Test NYTCB-1

Date:	7/24/2007	Test Number:	NYTCB-1	Model:	Ram 1500 Q.C.
Make:	Dodge	Vehicle I.D.#:	3B7HA18N32G103871		
Tire Size:	265/70 R17	Year:	2002	Odometer:	81292

*(All Measurements Refer to Impacting Side)



Vehicle Geometry -- mm (in.)

a	1981.2 (78.0)	b	1886 (74.25)
c	5778.5 (227.5)	d	1219.2 (48.0)
e	3562.4 (140.25)	f	996.95 (39.25)
g	727.08 (28.625)	h	1590.3 (62.61)
i	381 (15.0)	j	530.23 (20.875)
k	530.23 (20.875)	l	714.38 (28.125)
m	1727.2 (68.0)	n	1714.5 (67.5)
o	1168.4 (46.0)	p	82.55 (3.25)
q	774.7 (30.5)	r	469.9 (18.5)
s	393.7 (15.5)	t	1911.4 (75.25)

Wheel Center Height Front	381 (15.0)
Wheel Center Height Rear	384.18 (15.125)
Wheel Well Clearance (FR)	904.88 (35.625)
Wheel Well Clearance (RR)	962.03 (37.875)
Frame Height (FR)	635 (25.0)
Frame Height (RR)	454.03 (17.875)
Engine Type	8 CYL. GAS
Engine Size	4.7L
Transmition Type:	Automatic
	RWD

Weights kg (lbs)	Curb	Test Inertial	Gross Static
W-front	1285 (2833)	1266 (2791)	1266 (2791)
W-rear	1016.5 (2241)	1009.2 (2225)	1009.2 (2225)
W-total	2301.5 (5074)	2275.2 (5016)	2275.2 (5016)

Front GVWR	3650
Rear GVWR	3900
Total GVWR	6650

Note any damage prior to test: None

Figure 2. Vehicle Dimensions, Test NYTCB-1

vehicle. The test inertial and gross static weights were 2,279 kg (5,024 lbs). The test vehicle is shown in Figure 3, and vehicle dimensions are shown in Figure 4.

For test NYTCB-3, a 2003 Dodge Ram 1500 Quad Cab pickup truck was used as the test vehicle. The test inertial and gross static weights were 2,268 kg (5,001 lbs). The test vehicle is shown in Figure 5, and vehicle dimensions are shown in Figure 6.

The Suspension Method (12) was used to determine the vertical component of the center of gravity (c.g.) for the pickup trucks. This method is based on the principle that the c.g. of any freely suspended body is in the vertical plane through the point of suspension. The vehicle was suspended successively in three positions, and the respective planes containing the c.g. were established. The intersection of these planes pinpointed the location of the center of gravity. The longitudinal component of the c.g. was determined using the measured axle weights. The location of the final centers of gravity are shown in Figures 2, 4, 6, and 7 through 9.

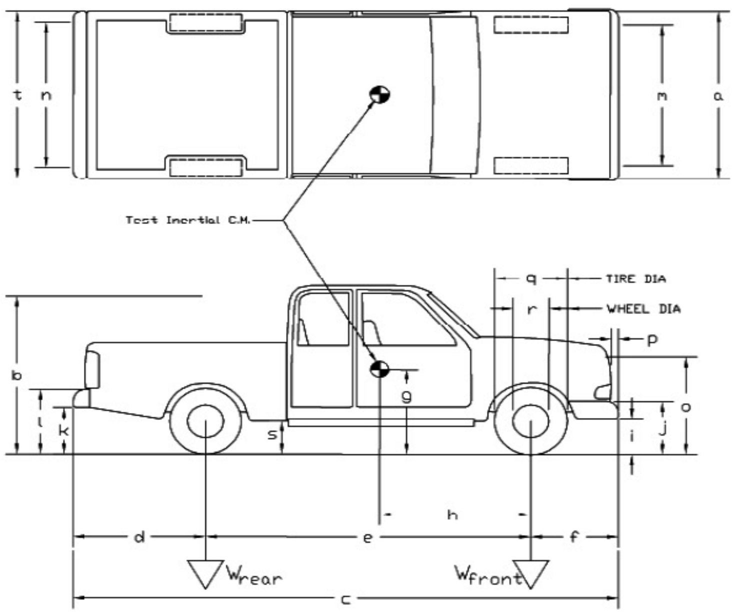
Square black and white-checkered targets were placed on the vehicle to aid in the analysis of the high-speed AOS videos, as shown in Figures 7 through 9. Checkered targets were placed at the c.g. on the left-side door, the right-side door, and the roof of the vehicle. The remaining targets were located for reference so that they could be viewed from the high-speed cameras for video analysis.

The front wheels of the test vehicle were aligned for camber, caster, and toe-in values of zero so that the vehicles would track properly along the guide cable. A 5B flash bulb was mounted on the left-quarter point of the vehicle's dash to pinpoint the time of impact with the test article on the high-speed video footage. The flash bulb was fired by a pressure tape switch mounted at the impact corner of the bumper. A remote controlled brake system was installed in the test vehicle so the vehicle could be brought safely to a stop after the test.

Figure 3. Test Vehicle, Test NYTCB-2

Date:	7/25/2007	Test Number:	NYTCB-2	Model:	Ram 1500 Q.C.
Make:	Dodge	Vehicle I.D.#:	1D7HA18K83J506255		
Tire Size:	265/70 R17	Year:	2002	Odometer:	96569

*(All Measurements Refer to Impacting Side)



Vehicle Geometry -- mm (in.)

a	1981.2 (78.0)	b	1917.7 (75.5)
c	5778.5 (227.5)	d	1206.5 (47.5)
e	3562.4 (140.25)	f	1009.7 (39.75)
g	711.2 (28.0)	h	1625.6 (64.0)
i	355.6 (14.0)	j	647.7 (25.5)
k	520.7 (20.5)	l	730.25 (28.75)
m	1727.2 (68.0)	n	1720.9 (67.75)
o	1124 (44.25)	p	88.9 (3.5)
q	774.7 (30.5)	r	469.9 (18.5)
s	381 (15.0)	t	1911.4 (75.25)

Wheel Center Height Front	381 (15.0)
Wheel Center Height Rear	384.18 (15.125)
Wheel Well Clearance (FR)	889 (35.0)
Wheel Well Clearance (RR)	965.2 (38.0)
Frame Height (FR)	444.5 (17.5)
Frame Height (RR)	635 (25.0)
Engine Type	6 CYL. GAS
Engine Size	3.7L
Transmition Type:	Automatic RWD

Weights kg (lbs)	Curb	Test Inertial	Gross Static
W-front	1232.9 (2718)	1216.1 (2681)	1216.1 (2681)
W-rear	1012 (2231)	1062.8 (2343)	1062.8 (2343)
W-total	2244.8 (4949)	2278.8 (5024)	2278.8 (5024)

Front GVWR	3650
Rear GVWR	3900
Total GVWR	6650

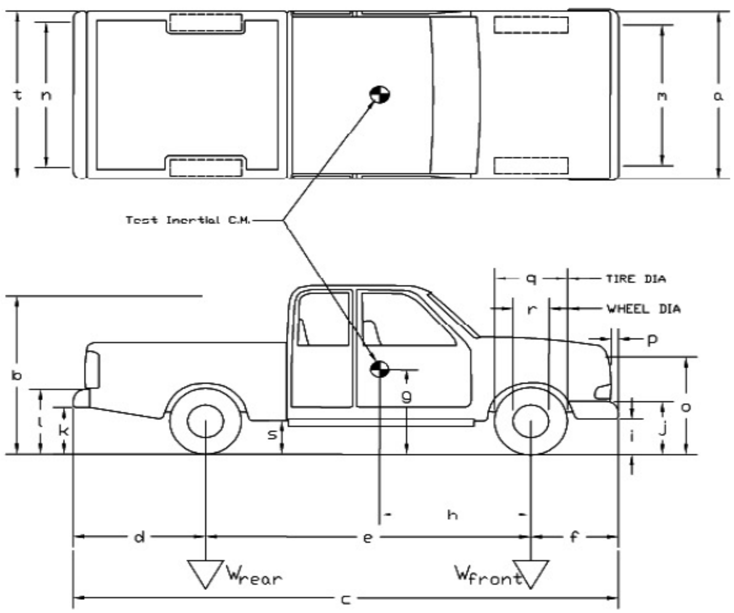
Note any damage prior to test: None

Figure 4. Vehicle Dimensions, Test NYTCB-2

Figure 5. Test Vehicle, Test NYTCB-3

Date:	8/30/2007	Test Number:	NYTCB-3	Model:	Ram 1500 Q.C.
Make:	Dodge	Vehicle I.D.#:	1D7HA18D53S233366		
Tire Size:	245/70 R17	Year:	2003	Odometer:	98929

*(All Measurements Refer to Impacting Side)



Vehicle Geometry -- mm (in.)

a	1978	(77.875)	b	1905	(75.0)
c	5784.9	(227.75)	d	1212.9	(47.75)
e	3562.4	(140.25)	f	1009.7	(39.75)
g	736.6	(29.0)	h	1569.7	(61.8)
i	406.4	(16.0)	j	723.9	(28.5)
k	508	(20.0)	l	711.2	(28.0)
m	1714.5	(67.5)	n	1720.9	(67.75)
o	1193.8	(47.0)	p	88.9	(3.5)
q	762	(30.0)	r	469.9	(18.5)
s	431.8	(17.0)	t	1911.4	(75.25)

Wheel Center Height Front	355.6	(14.0)
Wheel Center Height Rear	361.95	(14.25)
Wheel Well Clearance (FR)	927.1	(36.5)
Wheel Well Clearance (RR)	952.5	(37.5)
Frame Height (FR)	488.95	(19.25)
Frame Height (RR)	609.6	(24.0)
Engine Type	8 CYL. GAS	
Engine Size	5.7L HEMI	

Transmission Type:

Automatic

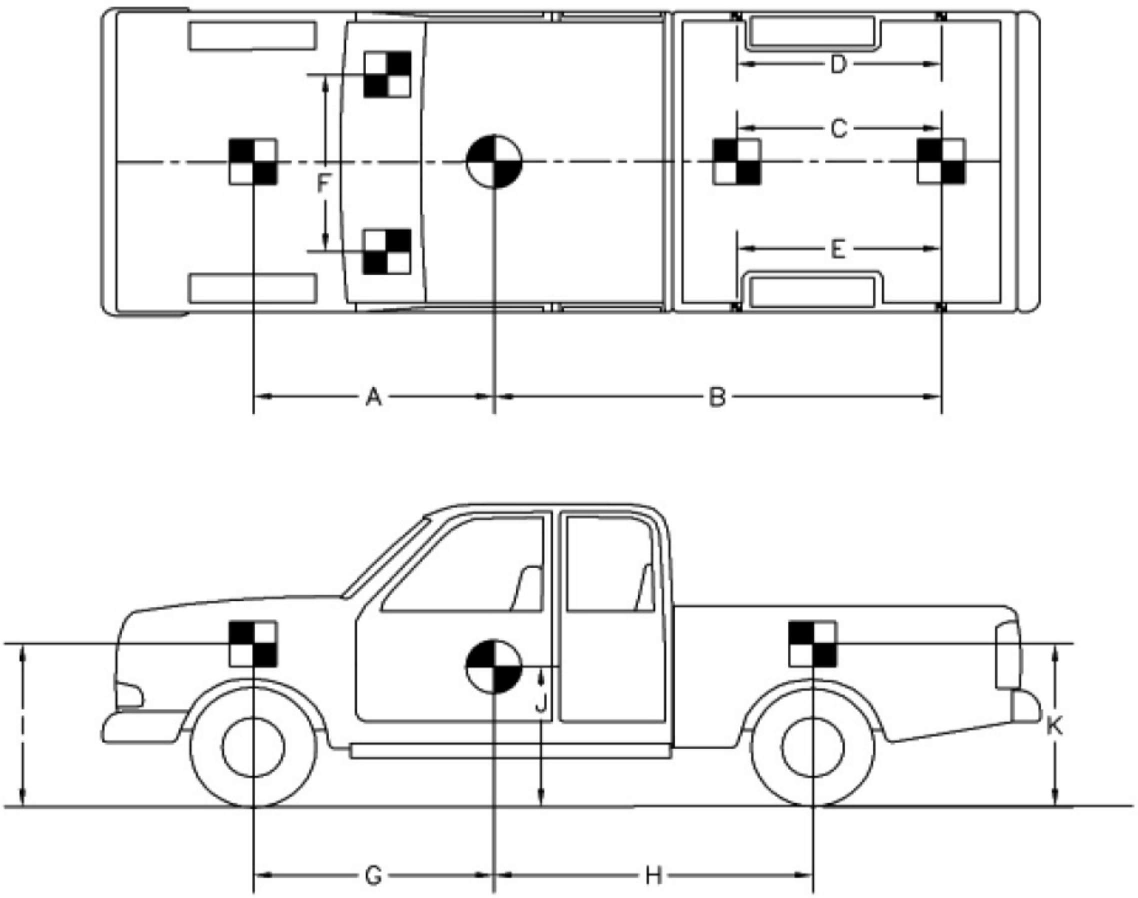
RWD

Weights kg (lbs)	Curb	Test Inertial	Gross Static
W-front	1297.7 (2861)	1264.6 (2788)	1264.6 (2788)
W-rear	1005.6 (2217)	1003.8 (2213)	1003.8 (2213)
W-total	2303.3 (5078)	2268.4 (5001)	2268.4 (5001)

Front GVWR	3650
Rear GVWR	3900
Total GVWR	6650

Note any damage prior to test: none

Figure 6. Vehicle Dimensions, Test NYTCB-3

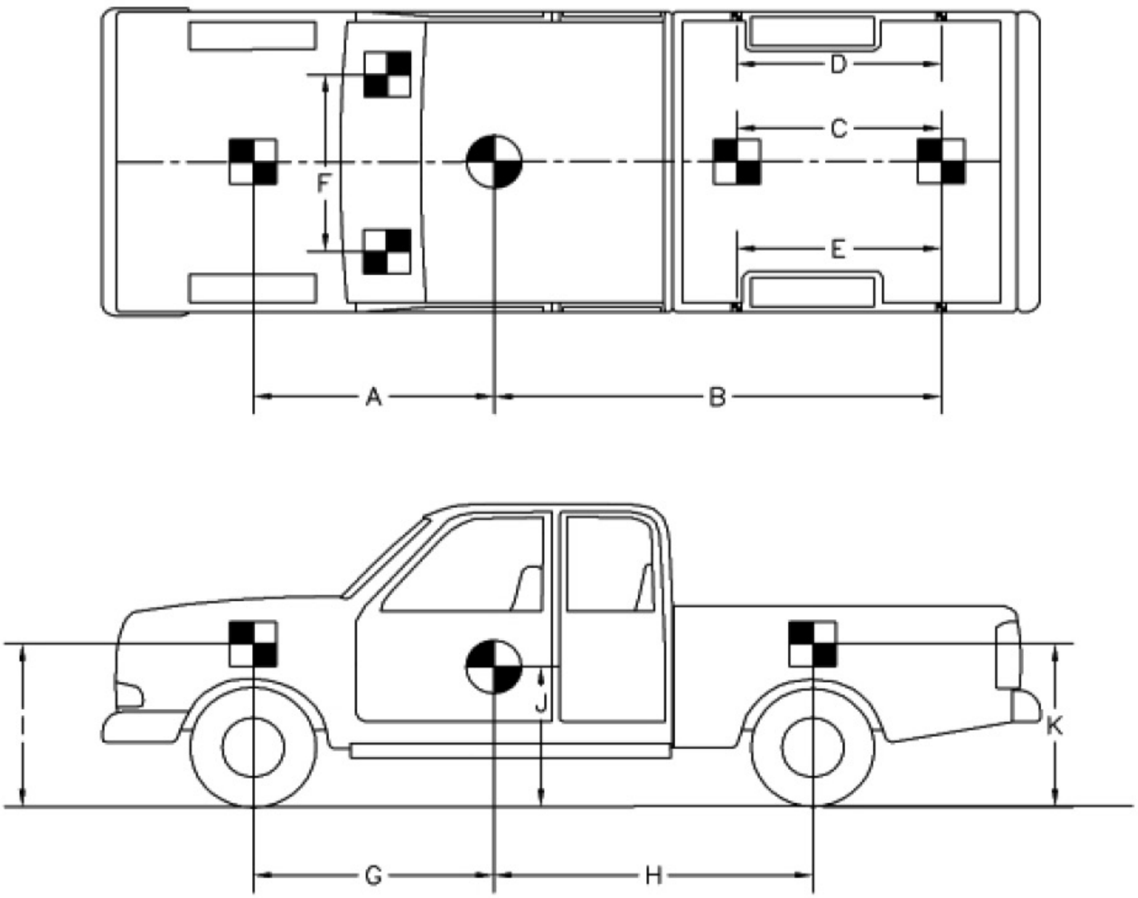


TEST #: NYTCB-1

TARGET GEOMETRY-- mm (in.)

A 1861 (73.25)	E 1791 (70.5)	I 1019 (40.125)
B 2737 (107.75)	F 1035 (40.75)	J 714 (28.125)
C 1219 (48.0)	G 1591 (62.625)	K 1080 (42.5)
D 1778 (70.0)	H 1972 (77.625)	

Figure 7. Vehicle Target Locations, Test NYTCB-1

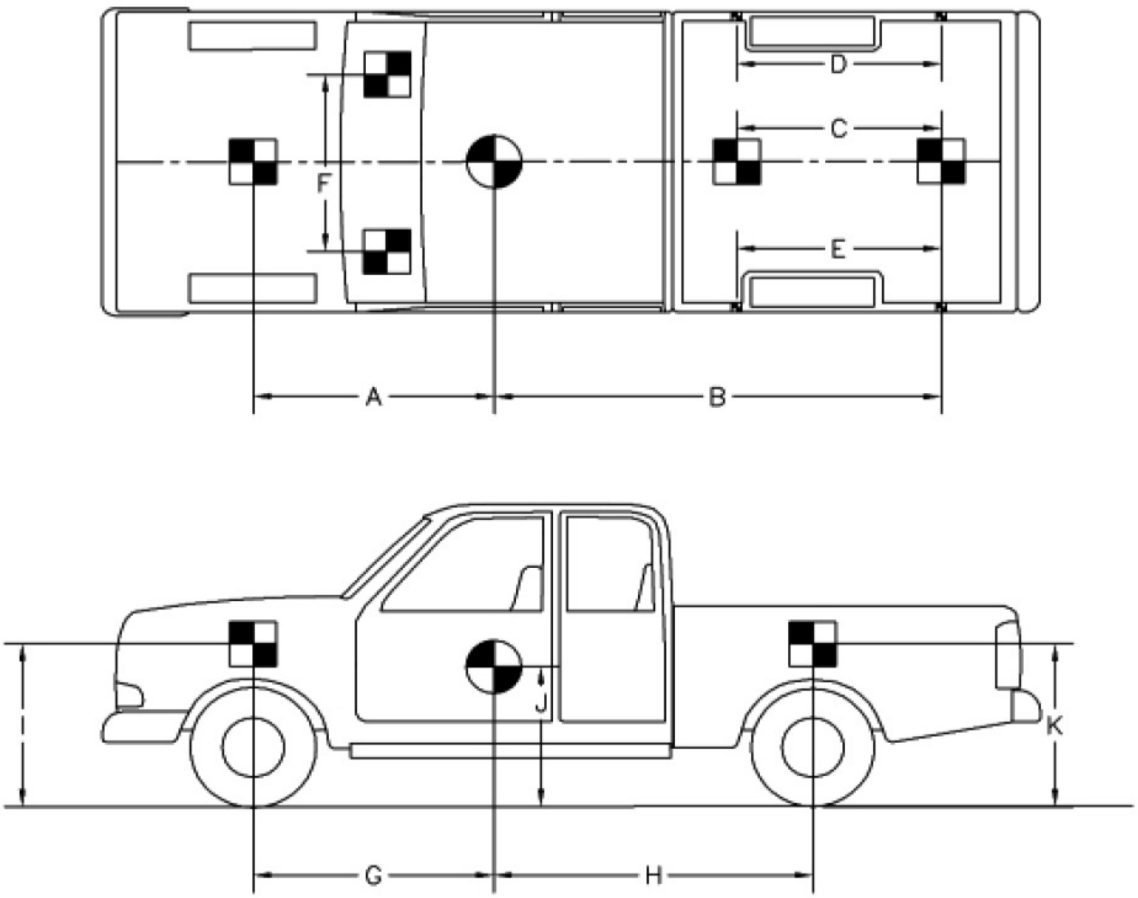


TEST #: NYTCB-2

TARGET GEOMETRY-- mm (in.)

A	1835	(72.25)	E	1759	(69.25)	I	997	(39.25)
B	2610	(102.75)	F	1016	(40.0)	J	711	(28.0)
C	1099	(43.25)	G	1626	(64.0)	K	1086	(42.75)
D	1759	(69.25)	H	1937	(76.25)			

Figure 8. Vehicle Target Locations, Test NYTCB-2



TEST #: NYTBC-3

TARGET GEOMETRY-- mm (in.)

A	1753	(69.0)	E	1626	(64.0)	I	1041	(41.0)
B	2565	(101.0)	F	1035	(40.75)	J	737	(29.0)
C	1219	(48.0)	G	1570	(61.8)	K	1060	(41.75)
D	1626	(64.0)	H	1993	(78.45)			

Figure 9. Vehicle Target Locations, Test NYTCB-3

4.4 Data Acquisition Systems

4.4.1 Accelerometers

One triaxial piezoresistive accelerometer system with a range of ±200 g's was used to measure the acceleration in the longitudinal, lateral, and vertical directions at a sample rate of 10,000 Hz. The environmental shock and vibration sensor/recorder system, Model EDR-4M6, was developed by Instrumented Sensor Technology (IST) of Okemos, Michigan and includes three differential channels as well as three single-ended channels. The EDR-4 was configured with 6 MB of RAM memory and a 1,500 Hz lowpass filter. "DynaMax 1 (DM-1)" and "DADiSP"computer software programs were used to analyze and plot the accelerometer data.

Another triaxial piezoresistive accelerometer system with a range of ±200 g's was also used to measure the acceleration in the longitudinal, lateral, and vertical directions at a sample rate of 3,200 Hz. The environmental shock and vibration sensor/recorder system, Model EDR-3, was developed by Instrumented Sensor Technology (IST) of Okemos, Michigan. The EDR-3 was configured with 256 kB of RAM memory and a 1,120 Hz lowpass filter. "DynaMax1 (DM-1)" and "DADiSP" computer software programs were used to analyze and plot the accelerometer data.

For test no. NYTCB-3, an additional accelerometer system was used to measure the acceleration in the longitudinal, lateral, and vertical directions at a sample rate of 10,000 Hz. The environmental shock and vibration sensor/recorder system, a two-Arm piezoresistive accelerometer, was developed by Endevco of San Juan Capistrano, California. Three accelerometers were used to measure each of the longitudinal, lateral, and vertical accelerations independently. Data was collected using a Sensor Input Module (SIM), Model TDAS3-SIM-16M, which was developed by Diversified Technical Systems, Inc. (DTS) of Seal Beach, California. The SIM was configured with 16 MB SRAM memory and 8 sensor input channels with 250 kB SRAM/channel. The SIM was mounted on a TDAS3-R4 module rack. The module rack is configured with isolated power/event/communications, 10BaseT Ethernet and RS232 communication, and an internal back-up battery. Both the SIM and module rack are crashworthy. “DTS TDAS Control” and “DADiSP” computer software programs and a customized Microsoft Excel worksheet were used to analyze and plot the accelerometer data.

4.4.2 Rate Transducers

An Analog Systems 3-axis rate transducer with a range of 1,200 degrees/sec in each of the three directions (pitch, roll, and yaw) was used to measure the rates of motion of the test vehicles. The rate transducer was mounted inside the body of the EDR-4M6 and recorded data at 10,000 Hz to a second data acquisition board inside the EDR-4M6 housing. The raw data measurements were then downloaded, converted to the proper Euler angles for analysis, and plotted. “DynaMax 1” and “DADiSP” computer software programs were used to analyze and plot the rate transducer data.

For test no. NYTCB-3, an additional angular rate sensor was used. The ARS-1500 has a range of 1,500 degrees/sec in each of the three directions (pitch, roll, and yaw) and was used to measure the rates of rotation of the test vehicle. The angular rate sensor was mounted on an aluminum block inside the test vehicle at the center of gravity and recorded data at 10,000 Hz to the SIM. The raw data measurements were then downloaded, converted to the proper Euler angles for analysis, and plotted. “DTS TDAS Control” and “DADiSP” computer software programs and a customized Microsoft Excel worksheet were used to analyze and plot the angular rate sensor data.

4.4.3 High-Speed Photography

For test no. NYTCB-1, four high-speed AOS VITcam digital video cameras, all with operating speeds of 500 frames/sec, were used to film the crash test. Four JVC digital video cameras and two Canon digital video cameras, all with standard operating speeds of 29.97 frames/sec, were also used to film the crash test. Camera details and a schematic of all ten camera locations for test no. NYTCB-1 are shown in Figure 10.

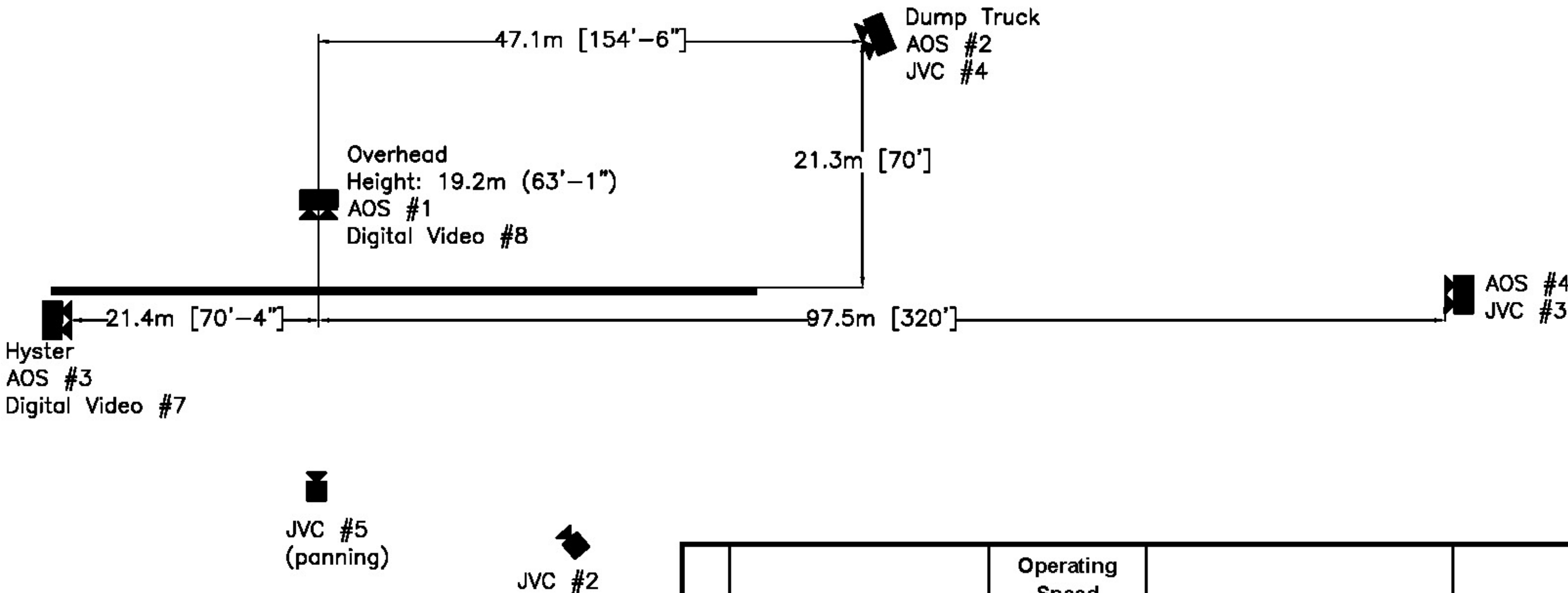
For test no. NYTCB-2, four high-speed AOS VITcam cameras, all with operating speeds of approximately 500 frames/sec, were used to film the crash test. Five JVC digital video cameras and two Canon digital video cameras, all with standard operating speeds of 29.97 frames/sec, were also used to film the crash test. Camera details and a schematic of all eleven camera locations for test no. NYTCB-2 are shown in Figure 11.

For test no. NYTCB-3, four high-speed AOS VITcam video cameras, and two high-speed VIS cameras, all with operating speeds of 500 frames/sec, were used to film the crash test. Five JVC digital video cameras and two Canon digital video cameras, all with standard operating speeds of 29.97 frames/sec, were also used to film the crash test. Camera details and a schematic of all thirteen camera locations for test no. NYTCB-3 are shown in Figure 12.

The AOS and VIS videos were analyzed using the ImageExpress MotionPlus and Weinberger Visart software, respectively. Actual camera speed and camera divergence factors were considered in the analysis of the high-speed videos.

4.4.4 Pressure Tape Switches

For test nos. NYTCB-1 through NYTCB-3, five pressure-activated tape switches, spaced at 2-m (6.56-ft) intervals, were used to determine the speed of the vehicle before impact. Each tape switch fired a strobe light which sent an electronic timing signal to the data acquisition system as the vehicle's left-front tire for test nos. NYTCB-1 and NYTCB-2 and the vehicle's right-front tire for test no. NYTCB-3 passed over it. Test vehicle speeds were determined from electronic timing mark data recorded using TestPoint software. Strobe lights and high-speed video analysis are used only as a backup in the event that vehicle speeds cannot be determined from the electronic data.



	No.	Type	Operating Speed (frames/sec)	Lens	Lens Setting
High-Speed Video	1	Vitcam CTM	500	Fixed 12.5mm	-
	2	Vitcam CTM	500	Sigma 24-135	70
	3	Vitcam CTM	500	Fixed 50mm	-
	4	Vitcam CTM	500	Sigma 70-200	135
Digital Video	2	JVC - GZ-MC40(Everio)	29.97		
	3	JVC - GZ-MC40(Everio)	29.97		
	4	JVC - GZ-MC40(Everio)	29.97		
	5	JVC - GZ-MC40(Everio)	29.97		
	7	Canon-ZR90	29.97		
	8	Canon-ZR90	29.97		

Figure 10. Locations of Cameras, Test NYTCB-1

	No.	Type	Operating Speed (frames/sec)	Lens	Lens Setting
High-Speed Video	1	Vitcam CTM	500	Fixed 12.5mm	-
	2	Vitcam CTM	500	Sigma Zoom 24-70	70
	3	Vitcam CTM	500	Fixed 50mm	-
	4	Vitcam CTM	500	Sigma 70-200	135
Digital Video	1	JVC - GZ-MC500 (Everio)	29.97		
	2	JVC - GZ-MC40u (Everio)	29.97		
	3	JVC - GZ-MC40u (Everio)	29.97		
	4	JVC - GZ-MC40u (Everio)	29.97		
	5	JVC - GZ-MC27u (Everio)	29.97		
	7	Canon-ZR90	29.97		
	8	Canon-ZR90	29.97		

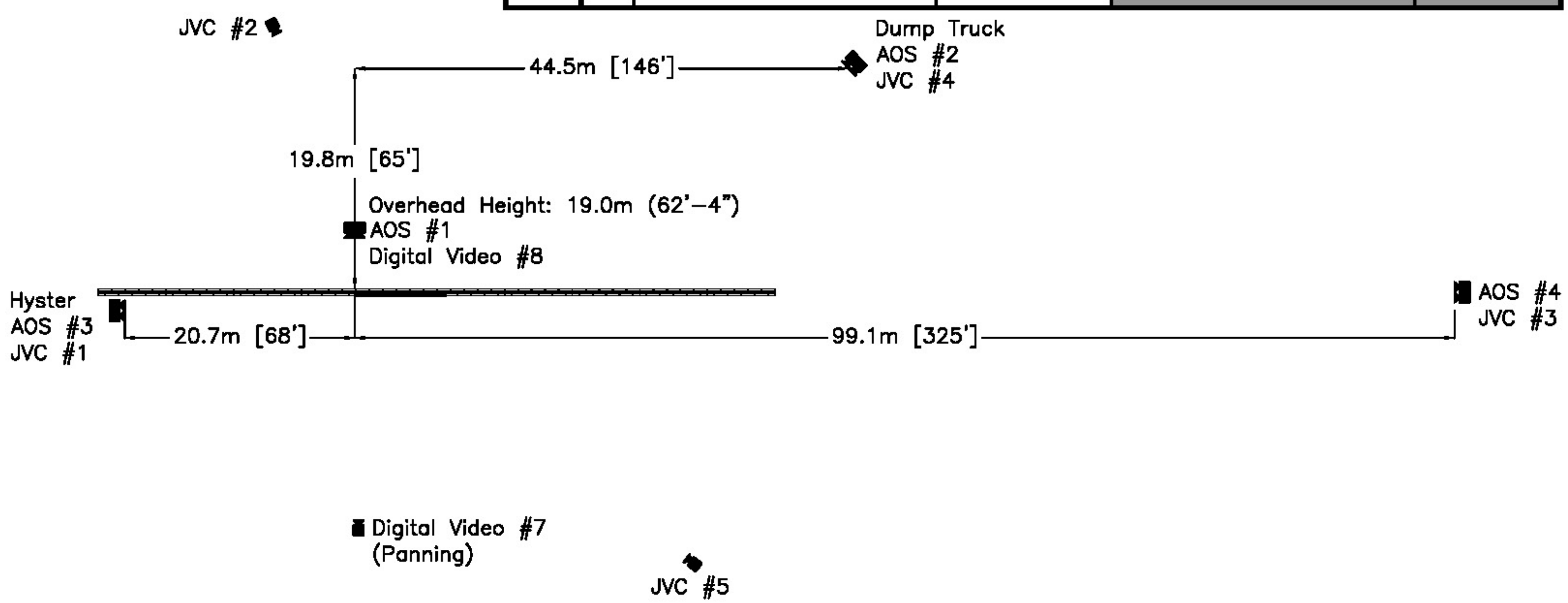


Figure 11. Locations of Cameras, Test NYTCB-2

	No.	Type	Operating Speed (frames/sec)	Lens	Lens Setting
High-Speed Video	1	Vitcam CTM	500	Kowa Fixed 8.5mm	-
	2	Vitcam CTM	500	Fuji Fixed 50mm	-
	3	Vitcam CTM	500	Sigma 24-70	50
	4	Vitcam CTM	500	Sigma 70-200	135
	7	VIS G2	500	Sigma 24-135	100
	17	Mini VIS	500	Fixed 12.5mm	-
Digital Video	1	JVC - GZ-MC500 (Everio)	29.97		
	2	JVC - GZ-MC40u (Everio)	29.97		
	3	JVC - GZ-MC40u (Everio)	29.97		
	4	JVC - GZ-MC40u (Everio)	29.97		
	5	JVC - GZ-MC27u (Everio)	29.97		
	7	Canon-ZR90	29.97		
	8	Canon-ZR90	29.97		

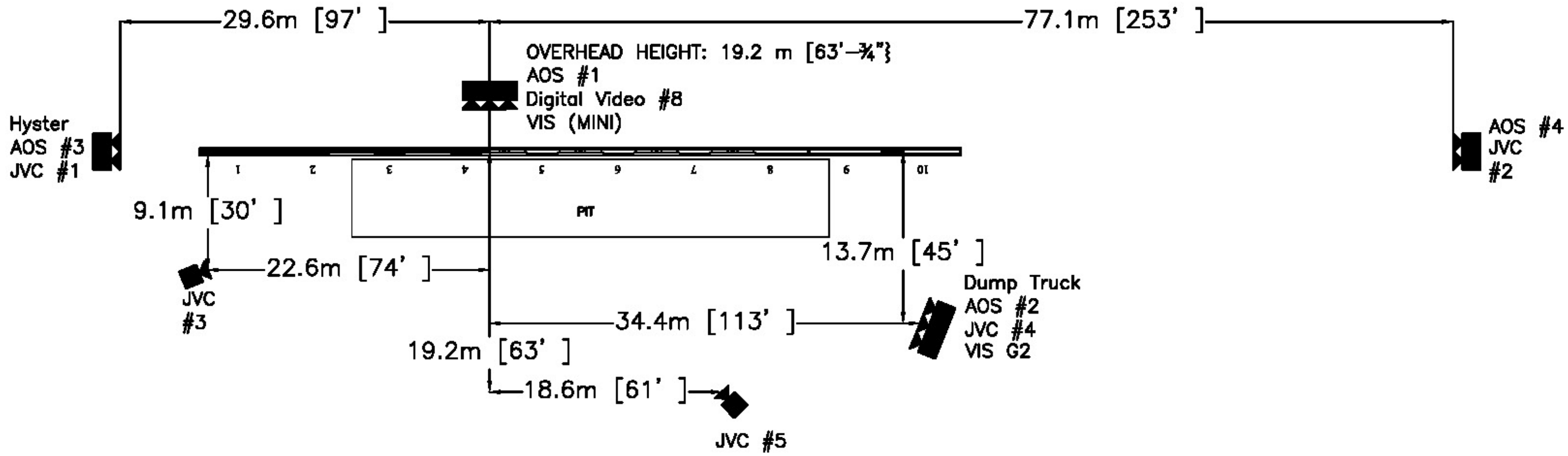


Figure 12. Locations of Cameras, Test NYTCB-3

5 DESIGN DETAILS - DESIGN NO. 1

5.1 Design Considerations

The NYSDOT designed and developed a box-beam stiffening system that was compatible with crashworthy, temporary concrete barrier sections and for the purpose of improving worker safety by reducing barrier deflections into active work-zones. For the stiffening system, several design considerations were required in order to allow the stiffened, temporary concrete barrier system to be practical and to meet real-world construction tolerances. First, it was necessary for the stiffening system to accommodate both vertical and horizontal alignment changes. Second, anchorage of the stiffening system to the barrier sections should be capable of transferring the impact loads while developing the flexural capacity of the box beam section. Finally, any portion of the stiffening system placed on the traffic-side face of the barrier must not significantly decrease the barrier's acceptable safety performance.

5.2 System Details

The 60.96-m (200-ft) long test installation consisted of box beam stiffened temporary concrete barrier sections in a free-standing configuration with both end sections anchored, as shown in Figures 13 through 23. The ten 6,096-mm (20-ft) long, temporary concrete barrier sections were placed on the tarmac with the first and last sections attached to the concrete. Box beam stiffeners were attached at three joints, as shown in Figures 24 and 25. The corresponding English-unit drawings are shown in Appendix A. Photographs of the test installation are shown in Figures 24 through 28.

The concrete used for the barrier sections consisted of a concrete mix with a minimum 28-day compressive strength of 21.0 MPa (3,000 psi). A minimum concrete cover of 38 mm (1.5 in.) was used along all rebar in the barrier. All the steel reinforcement in the barrier was ASTM A615

Grade 60 rebar. The section reinforcement details are shown in Figures 13 through 16.

Section reinforcement consisted of four No. 6 longitudinal bars, eight No. 4 bars for the vertical stirrups, four No. 6 lateral bars, and nine No. 4 bars for the anchor hole reinforcement loops. Each of the two lower longitudinal rebar was 5.83 m (19 ft - 1.5 in.) long, while each of the upper two longitudinal rebar was 5.89 m (19 ft - 4 in.) long. The vertical spacings of the lower and upper longitudinal bars was 171 mm (6.75 in.) and 648 mm (2 ft - 1.5 in.) from the ground to their centers, respectively. The vertical stirrup spacing varied longitudinally, as shown in Figure 15. The upper and lower lateral bars were 152 mm (6 in.) and 356 mm (14 in.) long, respectively. The vertical spacings of the lower and upper lateral bars were 191 mm (7.5 in.) and 476 mm (18.75 in.) from the ground to their centers, respectively. The 865-mm (34.0625-in.) long, anchor hole loops were bent into a U-shape, and they reinforced the anchor hole area, as shown in Figures 15 and 16.

The barrier sections used a connection key, as shown in Figures 17 through 20. The connection key was comprised of ASTM A36 13-mm (0.5-in.) thick, steel plates welded together to form the key shape. Two stiffeners were welded to the top plate with their interior faces in contact with the I-beam shape and 7.9 mm (0.31 in.) up from the bottom of the top plate, as shown in Figures 17 through 19.

A connection key was configured at each end of the section, as shown in Figure 15. The connection key consisted of one ASTM A500 steel tube and three ASTM A36 steel plates. Three U-shaped plates were welded on to the sides of the tube, as shown in Figure 20. A steel drop pin was inserted into the steel tubes of two adjoining sections to form the connection, as shown in Figure 17.

The end sections were fastened to the tarmac with nine 25-mm (1-in.) diameter by 394-mm (15.5-in.) long, A36 steel rods, five anchors and four anchors on the traffic and back sides, respectively, as shown in Figure 14. Each anchor rod was driven into a hole drilled in the concrete to an embedment depth of 127 mm (5 in.), as shown in Figure 13.

The three joints between barrier nos. 4 and 7 were stiffened with a box beam section, as shown in Figures 13 and 21 through 23. Each box beam stiffener consisted of a 152-mm x 152-mm x 4.8-mm (6-in. x 6-in. x 0.1875-in.) ASTM A500 Grade C box beam, which was 3,658 mm (12 ft) long. Two 19-mm (0.75 in.) holes were drilled through the barriers at an angle of 6 degrees, as shown in Figure 22. The box beams were connected to the barriers with 19-mm (0.75-in.) diameter by 432-mm (17-in.) long, Grade 5 continuously threaded rod and two 19-mm (0.75-in.) diameter nuts. An 83-mm (3.25-in.) outside diameter x 22-mm (0.875-in.) inside diameter x 9.5-mm (0.375-in.) thick Grade 5 fender washer was placed on the traffic side of the barrier between the barrier and the nut. A 203-mm x 203-mm x 6.4-mm (8-in. x 8-in. x 0.25-in.) A36 steel plate was placed on the back side of the barrier between the nut and the box beam section, as shown in Figure 21.

5.3 Special Features

As shown in Figure 23, the holes placed within the ends of the box beam stiffening rails were oversized. The oversized holes were utilized to allow for vertical alignment changes in the barrier system. For horizontal alignment changes, shim washers were designed for use when placed between the box beam rail and the back-side face of the temporary concrete barrier sections, as shown in Figure 21. Threaded rods were used to attach the box beam rails to the barrier sections. The length of the rods, or alternative hex head or dome head bolts, should possess sufficient length to allow for the placement of shims, if needed. As depicted in Figures 13, 21, and 23, large plate washers were used to retain the box beam rails and transfer the rod load to the top and bottom webs of each stiffening rail, rather than allowing the rod and nut to bend the washer into each beam’s bearing flange. Finally, the size of the box beam stiffening rail was selected to be consistent with the standard sizes used for the NYSDOT’s box beam guide rail and median barrier.

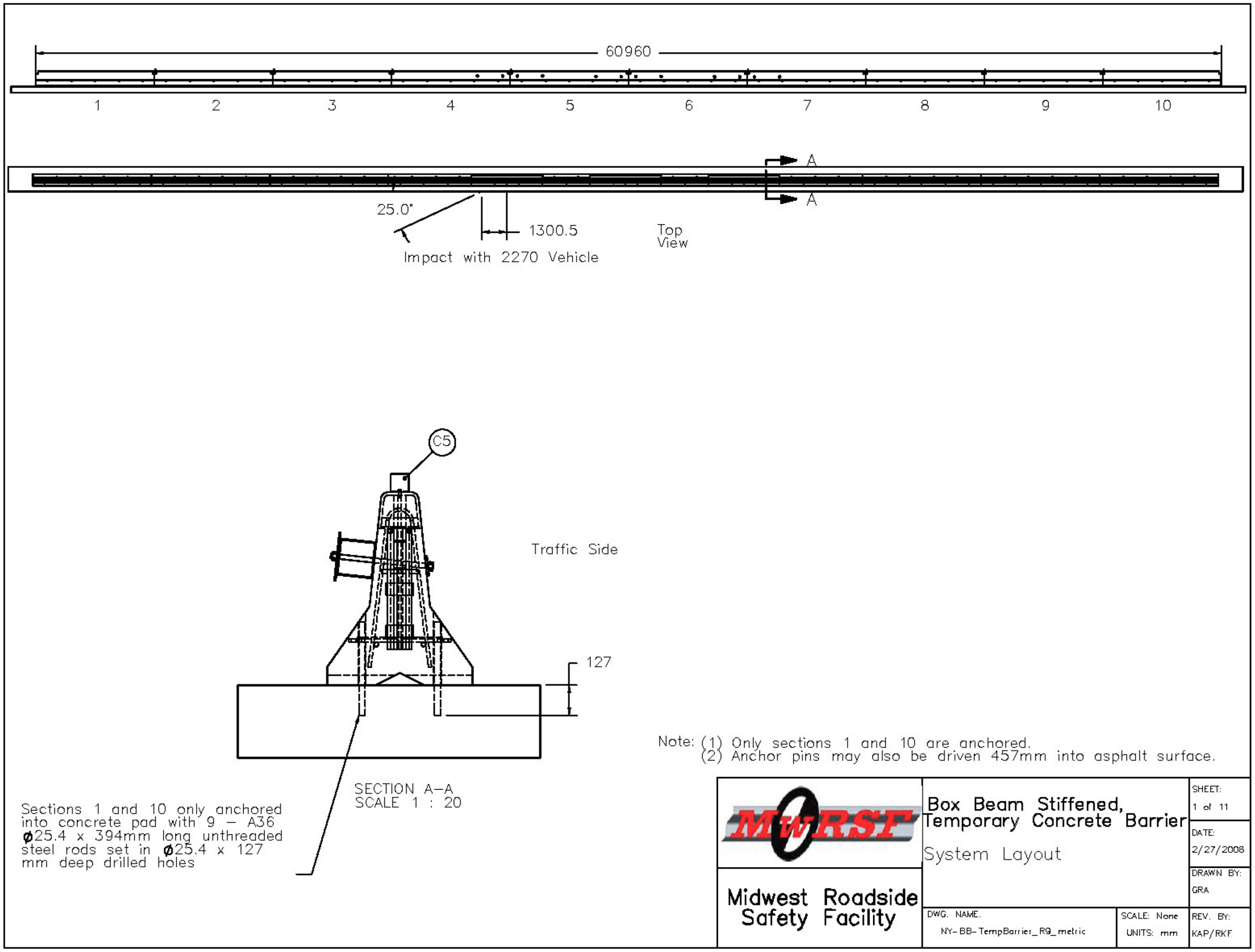


Figure 13. Stiffened Temporary Concrete Barrier System Layout, Test NYTCB-1

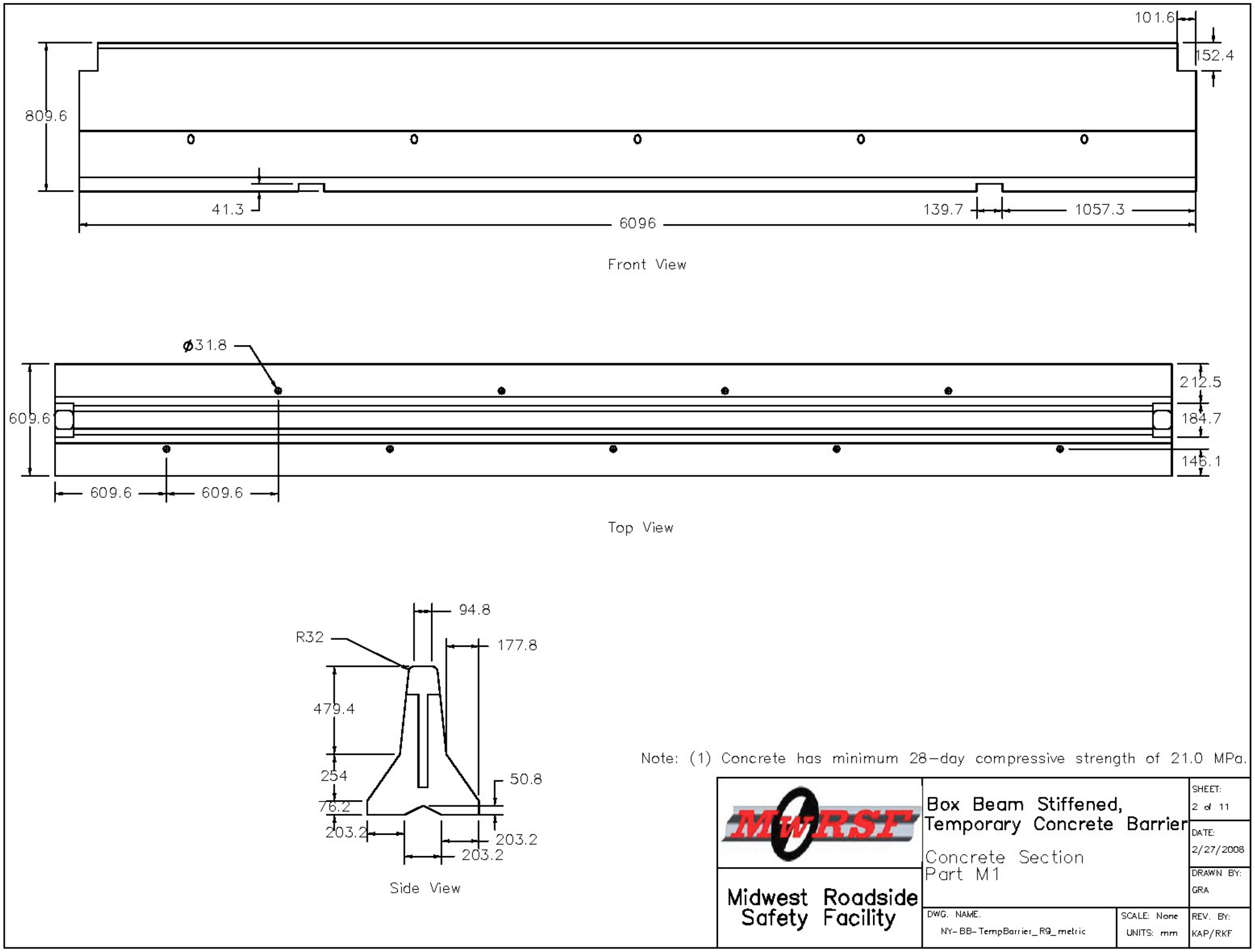


Figure 14. Temporary Concrete Barrier Details, Test NYTCB-1

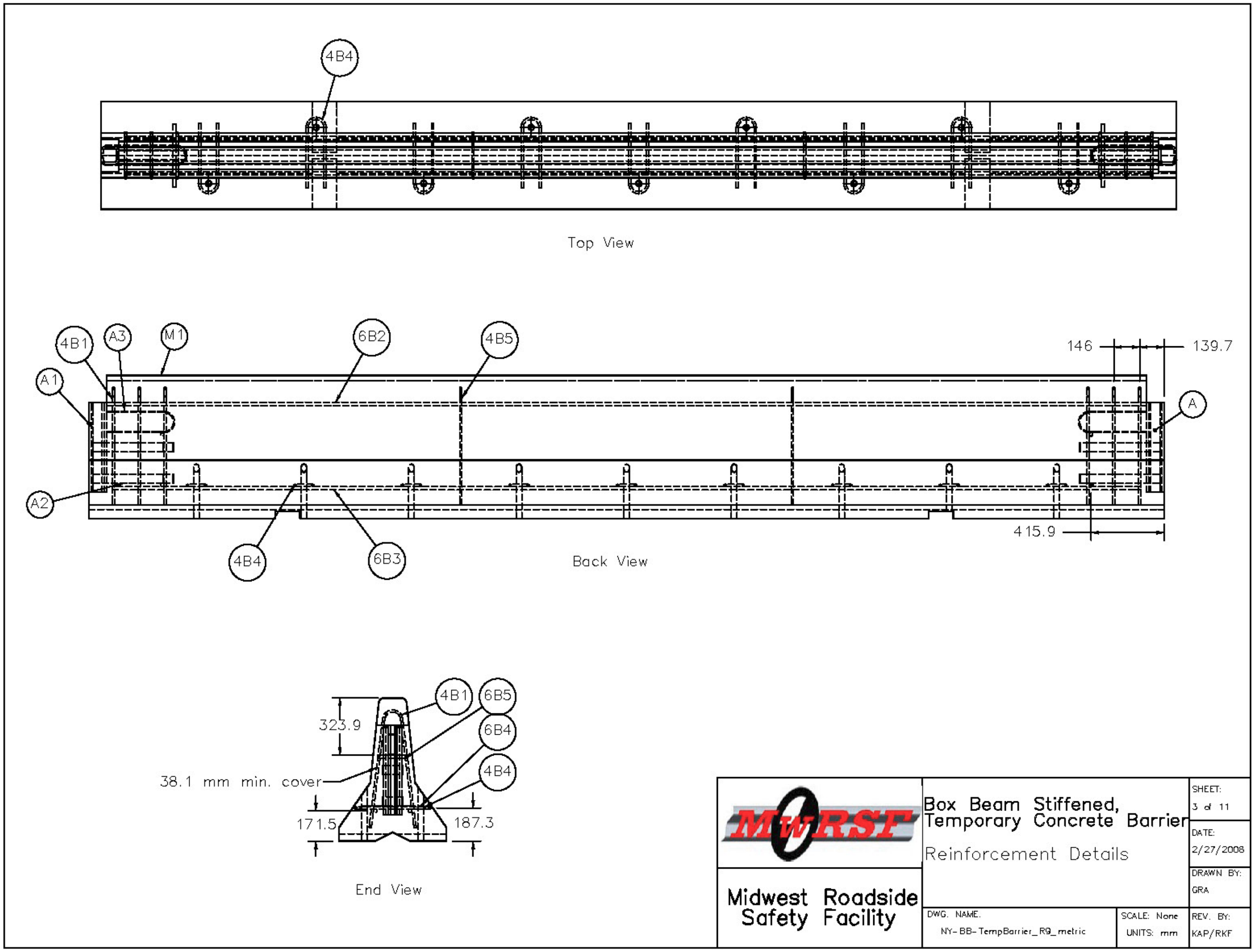


Figure 15. Temporary Concrete Barrier Reinforcement Details, Test NYTCB-1

NY-BB-TempBarrier					
Item No.	Bend Dia.	Qty.	Length	Material Spec	Bar Size
Smooth Anchor Rod	–	18	394mm	A36M	25.4mm
4B1	89mm	60	1407mm	A615 Gr. 60	12.7mm
4B4	89mm	90	868mm	A615 Gr. 60	12.7mm
4B5	89mm	20	1407mm	A615 Gr. 60	12.7mm
6B2	–	20	5893mm	A615 Gr. 60	19mm
6B3	–	20	5830mm	A615 Gr. 60	19mm
6B4	–	20	356mm	A615 Gr. 60	19mm
6B5	–	20	152mm	A615 Gr. 60	19mm

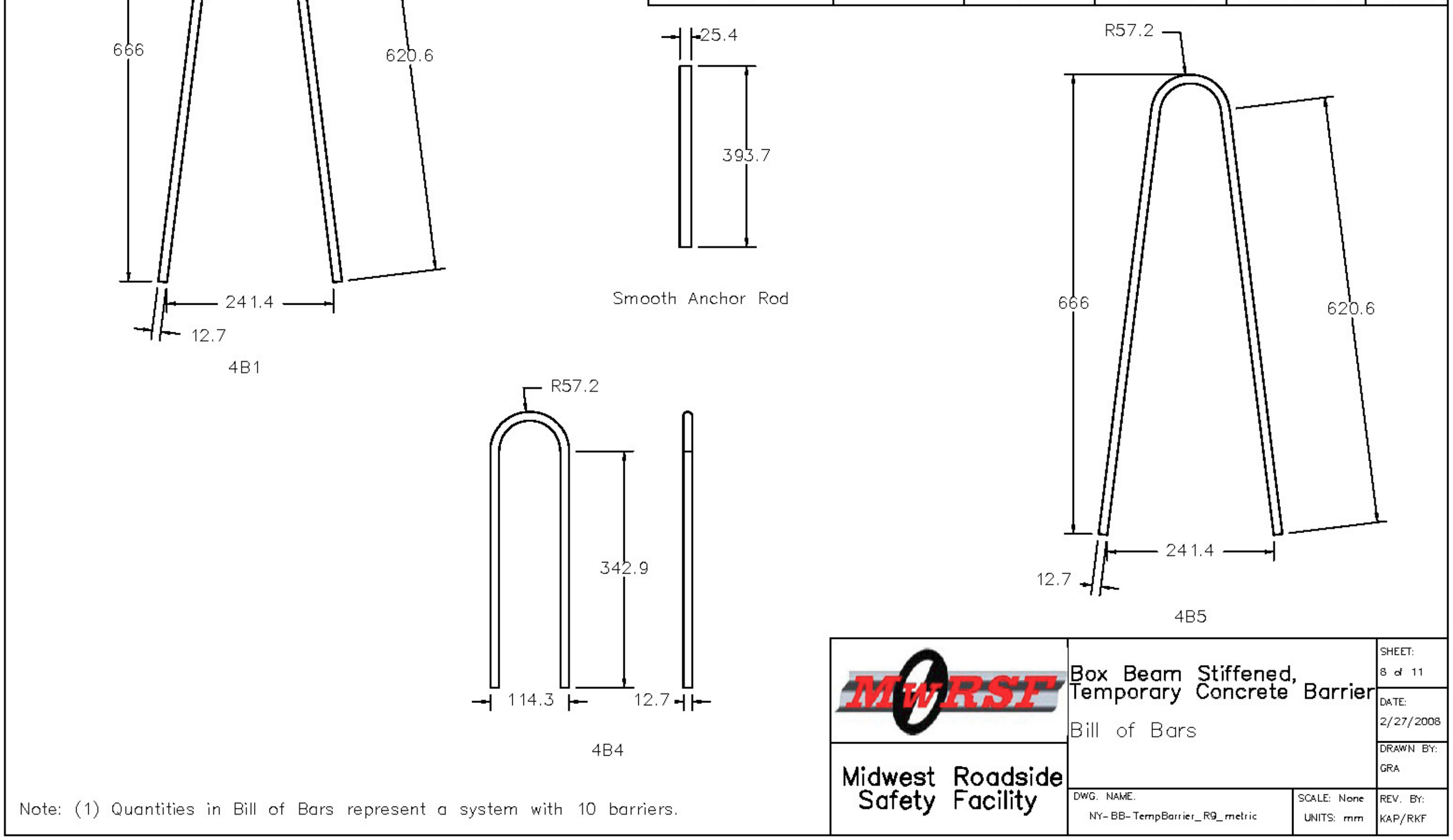


Figure 16. Bill of Bars, Test NYTCB-1

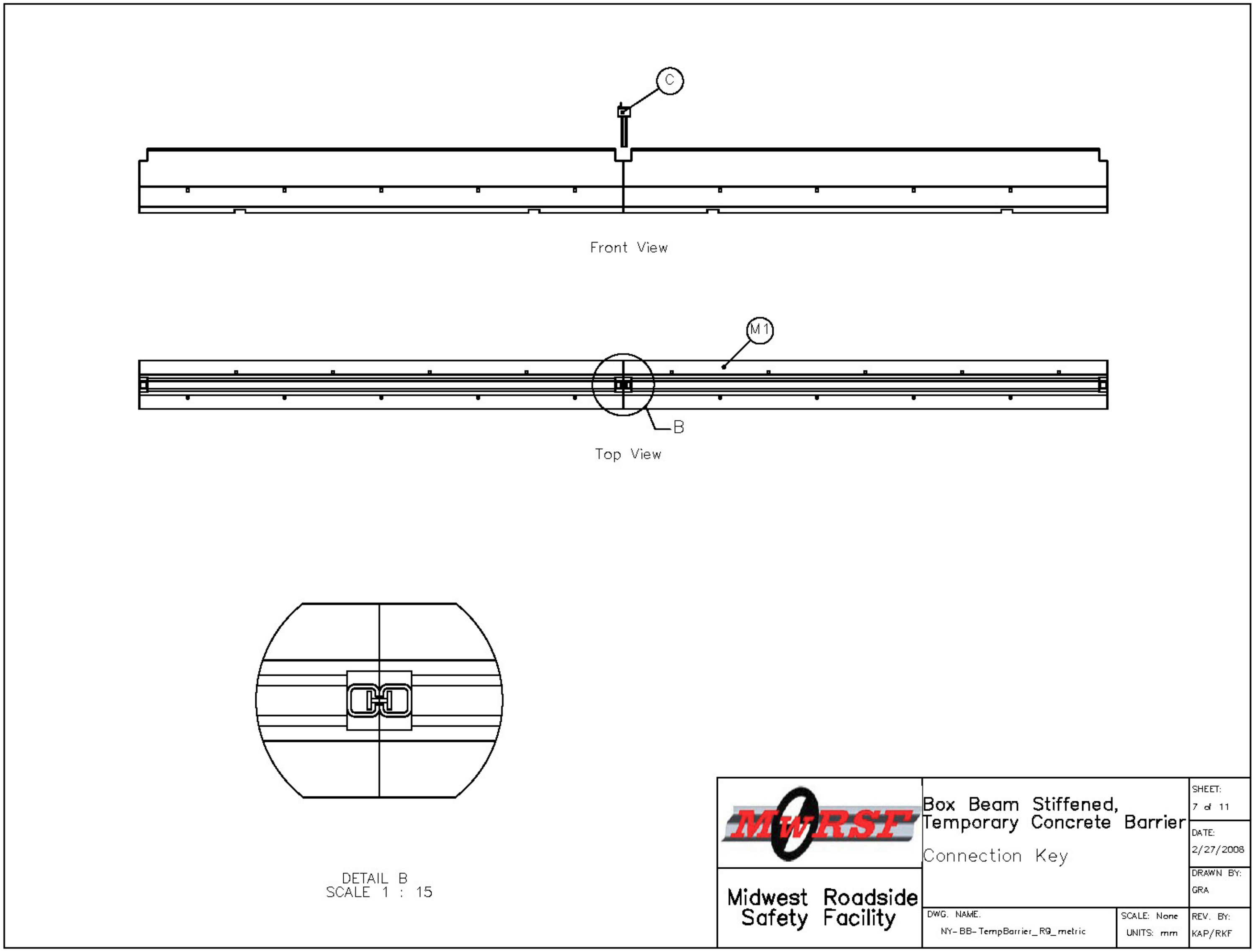


Figure 17. Temporary Concrete Barrier Connection Details, Test NYTCB-1

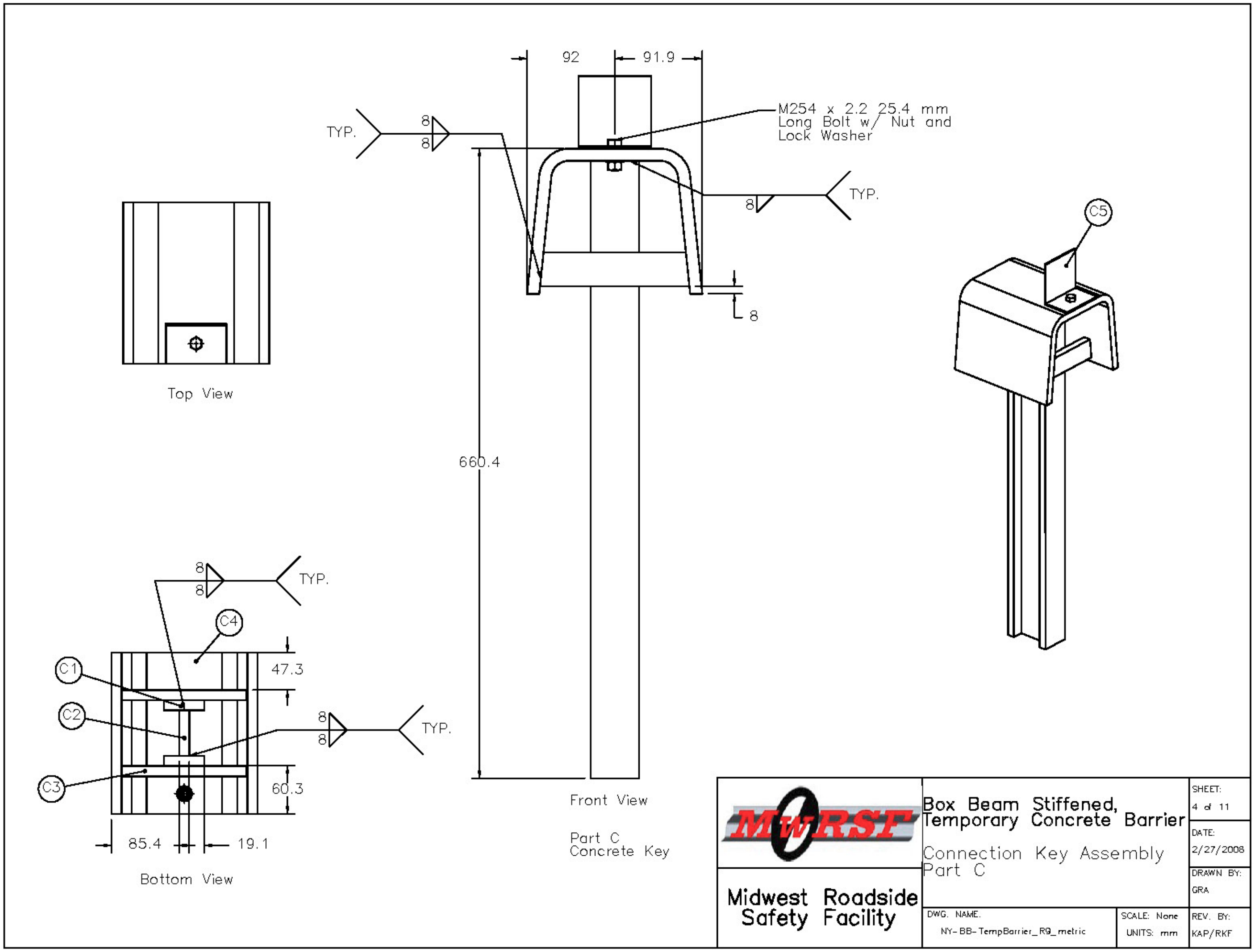


Figure 18. Connection Key Assembly Details, Test NYTCB-1

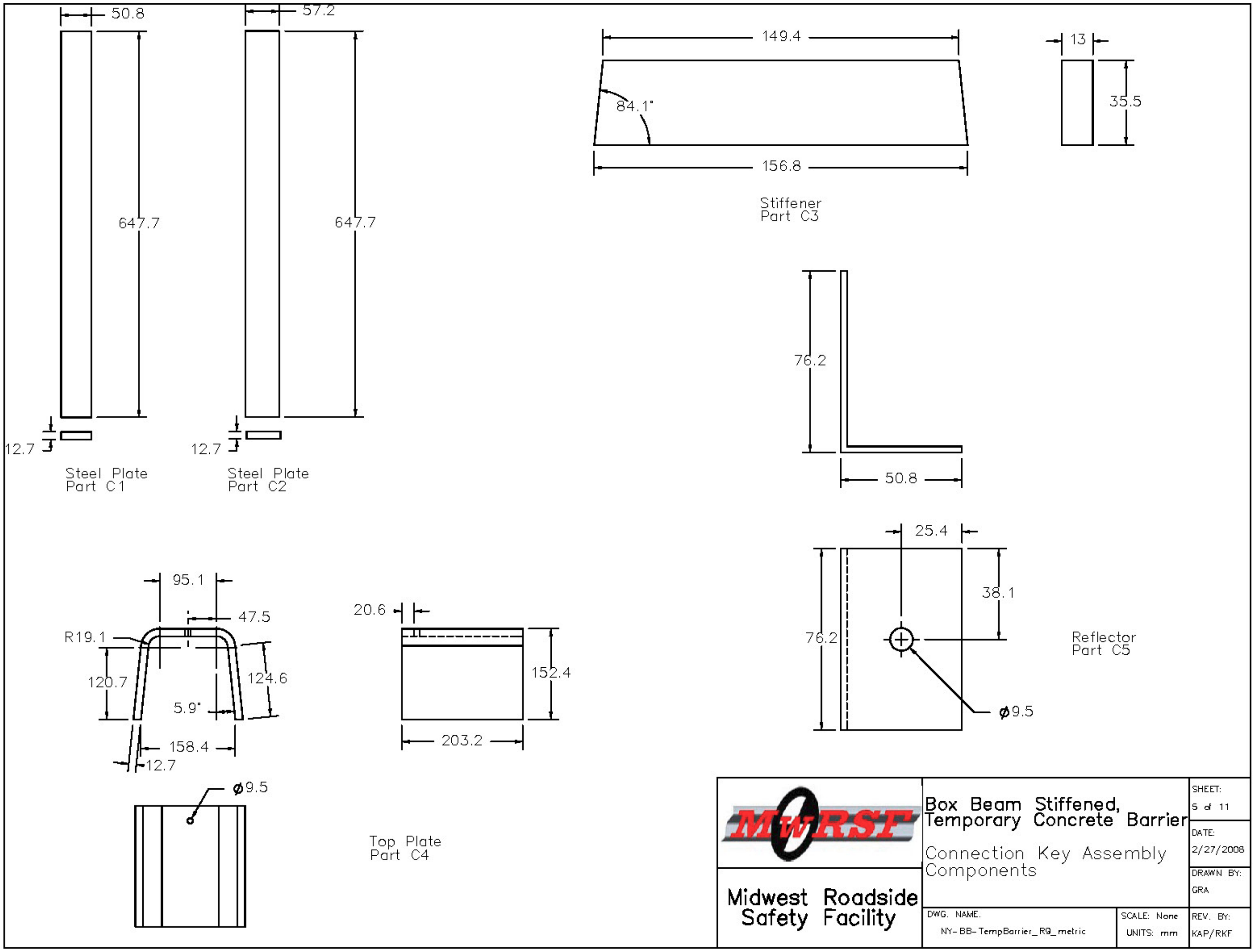


Figure 19. Connection Key Assembly Details, NYTCB-1

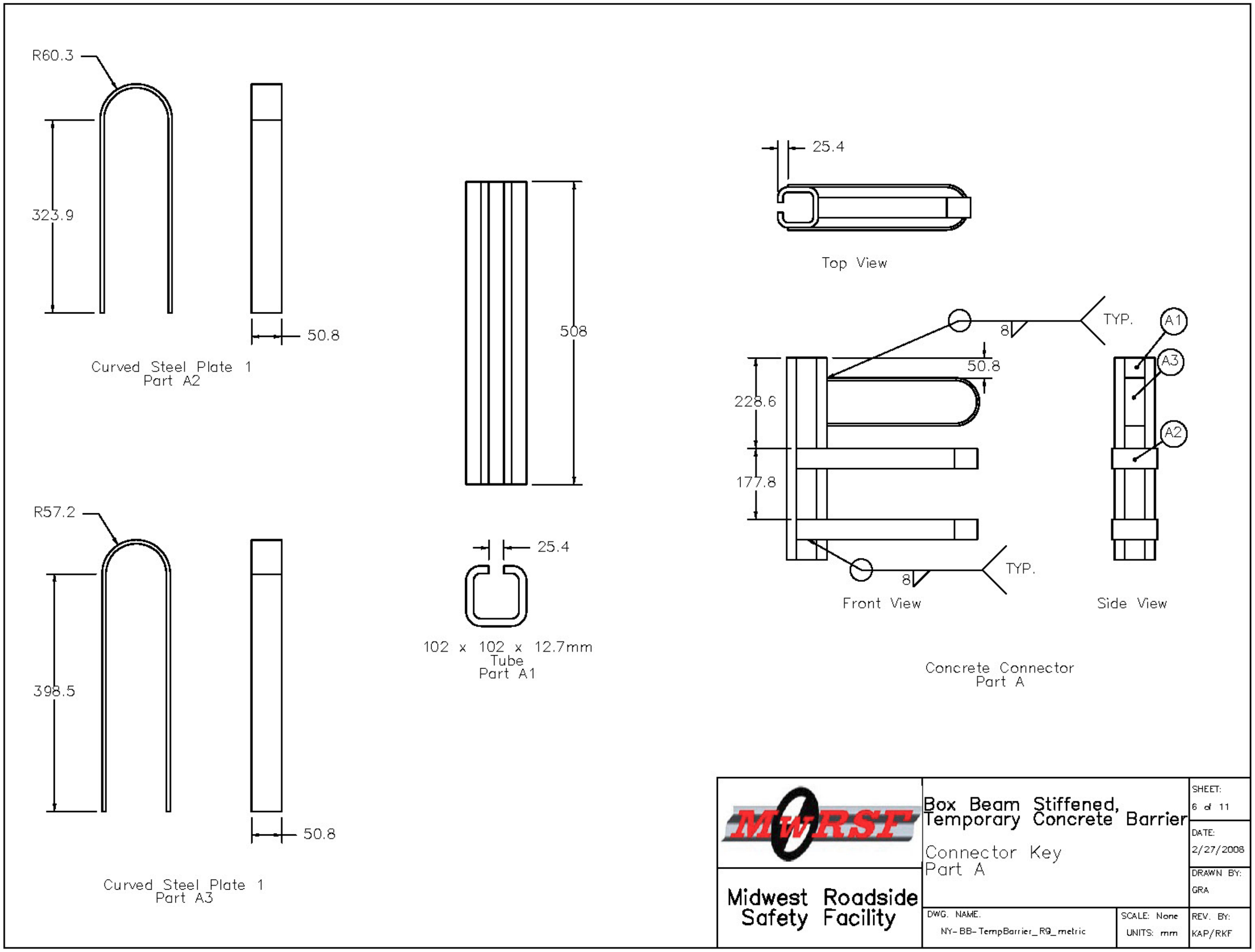


Figure 20. Temporary Concrete Barrier Connector Assembly Details, Test NYTCB-1

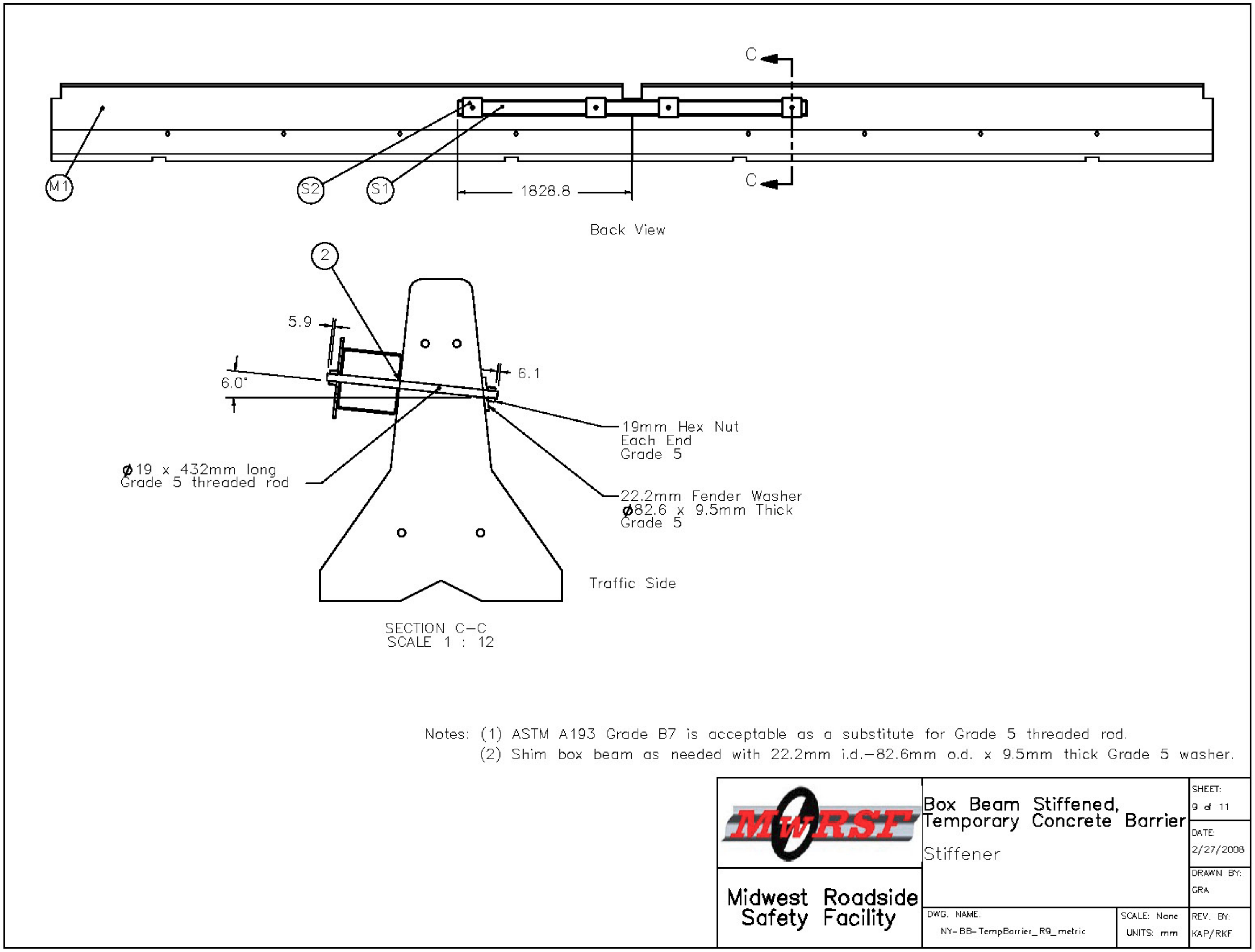


Figure 21. Box Beam Stiffener Details, Test NYTCB-1

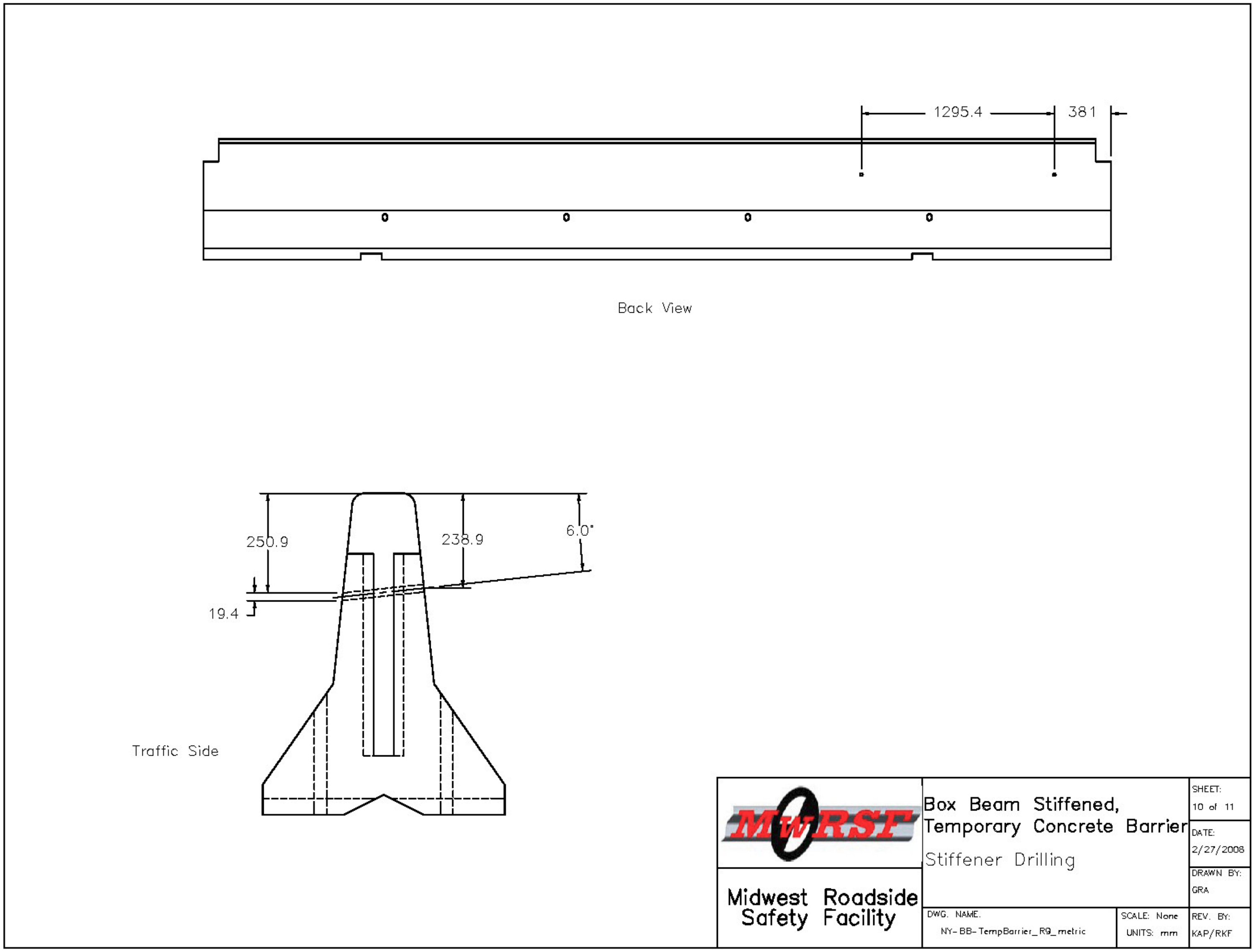


Figure 22. Temporary Concrete Barrier Stiffener Hole Details, Test NYTCB-1

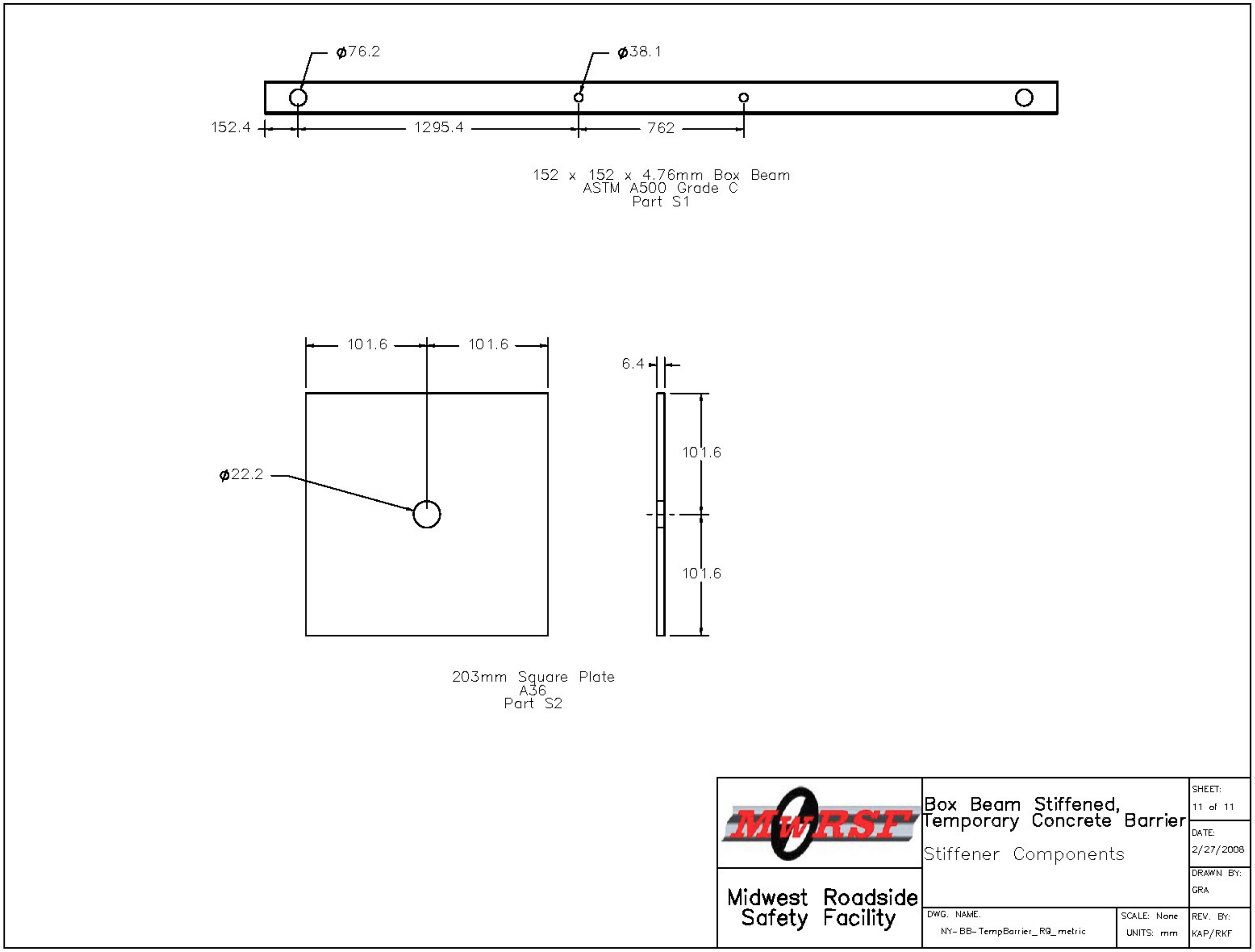


Figure 23. Box Beam Stiffener Details, Test NYTCB-1

Figure 24. Box Beam Stiffened Temporary Concrete Barrier, Test NYTCB-1

Figure 25. Box Beam Stiffeners, Test NYTCB-1

Figure 26. Box Beam Stiffener Attachment Bolts, Test NYTCB-1

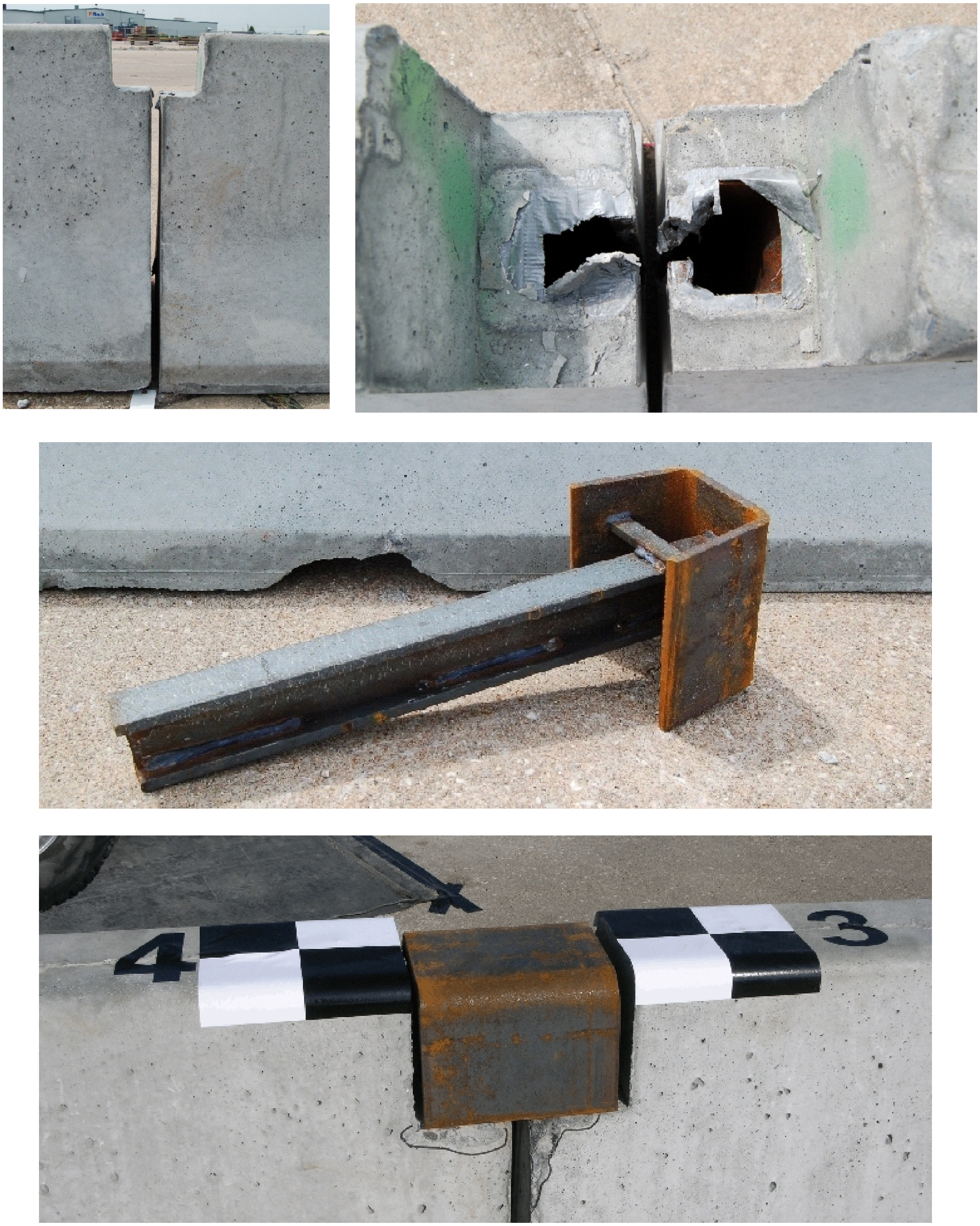


Figure 27. Connection Key, Test NYTCB-1

Figure 28. Anchored Barrier Ends, Test NYTCB-1

6 FULL-SCALE CRASH TEST NO. 1

6.1 Test NYTCB-1

The 2,275-kg (5,016-lb) pickup truck impacted the stiffened temporary concrete barrier system at a speed of 99.5 km/h (61.8 mph) and at an angle of 24.6 degrees. A summary of the test results and sequential photographs are shown in Figure 29. An English-unit summary of the test results and sequential photographs are shown in Appendix B. Additional sequential photographs are shown in Figures 30 through 32. Documentary photographs of the crash test are shown in Figures 33 and 34.

6.2 Test Description

Initial vehicle impact was to occur 1,300 mm (51.2 in.) upstream from the downstream end of barrier no. 4, as shown in Figure 35. Actual vehicle impact occurred at the targeted impact location. At 0.004 sec, the left-front quarter panel crushed inward. At 0.010 sec, the left-front tire became airborne. At 0.018 sec, barrier no. 4 deflected backward. At 0.022 sec, barrier no. 5 deflected backward. At 0.024 sec, the left-front tire ruptured as the tire was compressed between the vehicle and barrier no. 4. At 0.034 sec, the hood became ajar. At 0.042 sec, the front of the vehicle pitched upward. At 0.054 sec, the stiffener connecting barrier nos. 4 and 5 bent significantly. At this same time, the vehicle redirected. At 0.088 sec, the stiffener between barrier nos. 5 and 6 deflected. At 0.102 sec, the right-front tire became airborne. At 0.178 sec, barrier nos. 3 and 6 deflected. At 0.216 sec, the vehicle became parallel to the system with a resultant velocity of 85.4 km/h (53.1 mph). At 0.230 sec, the left-front bumper corner scraped along the top of barrier no. 5. At 0.242 sec, the stiffener between barrier nos. 6 and 7 deflected. At 0.244 sec, the left-rear tire contacted the system. At this same time, the front of the vehicle pitched downward. At 0.300 sec, the vehicle became airborne as the right-rear tire left the ground. At 0.394 sec, the vehicle rolled away from the system. At 0.402 sec, barrier no. 7 deflected with the vehicle positioned at the downstream end of barrier no. 6. At 0.468 sec, the right-front tire contacted the ground. At 0.486 sec, the system reached its maximum deflection. At 0.512 sec, barrier no. 8 deflected. At 0.524 sec, the front bumper contacted the ground. At this same time, the vehicle reached its maximum pitch angle. At 0.842 sec, the vehicle redirected toward the system. At 0.892 sec, the vehicle rolled toward the system. At 1.050 sec, the left-front bumper corner contacted barrier no. 8. At 1.534 sec, barrier no. 9 deflected backward. At 1.610 sec, barrier no. 10 pivoted about the anchored base with the vehicle positioned at its midline. At 1.890 sec, the vehicle redirected away from the system. At 1.942 sec, the vehicle exited the system at an angle of 7 degrees and at a resultant velocity of 62.9 km/h (39.1 mph). The vehicle came to rest 62.26 m (204 ft - 3 in.) downstream from impact and 4.57 m (15 ft) laterally behind a line projected parallel to the traffic-side face of the barrier. The trajectory and final position of the pickup truck are shown in Figures 29 and 36.

6.3 Barrier Damage

Damage to the barrier was moderate, as shown in Figures 37 through 41. Barrier damage consisted of contact marks, concrete cracking, barrier spalling, cracks, and deformed box beam sections. The length of vehicle contact along the system was approximately 38.3 m (125.8 ft), which spanned from 1.75 m (5 ft - 9 in.) upstream from the downstream end of barrier no. 4 through the downstream end of barrier no. 10.

Contact and tire marks were visible on the front face of barrier nos. 4 through 10. The back side of barrier no. 3 experienced concrete spalling 152 mm (6 in.) wide and 356 mm (14 in.) in height. The back upstream end of barrier no. 4 experienced concrete spalling 584 mm (23 in.) wide and 254 mm (10 in.) tall. The front downstream edge of barrier no. 4 also experienced concrete spalling 305 mm (12 in.) wide and 178 mm (7 in.) tall. A 381-mm (15-in.) wide by 127-mm (5-in.)

tall area of concrete spalling was found on the back side of barrier no. 5, beginning 762 mm (30 in.) downstream from the barrier's upstream end. The front side of barrier no. 5 also experienced concrete spalling 102 mm (4 in.) wide and 178 mm (7 in.) tall. Concrete spalling occurred on the top-front upstream end of barrier no. 6, measuring 51 mm (2 in.) wide by 76 mm (3 in.) tall. The bottom-front face of barrier no. 6 also experienced concrete spalling at 1,168 mm (46 in.) downstream from the upstream end, measuring 152 mm (6 in.) wide by 76 mm (3 in.) tall. Minor concrete spalling occurred at the bottom-front face of barrier no. 6, measuring 102 mm (4 in.) tall and 1,219 mm (48 in.) long. The back side of barrier no. 6 experienced significant concrete spalling, measuring 102 mm (4 in.) wide by 76 mm (3 in.) tall at the bottom-downstream corner of the barrier. Concrete spalling on the back side of barrier no. 6, measuring 127 mm (5 in.) wide by 76 mm (3 in.) tall, occurred at 838 mm (33 in.) upstream from the downstream end of the barrier. A 178-mm (7-in.) wide by 102-mm (4-in.) tall area of concrete spalling was found on the back side 533 mm (21 in.) downstream from the upstream end of barrier no. 7.

A 76-mm (3-in.) long crack was found on the back side of barrier no. 3 and began 1,219 mm (48 in.) from the downstream end of the barrier. Cracks were found on the back side of barrier no. 4 at 2,997 mm (118 in.), 3,658 mm (144 in.), and 4,699 mm (185 in.) downstream of the upstream end of the barrier. Hairline cracking was found on the back side at the downstream end of barrier no. 4 and at the upstream and downstream ends of barrier no. 5. Cracks were also found on the back side of barrier no. 5 and spanned from the top to the bottom of the barrier and were located 1,295 mm (51 in.), 1,828 mm (72 in.), 2,413 mm (95 in.), 3,073 mm (121 in.), and 3,683 mm (145 in.) downstream from the upstream end of the barrier. Two hairline cracks spanned the height of the front side of barrier no. 6 at 1,803 mm (71 in.) and 3,048 mm (120 in.) downstream of the upstream end of the barrier.

The joint between barrier nos. 2 and 3 was observed to have widened from its pre-test width. The joint between barrier nos. 3 and 4 rotated. The box beam stiffeners all experienced minor bending. The box beam rods at the front-downstream end of barrier no. 4 and front-upstream end of barrier no. 5 were sheared off. The downstream box beam rod was bent at the front of barrier no. 5. All connection keys remained undamaged. The anchor rods in barrier nos. 1 and 10 remained undamaged, and these barriers experienced no movement. Minor bending of the plate washers was observed. No buckling of the box beam webs nor bending of the box beam flanges was observed under the plate washers.

The permanent set of the barrier system is shown in Figure 37. The maximum lateral permanent set barrier deflection was 660 mm (26 in.) at the downstream end of barrier no. 4 and the upstream end of barrier no. 5, as measured in the field. The maximum lateral dynamic barrier deflection was 700 mm (27.6 in.) at the upstream end of barrier no. 5, as determined from high-speed digital video analysis. The working width of the system was found to be 1,311 mm (51.6 in.).

6.4 Vehicle Damage

Exterior vehicle damage was moderate, as shown in Figures 42 and 43. Occupant compartment deformations to the left side and center of the floorboard were judged insufficient to cause serious injury to the vehicle occupants. Maximum longitudinal deflections of 19 mm (0.75 in.) were located near the left-front corner of the left-side floor pan. Maximum lateral deflections of 38 mm (1.5 in.) were located near the left-front corner of the floorboard. Maximum vertical deflections of 32 mm (1.25 in.) were located near the left front of the floorboard. Complete occupant compartment deformations and the corresponding locations are provided in Appendix C.

Damage was concentrated on the left-front corner of the vehicle. The left corner of the front bumper deformed inward and the right side was detached. The left-front tire's side walls were punctured, and the tire deflated. The left-front quarter panel experienced scrapes above the wheel well and was deformed inward. The right-front quarter panel deformed inward and buckled near the hood. The left side experienced scrapes, contact marks, and dents. The left-rear wheel assembly disengaged from the vehicle. The tailgate, which experienced minor scraping and denting, disengaged, except that it remained attached by the right-side cable. The hood's front center was dented. The left headlight and left taillight disengaged from their housings. The lower-right side of the windshield experienced "spider-web" cracking. The lower-left side of the windshield experienced a crack that propagated to the center of the windshield. The roof and all other window glass remained undamaged.

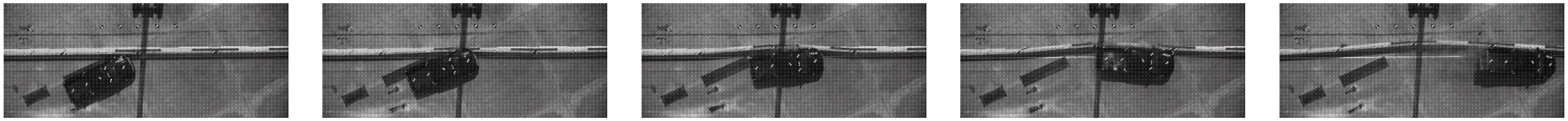
6.5 Occupant Risk Values

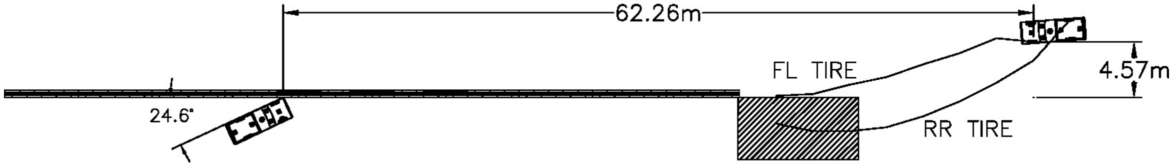
The longitudinal and lateral occupant impact velocities were determined to be -4.67 m/s (-15.32 ft/s) and 6.33 m/s (20.77 ft/s), respectively. The maximum 0.010-sec average occupant ridedown decelerations in the longitudinal and lateral directions were 4.72 g's and 8.36 g's, respectively. It is noted that the occupant impact velocities (OIV) and occupant ridedown decelerations (ORD) were within the suggested limits provided in the currently proposed Update to NCHRP Report No. 350. The THIV and PHD values were determined to be 7.45 m/s (24.44 ft/s) and 8.71 g's, respectively. The results of the occupant risk, as determined from the accelerometer data, are summarized in Figure 29. Results are shown graphically in Appendix D. The results from the rate transducer are shown graphically in Appendix D.

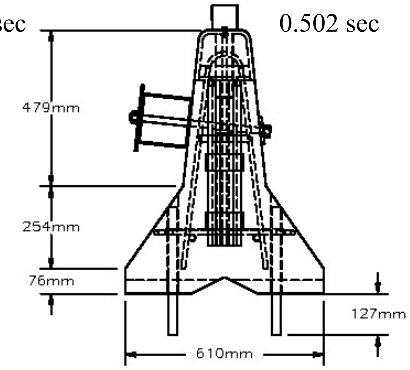
6.6 Discussion

The analysis of the test results for test no. NYTCB-1 showed that the stiffened temporary concrete barrier system with anchored ends adequately contained and redirected the 2270P vehicle with controlled lateral displacements of the barrier system. There were no detached elements nor fragments which showed potential for penetrating the occupant compartment nor presented undue hazard to other traffic. Deformations of, or intrusion into, the occupant compartment that could have caused serious injury did not occur. The test vehicle did not penetrate nor ride over the barrier system and remained upright during and after the collision. Vehicle roll, pitch, and yaw angular displacements were noted, but they were deemed acceptable because they did not adversely influence occupant risk safety criteria nor cause rollover. After collision, the vehicle's trajectory revealed minimum intrusion into adjacent traffic. In addition, the vehicle exited the barrier within the exit box. Therefore, test no. NYTCB-1 conducted on the stiffened temporary concrete barrier system with anchored end barriers was determined to be acceptable according to the TL-3 safety performance criteria of test designation no. 3-11 found in the currently proposed Update to NCHRP Report No. 350.

During the test, the anchor rods and nuts on the front-downstream end of barrier section no. 4 and the front-upstream end of barrier section no. 5, used to attach the box beam to the barrier, were sheared off. This result likely occurred as the vehicle was in contact with the barrier face and snagged on the protruding threaded rods and nuts. It should be noted that the rod and nut provide restraint for the box beam and the resulting barrier stiffening. As such, it is recommended that future design variations attempt to reduce the snag potential on the rod and nut as barrier deflections may increase with premature rod fracture. One alternative would be to incorporate dome head bolts on the traffic-side face of the barrier. This option was suggested during the construction of the barrier system.

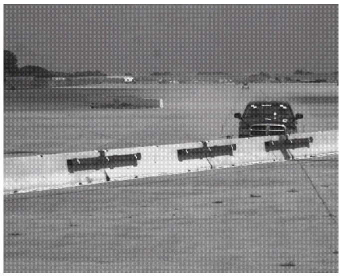




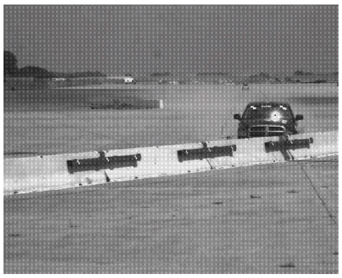


- Test Agency . . . . MwRSF
- Test Number NYTCB-1
- Date 7/24/07
- NCHRP 350 Update Test Designation 3-11
- Appurtenance . . . . Stiffened Temporary Concrete Barriers
- Total Length . . . . 60.96 m
- Key Elements - Barrier
  - Description . . . . New York TCB with Connection Keys
  - Length . . . . 6,096 mm
  - Base Width . . . . 610 mm
  - Height . . . . 810 mm
- Key Elements - Anchor Ends
  - Size . . . . 25 mm diameter ASTM A36 rod
  - Length . . . . 394 mm
  - Number per Barrier . . . . 5 traffic-side, 4 back-side
- Key Elements - Box Beam Stiffener
  - Size . . . . 152 mm x 152 mm x 4.8 mm
  - Length . . . . 3,658 mm
  - Connector Rod . . . . 19 mm diameter x 432 mm long Grade 5
  - Plate Washer . . . . 203 mm x 203 mm x 6.4 mm
- Type of Soil . . . . N/A
- Test Vehicle
  - Type/Designation 2270P
  - Make and Model . . . . 2002 Dodge Ram 1500 Quad Cab 4x2
  - Curb . . . . 2,302 kg
  - Test Inertial . . . . 2,275 kg
  - Gross Static . . . . 2,275 kg
- Impact Conditions
  - Speed . . . . 99.5 km/h
  - Angle . . . . 24.6 degrees
  - Impact Location . . . . 1,300 mm upstream from downstream end of barrier 4
- Exit Conditions
  - Speed . . . . 62.9 km/h
  - Angle . . . . 7 deg
  - Exit Box Criterion . . . . Pass
- Post-Impact Trajectory
  - Vehicle Stability . . . . Satisfactory
  - Stopping Distance . . . . 62.3 m downstream
    4.6 m laterally behind
- Occupant Impact Velocity
  - Longitudinal . . . . -4.67 m/s < 12.2 m/s
  - Lateral . . . . 6.33 m/s < 12.2 m/s
- Occupant Ridedown Deceleration
  - Longitudinal . . . . 4.72 g's < 20.49 g's
  - Lateral . . . . 8.36 g's < 20.49 g's
- THIV (not required) . . . . 7.45 m/s
- PHD (not required) . . . . 8.71 g's
- Test Article Damage . . . . Moderate
- Test Article Deflections
  - Permanent Set . . . . 660 mm
  - Dynamic . . . . 700 mm
  - Working Width . . . . 1,311 mm
- Vehicle Damage . . . . Moderate
  - VDS[13] 11-LFQ-3
  - CDC[14] 11-LYEN2
  - Maximum Deformation . . . . 38 mm
- Angular Displacements
  - Roll . . . . -10.5 deg
  - Pitch . . . . -11.4 deg
  - Yaw . . . . 28.0 deg

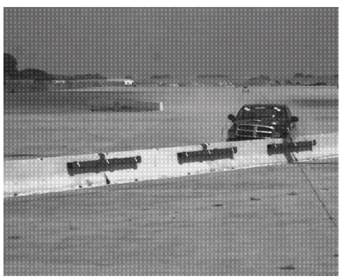
Figure 29. Summary of Test Results and Sequential Photographs, Test NYTCB-1



0.000 sec



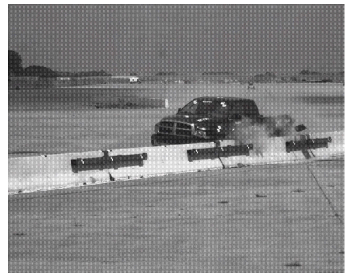
0.064 sec



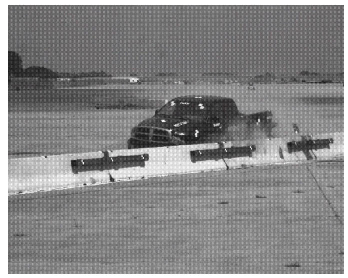
0.076 sec

0.134 sec

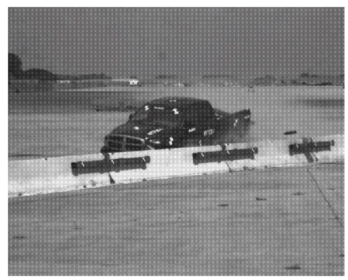
0.194 sec



0.296 sec

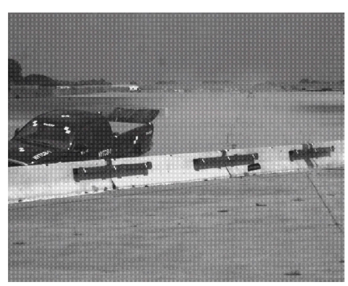


0.358 sec



0.426 sec

0.536 sec



0.696 sec

Figure 30. Additional Sequential Photographs, Test NYTCB-1

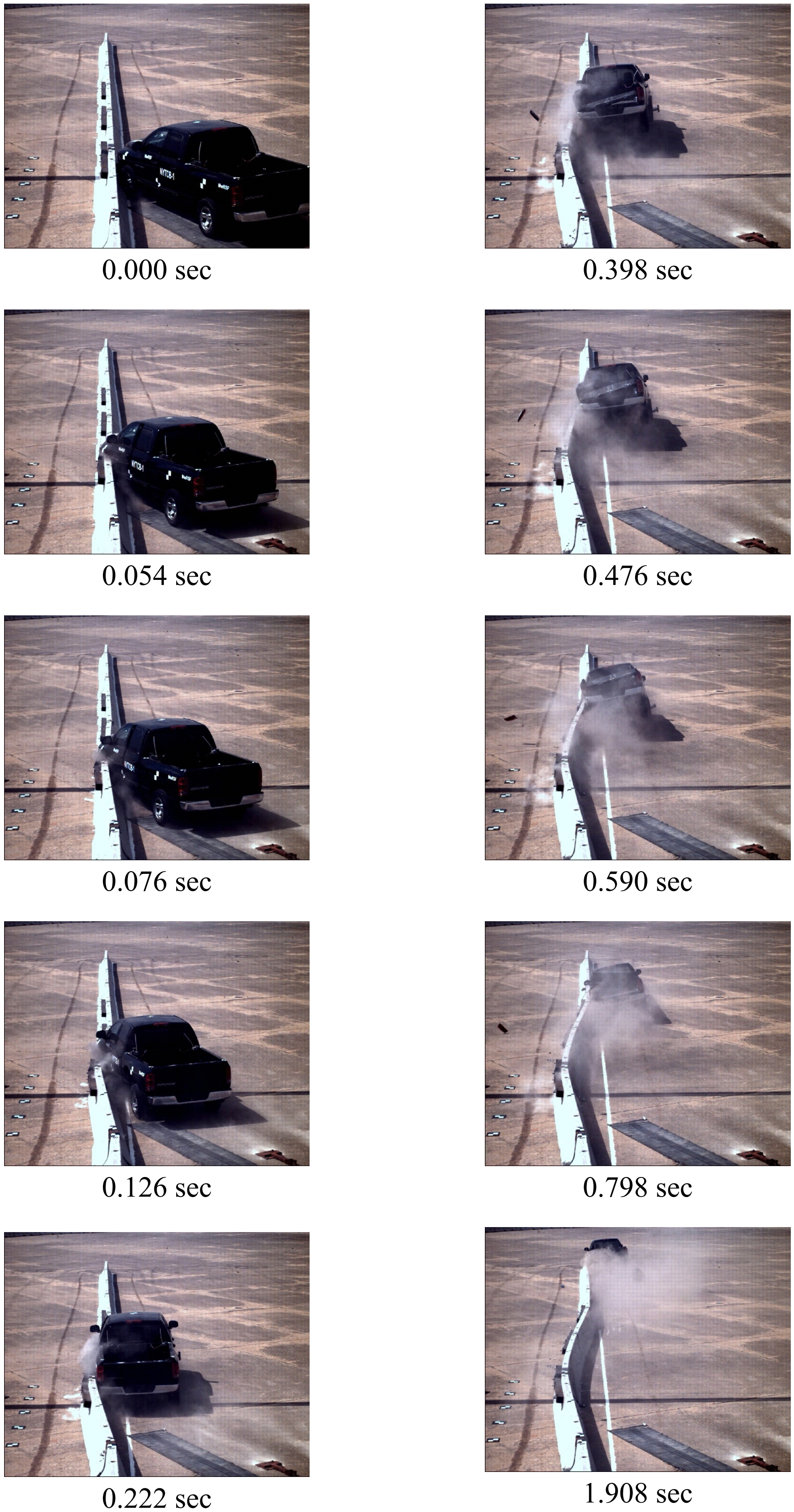


Figure 31. Additional Sequential Photographs, Test NYTCB-1

0.000 sec

0.060 sec

0.114 sec

0.182 sec

0.252 sec

0.414 sec

0.564 sec

0.842 sec

1.050 sec

1.752 sec

Figure 32. Additional Sequential Photos, Test NYTCB-1

Figure 33. Documentary Photographs, Test NYTCB-1

Figure 34. Documentary Photographs, Test NYTCB-1

Figure 35. Impact Location, Test NYTCB-1

Figure 36. Vehicle Final Position and Trajectory Marks, Test NYTCB-1

Figure 37. Temporary Barrier Damage, Test NYTCB-1

Figure 38. Temporary Barrier Damage, Test NYTCB-1

Figure 39. Barrier No. 5 Damage, Test NYTCB-1

Figure 40. Joint Connection Damage - Joints 2-3, 3-4, 4-5, and 5-6, Test NYTCB-1

Figure 41. Temporary Barrier Box Beam Stiffener Damage, Test NYTCB-1

Figure 42. Vehicle Damage, Test NYTCB-1

Figure 43. Vehicle Damage, Test NYTCB-1

7 DESIGN DETAILS - DESIGN NO. 2

The temporary concrete barrier system was identical to the previous system, except that the box beam stiffeners were removed, as shown in Figure 44. Once again, the 60.96-m (200-ft) long test installation consisted of temporary concrete barrier sections in a free-standing configuration with both end sections anchored. The system was constructed with the identical concrete barrier sections, connection keys, and anchored ends as in the stiffened system. Photographs of the test installation are shown in Figures 45 and 46. Complete system drawings in English and metric units are shown in Appendix E.

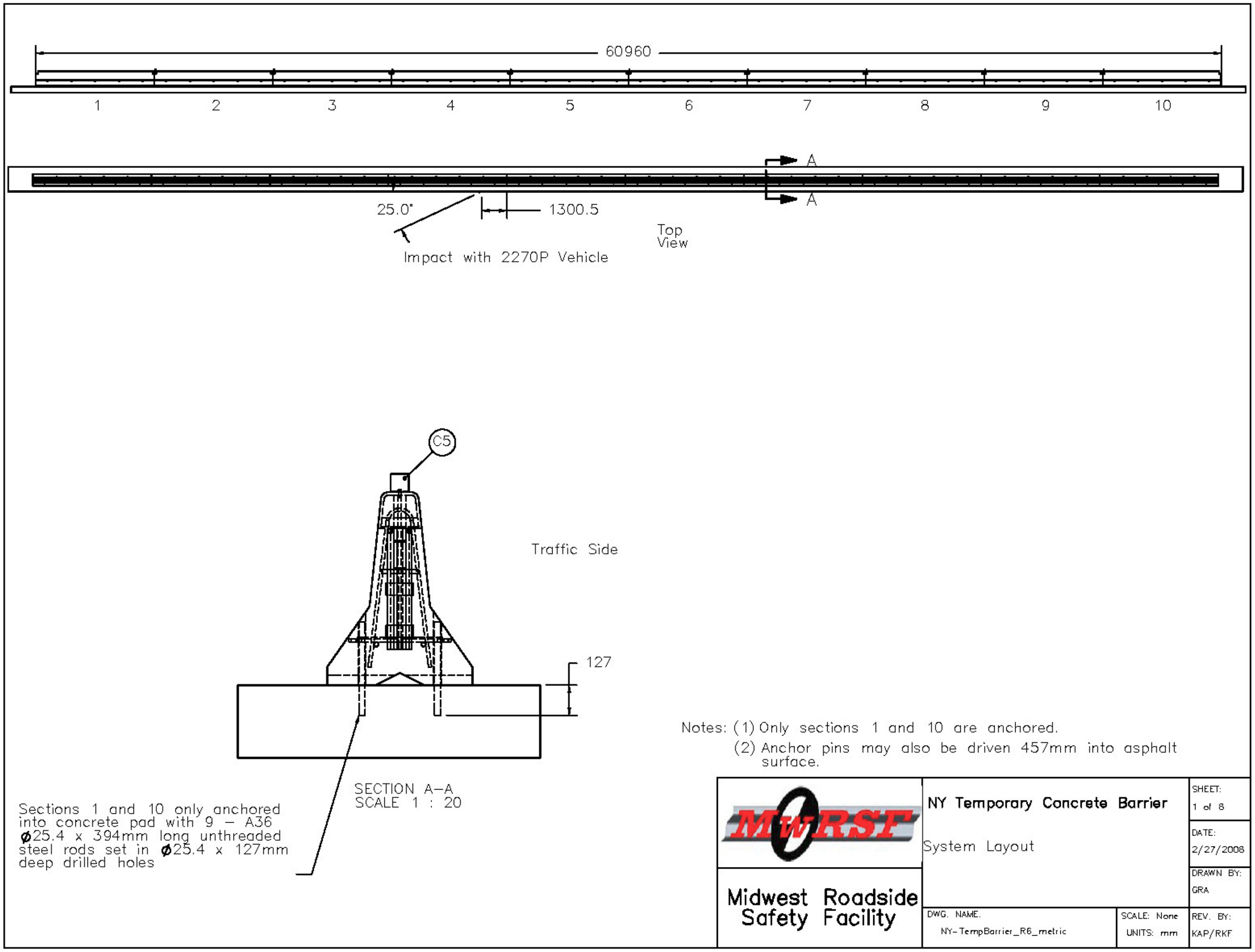


Figure 44. Unstiffened Temporary Concrete Barrier System Layout, Test NYTCB-2

Figure 45. Unstiffened Temporary Concrete Barrier, Test NYTCB-2

Figure 46. New York Temporary Concrete Barrier, Test NYTCB-2

8 FULL-SCALE CRASH TEST NO. 2

8.1 Test NYTCB-2

The 2,279-kg (5,024-lb) pickup truck impacted the unstiffened temporary concrete barrier system at a speed of 98.5 km/h (61.2 mph) and at an angle of 25.8 degrees. A summary of the test results and the sequential photographs are shown in Figure 47. An English-unit summary of the test results and sequential photographs are shown in Appendix B. Additional sequential photographs are shown in Figures 48 through 50. Documentary photographs of the crash test are shown in Figures 51 through 55.

8.2 Test Description

Initial vehicle impact was to occur 1,300 mm (51.2 in.) upstream from the downstream end of barrier no. 4, as shown in Figure 56. Actual vehicle impact occurred at the targeted impact location. Immediately after impact, the left-front quarter panel crushed inward. At 0.010 sec, barrier nos. 4 and 5 deflected away from traffic. At 0.012 sec, the left-front tire climbed the front face of barrier no. 4. At 0.032 sec, the vehicle yawed as it redirected. At 0.034 sec, the left-front quarter panel protruded over the top of the barrier. At 0.040 sec, the back side of barrier no. 4 experienced concrete spalling which disengaged from the barrier. At 0.042 sec, the vehicle climbed the front face of the system, and the vehicle's front end pitched upward. At 0.054 sec, concrete spalling occurred at the downstream end on the back side of barrier no. 3. At 0.056 sec, barrier no. 6 deflected backward due to movement of barrier no. 5. At 0.196 sec, barrier no. 7 deflected toward traffic. At 0.210 sec, barrier no. 3 moved slightly downstream. At 0.216 sec, the vehicle became parallel to the barrier with a resultant velocity of 82.7 km/h (51.4 mph). As the truck continued to redirect, it rolled toward the system. At 0.282 sec, the right-rear tire became airborne which resulted in the entire vehicle becoming airborne. At 0.296 sec, the front of the vehicle reached its maximum pitch upward and began pitching downward. At 0.420 sec, the vehicle exited the system at an angle of 4.7 degrees and a resultant velocity of 72.8 km/h (45.2 mph). At 0.554 sec, the right-front tire contacted the ground. At 0.556 sec, the right-front corner of the bumper contacted the ground. The vehicle continue downstream before coming to rest 58.8 m (192 ft - 11.5 in.) downstream from impact and 2.0 m (6 ft - 5 in.) laterally away from the traffic-side face of the barrier. The trajectory and final position of the truck are shown in Figures 47 and 57.

8.3 Barrier Damage

Damage to the barrier was moderate, as shown in Figures 58 through 61. Barrier damage consisted of tire and gouge marks, concrete barrier cracking, and spalling concrete. The length of the vehicle contact along the system was approximately 13.97 m (45.8 ft), which spanned from 1.78 m (70 in.) upstream from the downstream end of barrier no. 4 through the downstream end of barrier no. 6.

Contact marks were visible on the front face of barrier nos. 4 through 6. Tire marks were found 1,778 mm (70 in.) upstream from the downstream end of barrier no. 4 and continued through the downstream end of barrier no. 5. Tire marks were also found beginning at the midpoint of barrier no. 6 and continued through the end of barrier no. 6. Blue contact marks were found on barrier nos. 4 and 5.

Cracking was found on the front and back sides of barrier no. 4 from the center of the barrier to the downstream end. Major cracking was found throughout the front and back sides of barrier no. 5. Minor cracking was also found throughout the length of barrier no. 6 and on both the front and back sides.

The lower downstream-back corner of barrier no. 2 experienced concrete spalling measuring 127 mm (5 in.) wide and 102 mm (4 in.) tall. The lower upstream-back corner of barrier no. 3 also experienced concrete spalling measuring 76 mm (3 in.) wide and 229 mm (9 in.) tall. Barrier no. 4 experienced major concrete spalling at the lower front-downstream corner with a 305-mm (12-in.) wide by 254-mm (10-in.) tall piece removed. Minor concrete spalling began at impact and extended for a length of 1,194 mm (47 in.) downstream at the lower face of barrier no. 4. Major concrete spalling 229 mm (9 in.) wide by 305 mm (12 in.) tall was found on the upstream-front side of the top of barrier no. 5. The upper upstream-back corner of barrier no. 5 experienced concrete spalling measuring 152 mm (6 in.) wide by 178 mm (7 in.) tall. The upper downstream-back corner of barrier no. 5 also experienced concrete spalling measuring 76mm (3 in.) wide by 279mm (11 in.) tall. The lower-front face of barrier no. 5 experienced major concrete spalling 229 mm (9 in.) wide and 279 mm (11 in.) tall. A 711-mm (28-in.) long by 330-mm (13 in.) tall piece of concrete was removed from the lower-upstream end of the front side of barrier no. 6. Minor concrete spalling was located on the lower upstream-back side of barrier no. 6. Concrete spalling measuring 51mm (2 in.) wide and 254 mm (10 in.) tall was found on the upper-upstream corner of barrier no. 7.

All connection keys remained undamaged. The anchor rods in barrier nos. 1 and 10 remained undamaged, and these barriers encountered little to no movement.

The permanent set of the barrier system is shown in Figures 58 and 59. The maximum lateral permanent set barrier deflection was 1,003 mm (39.5 in.) at the downstream end of barrier no. 4 and the upstream end of barrier no. 5, as measured in the field. The maximum lateral dynamic barrier deflection was 1,023 mm (40.25 in.) at the midpoint of barrier no. 5, as determined from high-speed digital video analysis. The working width of the system was found to be 1,630 mm (64.2 in.).

8.4 Vehicle Damage

Exterior vehicle damage was moderate, as shown in Figures 62 and 63. Occupant compartment deformations to the left side and center of the floorboard were judged insufficient to cause serious injury to the vehicle occupants, as shown in Figure 64. Maximum longitudinal deflections of 76 mm (3 in.) were located near the left-front corner of the left-side floor pan. Maximum lateral deflections of 25 mm (1 in.) were located near the front center of the left-side floor pan. Maximum vertical deflections of 70 mm (2.75 in.) were located near the middle-front area of the left-side floor pan. Complete occupant compartment deformations and the corresponding locations are provided in Appendix C.

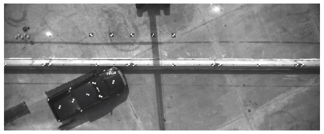
Damage was concentrated on the left-front corner of the vehicle. The left-front and right-front quarter panels buckled inward toward the engine compartment. The left corner of the front bumper deformed and both sides were partially detached from the vehicle. The left-front tire's side wall experienced a 127-mm (5-in.) long gash, and the tire deflated. The left-front wheel assembly was deformed into the wheel well. A small gouge was found in the left-rear tire, and the tire deflated. The left-front door was ajar at the top. Scrape marks and dents were found at the bottom of the left front and left-rear doors, the left-front and right-front quarter panels, the left-rear corner of the box, and the right-rear corner of the cab. The left side of the box portion separated from the cab. The left-rear axle deformed upward. The left-side headlight and taillight disengaged from the vehicle. The left side of the rear bumper buckled inward. The tailgate disengaged, except it remained attached by the left-side cable. The front frame on the left side was deformed. The left-side upper control arm and pin were bent and scraped. All window glass in the vehicle remained undamaged.

8.5 Occupant Risk Values

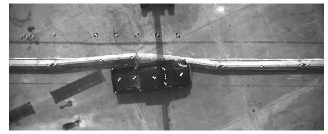
The longitudinal and lateral occupant impact velocities were determined to be -4.84 m/s (-15.88 ft/s) and 6.32 m/s (20.74 ft/s), respectively. The maximum 0.010-sec average occupant ridedown decelerations in the longitudinal and lateral directions were -5.44 g's and 8.09 g's, respectively. It is noted that the occupant impact velocities (OIV) and occupant ridedown decelerations (ORD) were within the suggested limits provided in the currently proposed Update to NCHRP Report No. 350. The THIV and PHD values were determined to be 7.59 m/s (24.89 ft/s) and 8.19 g's, respectively. The results of the occupant risk, as determined from the accelerometer data, are summarized in Figure 47. Results are shown graphically in Appendix F. The results from the rate transducer are shown graphically in Appendix F.

8.6 Discussion

The analysis of the test results for test no. NYTCB-2 showed that the unstiffened temporary concrete barrier system with anchored ends adequately contained and redirected the 2270P vehicle with controlled lateral displacements of the barrier system. There were no detached elements nor fragments which showed potential for penetrating the occupant compartment nor presented undue hazard to other traffic. Deformations of, or intrusions into, the occupant compartment that could have caused serious injury did not occur. The test vehicle did not penetrate nor ride over the barrier system and remained upright during and after the collision. Vehicle roll, pitch, and yaw angular displacements were noted, but they were deemed acceptable because they did not adversely influence occupant risk safety criteria nor cause rollover. After collision, the vehicle's trajectory revealed minimum intrusion into adjacent traffic lanes. In addition, the vehicle exited the barrier within the exit box. Therefore, test no. NYTCB-2 conducted on the unstiffened temporary concrete barrier system with anchored ends was determined to be acceptable according to the TL-3 safety performance criteria of test designation no. 3-11 found in the currently proposed Update to NCHRP Report No. 350.


0.000 sec


0.054 sec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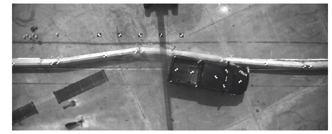
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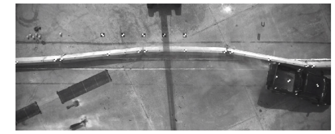
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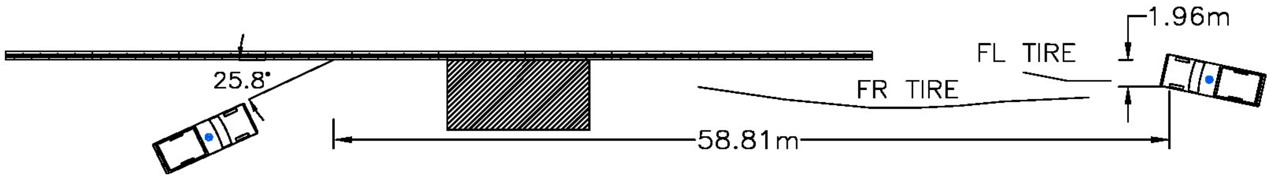
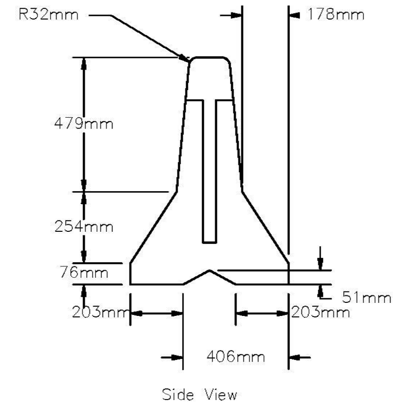




- Test Agency . . . . MwRSF
- Test Number NYTCB-2
- Date 7/25/07
- NCHRP 350 Update Test Designation 3-11
- Appurtenance . . . . Unstiffened Temporary Concrete Barriers
- Total Length . . . . 60.96 m
- Key Elements - Barrier
  - Description . . . . New York TCB with Connection Keys
  - Length . . . . 6,096 mm
  - Base Width . . . . 610 mm
  - Height . . . . 810 mm
- Key Elements - Anchor Ends
  - Size . . . . 25 mm diameter ASTM A36 rod
  - Length . . . . 394 mm
  - Number per Barrier . . . . 5 traffic-side, 4 back side
- Type of Soil . . . . N/A
- Test Vehicle
  - Type/Designation 2270P
  - Make and Model . . . . 2002 Dodge Ram 1500 Quad Cab 4x2
  - Curb . . . . 2,245 kg
  - Test Inertial . . . . 2,279 kg
  - Gross Static . . . . 2,279 kg
- Impact Conditions
  - Speed . . . . 98.5 km/h
  - Angle . . . . 25.8 degrees
  - Impact Location . . . . 1,300 mm upstream from downstream end of barrier 4
- Exit Conditions
  - Speed . . . . 72.8 km/h
  - Angle . . . . 4.7 degrees
  - Exit Box Criterion . . . . Pass
- Post-Impact Trajectory
  - Vehicle Stability . . . . Satisfactory
  - Stopping Distance . . . . 58.81 m downstream 1.96 m laterally away
- Occupant Impact Velocity
  - Longitudinal . . . . -4.84 m/s < 12.2 m/s
  - Lateral . . . . 6.32 m/s < 12.2 m/s
- Occupant Ridedown Deceleration
  - Longitudinal . . . . -5.44 g's < 20.49 g's
  - Lateral . . . . 8.09 g's < 20.49 g's
- THIV (not required) . . . . 7.59 g's
- PHD (not required) . . . . 8.19 g's
- Test Article Damage . . . . Moderate
- Test Article Deflections
  - Permanent Set . . . . 1,003 mm
  - Dynamic . . . . 1,023 mm
  - Working Width . . . . 1,630 mm
- Vehicle Damage . . . . Moderate
  - VDS[13] 11-LFQ-3
  - CDC[14] 11-LYEN4
  - Maximum Deformation . . . . . 76 mm
- Angular Displacements
  - Roll . . . . -12.4 deg
  - Pitch . . . . -10.6 deg
  - Yaw . . . . 43.1 deg

Figure 47. Summary of Test Results and Sequential Photographs, Test NYTCB-2

0.000 sec

0.020 sec

0.030 sec

0.070 sec

0.124 sec

0.172 sec

0.214 sec

0.256 sec

0.392 sec

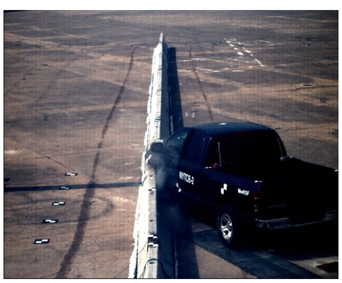
0.548 sec

Figure 48. Additional Sequential Photographs, Test NYTCB-2

0.000 sec

0.010 sec

0.028 sec



0.054 sec

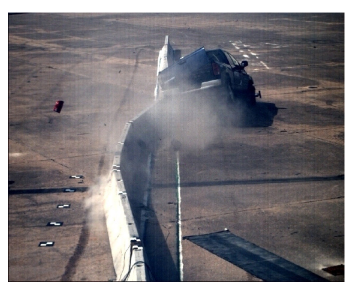
0.094 sec

0.210 sec

0.316 sec

0.460 sec

0.620 sec



0.722 sec

Figure 49. Additional Sequential Photographs, Test NYTCB-2

0.000 sec

0.036 sec

0.056 sec

0.150 sec

0.212 sec

0.296 sec

0.440 sec

0.630 sec

0.986 sec

2.654 sec

Figure 50. Additional Sequential Photographs, Test NYTCB-2

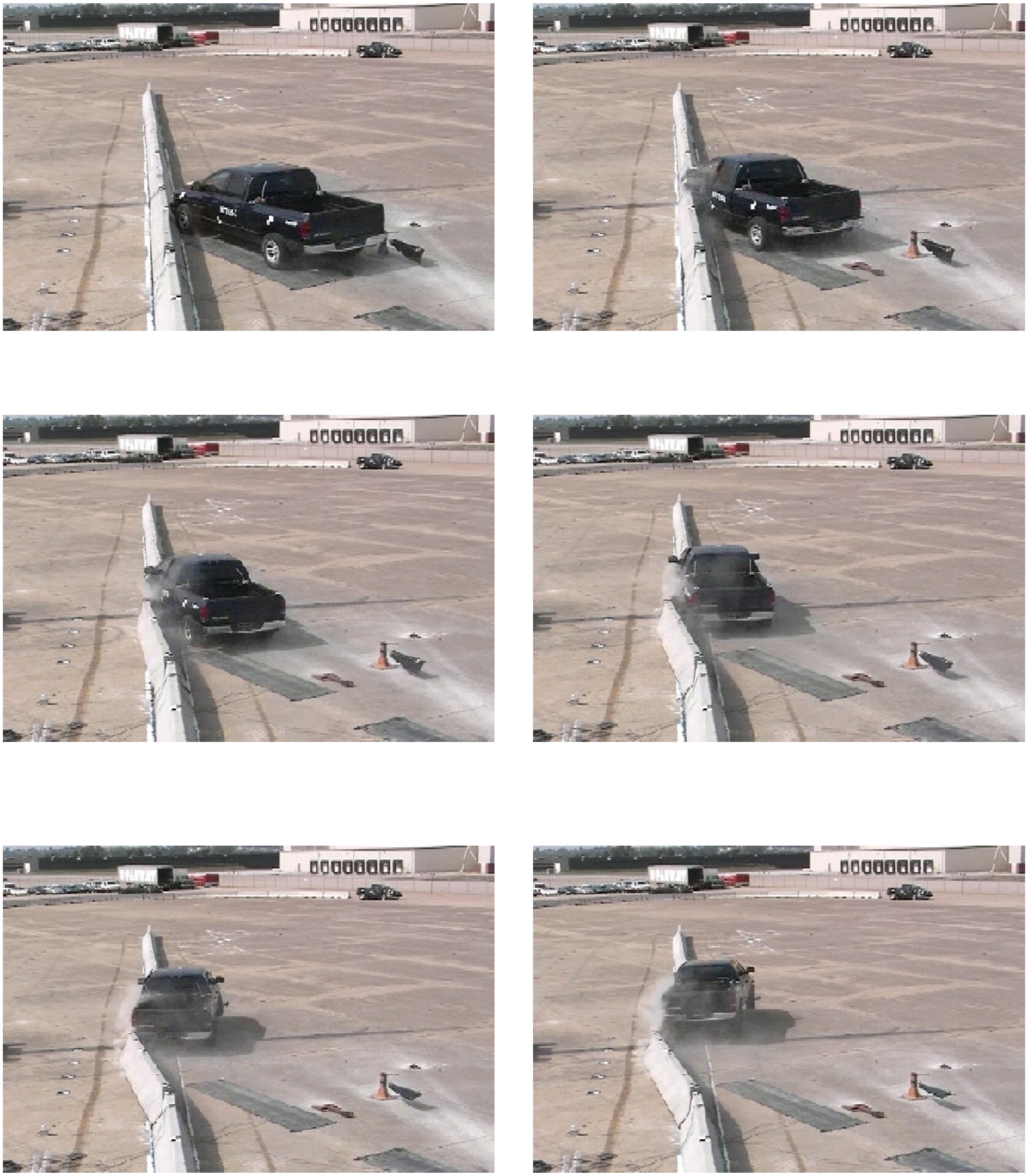


Figure 51. Documentary Photographs, Test NYTCB-2

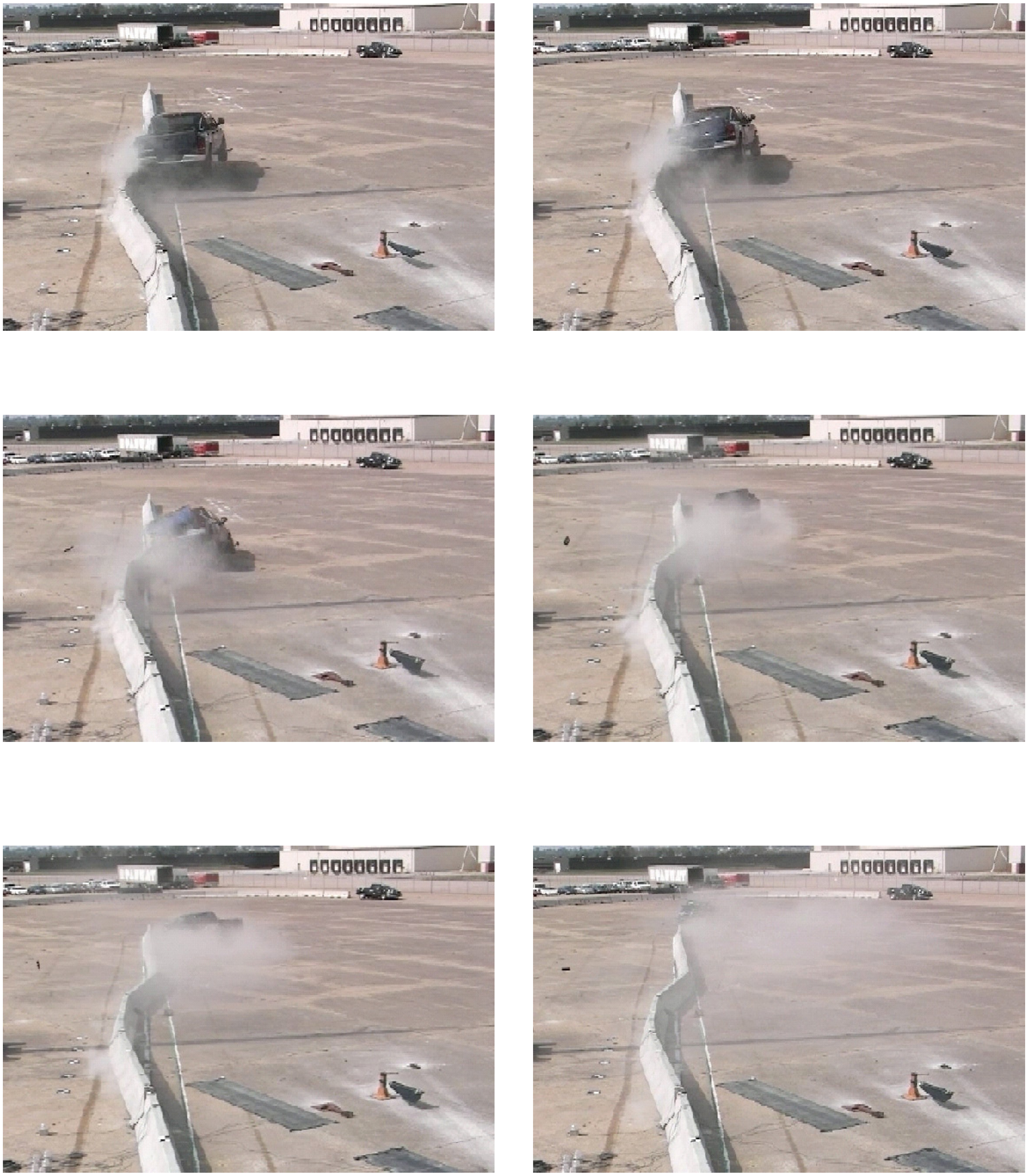


Figure 52. Documentary Photographs, Test NYTCB-2

Figure 53. Documentary Photographs, Test NYTCB-2

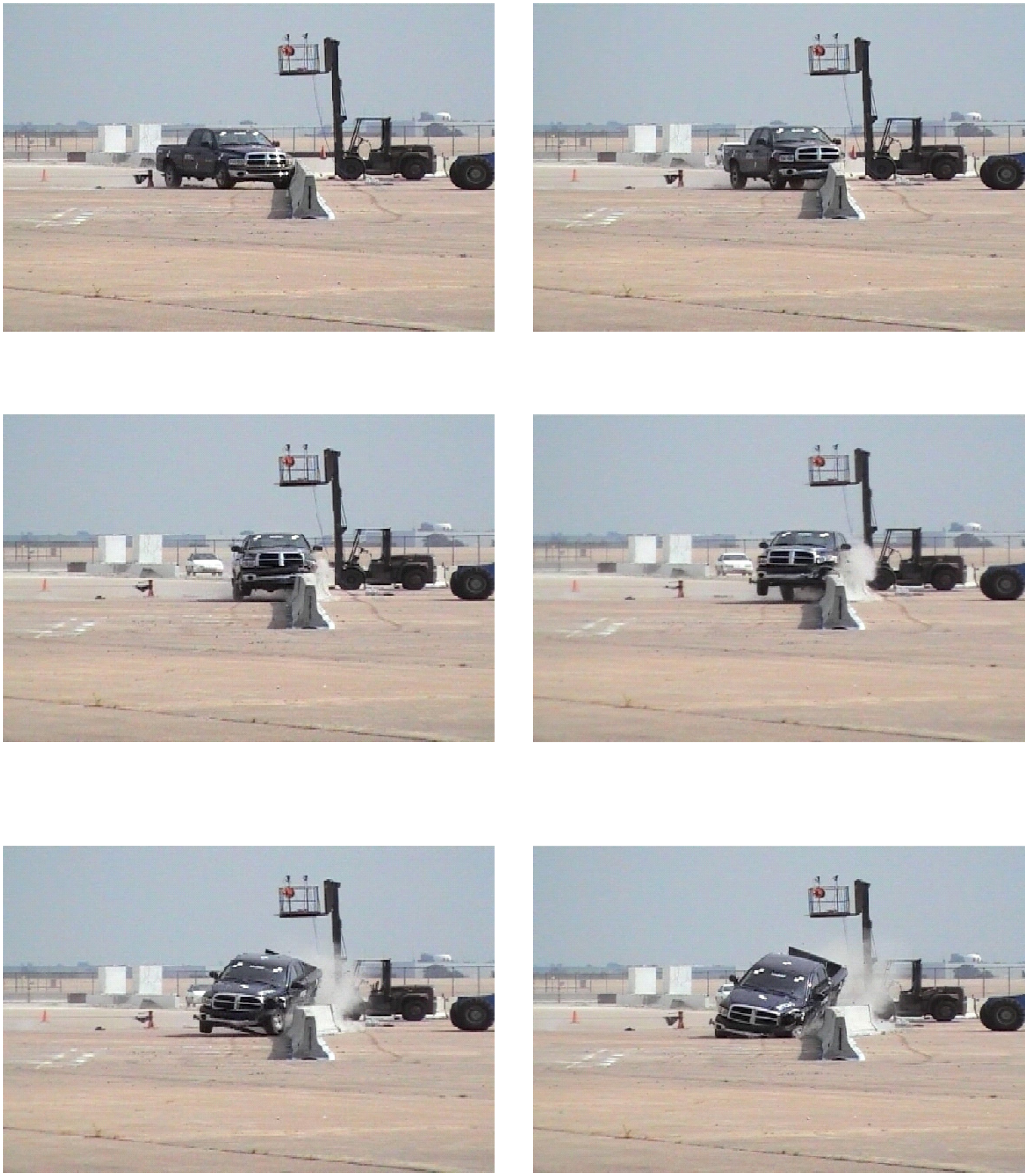


Figure 54. Documentary Photographs, Test NYTCB-2

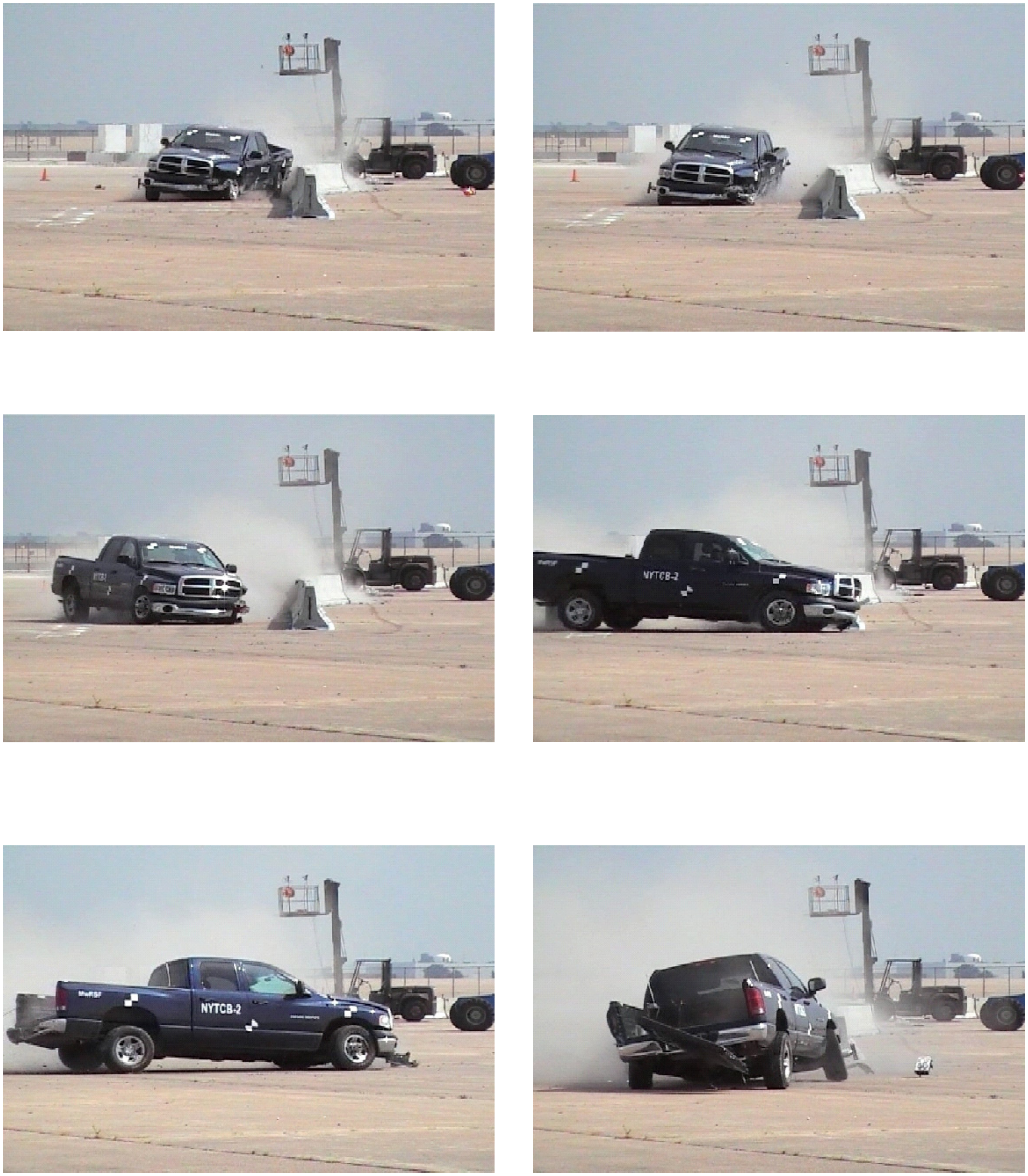


Figure 55. Documentary Photographs, Test NYTCB-2

Figure 56. Impact Location, Test NYTCB-2

Figure 57. Vehicle Final Position and Trajectory Marks, Test NYTCB-2

Figure 58. Temporary Barrier Damage, Test NYTCB-2

Figure 59. Temporary Barrier Damage, Test NYTCB-2

Figure 60. Barrier No. 5 Damage, Test NYTCB-2

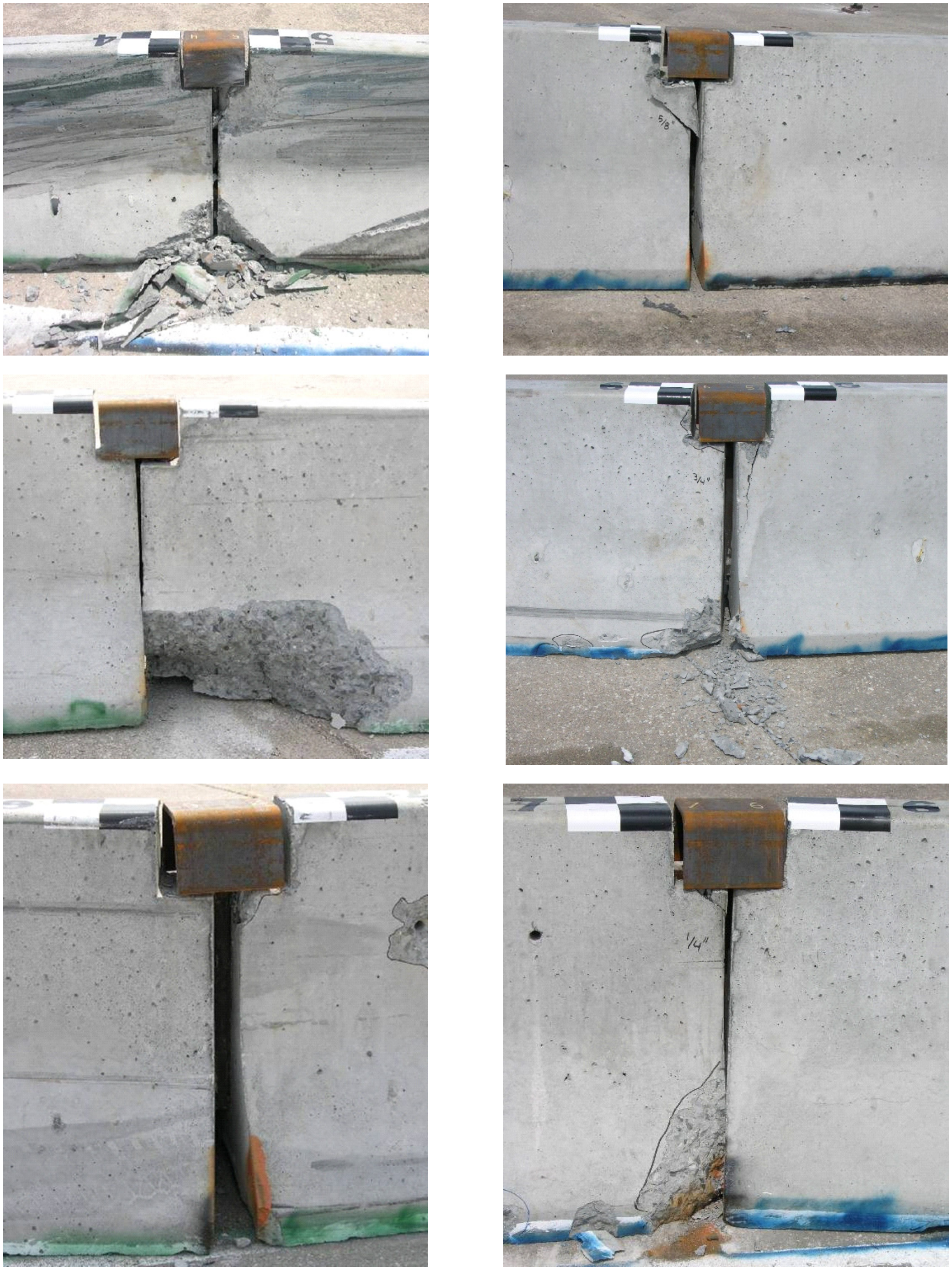


Figure 61. Joint Connection Damage for Joints 4-5, 5-6, and 6-7, Test NYTCB-2

Figure 62. Vehicle Damage, Test NYTCB-2

Figure 63. Vehicle Damage, Test NYTCB-2

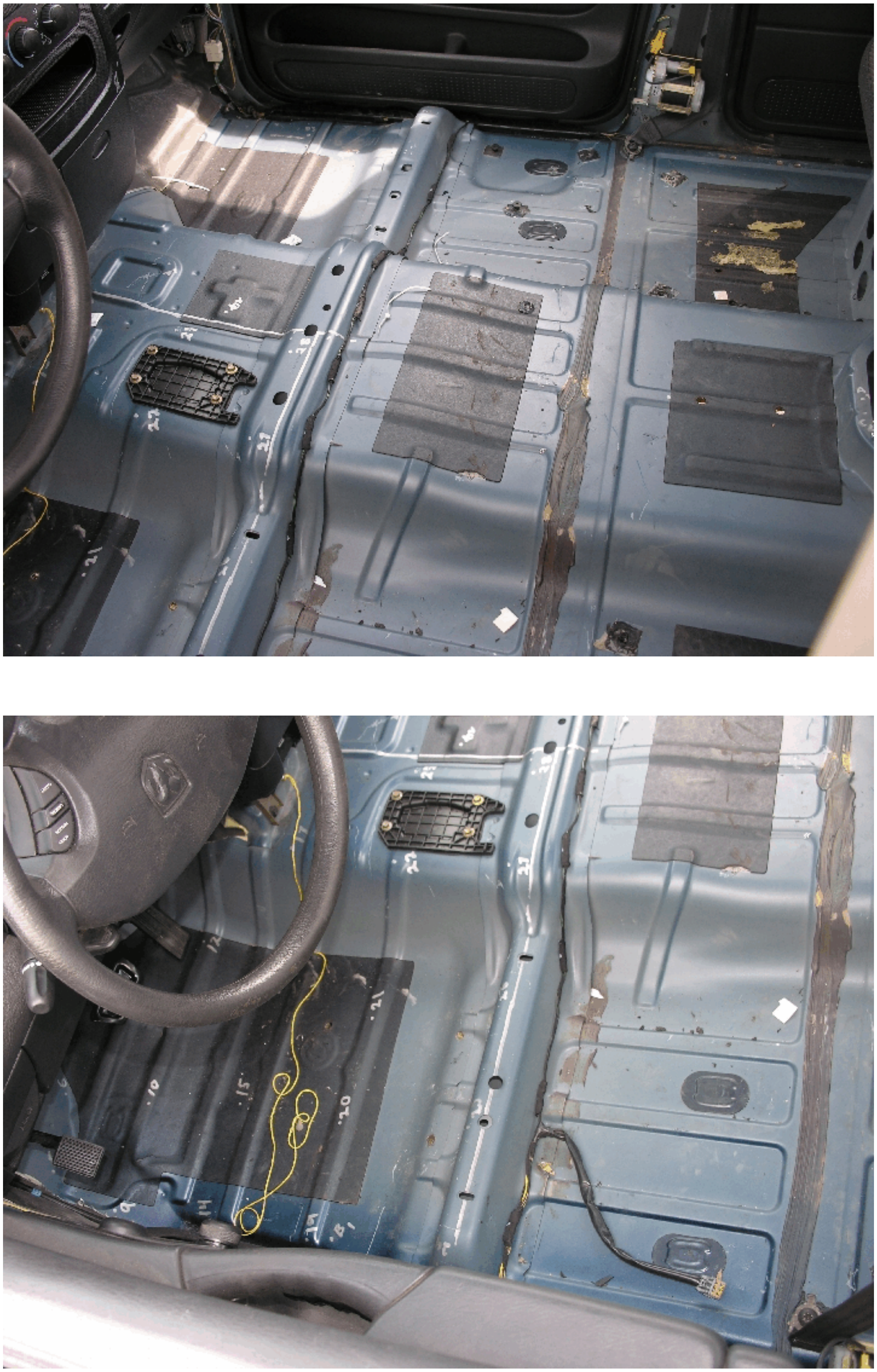


Figure 64. Occupant Compartment Deformation, Test NYTCB-2

9 DESIGN MODIFICATIONS - DESIGN NO. 3

The temporary concrete barrier system was identical to that of design no. 1, except for changing the size of the box beam stiffener and placing the system adjacent to a vertical drop off, as shown in Figures 65 and 68. For this installation, each box beam stiffener consisted of a 152-mm x 203-mm x 6.4-mm (6-in. x 8-in. x 0.25-in.) ASTM A500 Grade C box beam, which was 3,658 mm (12 ft) long. The stiffeners were connected to the barrier sections with the same connecting rod, except that the length was increased to 483 mm (19 in.), as shown in Figures 66 and 67. In addition, the six joints between barrier section nos. 2 and 8 were stiffened with a box beam stiffener. Furthermore, the system was installed with the back side of the sections placed 305 mm (12 in.) away from the edge of a bridge deck, as shown in Figure 65. Once again, the size of the box beam stiffening rail was selected to be consistent with the standard sizes used for the NYSDOT's box beam guide rail and median barrier.

The 60.96-m (200-ft) long, test installation consisted of temporary concrete barrier sections in a free-standing configuration with both end sections anchored. The system was constructed with identical concrete barrier sections, connection keys, and anchored ends as in the first and second designs. Photographs of the test installation are shown in Figures 68 through 69. Complete system drawings in English and metric units are shown in Appendix G.

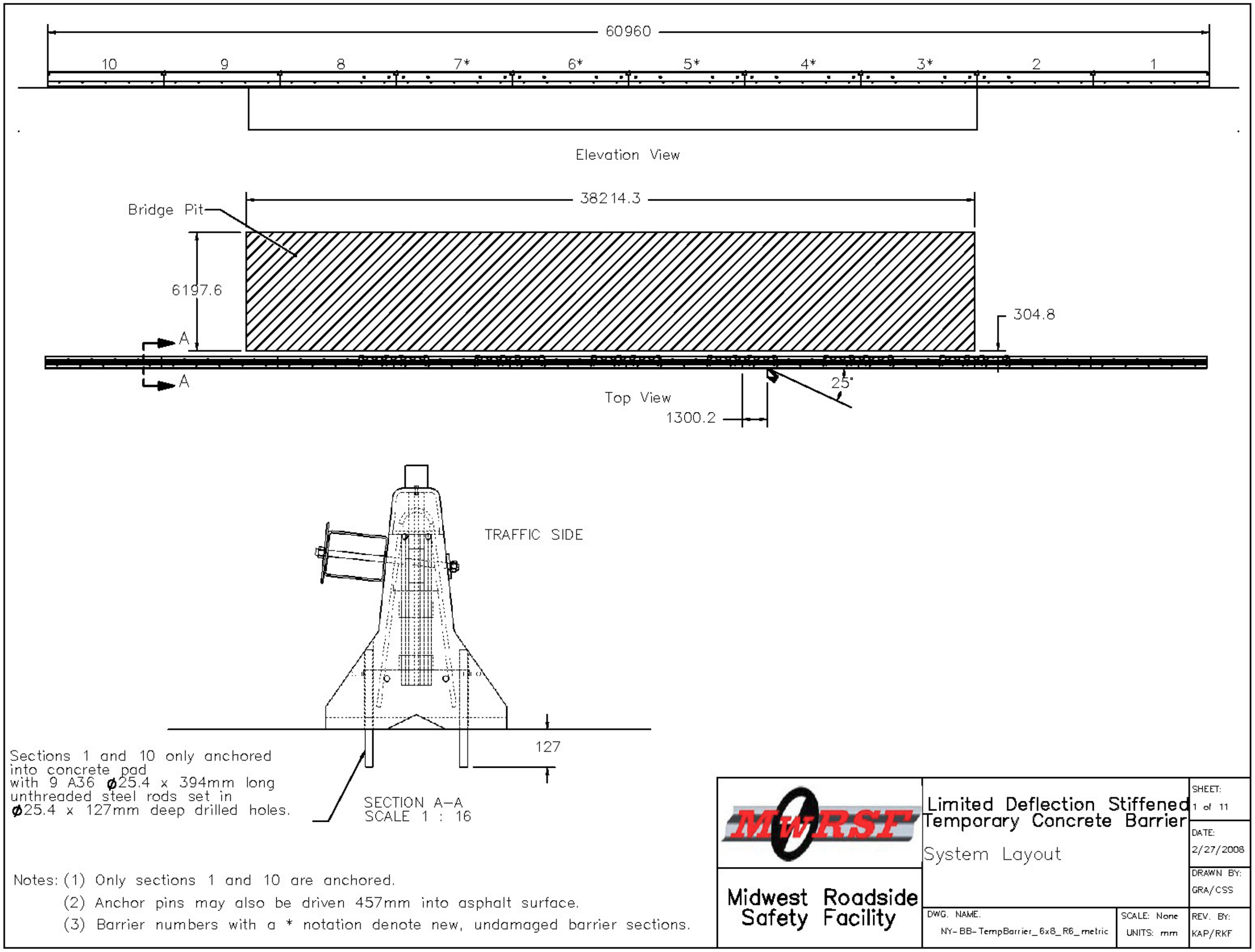


Figure 65. Stiffened Temporary Concrete Barrier System Layout, Test NYTCB-3

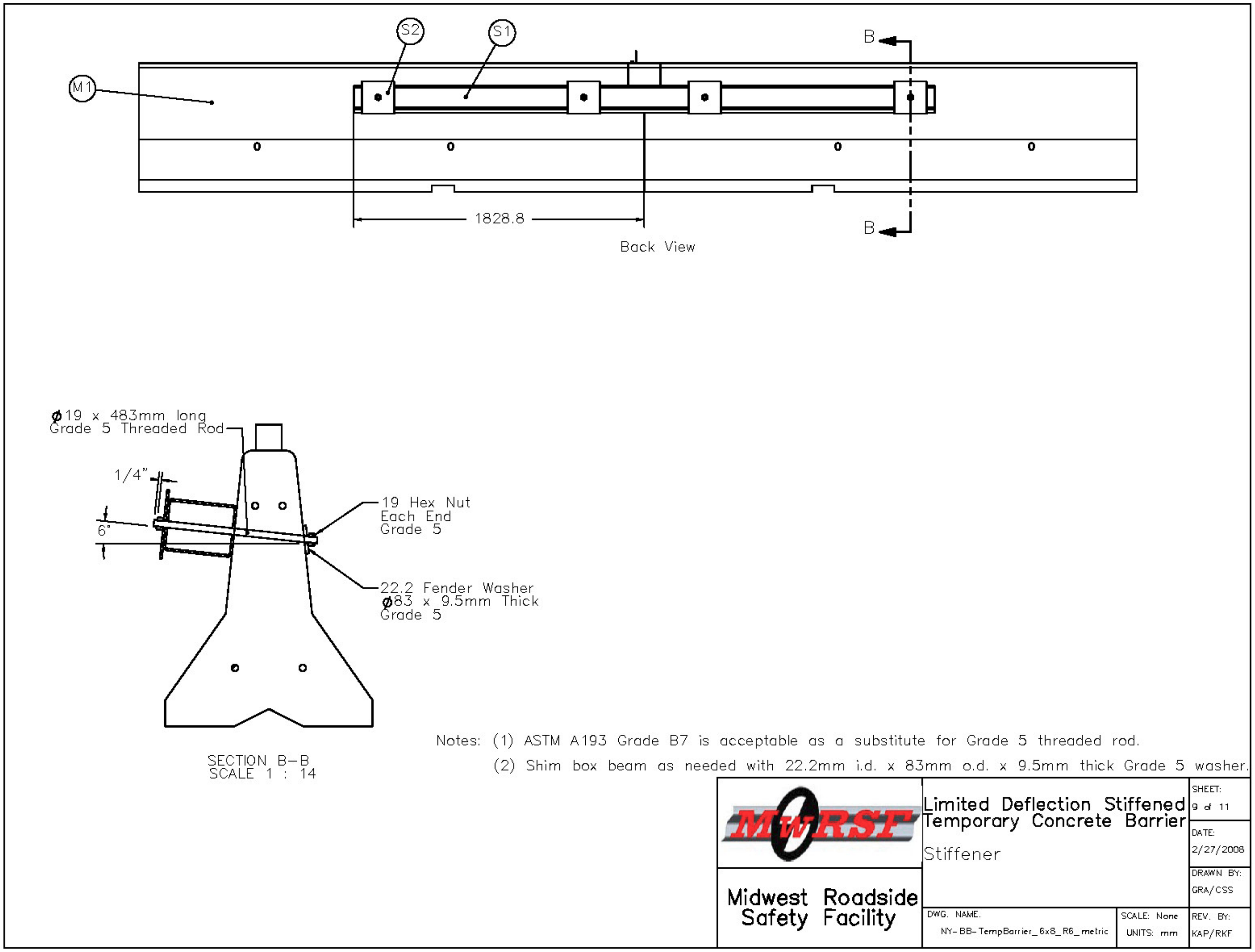


Figure 66. Box Beam Stiffener Details, Test NYTCB-3

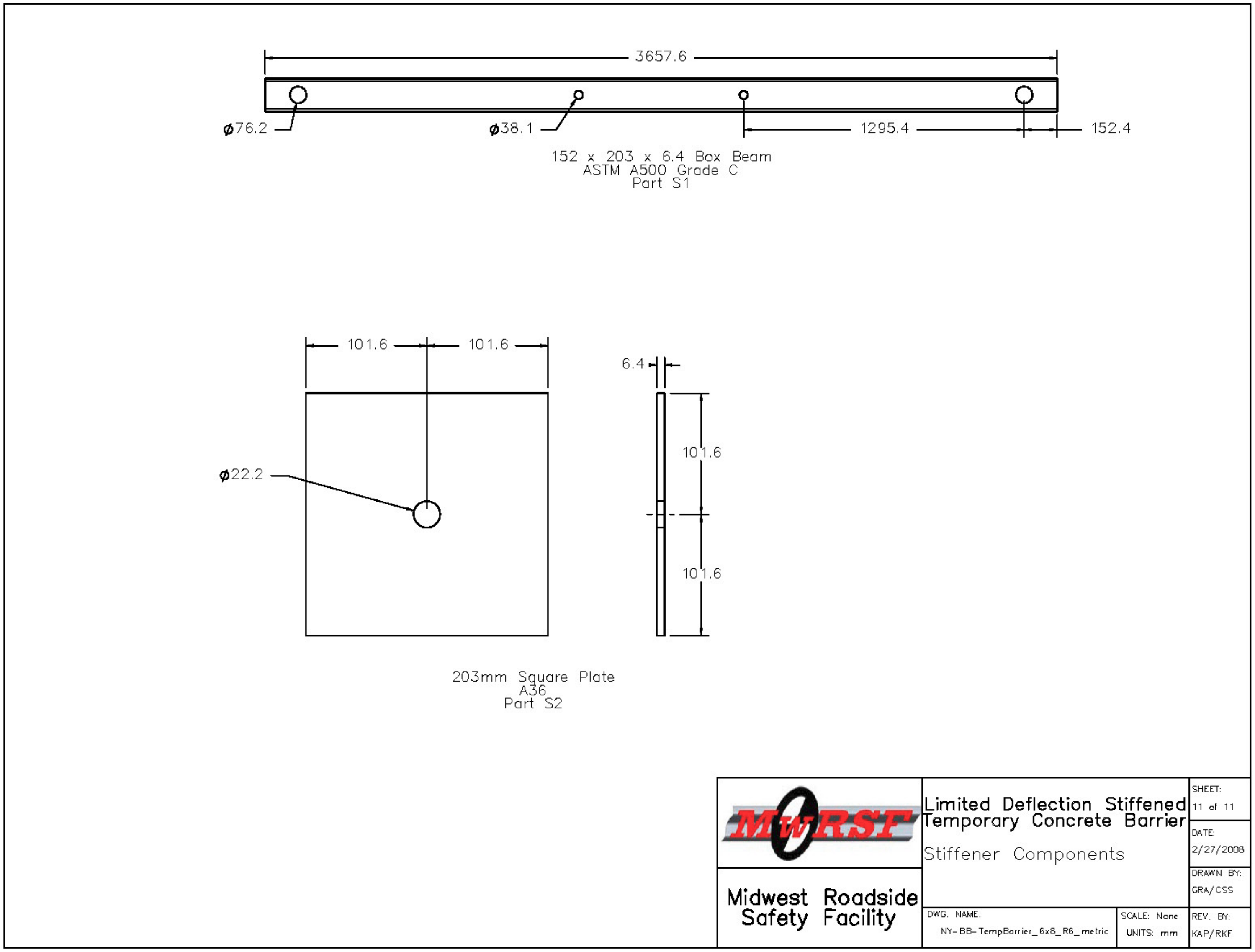


Figure 67. Box Beam Stiffener Details, Test NYTCB-3

Figure 68. Box Beam Stiffened Temporary Concrete Barrier System, Test NYTCB-3

Figure 69. Box Beam Stiffeners, Test NYTCB-3

10 FULL-SCALE CRASH TEST NO. 3

10.1 Test NYTCB-3

The 2,268-kg (5,001-lb) pickup truck impacted the stiffened temporary concrete barrier system at a speed of 102.2 km/h (63.5 mph) and at an angle of 24.4 degrees. A summary of the test results and sequential photographs are shown in Figure 70. An English-unit summary of the test results and sequential photographs are shown in Appendix B. Additional sequential photographs are shown in Figures 71 through 73. Documentary photographs are shown in Figures 74 and 75.

10.2 Test Description

Initial vehicle impact was to occur 1,300 mm (51.2 in.) upstream from the downstream end of barrier no. 4, as shown in Figures 65 and 76. Actual vehicle impact occurred at the targeted impact location. At 0.004 sec after impact, the right corner of the front bumper crushed inward. At 0.010 sec, the right-front tire climbed barrier no. 4. At 0.014 sec, the right-front tire ruptured as the tire was compressed between the vehicle and barrier no. 4. At 0.018 sec, barrier no. 4 deflected backward. At this same time, the box beam stiffener between barrier nos. 4 and 5 bent away from the barriers. At 0.026 sec, the right-front tire was airborne and in contact with the front face of barrier no. 4. At 0.028 sec, the hood became ajar. At 0.030 sec, barrier no. 5 deflected backward. At 0.032 sec, the vehicle redirected as the front of the vehicle was located near the joint between barrier nos. 4 and 5. At 0.036 sec, the front of the vehicle pitched upward. At 0.040 sec, the box beam stiffeners located at the joints between barrier nos. 3 and 4 and barrier nos. 5 and 6 bent away from the barriers. At 0.042 sec, the right-front door became ajar. At 0.056 sec, small concrete pieces disengaged at the joint between barrier nos. 3 and 4 as barrier no. 4 rotated. At 0.082 sec, concrete pieces disengaged from the base of barrier no. 5 as the barrier continued to deflect backward. At this same time, the right-side headlight disengaged from the vehicle. At 0.084 sec, the back-downstream corner of barrier no. 5 cracked. At 0.088 sec, barrier nos. 3 and 6 deflected backward. At 0.100 sec, the back-upstream corner of barrier no. 5 cracked. At 0.114 sec, the box beam stiffener between barrier nos. 2 and 3 bent away from the barriers. At 0.116 sec, the left-front tire became airborne with the front of the vehicle located at the middle of barrier no. 5. At 0.152 sec, the box beam stiffener between barrier nos. 6 and 7 bent away from the barriers. At 0.160 sec, the joint between barrier nos. 4 and 5 protruded beyond the edge of the bridge deck. At 0.172 sec, barrier no. 7 deflected backward. At 0.178 sec, the right-rear tire contacted the upstream end of barrier no. 5, and the entire right side of the vehicle was in contact with the system. At 0.192 sec, the right-rear tire climbed the front face of barrier no. 5. At 0.210 sec, the vehicle became parallel to the system with a resultant velocity of 80.7 km/h (50.1 mph). At 0.214 sec, the box beam stiffener between barrier nos. 6 and 7 bent. At 0.222 sec, the front of the vehicle ceased pitching upward. At 0.270 sec, the vehicle's right rear of the vehicle lost contact with the system. At 0.292 sec, the left-rear tire became airborne. At 0.320 sec, the back-upstream corner of barrier no. 6 and the back edge of barrier no. 5 protruded beyond the edge of the bridge deck. At 0.374 sec, barrier nos. 4 and 5 ceased movement. At 0.446 sec, the vehicle exited the system at an angle of 1.7 degrees and at a resultant velocity of 87.2 km/h (54.2 mph). At 0.498 sec, the system reached its maximum deflection. At 0.634 sec, the vehicle rolled slightly clockwise toward the barrier. At 0.710 sec, the front bumper of the vehicle contacted the ground, and the vehicle ceased pitching. At 0.786 sec, the right-front tire contacted the ground. At 0.798 sec, the vehicle rolled slightly counterclockwise away from the barrier. At 0.950 sec, the right-rear tire contacted the ground, and the vehicle ceased rolling counterclockwise. At 0.964 sec, the left-rear tire contacted the ground. The vehicle came to rest 57.69 m (189 ft - 3.25 in.) downstream from impact and 3.81 m (12 ft - 6 in.) laterally behind a line projected parallel to the traffic-side face of the barrier. The trajectory and final position of the vehicle are shown in

Figures 70 and 77.

10.3 Barrier Damage

Damage to the barrier was moderate, as shown in Figures 78 through 84. Barrier damage consisted of contact and gouge marks, concrete barrier cracking, spalling of the concrete, and deformed box beam sections. The length of vehicle contact along the temporary barrier system was approximately 31.7 m (104 ft), which spanned from 1,783 mm (70.2 in.) upstream from the downstream end of barrier no. 4 through 3,785 mm (149 in.) downstream from the upstream end of barrier no. 5 and from 1,753 mm (69 in.) downstream from the upstream end of barrier no. 6 through the downstream end of barrier no. 10.

Tire marks were visible on the front face of barrier nos. 4 through 10. Gouge marks were found on the upstream front face of barrier no. 5.

Cracking was found on the front and back sides of barrier no. 3. One 3.2-mm (0.125 in.) wide crack was found on the back side of barrier no. 3 and began 1,016 mm (40 in.) downstream from the upstream end of the barrier. Three hairline cracks were found on the front side of barrier no. 3 and began 1,676 mm (66 in.), 2,388 mm (94 in.),and 3,658 mm (144 in.) downstream from the upstream end of the barrier and traveled from the top to the bottom of the barrier. Major cracking was found throughout the front and back sides of barrier nos. 4 and 5. Hairline cracks were located on the back side of barrier no. 4 at 1,499 mm (59 in.), 2,413 mm (95 in.), 4,826 mm (190 in.), and 5,486 mm (216 in.) downstream from the upstream end of barrier no. 4. Two 1.6-mm (0.06-in.) wide cracks were located 3,048 mm (120 in.) and 3,607 mm (142 in.) downstream from the upstream end of the barrier with the front side experiencing hairline cracks at the same locations. A 3.2-mm (0.13-in.) wide crack was located on the back side of barrier no. 4 at 4,242 mm (167 in.) downstream from the upstream end of the barrier with the front side experiencing hairline cracking at the same location.

A 1.6-mm (0.06-in.) wide crack was located on the back side at 3,073 mm (121 in.) downstream from the upstream end of barrier no. 5. Three 6.4-mm (0.25-in.) cracks were found on the back side of barrier no. 5 at 1,422 mm (56 in.), 1,829 mm (72 in.), and 2,515 mm (99 in.) downstream from the upstream end of the barrier with hairline cracks on the front side at these same locations. A 3.2-mm (0.13-in.) wide crack was also found on the back side of barrier no. 5 at 3,759 mm (148 in.) downstream from the upstream end of the barrier with a hairline crack on the front side at this location. A hairline crack was located on the front and back sides of barrier no. 5 at 4,597 mm (181 in.) downstream from the upstream end of the barrier. Minor hairline cracking was located on the front of barrier no. 6 at 1,676 mm (66 in.), 2,337 mm (92 in.), 3,302 mm (130 in.), and 4,267 mm (168 in.) downstream from the upstream end of the barrier. One 1.6-mm (0.06-in.) wide crack was found on the front and back sides of barrier no. 7 at 1,829 mm (72 in.) downstream from the upstream end of the barrier.

Concrete spalling occurred on barrier nos. 3 through 7. The downstream corner of barrier no. 3 experienced minor concrete spalling. A 737-mm (29-in.) long and 216-mm (8.5-in.) tall piece of concrete was removed from the front side of barrier no. 4 near impact. Minor concrete spalling was found on the back-upstream end of barrier no. 4, the lower-front face of barrier no. 5, and the front faces of barrier nos. 6 and 7. A 686-mm (27-in.) long by 483-mm (19-in.) tall piece of concrete was removed from the lower back-downstream corner of barrier no. 5, and exposed the steel rebar.

The box beam stiffener located across the joint between barrier nos. 4 and 5 sustained significant bending. The box beam stiffener placed across the joints between barrier nos. 2 and 3, 3 and 4, 5 and 6, and 6 and 7 experienced minor bending. The box beam rods on the front sides of barrier nos. 4 through 6 were bent, and scrape marks were found on the corresponding nuts and washers. All connection keys remained undamaged, except for minor contact marks. The anchor rods in barrier nos. 1 and 10 remained undamaged, and these barriers experienced no movement. Minor bending of the plate washers was observed. No buckling of the box beam webs or bending of the box beam flanges was observed with the plate washers.

The permanent set of the barrier system is shown in Figure 78. The maximum lateral permanent set barrier deflection was 660 mm (26 in.) at the downstream end of barrier no. 4, as measured in the field. The center of gravity of barrier no. 5 was displaced 19 mm (0.75 in.) off of the bridge deck edge. The maximum lateral dynamic barrier deflection was 784 mm (30.9 in.) at the upstream end of barrier no. 5, as determined from high-speed digital analysis. The working width of the system was found to be 1,304 mm (51.3 in.).

10.4 Vehicle Damage

Exterior vehicle damage was moderate, as shown in Figures 85 and 86. Occupant compartment deformations to the right side and center of the floorboard were judged insufficient to cause serious injury to the vehicle occupants, as shown in Figure 87. Maximum longitudinal deflections of 89 mm (3.5 in.) were located near the middle-front area of the right-side floor pan. Maximum lateral deflections of 16 mm (0.625 in.) were located near the right-front door. Occupant compartment deformations and the corresponding locations are provided in Appendix C.

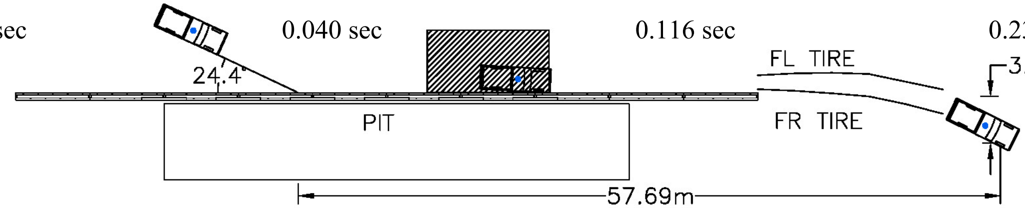
Damage was concentrated on the right-front corner of the vehicle. The right-front quarter panel deformed inward toward the engine compartment. The hood and the top of the right-side door were ajar. Scrapes and contact marks were found along the entire right side. The right-front wheel assembly rotated 36 degrees from normal position. The edge of the right-front steel rim was deformed and cracked. The right-front tire's sidewall was torn, and the tire deflated. The right-rear steel rim was deformed, and the tire deflated. The right-side upper control arm link to the power steering cylinder fractured. The right-side headlight disengaged from the vehicle. The lower-left side of the windshield had “spider-web” cracking. The roof, left side, and rear of the vehicle and all other window glass remained undamaged.

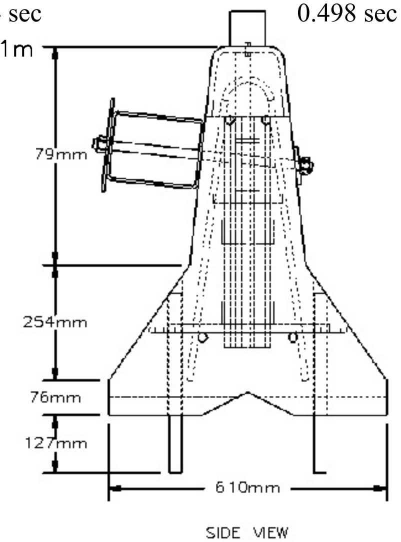
10.5 Occupant Risk Values

The occupant impact velocities and the occupant ridedown decelerations were calculated from both the DTS and the EDR-3. From the DTS, the longitudinal and lateral occupant impact velocities were determined to be -4.77 m/s (-15.64 ft/s) and 6.06 m/s (19.88 ft/s), respectively. From the EDR-3 data, the longitudinal and lateral occupant impact velocities were determined to be -5.32 m/s (-17.44 ft/s) and 6.86 m/s (22.50 ft/s), respectively. The maximum 0.010-sec average occupant ridedown decelerations in the longitudinal and lateral directions were -7.15 g’s and 6.64 g’s, respectively, as determined by the DTS data. The maximum 0.010-sec average occupant ridedown decelerations in the longitudinal and lateral directions were -7.85 g’s and 5.83 g’s, respectively, as determined from the EDR-3 data. It is noted that the occupant impact velocities (OIV) and the occupant ridedown decelerations (ORD) were within the suggested limits provided in currently proposed Update to NCHRP Report No. 350. The THIV and PHD values were determined to be 7.25 m/s (23.77 ft/s) and 7.93 g’s, respectively. The results of the occupant risk, as determined from the accelerometer data, are summarized in Figure 70. Results are shown graphically in Appendix H. Results from the rate transducer are shown graphically in Appendix H.

10.6 Discussion

The analysis of the test results for test no. NYTCB-3 showed that the stiffened temporary concrete barrier system with anchored ends adequately contained and redirected the 2270P vehicle with controlled lateral displacements of the barrier system. There were no detached elements nor fragments which showed potential for penetrating the occupant compartment nor presented undue hazard to other traffic. Deformations of, or intrusion into, the occupant compartment that could have caused serious injury did not occur. The test vehicle did not penetrate nor ride over the box beam stiffened temporary concrete barrier system and remained upright during and after the collision. Vehicle roll, pitch, and yaw angular displacements were noted, but they were deemed acceptable because they did not adversely influence occupant risk safety criteria nor cause rollover. After collision, the vehicle's trajectory revealed minimum intrusion into adjacent traffic lanes. In addition, the vehicle exited the barrier within the exit box. Therefore, test no. NYTCB-3 conducted on the stiffened temporary concrete barrier system with anchored ends was determined to be acceptable according to the TL-3 safety performance criteria of test designation no. 3-11 found in the currently proposed Update to NCHRP Report No. 350.

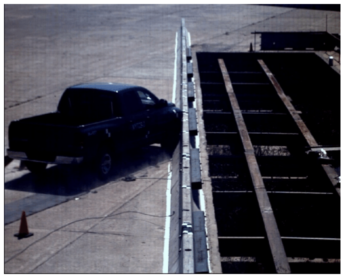




- Test Agency . . . . MwRSF
- Test Number NYTCB-3
- Date 8/30/07
- NCHRP 350 Update Test Designation 3-11
- Appurtenance . . . . Stiffened Temporary Concrete Barriers
- Total Length . . . . 60.96 m
- Barrier Offset . . . . 305 mm
- Key Elements - Barrier
  - Description . . . . New York TCB with Connection Keys
  - Length . . . . 6,096 mm
  - Base Width . . . . 610 mm
  - Height . . . . 810 mm
- Key Elements - Anchor Ends
  - Size . . . . 25 mm ASTM A36 rod
  - Length . . . . 394 mm
  - Number per Barrier . . . . 5 traffic-side, 4 back-side
- Key Elements - Box Beam Stiffener
  - Dimensions . . . . 152 mm x 203 mm x 6.4 mm
  - Length . . . . 3,658 mm
  - Connector Rod . . . . 19 mm diameter x 483 mm long Grade 5
- Type of Soil . . . . N/A
- Test Vehicle
  - Type/Designation 2270P
  - Make and Model . . . . 2003 Dodge Ram 1500 Quad Cab 4x2
  - Curb . . . . 2,303 kg
  - Test Inertial . . . . 2,268 kg
  - Gross Static . . . . 2,268 kg
- Impact Conditions
  - Speed . . . . 102.2 km/h
  - Angle . . . . 24.4 degrees
  - Impact Location . . . . 1,300 mm upstream from downstream end of barrier no. 4
- Exit Conditions
  - Speed . . . . 87.2 km/h
  - Angle . . . . 1.7 degrees
  - Exit Box Criterion . . . . Pass
- Post-Impact Trajectory
  - Vehicle Stability . . . . Satisfactory
  - Stopping Distance . . . . 57.69 m downstream
3.81 m laterally behind
- Occupant Impact Velocity (DTS)
  - Longitudinal . . . . -4.77 m/s < 12.2 m/s
  - Lateral . . . . 6.06 m/s < 12.2 m/s
- Occupant Ridedown Deceleration (DTS)
  - Longitudinal . . . . -7.15 g's < 20.49 g's
  - Lateral . . . . 6.64 g's < 20.49 g's
- Occupant Impact Velocity (EDR-3)
  - Longitudinal . . . . -5.32 m/s < 12.2 m/s
  - Lateral . . . . 6.86 m/s < 12.2 m/s
- Occupant Ridedown Deceleration (EDR-3)
  - Longitudinal . . . . -7.85 g's < 20.49 g's
  - Lateral . . . . 5.83 g's < 20.49 g's
- THIV (not required) . . . . 7.25 m/s
- PHD (not required) . . . . 7.93 g's
- Test Article Damage . . . . Moderate
- Test Article Deflections
  - Permanent Set . . . . 660 mm
  - Dynamic . . . . 784 mm
  - Working Width . . . . 1,304 mm
- Vehicle Damage . . . . Moderate
  - VDS[13] 1-RFQ-3
  - CDC[14] 1-RYEN2
  - Maximum Deformation . . . . 89 mm
- Angular Displacements
  - Roll . . . . -18.2 deg
  - Pitch . . . . 9.7 deg
  - Yaw . . . . -27.5 deg

Figure 70. Summary of Test Results and Sequential Photographs, Test NYTCB-3

Figure 71. Additional Sequential Photographs, Test NYTCB-3



0.000 sec

0.056 sec

0.128 sec

0.252 sec

0.398 sec

0.518 sec

0.784 sec

1.100 sec

1.374 sec

1.860 sec

Figure 72. Additional Sequential Photographs, Test NYTCB-3

0.000 sec

0.000 sec

0.118 sec

0.033 sec

0.198 sec

0.200 sec

0.258 sec

0.467 sec

0.362 sec

0.834 sec

Figure 73. Additional Sequential Photographs, Test NYTCB-3

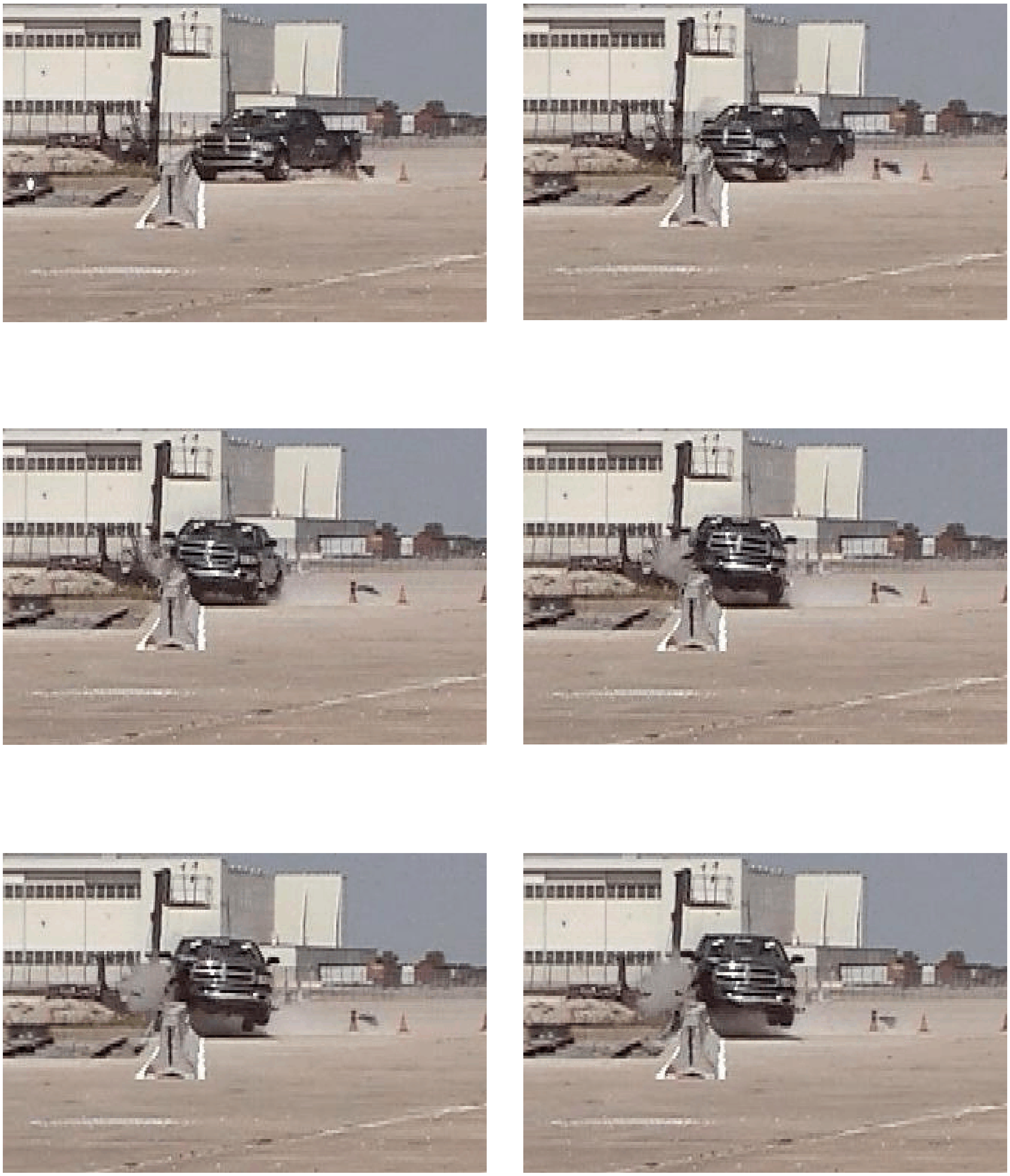


Figure 74. Documentary Photographs, Test NYTCB-3

Figure 75. Documentary Photographs, Test NYTCB-3

Figure 76. Impact Location, Test NYTCB-3

Figure 77. Vehicle Final Position and Trajectory Marks, Test NYTCB-3

Figure 78. Box Beam Stiffened Temporary Barrier Damage, Test NYTCB-3

Figure 79. Box Beam Stiffened Temporary Barrier Damage, Test NYTCB-3

Figure 80. Box Beam Stiffened Temporary Barrier Damage, Test NYTCB-3

Figure 81. Box Beam Stiffened Temporary Barrier Damage, Test NYTCB-3

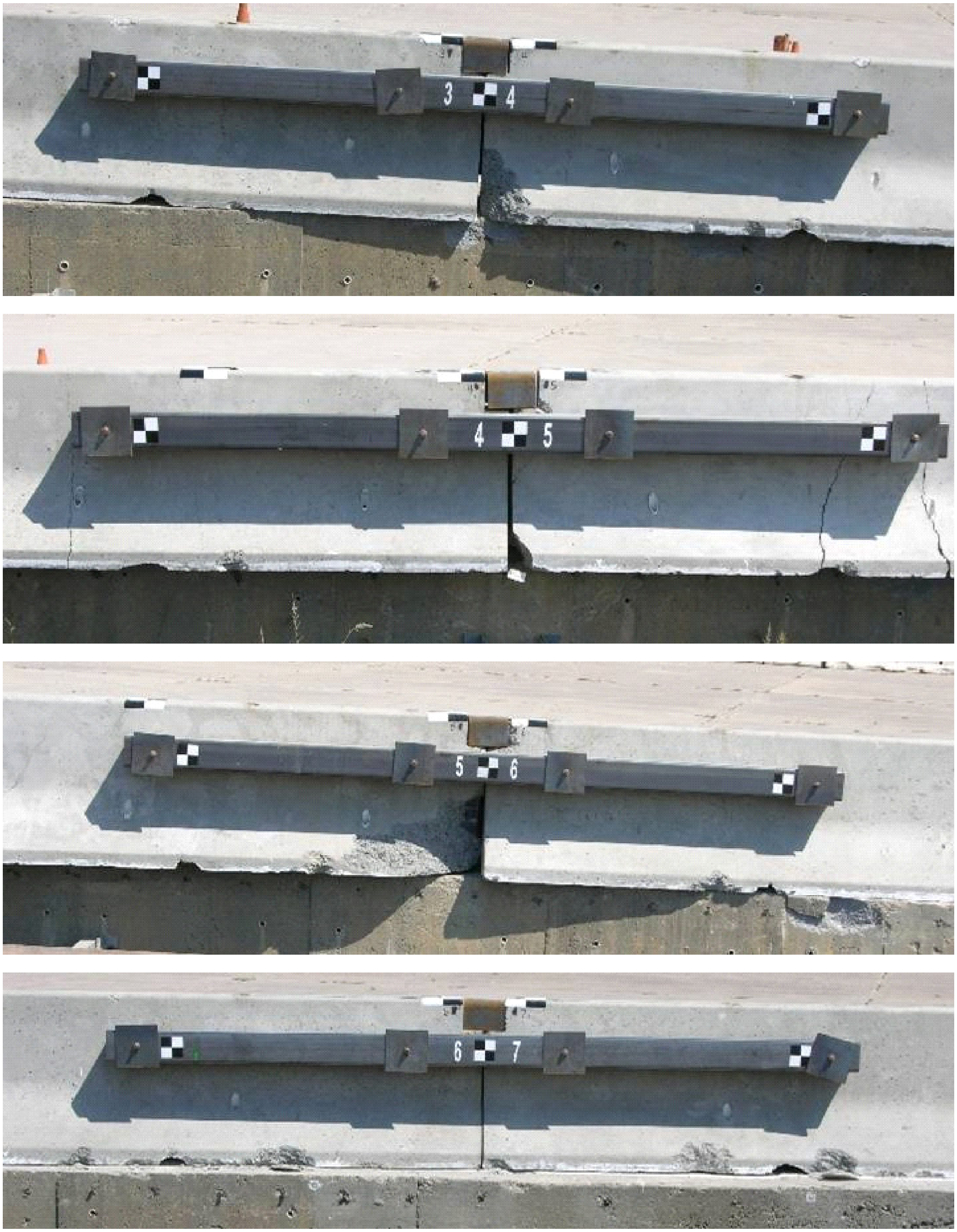


Figure 82. Joint Damage, Test NYTCB-3

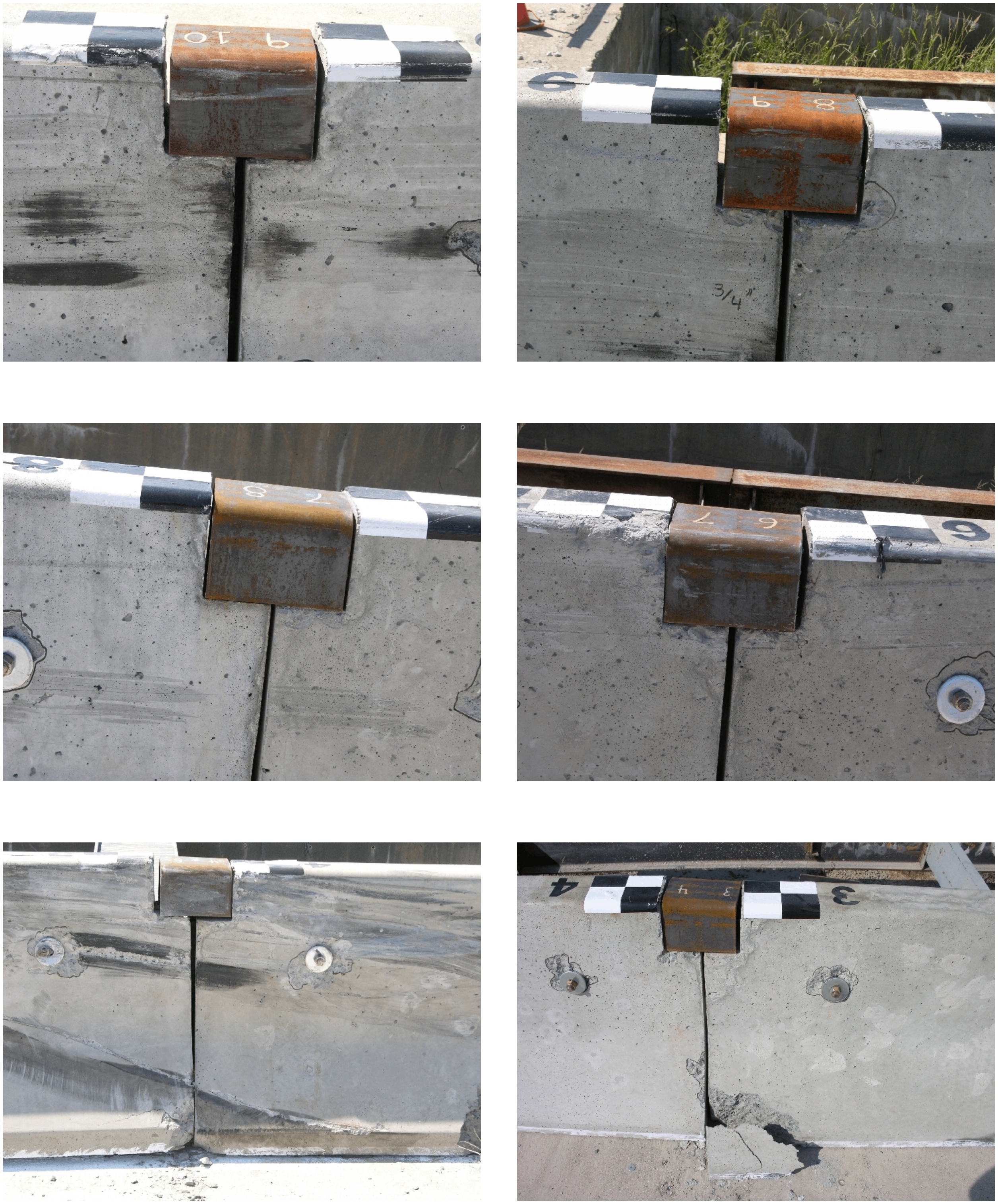


Figure 83. Joint Connection Damage, Test NYTCB-3

Figure 84. Connector Rod Damage, Test NYTCB-3

Figure 85. Vehicle Damage, Test NYTCB-3

Figure 86. Additional Vehicle Damage, Test NYTCB-3

Figure 87. Occupant Compartment Deformation, Test NYTCB-3

11 SUMMARY, CONCLUSIONS, AND DISCUSSION

This study set out to evaluate the potential for reducing barrier deflections through the use of box beam stiffening on an acceptable NYSDOT TCB design. In addition, all safety performance evaluations were to be performed using the criteria found in the currently proposed Update to NCHRP Report No. 350. The systems were constructed with ten 6,096-mm (20-ft) long, temporary concrete barrier sections utilizing a connection key between the barrier sections and with the first and last sections anchored to the tarmac and subjected to full-scale vehicle crash testing. Three full-scale crash tests were performed on the various temporary barrier systems. A summary of the safety performance evaluation of each of the three tests is provided in Table 3.

The first full-scale crash test, test no. NYTCB-1, was performed on a stiffened version of the temporary concrete barrier system according to test designation 3-11 of the currently proposed Update to NCHRP Report No. 350. This system consisted of 3,658-mm (12-ft) long, box beam stiffeners spanning each joint between barrier nos. 4 and 7. The box beam sections were configured with 152-mm x 152-mm x 4.8-mm (6-in. x 6-in. x 0.1875-in.) steel tubes. The first and last barrier sections were anchored into the concrete. The test consisted of a 2,275-kg (5,016-lb) pickup truck impacting the barrier system at a speed of 99.5 km/h (61.9 mph) and at an angle of 24.6 degrees, resulting in an impact severity of 151.01 kJ (111.34 kip-ft). The impact point for this test was 1.3 m (4 ft - 3 3/16 in.) upstream from the downstream end of barrier no. 4. The maximum permanent set and dynamic deflections were 660 mm (26 in.) and 700 mm (27.6 in.), respectively. The test results were found to meet all of the currently proposed Update to NCHRP Report No. 350 safety requirements as the pickup truck was safely redirected and brought to a controlled stop.

The second full-scale crash test, test no. NYTCB-2, was performed on an unstiffened version of the temporary concrete barrier system according to test designation 3-11 of the currently proposed

Update to NCHRP Report No. 350. This system consisted of free-standing temporary concrete barriers with the first and last barrier sections anchored to the concrete. The test consisted of a 2,279-kg (5,024-lb) pickup truck impacting the barrier system at a speed of 98.5 km/h (61.2 mph) and at an angle of 25.8 degrees, resulting in an impact severity of 161.62 kJ (119.16 kip-ft). The impact point for this test was 1.3 m (4 ft - 3 3/16 in.) upstream from the downstream end of barrier no. 4. The maximum permanent set and dynamic deflections were 1,003 mm (39.5 in.) and 1,023 mm (40.3 in.), respectively. The test results were found to meet all of the currently proposed Update to NCHRP Report No. 350 safety requirements as the pickup truck was safely redirected and brought to a controlled stop.

The third full-scale crash test, test no. NYTCB-3, was performed on a stiffened version of the temporary concrete barrier system according to test designation 3-11 of the currently proposed Update to NCHRP Report No. 350. This system consisted of 3,658-mm (12-ft) long, box beam stiffeners spanning each joint between barrier nos. 2 and 8. The box beam sections were configured with 152-mm x 203-mm x 6.4-mm (6-in. x 8-in. x 0.25-in.) steel tubes. In addition, the system was installed with the back side of the barriers placed 305 mm (12 in.) from the edge of a bridge deck. The first and last barrier sections were anchored to the concrete. The test consisted of a 2,268-kg (5,001-lb) pickup truck impacting the barrier system at a speed of 102.2 km/h (63.5 mph) and at an angle of 24.4 degrees, resulting in an impact severity of 156.03 kJ (115.04 kip-ft). The impact point for this test was 1.3 m (4 ft - 3 3/16 in.) upstream from the downstream end of barrier no. 4. The maximum permanent set and dynamic deflections were 660 mm (26 in.) and 784 mm (30.9 in.), respectively. The test results were found to meet all of the currently proposed Update to NCHRP Report No. 350 safety requirements as the pickup truck was safely redirected and brought to a controlled stop.

Following a review of the test results, it was evident that all three crash tests were performed with approximately the same impact severity (I.S.) when considering the combined effect of vehicle mass, impact speed, and impact angle. In summary, the impact severities were 151.01 kJ (111.34 kip-ft), 161.62 kJ (119.16 kip-ft), and 156.03 kJ (115.04 kip-ft) for test nos. NYTCB-1, NYTCB-2, and NYTCB-3, respectively. The maximum dynamic deflections observed during test nos. NYTCB-1, NYTCB-2, and NYTCB-3 were 700 mm (27.6 in.), 1,023 mm (40.3 in.), and 784 mm (30.9 in.), respectively.

Upon examination of the I.S. values and maximum dynamic deflections, it was evident that the box beam stiffening system was effective in reducing barrier deflections. In general, the box beam system reduced dynamic deflections from 23 to 32 percent over those observed for the non-stiffened TCB. Two sizes of box beam rails were evaluated. Unfortunately, the two rail sizes were implemented in tests that were not directly comparable. The smaller tube size was installed on a barrier system supported by a wide concrete foundation (test no. NYTCB-1), while the larger tube size was installed on a barrier system adjacent to a vertical drop off (test no. NYTCB-3). Even though larger barrier deflections were observed in test no. NYTCB-3 as compared to NYTCB-1, the larger tube size likely contributed to reduced barrier deflections, especially since several barrier sections had lost partial contact with the concrete foundation as their bases had moved past the deck edge.

As noted previously, the free-standing temporary concrete barrier system, with end sections pinned on each end, was impacted in test no. NYTCB-2 and resulted in permanent set and dynamic deflections of 1,003 mm (39.5 in.) and 1,023 mm (40.3 in.), respectively. On the contrary, TTI test no. 473220-14 was performed on a similar barrier system, but without the end sections pinned, thus resulting in permanent set and dynamic deflections of 1,270 mm (50.0 in.) and 1,270 mm (50.0 in.), respectively. The impact severities for test nos. NYTCB-2 and 473220-14 were 161.62 kJ (119.16 kip-ft) and 151.83 kJ (111.94 kip-ft). Since test no. NYTCB-2 was slightly more severe than test no. 473220-14, it was clear that pinning the end barrier sections decreased deflections by nearly 20 percent.

At this time, it is not believed to be highly beneficial to use stronger stiffening elements than those used in test no. NYTCB-3 and placed across the joints of the barrier sections. This opinion is based upon the fact that significant flexibility remains within the barrier section itself. It should be noted that the barrier performed well but was likely near its ultimate strength as significant cracking and bending was observed in several barrier sections. If desirable, modest increases in steel reinforcement could reduce damage and barrier flexing during extreme impact events. At the ends of several barrier sections and in all tests, the toe regions of the sections fractured with significant loss of concrete, thus reducing the moment capacity of the joints under loading and during barrier translation and rotation. If the toe regions were to have remained intact during the impact event, lower deformations to the box beam rails would likely have resulted. Once again, modest increases in steel reinforcement at the section ends and in the toes should provide increased moment capacity at the joints, thus resulting in an increased propensity for further reducing barrier deflections.

If additional steel reinforcement is implemented in the barrier sections, there would likely be greater benefit from implementing the larger box sections to stiffen the barrier system.

Table 3. Summary of Safety Performance Evaluation Results

Evaluation Factors	Evaluation Criteria	Test NYTCB-1	Test NYTCB-2	Test NYTCB-3
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.	S	S	S
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. Deformations of, or intrusions into, the occupant compartment should not exceed limits set forth in Section 5.3 and Appendix E of the currently proposed Update to NCHRP Report No. 350.	S	S	S
	F. The vehicle should remain upright during and after collision. The maximum roll and pitch angles are not to exceed 75 degrees.	S	S	S
	H. Longitudinal and lateral occupant impact velocities should fall below the preferred value of 9.1 m/s (30.0 ft/s), or at least below the maximum allowable value of 12.2 m/s (40.0 ft/s).	S	S	S
	I. Longitudinal and lateral occupant ridedown accelerations should fall below the preferred value of 15.0 g's, or at least below the maximum allowable value of 20.49 g's.	S	S	S
Vehicle Trajectory	M. After impact, the vehicle shall exit the barrier within the exit box.	S	S	S

S - Satisfactory
U - Unsatisfactory
NA - Not Available

12 RECOMMENDATIONS

Stiffened and unstiffened versions of the New York State DOT's temporary concrete barrier system with anchored ends, as described in this report, were successfully crash tested according to the criteria found in the currently proposed Update to NCHRP Report No. 350. The test results indicate that these designs are suitable for use on Federal-aid highways. However, any significant modifications made to the stiffened and unstiffened designs would require additional analysis and can only be verified through the use of full-scale crash testing.

The second stiffened system was tested with a clear gap of 305 mm (12 in.) between the back side of the barriers and the bridge deck edge. As observed in test no. NYTCB-3, the center of gravity of one barrier section was shoved beyond the edge of the bridge deck. However, its connection to the other sections prevented it from falling off. Thus, the stiffened versions of New York State's temporary concrete barrier system are recommended for use over the normal range of accidents involving vehicles of 2,268 kg (5,000 lbs) or less. In addition, the stiffened TCB can be placed with a 305 mm (12 in.) gap between the bridge deck edge and the back side of the barrier sections.

13 REFERENCES

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14 APPENDICES

APPENDIX A

English-Unit System Drawings, Test NYTCB-1

Figure A-1. Stiffened Temporary Concrete Barrier System Layout (English), Test NYTCB-1

Figure A-2. Temporary Concrete Barrier Details (English), Test NYTCB-1

Figure A-3. Temporary Concrete Barrier Reinforcement Details (English), Test NYTCB-1

Figure A-4. Bill of Bars (English), Test NYTCB-1

Figure A-5. Temporary Concrete Barrier Connection Details (English), Test NYTCB-1

Figure A-6. Connection Key Assembly Details (English), Test NYTCB-1

Figure A-7. Connection Key Assembly Details (English), Test NYTCB-1

Figure A-8. Temporary Concrete Barrier Connector Assembly Details (English), Test NYTCB-1

Figure A-9. Box Beam Stiffener Details (English), Test NYTCB-1

Figure A-10. Temporary Concrete Barrier Stiffener Hole Details (English), Test NYTCB-1

Figure A-11. Box Beam Stiffener Details (English), Test NYTCB-1

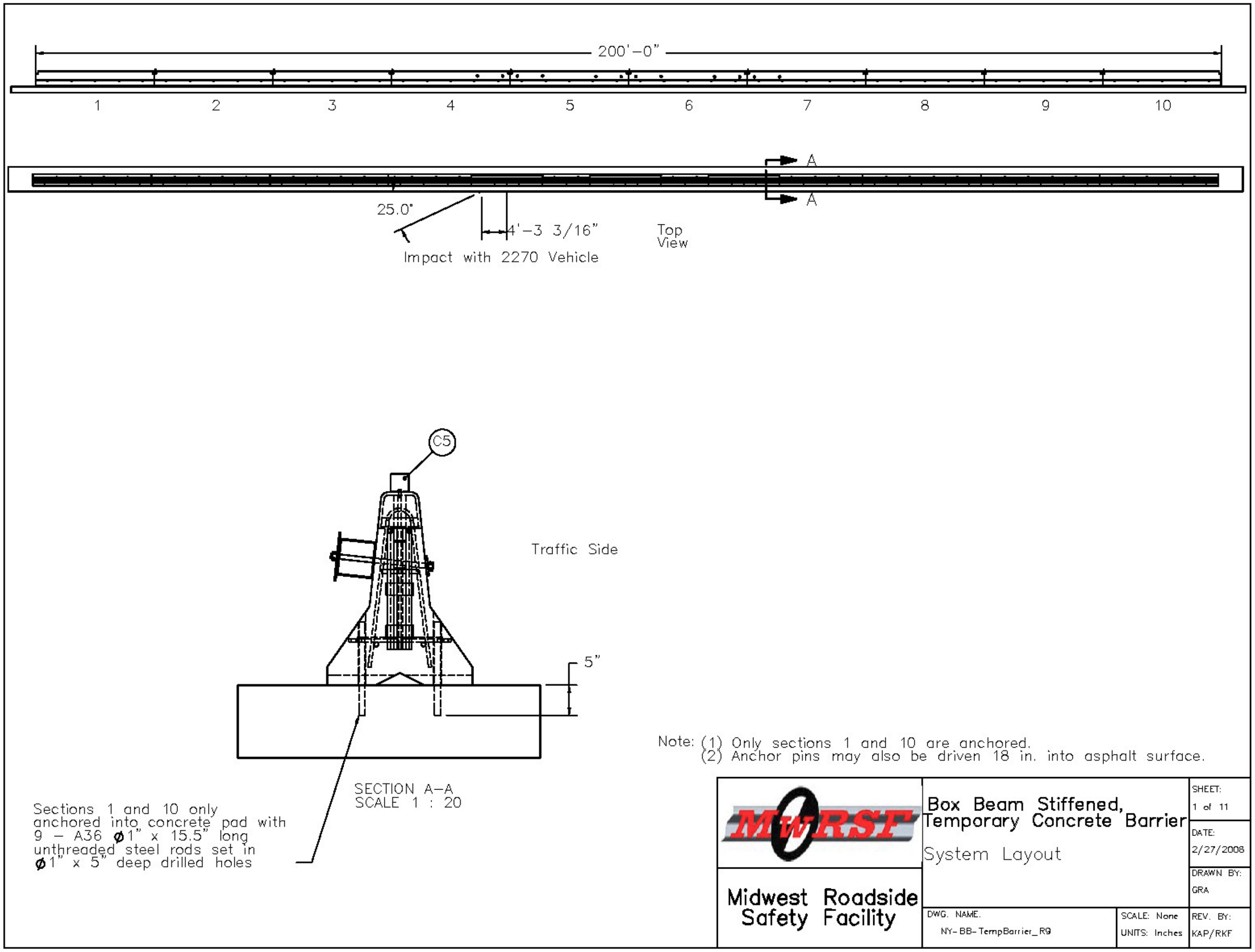


Figure A-1. Stiffened Temporary Concrete Barrier System Layout (English), Test NYTCB-1

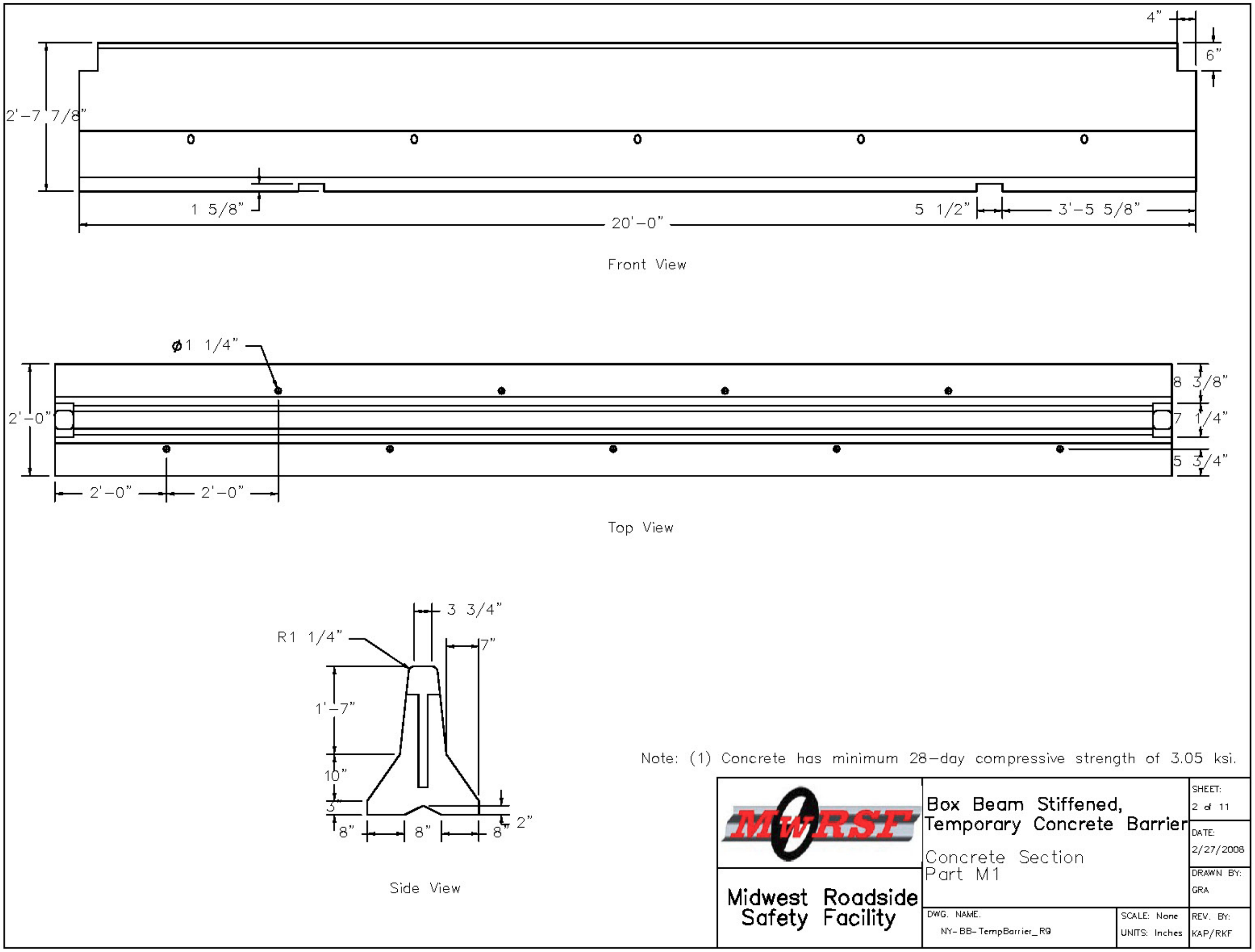


Figure A-2. Temporary Concrete Barrier Details (English), Test NYTCB-1

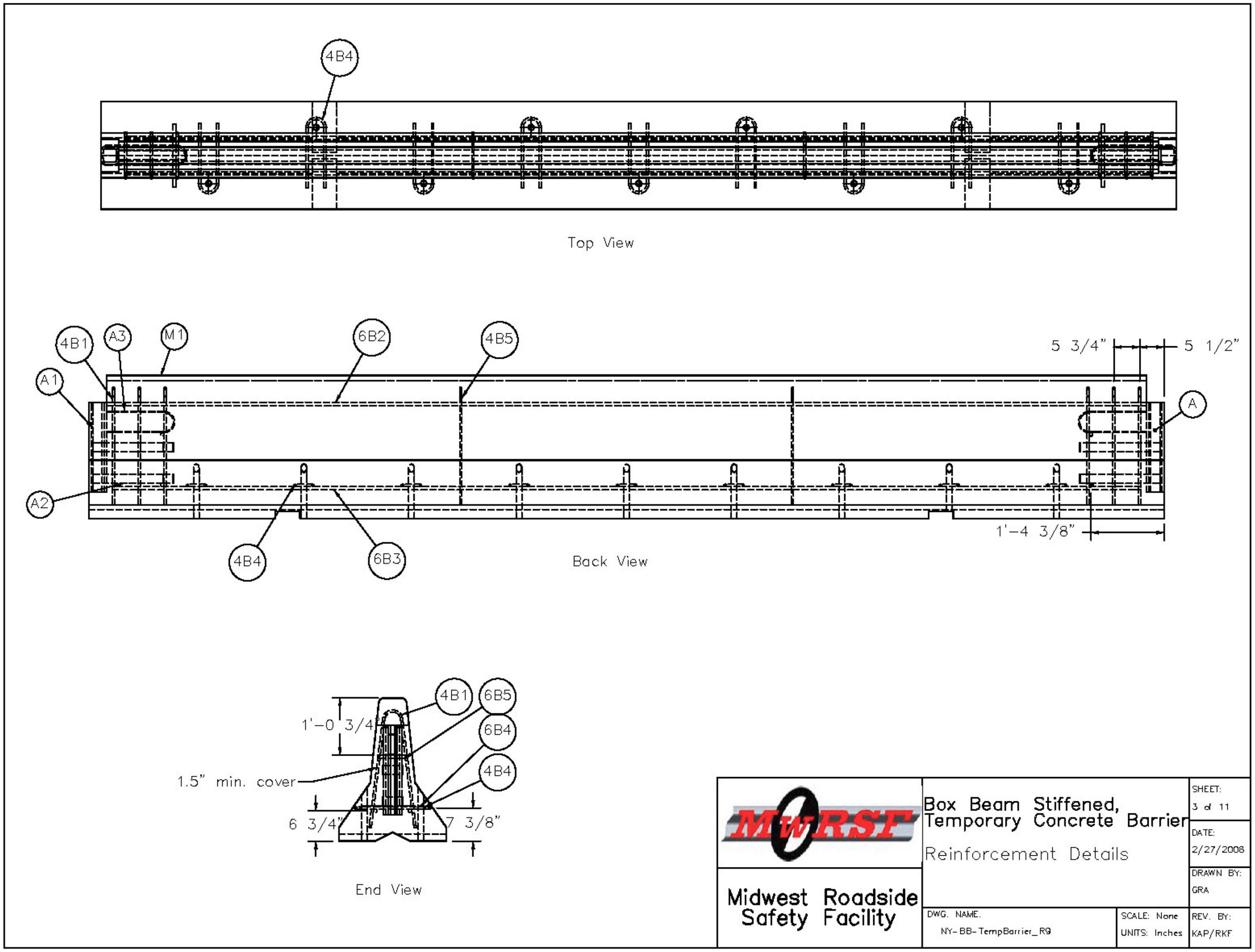
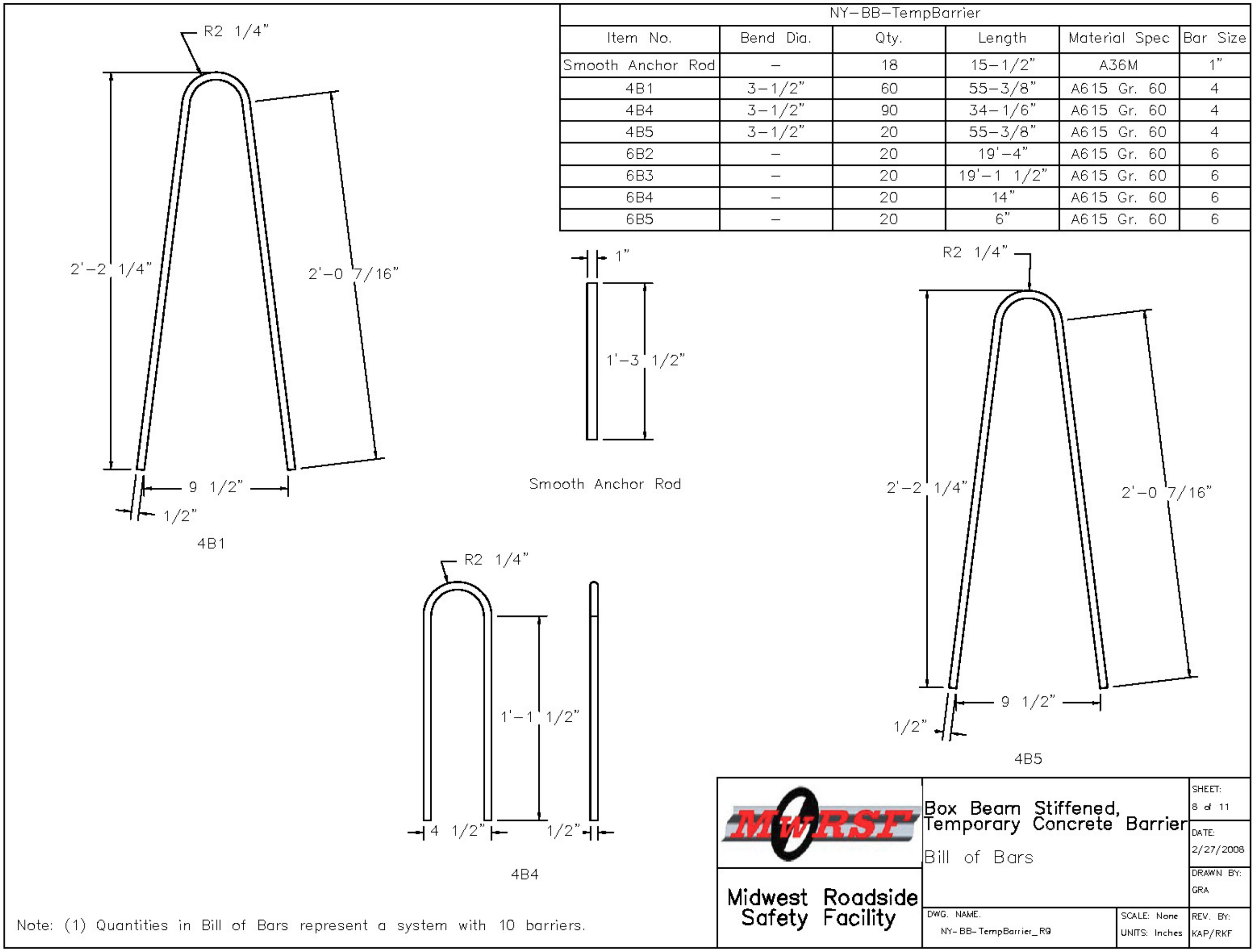


Figure A-3. Temporary Concrete Barrier Reinforcement Details (English), Test NYTCB-1



NY-BB-TempBarrier

Item No.	Bend Dia.	Qty.	Length	Material Spec	Bar Size
Smooth Anchor Rod	–	18	15-1/2"	A36M	1"
4B1	3-1/2"	60	55-3/8"	A615 Gr. 60	4
4B4	3-1/2"	90	34-1/6"	A615 Gr. 60	4
4B5	3-1/2"	20	55-3/8"	A615 Gr. 60	4
6B2	–	20	19'-4"	A615 Gr. 60	6
6B3	–	20	19'-1 1/2"	A615 Gr. 60	6
6B4	–	20	14"	A615 Gr. 60	6
6B5	–	20	6"	A615 Gr. 60	6

Figure A-4. Bill of Bars (English), Test NYTCB-1

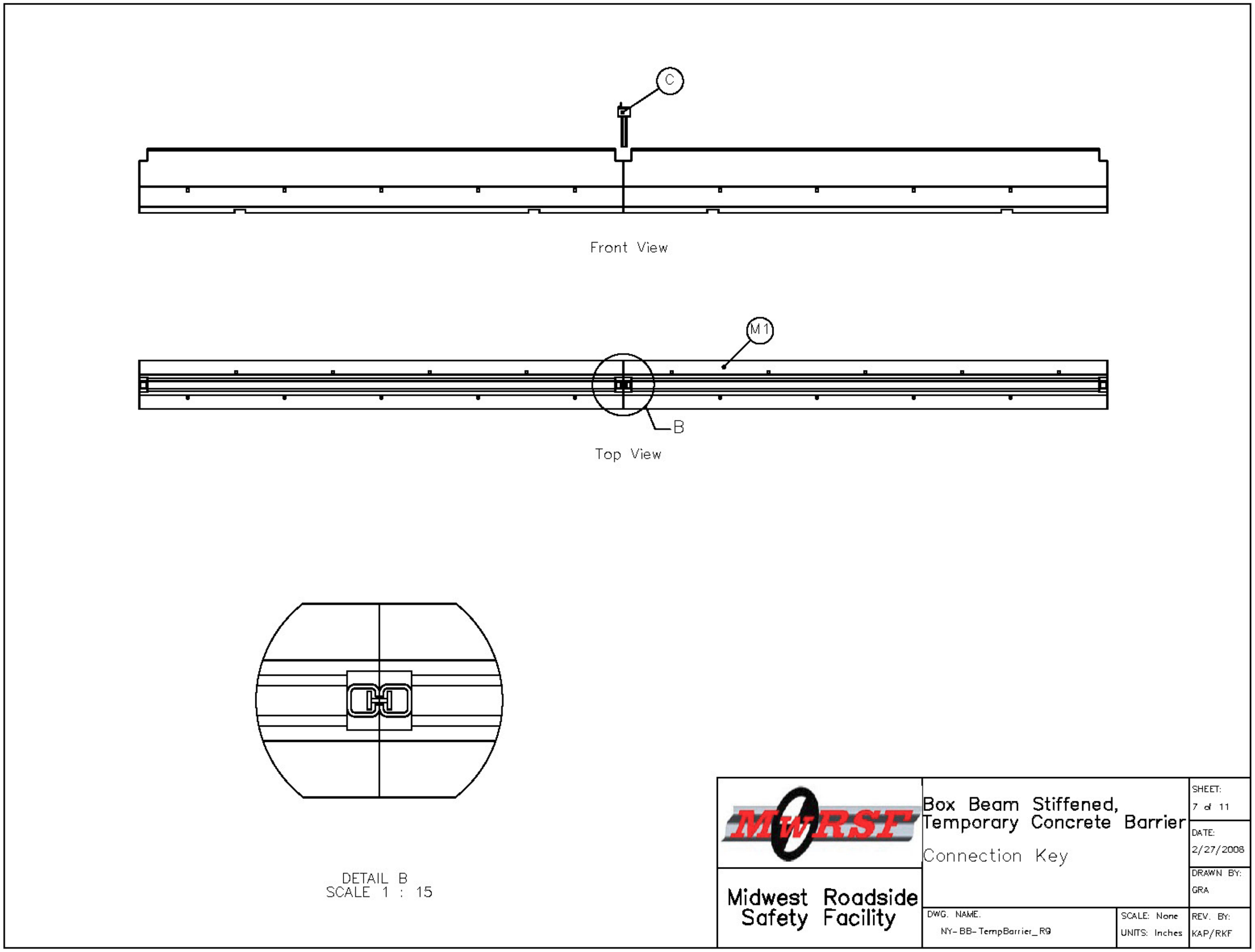


Figure A-5. Temporary Concrete Barrier Connection Details (English), Test NYTCB-1

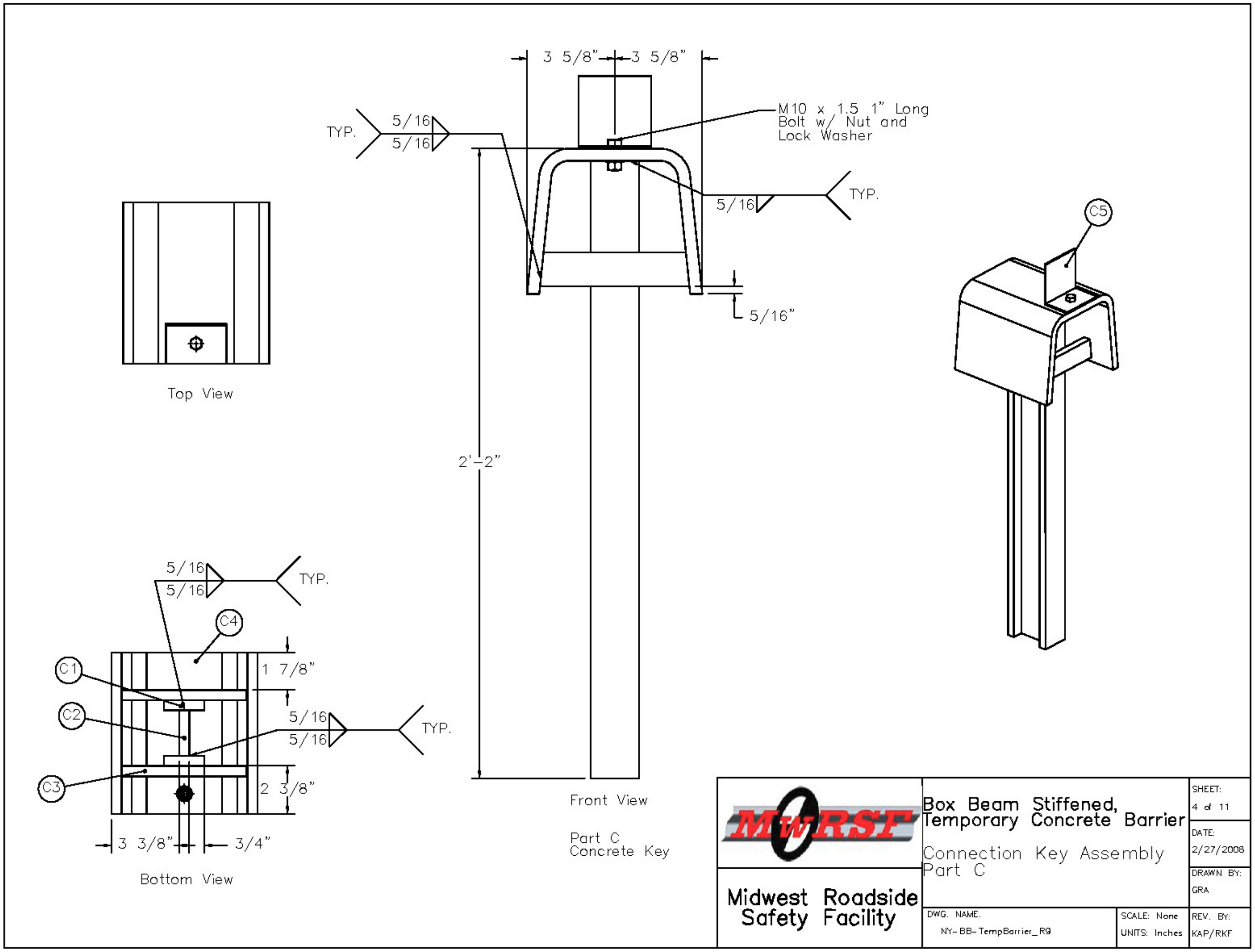


Figure A-6. Connection Key Assembly Details (English), Test NYTCB-1

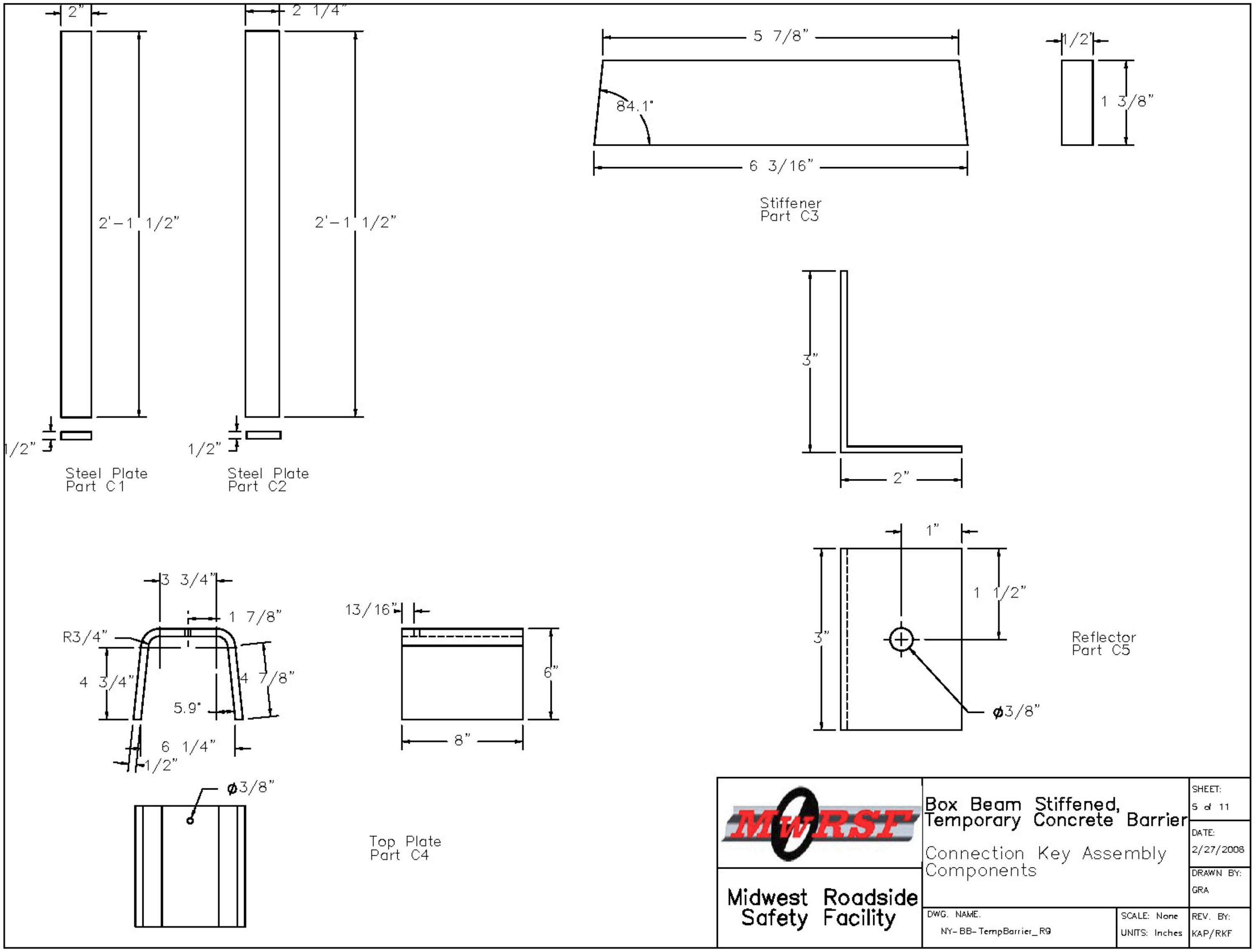


Figure A-7. Connection Key Assembly Details (English), NYTCB-1

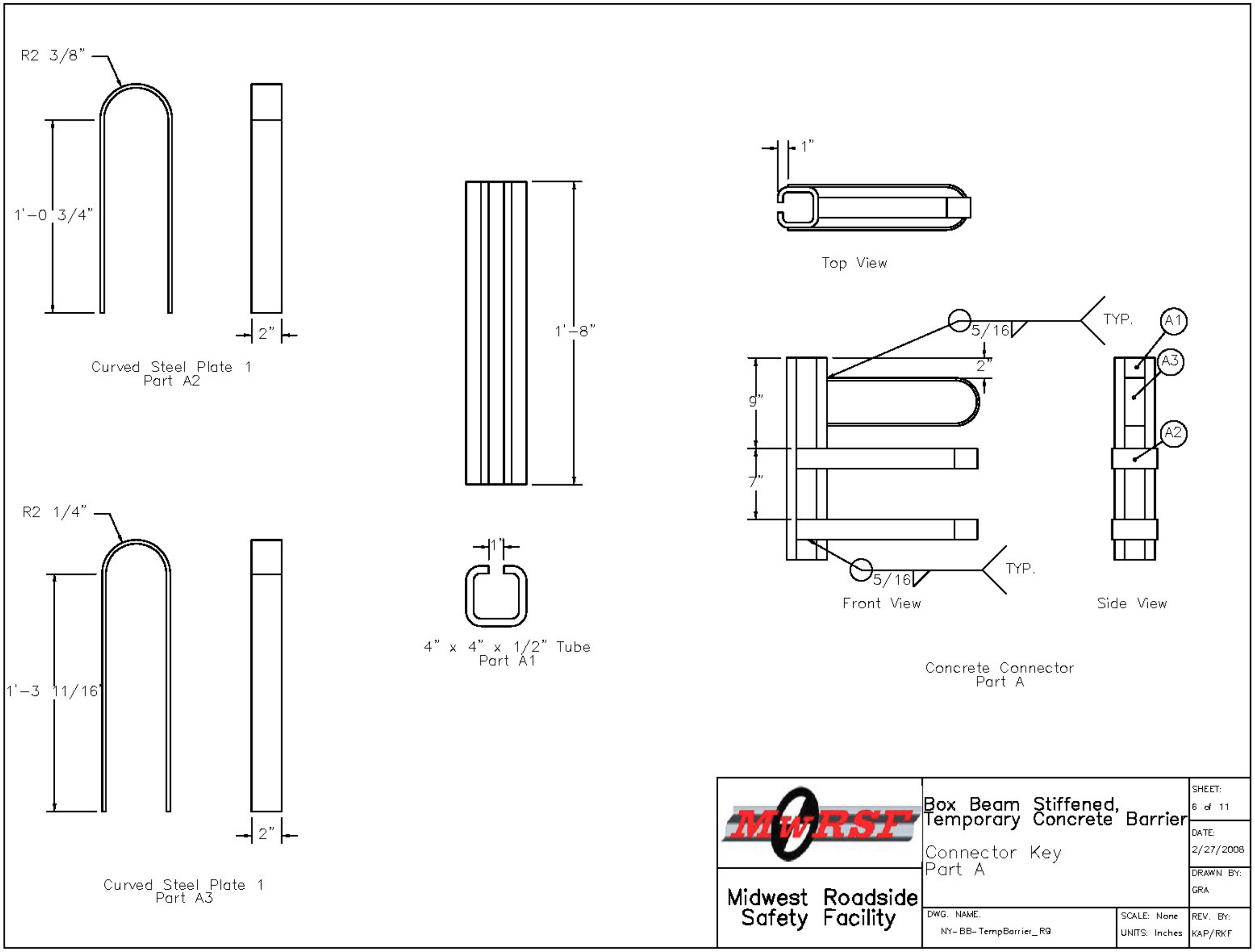


Figure A-8. Temporary Concrete Barrier Connector Assembly Details (English), Test NYTCB-1

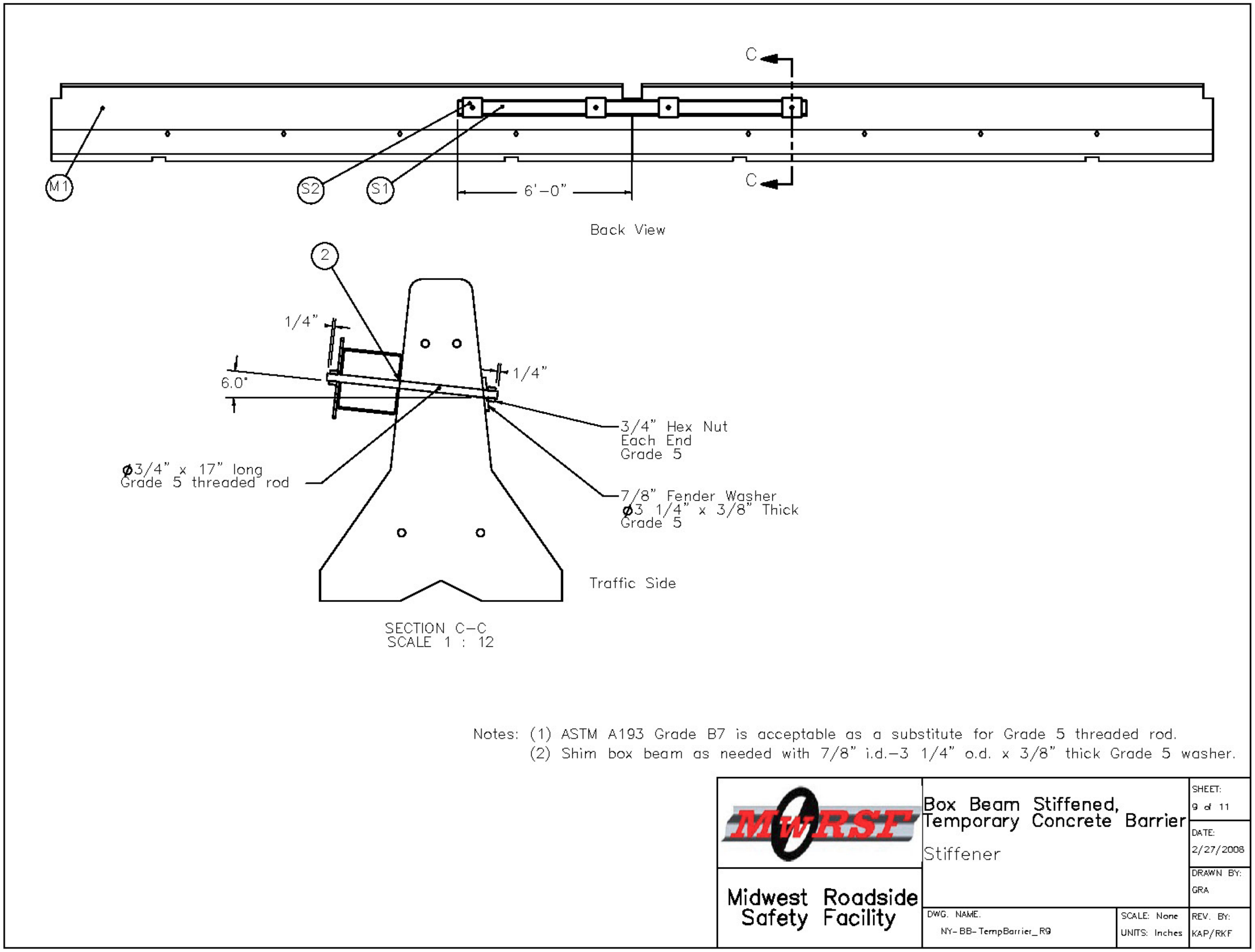


Figure A-9. Box Beam Stiffener Details (English), Test NYTCB-1

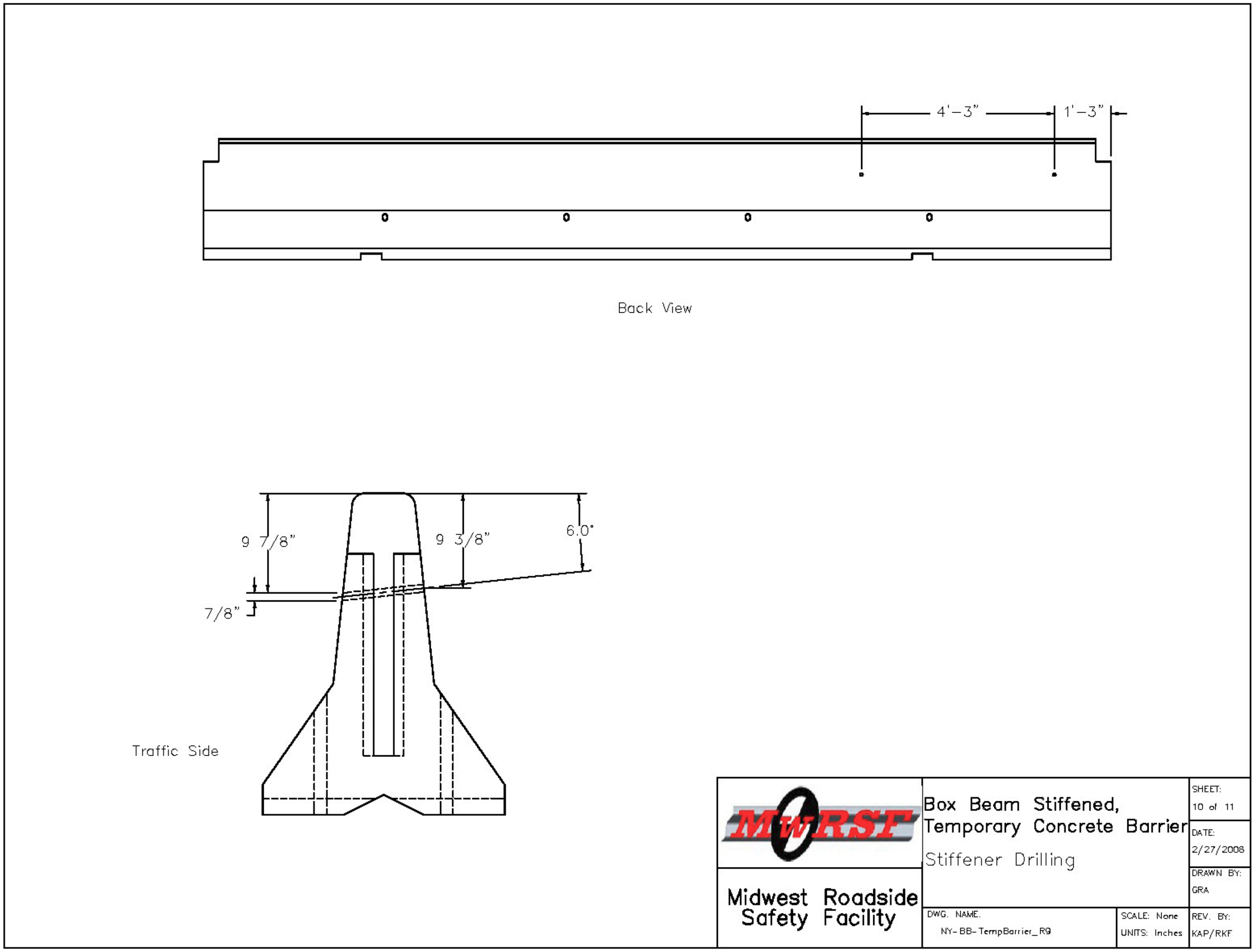


Figure A-10. Temporary Concrete Barrier Stiffener Hole Details (English), Test NYTCB-1

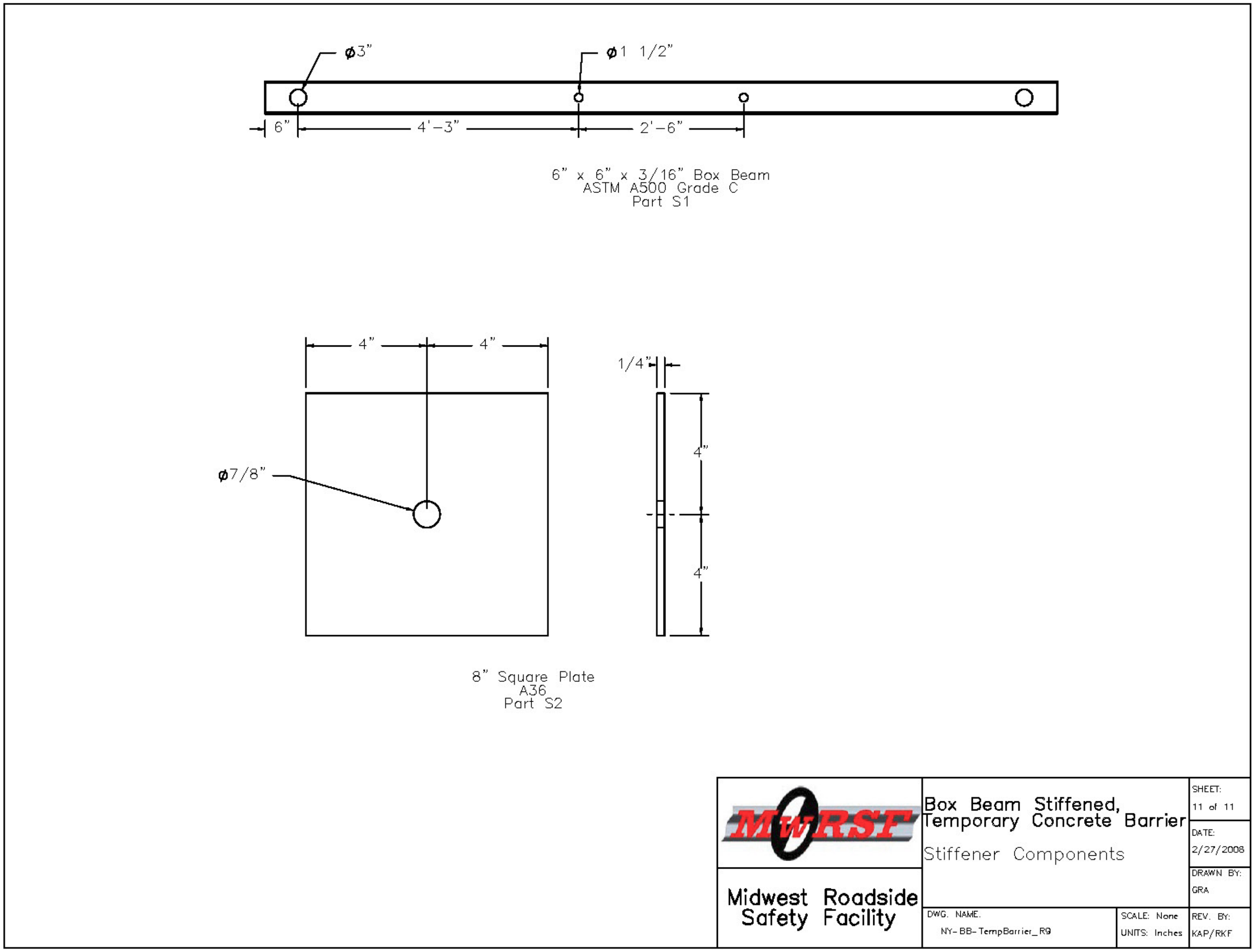


Figure A-11. Box Beam Stiffener Details (English), Test NYTCB-1

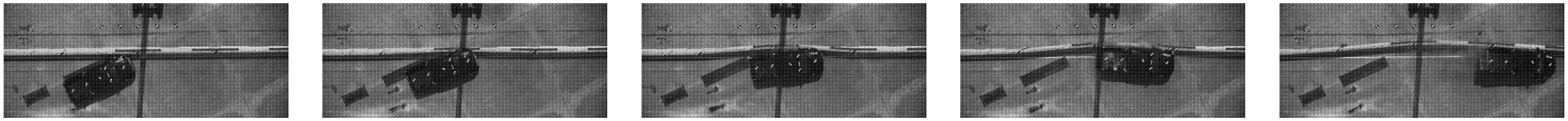
APPENDIX B

Test Summary Sheets in English Units

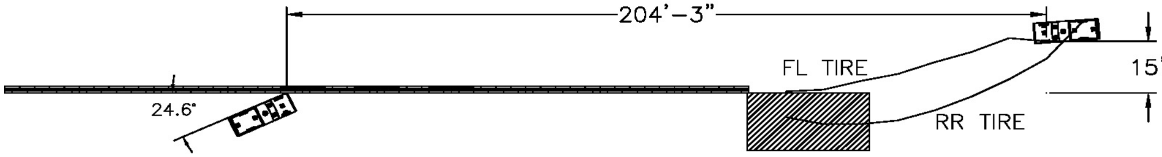
Figure B-1. Summary of Test Results and Sequential Photographs (English), Test NYTCB-1

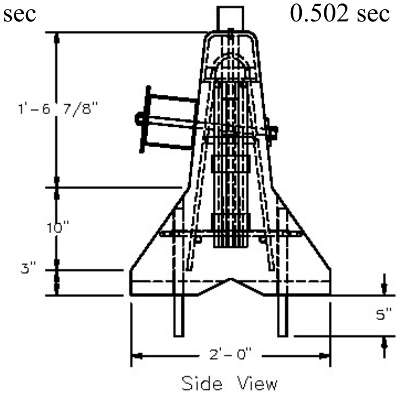
Figure B-2. Summary of Test Results and Sequential Photographs (English), Test NYTCB-2

Figure B-3. Summary of Test Results and Sequential Photographs (English), Test NYTCB-3



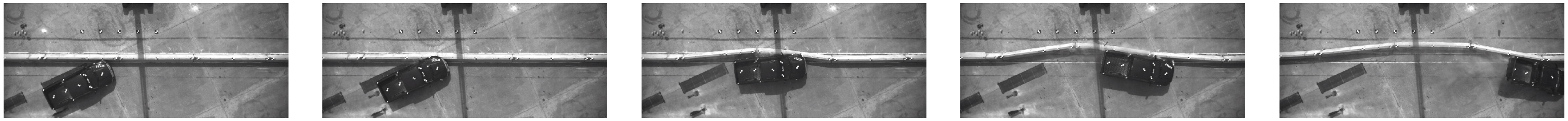
0.000 sec 0.080 sec 0.168 sec 0.276 sec 0.502 sec



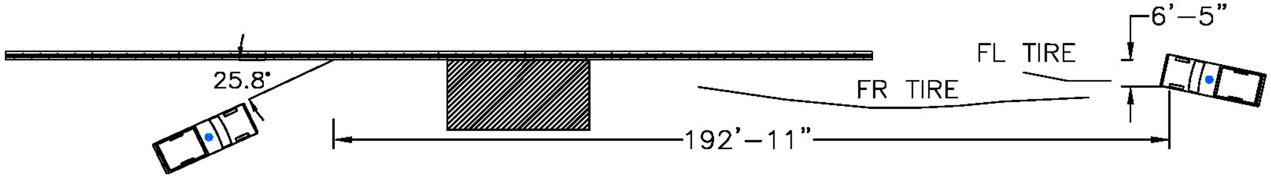


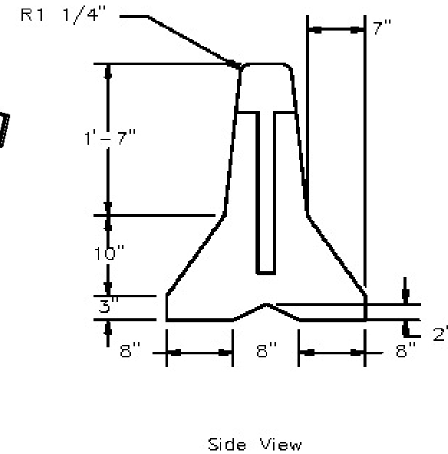
- Test Agency .... MwRSF
- Test Number NYTCB-1
- Date 7/24/07
- NCHRP 350 Update Test Designation 3-11
- Appurtenance .... Stiffened Temporary Concrete Barriers
- Total Length .... 200 ft
- Key Elements - Barrier
  - Description .... New York TCB with Connection Keys
  - Length .... 20 ft
  - Base Width .... 24 in.
  - Height .... 32 in.
- Key Elements - Anchor Ends
  - Size .... 1 in. diameter ASTM A36 rod
  - Length .... 15.5 in.
  - Number per Barrier .... 5 traffic-side, 4 back-side
- Key Elements - Box Beam Stiffener
  - Size .... 6 in. x 6 in. x 0.1875 in.
  - Length .... 144 in.
  - Connector Rod .... 0.75 in. diameter x 17 in. long Grade 5
  - Plate Washer .... 8 in. x 8 in. x 0.5 in.
- Type of Soil .... N/A
- Test Vehicle
  - Type/Designation 2270P
  - Make and Model .... 2002 Dodge Ram 1500 Quad Cab 4x2
  - Curb .... 5,074 lbs
  - Test Inertial .... 5,016 lbs
  - Gross Static .... 5,016 lbs
- Impact Conditions
  - Speed .... 99.5 km/h
  - Angle .... 24.6 degrees
  - Impact Location .... 51.1875 in. upstream from downstream end of barrier 4
- Exit Conditions
  - Speed .... 39.1 mph
  - Angle .... 7 deg
  - Exit Box Criterion .... Pass
- Post-Impact Trajectory
  - Vehicle Stability .... Satisfactory
  - Stopping Distance .... 204.4 ft downstream
15.1 ft laterally behind
- Occupant Impact Velocity
  - Longitudinal .... -15.32 ft/s < 40 ft/s
  - Lateral .... 20.77 ft/s < 40 ft/s
- Occupant Ridedown Deceleration
  - Longitudinal .... 4.72 g's < 20.49 g's
  - Lateral .... 8.36 g's < 20.49 g's
- THIV (not required) .... 24.44 ft/s
- PHD (not required) .... 8.71 g's
- Test Article Damage .... Moderate
- Test Article Deflections
  - Permanent Set .... 26.0 in.
  - Dynamic .... 27.6 in.
  - Working Width .... 51.6 in.
- Vehicle Damage .... Moderate
  - VDS[13] 11-LFQ-3
  - CDC[14] 11-LYEN2
  - Maximum Deformation .... 1.5 in.
- Angular Displacements
  - Roll .... -10.5 deg
  - Pitch .... -11.4 deg
  - Yaw .... 28.0 deg

Figure B-1. Summary of Test Results and Sequential Photographs (English), Test NYTCB-1



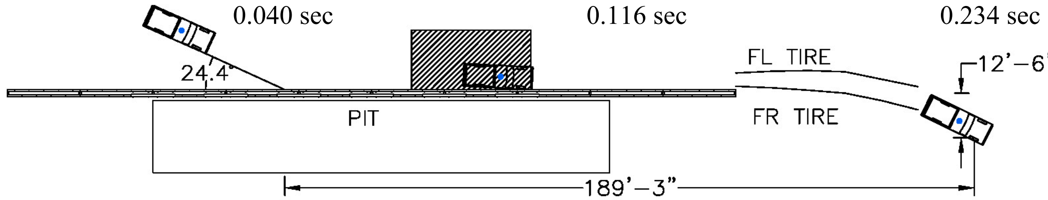
0.000 sec | 0.054 sec | 0.184 sec | 0.358 sec | 0.676 sec

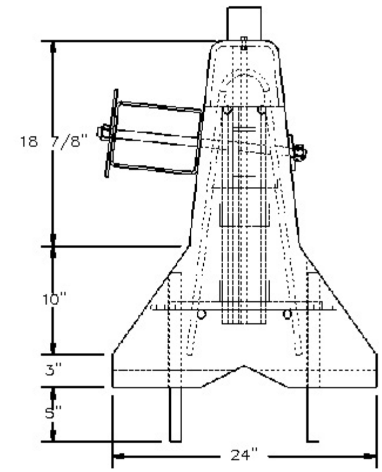




- Test Agency .... MwRSF
- Test Number NYTCB-2
- Date 7/25/07
- NCHRP 350 Update Test Designation 3-11
- Appurtenance .... Unstiffened Temporary Concrete Barriers
- Total Length .... 200 ft
- Key Elements - Barrier
  - Description .... New York TCB with Connection Keys
  - Length .... 20 ft
  - Base Width .... 24 in.
  - Height .... 32 in.
- Key Elements - Anchor Ends
  - Size .... 1 in. diameter ASTM A36 rod
  - Length .... 15.5 in.
  - Number per Barrier .... 5 traffic-side, 4 back-side
- Type of Soil .... N/A
- Test Vehicle
  - Type/Designation 2270P
  - Make and Model .... 2002 Dodge Ram 1500 Quad Cab 4x2
  - Curb .... 4,949 lbs
  - Test Inertial .... 5,024 lbs
  - Gross Static .... 5,024 lbs
- Impact Conditions
  - Speed .... 61.2 mph
  - Angle .... 25.8 degrees
  - Impact Location .... 4 ft - 3.1875 in. upstream from downstream end of barrier 4
- Exit Conditions
  - Speed .... 45.3 mph
  - Angle .... 4.7 degrees
  - Exit Box Criterion .... Pass
- Post-Impact Trajectory
  - Vehicle Stability .... Satisfactory
  - Stopping Distance .... 94.5 ft downstream, 6.4 ft laterally away
- Occupant Impact Velocity
  - Longitudinal .... -15.87 ft/s < 40 ft/s
  - Lateral .... 20.73 ft/s < 40 ft/s
- Occupant Ridedown Deceleration
  - Longitudinal .... -5.44 g's < 20.49 g's
  - Lateral .... 8.09 g's < 20.49 g's
- THIV (not required) .... 24.89 ft/s
- PHD (not required) .... 8.19 g's
- Test Article Damage .... Moderate
- Test Article Deflections
  - Permanent Set .... 39.5 in.
  - Dynamic .... 40.3 in.
  - Working Width .... 64.2 in.
- Vehicle Damage .... Moderate
  - VDS[13] 11-LFQ-3
  - CDC[14] 11-LYEN4
  - Maximum Deformation ..... 3 in.
- Angular Displacements
  - Roll .... -12.4 deg
  - Pitch .... -10.6 deg
  - Yaw .... 43.1 deg

Figure B-2. Summary of Test Results and Sequential Photographs (English), Test NYTCB-2





- Test Agency . . . . MwRSF
- Test Number NYTCB-3
- Date 8/30/07
- NCHRP 350 Update Test Designation 3-11
- Appurtenance . . . . Stiffened Temporary Concrete Barriers
- Total Length . . . . 200 ft
- Barrier Offset . . . . 12 in.
- Key Elements - Barrier
  - Description . . . . New York TCB with Connection Keys
  - Length . . . . 20 ft
  - Base Width . . . . 24 in.
  - Height . . . . 32 in.
- Key Elements - Anchor Ends
  - Size . . . . 1 in. diameter ASTM A36 rod
  - Length . . . . 15.5 in.
  - Number per Barrier . . . . 5 traffic-side, 4 back-side
- Key Elements - Box Beam Stiffener
  - Dimensions . . . . 6 in. x 8 in. x 0.25 in.
  - Length . . . . 144 in.
  - Connector Rod . . . . 0.75 in. diameter x 19 in. long Grade 5
- Type of Soil . . . . N/A
- Test Vehicle
  - Type/Designation 2270P
  - Make and Model . . . . 2003 Dodge Ram 1500 Quad Cab 4x2
  - Curb . . . . 5,078 lbs
  - Test Inertial . . . . 5,001 lbs
  - Gross Static . . . . 5,001 lbs
- Impact Conditions
  - Speed . . . . 63.5 mph
  - Angle . . . . 24.4 degrees
  - Impact Location . . . . 4 ft - 3.1875 in. upstream from downstream end of barrier no. 4
- Exit Conditions
  - Speed . . . . 54.2 mph
  - Angle . . . . 1.7 degrees
  - Exit Box Criterion . . . . Pass
- Post-Impact Trajectory
  - Vehicle Stability . . . . Satisfactory
  - Stopping Distance . . . . 189 ft - 3 in. downstream
    12 ft - 6 in. laterally behind
- Occupant Impact Velocity (DTS)
  - Longitudinal . . . . -15.64 ft/s < 40 ft/s
  - Lateral . . . . 19.88 ft/s < 40 ft/s
- Occupant Ridedown Deceleration (DTS)
  - Longitudinal . . . . -7.15 g's < 20.49 g's
  - Lateral . . . . 6.64 g's < 20.49 g's
- Occupant Impact Velocity (EDR-3)
  - Longitudinal . . . . -17.44 ft/s < 40 ft/s
  - Lateral . . . . 22.50 ft/s < 40 ft/s
- Occupant Ridedown Deceleration (EDR-3)
  - Longitudinal . . . . -7.85 g's < 20.49 g's
  - Lateral . . . . 5.83 g's < 20.49 g's
- THIV (not required) . . . . 23.77 ft/s
- PHD (not required) . . . . 7.93 g's
- Test Article Damage . . . . Moderate
- Test Article Deflections
  - Permanent Set . . . . 26 in.
  - Dynamic . . . . 30.9 in.
  - Working Width . . . . 51.3 in.
- Vehicle Damage . . . . Moderate
  - VDS[13] 1-RFQ-3
  - CDC[14] 1-RYEN2
  - Maximum Deformation . . . . 3.5 in.
- Angular Displacements
  - Roll . . . . -18.2 deg
  - Pitch . . . . 9.7 deg
  - Yaw . . . . -27.5 deg

Figure B-3. Summary of Test Results and Sequential Photographs (English), Test NYTCB-3

APPENDIX C

Occupant Compartment Deformation Data

Figure C-1. Occupant Compartment Deformation Data Set 1, Test NYTCB-1

Figure C-2. Occupant Compartment Deformation Data Set 2, Test NYTCB-1

Figure C-3. Occupant Compartment Deformation Index (OCDI), Test NYTCB-1

Figure C-4. Occupant Compartment Deformation Data Set 1, Test NYTCB-2

Figure C-5. Occupant Compartment Deformation Data Set 2, Test NYTCB-2

Figure C-6. Occupant Compartment Deformation Index (OCDI), Test NYTCB-2

Figure C-7. Occupant Compartment Crush Data, Test NYTCB-3

VEHICLE PRE/POST CRUSH INFO
Set-1

TEST: NYTCB-1
VEHICLE: 2002 Dodge Ram 1500

POINT	X	Y	Z	X'	Y'	Z'	DEL X	DEL Y	DEL Z
1	29.25	-29	-1.5	28.5	-27.5	-1	-0.75	1.5	0.5
2	32.5	-19	-3.25	32	-18.25	-2.5	-0.5	0.75	0.75
3	30	-13	-1	30.25	-12.25	-1	0.25	0.75	0
4	28.25	-9.75	0	28	-9	0	-0.25	0.75	0
5	26.5	-29	-5.25	26.25	-28.5	-5.25	-0.25	0.5	0
6	27.5	-22	-5.75	27.5	-21.5	-5.5	0	0.5	0.25
7	27.75	-16	-5.5	27.75	-15	-5.25	0	1	0.25
8	25	-8.5	-2.75	25	-8.25	-2.75	0	0.25	0
9	23	-29.25	-8.25	23	-29	-8.25	0	0.25	0
10	22.75	-23.25	-8	22.75	-23.25	-7.5	0	0	0.5
11	22.75	-16.5	-8	22.75	-16.5	-7.75	0	0	0.25
12	21.5	-9	-3.75	21.5	-8.5	-3.75	0	0.5	0
13	18.25	-31	-10.5	18.5	-30.75	-10.5	0.25	0.25	0
14	18.5	-21.25	-9.75	18.5	-21.25	-9.5	0	0	0.25
15	19	-10.5	-8.5	18.75	-10	-8.25	-0.25	0.5	0.25
16	15	-4	-1.75	15	-4	-1.75	0	0	0
17	13.5	-30.75	-10.25	13.5	-30.75	-10.5	0	0	-0.25
18	14	-22	-9.5	14	-22	-9.25	0	0	0.25
19	14.25	-11.25	-9.25	14.25	-11	-9.25	0	0.25	0
20	11.5	-3.25	-2	11.5	-3.25	-2	0	0	0
21	6.75	-30.5	-9.75	6.75	-30.5	-9.75	0	0	0
22	8	-21	-9.25	8	-20.75	-9.25	0	0.25	0
23	7.5	-10.25	-8.25	7.5	-10.25	-8.25	0	0	0
24	7	-1.5	-1.75	6.75	-1.5	-2	-0.25	0	-0.25
25	0.75	-28.5	-5.75	0.75	-28.5	-5.75	0	0	0
26	0.5	-21.25	-5	0.5	-21.25	-5.25	0	0	-0.25
27	0.5	-12.5	-4.75	0.5	-12.25	-5	0	0.25	-0.25
28	0.5	-2.75	-1.5	0.5	-2.75	-1.75	0	0	-0.25
29							0	0	0
30							0	0	0
31							0	0	0
32							0	0	0
33							0	0	0
34							0	0	0
35							0	0	0

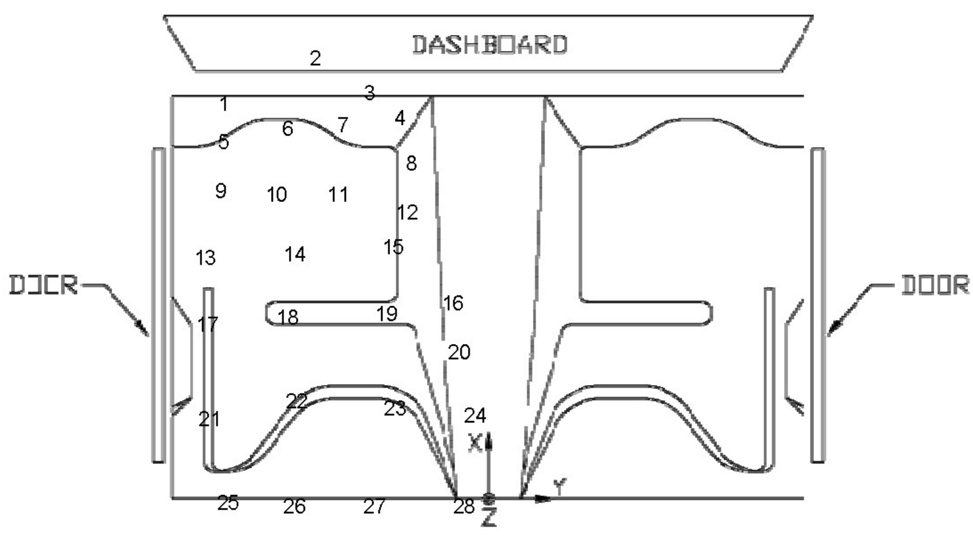


Figure C-4. Occupant Compartment Deformation Data Set 1, Test NYTCB-1

VEHICLE PRE/POST CRUSH INFO
Set-2

TEST: NYTCB-1
VEHICLE: 2002 Dodge Ram 1500

POINT	X	Y	Z	X'	Y'	Z'	DEL X	DEL Y	DEL Z
1	52.75	-26	-0.75	52	-24.5	0.25	-0.75	1.5	1
2	56	-16	-3.5	55.5	-15.25	-2.25	-0.5	0.75	1.25
3	53.5	-10	-1.5	53.75	-9.25	-1.25	0.25	0.75	0.25
4	51.75	-6.75	-1	51.5	-6	-0.75	-0.25	0.75	0.25
5	50	-26	-4.25	49.75	-25.5	-4	-0.25	0.5	0.25
6	51	-19	-5.75	51	-18.5	-4.75	0	0.5	1
7	51.25	-13	-6	51.25	-12	-5.5	0	1	0.5
8	48.5	-5.5	-3.75	48.5	-5.25	-3.5	0	0.25	0.25
9	46.5	-26.25	-7	46.5	-26	-7	0	0.25	0
10	46.25	-20.25	-7.5	46.25	-20.25	-7	0	0	0.5
11	46.25	-13.5	-8	46.25	-13.5	-7.75	0	0	0.25
12	45	-6	-4.75	45	-5.5	-4.5	0	0.5	0.25
13	41.75	-28	-9	42	-27.75	-9	0.25	0.25	0
14	42	-18.25	-9.25	42	-18.25	-9	0	0	0.25
15	42.5	-7.5	-9	42.25	-7	-9	-0.25	0.5	0
16	38.5	-1	-3	38.5	-1	-3	0	0	0
17	37	-27.75	-8.75	37	-27.75	-8.75	0	0	0
18	37.5	-19	-9	37.5	-19	-8.5	0	0	0.5
19	37.75	-8.25	-9.75	37.75	-8	-9.5	0	0.25	0.25
20	35	-0.25	-3.5	35	-0.25	-3.25	0	0	0.25
21	30.25	-27.5	-7.75	30.25	-27.5	-7.75	0	0	0
22	31.5	-18	-7.5	31.5	-17.75	-8.5	0	0.25	-1
23	31	-7.25	-8.75	31	-7.25	-8.75	0	0	0
24	30.5	1.5	-3.5	30.25	1.5	-3.25	-0.25	0	0.25
25	24.25	-25.5	-4	24.25	-25.5	-4	0	0	0
26	24	-18.25	-4.5	24	-18.25	-4.5	0	0	0
27	24	-9.5	-5	24	-9.25	-5	0	0.25	0
28	24	0.25	-3	24	0.25	-2.75	0	0	0.25
29							0	0	0
30							0	0	0
31							0	0	0
32							0	0	0
33							0	0	0
34							0	0	0
35							0	0	0

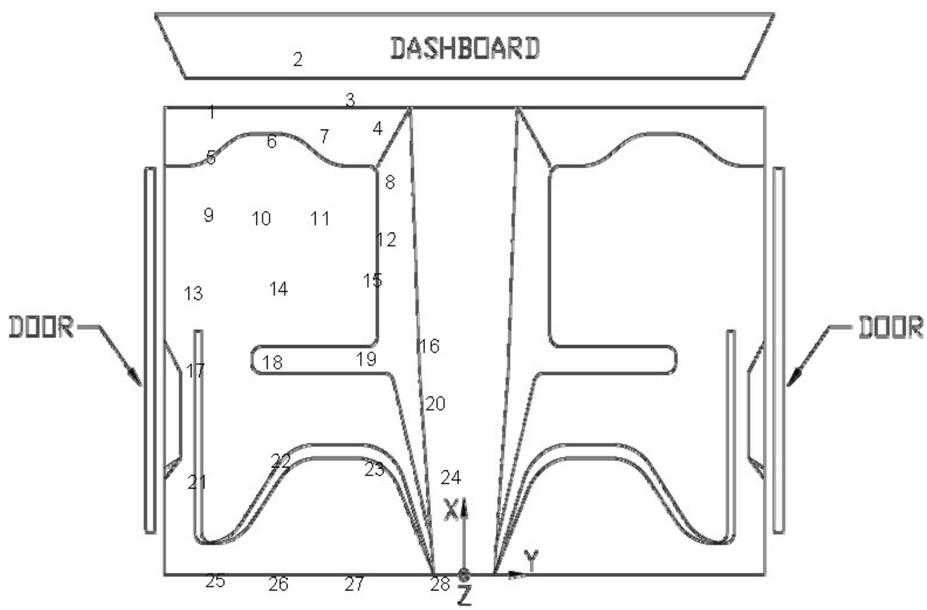


Figure C-5. Occupant Compartment Deformation Data Set 2, Test NYTCB-1

Occupant Compartment Deformation Index (OCDI)

Test No. NYTCB-1
Vehicle Type: 2002 Dodge Ram 1500

OCDI = XXABCDEFGHI

XX = location of occupant compartment deformation

A = distance between the dashboard and a reference point at the rear of the occupant compartment, such as the top of the rear seat or the rear of the cab on a pickup

B = distance between the roof and the floor panel

C = distance between a reference point at the rear of the occupant compartment and the motor panel

D = distance between the lower dashboard and the floor panel

E = interior width

F = distance between the lower edge of right window and the upper edge of left window

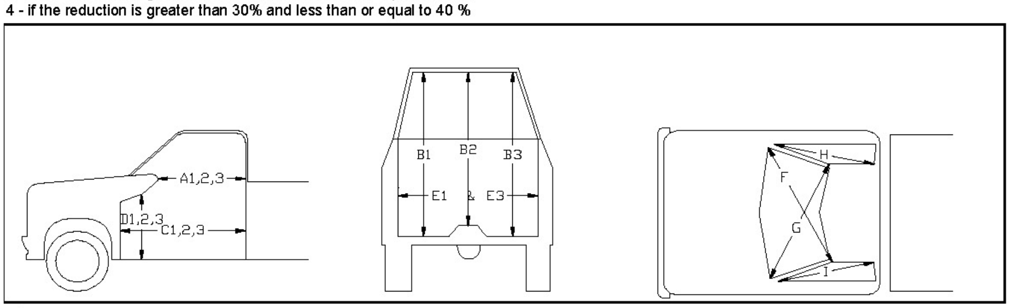
G = distance between the lower edge of left window and the upper edge of right window

H= distance between bottom front corner and top rear corner of the passenger side window

I= distance between bottom front corner and top rear corner of the driver side window

Severity Indices

0 - if the reduction is less than 3%
1 - if the reduction is greater than 3% and less than or equal to 10 %
2 - if the reduction is greater than 10% and less than or equal to 20 %
3 - if the reduction is greater than 20% and less than or equal to 30 %
4 - if the reduction is greater than 30% and less than or equal to 40 %



where,
1 = Passenger Side
2 = Middle
3 = Driver Side

Location:

Measurement	Pre-Test (in.)	Post-Test (in.)	Change (in.)	% Difference	Severity Index
A1	56.25	56.50	0.25	0.44	0
A2	54.00	54.00	0.00	0.00	0
A3	55.00	55.00	0.00	0.00	0
B1	43.75	44.00	0.25	0.57	0
B2	42.50	42.50	0.00	0.00	0
B3	46.75	47.00	0.25	0.53	0
C1	67.00	65.50	-1.50	-2.24	0
C2	48.00	48.00	0.00	0.00	0
C3	65.50	65.25	-0.25	-0.38	0
D1	23.50	24.00	0.50	2.13	0
D2	13.75	14.00	0.25	1.82	0
D3	22.50	22.50	0.00	0.00	0
E1	65.50	65.50	0.00	0.00	0
E3	64.75	64.75	0.00	0.00	0
F	58.00	58.00	0.00	0.00	0
G	57.50	57.50	0.00	0.00	0
H	36.75	36.75	0.00	0.00	0
I	38.25	38.50	0.25	0.65	0

Note: Maximum sevrity index for each variable (A-I) is used for determination of final OCDI value

	XX	A	B	C	D	E	F	G	H	I
Final OCDI:	LF	0	0	0	0	0	0	0	0	0

Figure C-6. Occupant Compartment Deformation Index (OCDI), Test NYTCB-1

VEHICLE PRE/POST CRUSH INFO
Set-1

TEST: NYTCB-2
VEHICLE: 2003 Dodge Ram 1500

	23	3							
POINT	X	Y	Z	X'	Y'	Z'	DEL X	DEL Y	DEL Z
1	30	-28.75	0	28.5	-28	1.5	-1.5	0.75	1.5
2	32.5	-24	-0.75	29.5	-23.25	2	-3	0.75	2.75
3	33.5	-18	-1	32	-17	1	-1.5	1	2
4	29.5	-11	1	30	-11.75	1.5	0.5	-0.75	0.5
5	26.5	-29	-4.75	26	-29	-4	-0.5	0	0.75
6	28	-24.25	-5.25	27.5	-24.25	-4.5	-0.5	0	0.75
7	29	-17	-5	28	-16.75	-4	-1	0.25	1
8	28.5	-10.25	-2.5	28.5	-10.5	-2.5	0	-0.25	0
9	23.5	-30.25	-7.5	23.25	-30.5	-7.5	-0.25	-0.25	0
10	23.25	-23	-7.5	22.75	-23.5	-7	-0.5	-0.5	0.5
11	23.25	-17.25	-7.5	23	-17	-7.25	-0.25	0.25	0.25
12	23.25	-11.5	-7.75	23.5	-11	-7.5	0.25	0.5	0.25
13	21	-8	-2.75	20.75	-8.25	-2.5	-0.25	-0.25	0.25
14	17.75	-29.25	-9	17.5	-28.5	-9	-0.25	0.75	0
15	18	-21.5	-9	18	-21	-9	0	0.5	0
16	18	-13.75	-9.25	17.75	-13	-9.5	-0.25	0.75	-0.25
17	15.25	-7.25	-2.5	15.25	-7.25	-2.75	0	0	-0.25
18	15	-2	-2.5	15.25	-2	-2.5	0.25	0	0
19	11	-29	-8.5	10.5	-28.25	-8.5	-0.5	0.75	0
20	11	-22	-8.5	10.75	-21	-8.5	-0.25	1	0
21	10.75	-15.25	-8.75	10.75	-15.25	-8.75	0	0	0
22	8.25	-7.5	-3	8.5	-7.5	-3	0.25	0	0
23	8.5	-1.5	-2.75	8.5	-1.5	-2.5	0	0	0.25
24	1	-29	-5	1	-29	-5	0	0	0
25	1	-22	-4.5	1	-22	-4.5	0	0	0
26	0.75	-15.25	-5	0.75	-15.25	-5	0	0	0
27	1.25	-8	-2.5	1.25	-8	-2.5	0	0	0
28	1	-1.75	-2.5	1	-1.75	-2.5	0	0	0
29							0	0	0
30							0	0	0
31							0	0	0
32							0	0	0
33							0	0	0
34							0	0	0
35							0	0	0

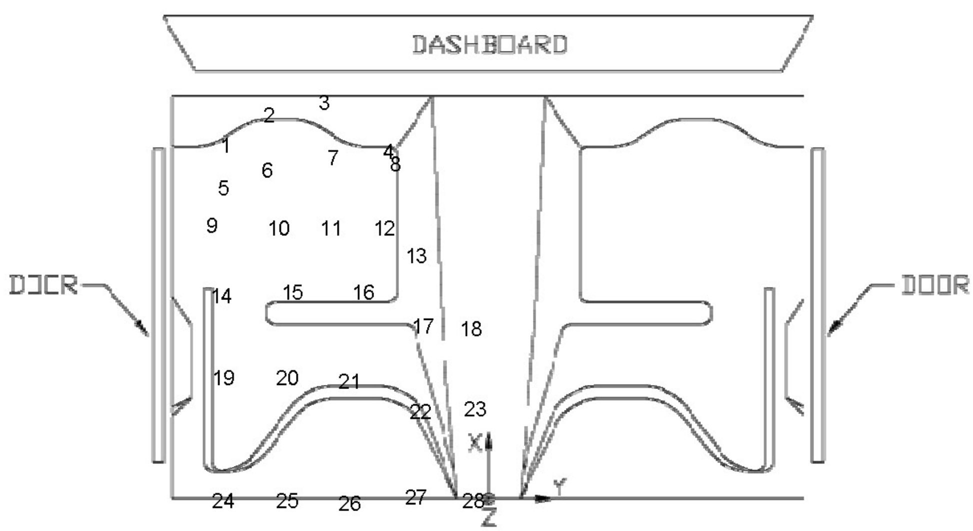


Figure C-7. Occupant Compartment Deformation Data Set 1, Test NYTCB-2

VEHICLE PRE/POST CRUSH INFO
Set-2

TEST: NYTCB-2
VEHICLE: 2003 Dodge Ram 1500

POINT	X	Y	Z	X'	Y'	Z'	DEL X	DEL Y	DEL Z
1	53	-25.75	-2.75	51.5	-25	-2	-1.5	0.75	0.75
2	55.5	-21	-3	52.5	-20.25	-1	-3	0.75	2
3	56.5	-15	-3	55	-14	-1.25	-1.5	1	1.75
4	52.5	-8	0	53	-8.75	0	0.5	-0.75	0
5	49.5	-26	-7.25	49	-26	-6.75	-0.5	0	0.5
6	51	-21.25	-7.5	50.5	-21.25	-6.75	-0.5	0	0.75
7	52	-14	-6.5	51	-13.75	-5	-1	0.25	1.5
8	51.5	-7.25	-3.5	51.5	-7.5	-3.25	0	-0.25	0.25
9	46.5	-27.25	-10	46.25	-27.5	-10	-0.25	-0.25	0
10	46.25	-20	-9.5	45.75	-20.5	-8.75	0	-0.5	0.75
11	46.25	-14.25	-9.25	46	-14	-8.5	-0.25	0.25	0.75
12	46.25	-8.5	-8.75	46.5	-8	-8.5	0.25	0.5	0.25
13	44	-5	-3.5	43.75	-5.25	-3	-0.25	-0.25	0.5
14	40.75	-26.25	-11.5	40.5	-25.5	-11.25	-0.25	0.75	0.25
15	41	-18.5	-11	41	-18	-10.75	0	0.5	0.25
16	41	-10.75	-10.5	40.75	-10	-10.5	-0.25	0.75	0
17	38.25	-4.25	-3.25	38.25	-4.25	-3.25	0	0	0
18	38	1	-2.5	38.25	1	-2.5	0.25	0	0
19	34	-26	-10.75	33.5	-25.25	-11	-0.5	0.75	-0.25
20	34	-19	-10.5	33.75	-18	-10.5	-0.25	1	0
21	33.75	-12.25	-10.25	33.75	-12.25	-10	0	0	0.25
22	31.25	-4.5	-3.25	31.5	-4.5	-3.5	0.25	0	-0.25
23	31.5	1.5	-2.75	31.5	1.5	-2.75	0	0	0
24	24	-26	-7.25	24	-26	-7.25	0	0	0
25	24	-19	-6.25	24	-19	-6.25	0	0	0
26	23.75	-12.25	-6	23.75	-12.25	-6	0	0	0
27	24.25	-5	-3.25	24.25	-5	-3.25	0	0	0
28	24	1.25	-2.75	24	1.25	-2.5	0	0	0.25
29							0	0	0
30							0	0	0
31							0	0	0
32							0	0	0
33							0	0	0
34							0	0	0
35							0	0	0

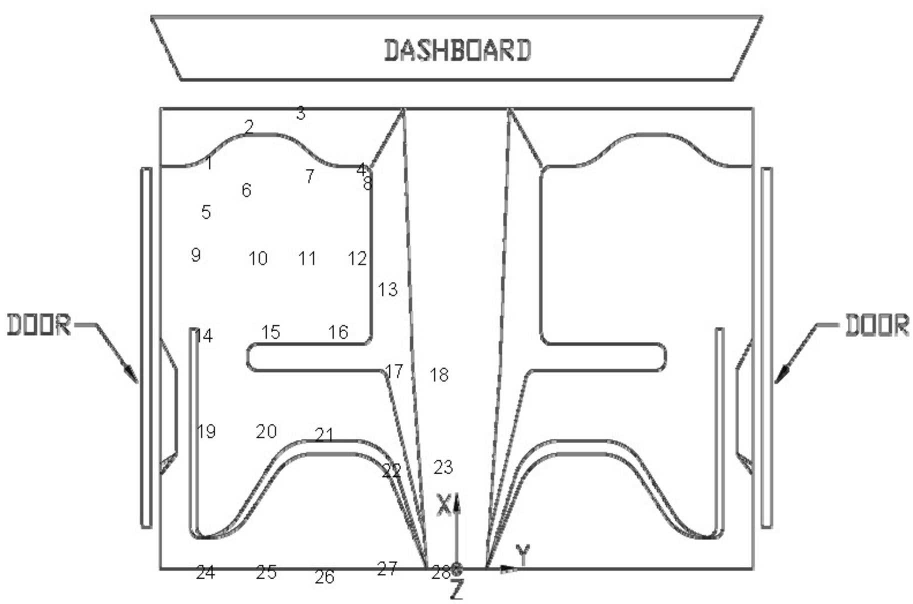


Figure C-8. Occupant Compartment Deformation Data Set 2, Test NYTCB-2

Occupant Compartment Deformation Index (OCDI)

Test No. NYTCB-2
Vehicle Type: 2003 Dodge Ram 1500

OCDI = XXABCDEFGHI

XX = location of occupant compartment deformation

A = distance between the dashboard and a reference point at the rear of the occupant compartment, such as the top of the rear seat or the rear of the cab on a pickup

B = distance between the roof and the floor panel

C = distance between a reference point at the rear of the occupant compartment and the motor panel

D = distance between the lower dashboard and the floor panel

E = interior width

F = distance between the lower edge of right window and the upper edge of left window

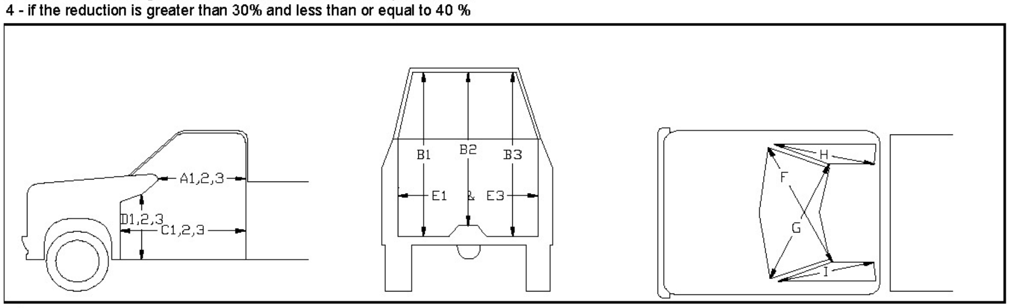
G = distance between the lower edge of left window and the upper edge of right window

H= distance between bottom front corner and top rear corner of the passenger side window

I= distance between bottom front corner and top rear corner of the driver side window

Severity Indices

0 - if the reduction is less than 3%
1 - if the reduction is greater than 3% and less than or equal to 10 %
2 - if the reduction is greater than 10% and less than or equal to 20 %
3 - if the reduction is greater than 20% and less than or equal to 30 %
4 - if the reduction is greater than 30% and less than or equal to 40 %



where,
1 = Passenger Side
2 = Middle
3 = Driver Side

Location:

Measurement	Pre-Test (in.)	Post-Test (in.)	Change (in.)	% Difference	Severity Index
A1	53.75	53.50	-0.25	-0.47	0
A2	50.25	50.25	0.00	0.00	0
A3	53.75	54.00	0.25	0.47	0
B1	47.75	47.75	0.00	0.00	0
B2	42.25	42.25	0.00	0.00	0
B3	47.50	47.50	0.00	0.00	0
C1	64.75	63.25	-1.50	-2.32	0
C2	46.75	47.00	0.25	0.53	0
C3	65.00	65.00	0.00	0.00	0
D1	23.50	23.50	0.00	0.00	0
D2	14.00	14.00	0.00	0.00	0
D3	22.50	22.50	0.00	0.00	0
E1	65.50	65.50	0.00	0.00	0
E3	64.75	64.75	0.00	0.00	0
F	58.00	58.00	0.00	0.00	0
G	58.25	58.25	0.00	0.00	0
H	37.50	37.50	0.00	0.00	0
I	38.00	38.00	0.00	0.00	0

Note: Maximum sevrity index for each variable (A-I) is used for determination of final OCDI value

	XX	A	B	C	D	E	F	G	H	I
Final OCDI:	RF	0	0	0	0	0	0	0	0	0

Figure C-9. Occupant Compartment Deformation Index (OCDI), Test NYTCB-2

NYTCB-3

Comparison interior crush measurements

Lateral measurements taken from left door seam to right door seam.
Longitudinal measurements taken from b-pillar string line (see photo)

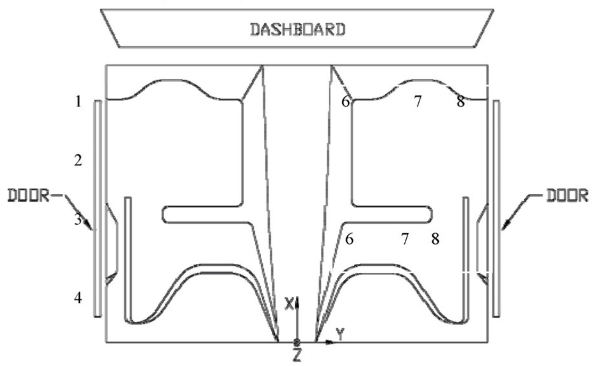
Direction:			
Lateral	1	67.5	Front of door
Lateral	2	69.1875	Midspan (front of door to front of seat)
Lateral	3	69	Front of seat
Lateral	4	69.5	Front of seat belt
Lateral	5	68	Back of door
Longitudinal	6	49.875	MIN. CRUSH
Longitudinal	7	46.25	MAX. CRUSH
Longitudinal	8	48.25	MIN. CRUSH

Reference Vehicle (no damage)

1	68.125	Front of door
2	69.75	Midspan (front of door to front of seat)
3	69.25	Front of seat
4	68.75	Front of seat belt
5	68	Back of door
6	50	MIN. CRUSH
7	49.75	MAX. CRUSH
8	49.25	MIN. CRUSH

Total crush at each point.

1	0.625	Front of door
2	0.5625	Midspan (front of door to front of seat)
3	0.25	Front of seat
4	0.25	Front of seat belt
5	0	Back of door
6	0.125	MIN. CRUSH
7	3.5	MAX. CRUSH
8	1	MIN. CRUSH



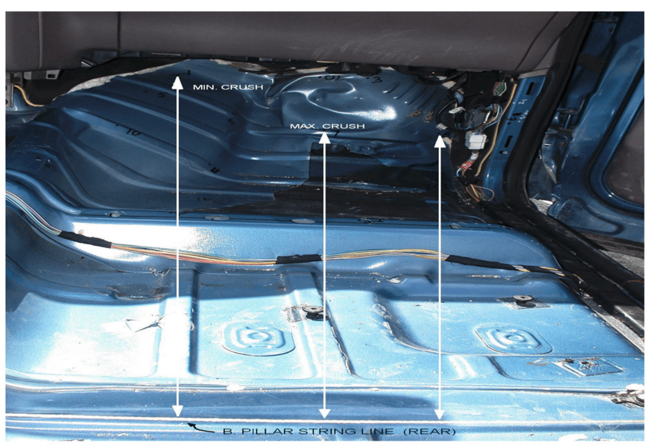


Figure C-10. Occupant Compartment Crush Data, Test NYTCB-3

APPENDIX D

Accelerometer and Rate Transducer Data Analysis, Test NYTCB-1

Figure D-1. Graph of Longitudinal Deceleration, Test NYTCB-1

Figure D-2. Graph of Longitudinal Occupant Impact Velocity, Test NYTCB-1

Figure D-3. Graph of Longitudinal Occupant Displacement, Test NYTCB-1

Figure D-4. Graph of Lateral Deceleration, Test NYTCB-1

Figure D-5. Graph of Lateral Occupant Impact Velocity, Test NYTCB-1

Figure D-6. Graph of Lateral Occupant Displacement, Test NYTCB-1

Figure D-7. Graph of Roll, Pitch, and Yaw Angular Displacements, Test NYTCB-1

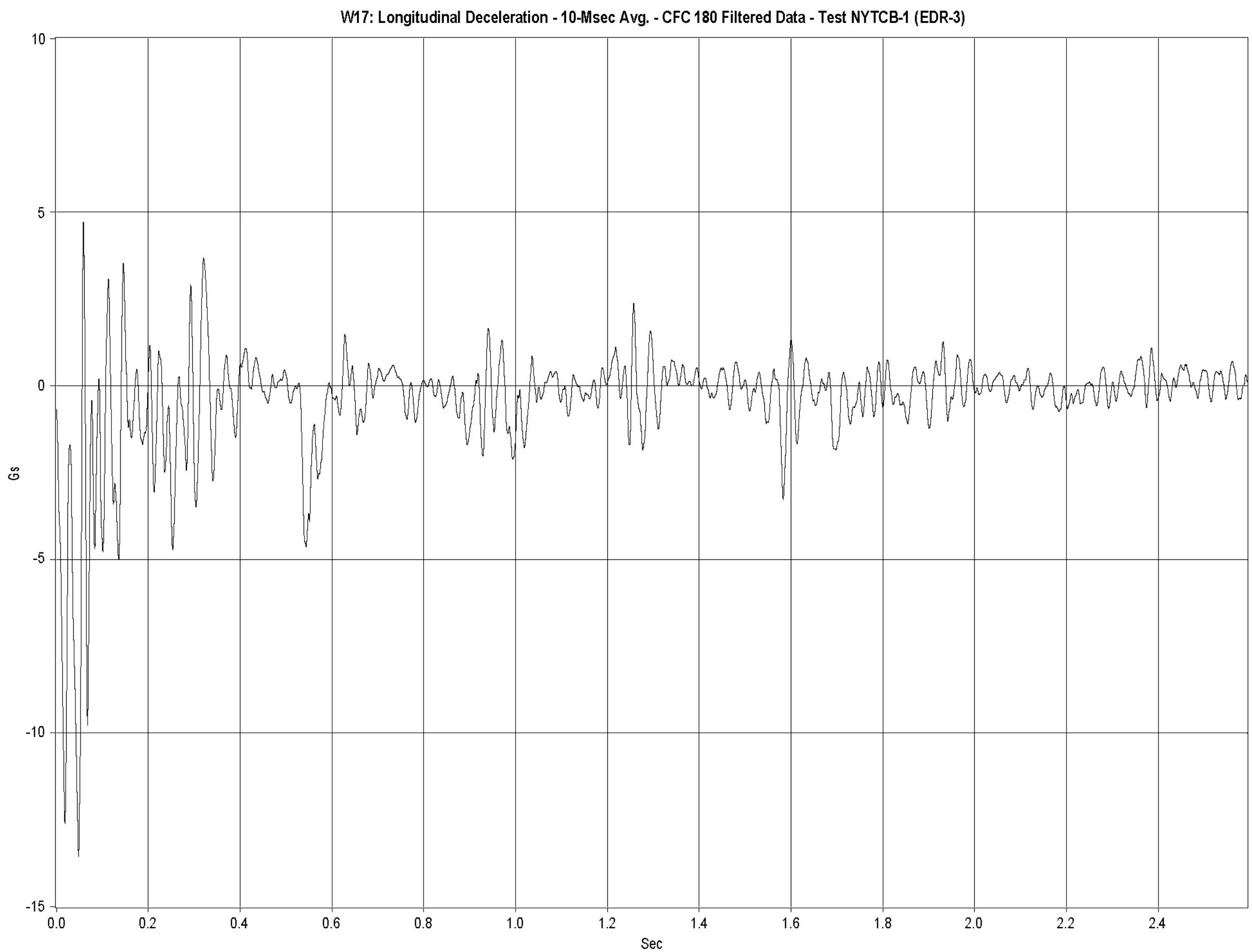


Figure D-1. Graph of Longitudinal Deceleration, Test NYTCB-1

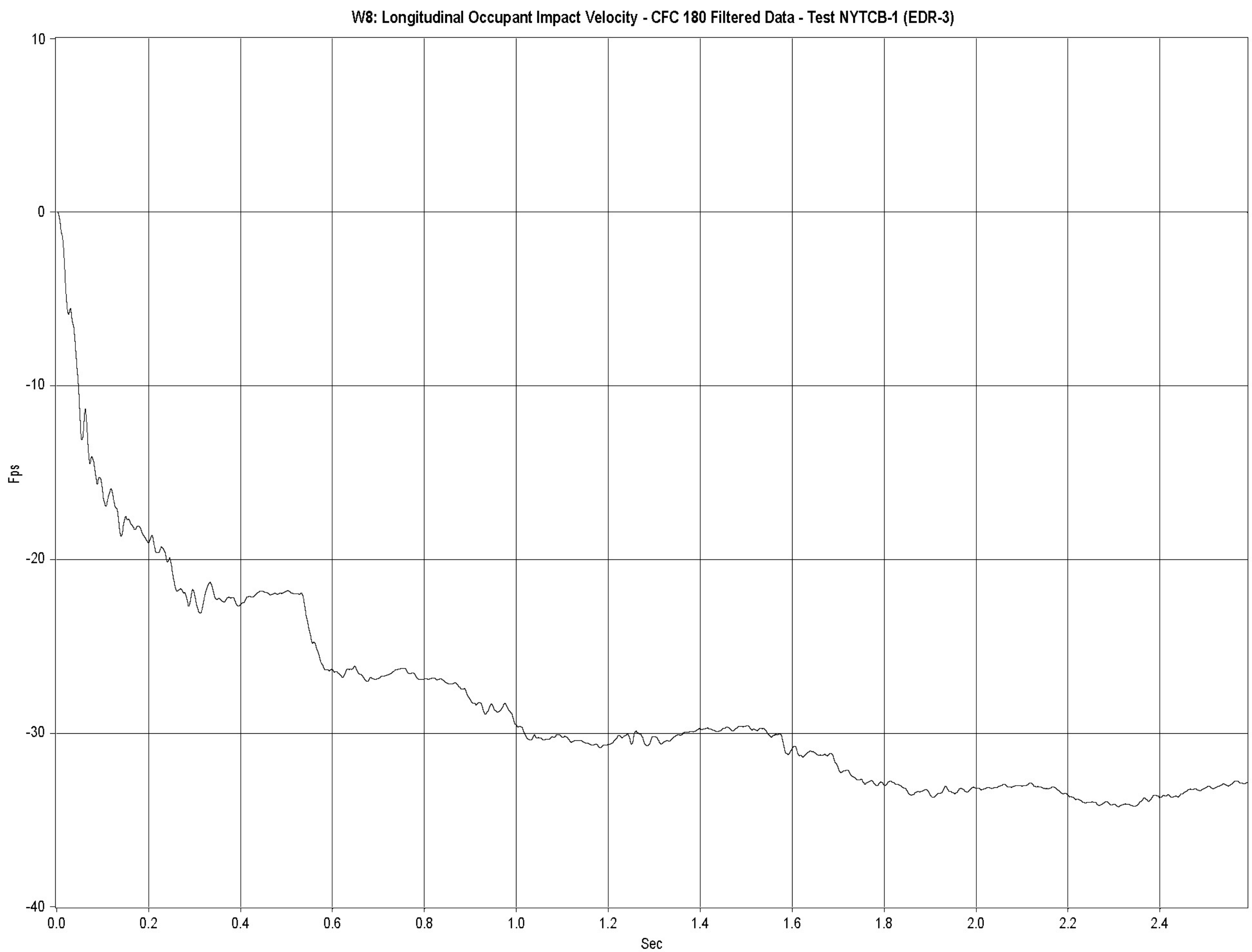


Figure D-2. Graph of Longitudinal Occupant Impact Velocity, Test NYTCB-1

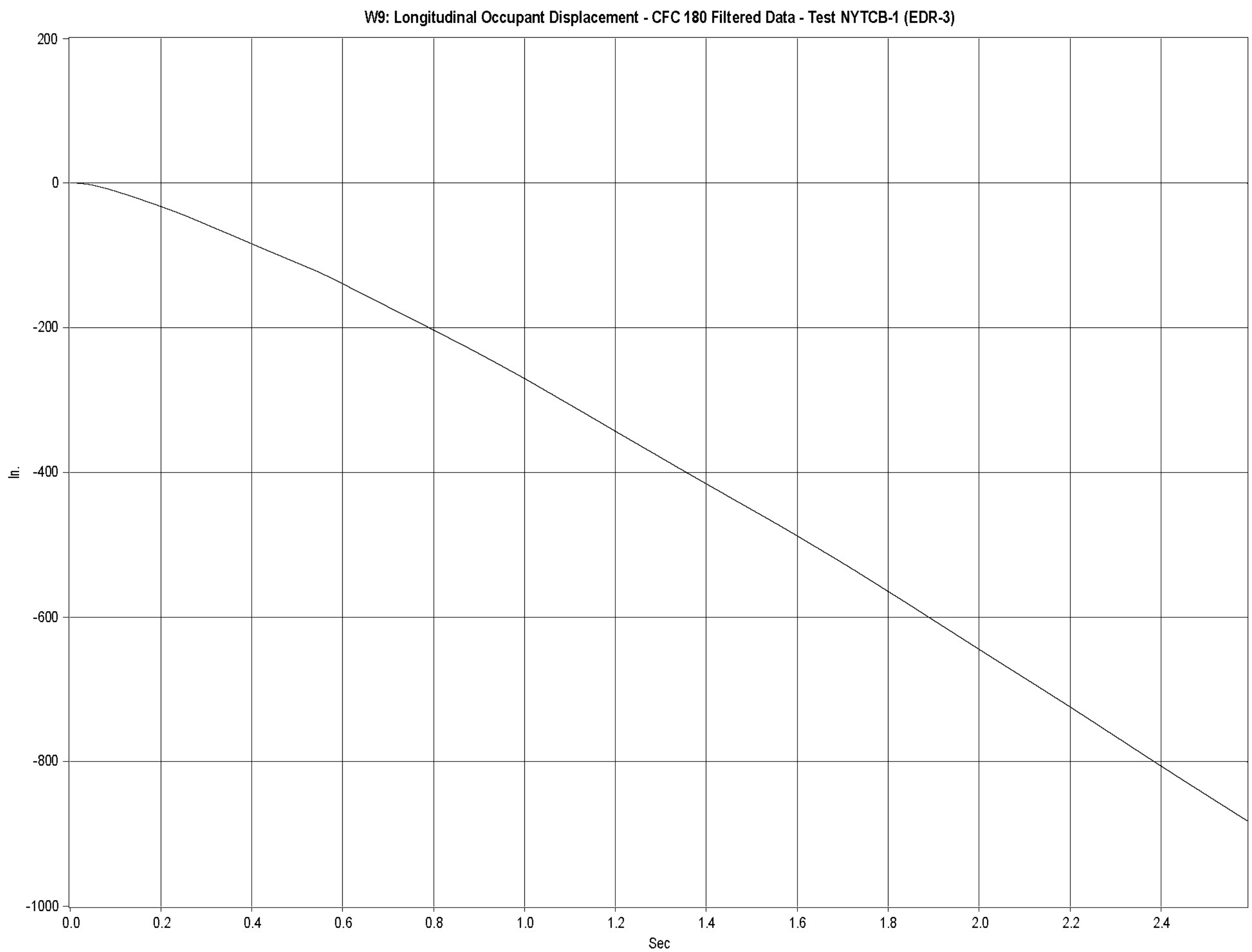


Figure D-3. Graph of Longitudinal Occupant Displacement, Test NYTCB-1

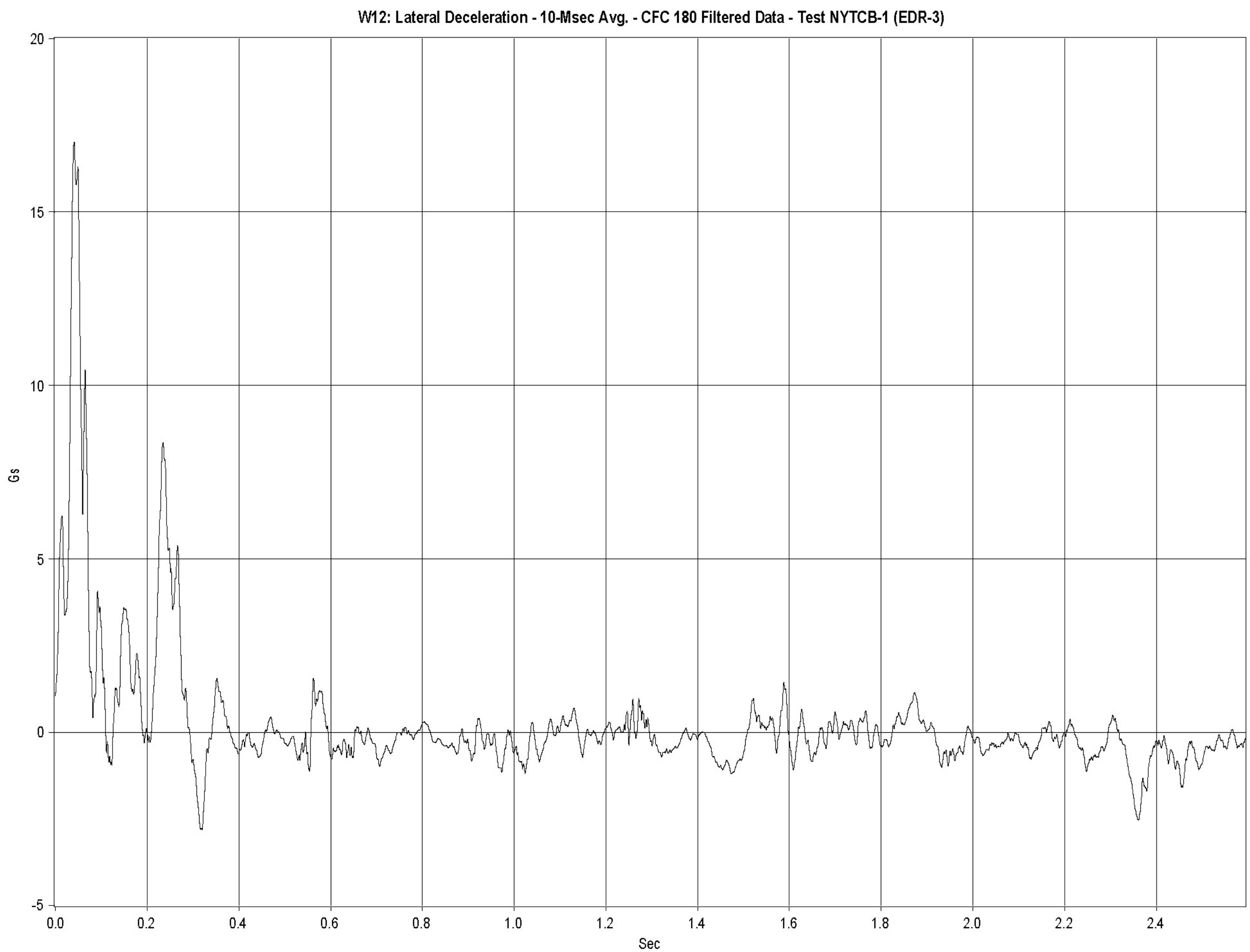


Figure D-4. Graph of Lateral Deceleration, Test NYTCB-1

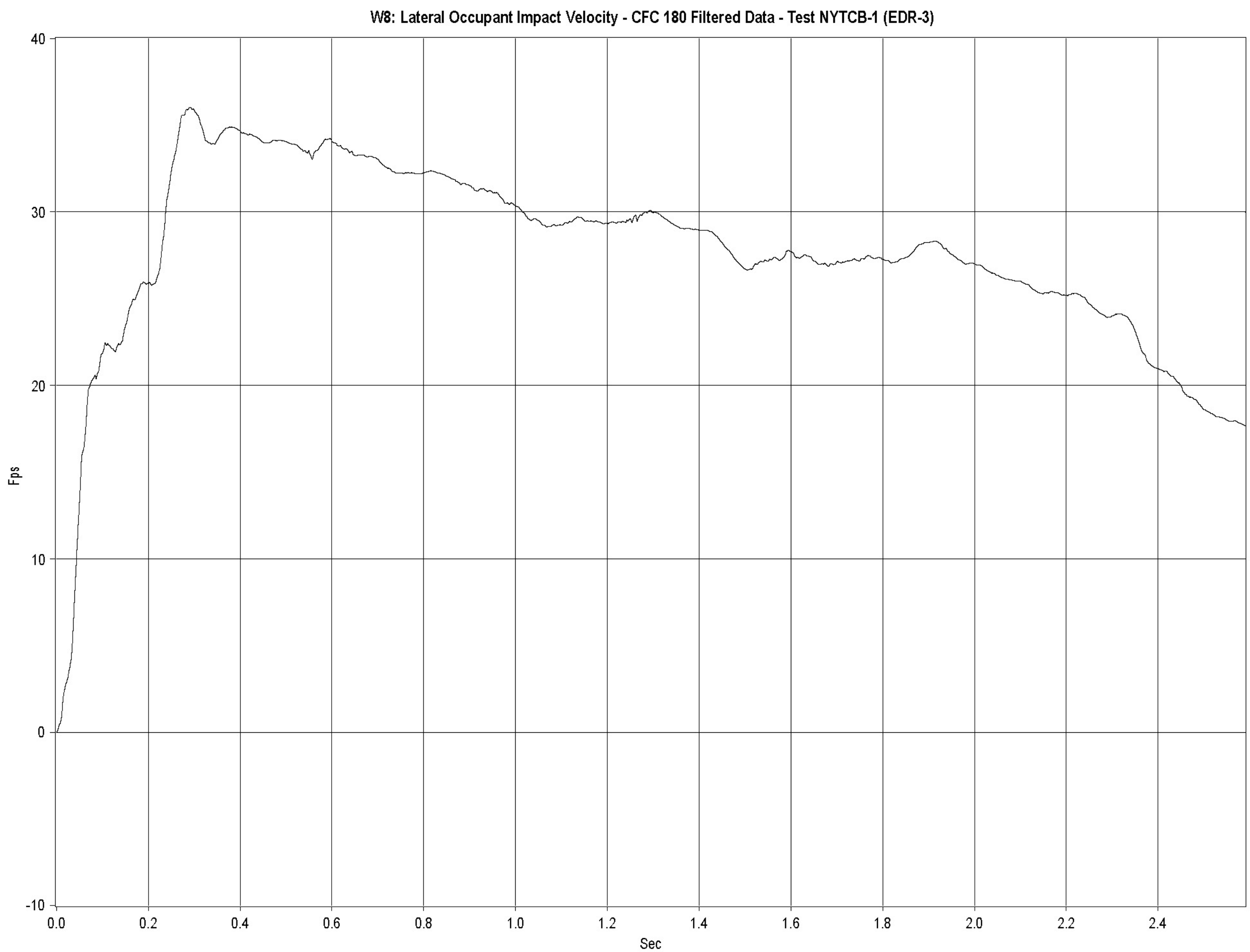


Figure D-5. Graph of Lateral Occupant Impact Velocity, Test NYTCB-1

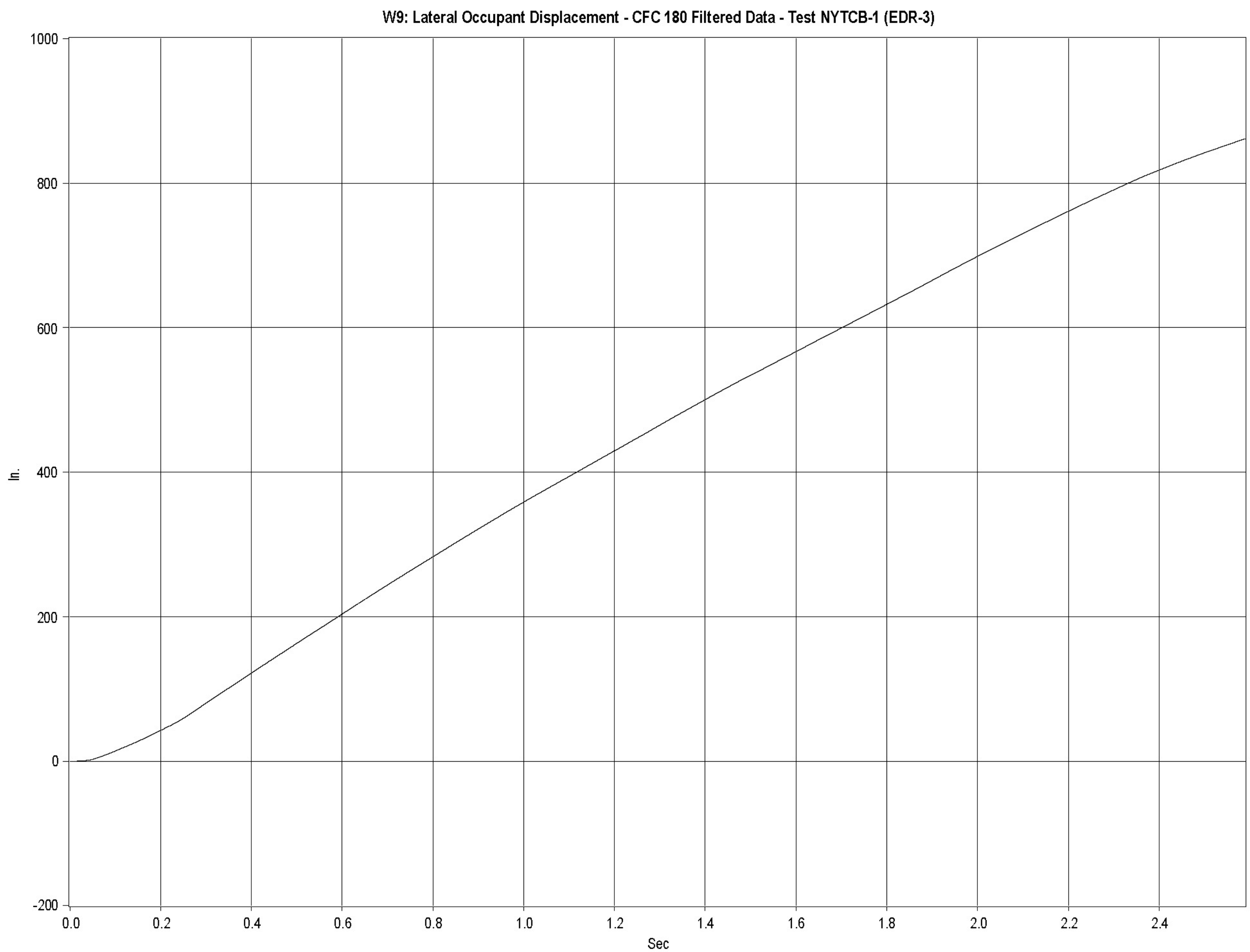


Figure D-6. Graph of Lateral Occupant Displacement, Test NYTCB-1

Figure D-7. Graph of Roll, Pitch, and Yaw Angular Displacements, Test NYTCB-1

APPENDIX E

Metric- and English-Unit System Drawings, Test NYTCB-2

Figure E-1. Unstiffened Temporary Concrete Barrier System Layout, Test NYTCB-2

Figure E-2. Temporary Concrete Barrier Details, Test NYTCB-2

Figure E-3. Temporary Concrete Barrier Reinforcement Details, Test NYTCB-2

Figure E-4. Bill of Bars, Test NYTCB-2

Figure E-5. Temporary Concrete Barrier Connection Details, Test NYTCB-2

Figure E-6. Connection Key Assembly Details, Test NYTCB-2

Figure E-7. Connection Key Assembly Details, Test NYTCB-2

Figure E-8. Temporary Concrete Barrier Connector Assembly Details, Test NYTCB-2

Figure E-9. Unstiffened Temporary Concrete Barrier System Layout (English), Test NYTCB-2

Figure E-10. Temporary Concrete Barrier Details (English), Test NYTCB-2

Figure E-11. Temporary Concrete Barrier Reinforcement Details (English), Test NYTCB-2

Figure E-12. Bill of Bars (English), Test NYTCB-2

Figure E-13. Temporary Concrete Barrier Connection Details (English), Test NYTCB-2

Figure E-14. Connection Key Assembly Details (English), Test NYTCB-2

Figure E-15. Connection Key Assembly Details (English), Test NYTCB-2

Figure E-16. Temporary Concrete Barrier Connector Assembly Details (English), Test NYTCB-2

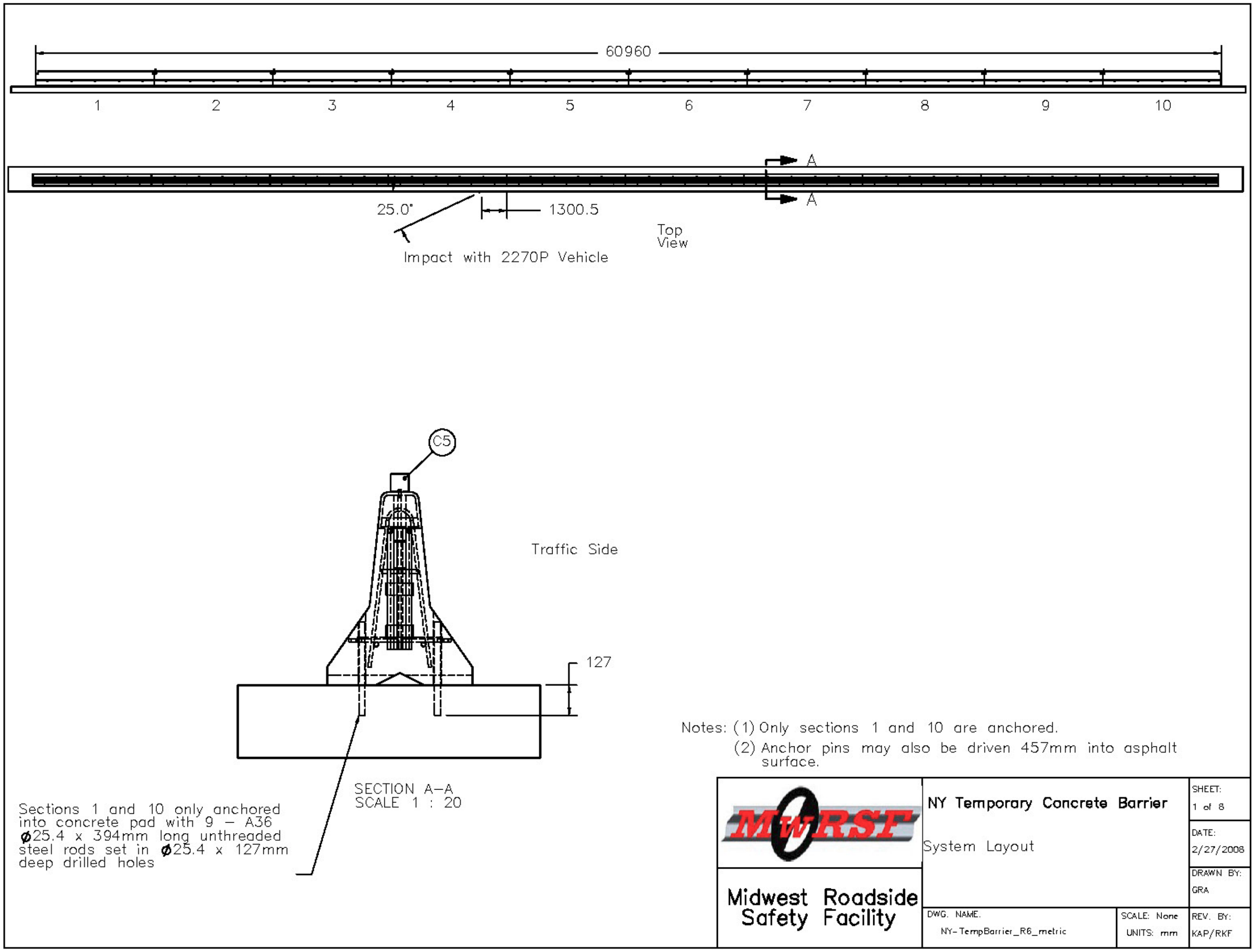


Figure E-1. Unstiffened Temporary Concrete Barrier System Layout, Test NYTCB-2

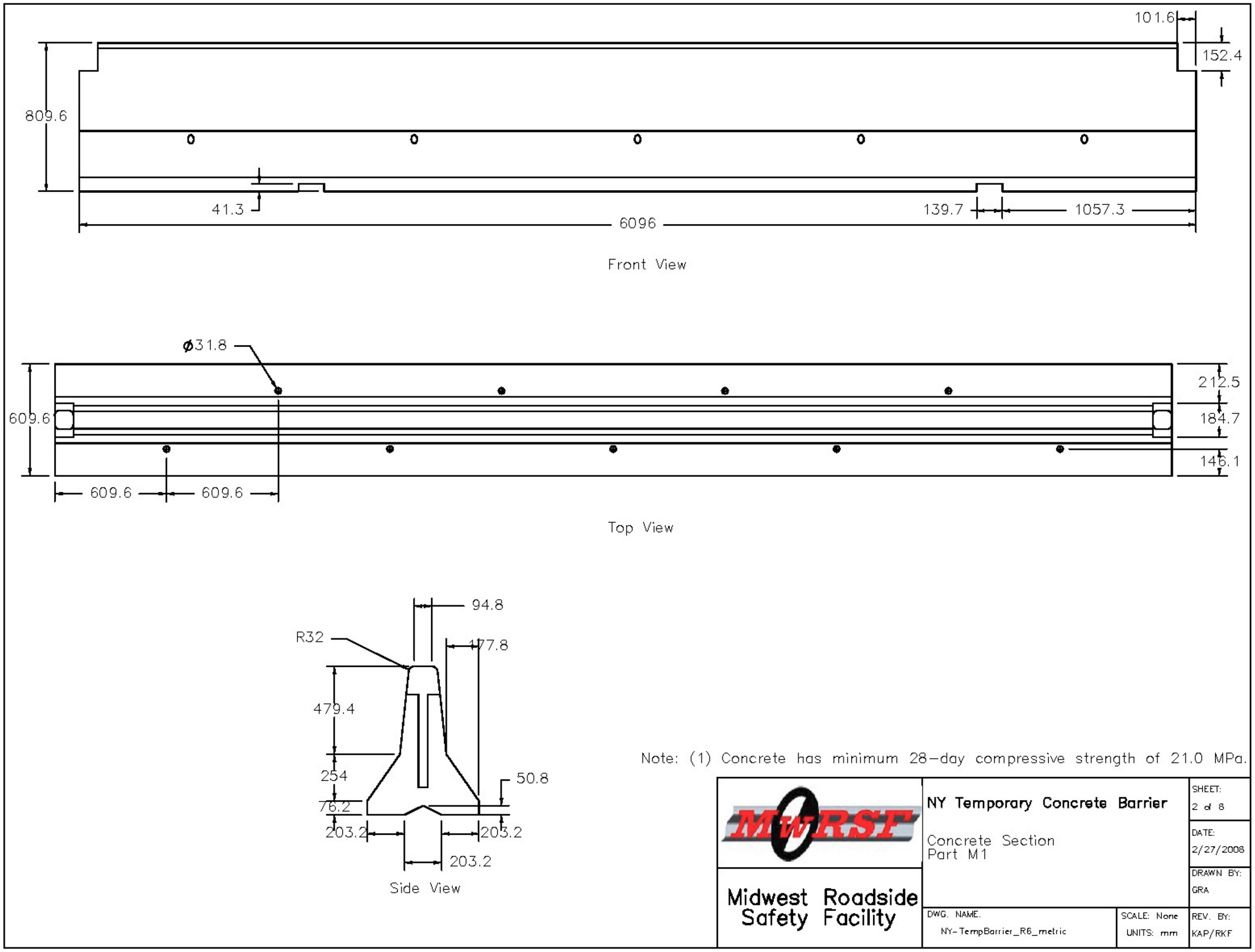


Figure E-2. Temporary Concrete Barrier Details, Test NYTCB-2

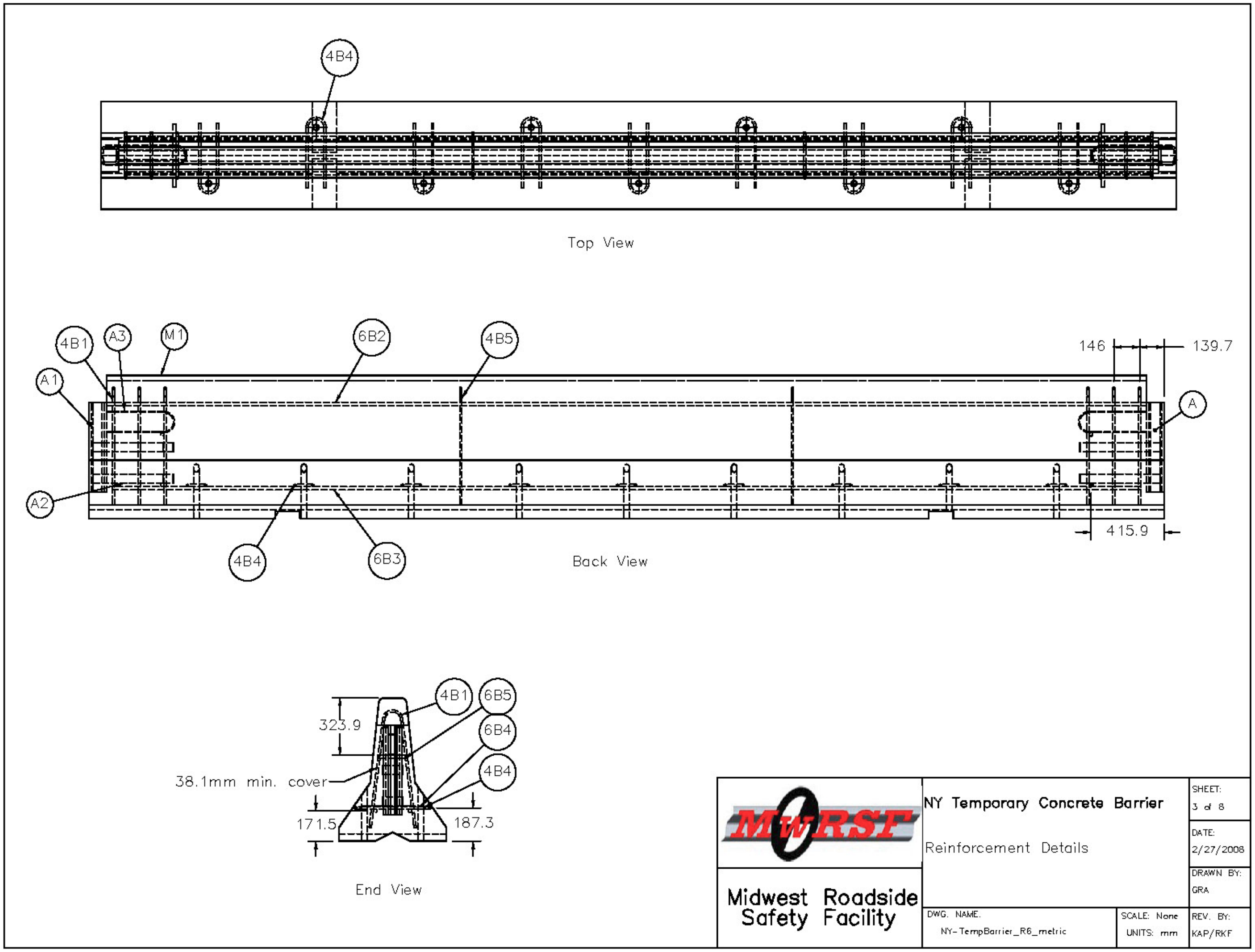
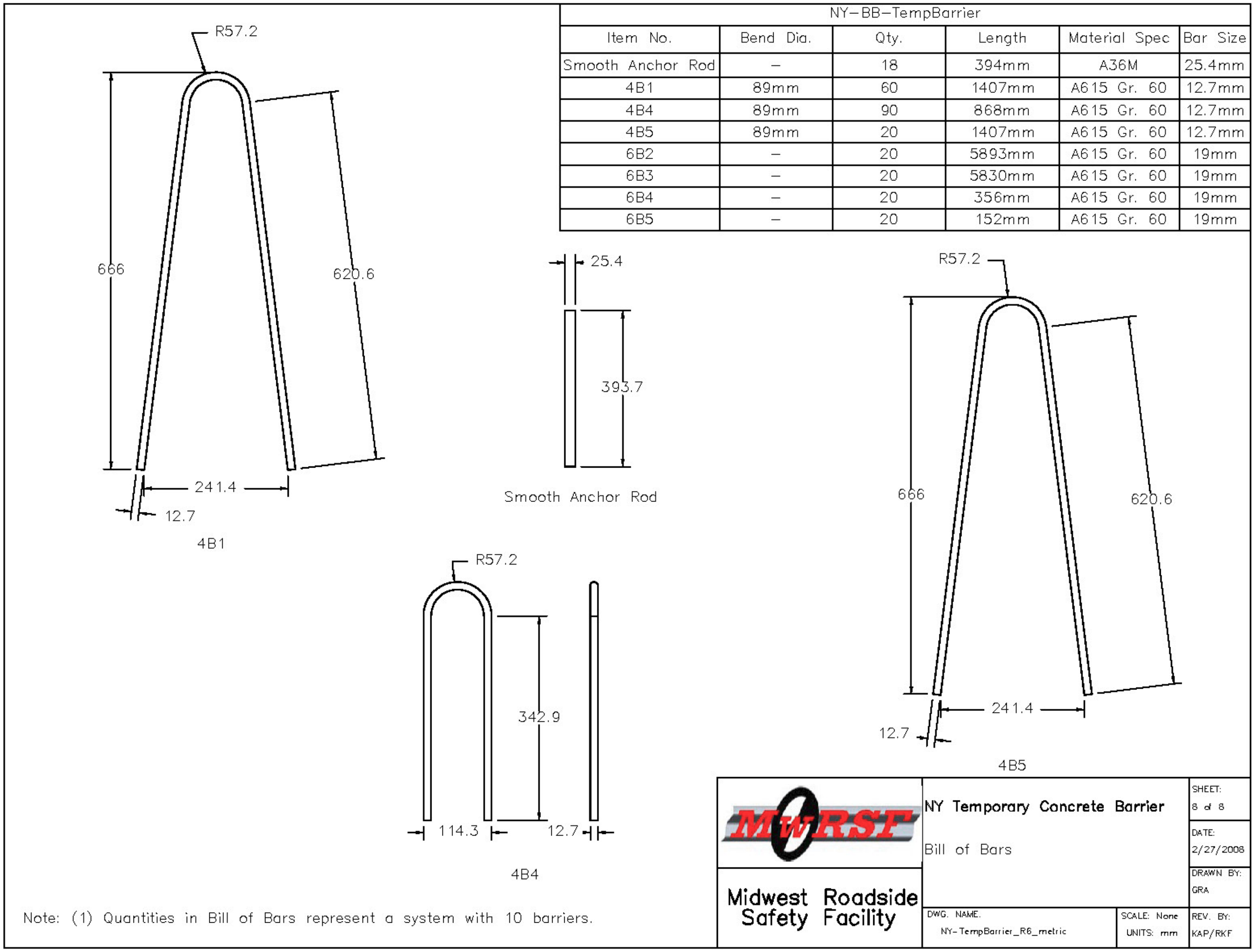


Figure E-3. Temporary Concrete Barrier Reinforcement Details, Test NYTCB-2



NY-BB-TempBarrier					
Item No.	Bend Dia.	Qty.	Length	Material Spec	Bar Size
Smooth Anchor Rod	–	18	394mm	A36M	25.4mm
4B1	89mm	60	1407mm	A615 Gr. 60	12.7mm
4B4	89mm	90	868mm	A615 Gr. 60	12.7mm
4B5	89mm	20	1407mm	A615 Gr. 60	12.7mm
6B2	–	20	5893mm	A615 Gr. 60	19mm
6B3	–	20	5830mm	A615 Gr. 60	19mm
6B4	–	20	356mm	A615 Gr. 60	19mm
6B5	–	20	152mm	A615 Gr. 60	19mm

Figure E-4. Bill of Bars, Test NYTCB-2

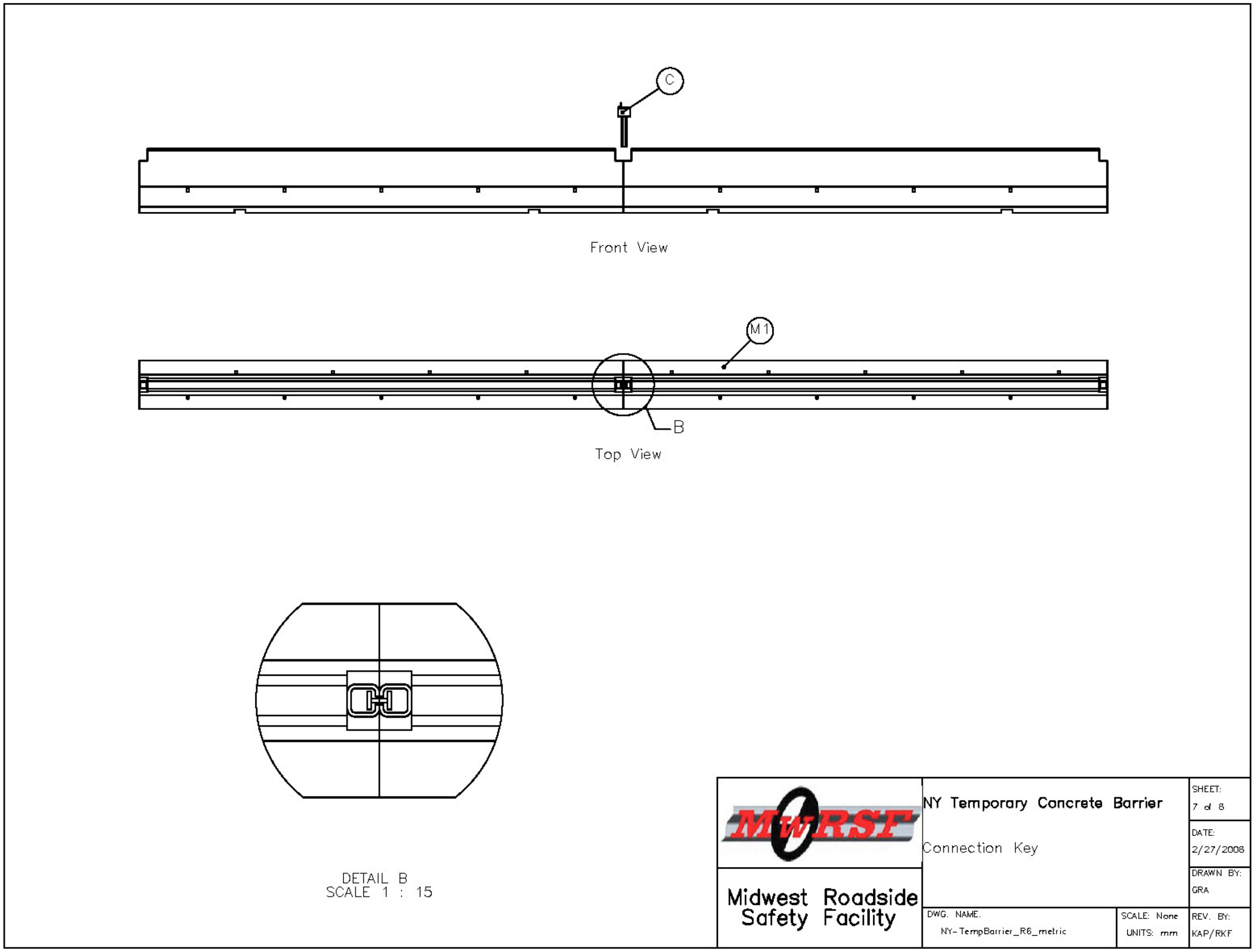


Figure E-5. Temporary Concrete Barrier Connection Details, Test NYTCB-2

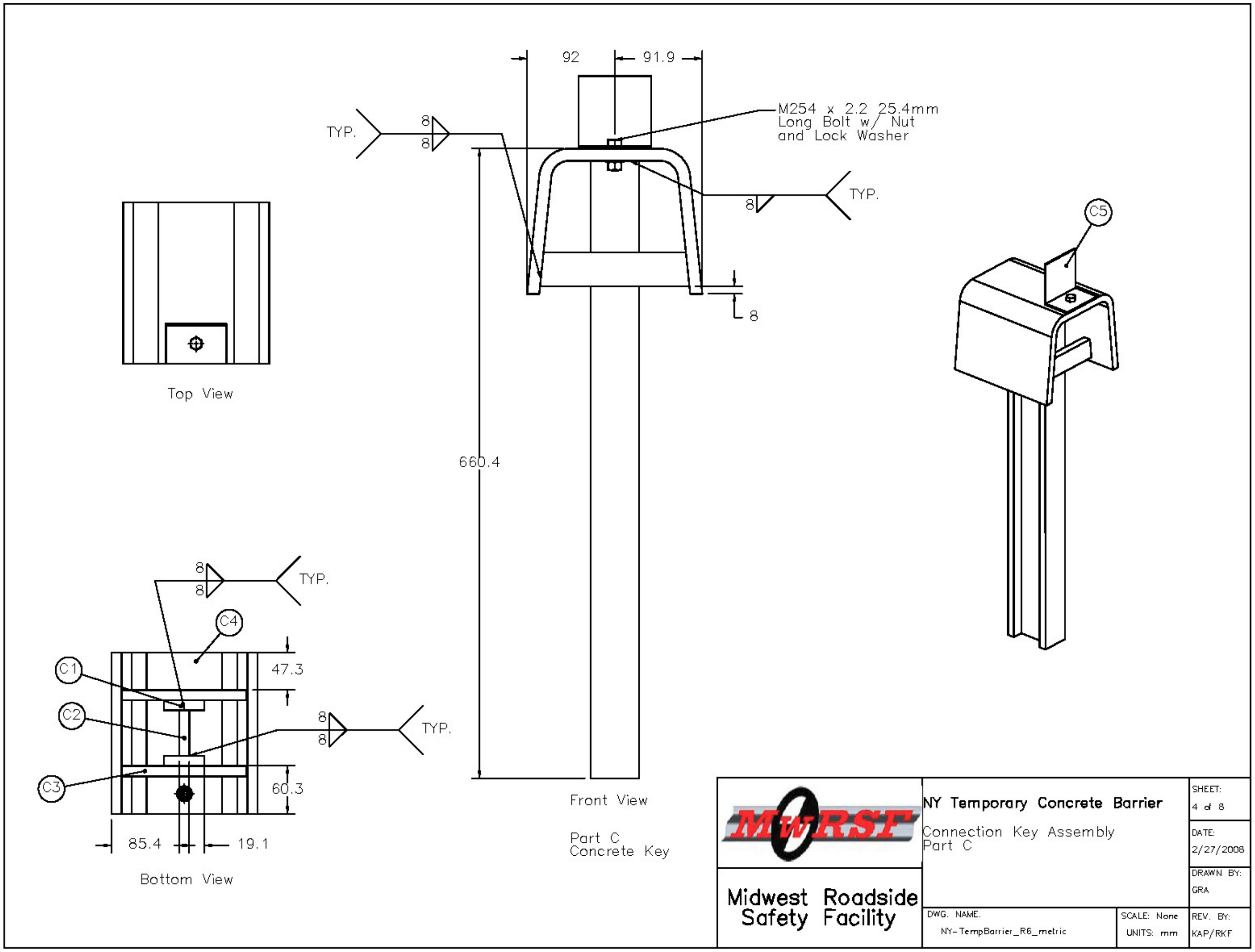


Figure E-6. Connection Key Assembly Details, Test NYTCB-2

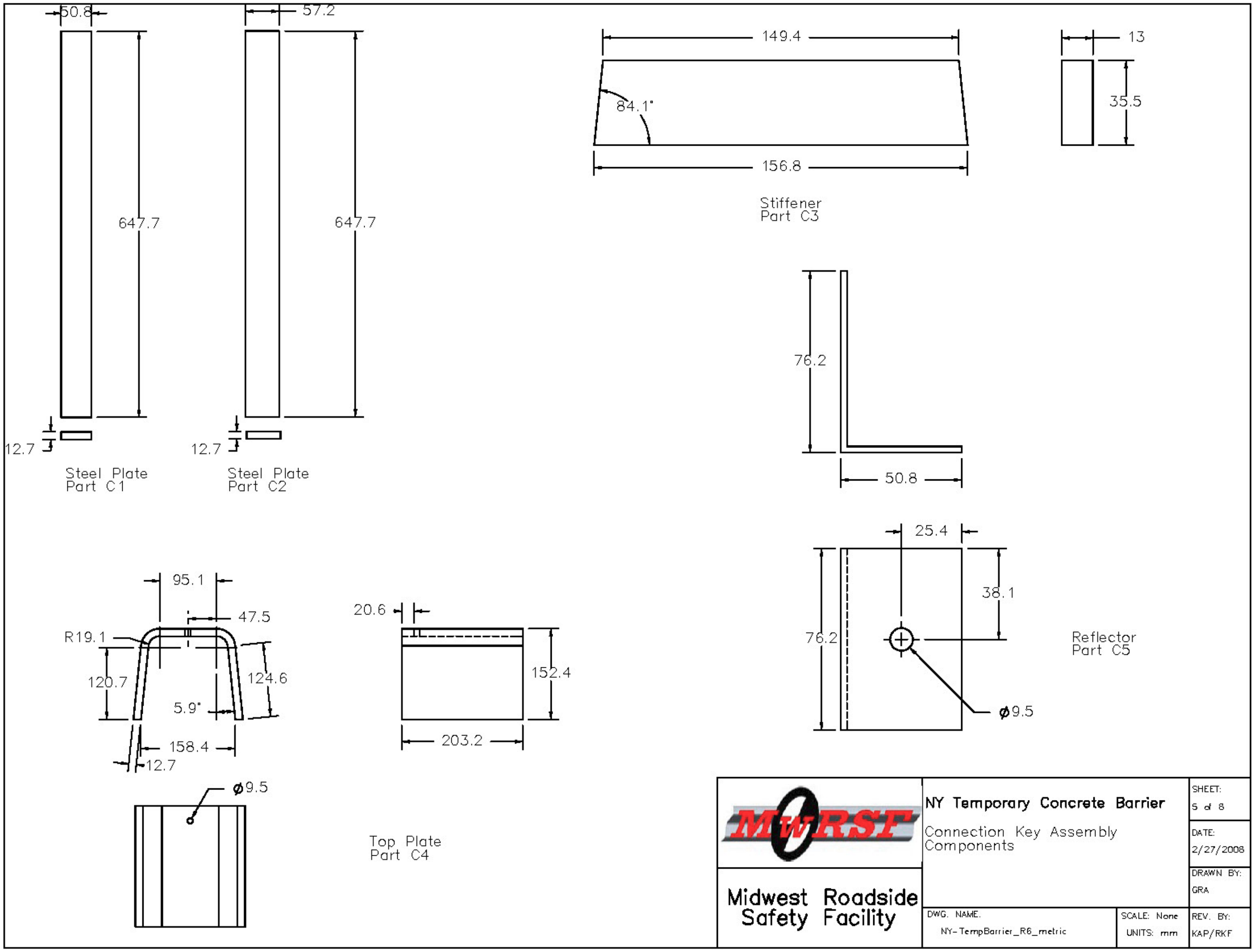


Figure E-7. Connection Key Assembly Details, Test NYTCB-2

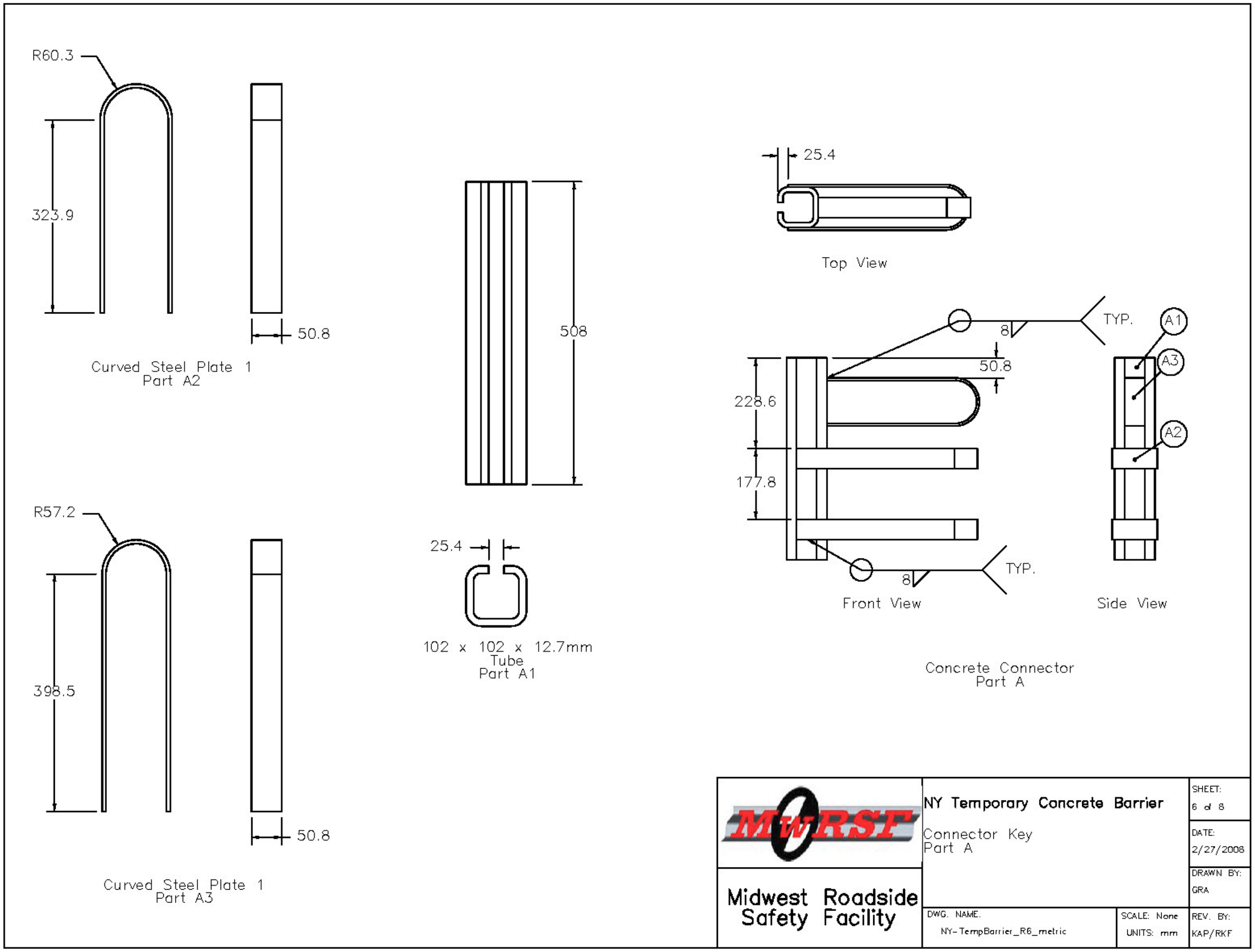


Figure E-8. Temporary Concrete Barrier Connector Assembly Details, Test NYTCB-2

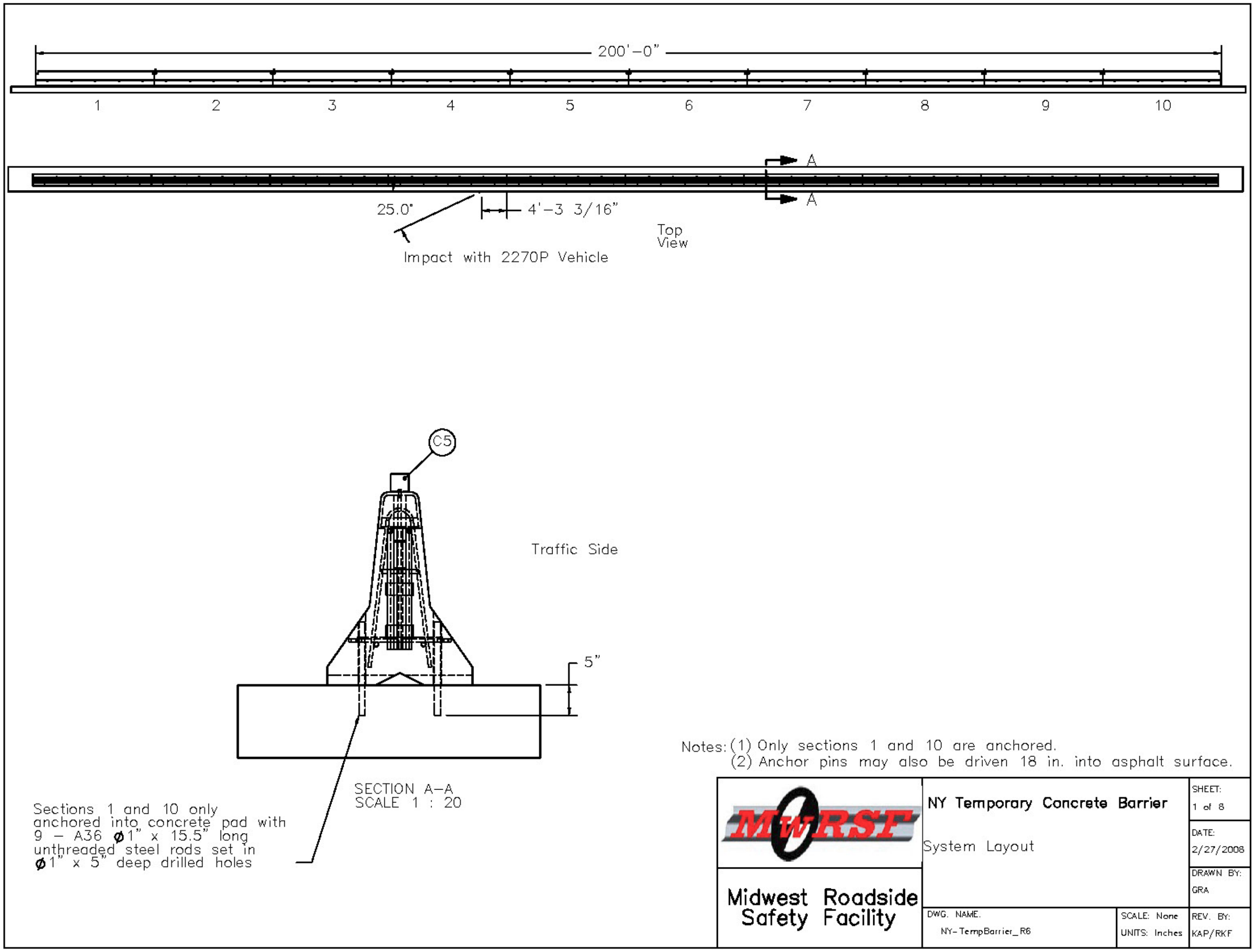


Figure E-9. Unstiffened Temporary Concrete Barrier System Layout (English), Test NYTCB-2

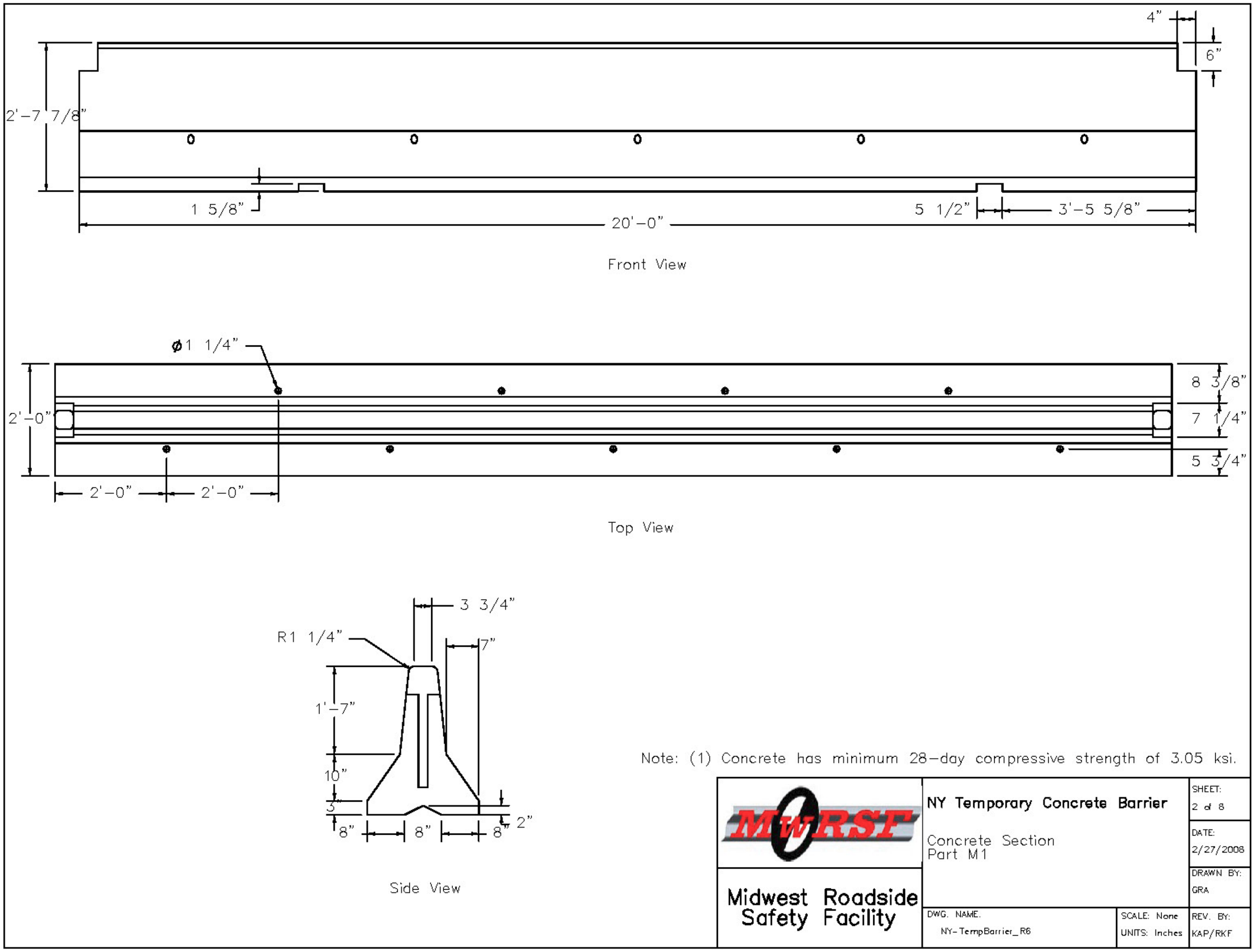


Figure E-10. Temporary Concrete Barrier Details (English), Test NYTCB-2

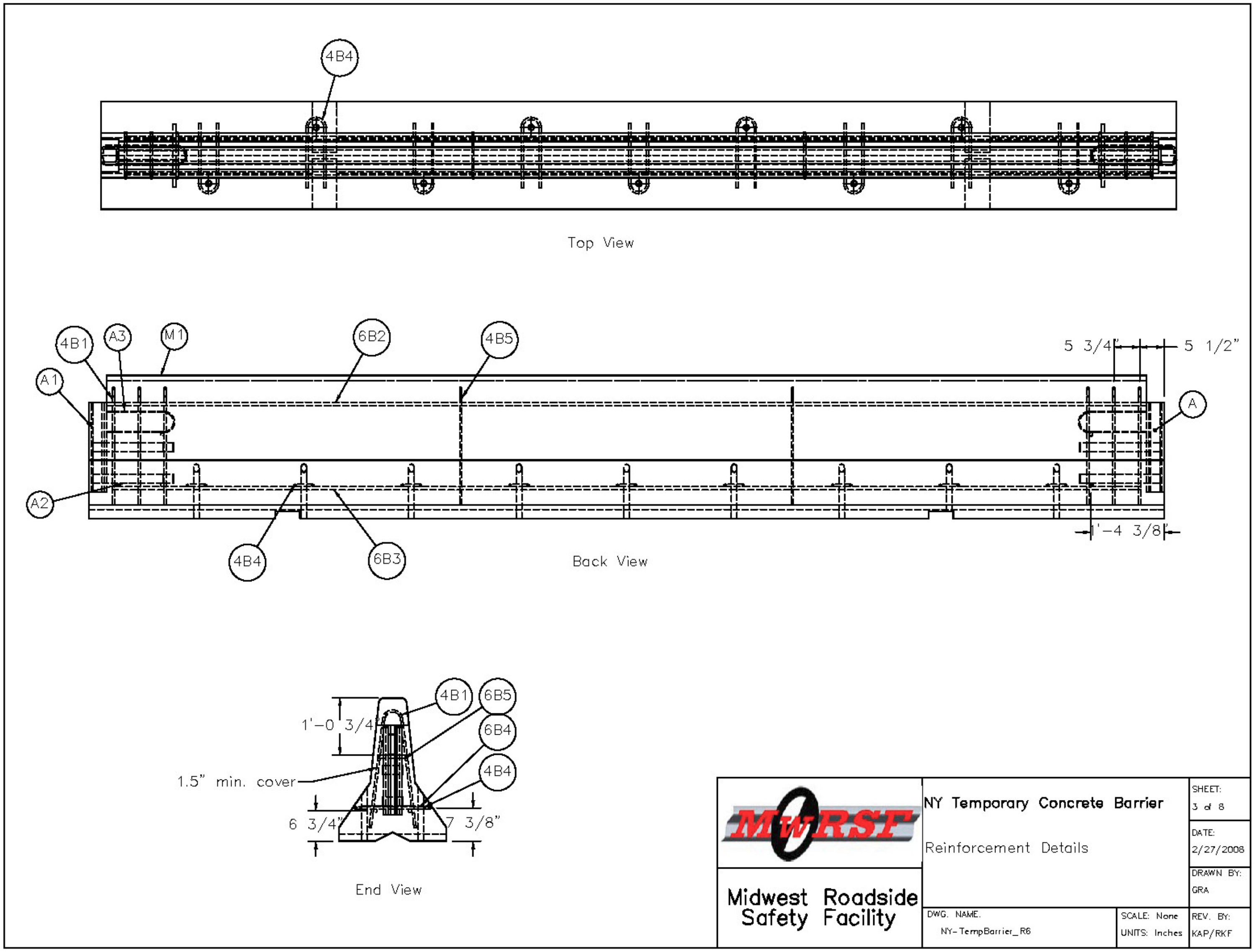
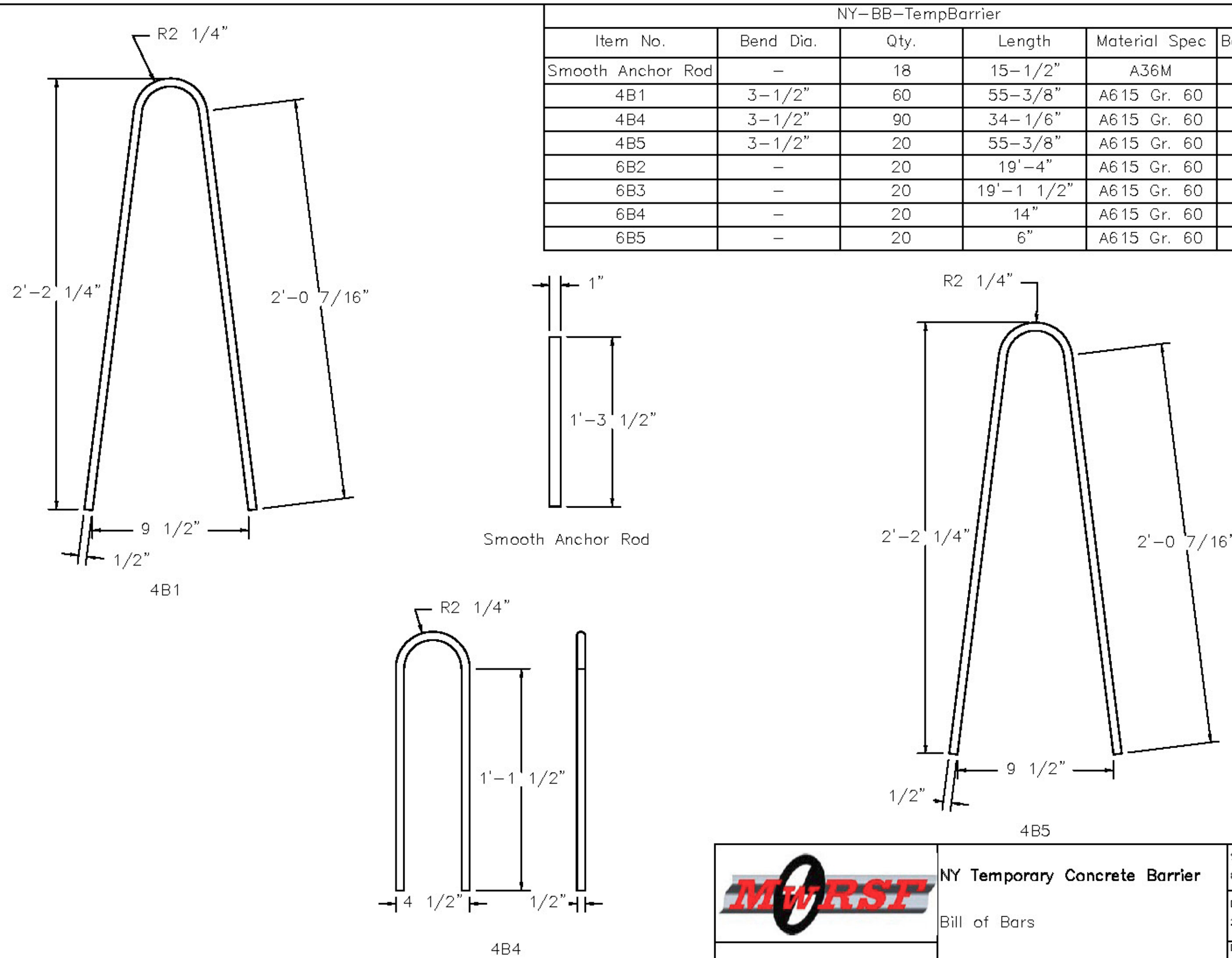


Figure E-11. Temporary Concrete Barrier Reinforcement Details (English), Test NYTCB-2

NY-BB-TempBarrier					
Item No.	Bend Dia.	Qty.	Length	Material Spec	Bar Size
Smooth Anchor Rod	–	18	15-1/2"	A36M	1"
4B1	3-1/2"	60	55-3/8"	A615 Gr. 60	4
4B4	3-1/2"	90	34-1/6"	A615 Gr. 60	4
4B5	3-1/2"	20	55-3/8"	A615 Gr. 60	4
6B2	–	20	19'-4"	A615 Gr. 60	6
6B3	–	20	19'-1 1/2"	A615 Gr. 60	6
6B4	–	20	14"	A615 Gr. 60	6
6B5	–	20	6"	A615 Gr. 60	6



Note: (1) Quantities in Bill of Bars represent a system with 10 barriers.

MwRSF Midwest Roadside Safety Facility	NY Temporary Concrete Barrier		SHEET: 8 of 8
	Bill of Bars		DATE: 2/27/2008
			DRAWN BY: GRA
	DWG. NAME. NY-TempBarrier_R6	SCALE: None UNITS: Inches	REV. BY: KAP/RKF

Figure E-12. Bill of Bars (English), Test NYTCB-2

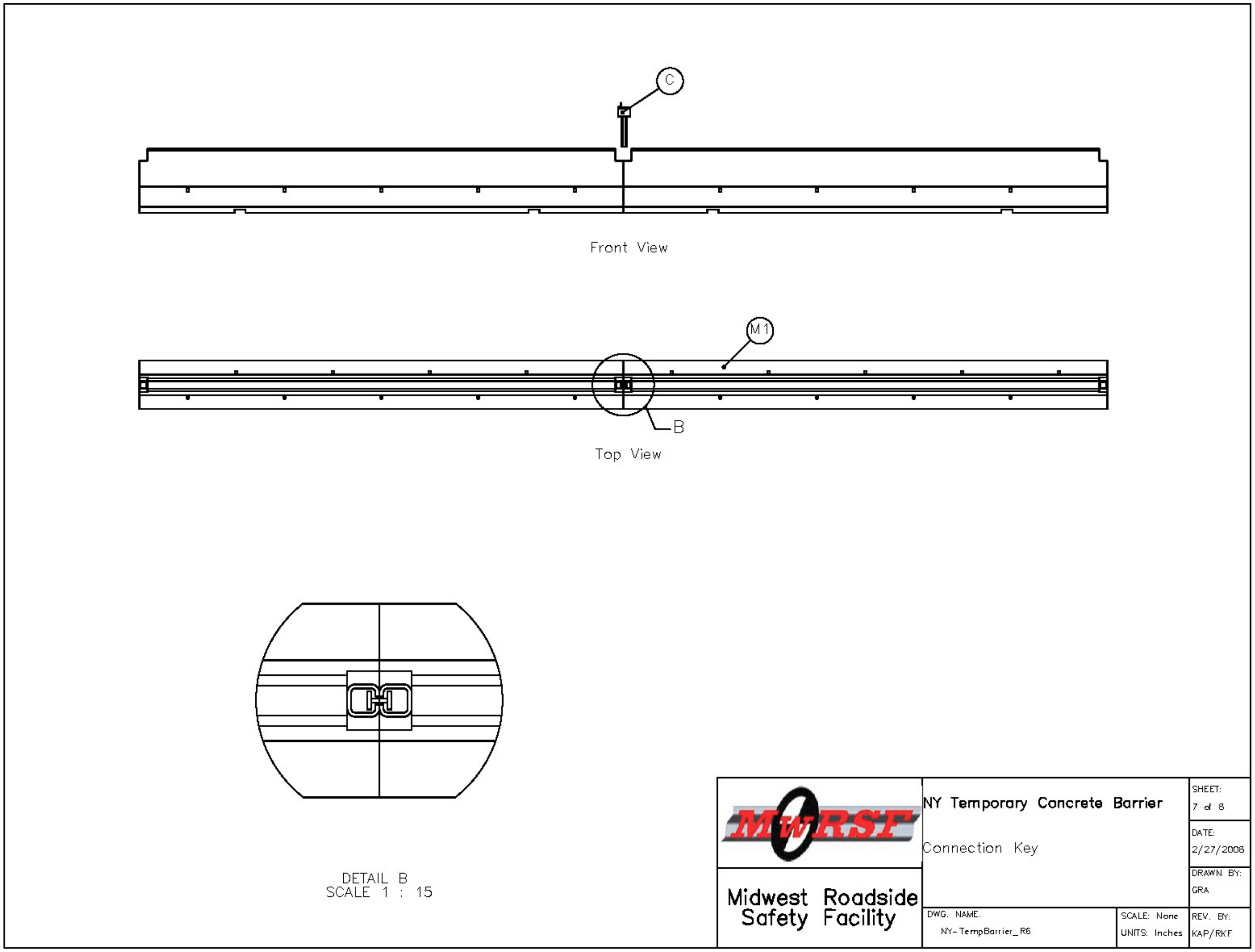


Figure E-13. Temporary Concrete Barrier Connection Details (English), Test NYTCB-2

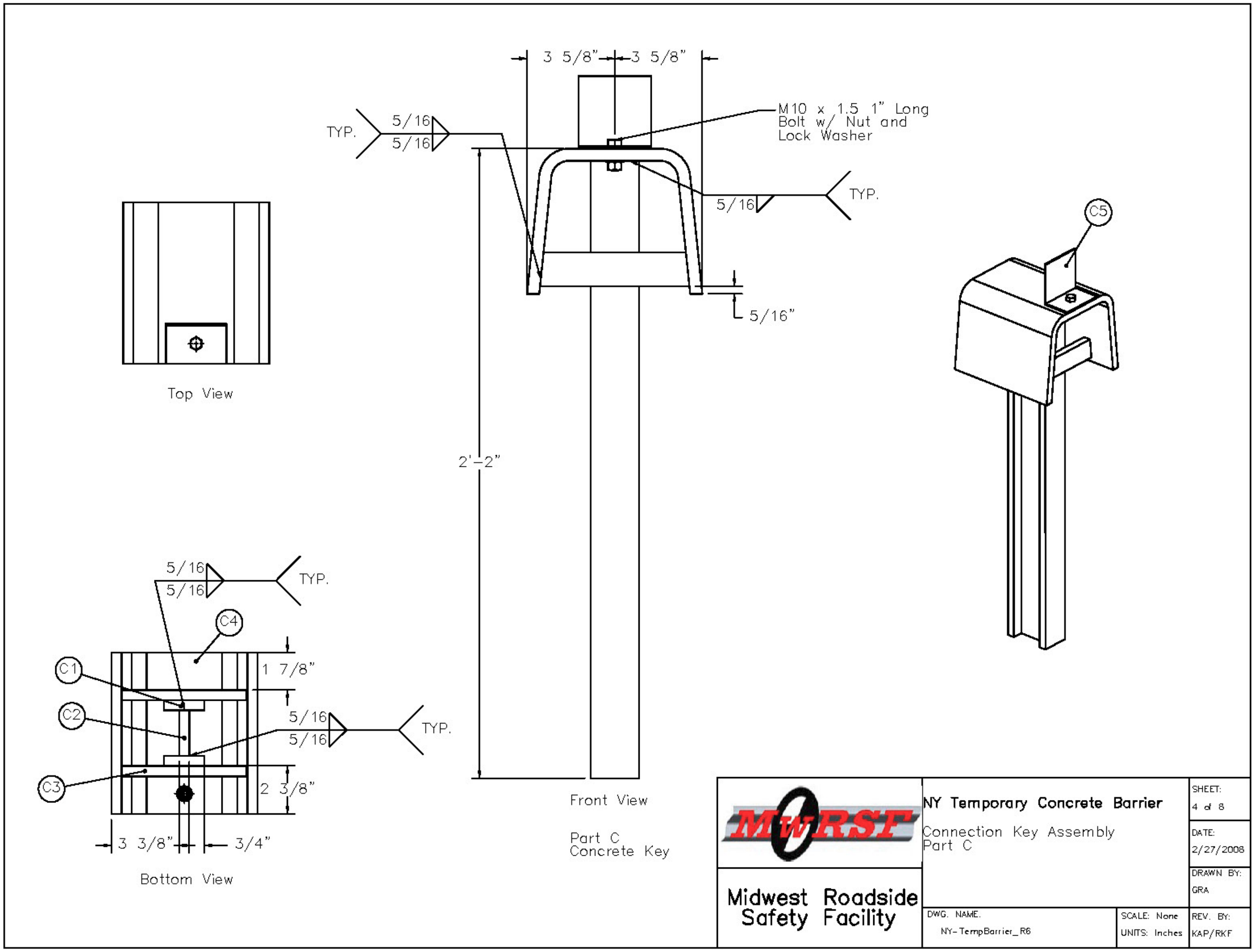


Figure E-14. Connection Key Assembly Details (English), Test NYTCB-2

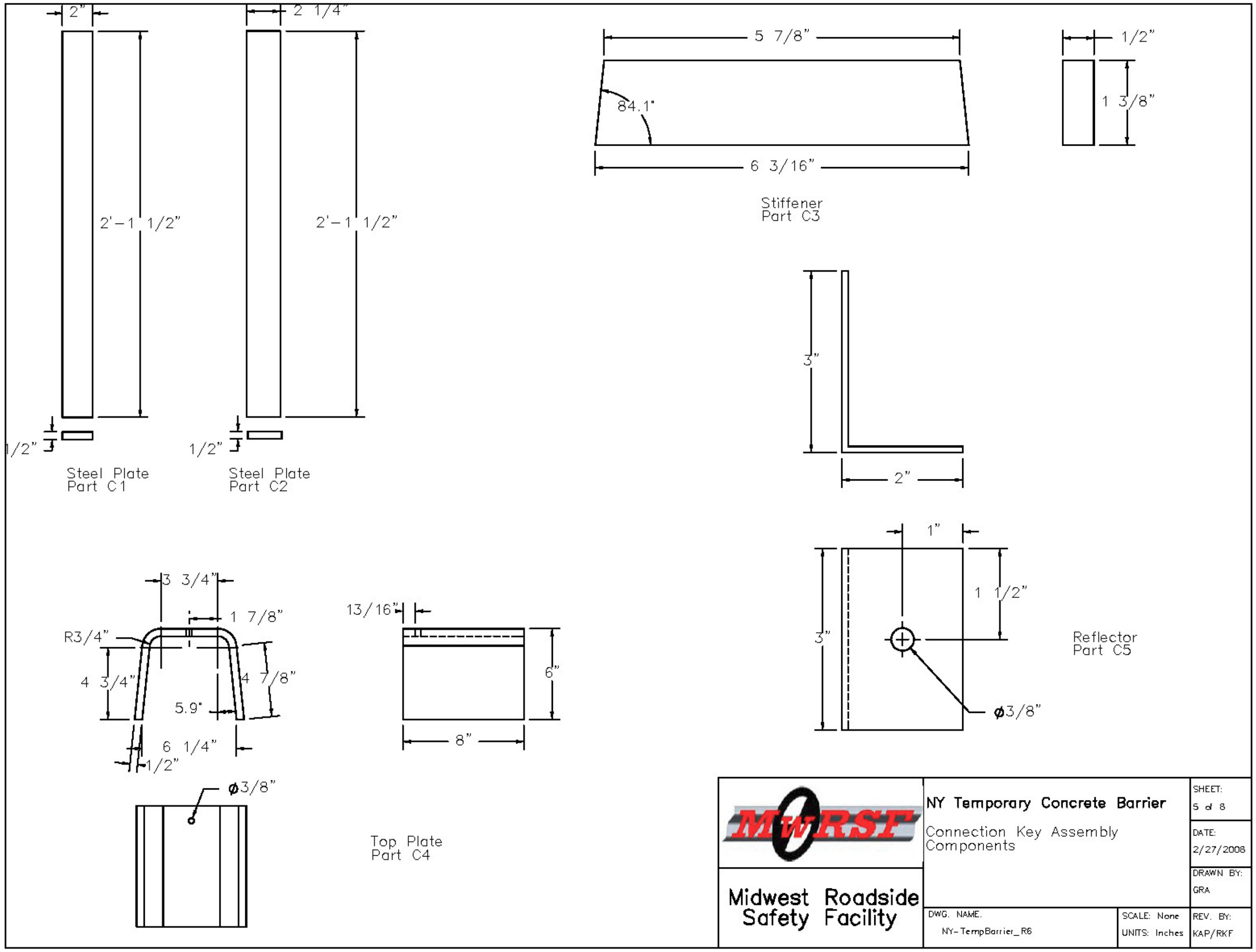


Figure E-15. Connection Key Assembly Details (English), Test NYTCB-2

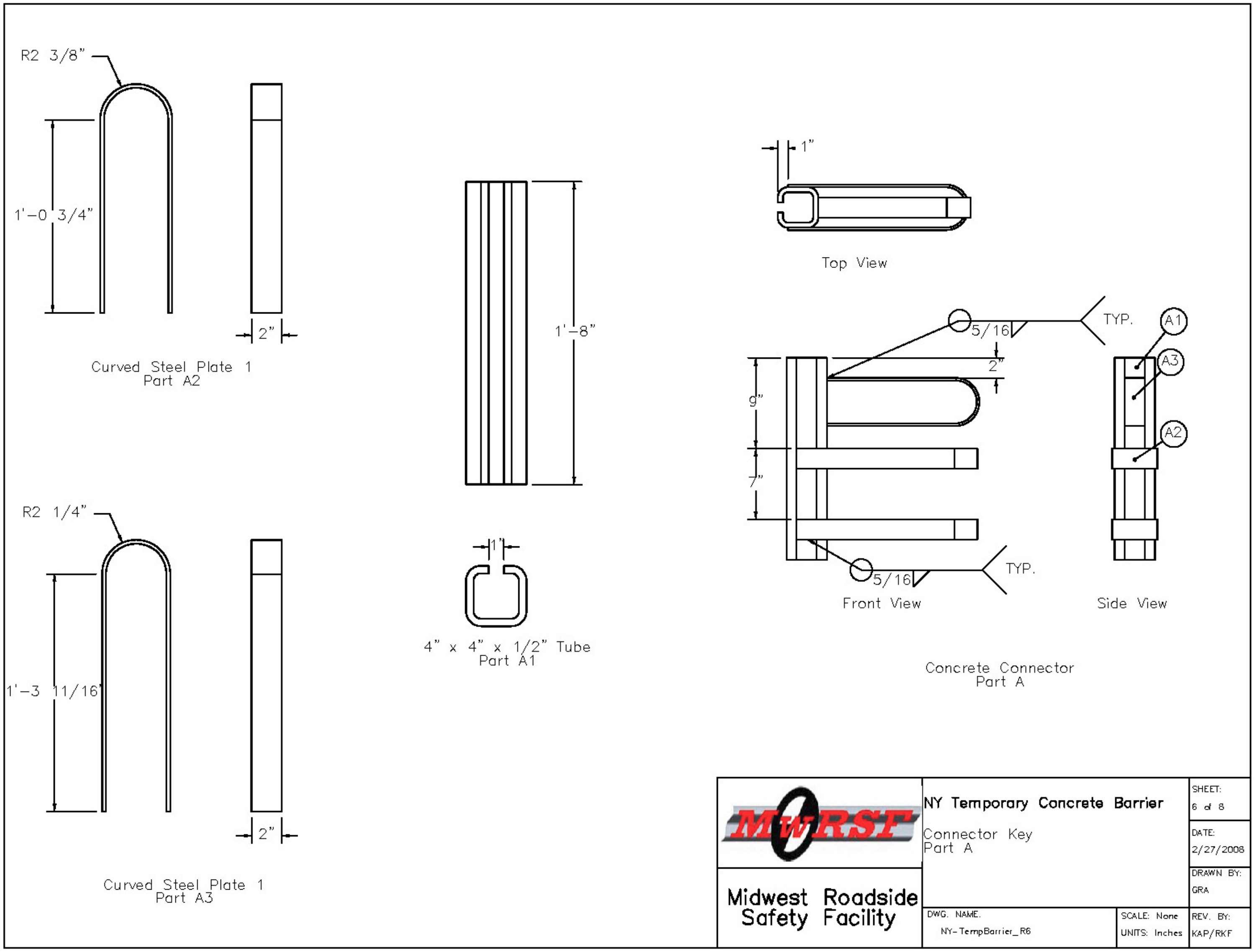


Figure E-16. Temporary Concrete Barrier Connector Assembly Details (English), Test NYTCB-2

APPENDIX F

Accelerometer and Rate Transducer Data Analysis, Test NYTCB-2

Figure F-1. Graph of Longitudinal Deceleration, Test NYTCB-2

Figure F-2. Graph of Longitudinal Occupant Impact Velocity, Test NYTCB-2

Figure F-3. Graph of Longitudinal Occupant Displacement, Test NYTCB-2

Figure F-4. Graph of Lateral Deceleration, Test NYTCB-2

Figure F-5. Graph of Lateral Occupant Impact Velocity, Test NYTCB-2

Figure F-6. Graph of Lateral Occupant Displacement, Test NYTCB-2

Figure F-7. Graph of Roll, Pitch, and Yaw Angular Displacements, Test NYTCB-2

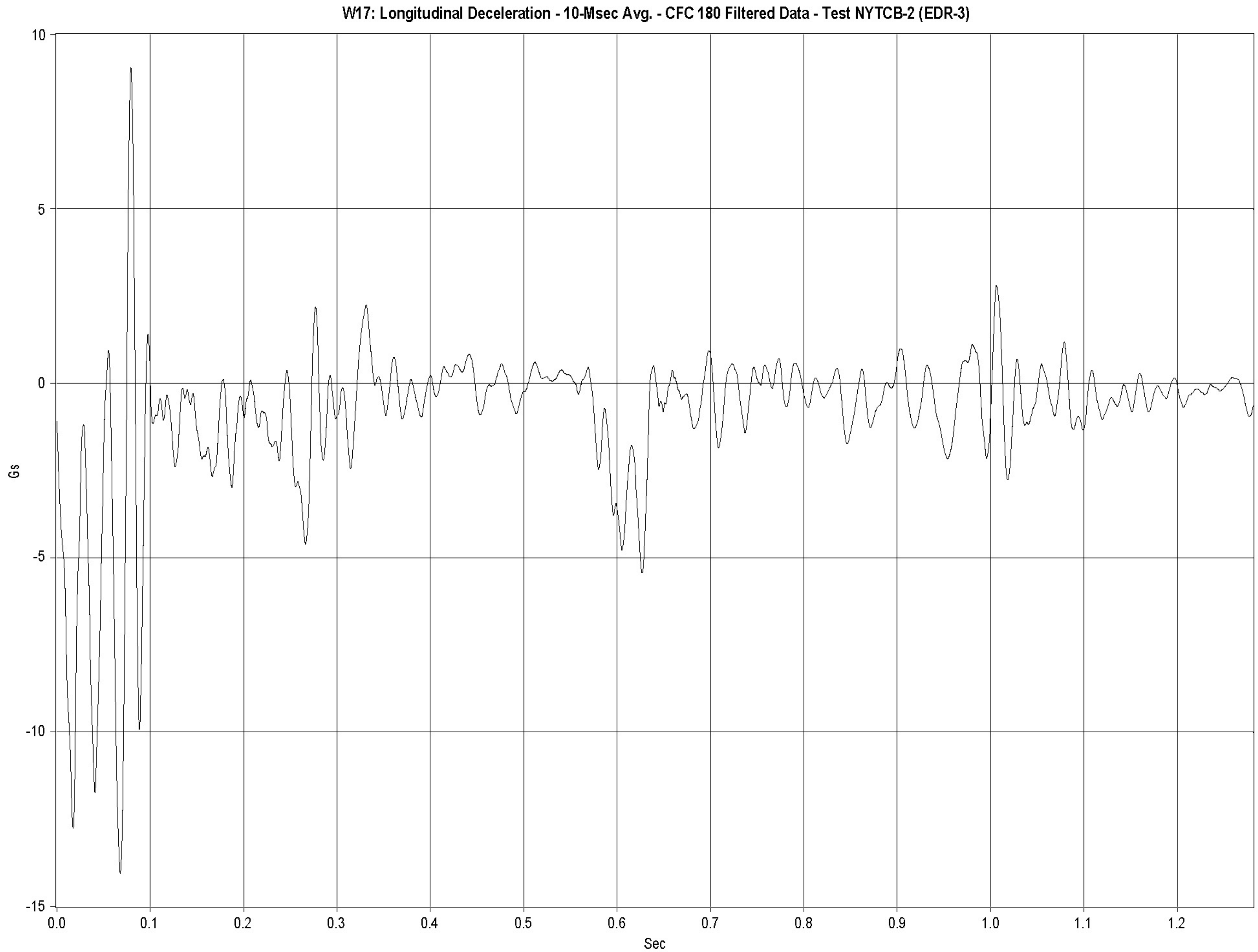


Figure F-1. Graph of Longitudinal Deceleration, Test NYTCB-2

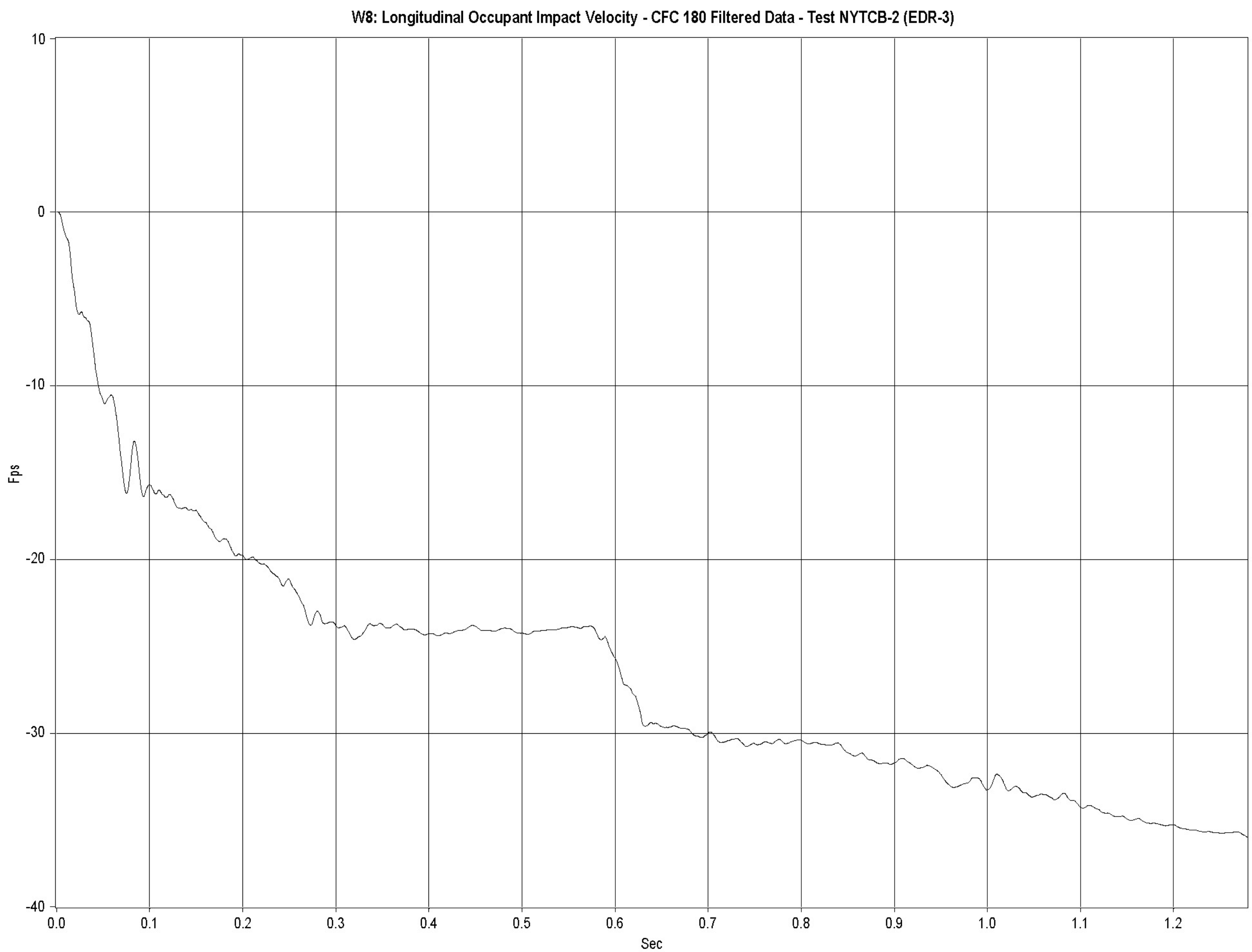


Figure F-2. Graph of Longitudinal Impact Velocity, Test NYTCB-2

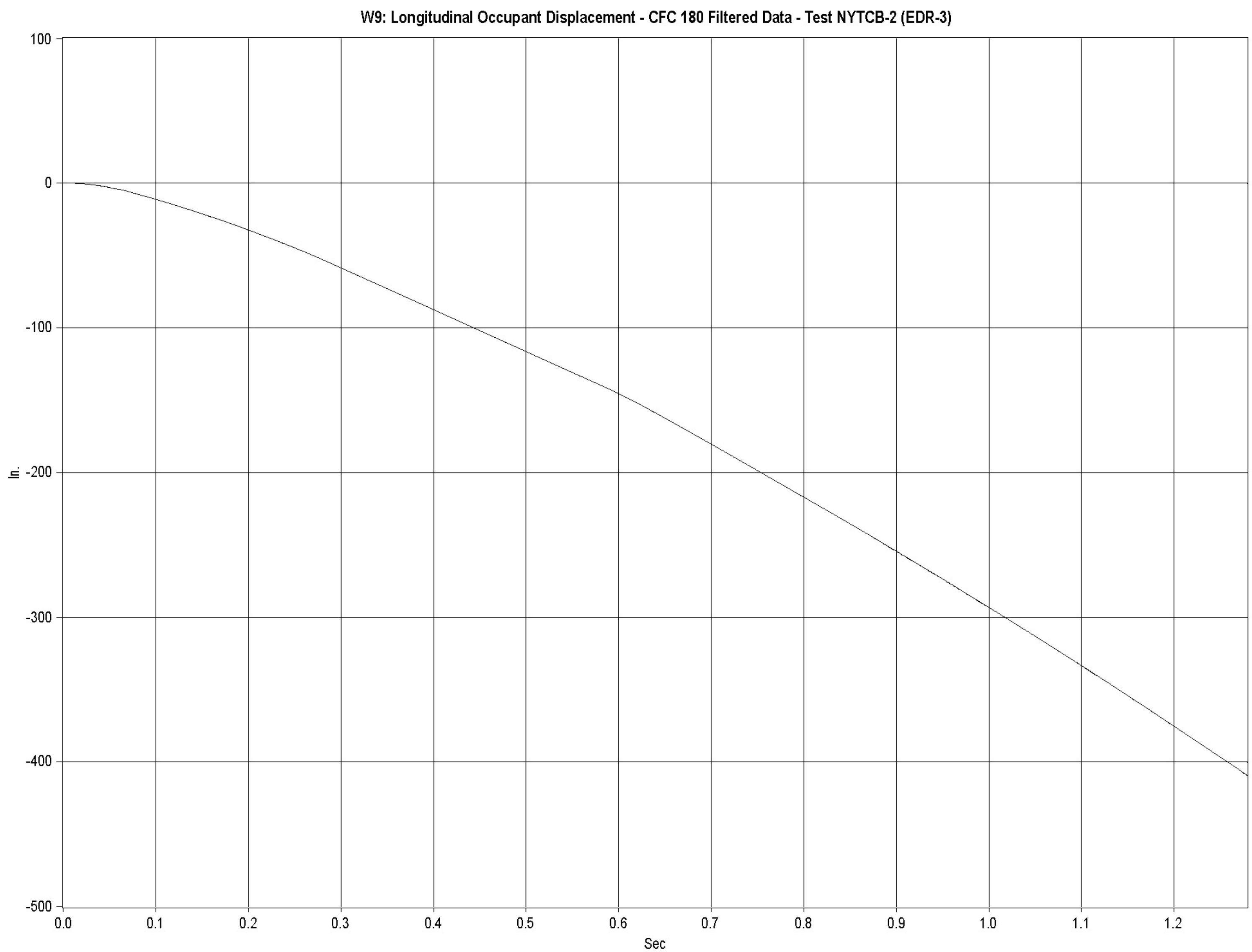


Figure F-3. Graph of Longitudinal Occupant Displacement, Test NYTCB-2

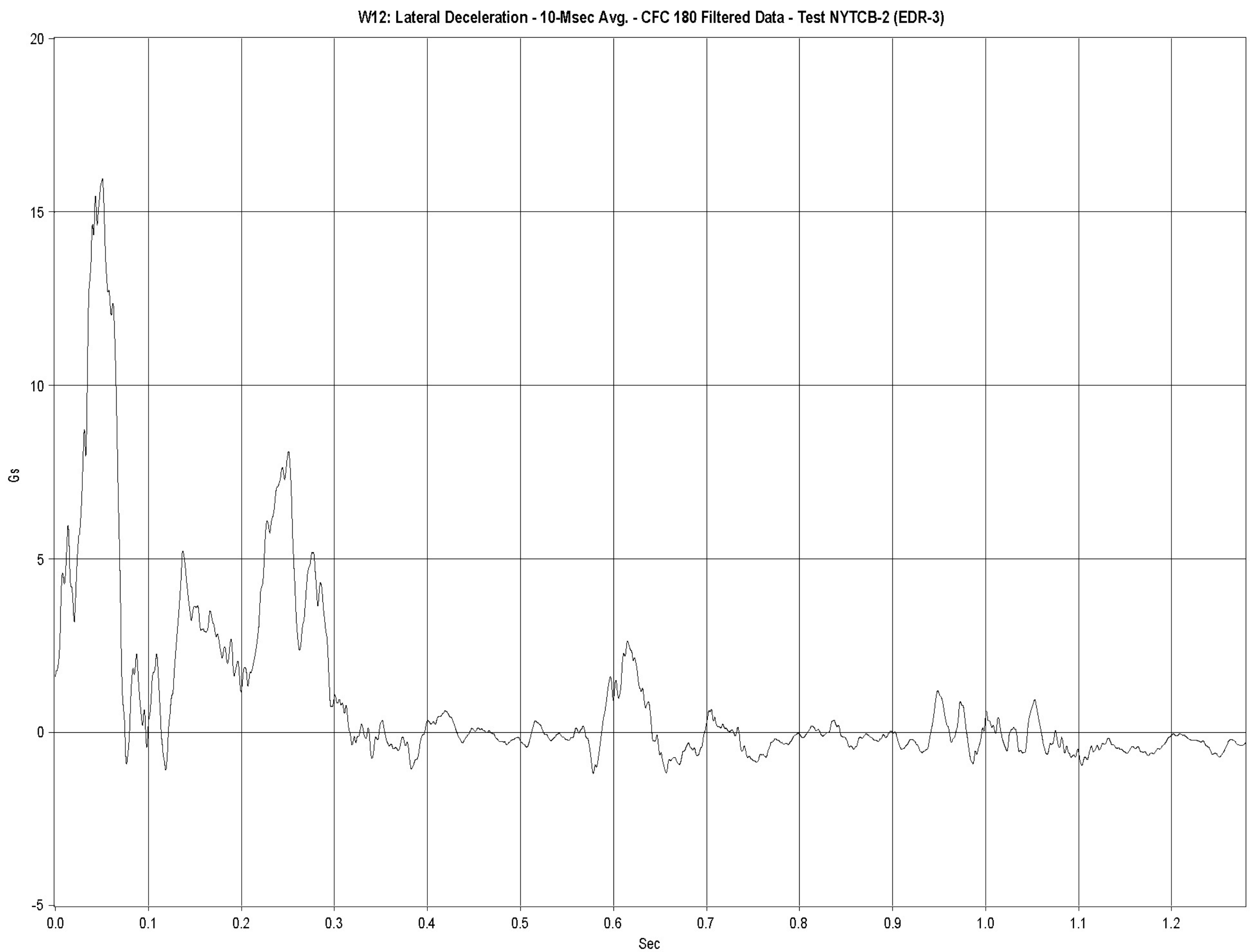


Figure F-4. Graph of Lateral Deceleration, Test NYTCB-2

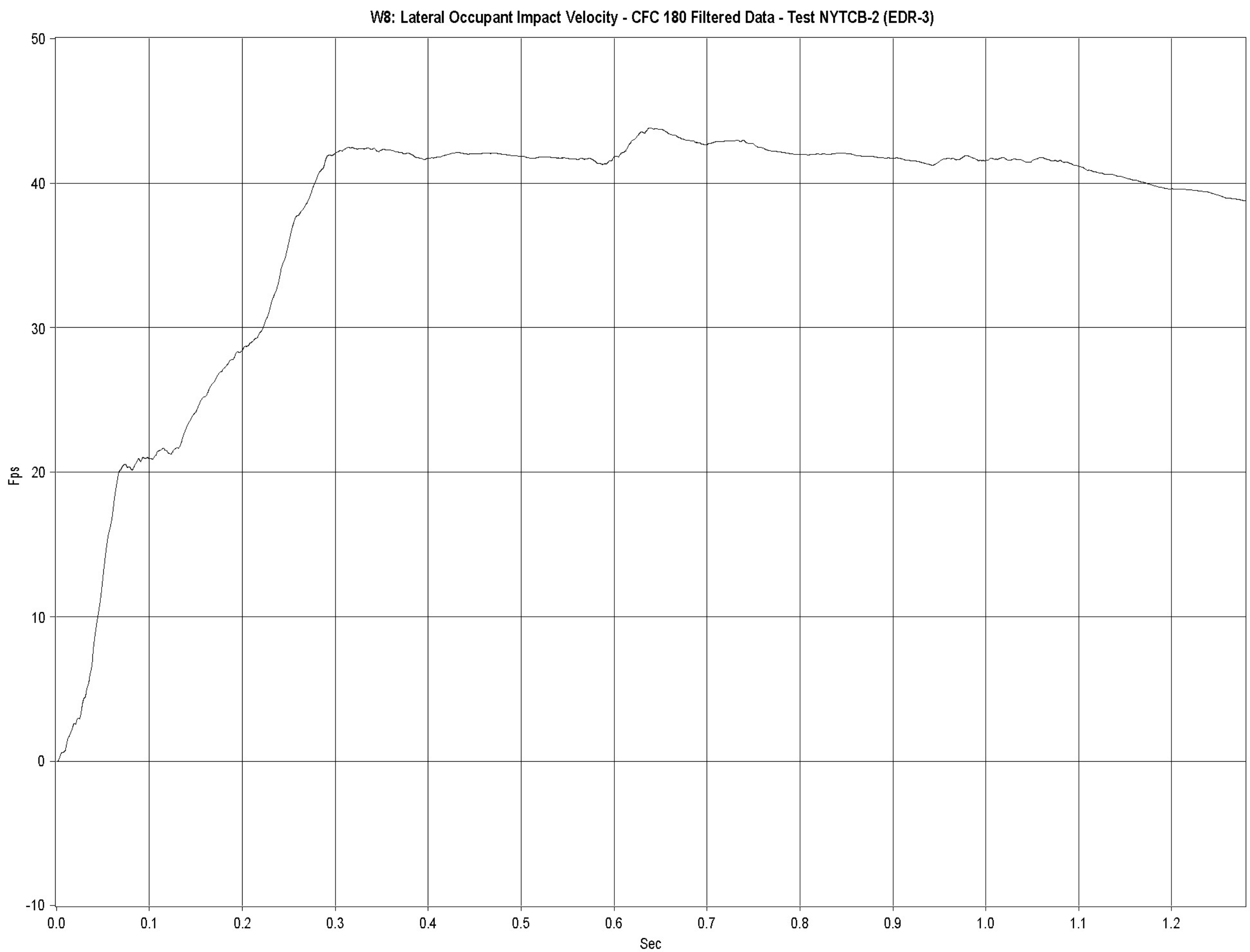


Figure F-5. Graph of Lateral Occupant Impact Velocity, Test NYTCB-2

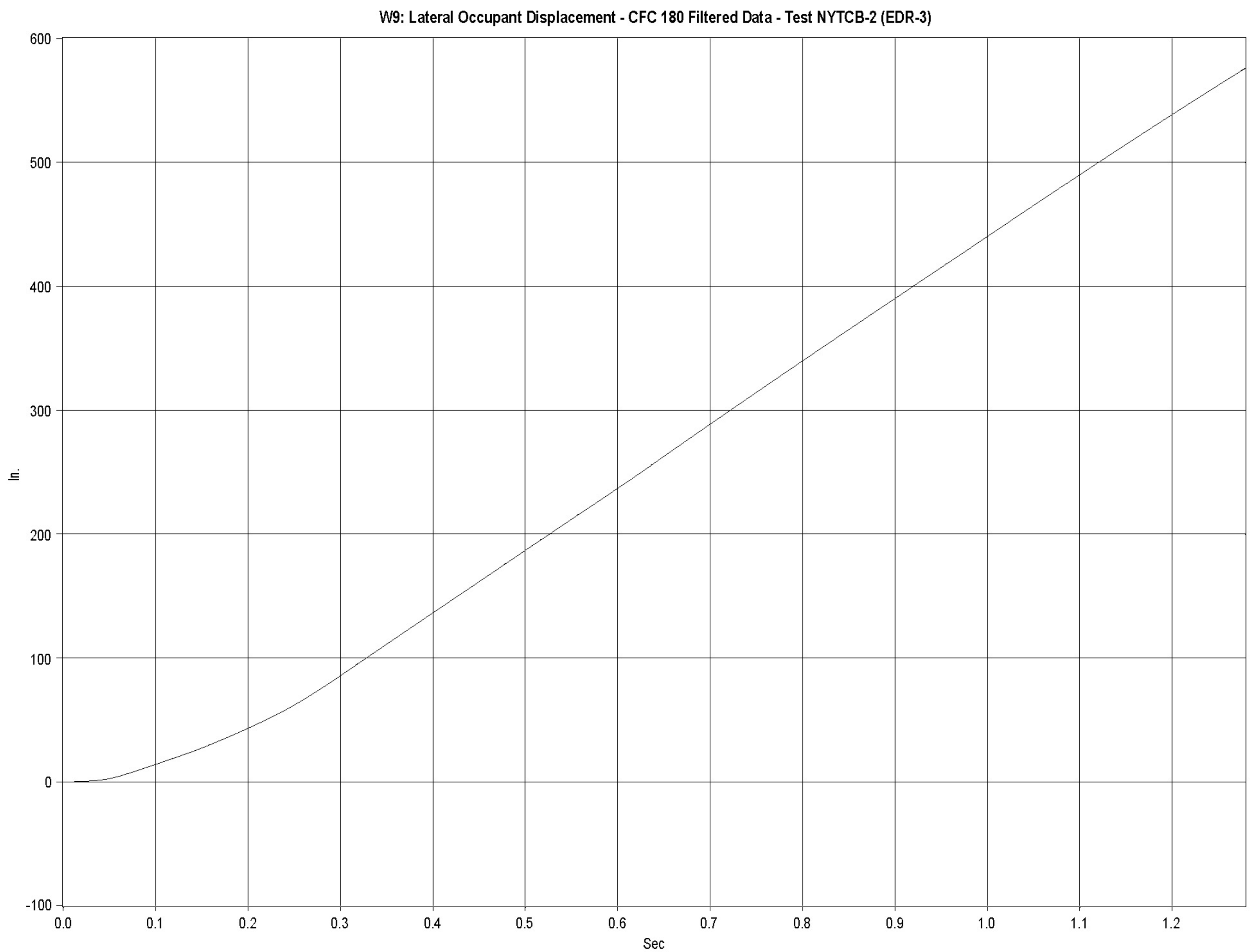


Figure F-6. Graph of Lateral Occupant Displacement, Test NYTCB-2

Figure F-7. Graph of Roll, Pitch, and Yaw Angular Displacements, Test NYTCB-2

APPENDIX G

Metric- and English-Unit System Drawings, Test NYTCB-3

Figure G-1. Stiffened Temporary Concrete Barrier System Layout, Test NYTCB-3

Figure G-2. Temporary Concrete Barrier Details, Test NYTCB-3

Figure G-3. Temporary Concrete Barrier Reinforcement Details, Test NYTCB-3

Figure G-4. Bill of Bars, Test NYTCB-3

Figure G-5. Temporary Concrete Barrier Connection Details, Test NYTCB-3

Figure G-6. Connection Key Assembly Details, Test NYTCB-3

Figure G-7. Connection Key Assembly Details, Test NYTCB-3

Figure G-8. Temporary Concrete Barrier Connector Assembly Details, Test NYTCB-3

Figure G-9. Box Beam Stiffener Details, Test NYTCB-3

Figure G-10. Temporary Concrete Barrier Stiffener Hole Details, Test NYTCB-3

Figure G-11. Box Beam Stiffener Details, Test NYTCB-3

Figure G-12. Stiffened Temporary Concrete Barrier System Layout (English), Test NYTCB-3

Figure G-13. Temporary Concrete Barrier Details (English), Test NYTCB-3

Figure G-14. Temporary Concrete Barrier Reinforcement Details (English), Test NYTCB-3

Figure G-15. Bill of Bars (English), Test NYTCB-3

Figure G-16. Temporary Concrete Barrier Connection Details (English), Test NYTCB-3

Figure G-17. Connection Key Assembly Details (English), Test NYTCB-3

Figure G-18. Connection Key Assembly Details (English), Test NYTCB-3

Figure G-19. Temporary Concrete Barrier Connector Assembly Details (English), Test NYTCB-3

Figure G-20. Box Beam Stiffener Details (English), Test NYTCB-3

Figure G-21. Temporary Concrete Barrier Stiffener Hole Details (English), Test NYTCB-3

Figure G-22. Box Beam Stiffener Details (English), Test NYTCB-3

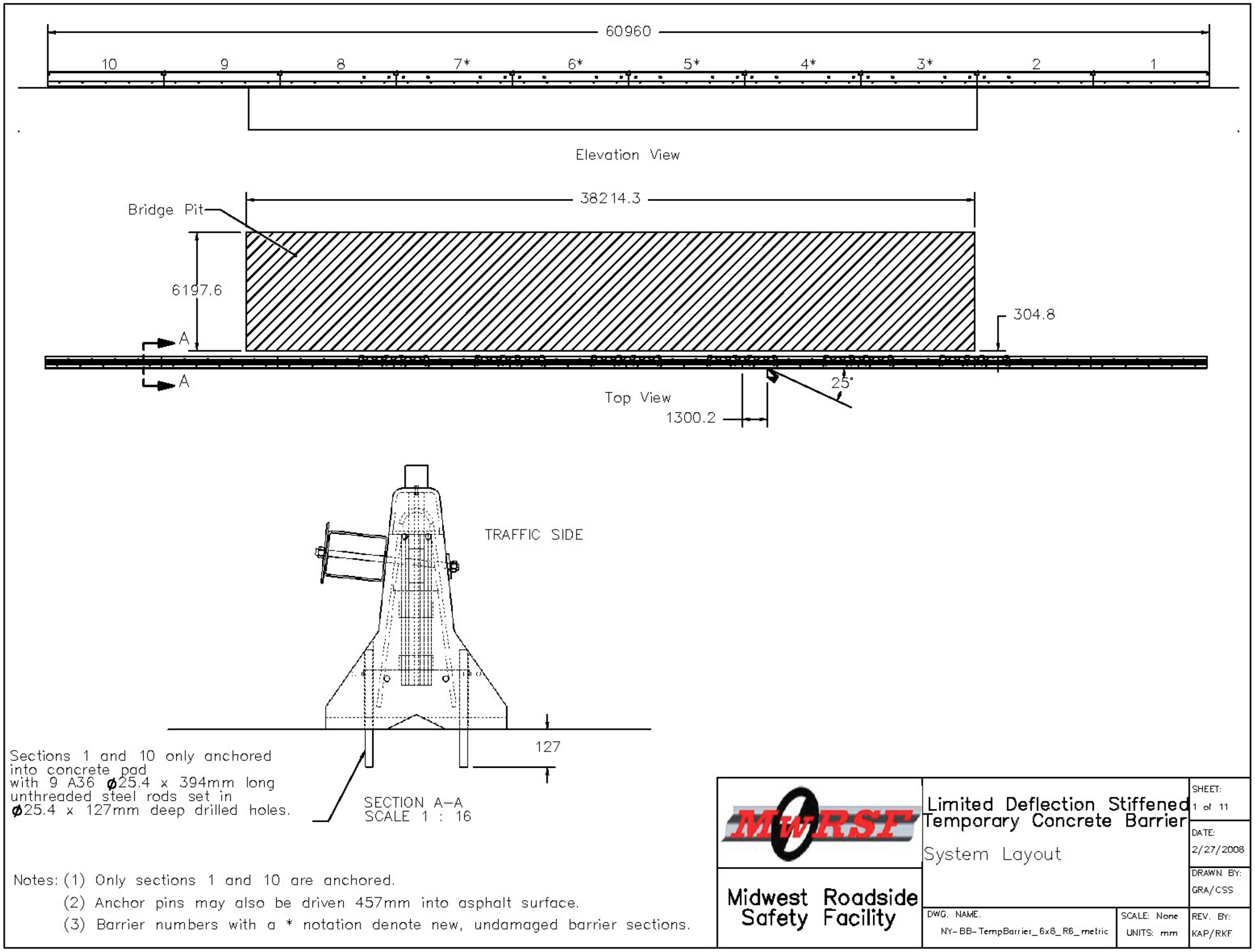


Figure G-1. Stiffened Temporary Concrete Barrier System Layout, Test NYTCB-3

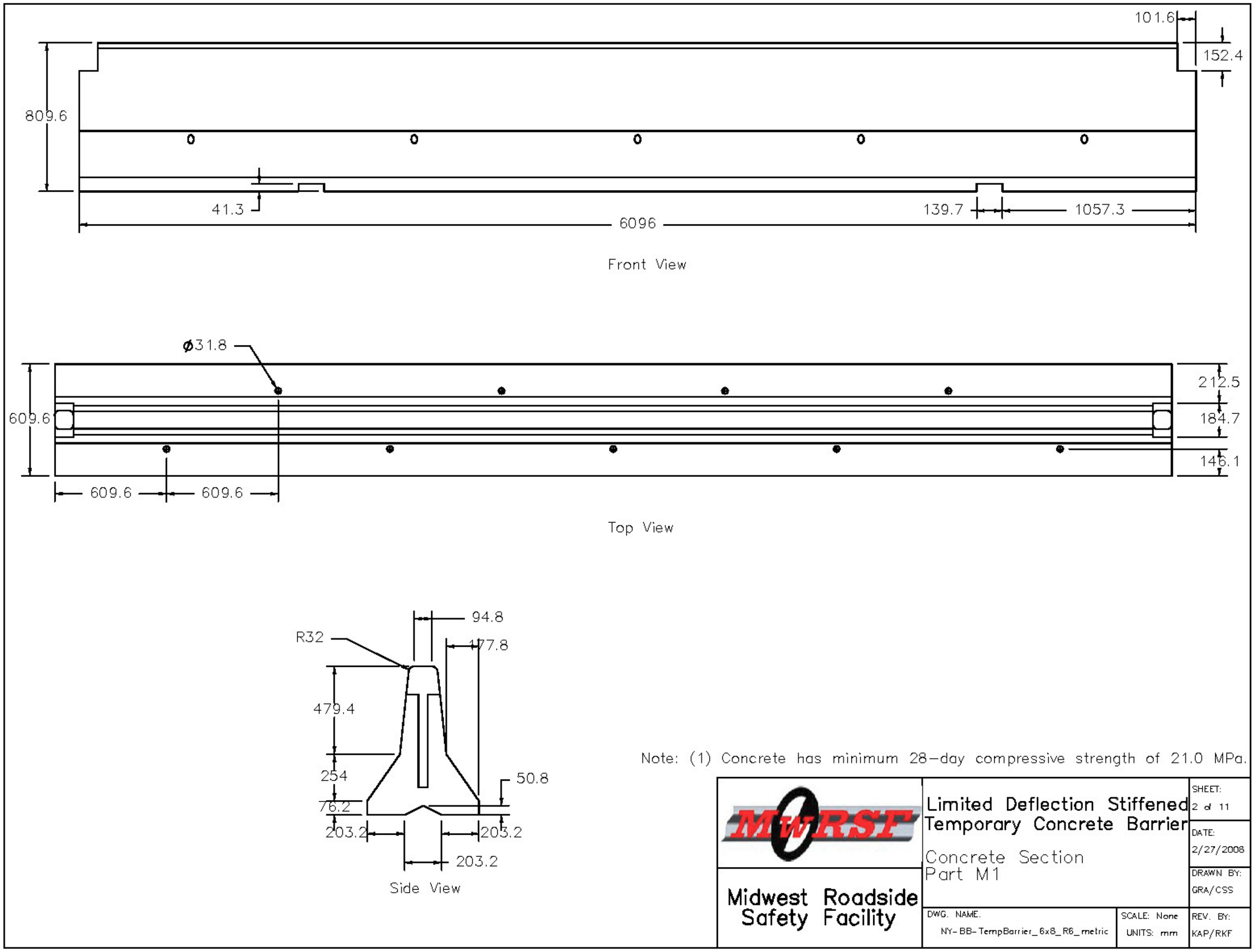


Figure G-2. Temporary Concrete Barrier Details, Test NYTCB-3

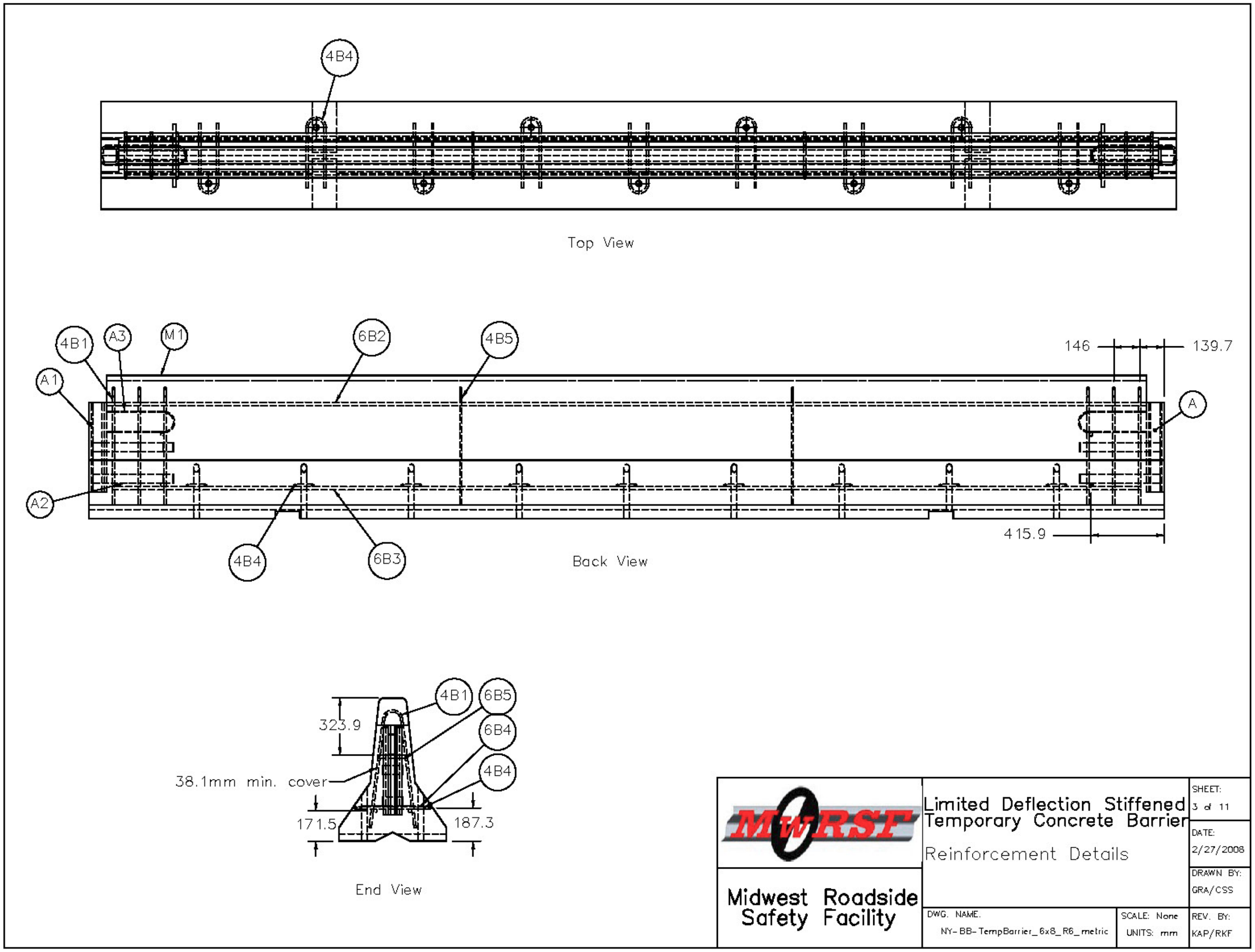
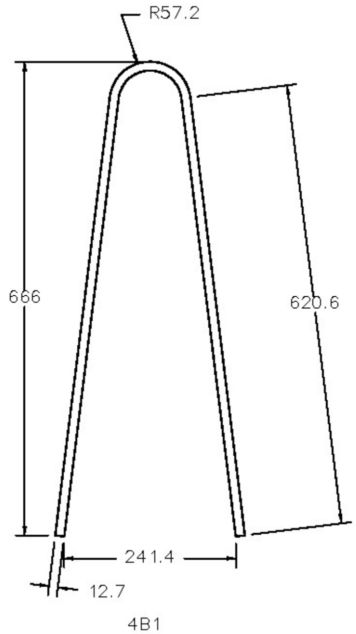
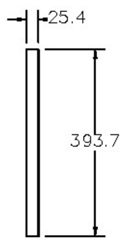


Figure G-3. Temporary Concrete Barrier Reinforcement Details, Test NYTCB-3

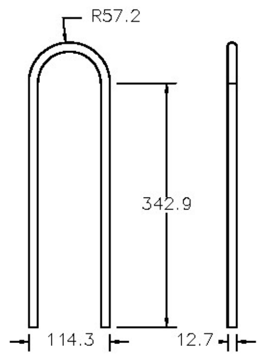
NY–BB–TempBarrier					
Item No.	Bend Dia.	Qty.	Length	Material Spec	Bar Size
Smooth Anchor Rod	–	18	394mm	A36M	25.4mm
4B1	89mm	60	1407mm	A615 Gr. 60	12.7mm
4B4	89mm	90	868mm	A615 Gr. 60	12.7mm
4B5	89mm	20	1407mm	A615 Gr. 60	12.7mm
6B2	–	20	5893mm	A615 Gr. 60	19mm
6B3	–	20	5830mm	A615 Gr. 60	19mm
6B4	–	20	356mm	A615 Gr. 60	19mm
6B5	–	20	152mm	A615 Gr. 60	19mm



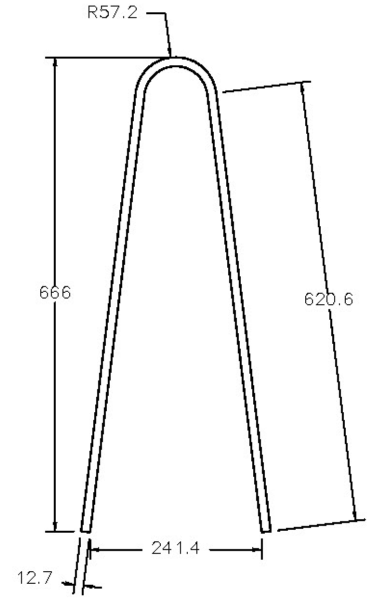
4B1



Smooth Anchor Rod



4B4



4B5

Note: (1) Quantities in Bill of Bars represent a system with 10 barriers.

Midwest Roadside Safety Facility

Limited Deflection Stiffened Temporary Concrete Barrier

Bill of Bars

SHEET: 8 of 11

DATE: 2/27/2008

DRAWN BY: GRA/CSS

DWG. NAME. NY-BB-TempBarrier_6x8_R6_metric

SCALE: None UNITS: mm

REV. BY: KAP/RKF

Figure G-4. Bill of Bars, Test NYTCB-3

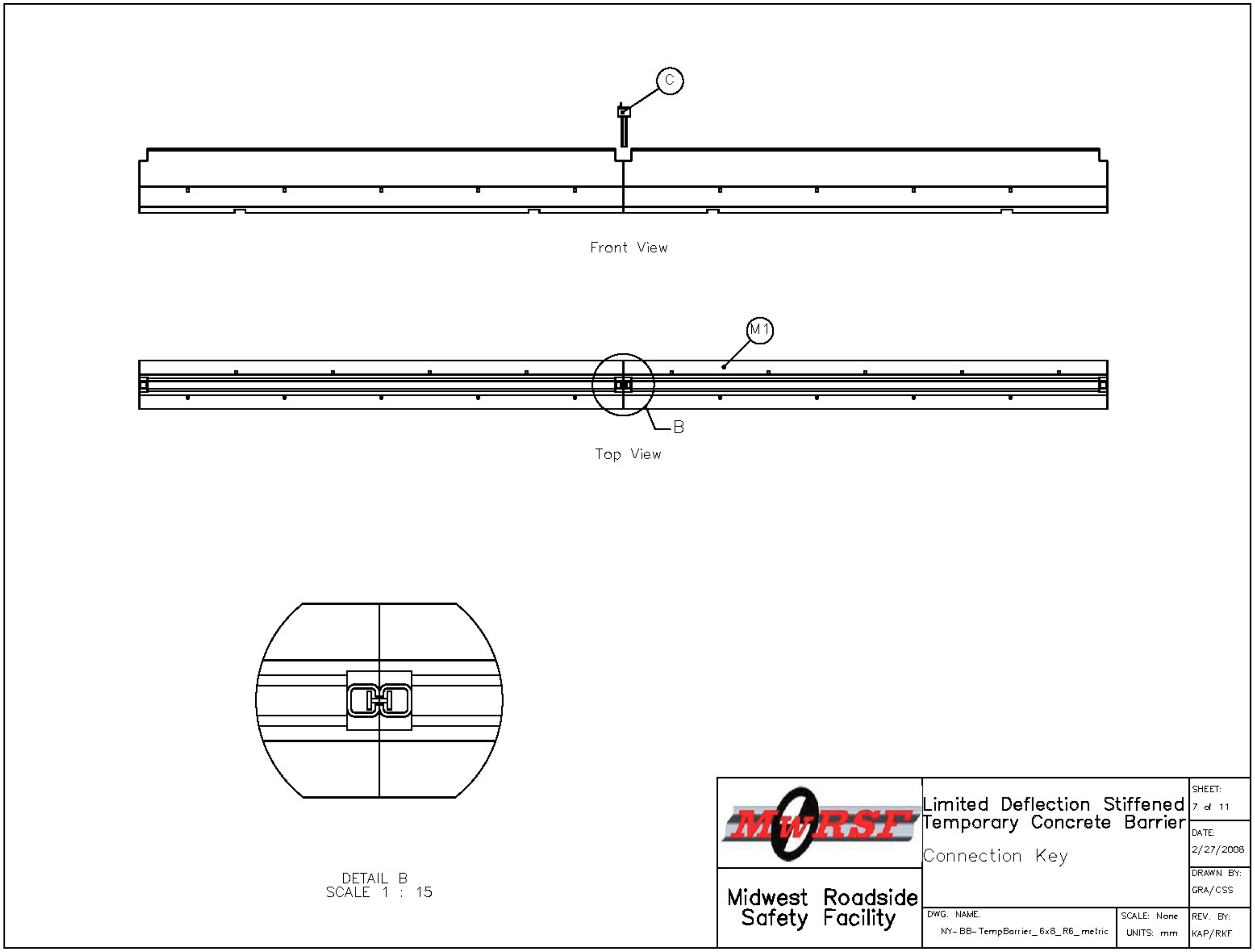


Figure G-5. Temporary Concrete Barrier Connection Details, Test NYTCB-3

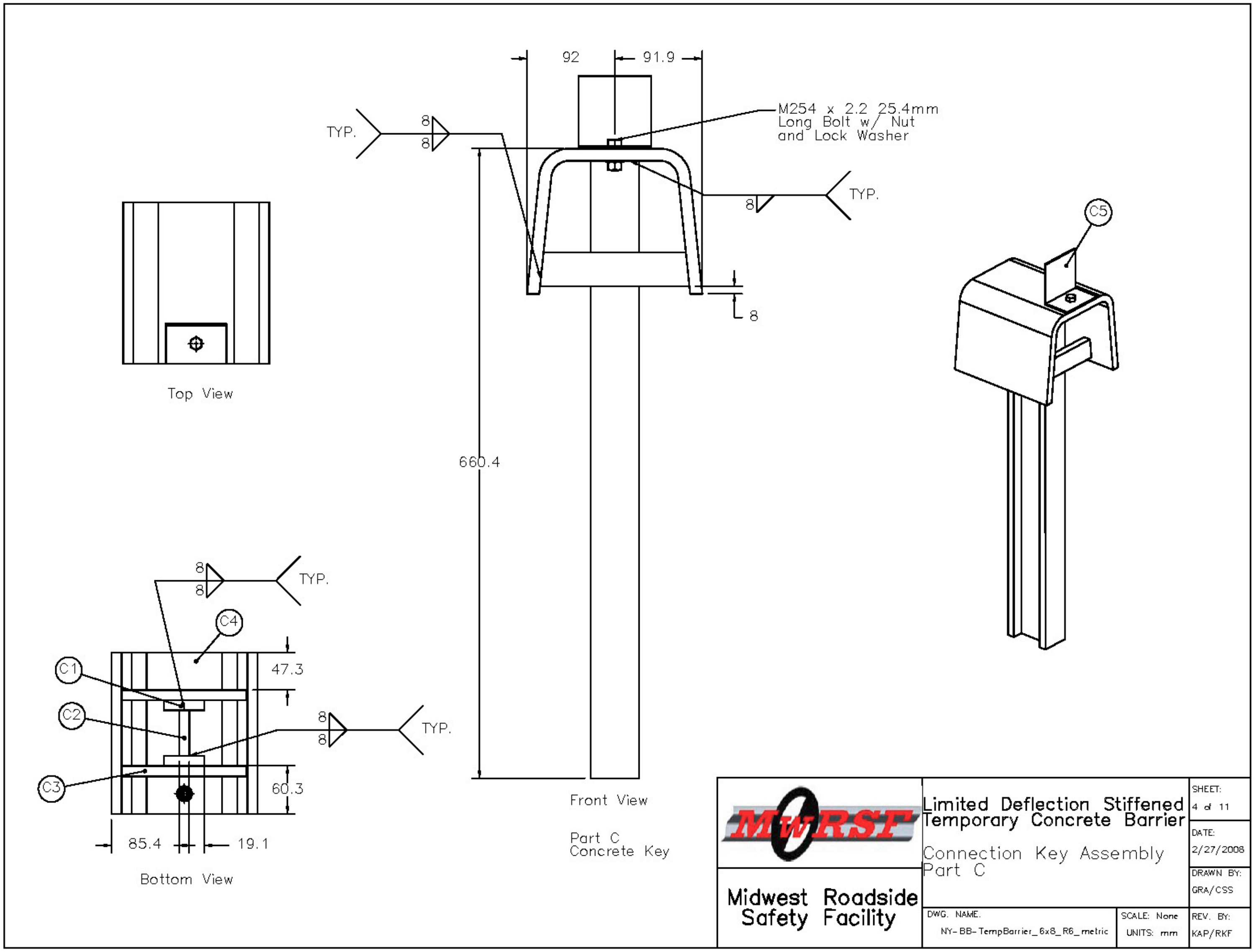


Figure G-6. Connection Key Assembly Details, Test NYTCB-3

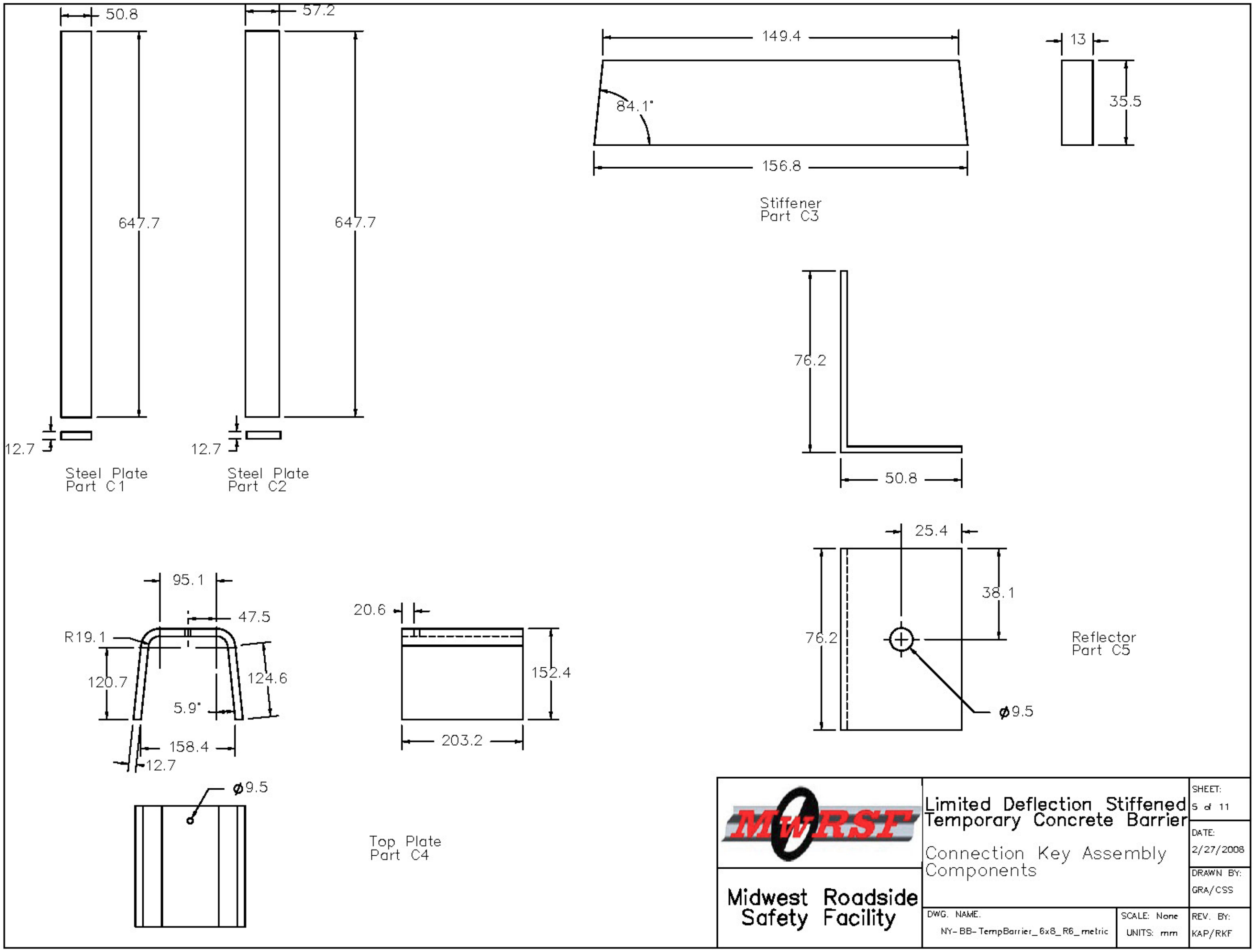


Figure G-7. Connection Key Assembly Details, Test NYTCB-3

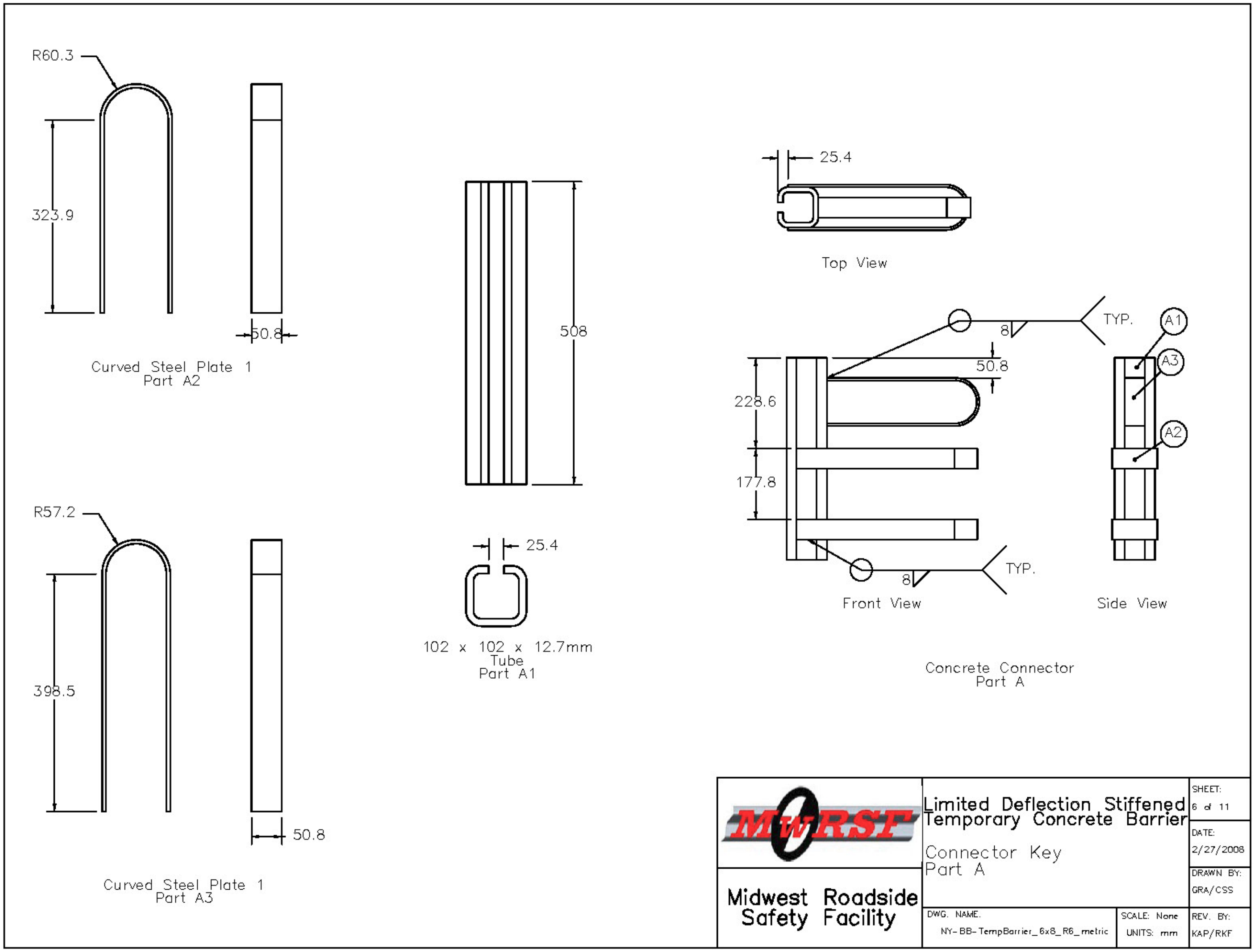


Figure G-8. Temporary Concrete Barrier Connector Assembly Details, Test NYTCB-3

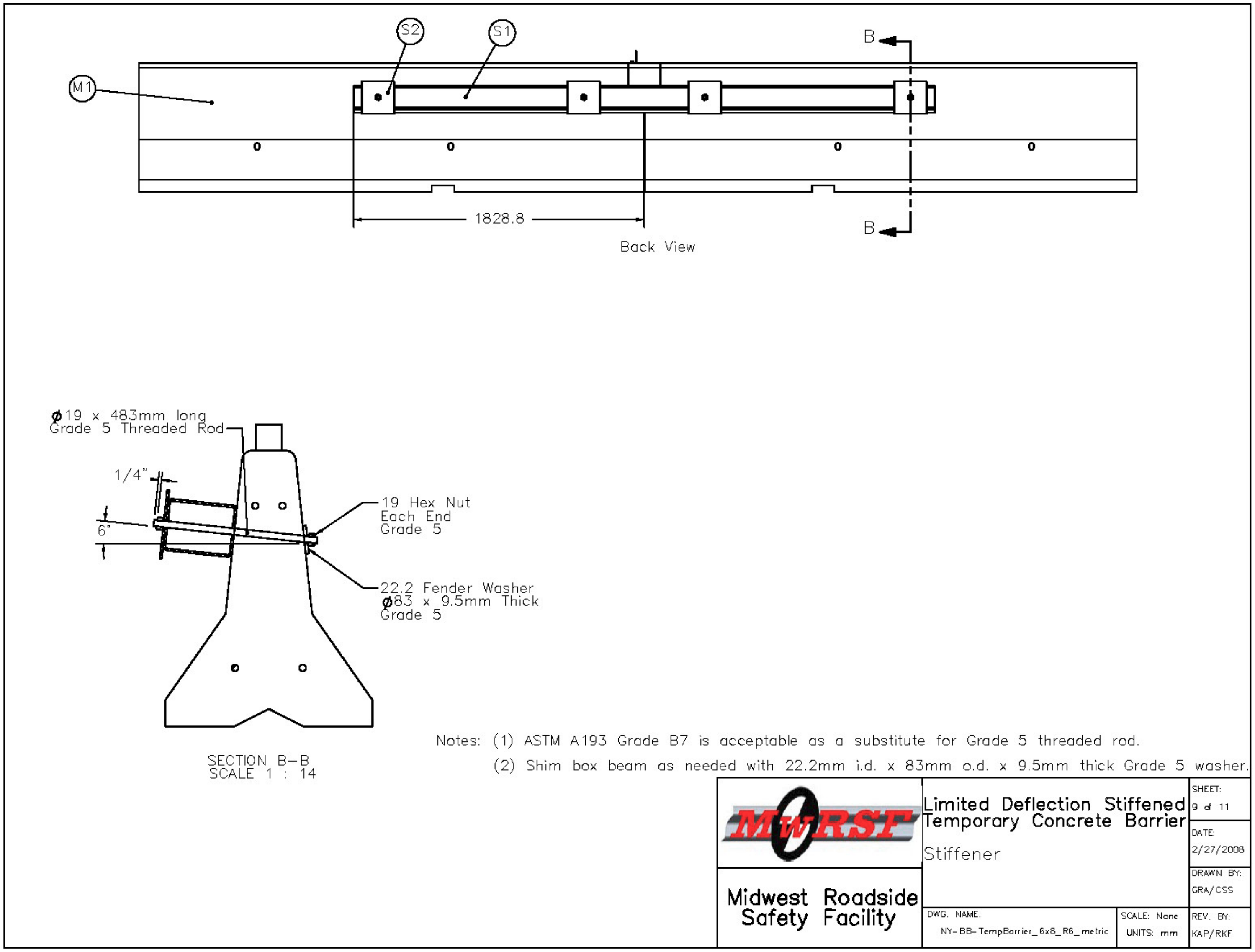


Figure G-9. Box Beam Stiffener Details, Test NYTCB-3

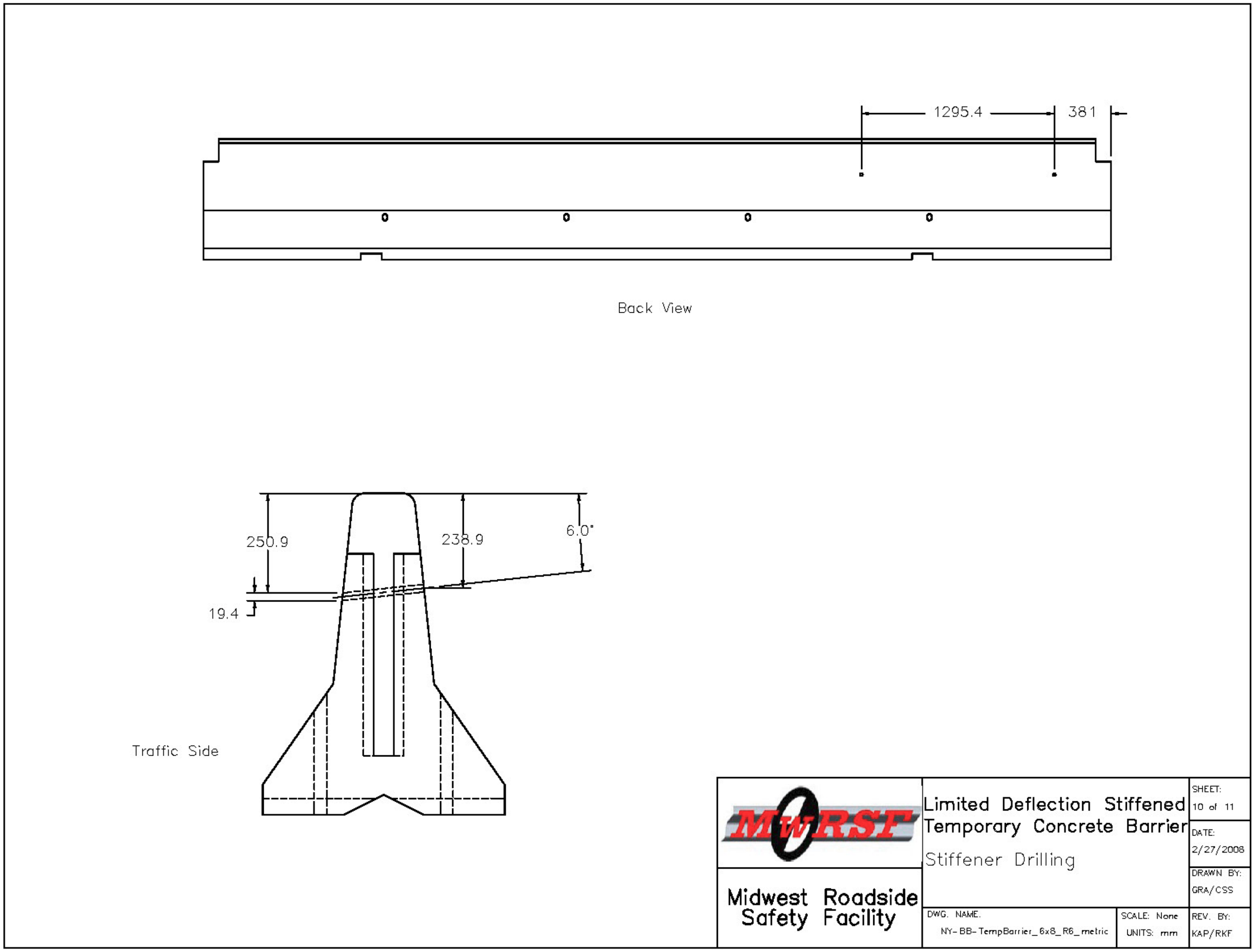


Figure G-10. Temporary Concrete Barrier Stiffener Hole Details, Test NYTCB-3

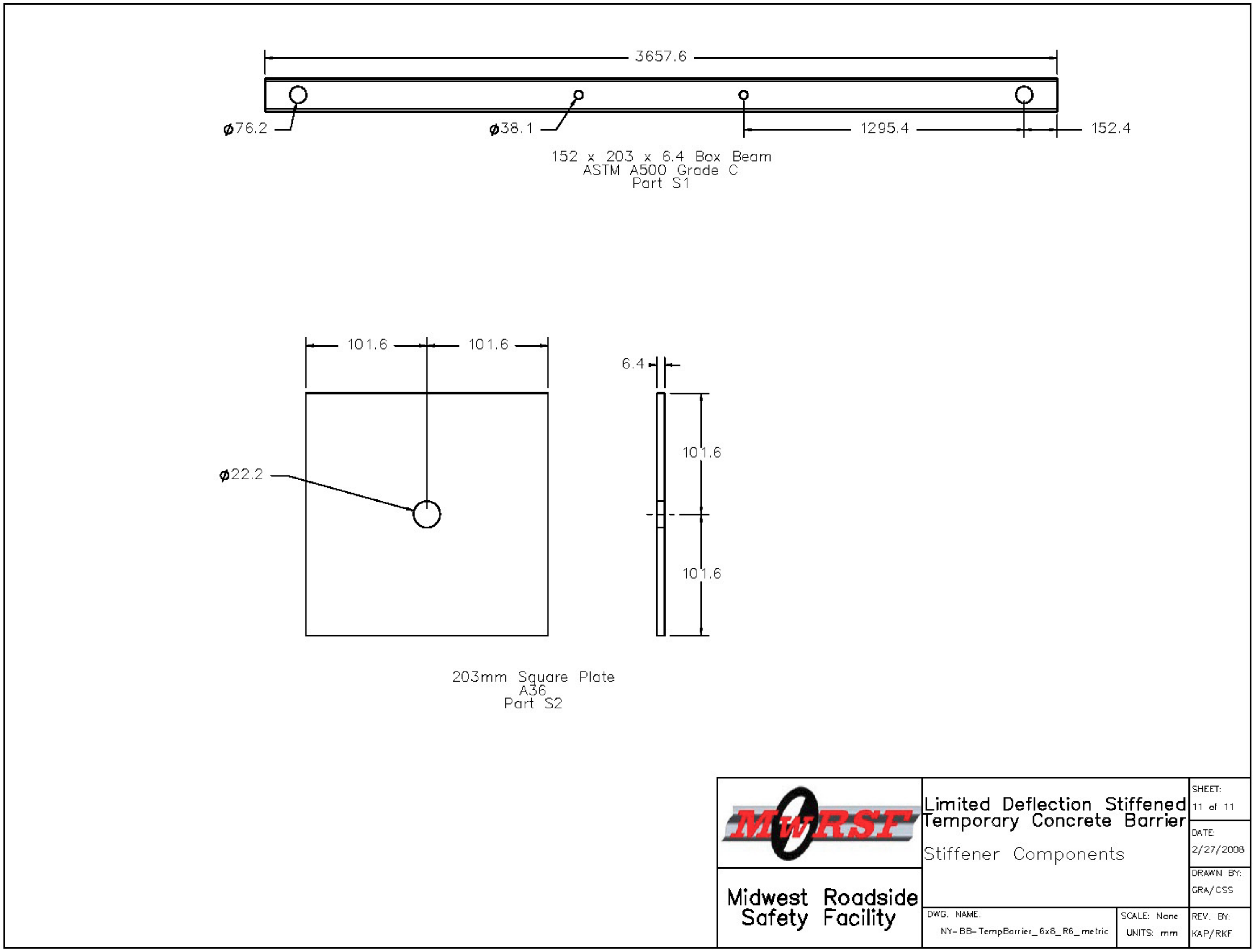


Figure G-11. Box Beam Stiffener Details, Test NYTCB-3

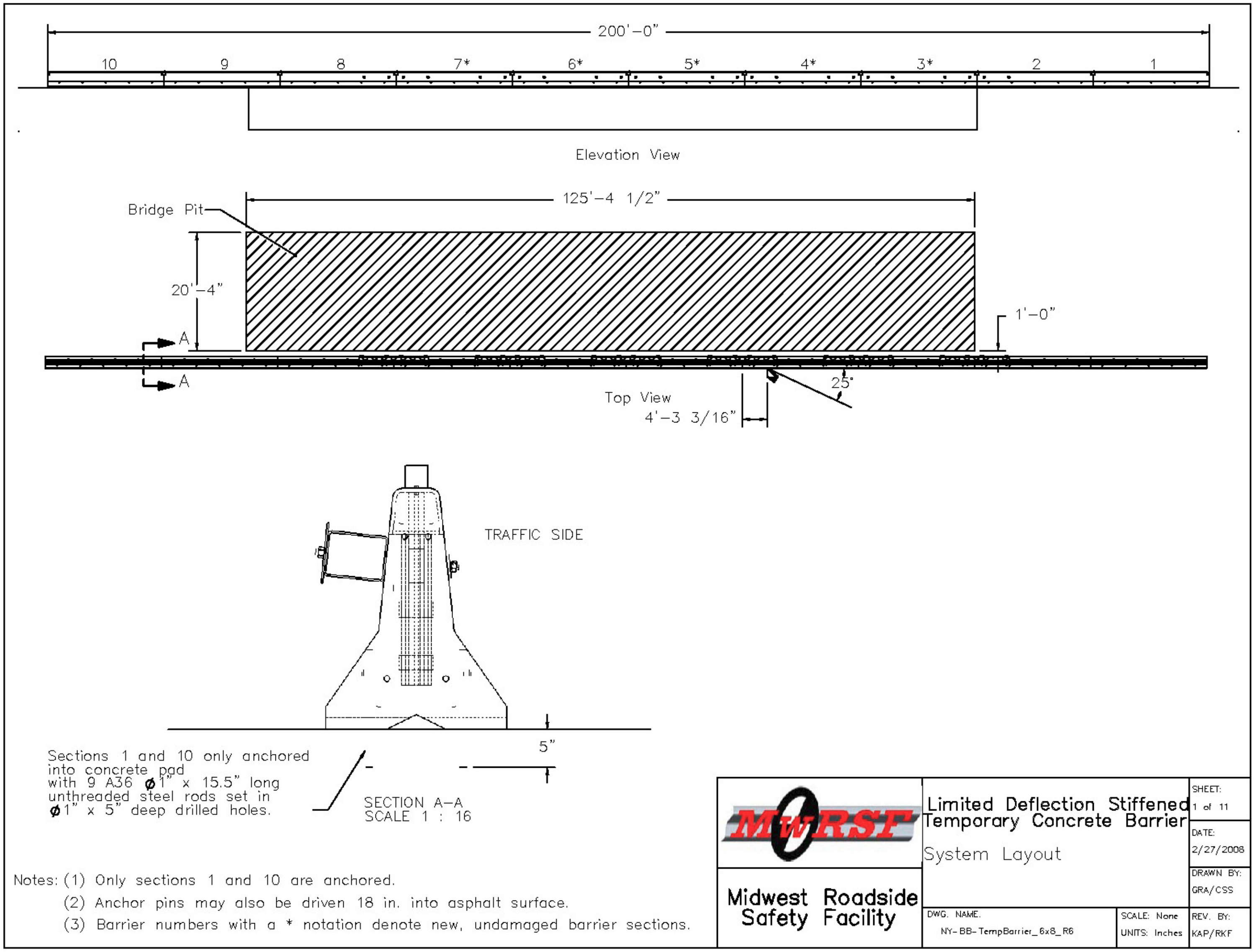


Figure G-12. Stiffened Temporary Concrete Barrier System Layout (English), Test NYTCB-3

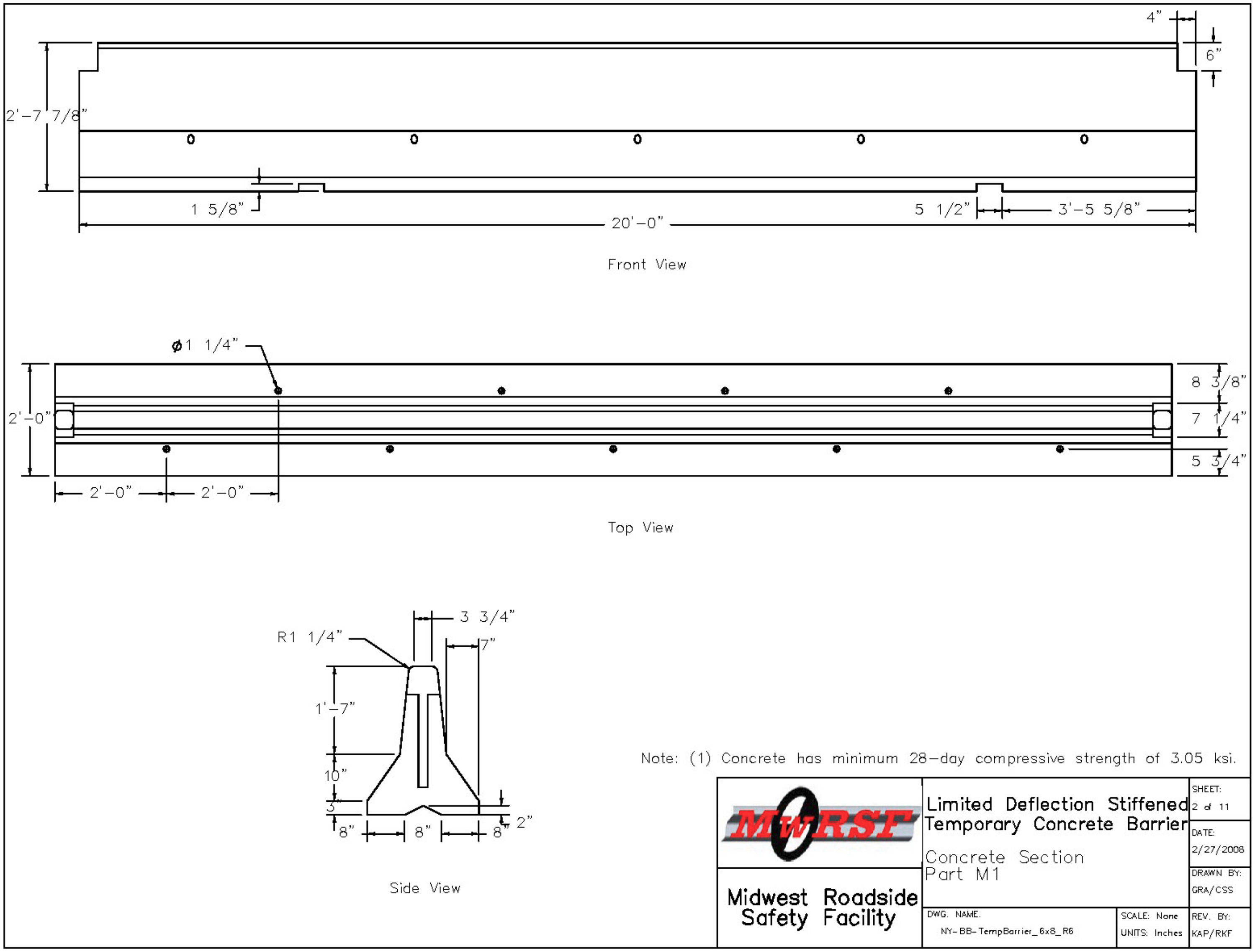


Figure G-13. Temporary Concrete Barrier Details (English), Test NYTCB-3

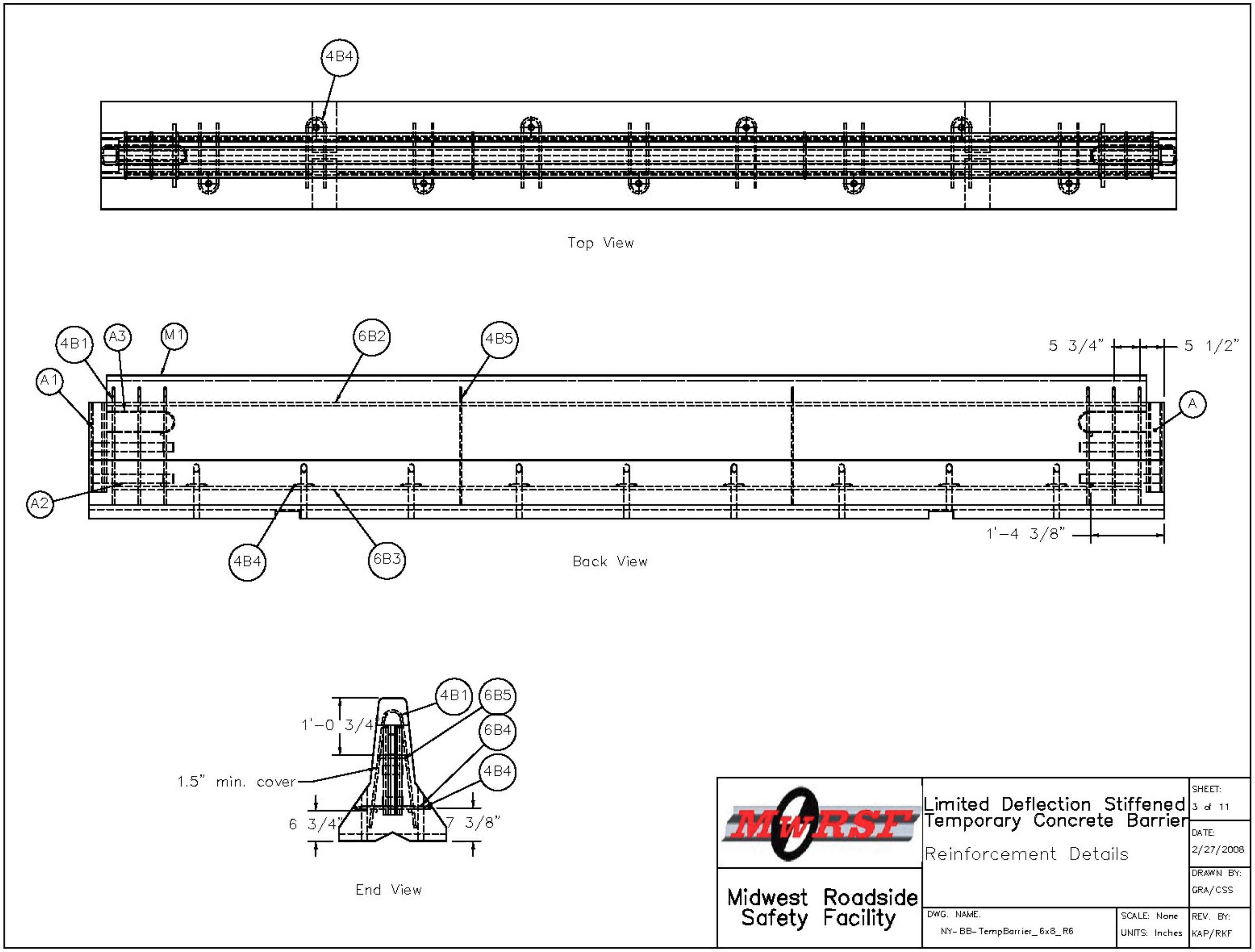
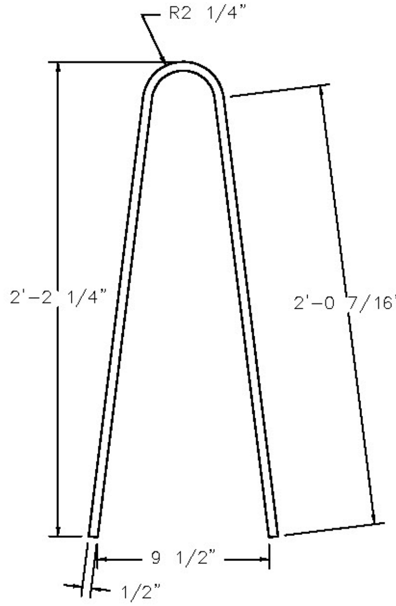
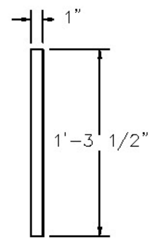


Figure G-14. Temporary Concrete Barrier Reinforcement Details (English), Test NYTCB-3

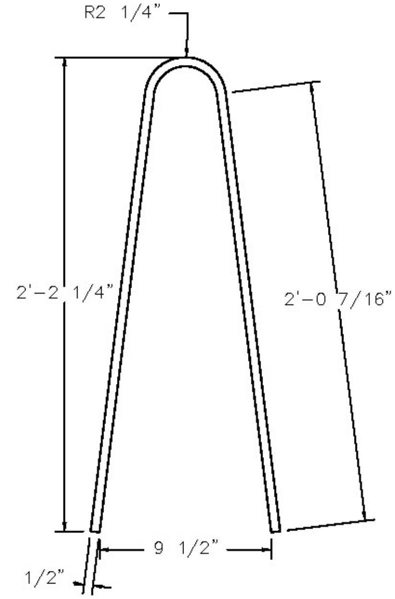
NY–BB–TempBarrier					
Item No.	Bend Dia.	Qty.	Length	Material Spec	Bar Size
Smooth Anchor Rod	–	18	15–1/2"	A36M	1"
4B1	3–1/2"	60	55–3/8"	A615 Gr. 60	4
4B4	3–1/2"	90	34–1/6"	A615 Gr. 60	4
4B5	3–1/2"	20	55–3/8"	A615 Gr. 60	4
6B2	–	20	19'–4"	A615 Gr. 60	6
6B3	–	20	19'–1 1/2"	A615 Gr. 60	6
6B4	–	20	14"	A615 Gr. 60	6
6B5	–	20	6"	A615 Gr. 60	6



4B1



Smooth Anchor Rod



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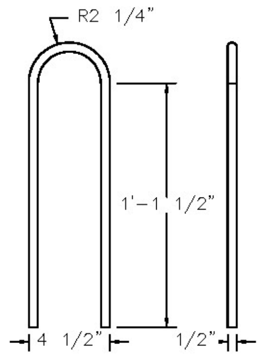

4B4

Note: (1) Quantities in Bill of Bars represent a system with 10 barriers.

Midwest Roadside Safety Facility

Limited Deflection Stiffened Temporary Concrete Barrier

Bill of Bars

SHEET: 8 of 11

DATE: 2/27/2008

DRAWN BY: GRA/CSS

DWG. NAME. NY-BB-TempBarrier_6x8_R6

SCALE: None

UNITS: Inches

REV. BY: KAP/RKF

Figure G-15. Bill of Bars (English), Test NYTCB-3

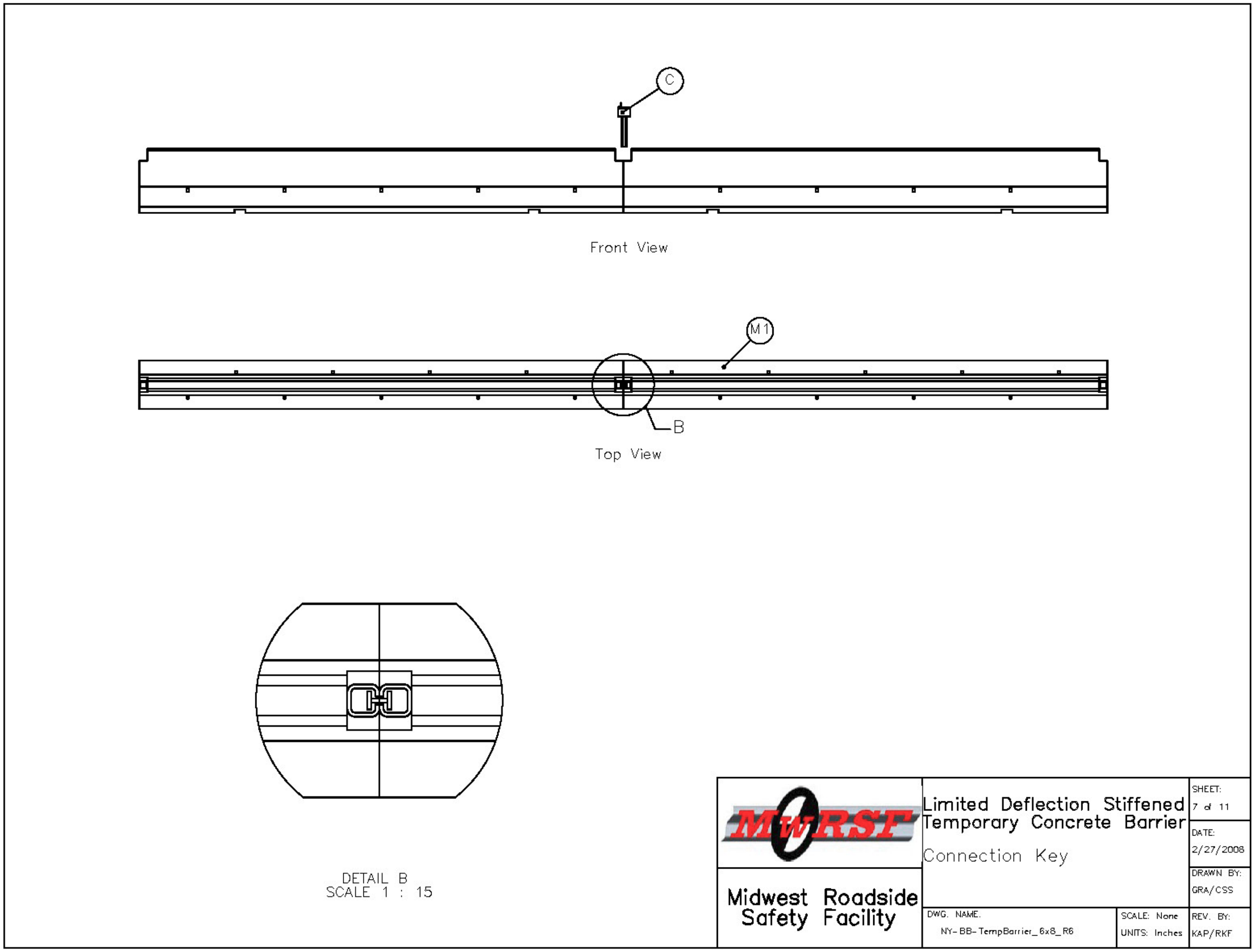

Figure G-16. Temporary Concrete Barrier Connection Details (English), Test NYTCB-3

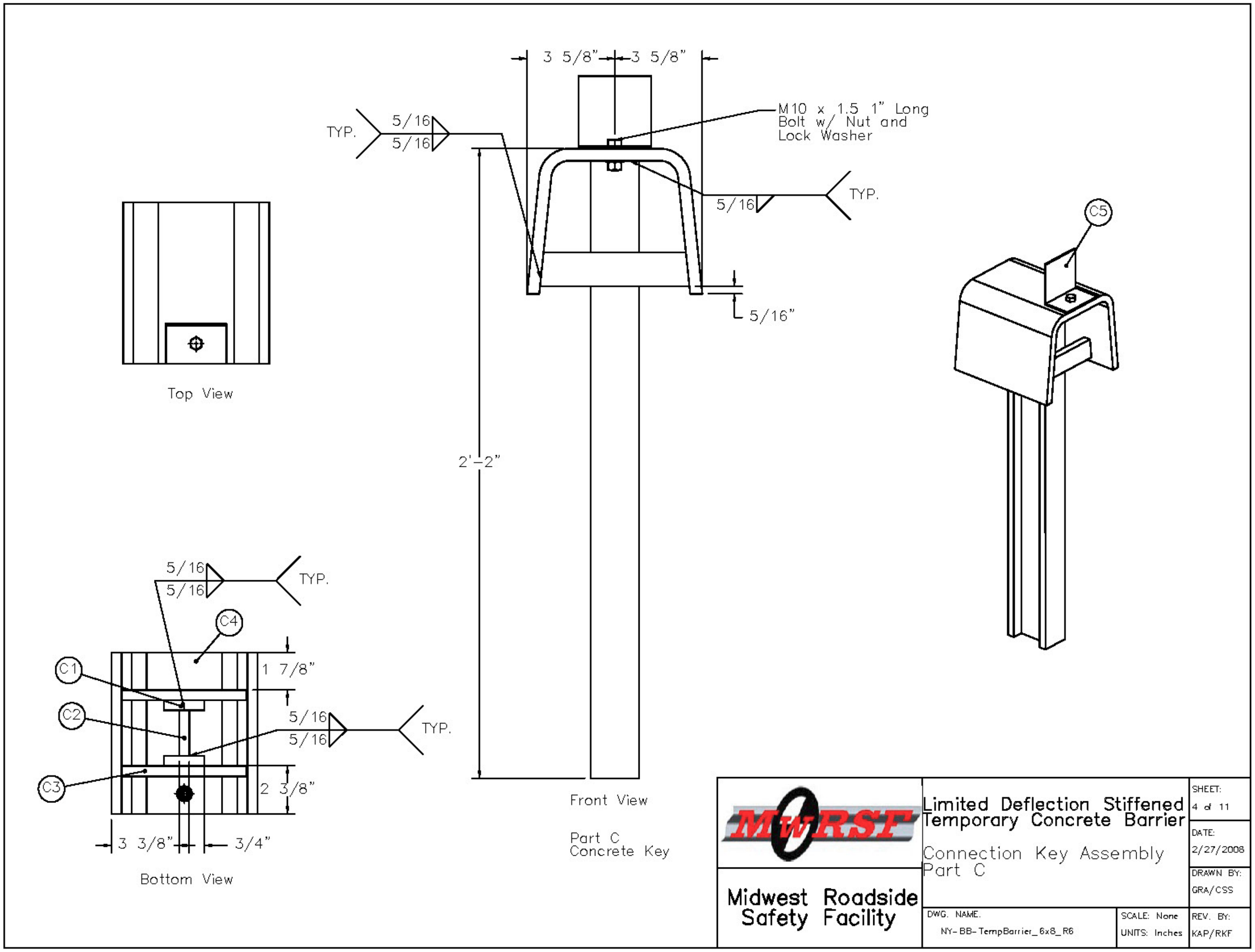

Figure G-17. Connection Key Assembly Details (English), Test NYTCB-3

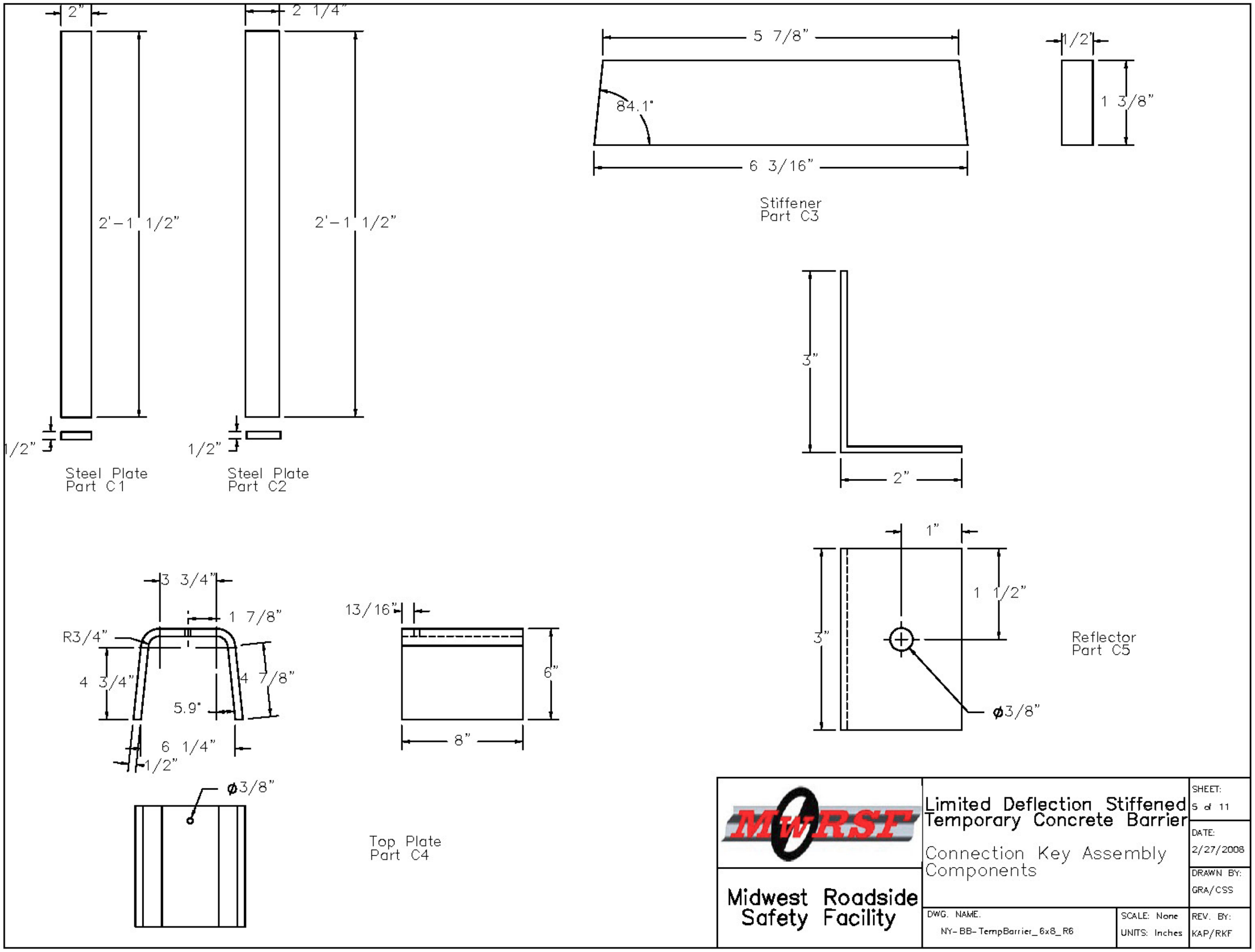

Figure G-18. Connection Key Assembly Details (English), Test NYTCB-3

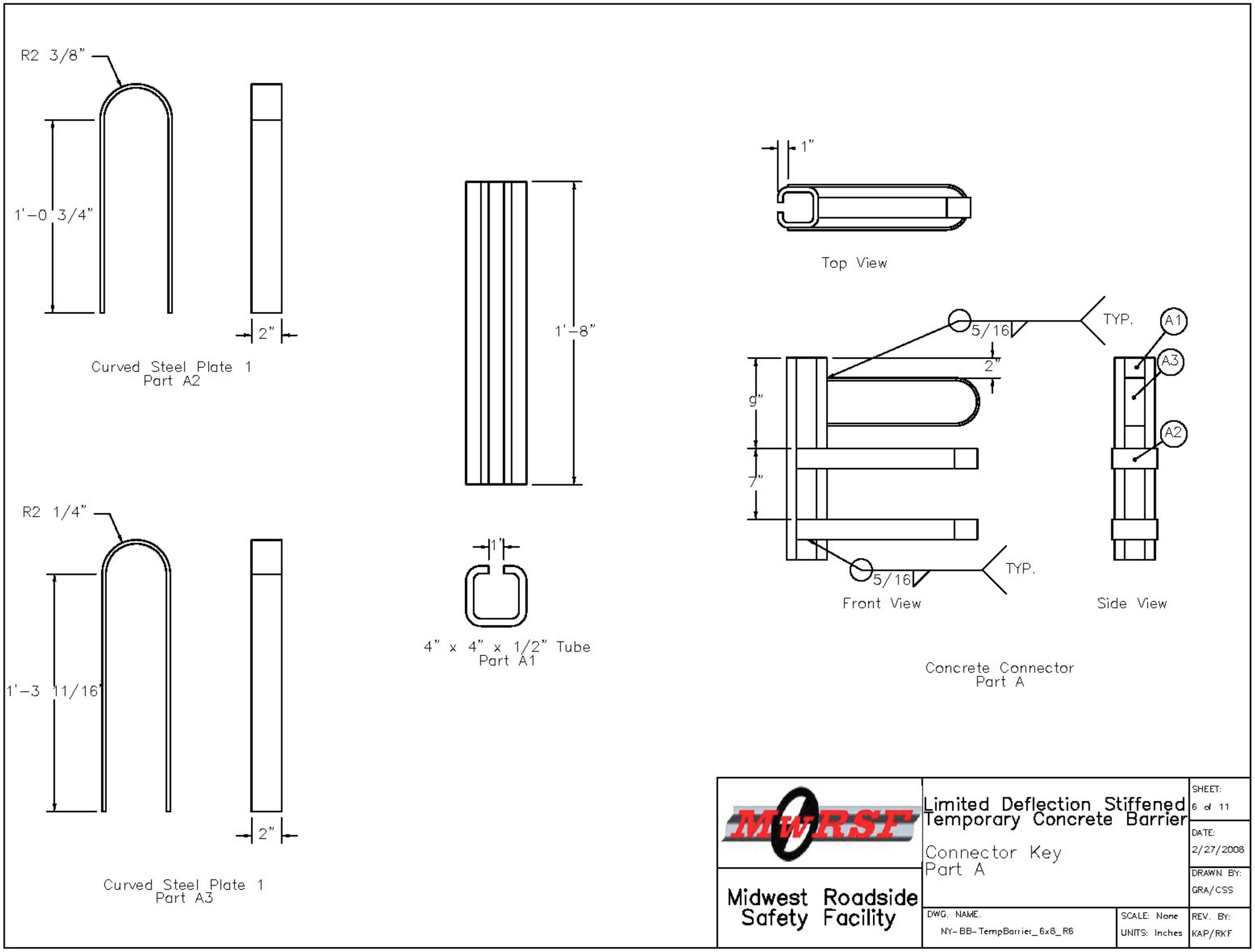

Figure G-19. Temporary Concrete Barrier Connector Assembly Details (English), Test NYTCB-3

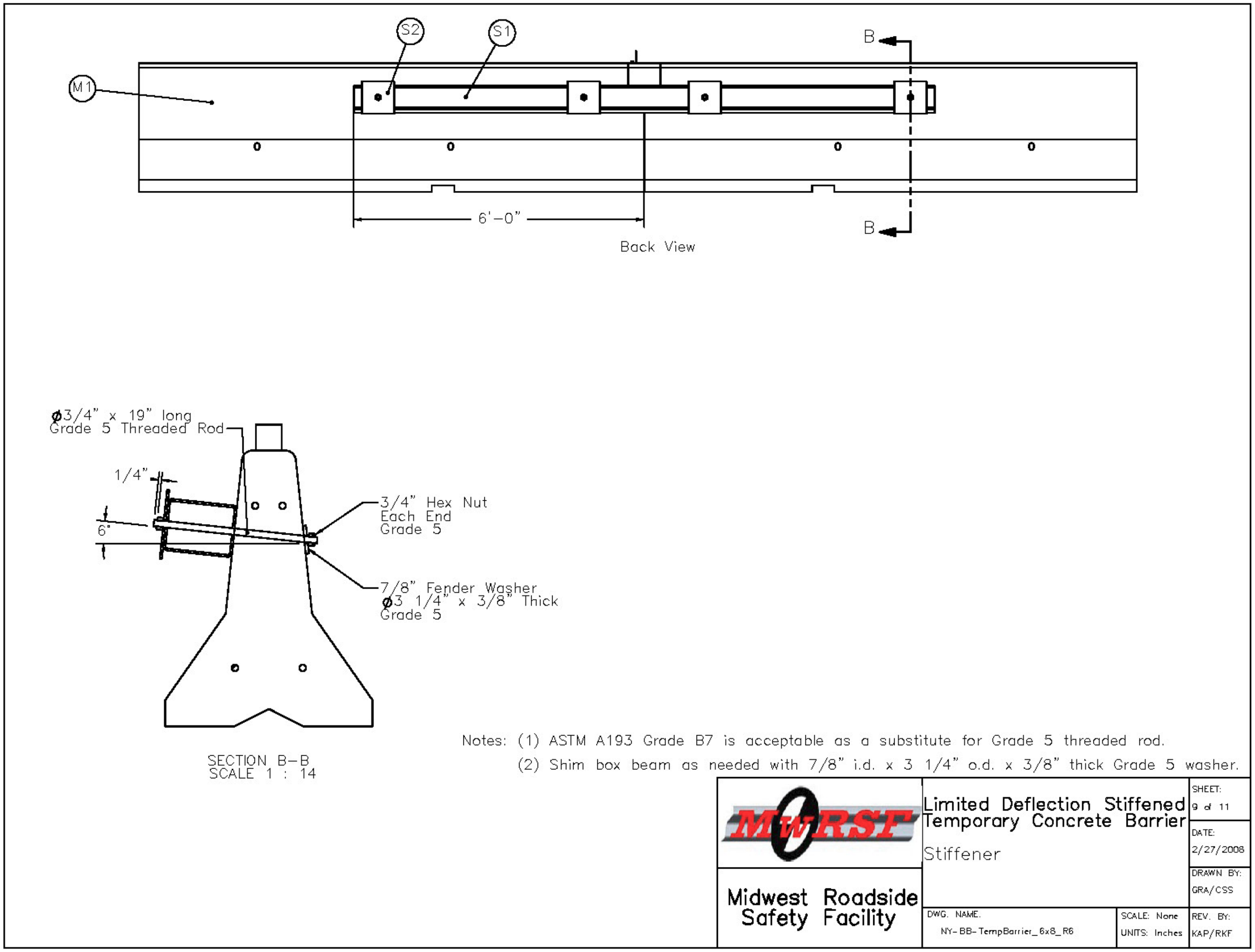

Figure G-20. Box Beam Stiffener Details (English), Test NYTCB-3

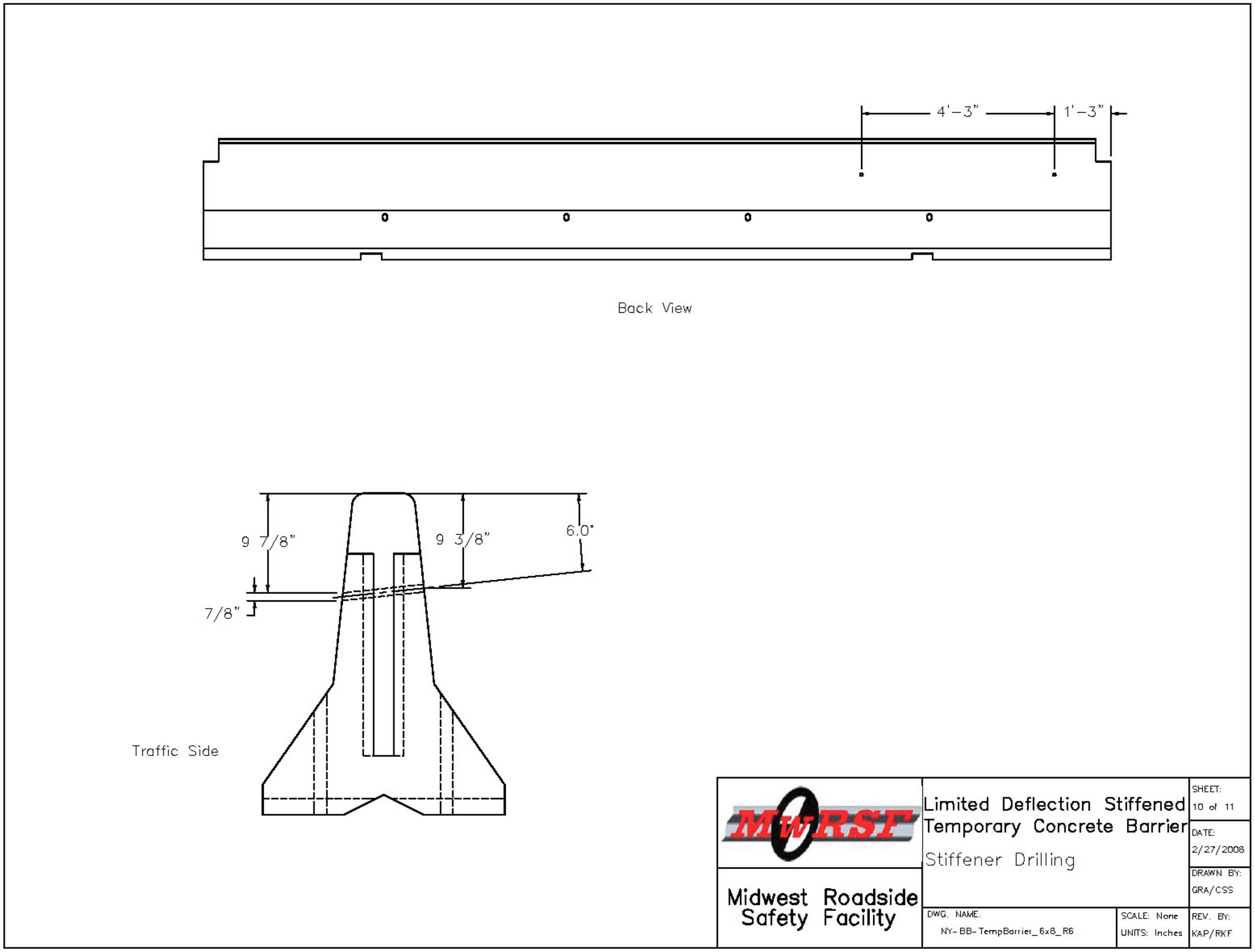

Figure G-21. Temporary Concrete Barrier Stiffener Hole Details (English), Test NYTCB-3

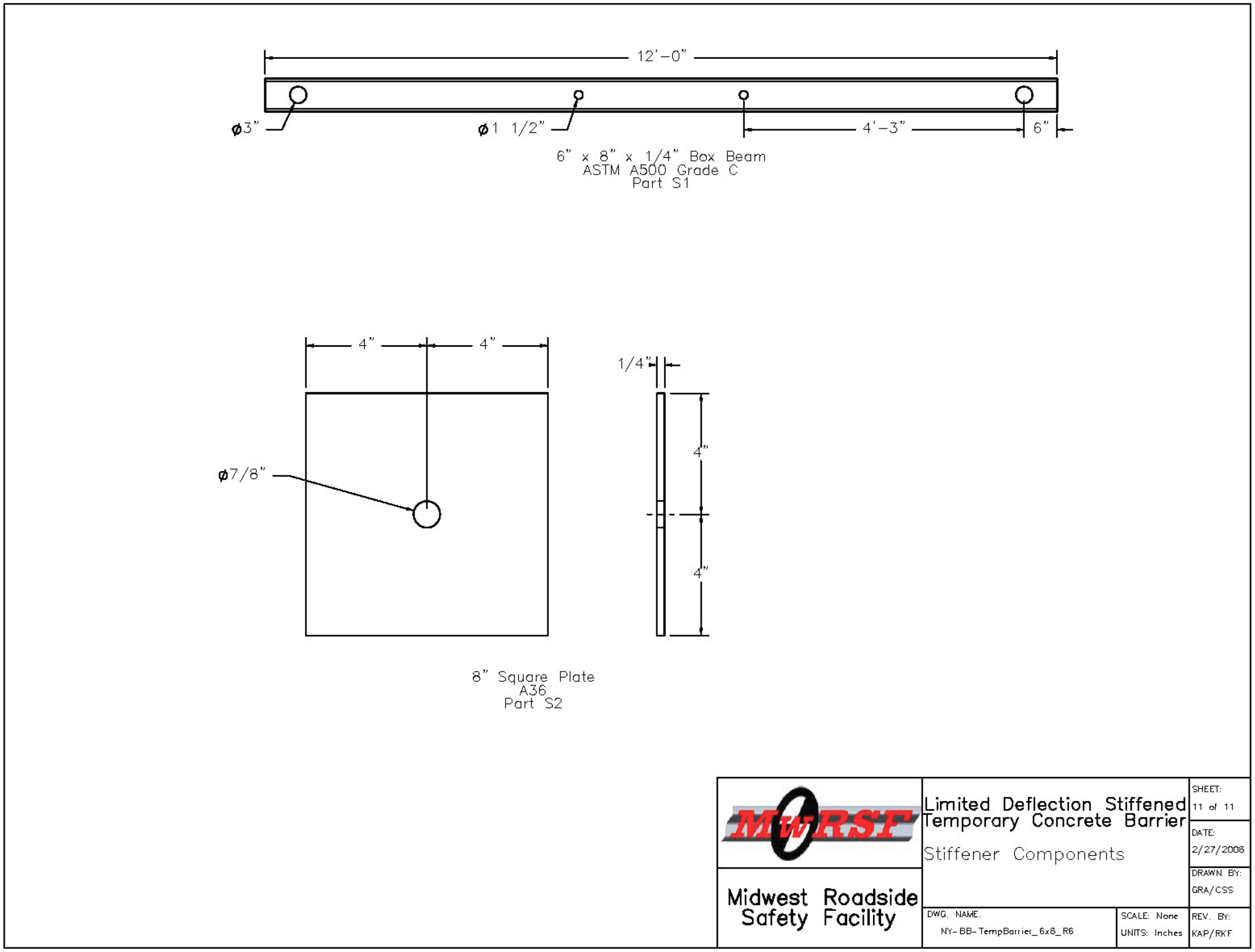

Figure G-22. Box Beam Stiffener Details (English), Test NYTCB-3

APPENDIX H

Accelerometer and Rate Transducer Data Analysis, Test NYTCB-3

Figure H-1. Graph of Longitudinal Deceleration, Test NYTCB-3

Figure H-2. Graph of Longitudinal Occupant Impact Velocity, Test NYTCB-3

Figure H-3. Graph of Longitudinal Occupant Displacement, Test NYTCB-3

Figure H-4. Graph of Lateral Deceleration, Test NYTCB-3

Figure H-5. Graph of Lateral Occupant Impact Velocity, Test NYTCB-3

Figure H-6. Graph of Lateral Occupant Displacement, Test NYTCB-3

Figure H-7. Graph of Roll, Pitch, and Yaw Angular Displacements, Test NYTCB-3

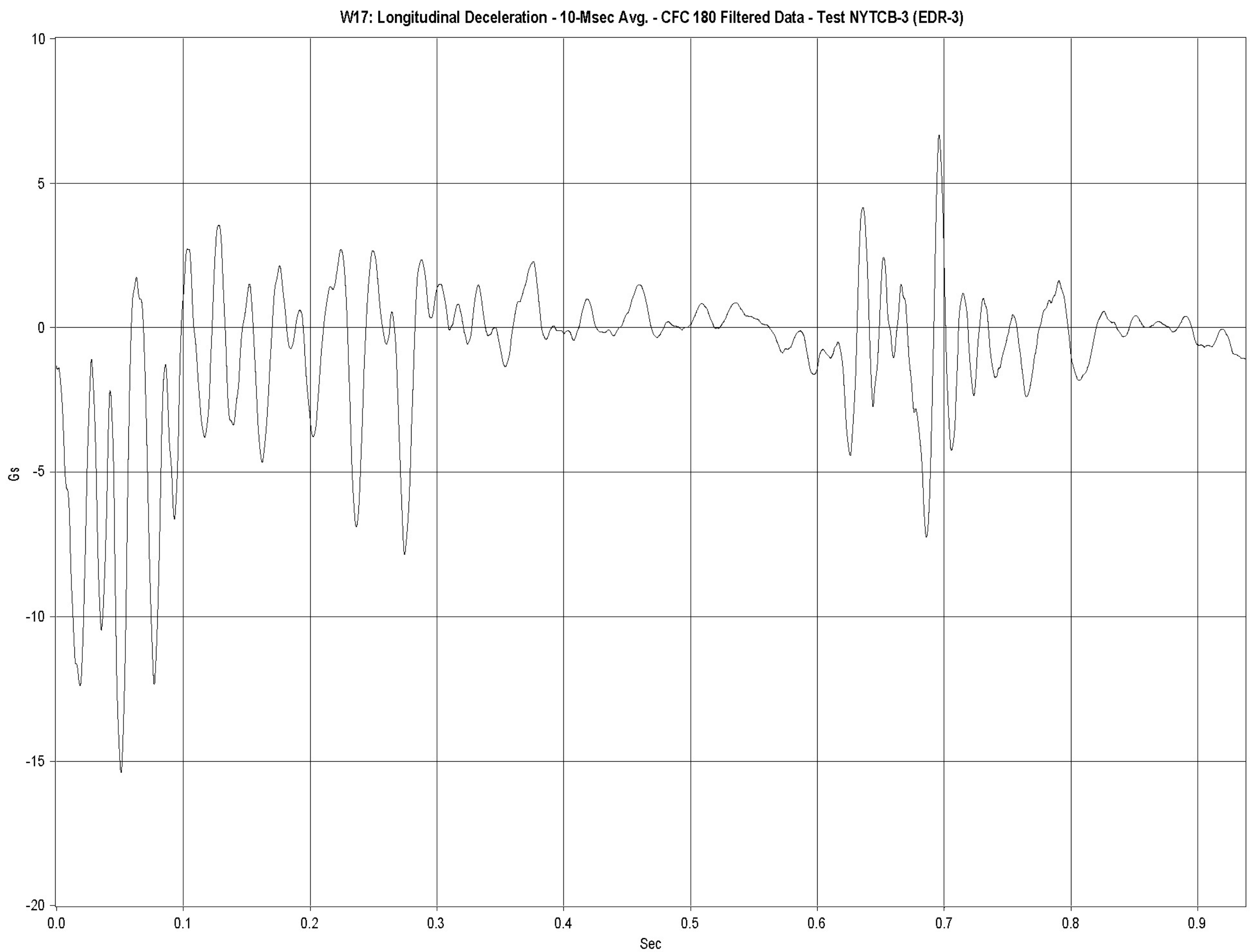

Figure H-1. Graph of Longitudinal Deceleration, Test NYTCB-3

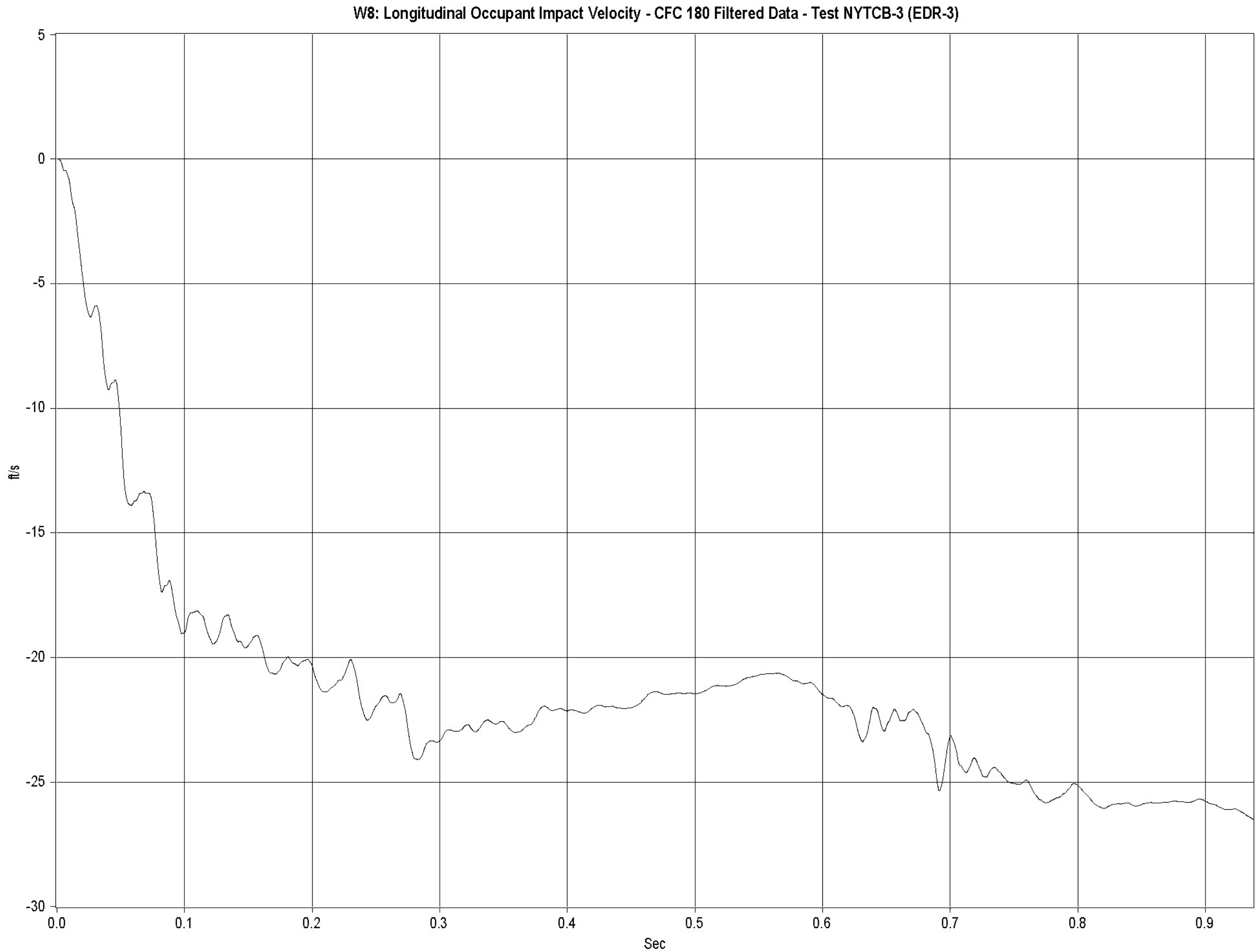

Figure H-2. Graph of Longitudinal Impact Velocity, Test NYTCB-3

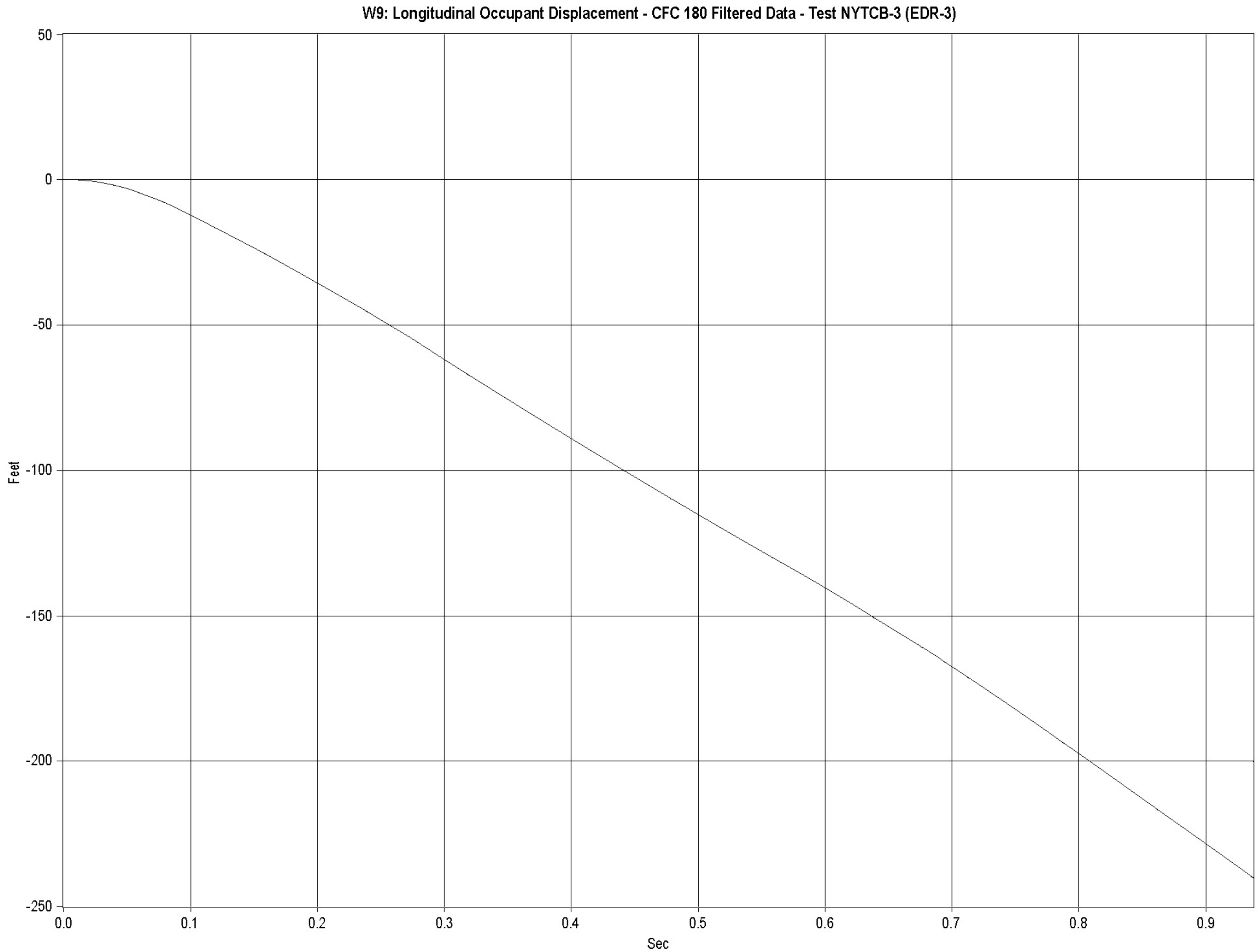

Figure H-3. Graph of Longitudinal Impact Displacement, Test NYTCB-3

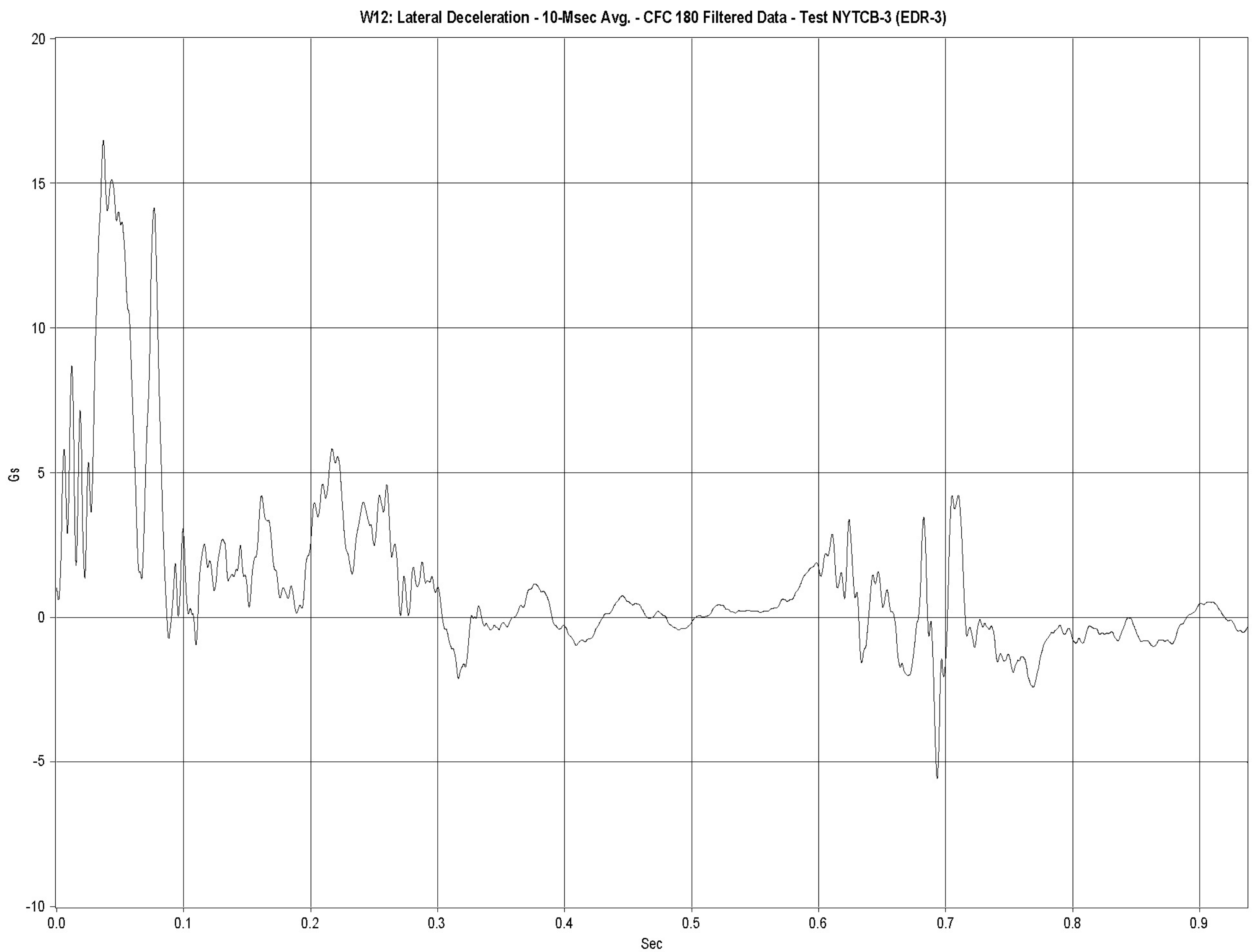

Figure H-4. Graph of Lateral Deceleration, Test NYTCB-3

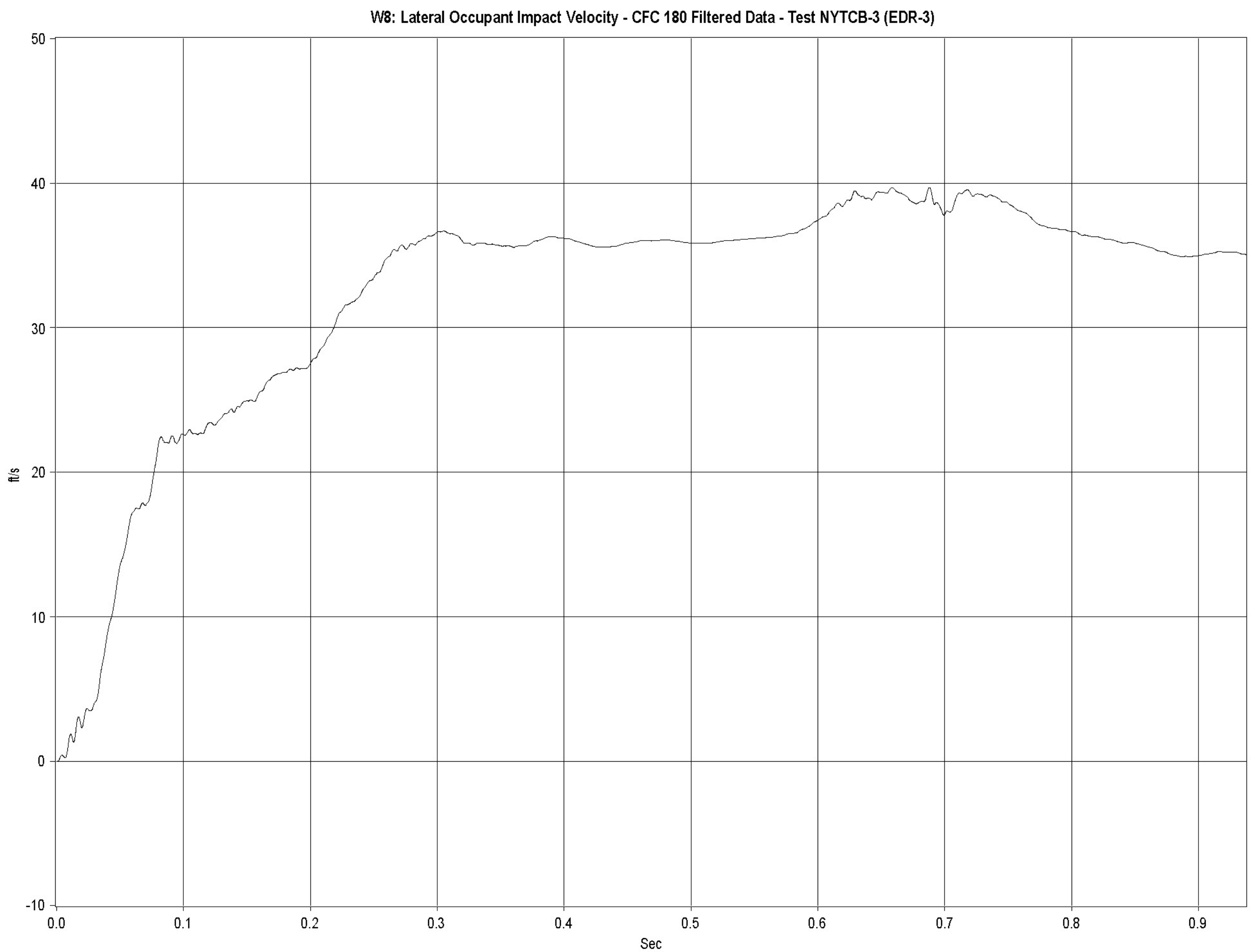

Figure H-5. Graph of Lateral Occupant Impact Velocity, Test NYTCB-3

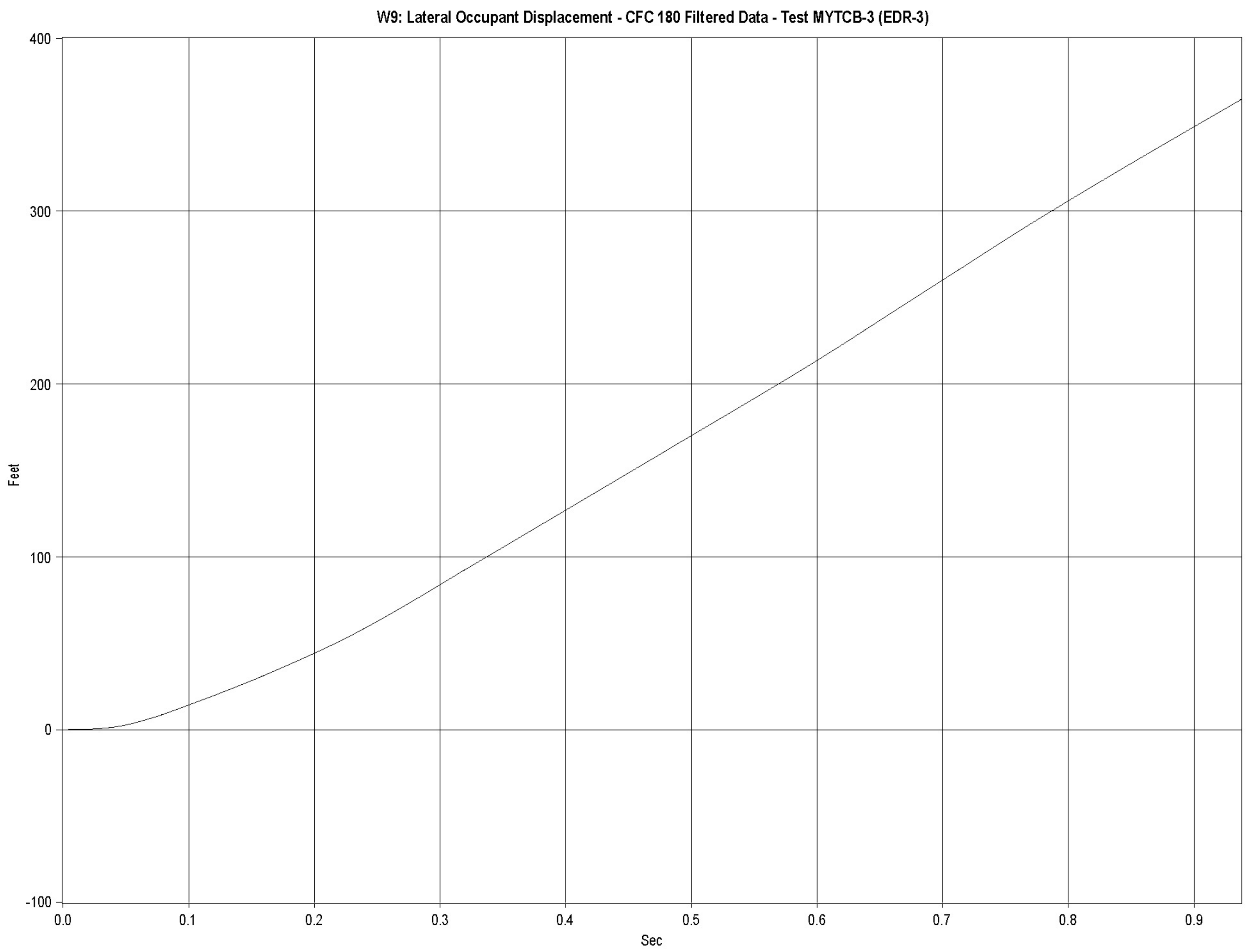

Figure H-6. Graph of Lateral Occupant Displacement, Test NYTCB-3

Figure H-7. Graph of Roll, Pitch, and Yaw Angular Displacements, Test NYTCB-3

APPENDIX I

Material Specifications

JERSEY PRECAST CORP.

1000 Somerset St., New Brunswick, NJ 08901
P.O. Box 7443, North Brunswick, NJ 08902
Phone: 732-249-8973 • Fax: 732-249-9720
E-Mail: jrzprecast@aol.com
www.jerseyprecast.com

ENGINEERING DESIGN

pci CERTIFIED PLANT

Date:	June 13, 2007		
Company:	Midwest Roadside Safety Facility- University of Nebraska	**Proposal #**	07-198
Attention:	Gregg Averill	**Location:**	Lincoln, Nebraska
Phone:	402-472-2022	**Reference:**	
Fax:	402-709-2943 gaverill@bigred.unl.edu		

JERSEY PRECAST CORPORATION PROPOSES TO MANUFACTURE AND DELIVER THE FOLLOWING:

Approximate Lft: 240

12 pcs Precast Temporary Construction Barrier 24" x 32"x **20'** @ $ 31.00 /Lft
M619-3R1 with pin holes
4000 psi Grey concrete, uncoated reinforcing, with uncoated steel interlocks

PICKED-UP - 400 LBS/LFT

Excludes: anchor bolts, washers, reflectors, delinineators, stripes, fence post sleeves, and layout drawings

Terms:
Quote valid for 30 days
Payment at time of delivery or pick-up

Plus applicable taxes

Approved by: ______________________
Purchase Order #:
Please sign and return by fax

Yours truly
Paul Dentel

*etal Products, Inc.
rth 38th Street
NE 68504-1998

Telephone: (402) 466-2329
Main Office Fax: (402) 466-9140
Rotational Molds Division Fax: (402) 466-0937
Internet E-mail: rmp@riversmetal.com

Sales Order: 75571

rder: 75571

Sales Order

Page 1 of 1

s:	Ship To:
ersity of Nebraska - Lincoln Administration Building oln NE 68588-0439	University of Nebraska - Lincoln UNL-Midwest Roadside Safety 1901 'Y' STREET BUILDING C LINCOLN NE 68588-0601 SHIPPED JUL 12 2007 RIVERS METAL PROD

ate: 7/5/2007 PO Number: VERBAL CURT FOB: RMP
By: 7/11/2007 Sales Rep: Roger Harris Resale ID.
ns: Net 30 Days Ship Via: Customer

EN READY CURT 326-8122

Order Qty	Part Number/Description	Revision	Unit Price	Ext. Price
3.00 EA	DRILL6"X3/16"SQ.TUBE DRILL 6" X 6" X 3/16" SQUARE TUBES		191.50000 /E	$574.50
Release 1	**Date** 7/11/2007	**Quantity** 3.00		
24.00 EA	PLASMACUT1/4HRPLATE PLASMA CUT 1/4" HOT ROLL PLATE 8" X 8" WITH 7/8" HOLE IN CENTER		5.85000 /E	$140.40
Release 1	**Date** 7/11/2007	**Quantity** 24.00		
2.50 EA	HR1 1" Hot Roll Round 20' 2 FULL LENGTHS CUT 1EA. 120.00"		45.49875 /E **Discount:**	$113.75 -$17.06
Release 1	**Date** 7/11/2007	**Quantity** 2.50		

Signature

Line Total:	$811.59
Miscellaneous Total:	$0.00
Total:	$811.59

.oducts, Inc.
..th 38th Street
.coln NE 68504-1998

Telephone: ...
Main Office Fax: (402) 466-9140
Rotational Molds Division Fax: (402) 466-0937
Internet E-mail: rmp@riversmetal.com

Invoice: 624807

Invoice

Page: 1 of 1
Date: 9/5/2007

Bill To:
Accounts Payable
University of Nebraska - Lincoln
401 Administration Building
Lincoln NE 68588-0439

Ship To:

University of Nebraska - Lincoln
[redacted]

PO Number: [redacted]
Sales Rep: Paul Mara
Packing Slip:

Terms: Net 30 Days
Ordered: 9/5/2007
Sales Tax ID: 0305-256-556

F.O.B RMP
Ship Via: Pick-up
Ship Date: 9/5/2007

Line	Quantity	Part Number/Description	Revision	Unit Price	Ext Price
1	3.00EA	RT8614 8 X 6 X 1/4 HR RECT TUBE X 24' ***This material was not charged on invoice number 624623 line 2 was a labor only charge***		483.33330 EA	$1,450.00
		- Taxes -	Taxable Amount	Percent	Amount
		Government	$1,450.00		
Payment Schedule		Due Date	Amount		
		10/5/2007	$1,450.00		

Please remit this amount: $1,450.00