DEVELOPMENT OF AN ECONOMICAL GUARDRAIL SYSTEM FOR USE ON WIRE-FACED, MSE WALLS

Publication No. FHWA-CFL/TD-12-009 FEBRUARY 2012

U.S. Department
of Transportation
Federal Highway Administration

Federal Lands Highway
Commitment to Excellence

CENTRAL FEDERAL LANDS HIGHWAY DIVISION
12300 WEST DAKOTA AVENUE
Lakewood, CO 80228

FOREWORD

The Federal Lands Highway Division (FLHD) designs and constructs numerous wire-faced, mechanically-stabilized (MSE) walls across the U.S. These MSE walls are utilized to support highways and roadways built on sloped terrain which may carry significant vehicular traffic. The FLHD designs and constructs vehicular barrier systems which are placed within the exterior region of MSE walls. This report contains the research results aimed at the development of economical and crashworthy barrier systems for placement on top of and near the exterior edge of MSE walls.

The objective for this study was to develop an economical barrier system for safely treating vertical drop-offs located at the outside edge of wire-faced, MSE walls. The new barrier system was to be capable of providing acceptable safety performance during high-speed, high-energy passenger car impacts, be easily maintained, and not impart unreasonable damage to the MSE wall system and was to be evaluated according to the Test Level 3 (TL-3) safety performance criteria set forth in the American Association of State Highway and Transportation Officials (AASHTO) Manual for Assessing Safety Hardware (MASH).

The study included numerous design concepts, significant dynamic component testing to determine post type, length, and placement, and development of a non-blocked version of the MGS with steel posts placed at the slope break point of a 3H:1V fill slope. Full-scale crash testing was successfully used to evaluate the proposed design. TL-3 and TL-2 guidance was provided regarding the placement of a non-blocked, steel-post version of the MGS on wire-faced, MSE walls. The results from this study are recommended for use to update Central Federal Lands Highway Division's (CFLHD) Standard Detail C255-50, dated August 18, 2008, regarding semi-rigid barriers installed on welded, wire-face, MSE walls.

F. David Zanetell, P.E., Director of Project Delivery
Federal Highway Administration
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Notice

Quality Assurance Statement

DEVELOPMENT OF AN ECONOMICAL GUARDRAIL SYSTEM FOR USE ON WIRE-FACED, MSE WALLS

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MwRSF Research Report No. TRP-03-235-11

February 2012

UNCERTAINTY OF MEASUREMENT STATEMENT

The Midwest Roadside Safety Facility (MwRSF) has determined the uncertainty of measurements for several parameters involved in standard full-scale crash testing and non-standard testing of roadside safety features. Information regarding the uncertainty of measurements for critical parameters is available upon request by the sponsor and the Federal Highway Administration.

INDEPENDENT APPROVING AUTHORITY

The Independent Approving Authority (IAA) for the data contained herein was Mr. Scott Rosenbaugh.

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16. Abstract

Wire-faced, mechanically-stabilized earth (MSE) walls provide an economical method for constructing vertical structures for supporting roadways where local topography or high land costs preclude the use of conventional fill slopes. Corrugated guardrail is often used for shielding high vertical drop-offs associated with MSE walls. The Midwest Guardrail System (MGS) was modified to decrease the overall width of the MSE wall structure. Dynamic component testing was utilized to determine the post-soil behavior of steel and wood posts embedded in compacted, soil materials used for constructing wire-faced, MSE walls as well as to evaluate the effects of sloped terrain and different installation methods. Twenty-six dynamic tests were performed to evaluate the propensity for MSE wall damage, select post length, and determine post material and section. The standard MGS was modified by removing the 12-in. (305-mm) deep wood spacer blocks and by incorporating W-beam backup plates. All other MGS features were maintained, including the 6-ft (1.8-m) long W6x8.5 (W152x12.6) steel posts, rail splices at mid-span locations, 31-in. (787-mm) top mounting height, and 75-in. (1,905-mm) post spacing. The non-blocked MGS was installed with the posts driven at the slope break point of a 3H:1V fill slope. The modified MGS was successfully crash tested using both 1100C small car and 2270P pickup truck vehicles according to Test Level 3 (TL-3) safety performance guidelines provided in the Manual for Assessing Safety Hardware (MASH). The MSE wall was not damaged during the testing programs. The non-blocked MGS is recommended for use with wire-faced, MSE walls when placed at the slope break point of a 3H:1V fill slope. The modified MGS reduces the required width of the MSE wall, thus resulting in decreased construction costs.

17. Key Words **MECHANICALLY-STABILIZED EARTH, MSE, MIDWEST GUARDRAIL SYSTEM, MGS, SLOPE BREAK POINT, SBP, TEST LEVEL 3, TL-3**	18. Distribution Statement No restriction. This document is available to the public from the sponsoring agency at the website http://www.cflhd.gov.

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SI* (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
		AREA		
in^2	square inches	645.2	square millimeters	mm^2
ft^2	square feet	0.093	square meters	m^2
yd^2	square yard	0.836	square meters	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	square kilometers	km^2
		VOLUME		
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.028	cubic meters	m^3
yd^3	cubic yards	0.765	cubic meters	m^3
		NOTE: volumes greater than 1,000 L shall be shown in m^3		
		MASS		
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short ton (2,000 lb)	0.907	megagrams (or “metric ton”)	Mg (or "t")
		TEMPERATURE (exact degrees)		
°F	Fahrenheit	5(F-32)/9 or (F-32)/1.8	Celsius	°C
		ILLUMINATION		
fc	foot-candles	10.76	lux	lx
fl	foot-Lamberts	3.426	candela per square meter	cd/m^2
		FORCE & PRESSURE or STRESS		
lbf	poundforce	4.45	newtons	N
lbf/in^2	poundforce per square inch	6.89	kilopascals	kPa

APPROXIMATE CONVERSIONS FROM SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
		AREA		
mm^2	square millimeters	0.0016	square inches	in^2
m^2	square meters	10.764	square feet	ft^2
m^2	square meters	1.195	square yard	yd^2
ha	hectares	2.47	acres	ac
km^2	square kilometers	0.386	square miles	mi^2
		VOLUME		
mL	milliliter	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m^3	cubic meters	35.314	cubic feet	ft^3
m^3	cubic meters	1.307	cubic yards	yd^3
		MASS		
g	grams	0.035	ounces	oz
kg	kilograms	2.202	pounds	lb
Mg (or "t")	megagrams (or “metric ton”)	1.103	short ton (2,000 lb)	T
		TEMPERATURE (exact degrees)		
°C	Celsius	1.8C+32	Fahrenheit	°F
		ILLUMINATION		
lx	lux	0.0929	foot-candles	fc
cd/m^2	candela per square meter	0.2919	foot-Lamberts	fl
		FORCE & PRESSURE or STRESS		
N	newtons	0.225	poundforce	lbf
kPa	kilopascals	0.145	poundforce per square inch	lbf/in^2

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

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ACRONYMS, ABBREVIATIONS, AND SYMBOLS

Acronym		Definition
AASHTO	-	American Association of State Highway and Transportation Officials
AOS	-	AOS Technologies AG
ASI	-	Acceleration Severity Index
ASTM	-	American Society for Testing and Materials
B.S.B.A.	-	Bachelor of Science in Business Administration
B.S.M.A.	-	Bachelor of Science in Management Accounting
BCT	-	Breakaway Cable Terminal
c.g.	-	center of gravity
CFL		Central Federal Lands
CFLHD	-	Central Federal Lands Highway Department
deg	-	degree
DM-1	-	DynaMax 1
DOT	-	Department of Transportation
DTS	-	Diversified Technical Systems, Incorporated
EDR		Event Data Recorder
E.I.T.	-	Engineer in Training
FHWA	-	Federal Highway Administration
FLHD	-	Federal Lands Highway Division
ft	-	foot
ft/s	-	feet per second
g	-	gram
g's	-	g-force, acceleration due to gravity at the Earth's surface
h		hour
H	-	Horizontal
Hz	-	Hertz
IAA	-	Independent Approving Authority
in.	-	inch
IST	-	Instrumented Sensor Technology, Incorporated
JVC	-	Victor Company of Japan, Limited
kB	-	kilobyte
kg	-	kilogram
kip-in.	-	thousand pounds-force inches
kips	-	thousand pounds-force
kJ	-	kilojoules
km	-	kilometer
km/h	-	kilometers per hour

kN	-	kilonewton
lb	-	pound(s)
m	-	meter
m/s	-	meters per second
MASH	-	Manual for Assessing Safety Hardware
MB	-	megabyte
MGS	-	Midwest Guardrail System
mm	-	millimeter
mph	-	miles per hour
M.S.C.E.	-	Master of Science in Civil Engineering
MSE	-	Mechanically-Stabilized Earth
M.S.M.E.	-	Master of Science in Mechanical Engineering
MwRSF	-	Midwest Roadside Safety Facility
N	-	Newton
NA	-	not applicable
NCHRP	-	National Cooperative Highway Research Program
NHS	-	National Highway System
no.	-	number
nos.	-	numbers
OIVs	-	occupant impact velocities
ORAs	-	occupant ridedown accelerations
P.E.	-	Professional Engineer
Ph.D.	-	Doctor of Philosophy
PHD	-	Post-Impact Head Deceleration
pm	-	post meridiem
R&D	-	research and development
RAM	-	random-access memory
s	-	second
SAE	-	Society of Automotive Engineers
SBP	-	slope break point
sec	-	second
SIM	-	Sensor Input Module
SRAM	-	static random-access memory
SUV	-	sport utility vehicle
SYP	-	Southern Yellow Pine
THIV	-	Theoretical Head Impact Velocity
TL	-	Test Level
U.S.	-	United States
V	-	Vertical
vs.	-	versus

° F - degrees Fahrenheit
‘ - foot
“ - inch
% - percent
σ_w - yield strength of W-beam rail
t_w - thickness of W-beam rail
D_b - bolt diameter
F_v - shear force

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EXECUTIVE SUMMARY

Wire-faced, mechanically-stabilized earth (MSE) walls provide an economical method for constructing vertical structures for supporting roadways where local topography or high land costs preclude the use of conventional fill slopes. While an economical solution for slope stability, MSE walls create safety issues by producing deep vertical drop-offs adjacent to the roadway. For years, the Federal Lands Highway Division (FLHD) has designed and constructed a large number of MSE walls across the United States (U.S.). The accepted practice has been to install the face of conventional, wood-post W-beam guardrail nearly 10 ft (3.0 m) away from the exterior face of an MSE wall, when considering 2 ft (0.6 m) of level surface behind the posts, an adjacent 3H:1V fill slope, and a 2-ft (0.6-m) fill height. Thus, it became desirable to place the barrier systems closer to the exterior edge of the MSE wall. Unfortunately, no methods were currently available for anchoring these barriers at or near the exterior face.

The primary research objective for this study was to develop an economical barrier system for safely treating vertical drop-offs located at the outside edge of wire-faced, MSE walls. During high-speed, high-energy impacts with passenger vehicles, the new barrier system should not impart unreasonable damage to the MSE wall system. The new barrier system should be easily maintained without requiring extensive repairs to the MSE wall structure. Several design concepts were considered for a new barrier system positioned closer to the exterior edge of wire-faced, MSE walls. The standard MGS along with its design variations were also considered. The new or modified barrier system was to be evaluated according to the Test Level 3 (TL-3) safety performance criteria set forth in the American Association of State Highway and Transportation Officials (AASHTO) Manual for Assessing Safety Hardware (MASH).

For this study, the Midwest Guardrail System (MGS) was extensively reviewed and considered for use in shielding the vertical drop-offs associated for MSE walls. From a review, the MGS was shown to provide acceptable safety performance when used for shielding wide, transverse culvert structures as well as fill slopes as steep as 2H:1V.

Multiple design concepts were considered for treating vertical drop-offs at the exterior face of wire-faced, MSE wall. As part of the brainstorming and selection process, several factors were considered, including: (1) control of overall project costs; (2) environmental impacts; (3) use of an economical barrier system; (4) concerns for MSE wall damage; (5) use 3H:1V fill slope at the top outer edge of MSE wall; (6) use of beam and post barriers for aesthetics; (7) constructability, maintenance, and repair of barrier system; and (8) approximate dynamic deflection and assumed vehicle trajectory for high-speed, high-energy vehicular impacts into semi-rigid guardrail systems. After considering concerns for constructability and repair, those barrier systems with deeply-embedded reinforced concrete foundations in combination with tension elements were eliminated from further investigation and comparison. Later, five design concepts were subjected to a basic cost analysis and system comparison. Following this effort, the project team chose to further develop a non-blocked version of the MGS with the posts placed at the slope break point of a 3H:1V fill slope.

Dynamic component testing was utilized to determine the post-soil behavior of steel and wood posts embedded in compacted, soil materials used for constructing wire-faced, MSE walls as well as to evaluate the effects of sloped terrain and different installation methods. Twenty-six dynamic tests were performed to evaluate the propensity for MSE wall damage, select post length, and determine post material and section. Following the post testing program, a non-blocked version of the MGS was recommended for evaluation within a crash testing program using: (1) steel W-beam backup plates; (2) 6-ft (1.8-m) long posts manufactured from either W6x8.5 (W152x12.6) or W6x9 (W152x13.4) steel sections; (3) posts driven at the slope break point of a 3H:1V fill slope adjacent to and on top of a wire-faced, MSE wall; and (4) posts installed using a 40-in. (1,016-mm) embedment depth. All other MGS features were maintained, including, rail splices at mid-span locations, 31-in. (787-mm) top mounting height, and 75-in. (1,905-mm) post spacing.

A full-size, MGS and MSE wall system was constructed for testing and evaluation. The non-blocked MGS was constructed with the back side of the steel posts positioned approximately 2 ft – 9 in. (0.84 m) away from the inside edge of the wall facing fill or 5 ft – 9 in. (1.75 m) away from the outer edge of the wire-faced, MSE wall. The modified MGS system was crash tested successfully using the 1100C small car and 2270P pickup truck vehicles according to the Test Level 3 (TL-3) safety performance guidelines provided in MASH. In both crash tests, no damage was observed in the MSE wall system. As a result of the extensive dynamic component testing and full-scale vehicle crash testing programs, the non-blocked MGS was recommended for use with wire-faced, MSE walls when placed at the slope break point of a 3H:1V fill slope. The modified MGS reduces the required width of the MSE wall, thus resulting in decreased construction costs.

For this research study, the test results and findings are contained in two different reports. The first report contains the design review of the MGS, design considerations, a summary of the dynamic component testing program, details for the MGS and MSE wall systems, the MASH full-scale crash testing requirements, results from the two full-scale crash tests, as well as a project summary, overall conclusions, and recommendations. This report (TRP-03-235-11) is entitled, "*Development of an Economical Guardrail System for Use on Wire-Faced, MSE Walls*." The second report contains the procedures utilized for the dynamic bogie testing program, results from the 26 dynamic post tests, as well as a post testing summary with conclusions and recommendations specific to the component testing program. This report (TRP-03-231-11) is entitled, "*Investigation and Dynamic Component Testing of Wood and Steel Posts for MGS on a Wire-Faced, MSE Wall*."

Following the completion of the research program noted above, MwRSF researchers also determined the minimum lateral barrier offset for wire-faced MSE wall systems which utilize a 3H:1V fill slope. For non-blocked MGS systems, the back side of steel posts are recommended to be placed a minimum of 1 ft (0.30 m) away from the inside edge of the wall facing fill or 4 ft (1.22 m) away from the outer edge of the MSE wall, whichever results in the largest lateral offset between the post and exterior wall face. For this recommendation, the minimum lateral offset between the rail face and outer edge of the MSE wall would be 4 ft – 9 ¼ in. (1.45 m). For varying thickness of select wall backfill and different widths for the 3H:1V fill slope, three different configurations were prepared to demonstrate the recommended guidance regarding the minimum lateral offset for the steel posts, as shown in Figures ES-1 through ES-3. This design guidance is suitable for use under both TL-2 and TL-3 roadside applications.

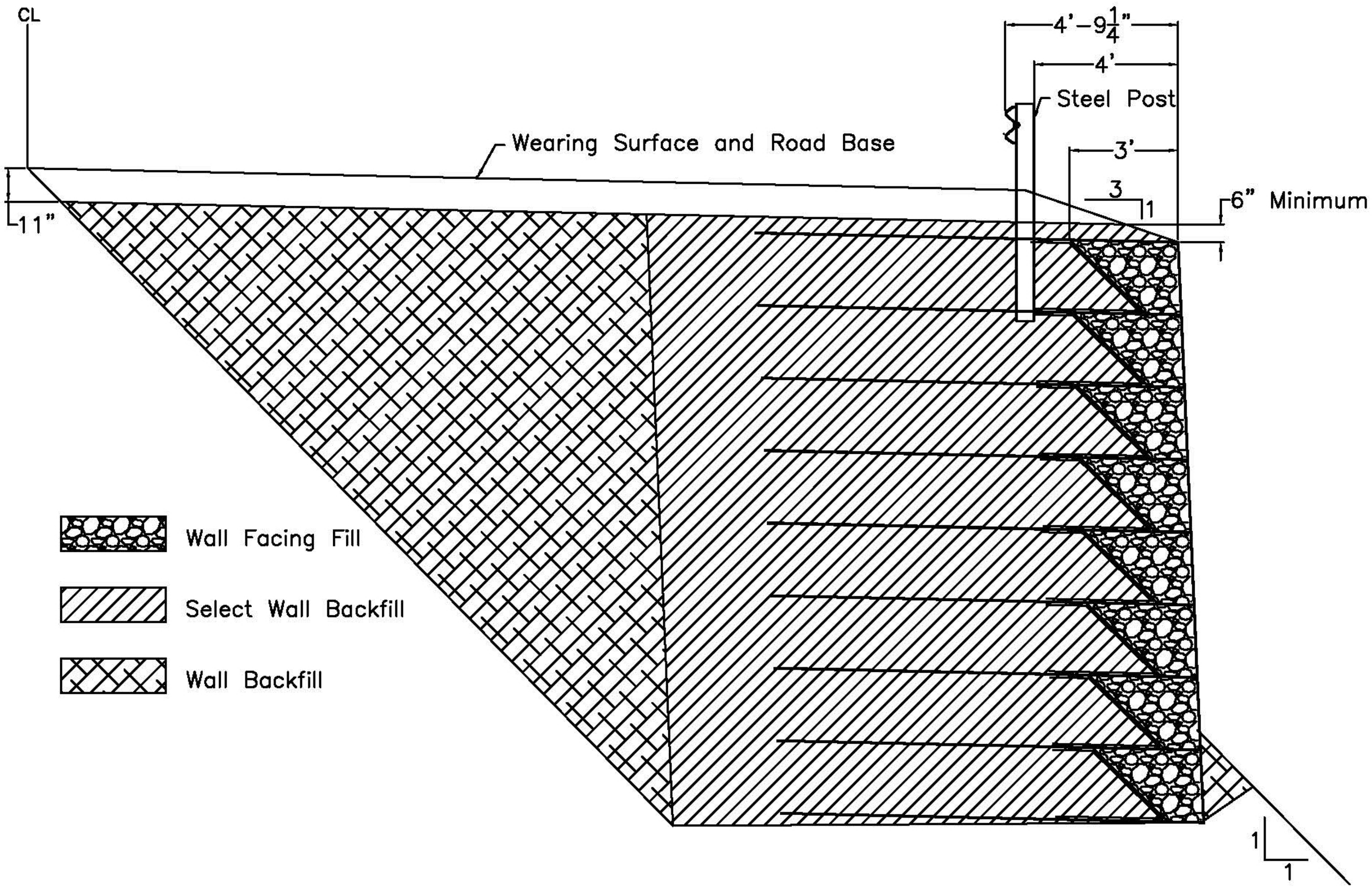


Figure ES-1. Schematic. Non-Blocked, Steel-Post MGS Centered at Slope Break Point with Minimum Lateral Offset.

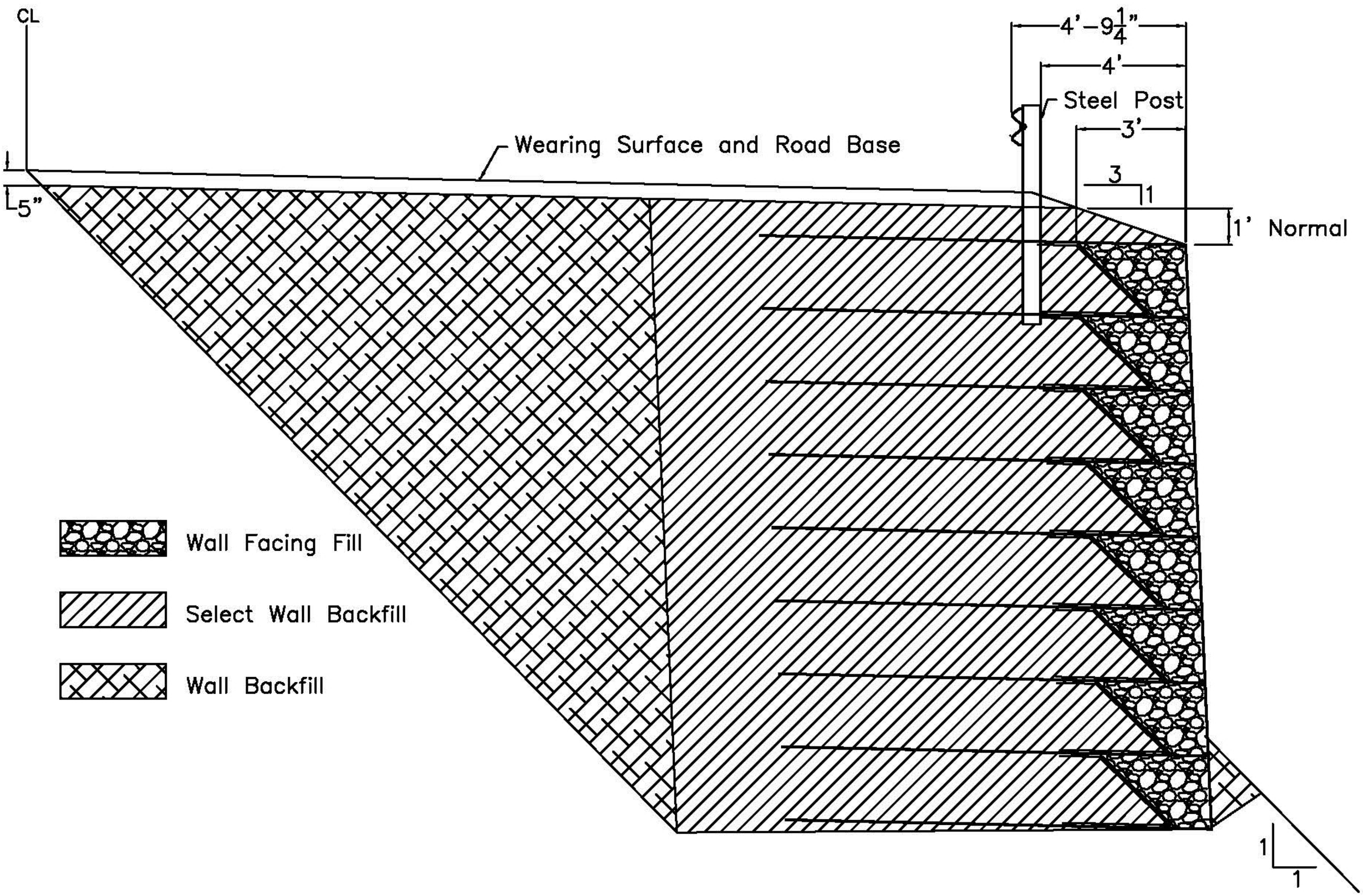


Figure ES-2. Schematic. Non-Blocked, Steel-Post MGS Centered at Slope Break Point with Minimum Lateral Offset.

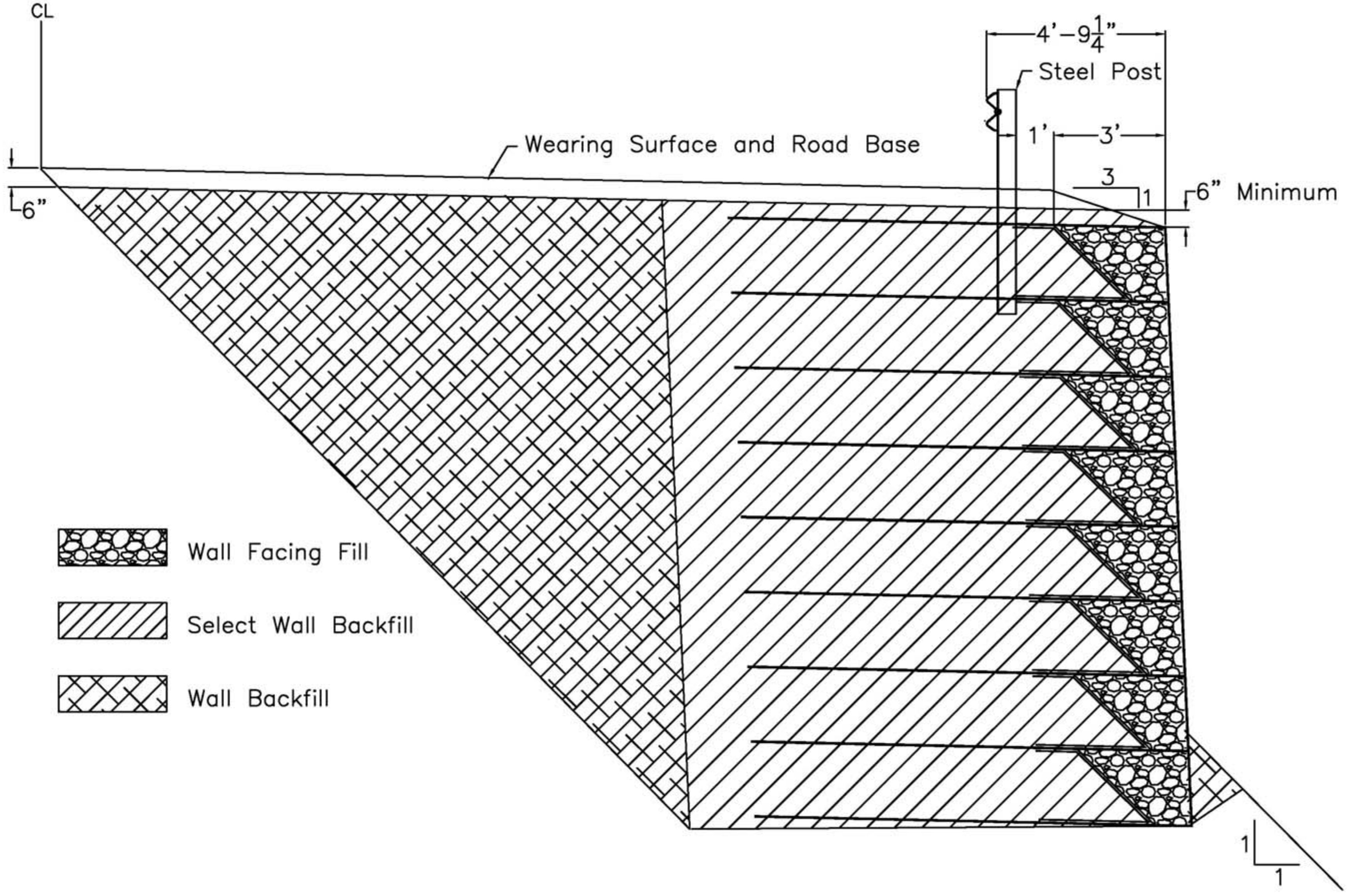


Figure ES-3. Schematic. Non-Blocked, Steel-Post MGS with Minimum Lateral Offset.

CHAPTER 1. INTRODUCTION

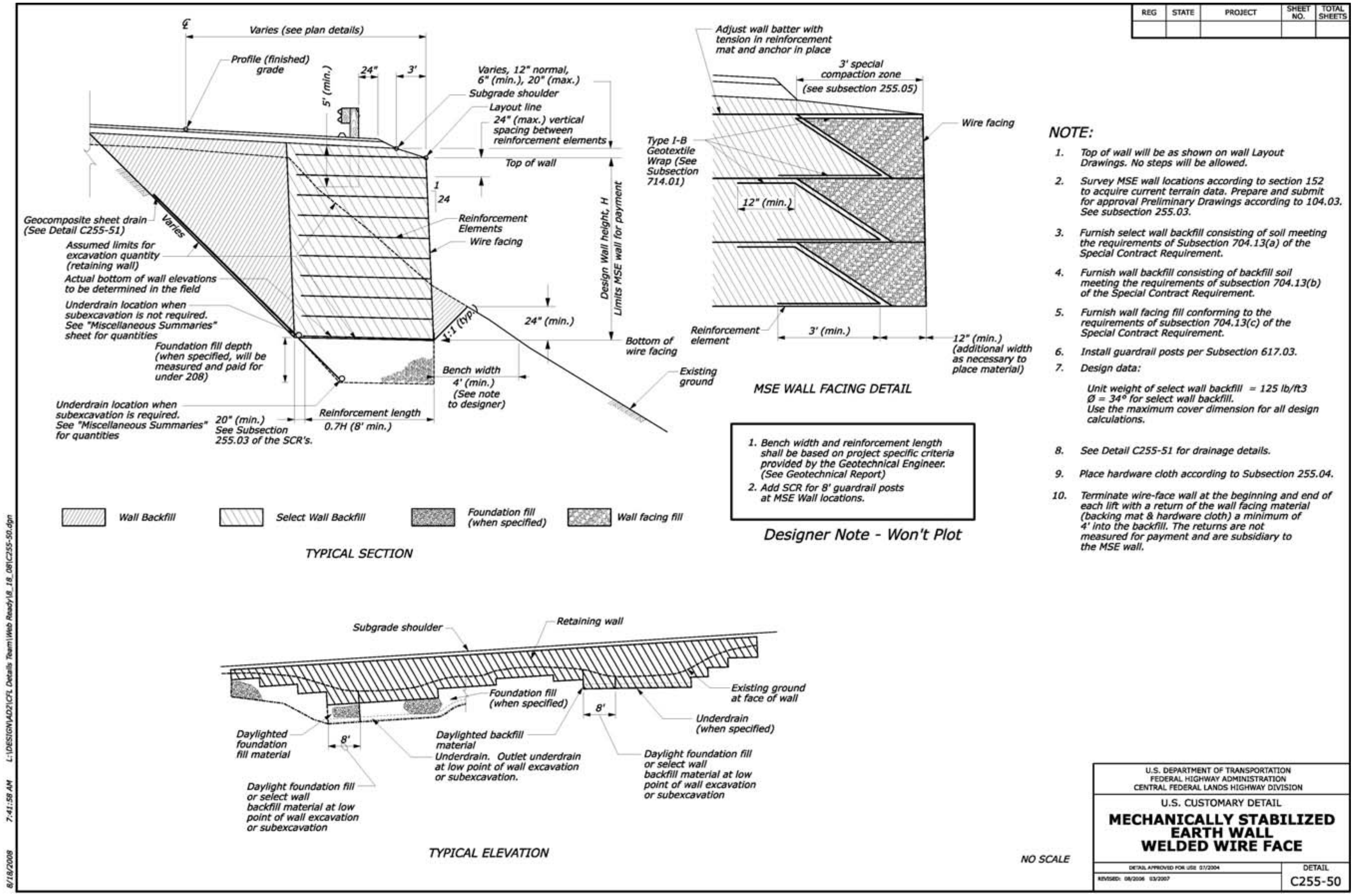
1.1 BACKGROUND

Wire-faced, mechanically-stabilized earth (MSE) walls provide an economical method for constructing nearly vertical walls adjacent to roadways where the local topography or the high cost of land precludes the use of conventional fill slopes. These MSE walls incorporate wire-mesh layers, cages, or baskets for surrounding and containing the angular aggregate or larger stones. The sequential placement of these layers or cages allow for a nearly vertical surface to be formed at the outside edge of the structure. While an economical solution for slope stability, MSE walls create safety issues by producing deep vertical drop-offs adjacent to the roadway that require the installation of a barrier system.

The Federal Lands Highway Division (FLHD) of the Federal Highway Administration (FHWA) designs and constructs a large number of wire-faced, MSE walls throughout the United States (U.S.). Within the Central Federal Lands Highway Division (CFLHD), Standard Detail C255-50 dated August 18, 2008 provides significant information regarding the general configuration of welded wire face MSE walls, as shown in Figures 1 and 2[1]. According to the CFLHD details, MSE wall systems are constructed using multiple layers of rock and reinforcing elements vertically placed on top of one another. The outer vertical edge consists of a special compaction zone of wall facing fill measuring approximately 3 ft (0.91 m) wide. The maximum layer height of compacted fill material is 2 ft (0.61 m) between the horizontal reinforcement elements. Above the last reinforcement element, the MSE wall system contains one additional layer of select wall backfill. The top layer of select wall backfill ranges in thickness from 6 in. (0.15 m) to 20 in. (0.51 m), but it is 1 ft (0.30 m) thick in "normal" configurations. Subsequently, a combined layer of road base material and wearing surface covers the top of the MSE wall system. However, CFLHD's C255-50 detail does not specify a range in thickness for the combined layer of road base material and wearing surface.

According to Standard Detail C255.50, CFLHD's accepted practice is to install conventional, wood-post W-beam guardrail 2 ft (0.61 m) laterally away from the slope break point (SBP), as measured to the backside of the wood posts. For this configuration, wood guardrail posts utilize a minimum embedment depth of 5 ft (1.52 m), as measured from the post base to the top of the select wall backfill material. For a 1-ft (0.30-m) thick layer of road base and wearing surface, the total embedment depth for wood posts could easily reach 6 ft (1.83 m), thus resulting in post lengths of 8 ft (2.44 m) or more. Depending on the size and grade of a wood post, concerns may exist for premature post fracture in standard W-beam guardrail systems configured with a 6-ft (1.83-m) embedment depth. Premature wood post fracture may potentially compromise the safety performance of wood-post, W-beam guardrail systems.

Using a "normal" 1-ft (0.30-m) thick top layer of select wall backfill and a 3-ft (0.91 m) wide special compaction zone of select wall facing fill, the soil terrain at the outer top region of the MSE wall would conform to a 3H:1V fill slope. Assuming a 1 ft (0.30 m) thick layer of road base and wearing surface above the top layer of select wall backfill in combination with a 3H:1V fill slope, the slope break point would occur approximately 6 ft (1.83 m) laterally away from the outer vertical edge of the MSE wall system. Therefore, a typical roadside cross section could be



1. Bench width and reinforcement length shall be based on project specific criteria provided by the Geotechnical Engineer. (See Geotechnical Report)
2. Add SCR for 8' guardrail posts at MSE Wall locations.

Designer Note - Won't Plot

NOTE:

1. Top of wall will be as shown on wall Layout Drawings. No steps will be allowed.
2. Survey MSE wall locations according to section 152 to acquire current terrain data. Prepare and submit for approval Preliminary Drawings according to 104.03. See subsection 255.03.
3. Furnish select wall backfill consisting of soil meeting the requirements of Subsection 704.13(a) of the Special Contract Requirement.
4. Furnish wall backfill consisting of backfill soil meeting the requirements of subsection 704.13(b) of the Special Contract Requirement.
5. Furnish wall facing fill conforming to the requirements of subsection 704.13(c) of the Special Contract Requirement.
6. Install guardrail posts per Subsection 617.03.
7. Design data:

   Unit weight of select wall backfill = 125 lb/ft3
   Ø = 34° for select wall backfill.
   Use the maximum cover dimension for all design calculations.

8. See Detail C255-51 for drainage details.
9. Place hardware cloth according to Subsection 255.04.
10. Terminate wire-face wall at the beginning and end of each lift with a return of the wall facing material (backing mat & hardware cloth) a minimum of 4' into the backfill. The returns are not measured for payment and are subsidiary to the MSE wall.

U.S. DEPARTMENT OF TRANSPORTATION
FEDERAL HIGHWAY ADMINISTRATION
CENTRAL FEDERAL LANDS HIGHWAY DIVISION

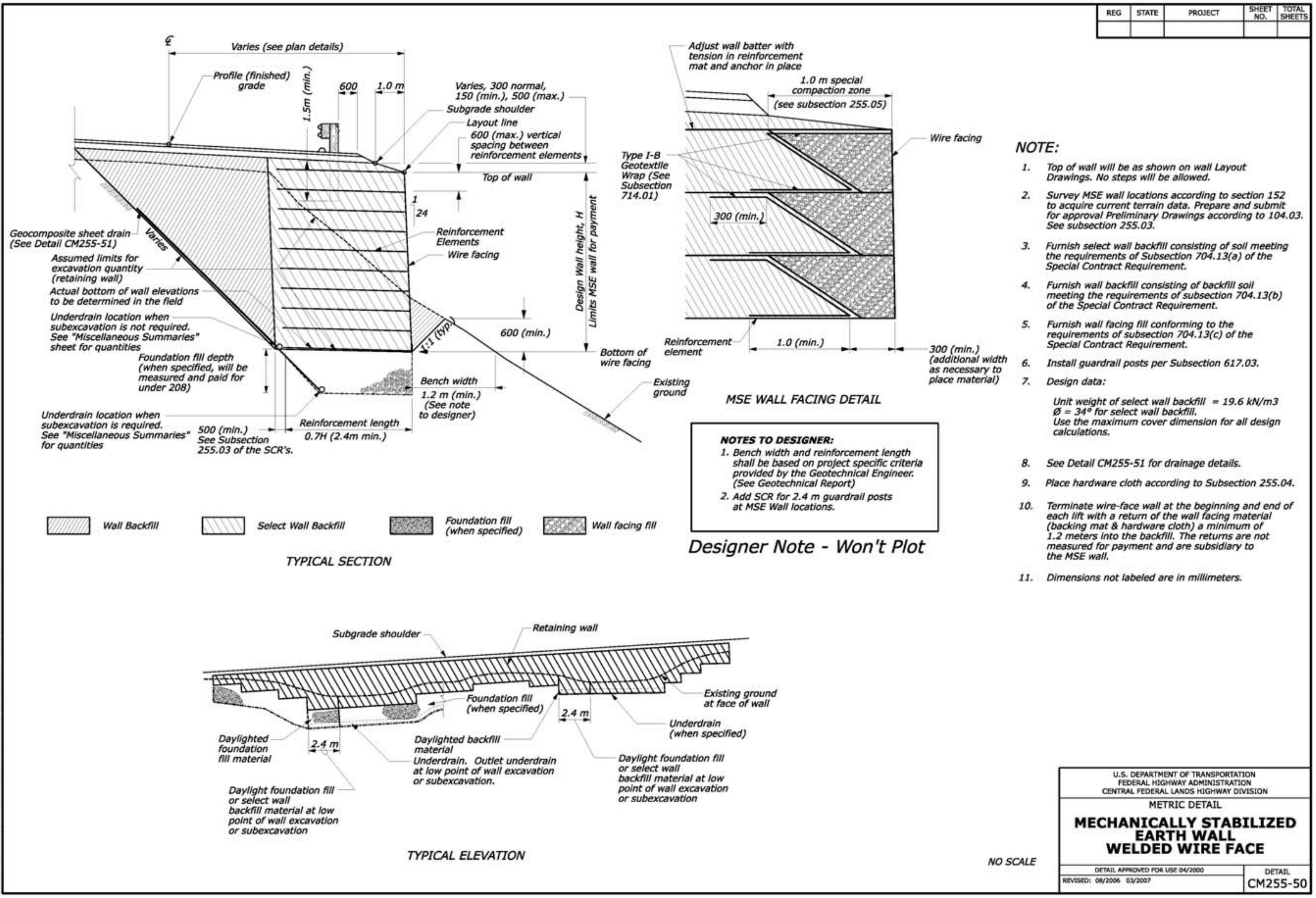
U.S. CUSTOMARY DETAIL

**MECHANICALLY STABILIZED
EARTH WALL
WELDED WIRE FACE**

DETAIL APPROVED FOR USE 07/2004
REVISED: 08/2006 03/2007

DETAIL
C255-50

Figure 1. Schematic. CFLHD's Standard Detail C255-50.



NOTES TO DESIGNER:

1. Bench width and reinforcement length shall be based on project specific criteria provided by the Geotechnical Engineer. (See Geotechnical Report)
2. Add SCR for 2.4 m guardrail posts at MSE Wall locations.

Designer Note - Won't Plot

NOTE:

1. Top of wall will be as shown on wall Layout Drawings. No steps will be allowed.
2. Survey MSE wall locations according to section 152 to acquire current terrain data. Prepare and submit for approval Preliminary Drawings according to 104.03. See subsection 255.03.
3. Furnish select wall backfill consisting of soil meeting the requirements of Subsection 704.13(a) of the Special Contract Requirement.
4. Furnish wall backfill consisting of backfill soil meeting the requirements of subsection 704.13(b) of the Special Contract Requirement.
5. Furnish wall facing fill conforming to the requirements of subsection 704.13(c) of the Special Contract Requirement.
6. Install guardrail posts per Subsection 617.03.
7. Design data:

   Unit weight of select wall backfill = 19.6 kN/m3
   Ø = 34° for select wall backfill.
   Use the maximum cover dimension for all design calculations.

8. See Detail CM255-51 for drainage details.
9. Place hardware cloth according to Subsection 255.04.
10. Terminate wire-face wall at the beginning and end of each lift with a return of the wall facing material (backing mat & hardware cloth) a minimum of 1.2 meters into the backfill. The returns are not measured for payment and are subsidiary to the MSE wall.
11. Dimensions not labeled are in millimeters.

U.S. DEPARTMENT OF TRANSPORTATION
FEDERAL HIGHWAY ADMINISTRATION
CENTRAL FEDERAL LANDS HIGHWAY DIVISION

METRIC DETAIL

MECHANICALLY STABILIZED EARTH WALL WELDED WIRE FACE

DETAIL APPROVED FOR USE 04/2000
REVISED: 08/2006 03/2007
DETAIL CM255-50

Figure 2. Schematic. CFLHD's Standard Detail C255-50. (continued.)

configured with 2-ft (0.61-m) wide level terrain behind the guardrail posts and a 6-ft (1.83-m) wide 3H:1V fill slope extending to the vertical edge of the MSE wall system. The fill slope would contain 2 ft (0.61 m) of road base, wearing surface, and top layer of select wall backfill. Using this common configuration, CFLHD's accepted practice would result in a guardrail system being installed 8 ft (2.44 m) away from the exterior face of the MSE wall, as measured to the backside of the wood posts. Typically, wood-post, W-beam guardrail systems are configured with 6-in. x 8-in. (152-mm x 203-mm) posts and offset blocks in combination with a 3¼-in. (83-mm) deep rail section. For this common roadside configuration, the front face of the W-beam rail would be 9 ft - 7¼ in. (2.93 m) laterally away from the exterior vertical face of the MSE wall, as shown in Figure 3. Large lateral barrier offsets will increase the cost of the MSE wall structure and potentially result in additional environmental impacts on FLHD projects.

Unfortunately, methods for anchoring crashworthy barrier systems at or near the outside face of a wire-faced, MSE wall were unavailable. As a result, there existed a need to develop an economical barrier system that would either reduce the large lateral barrier offset to or near 0 ft (0 m) when placing low-cost standard W-beam guardrails on wire-faced MSE walls or decrease the overall width of the MSE wall structure. In addition, the development of an economical barrier system would possibly help to define or clarify the minimum lateral offset between the barrier and the outer edge of the MSE wall system.

W-beam guardrail systems are normally used to prevent motorists from striking serious hazards adjacent to low- and medium-service level highways. During design impact event, these barriers rely on energy dissipation associated with the rotation of guardrail posts in soil and incur significant dynamic deflections. The economics of wire-faced, MSE wall construction would dictate minimizing the lateral width required for the shoulder, guardrail system, and soil fill placed behind the guardrail. Additionally, the tradeoff between damage incurred to the wire-faced, MSE wall during a vehicular impact event and the initial cost of construction is an important consideration.

A design of a cantilevered, W-beam barrier system was submitted to the Midwest Roadside Safety Facility (MwRSF) project team for review. This modified barrier system was configured for attachment to the exterior vertical surface of wire-faced, MSE walls and incorporated long, exterior-mounted, vertical posts and/or rigid sleeves for anchoring guardrail posts, as well as costly foundation hardware placed within the MSE wall, such as long steel anchor rods, plates, and reinforced concrete beams. Unfortunately, this unique barrier and anchorage system, along with other similar systems, have not been previously crash tested and evaluated according to impact safety standards. It is our opinion that an exterior-mounted, crashworthy barrier system would likely be very expensive to construct and difficult to maintain and repair when considering the structural elements that are embedded deep into the MSE wall. The connection between the foundation and barrier system would have required tension elements at fairly close spacing, such as at 6 ft – 3 in. (1.90 m) centers. For this configuration, it would be extremely cumbersome to construct the MSW wall system when placing and compacting the select wall backfill material around the tension elements. Secondarily, repair of these types of barrier systems would be impractical. In addition, these systems would likely result in greater concerns for damage to the MSE wall structure during vehicular impact events.

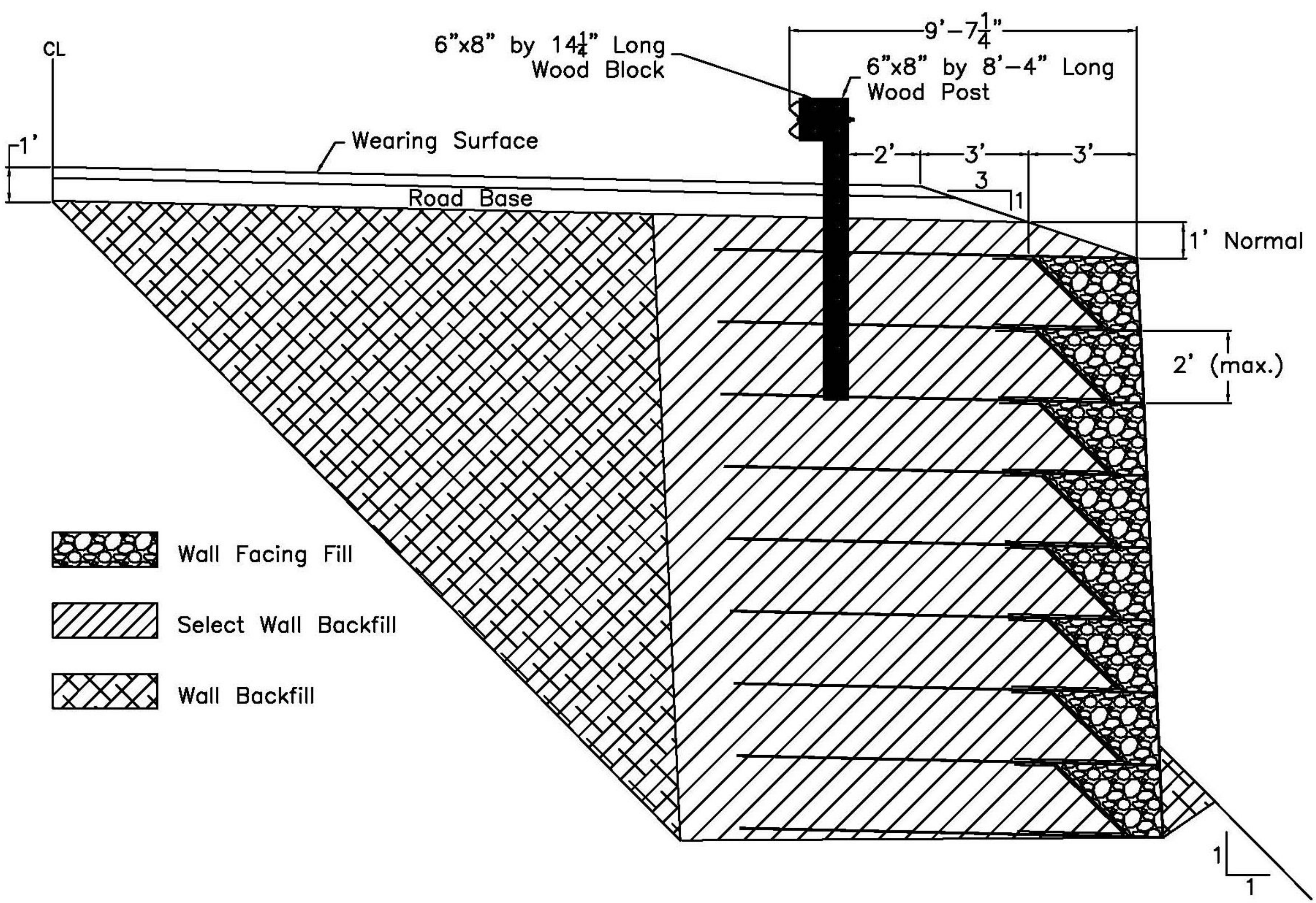


Figure 3. Schematic. Baseline Configuration for W-Beam Guardrail and MSE Wall.

Full-scale crash testing of strong-post, W-beam guardrails installed in rigid foundations, such as solid rock, asphalt pavements, and concrete mow strips, has shown that preventing the posts from absorbing energy by rotating in the soil severely limits the barrier's ability to contain and redirect large passenger vehicles, such as light trucks and sport utility vehicles (SUVs).[2,3] Therefore, the optimum barrier system would minimize damage to the wire-faced, MSE wall structure and decrease the required lateral offset between the guardrail face and the outside vertical edge of the wall system.

In recent years, the Midwest Guardrail System (MGS) has demonstrated improved vehicle containment, safety performance, and redirective capacity over that provided by conventional, strong-post, W-beam guardrail systems. [See references 4-13.] The MGS utilizes mid-span guardrail splices, an increased top rail mounting height of 31 in. (787 mm), an increased blockout depth of 12 in. (305 mm), and a reduced post embedment of 40 in. (1,016 mm). From the seemingly simple design changes, the redirective capacity of the MGS has proven to be more than double that provided by standard W-beam guardrail systems. [See references 4-13.] The MGS has also been shown to provide satisfactory safety performance when used in combination with curbs, culverts, slopes, and other roadside anomalies. Thus, the standard MGS, its existing variations, as well as any potential design modifications, were also considered for use in shielding the hazardous, vertical drop-offs created by the construction of wire-faced, MSE walls.

1.2 OBJECTIVE

The primary research objective was to develop an economical barrier system for safely treating vertical drop-offs located at the outside edge of wire-faced, MSE wall systems. During high-speed, high-energy impacts with passenger vehicles, the new barrier system should not impart unreasonable damage to the MSE wall system when positioned at the minimum lateral offset between the post and edge of the MSE wall system. The new barrier system should be easily maintained without requiring extensive repairs to the MSE wall structure. Several design concepts were to be considered for a new barrier system that was positioned closer to the exterior edge of wire-faced, MSE walls. In addition, the standard MGS along with its design variations were to be considered for use or modification. The new or modified barrier system was to be evaluated according to the Test Level 3 (TL-3) safety performance criteria set forth in the American Association of State Highway and Transportation Officials (AASHTO) *Manual for Assessing Safety Hardware* (MASH).[14] Design guidance for TL-2 impact conditions will also be available in the final recommendations.

1.3 SCOPE

The research objectives were achieved through the completion of multiple tasks within the research and development effort. First, a design review, comparisons, and evaluations were performed on various barrier concepts and systems. Dynamic component testing was then utilized to determine the post-soil behavior of steel and wood posts placed in compacted soil material representative of that typically used for the construction of wire-faced, MSE walls. This post testing program was also used to evaluate the propensity for damage to the MSE wall system, select the appropriate post length, and determine the post material type. After considering various barrier concepts, the standard MGS was modified by removing the 12-in.

(305-mm) deep wood spacer blocks and by incorporating steel W-beam backup plates. Subsequently, the modified barrier system was installed at the slope break point of a 3H:1V fill slope using a 6-ft (1.8 m) lateral offset between the steel post's centerline and the outer edge of the MSE wall as shown in Figure 4. The modified MGS was crash tested and evaluated according to the TL-3 safety performance guidelines provided in MASH using 1100C small car and 2270P pickup truck vehicles striking at a target impact speed of 62 mph (100 km/h) and a target impact angle of 25 degrees. Finally, conclusions and recommendations were made that pertained to the safety performance of the non-blocked, MGS installed on top of a wire-faced, MSE wall system.

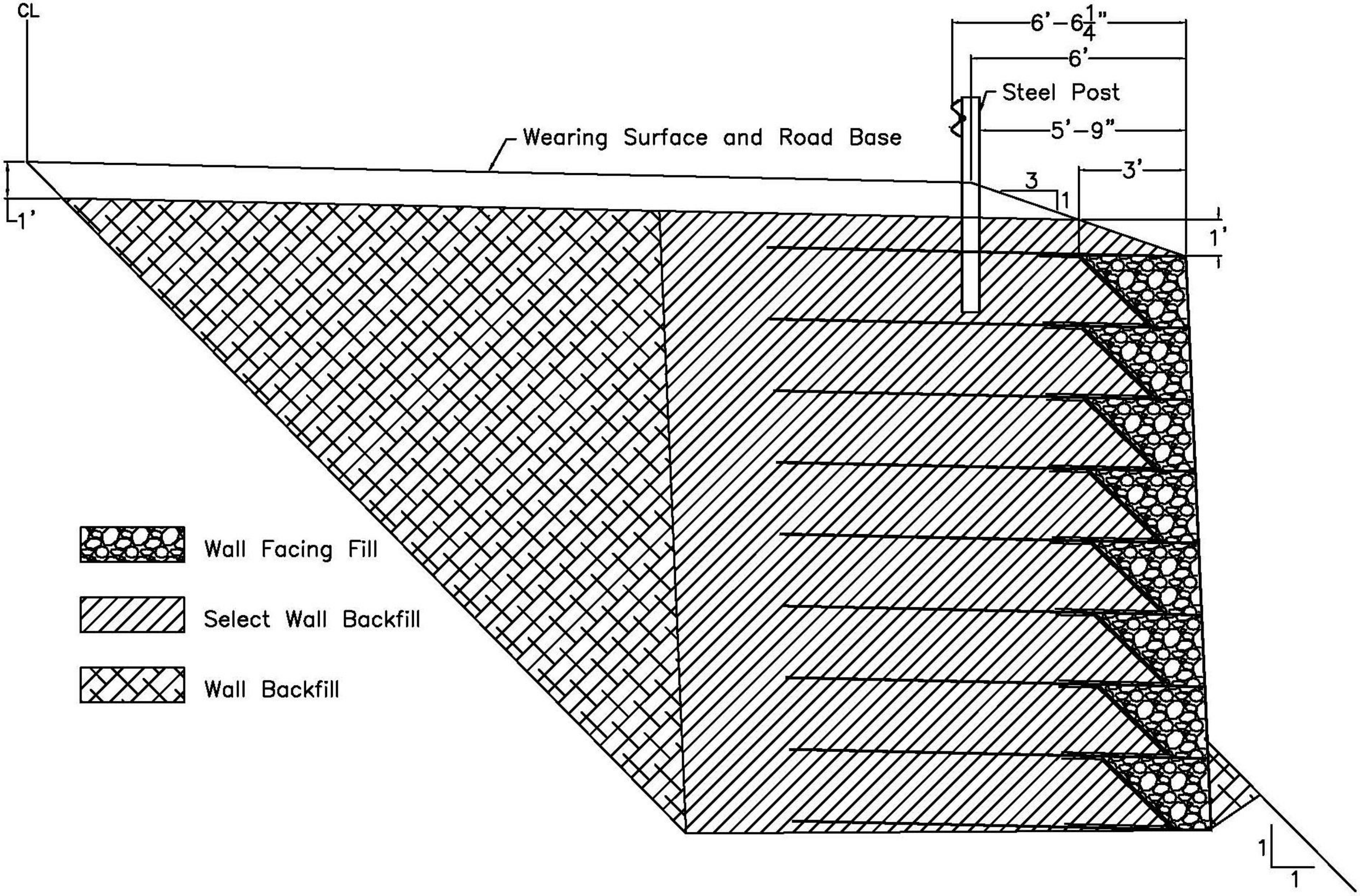


Figure 4. Schematic. Non-Blocked, Steel-Post MGS System Centered at Slope Break Point.

CHAPTER 2. REVIEW OF MIDWEST GUARDRAIL SYSTEM (MGS)

The MGS has demonstrated excellent safety performance when modified for use in treating hazardous terrain. More specifically, full-scale crash testing has demonstrated that the MGS can successfully contain and redirect heavy passenger vehicles when placed in close proximity to both vertical drop-offs adjacent culverts headwalls and 2H:1V fill slopes. [See references 15-18.]

First, the MGS was adapted to span across concrete box culverts measuring 24-ft (7.3 m) wide or less, as measured parallel to the roadway.[15,16] The long-span MGS system utilized three timber breakaway CRT posts, measuring 6 in. (152 mm) wide by 8 in. (203 mm) deep by 6 ft (1,829 mm) long and spaced on 6 ft – 3 in. (1,905 mm) centers, both on the upstream and downstream ends of the culvert system. During the crash testing program, the MGS contained a 2270P pickup truck even after allowing it to extend approximately 3 ft (0.9 m) beyond the edge of the vertical drop off and later redirected it back onto the traveled-way without serious risk to the occupants.

The MGS was also modified to allow for post placement at the slope break point of a 2H:1V fill slope.[17,18] This MGS design variation incorporated W6x9 (W152x13.4) steel posts measuring 9 ft (2.7 m) long and spaced on 6 ft – 3 in. (1,905 mm) centers. For this study, the modified MGS safely contained and redirected a 2270P pickup truck even when a maximum dynamic barrier deflection of 57.6 in. (1,463 mm) was observed.

Both MGS design variations were successfully crash tested and evaluated according to the TL-3 safety performance guidelines provided in MASH. Based on these results, the research team believed that the MGS should be considered for modification and use on top of or near the outer edge of wire-faced, MSE walls.

CHAPTER 3. DESIGN CONSIDERATIONS

Multiple design concepts were considered for use in treating vertical drop-offs created with the construction of wire-faced, MSE wall systems. As part of the brainstorming and selection process, several factors were considered, including: (1) control of overall project costs through a reduction in the lateral offset used for placing barrier systems or a decrease in the overall width of the MSE wall structure; (2) environmental impacts on FLHD projects, such as increased excavation into mountainous terrain or increased structure encroachment into nearby streams and forests; (3) use of an economical barrier system; (4) concerns for damage to the wire-faced, MSE wall structure; (5) MwRSF and CFLHD personnel agreed that placement of a 3H:1V fill slope at the top outer edge of MSE wall structure could be reasonably maintained, should not easily erode, and should form basis of analysis for most barrier concepts; (6) use of beam and post barriers either possessing flexibility to address aesthetics or providing openness for enhanced visualization of surroundings; (7) constructability, maintenance, and repair of the new barrier system; and (8) approximate dynamic deflection and assumed trajectory for high-speed, high-energy vehicular impacts into semi-rigid guardrail systems.

Early in the study, CFLHD personnel and vendors of MSE wall systems provided various concepts for placing W-beam guardrail systems on top of or at the outer vertical edge of the MSE walls. These barrier designs used rigid steel sleeves for anchoring guardrail posts, which may have reduced concerns for inflicting significant damage to wire-faced, MSE wall systems near the outer edge. These barrier designs often utilized costly foundation hardware, including the use of long steel anchor rods and plates as well as reinforced concrete foundations. Unfortunately, the crashworthiness of exterior-mounted, barrier and anchorage systems have not been verified through full-scale vehicle crash testing programs.

Using the FLHD and MSE wall vendor details, MwRSF prepared two simple barrier concepts for consideration and discussion, as shown in Figures 5 and 6. For these design concepts, long tension elements in combination with deeply-embedded reinforced concrete foundations would be required to restrain the posts and/or supporting rigid sleeves. In addition, the spacing of the long tension elements would be fairly close, or assumed to occur at 6 ft – 3 in. (1,90 m) centers. Unfortunately and for these design concepts, the research team believed that it would be difficult to construct the MSE wall structure while compacting fill around the long, sloped tension elements, one or two per post location. In addition, it was deemed impractical to repair any damaged tension elements or reinforced concrete foundations within the MSE wall structure in the event that damage occurred. After considering concerns for constructability and repair, barrier concepts with deeply-embedded reinforced concrete foundations in combination with long, sloped tension elements were eliminated from further investigation and comparison.

As noted previously, MwRSF prepared a baseline barrier configuration for use on top wire-faced MSE walls using CFLHD’s accepted practice. For this baseline configuration, a wood-post, W-beam guardrail system was installed 8 ft (2.44 m) away from the exterior face of the MSE wall, as shown in Figure 3. Recall, this barrier system was configured with 6-in. x 8-in. (152-mm x 203-mm) wood posts and offset blocks in combination with a 3¼-in. (83-mm) deep rail section, thus positioning the rail face 9 ft - 7¼ in. (2.93 m) laterally away from the exterior edge of the MSE wall.

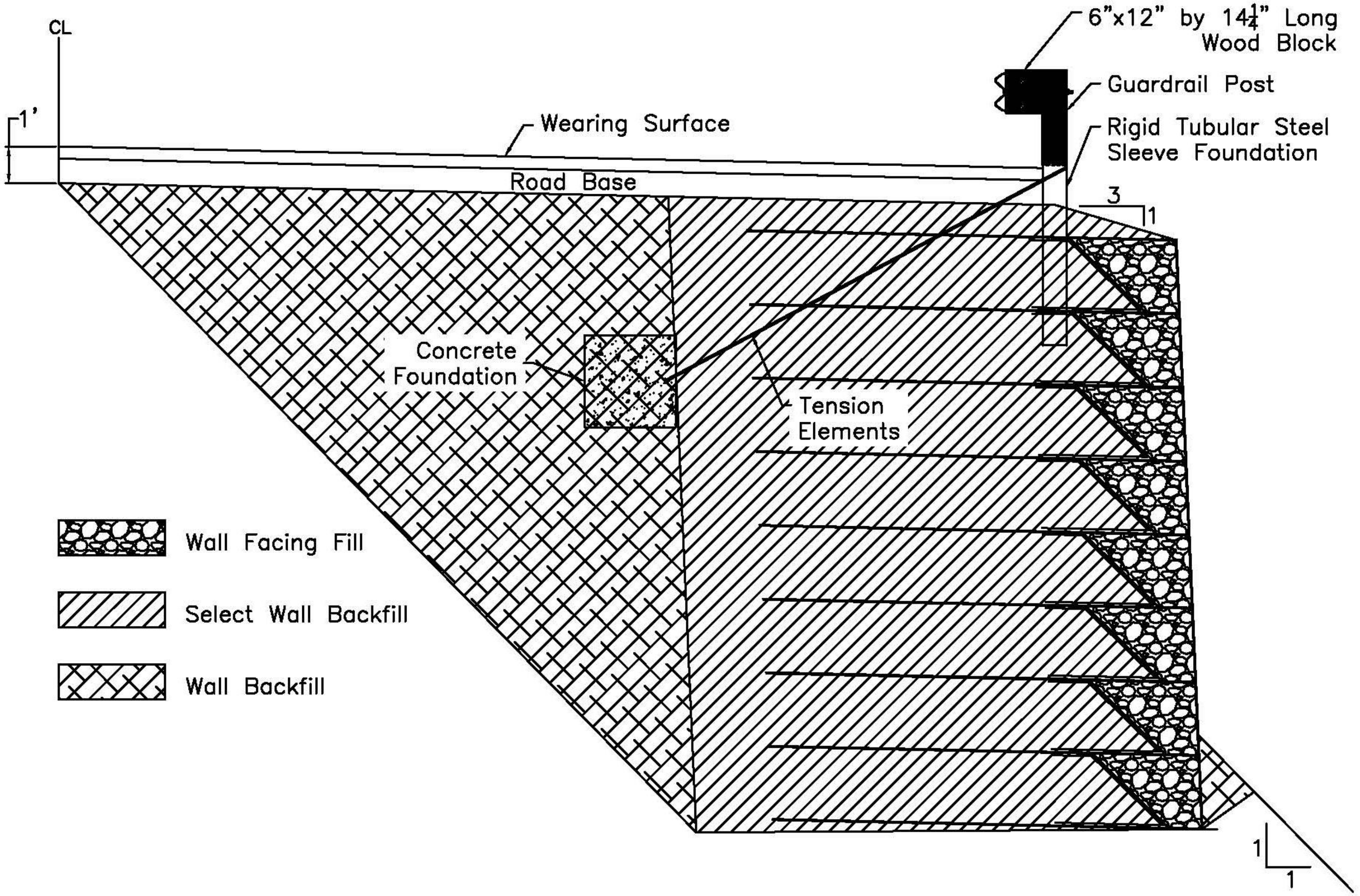


Figure 5. Schematic. MGS System with Rigid Sleeve, Concrete Foundation, and Tension Elements.

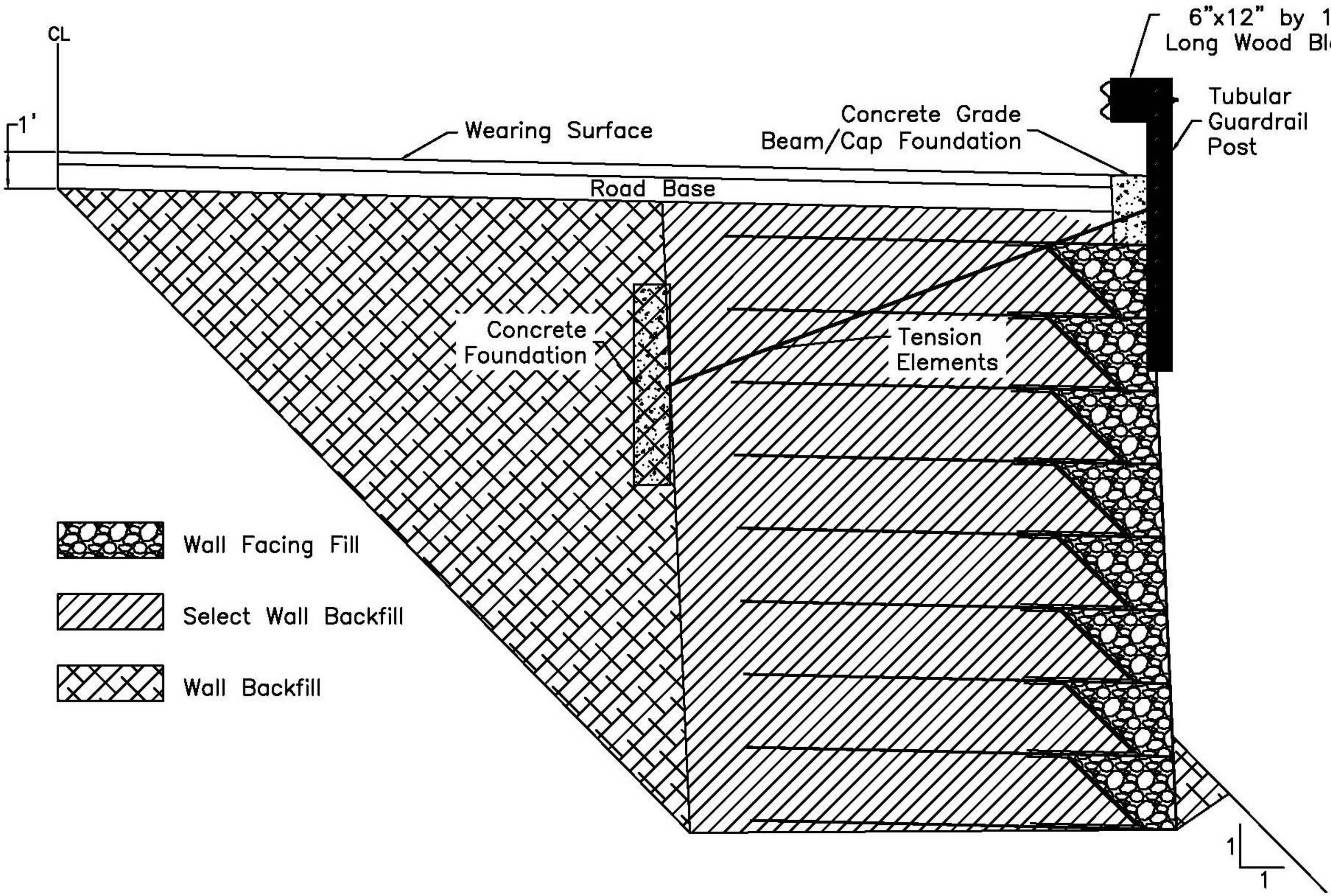


Figure 6. Schematic. MGS System with Tubular Post, Concrete Foundations, and Tension Elements.

Using the design factors noted above, five additional barrier concepts were prepared for consideration and discussion. Later, these barrier concepts were compared to one another using a basic, incremental-cost analysis, which considered differences in system components and varied widths of MSE wall.

Four initial barrier concepts were configured using features from the MGS. Concept no. 1 consisted of a standard MGS located 24 in. (610 mm) forward from the slope break point (SBP), as measured to back of the steel post, as shown in Figure 7. This concept was very similar to the baseline barrier configuration depicted in Figure 3. However, Concept No. 1 incorporated the MGS features, a steel post in lieu of a wood post, and a 12-in. (302-mm) versus 8-in. (203-mm) deep wood offset block. As a result, Concept No. 1 became the modified baseline configuration for use in the basic incremental-cost analysis. Concept no. 2, as depicted in Figure 8, consisted of a non-blocked MGS located 24 in. (610 mm) forward from the slope break point, as measured to back of steel post. A standard MGS with the steel post centered at the slope break point was selected for Concept no. 3, as shown in Figure 9. Finally, Concept no. 4 utilized a non-blocked MGS with the steel post centered at the slope break point, as depicted in Figure 10

One additional barrier concept was proposed which did not utilize the approximately 6-ft (1.8-m) wide, 3H:1V fill slope. Instead, the final barrier concept utilized a heavily-reinforced concrete slab and grade beam system that was placed on a mostly level surface. As depicted in Figure 11, Concept no. 5 incorporated an aesthetic, glue-laminated (glulam) timber rail and post system which was placed at the top exterior edge of the wire-faced, MSE wall system using steel mounting brackets which attached to the concrete slab and grade beam.

Subsequently, the five barrier concepts were compared using relative reductions in the required width of the MSE wall structure as the primary metric along with reductions in the cost of the wire-faced, MSE wall structure as a function of width and changes in the installation cost for the various barrier systems. Concept no. 1 served as the basis for comparison; since, the barrier face was farthest from the outside edge of the MSE wall structure and required the greatest structure width.

A comparison of the five barrier concepts is shown in Table 1. From this information, an incremental decrease in the required width of MSE wall structure was observed with the progression of Concept nos. 1 through 5. The cost analysis was based on the assumption that (1) the MSE wall was placed on a 1H:1V fill slope and (2) each 1ft (0.3 m) reduction in lateral barrier offset would result in a 1 ft (0.3 m) reduction in the height of the MSE wall. CFLHD personnel provided a cost for the MSE wall to be approximately \$50/ft^2. When considering a 1-ft (0.3-m) height reduction, a net cost reduction of \$50 per linear ft of MSE wall was used in the analysis. For example, Concept no. 2 provides a 1 ft (0.3 m) reduction in wall width as compared to Concept no. 1 due to the elimination of the 12-in. (305- mm) deep timber spacer blocks. Thus, the front face of the barrier is placed 1 ft (0.3 m) closer to the outside edge of the MSE wall system and results in a cost reduction of \$52/ft. When compared to Concept no. 1, the greatest cost reduction for the MSE wall structure was determined as \$450/ft for Concept no. 5.

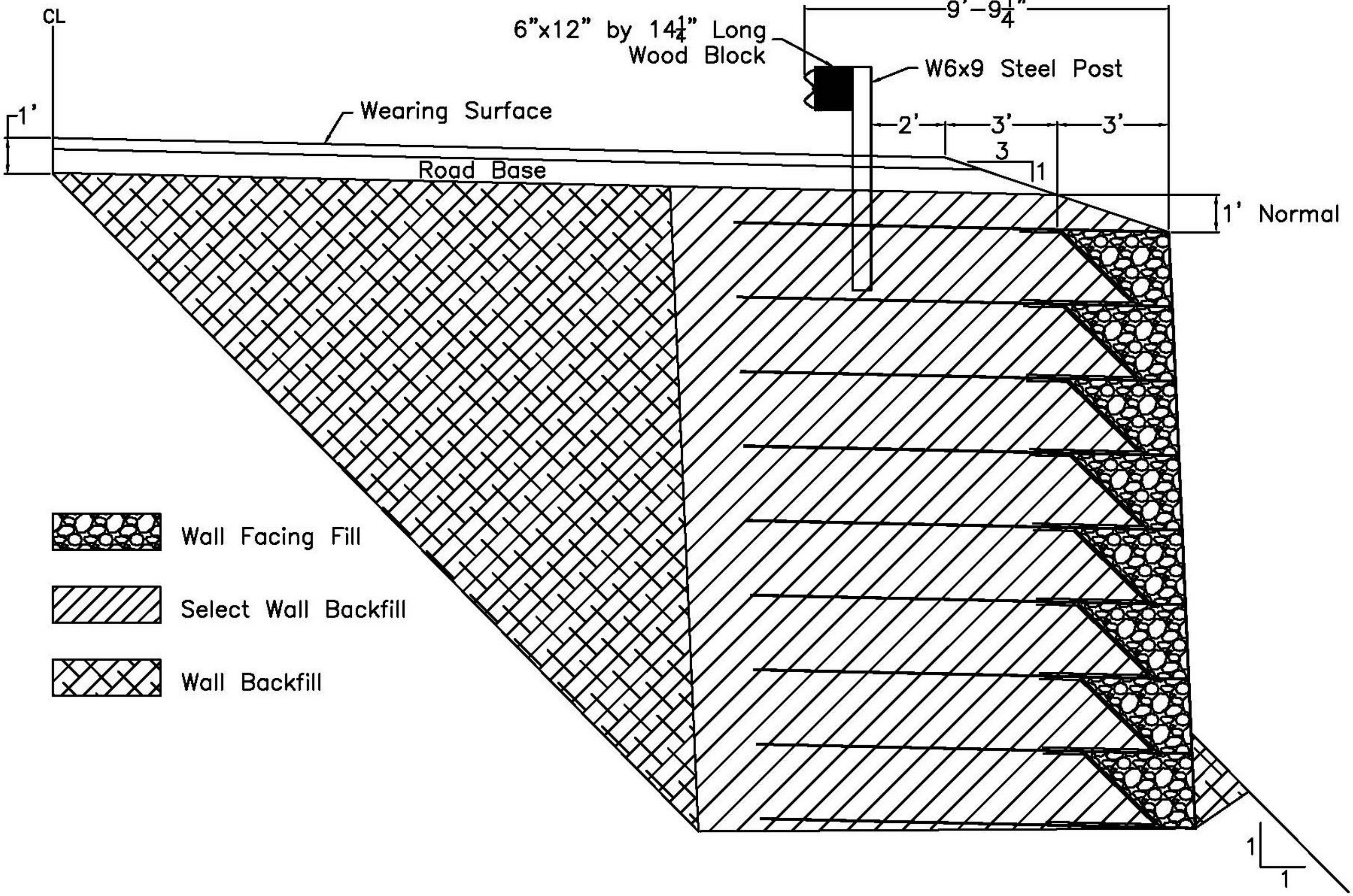


Figure 7. Schematic. Concept No. 1 – Steel-Post MGS at 2 ft (0.6 m) from Slope Break Point (Modified Baseline).

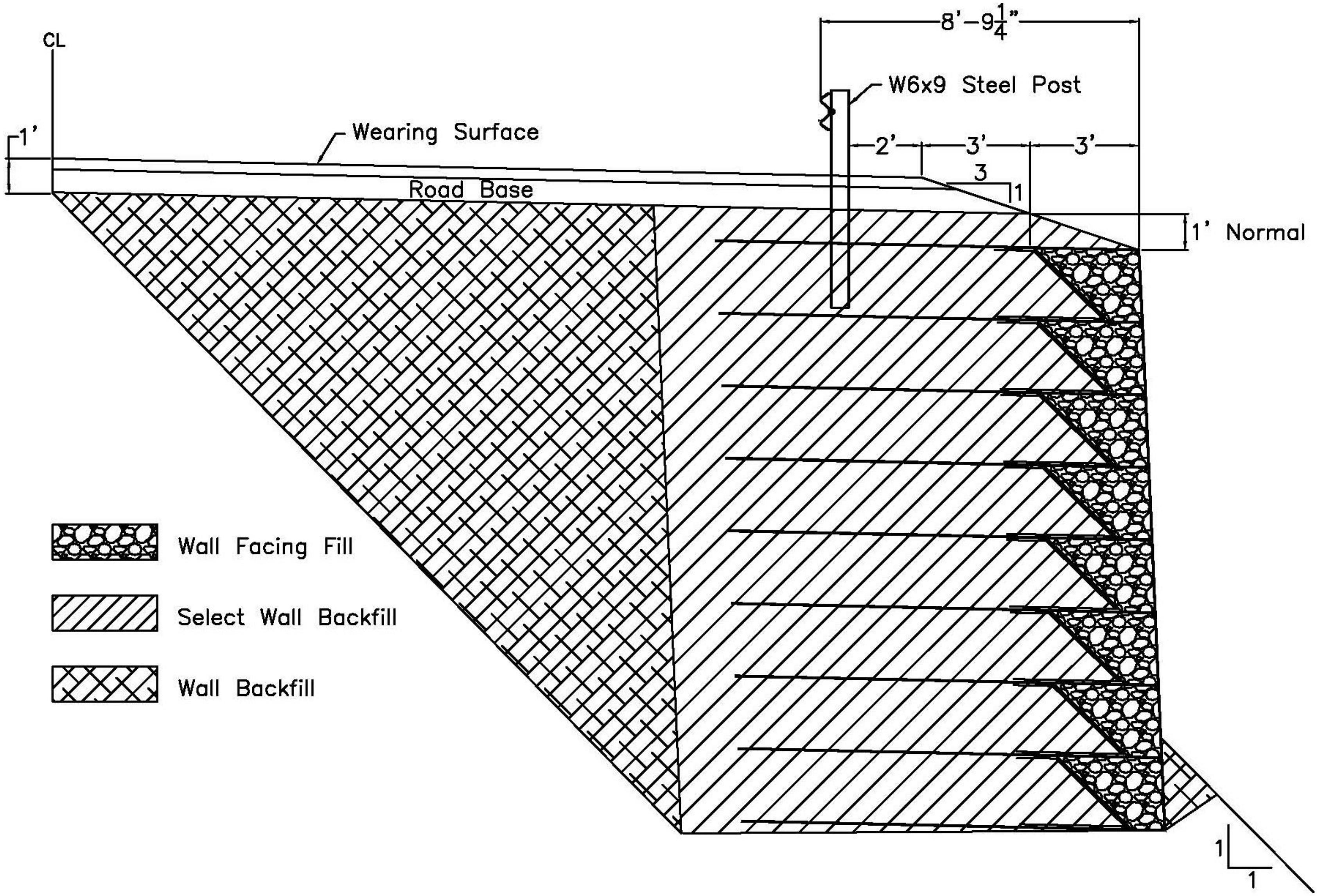


Figure 8. Schematic. Concept No. 2 – Non-Blocked, Steel-Post MGS at 2 ft (0.6 m) from Slope Break Point.

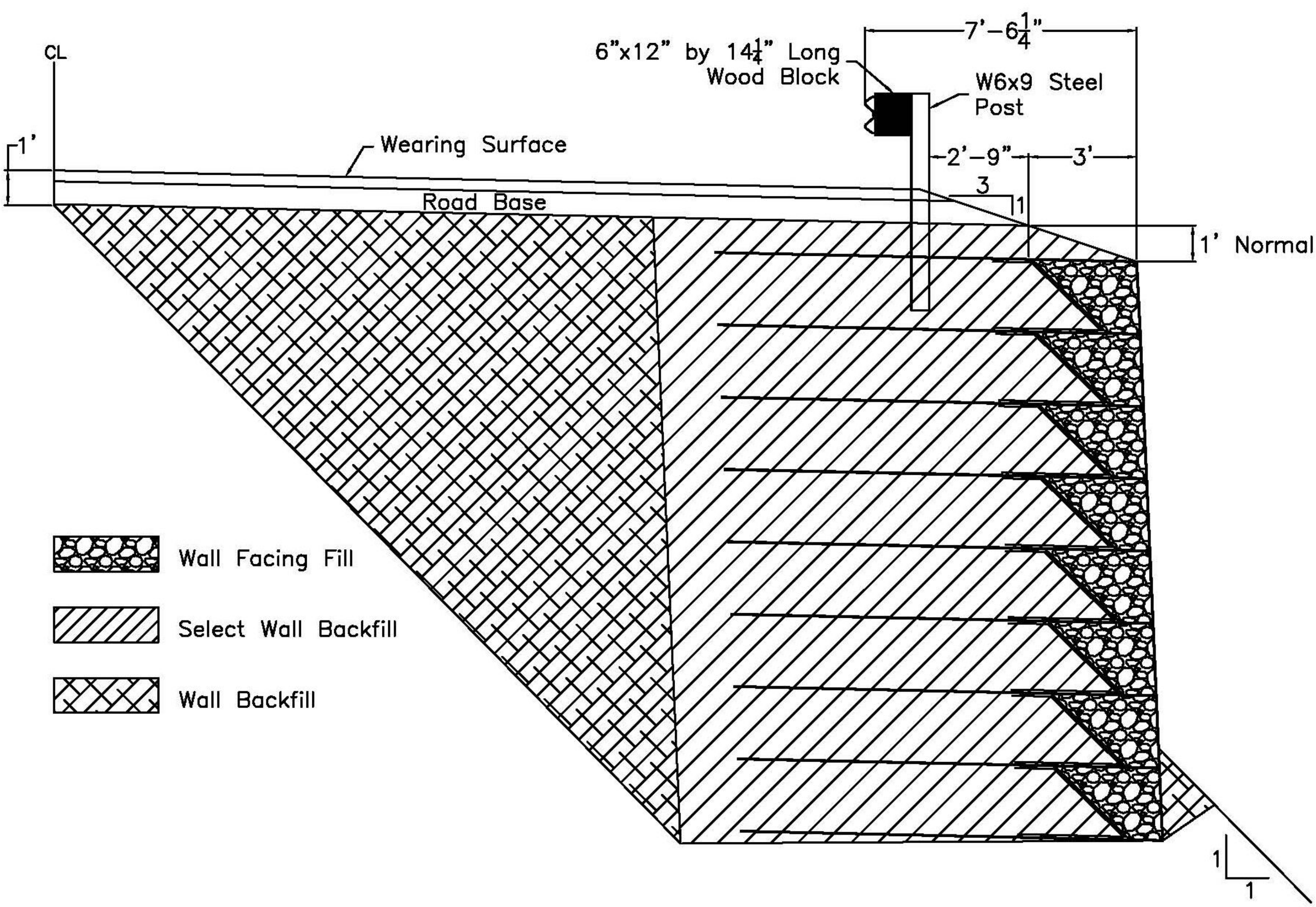


Figure 9. Schematic. Concept No. 3 – Steel-Post MGS Centered at Slope Break Point.

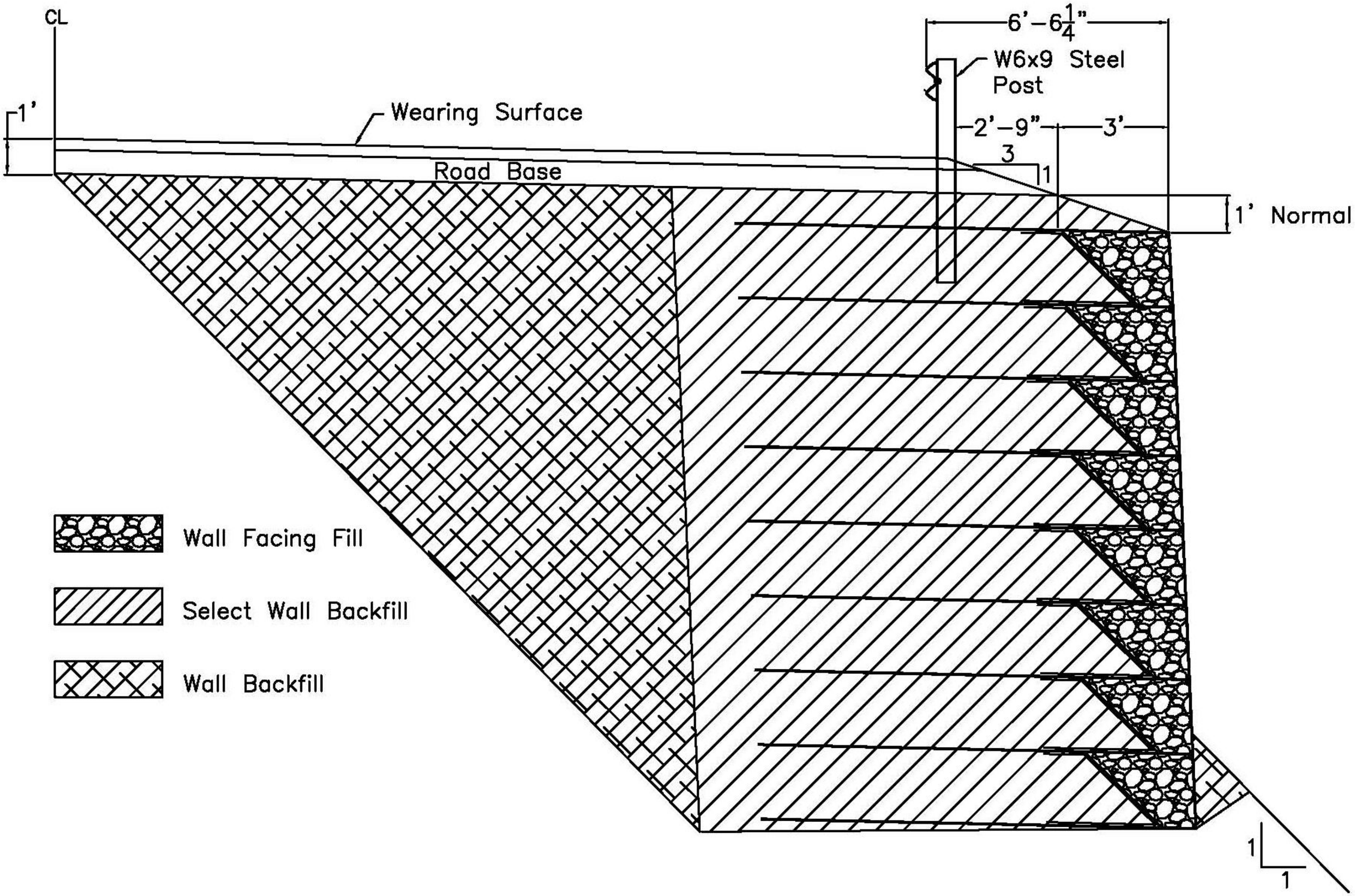


Figure 10. Schematic. Concept No. 4 – Non-Blocked, Steel-Post MGS Centered at Slope Break Point.

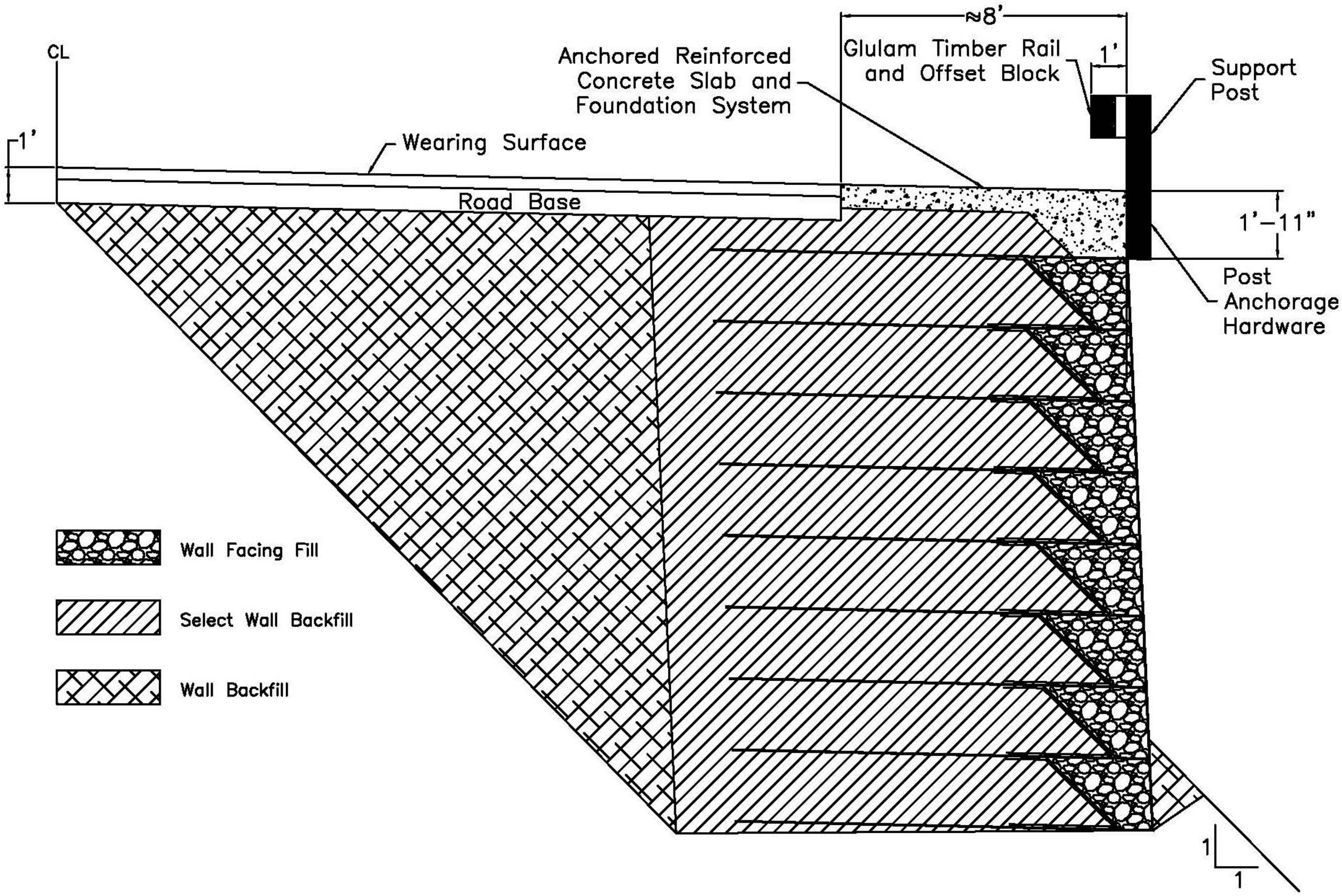


Figure 11. Schematic. Concept No. 5 – Glulam Timber Railing System with Structural Slab and Steel Anchorage Hardware.

Table 1. Comparison of Barrier Concepts for Use on Wire-Faced, MSE Wall System.

Concept No.	System Description	Reduction Wall Width (ft)	Reduction Wall Cost ($/linear ft)	Reduction Barrier Cost ($/linear ft)	Net Cost Reduction ($/ft)
1	Standard MGS - Steel Post - 2 ft from SBP to Back of Post - 6 ft Post Length	NA	NA	NA	NA
2	Non-Blocked MGS - Steel Post - 2 ft from SBP to Back of Post - 6 ft Post Length	1 ft	$50/ft	$2/ft	$52/ft
3	Standard MGS - Steel Post - Post Centered at SBP - Est. 7 to 8 ft Post Length	2.25 ft	$112/ft	**($8/ft)**	$104/ft
4	Non-Blocked MGS - Steel Post - Post Centered at SBP - Est. 7 to 8 ft Post Length	3.25 ft	$162/ft	**($4/ft)**	$158/ft
5	Glulam Timber Rail and Post - 1 ft from Rail Face to Edge	9 ft	$450/ft	**($800/ft)**	**($350/ft)**

When the costs of barrier construction were evaluated, only one barrier concept (Concept no. 2) was found to be more economical than a standard MGS guardrail. The net cost reduction for this concept was found to be less than $2/ft and occurred due to the removal of the timber spacer blocks, the use of a shorter guardrail bolt, and the addition of a steel backup plate. Concept nos. 3 and 4 were estimated to be more costly than Concept no. 1 as a result of the anticipated need to increase post length near the 3H:1V fill slope. Concept no. 5 provided the greatest increase in barrier costs, $800/ft, as compared to Concept no. 1. This large increase resulted from the high material and labor costs associated with the construction of a side-mounted, glulam timber beam and post system with attachment to the heavily-reinforced, concrete slab and grade beam system.

Barrier costs and savings in MSE wall construction were combined to produce a net reduction in construction costs for each option. Each of the MGS barrier alternatives (Concept nos. 2 through 4) provided a net cost reduction for the MSE wall and barrier systems when compared to the baseline condition of Concept no. 1. For example, Concept no. 4 (i.e., non-blocked MGS with steel posts placed at the slope break point) provided the greatest net cost reduction of $158/ft when compared to the baseline configuration. Alternatively, the glulam timber beam and post configuration (Concept no. 5) actually produced a net cost increase when compared to baseline configuration (Concept no. 1). Based on the cost analysis and system comparison, the CFLHD-MwRSF project team selected Concept no. 4 for further development and use on wire-faced, MSE walls.

CHAPTER 4. BARRIER DESIGN ISSUES

The implementation of Concept no. 4 for use with a wire-faced, MSE wall system presents three potential problems, including: (1) failure of the rail to release from the posts; (2) rail rupture arising from contact with a post flange; and (3) overly stiff guardrail posts.

If a guardrail fails to release from a post, the rail element can be pulled down when the post rotates in the soil. In extreme cases, the rail will become disengaged from the vehicle and allow it to override the barrier. Standard MGS systems incorporate a button head post bolt and a wood spacer block. The small button head is more easily pulled through the post bolt slot, and the soft wood behind the rail eliminates the risk of the rail becoming pinched between the bolt head and the post flange. Elimination of the blockout could allow the rail to be pinched which would alter rail release characteristics. Further, removing the blockout and placing the posts in very stiff soil, such as in a MSE wall system, would be expected to change the nature of post deformation during an impact. The stiffened post would not deflect in advance of the impacting vehicle. Thus, the stiff post would be more likely to be contacted by the front wheel and pushed down parallel to the rail. In this situation, the post bolt could be pushed parallel to the rail without generating a significant pull-out force.

The post bolt pullout problem was examined using first principles. Initially, the size of the shoulder on a standard post bolt was examined to determine if the rail element could actually become tightly pinched between the bolt head and the post flange. This dimensional analysis showed that a single layer of guardrail could not become tightly pinched and thus, a standard post bolt with an underside lug could possibly be used with the MGS without blocks.

The second post bolt pull-out issue that was investigated related to the potential motion of the post parallel to the rail. In this situation, the post bolt would quickly reach the end of the slot in the rail. In this loading condition, the post bolt would need to begin to tear out the end of the slot in order to release the rail from the post. The shear force required to yield the region of the guardrail in contact with the side of the bolt was calculated using the bolt bearing equation shown below:

$$F_v = (\sigma_w)(t_w)(D_b) = 3{,}400 \text{ lb } (15.1 \text{ kN})$$

where σ_w = yield strength of W-beam rail = 50 ksi
t_w = thickness of W-beam rail = 0.109 in.
D_b = bolt diameter = 0.625 in.

After the W-beam begins to yield, it will initially begin to buckle, which would produce out-of-plane tearing in the guardrail. A great number of out-of-plane tearing tests were conducted during development of the BEST guardrail end terminal. [See references 19-21.] The BEST impact head causes out-of-plane tearing to cut a W-beam guardrail into four longitudinal strips. Static compression tests with the W-beam rail pushed over the hardened cutters demonstrated that out-of-plane tearing forces were generally below the estimated bearing yield force shown above. Never-the-less, a 25 percent dynamic load factor was applied to the bearing force to produce a tear-out force estimate of 4,200 lb (18.7 kN).

The post was modeled as a cantilever with a 4,200-lb (18.7-kN) resistive force at the top and a tire impact load applied 16 in. (406 mm) above the ground. This load condition was found to produce a plastic moment at the base of the post when the tire load approached 13,000 lb (57.8 kN). This loading would produce approximately 5.5 g's on the MASH 1100C test vehicle. Note that this acceleration is only slightly higher than those experienced on some roller coasters. Hence, the force required to reduce bolt tear out along the rail should not produce unsafe decelerations, even for impacts with an 1100C small car vehicle.

The concern about tearing of the guardrail when it contacted a post flange was resolved by reviewing prior crash test findings. Historical testing has shown that small cuts can be produced in a W-beam guardrail when it becomes trapped between the edge of a post flange and an impacting vehicle.[22] The traditional solution to this problem has been to incorporate plates to prevent the rail from directly contacting a post. This inexpensive solution was incorporated into the new barrier.

The final concern was that excessively stiff guardrail posts would not absorb enough energy and thereby lead to rail rupture. Note that guardrail posts were expected to be significantly stiffer because the posts were driven into a well-compacted, crushed limestone soil material adjacent to the baskets of large rocks and with the bottoms of the posts penetrating into the wire-mesh layers of compacted, crushed limestone. The large rocks inside the wire baskets were essentially constrained from any significant movement. Thus, the base of the posts adjacent to the baskets of rocks and penetrating into the wire-mesh layers would likely be constrained against lateral movement and rotation, thus potentially resulting in premature lateral torsional buckling and reduced energy dissipation. In order to investigate the post stiffness when installed in a MSE wall system, a series of dynamic bogie tests were conducted to determine the appropriate guardrail post length to support the guardrail and prevent damage to the MSE wall system. As summarized below, these dynamic post tests in the MSE wall produced high soil resistance, but the posts did not fail in lateral torsional buckling.

CHAPTER 5. DYNAMIC COMPONENT TESTING

5.1 OVERVIEW

Dynamic component testing was utilized to determine the post-soil behavior of steel and wood posts placed in compacted, soil material representative of that used for constructing wire-faced, MSE walls. This post testing program was also used to: (1) investigate the dynamic response of posts placed on 3H:1V fill slopes using alternative post installation methods; (2) evaluate the propensity for rotating posts to inflict damage to the MSE wall system; (3) select the appropriate post length ranging between 6 and 9 ft (1.8 and 2.7 m); and (4) evaluate common guardrail post sections, including 6-in. x 8-in. (152-mm x 203-mm) wood posts as well as W6x9 (W152x13.4) and W6x8.5 (W152 x 12.6) steel sections. Further details can be found in a MwRSF research report, entitled *Investigation and Dynamic Testing of Wood and Steel Posts for MGS on a Wire-Faced, MSE Wall.*[23]

A total of twenty-six dynamic tests were conducted during four rounds of testing on 6-in. x 8-in. (152-mm x 203-mm) wood posts, W6x16 (W152x23.8) steel posts, W6x9 (W152x13.4) steel posts, and W6x8.5 (W152 x 12.6) steel posts of multiple lengths and soil embedment depths. The posts were impacted 24⅞ in. (632 mm) above the ground line.

For each bogie test, raw acceleration data was acquired and filtered, and then force vs. displacement and energy vs. displacement graphs were plotted. From the energy vs. displacement graphs, the average post-soil forces were calculated for displacements of 15 and 20 in. (381 and 508 mm) at the center rail height. Different soil gradations, terrain (i.e., level or sloped fill), installation methods, and levels of soil compaction were evaluated. A summary of test results for the four rounds of post testing are shown in Tables 2 through 7.

Table 2. Round 1 Summary - 6-in. x 8-in. (152-mm x 203-mm) Wood Posts with 40-in. (1,016-mm) Embedment Depth at 25 mph (40.2 km/h).

Test No.	Soil Gradation	Impact Velocity mph (km/h)	Peak Force		Average Force		Total Energy kip-in. (kJ)	Maximum Deflection in. (mm)	Failure Type
			Force kips (kN)	Deflection in. (mm)	@ 15 in. kips (kN)	@ 20 in. kips (kN)			
GWB-10	AASHTO Grading B (strong soil) - Y	24.7 (39.8)	14.6 (64.9)	1.9 (48)	6.0 (26.9)	5.8 (26.0)	223.5 (25.3)	45.5 (1,155)	Rotation in Soil
GWB-11	AASHTO Grading B (strong soil) - Y	24.7 (39.8)	14.8 (65.8)	1.9 (48)	6.3 (28.0)	6.2 (27.6)	233.5 (26.4)	45.8 (1,164)	Rotation in Soil
Average		24.7 (39.8)	14.7 (65.3)	1.9 (48)	6.2 (27.5)	6.0 (26.8)	228.5 (25.8)	45.6 (1,159)	

Table 3. Round 1 Summary - 6-in. x 8-in. (152-mm x 203-mm) Wood Posts with 40-in. (1,016-mm) Embedment Depth at 20 mph (32.2 km/h).

Test No.	Soil Gradation	Impact Velocity mph (km/h)	Peak Force		Average Force		Total Energy kip-in. (kJ)	Maximum Deflection in. (mm)	Failure Type
			Force kips (kN)	Deflection in. (mm)	@ 15 in. kips (kN)	@ 20 in. kips (kN)			
GWB-1	AASHTO Grading B (strong soil) - Y	20.7 (33.3)	9.7 (43.0)	1.6 (40)	5.2 (23.1)	5.2 (23.1)	222.0 (25.1)	48.5 (1,233)	Rotation in Soil
GWB-2	AASHTO Grading B (strong soil) - Y	19.8 (31.8)	12.3 (54.9)	1.5 (39)	6.6 (29.5)	6.4 (28.6)	205.0 (23.2)	45.9 (1,165)	Rotation in Soil
GWB-6	AASHTO Grading B (strong soil) - X	19.6 (31.5)	8.7 (38.9)	1.6 (41)	6.5 (28.8)	6.2 (27.5)	177.3 (20.0)	40.5 (1,029)	Rotation in Soil
GWB-7	AASHTO Grading B (strong soil) - Y	19.0 (30.6)	8.6 (38.0)	2.6 (66)	5.7 (25.3)	5.9 (26.4)	207.5 (23.4)	40.8 (1,036)	Rotation in Soil
Average		19.8 (31.8)	9.8 (43.7)	1.8 (46)	6.0 (26.7)	5.9 (26.4)	202.9 (22.9)	43.9 (1,116)	
GWB-5*	2- to 4-in. Dia. Limestone	19.7 (31.7)	8.4 (37.3)	1.3 (33)	3.6 (16.1)	3.5 (15.6)	126.3 (14.3)	56.2 (1,428)	Rotation in Soil

*Embedded in 2-4-in. limestone – not included in average of strong soil tests

Table 4. Round 1 Summary - 6-in. x 8-in.(152-mm x 203-mm) Wood Posts with 40-in. (1,016-mm) Embedment Depth at 15 mph (24.1 km/h).

Test No.	Soil Gradation	Impact Velocity mph (km/h)	Peak Force		Average Force		Total Energy kip-in. (kJ)	Maximum Deflection in. (mm)	Failure Type
			Force kips (kN)	Deflection in. (mm)	@ 15 in. kips (kN)	@ 20 in. kips (kN)			
GWB-3	AASHTO Grading B (strong soil) - Y	15.1 (24.4)	8.3 (36.9)	1.1 (27)	4.5 (20.1)	4.3 (19.3)	141.9 (16.0)	52.8 (1,341)	Rotation in Soil
GWB-4	AASHTO Grading B (strong soil) - Y	14.3 (23.1)	10.2 (45.2)	1.2 (30)	3.8 (17.1)	3.7 (16.4)	129.3 (14.6)	44.9 (1,140)	Rotation in Soil
GWB-8	AASHTO Grading B (strong soil) - Y	15.1 (24.3)	8.7 (38.5)	1.2 (29)	4.1 (18.5)	4.1 (18.0)	144.9 (16.4)	43.3 (1,101)	Rotation in Soil
GWB-9	AASHTO Grading B (strong soil) - Y	14.5 (23.3)	6.6 (29.4)	1.0 (26)	3.6 (16.1)	3.6 (15.8)	127.7 (14.4)	42.7 (1,085)	Rotation in Soil
Average		14.8 (23.8)	8.4 (37.5)	1.1 (28)	4.0 (17.9)	3.9 (17.4)	136.0 (15.4)	45.9 (1,166)	

Table 5. Round 2 Testing Results - W6x16 (W152x23.8) Steel Posts v.s 6-in. x 8-in. (152-mm x 203-mm) Wood Posts with 40-in. (1,016-mm) Embedment Depth at 20 mph (32.2 km/h).

Test No.	Impact Velocity mph (km/h)	Peak Force		Average Force		Total Energy kip-in. (kJ)	Maximum Deflection in. (mm)	Failure Type
		Force kips (kN)	Deflection in. (mm)	@ 15 in. kips (kN)	@ 20 in. kips (kN)			
W6x16 (W152x23.8) Steel Posts								
GWB-12	19.0 (30.6)	12.8 (57.1)	9.9 (251)	11.0 (49.1)	10.3 (45.8)	236.1 (26.7)	33.8 (860)	Rotation in Soil
GWB-13	19.2 (30.8)	12.8 (57.1)	6.6 (169)	11.0 (48.9)	10.4 (46.3)	247.7 (28.0)	31.3 (795)	Rotation in Soil
Average	19.1 (30.7)	12.8 (57.1)	8.3 (210)	11.0 (49.0)	10.4 (46.1)	241.9 (27.3)	32.6 (828)	
6-in. x 8-in. (152-mm x 203-mm) SYP Wood Posts								
GWB-14	19.3 (31.0)	14.6 (65.0)	2.9 (74)	11.6 (51.5)	10.5 (46.6)	232.0 (26.2)	31.7 (805)	Rotation in Soil
GWB-15	19.6 (31.6)	13.5 (60.2)	4.0 (102)	11.3 (50.5)	10.3 (45.8)	225.6 (25.5)	30.0 (761)	Rotation in Soil
Average	19.5 (31.3)	14.1 (62.6)	3.5 (88)	11.5 (51.0)	10.4 (46.2)	228.8 (25.8)	30.8 (783)	

Table 6. Round 3 Testing Results - 6-in. x 8-in. (152-mm x 203-mm) Wood Posts vs. W6x9 (W152x13.4) and W6x8.5 (W152x12.6) Steel Posts at 20 mph (32.2 km/h) with Varying Embedment Depths and Posts at 3H:1V Slope Break Point.

Test No.	Embedment Depth in. (mm)	Impact Velocity mph (km/h)	Peak Force		Average Force		Total Energy kip-in. (kJ)	Maximum Deflection in. (mm)	Failure Type
			Force kips (kN)	Deflection in. (mm)	@ 15 in. kips (kN)	@ 20 in. kips (kN)			
6-in. x 8 in. (152-mm x 203-mm) SYP Wood Posts									
GWR4-1	52 (1,321)	20.5 (33.1)	11.1 (49.5)	1.6 (40)	NA	NA	21.0 (2.4)	4.1 (104)	Post Fracture
W6x9 (W152x13.4) Steel Posts									
GWR5-1 [1]	52 (1,321)	20.0 (32.1)	15.1 (67.2)	3.7 (93)	10.9 (48.4)	9.8 (43.5)	237.4 (26.8)	35.4 (900)	Soil Rotation & Post Yielding
GWR5-2	52 (1,321)	20.8 (33.4)	15.6 (69.5)	2.8 (72)	11.1 (49.3)	10.2 (45.2)	251.2 (28.4)	33.2 (844)	Soil Rotation & Post Yielding
W6x8.5 (W152x12.6) Steel Posts									
GWR5-3	46 (1,168)	19.9 (32.0)	14.7 (65.6)	2.7 (69)	9.9 (44.2)	9.0 (40.0)	221.5 (25.0)	34.8 (883)	Soil Rotation & Post Yielding
GWR5-4	40 (1,016)	20.6 (33.2)	14.0 (62.1)	2.9 (74)	9.9 (43.9)	9.3 (41.5)	237.1 (26.8)	34.5 (877)	Soil Rotation & Post Yielding

[1] Post driven.

Table 7. Round 4 Testing Results – W6x9 (W152x13.4) Steel Posts vs. W6x8.5 (W152x12.6) Steel Posts with Varying Embedment Depths and Posts Driven at 3H:1V Slope Break Point.

Test No.	Embedment Depth in. (mm)	Impact Velocity mph (km/h)	Peak Force		Average Force		Total Energy kip-in. (kJ)	Maximum Deflection in. (mm)	Failure Type
			Force kips (kN)	Deflection in. (mm)	@ 15 in. kips (kN)	@ 20 in. kips (kN)			
W6x9 (W152x13.4) Steel Posts, 52-in. (1,321-mm) Embedment Depth									
GWBR5-1	52 (1,321)	21.1 (34.0)	16.2 (72.0)	2.7 (70)	10.1 (44.9)	8.9 (39.6)	211.0 (23.8)	28.5 (724)	Soil Rotation, Post Yielding
GWBR5-4	52 (1,321)	22.3 (35.9)	15.1 (67.1)	3.3 (83)	9.9 (43.8)	9.1 (40.4)	235.7 (26.6)	34.2 (869)	Soil Rotation, Post Yielding
Average	52 (1,321)	21.7 (34.9)	15.6 (69.6)	3.0 (77)	10.0 (44.4)	9.0 (40.0)	223.4 (25.2)	31.4 (797)	
W6x9 (W152x13.4) Steel Posts, 46-in. (1,168-mm) Embedment Depth									
GWBR5-2	46 (1,168)	19.4 (31.2)	15.1 (67.1)	3.2 (80)	10.2 (45.2)	9.3 (41.5)	240.8 (27.2)	35.0 (889)	Soil Rotation, Post Yielding
GWBR5-5	46 (1,168)	23.9 (38.5)	14.4 (64.0)	4.5 (115)	9.7 (43.1)	8.9 (39.4)	244.5 (27.6)	38.5 (978)	Soil Rotation, Post Yielding
Average	46 (1,168)	21.6 (34.8)	14.7 (65.5)	3.8 (98)	9.9 (44.1)	9.1 (40.4)	242.7 (27.4)	36.7 (933)	
W6x8.5 (W152x12.6) Steel Posts, 40-in. (1,016-mm) Embedment Depth									
GWBR5-3	40 (1,016)	22.1 (35.6)	13.3 (59.2)	3.5 (89)	9.7 (43.3)	9.4 (41.9)	305.4 (34.5)	43.7 (1,109)	Soil Rotation, Post Yielding
GWBR5-6	40 (1,016)	22.9 (36.8)	14.0 (62.2)	3.2 (82)	9.9 (43.9)	9.3 (41.2)	251.7 (28.4)	38.2 (969)	Soil Rotation, Post Yielding
Average	40 (1,016)	22.5 (36.2)	13.6 (60.7)	3.4 (85)	9.8 (43.6)	9.3 (41.6)	278.6 (31.5)	40.9 (1,039)	

5.2 ROUND 1 TESTING

Eleven tests were performed on 6-in. x 8-in. (152-mm x 203-mm) wood posts embedded 40 in. (1,016 mm) in different soils and impacted at various speeds. Two major conclusions came from this round of testing. First, the resistance to post rotation provided by the 2-in. to 4-in. (51-mm to 102-mm) wall-facing rock was dramatically less than that observed in standard strong soil, e.g., AASHTO Grading B. Thus, a standard MGS should not be configured with posts placed in larger wall-facing rock. Second, testing at various impact speeds demonstrated an increase in force and energy absorbed with increases in impact velocity. A 50 percent increase in average force occurred when comparing the 20 mph (32 km/h) tests to the 15 mph (24 km/h) tests, but a minimal increase occurred between the 20 mph (32 km/h) and 25 mph (40 km/h) tests. Further testing would be required to determine whether this phenomenon was the result of the soil inertia, the dynamic properties of the soil, or some other unknown cause.

5.3 ROUND 2 TESTING

Four dynamic posts tests were performed - two tests on 6-in. x 8-in. (152-mm x 203-mm) wood posts and two tests on W6x16 (W152x23.8) steel posts. A W6x16 (W152x23.8) steel section was used in lieu of a W6x9 (W152x13.4) steel section to determine the post-soil resistance of an embedded guardrail post. The heavier post section had a similar flange width but provided reduced concerns for plastic deformations. All four posts were embedded 40 in. (1,016 mm) into a well-compacted, strong soil and impacted at 20 mph (32 km/h). The test results showed that the post-soil resistance for standard wood and steel posts was nearly identical. This finding supports the common, industry-wide assumption that the two post types provide equivalent post-soil resistance for guardrail systems. As such, it is the researcher’s opinion that the standard MGS installed in level terrain would perform in an acceptable manner when supported by 6-in. x 8-in. (152-mm x 203-mm) wood posts using a 6-ft (1.8-m) length and a 40-in. (1,016-mm) embedment depth.

5.4 ROUND 3 TESTING

Five tests were performed on wood and steel posts placed at the slope break point of a 3H:1V fill slope with various embedment depths, ranging between 40 in. and 52 in. (1,016 mm and 1,321 mm). A 6-in. x 8-in. (152-mm x 203-mm) wood post with a 52-in. (1,321-mm) post embedment depth was shown to fracture and thus could not provide the required energy absorption for an MGS post. The steel post tests resulted in similar resistances to post rotation regardless of the embedment depth due to plastic bending of the posts during all of the tests. Due to a failure observed in the first test within Round 3, the wood post test matrix was temporarily aborted. As a result, the dynamic post-soil behavior and an acceptable length for a 6-in x 8-in. (152-mm x 203 mm) wood post was not determined for MSE wall applications. Further bogie testing of wood posts installed at the slope break point of a 3H:1V fill slope is planned for a follow-on research and testing program to determine an acceptable post length. If that wood post testing program is successful, the implementation of wood posts into the barrier system may be hindered unless an acceptable post installation method is developed for MSE wall applications.

The cross-sectional area is much larger for wood posts than for steel guardrail posts. Thus, it may be difficult to either drive wood posts or install them using the auger, backfill, and tamping method due to the roller-compacted, strong soil and steel wire mesh found within the upper surface of a wire-faced, MSE wall. Based on post-soil performance, reliability, and ease of installation, steel posts versus wood posts were recommended for continued evaluation for a non-blocked, MGS installed on a wire-faced, MSE wall system.

5.5 ROUND 4 TESTING

Six dynamic component tests were performed to evaluate standard steel posts, ranging from 6 to 7 ft (1.8 and 2.1 m) in length, installed adjacent to and on top of a wire-faced MSE wall system. The posts were driven into a roller-compacted, strong soil at the slope break point of a 3H:1V fill slope. Multiple embedment depths, ranging from 40 in. to 52 in. (1,016 mm to 1,321 mm), were again evaluated. From the test results, these steel posts of different lengths provide similar post-soil behavior (i.e., force versus deflection curves) through the deflections of 15 to 20 in. (381 to 408 mm) or within the expected performance for typical W-beam guardrail systems. However, the 6-ft (1.8-m) long posts with a 40-in. (1,016-mm) embedment depth provided improved energy absorption as compared to the steel posts with embedment depths of 46 and 52 in. (1,168 and 1.321 mm). The greater embedment depths resulted in higher peak post-soil resistance, increased greater post bending, but reduced post rotation. The larger embedment depths caused the point of rotation (plastic bending hinge) to be farther below the groundline, thus resulting in a lower maximum deflection and decreased energy absorption. On the other hand, the lower embedment depths allowed for more post rotation through the soil and less post bending, thus resulting in larger deflections and increased energy absorption. The results from the Round 4 testing program are also shown in Figures 12 and 13.

5.6 POST DESIGN CONSIDERATIONS AND SYSTEM RECOMMENDATIONS

From the Rounds 3 and 4 component testing programs, post-soil forces and energy dissipation characteristics for steel posts were compared to those results obtained from the original MGS research and development program. [See references 4-6, 24.] From that original study, the baseline average post-soil resistance for standard steel posts installed in level terrain was found to be approximately 6.4 kips (28.5 kN) over 15 in. (381 mm) of deflection. From the FHWA testing program described herein, a standard 6-ft (1.8-m) long steel guardrail post installed at the slope break point of the sloped MSE wall system provided an average post-soil resistance of 9.8 kips (43.6 kN) over 15 in. (381 mm) of deflection. Thus, the research team believed that the 6-ft (1.8-m) long steel post would allow the MGS to perform in an acceptable manner and meet current impact safety standards but with reduced barrier deflections from those observed in the original R&D program.

Following the completion of the post testing program, a non-blocked version of the MGS was recommended for evaluation within a crash testing program using: (1) steel W-beam backup plates; (2) 6-ft (1.8-m) long posts manufactured from either W6x8.5 (W152x12.6) or W6x9 (W152x13.4) steel sections; (3) posts driven at the slope break point of a 3H:1V fill slope adjacent to and on top of a wire-faced, MSE wall; and (4) posts installed using a 40-in. (1,016-mm) embedment depth.

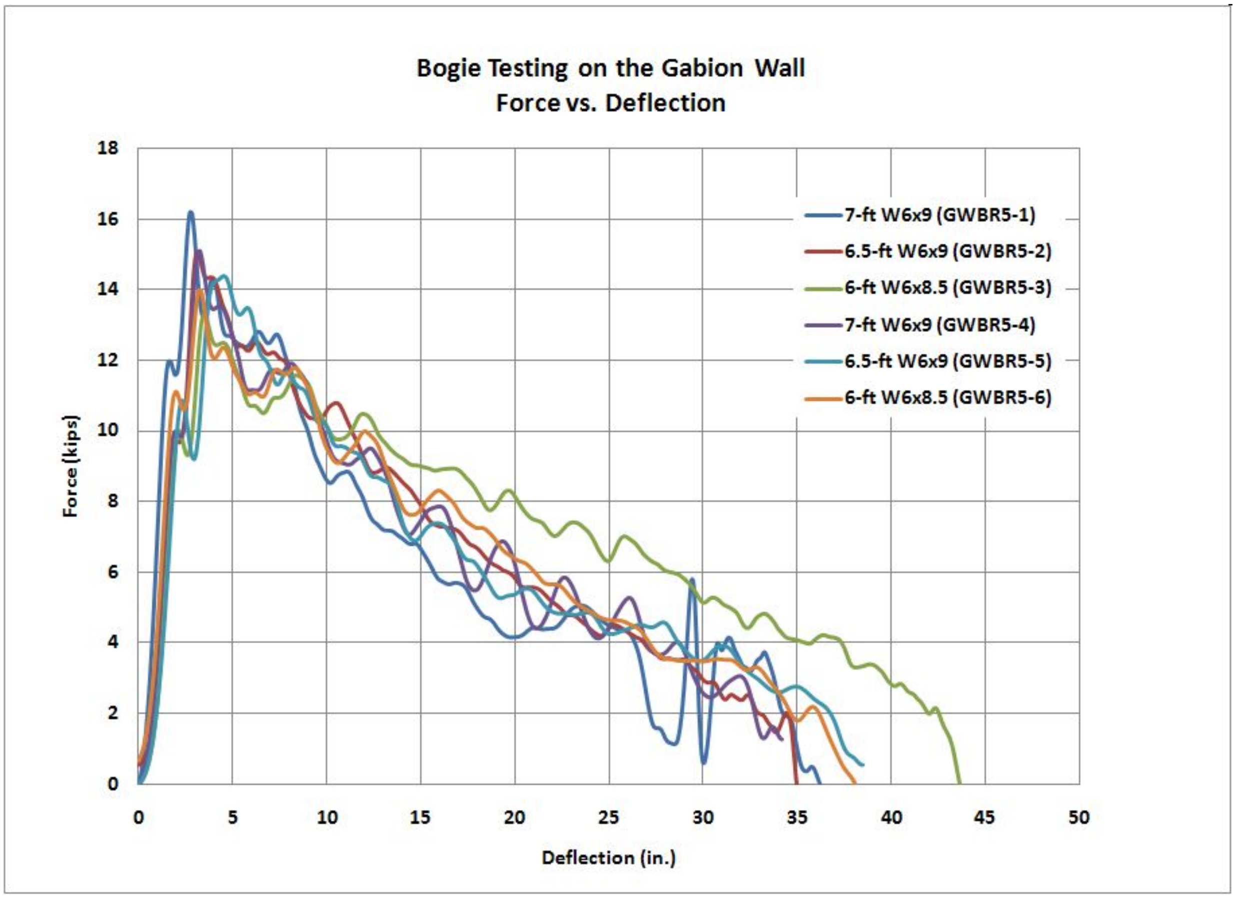


Figure 12. Graph. Round 4 Results from Dynamic Post Testing on the Wire-Faced, MSE Wall.

Figure 13. Photo. Typical Damage - 6-ft (1.8-m) Long, W6x8.5 (W152x12.6) Post at Breakpoint of 3H:1V Fill Slope.

CHAPTER 6. SYSTEM DESIGN DETAILS

The standard MGS formed the basis for the barrier system utilized with the wire-faced, mechanically-stabilized earth (MSE) wall system. However, the MGS was modified by removing the 12-in. (305-mm) deep wood spacer blocks and incorporating W-beam backup plates. In addition, all other MGS features were maintained, including the use of 6-ft (1.8-m) long W6x8.5 (W152x12.6) steel posts, rail splices at mid-span locations, a 31-in. (787-mm) top mounting height, as well as the 75-in. (1,905-mm) post spacing. The non-blocked MGS was installed at the slope break point of a 3H:1V fill slope using an approximate lateral offset of 6 ft (1.8 m) from the post centerline to the outer edge of the wire-faced, MSE wall.

The test installation was 175 ft (53.3 m) long and consisted of standard 12-gauge (2.66-mm thick) corrugated W-beam guardrail supported by steel posts, as shown in Figures 14 through 30. Photographs of the test installation are shown in Figures 31 through 45. Material specifications, mill certifications, and certificates of conformity for the system materials are shown in Appendix A.

The entire system was constructed with twenty-nine guardrail posts. Post nos. 3 through 27 were galvanized ASTM A36 W6x8.5 (W152x12.6) steel sections measuring 72 in. (1,829 mm) long. Post no. 1, 2, 28, and 29 utilized timber Breakaway Cable Terminal (BCT) posts measuring 5½ in. wide x 7½ in. deep x 46 in. long (140 mm x 190 mm x 1,168 mm) and were placed in 72-in. (1,829-mm) long steel foundation tubes, as shown in Figures 14, 26, and 28. A tangent anchorage system was utilized on the upstream and downstream ends of the guardrail system in order to develop the barrier’s tensile capacity. The anchorage system consisted of timber posts, foundation tubes, anchor cables, bearing plates, rail brackets, and channel struts, which closely resembled the hardware used in the Modified BCT system.

Post nos. 1 through 29 were spaced on 75 in. (1,905 mm) centers. For posts nos. 3 through 27, the soil embedment depth was 40 in. (1,016 mm), as shown in Figure 24. Post nos. 9 through 21 were driven into the soil at the slope break point of the 6-ft (1,829-mm) wide, 3H:1V fill slope located on the wire-faced, MSE wall. Wood spacer blockouts were not used to offset the rail away from the front face of the steel posts. However, 12-gauge (2.66-mm thick) W-Beam backup plates, measuring 12 in. (305 mm) long, were located between the rail and the front face of the steel posts, as shown in Figure 24.

Standard 12-gauge (2.66-mm thick) W-beam rails with additional post bolt slots at half-post spacing intervals were placed between post nos. 1 and 29, as shown in Figures 14 and 25. The top mounting height of the W-beam guardrail was 31 in. (787 mm) with a 24⅞ in. (632 mm) center height. Rail splices were placed at the mid-span locations between posts, as shown in Figures 14 and 26. All guardrail splice connections between the rail sections were lapped in the direction of traffic to reduce vehicle snag at the splice during the crash tests.

The actual, wire-faced, MSE wall system measured 84 ft (25.6 m) in length and was configured with a 3H:1V fill slope at its outer edge. The MSE wall system was positional longitudinally between post nos. 8 through 22, as shown in Figures 16 and 17. The MSE wall system was placed within an excavated pit measuring 11 ft – 10 in. (3.6 m) wide by 7 ft (2.1 m) deep with three 2-ft (0.6-m) thick layers of roller-compacted, course, crushed limestone material. The soil-aggregate material met the Grading B specifications of AASHTO M147-65 denoted in MASH and NCHRP Report No. 350, which also closely conformed to the select wall backfill materials denoted in Sections 255 and 704 of the 2003 FHWA *Standard Specifications for Construction of Roads and Bridges on Federal Highway Projects*.[14,25,26] The outer region of the bottom two layers contained a wall facing fill material that consisted of 4 to 6-in. (102 to 152-mm) diameter rocks that were placed by hand. A 4-ft (1.2-m) wide void space was excavated behind the MSE wall system. Steel-wire reinforcement mats were used to construct and stabilize the MSE wall system, as shown in Figures 17 through 23. The MSE wall installation manual is shown in Appendix B.

For test no. MGSGW-1 (1100C small car test), the W-beam backup plates at post nos. 14 through 17 were longitudinally shifted to different positions in order to determine whether rail slot alignment, or mis-alignment, affects post bolt release away from the rail. The bolt heads were also positioned at different locations within the guardrail slots. For post nos. 14 and 16, the guardrail slots and W-beam backup plate slots were mis-aligned. For post nos. 15 and 17, the guardrail slots and W-beam backup plate slots were aligned with one another. The four post bolts and rail slots are depicted in Figure 42.

For test no. MGSGW-2 (2270P pickup truck test), the head of the post bolts were positioned at different locations within the guardrail slots. For post nos. 12 through 17, three different locations were considered - the upstream end of the slot, the downstream end of the slot, and centered in slot. These configurations are shown in Figures 43 through 45.

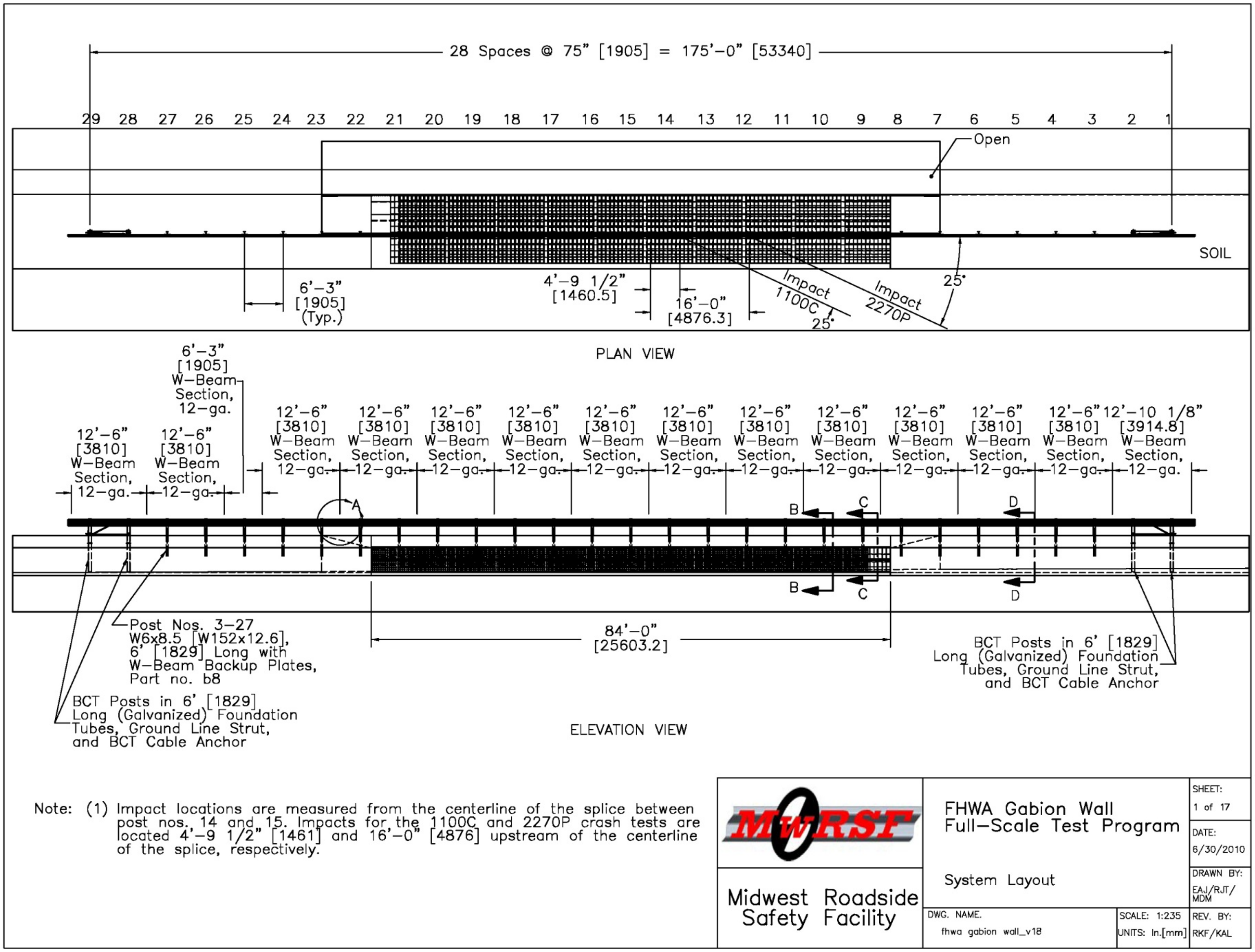
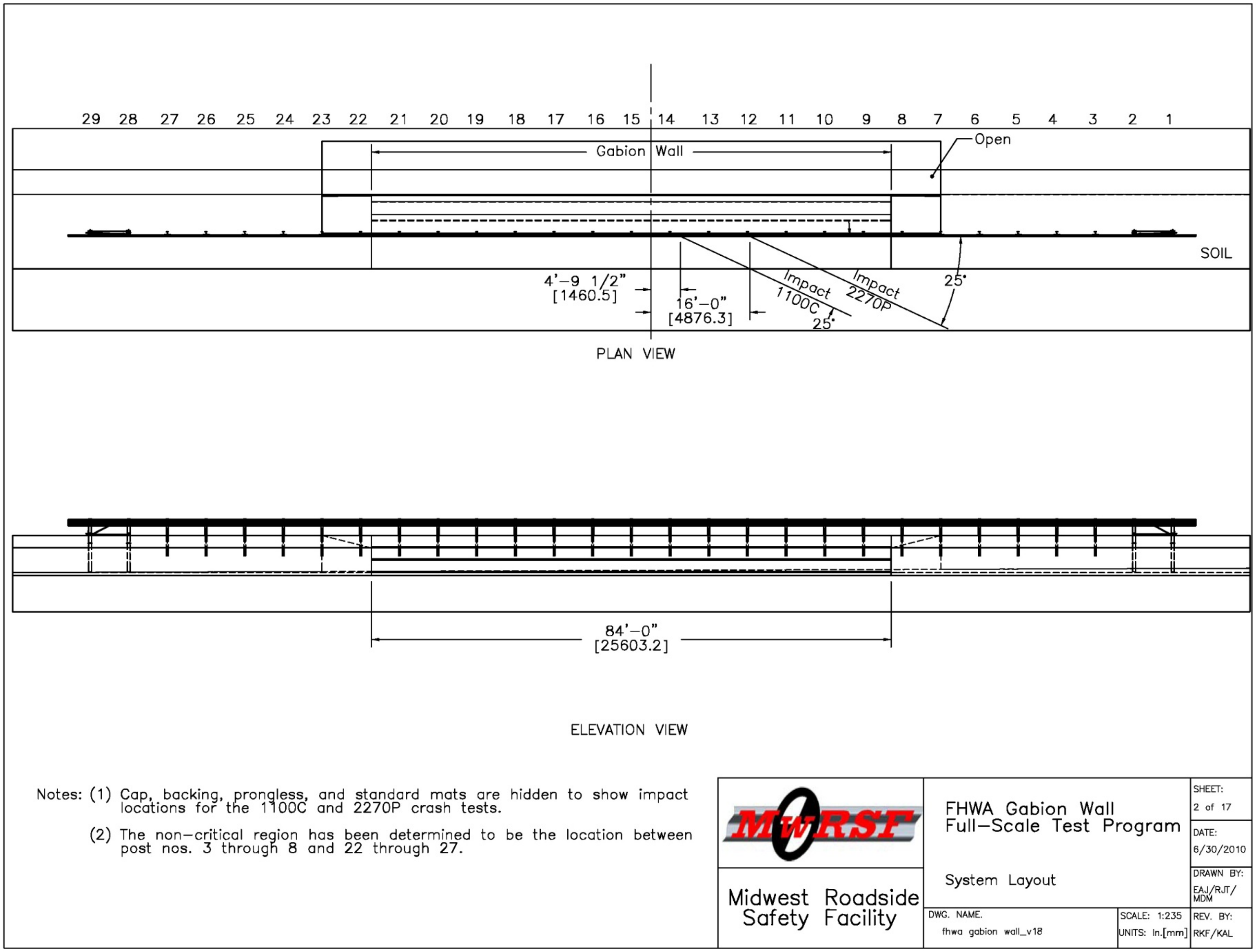


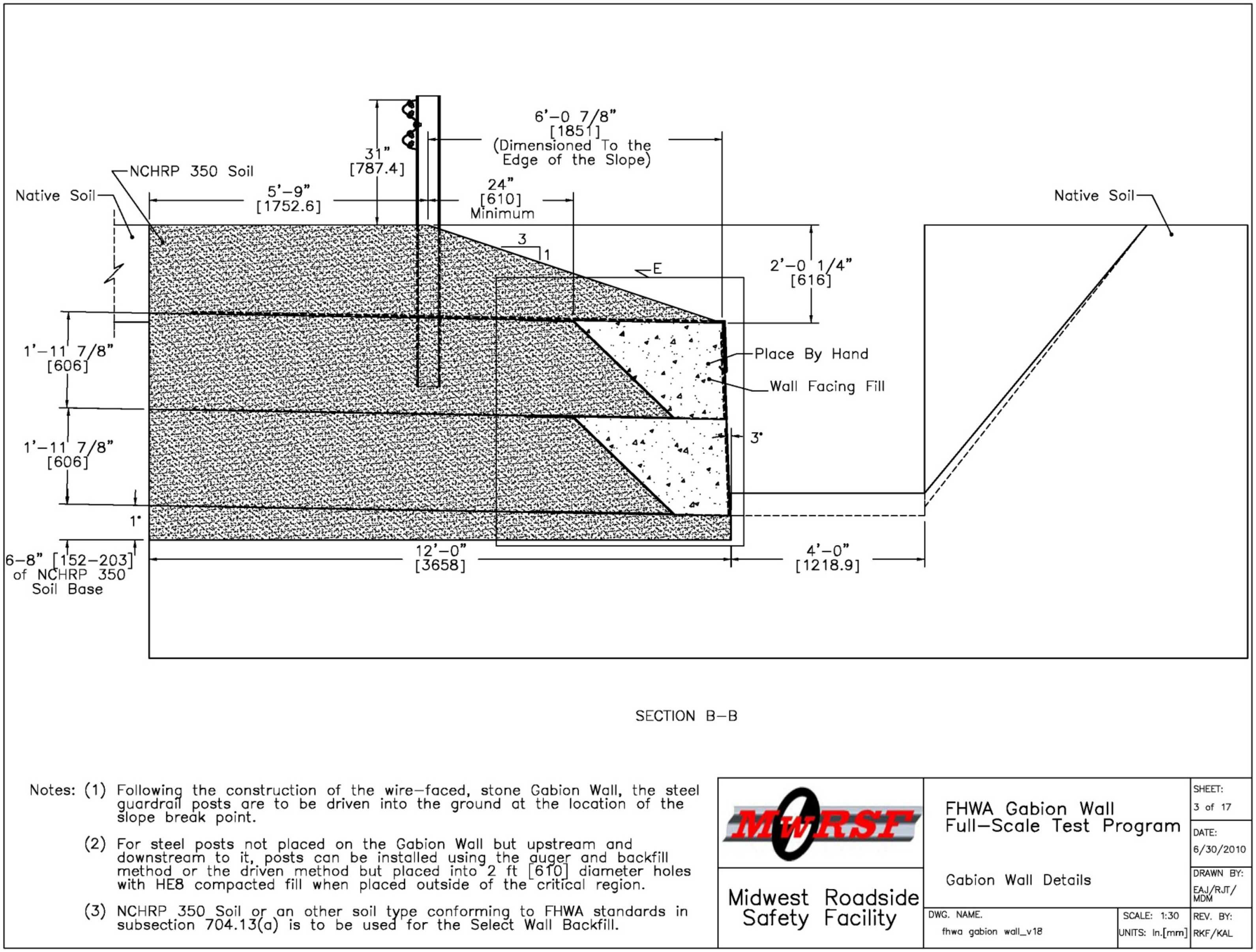
Figure 14. Schematic. Test Installation Layout, Test Nos. MGSGW-1 and MGSGW-2.



Notes: (1) Cap, backing, prongless, and standard mats are hidden to show impact locations for the 1100C and 2270P crash tests.

(2) The non-critical region has been determined to be the location between post nos. 3 through 8 and 22 through 27.

Figure 15. Schematic. System Layout Details, Test Nos. MGSGW-1 and MGSGW-2.



Notes: (1) Following the construction of the wire-faced, stone Gabion Wall, the steel guardrail posts are to be driven into the ground at the location of the slope break point.

(2) For steel posts not placed on the Gabion Wall but upstream and downstream to it, posts can be installed using the auger and backfill method or the driven method but placed into 2 ft [610] diameter holes with HE8 compacted fill when placed outside of the critical region.

(3) NCHRP 350 Soil or an other soil type conforming to FHWA standards in subsection 704.13(a) is to be used for the Select Wall Backfill.

Figure 16. Schematic. MSE Wall Details, Test Nos. MGSGW-1 and MGSGW-2.

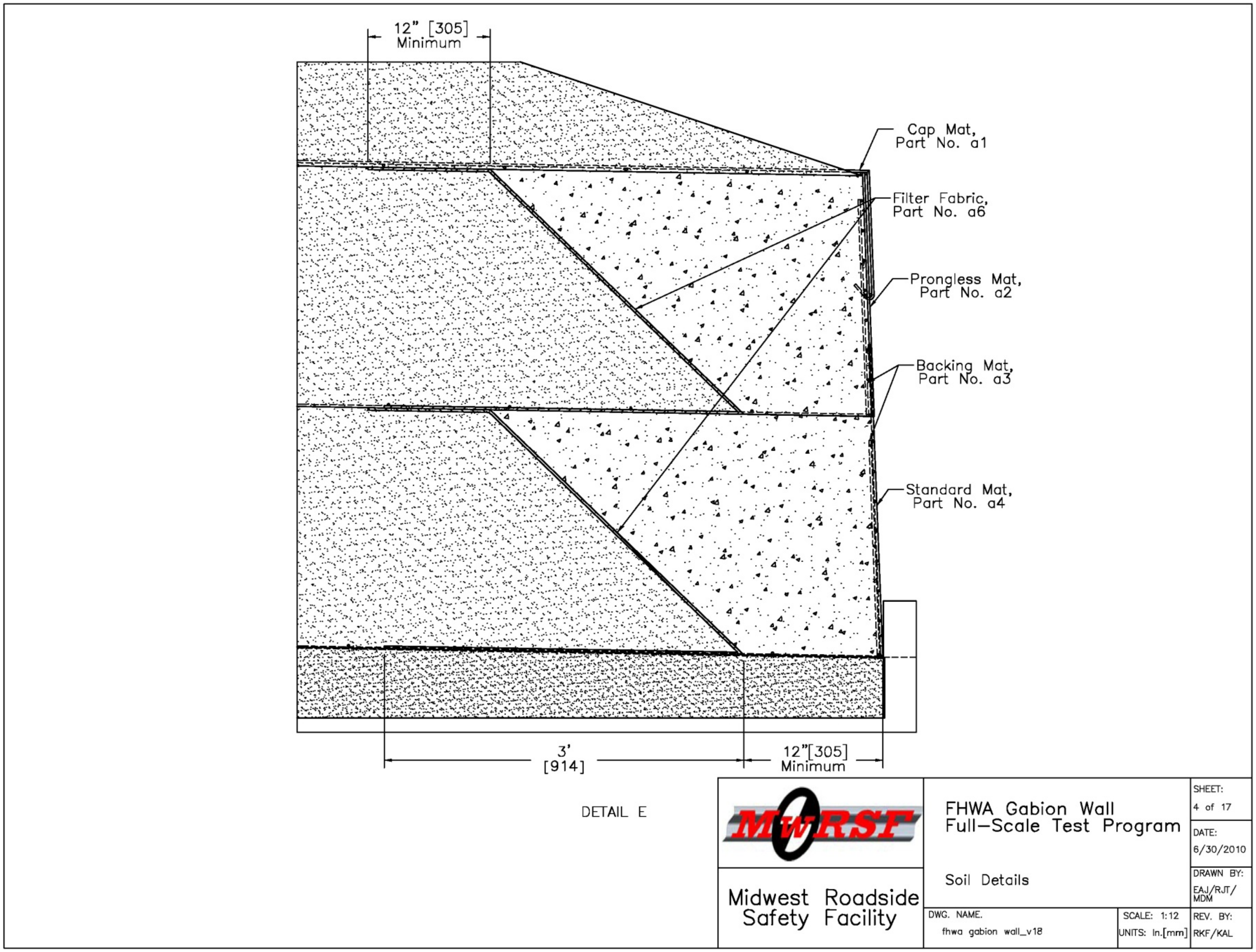


Figure 17. Schematic. Soil Details, Test Nos. MGSGW-1 and MGSGW-2.

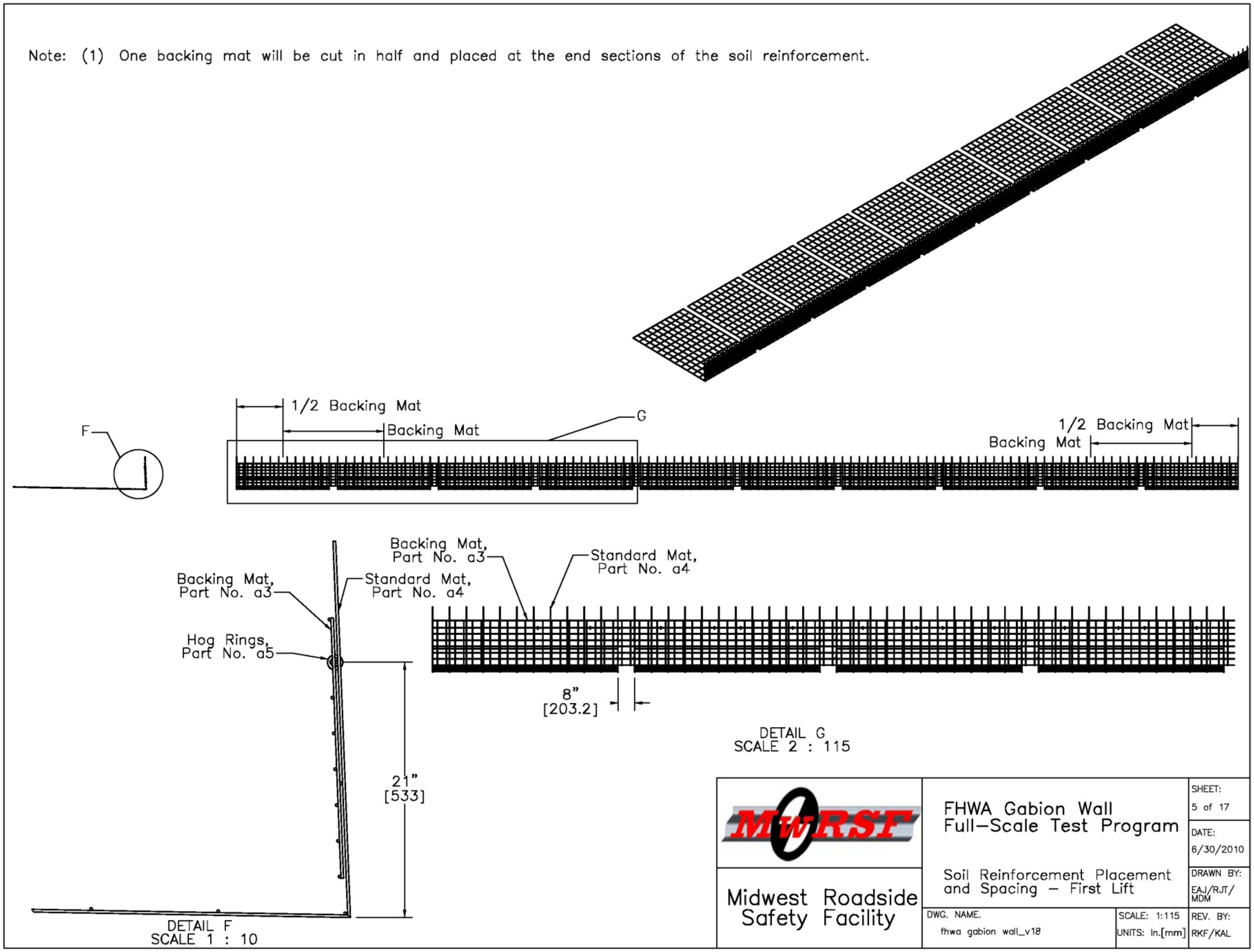


Figure 18. Schematic. Soil Reinforcement Placement and Spacing, Test Nos. MGSGW-1 and MGSGW-2.

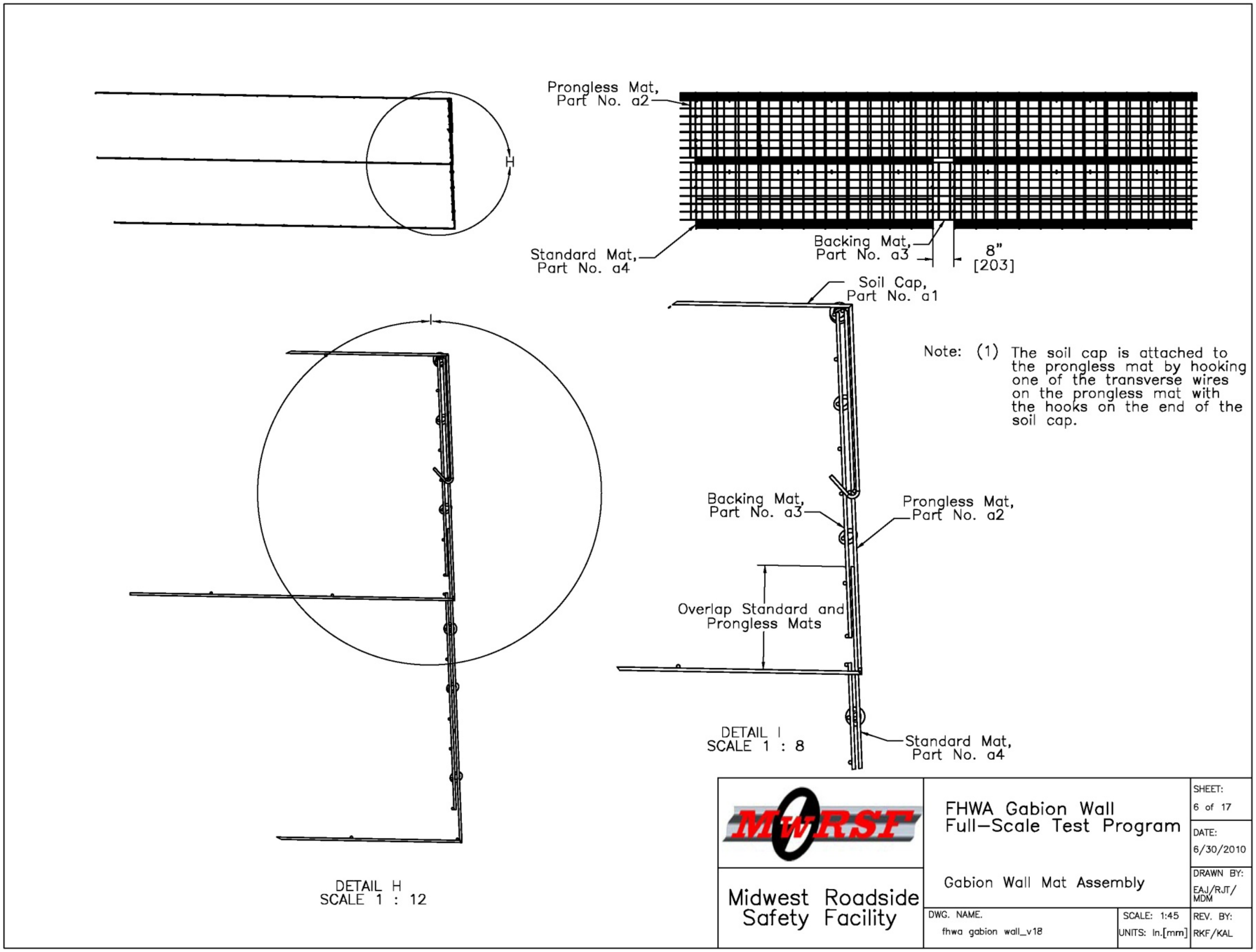


Figure 19. Schematic. MSE Wall Mat Assembly, Test Nos. MGSGW-1 and MGSGW-2.

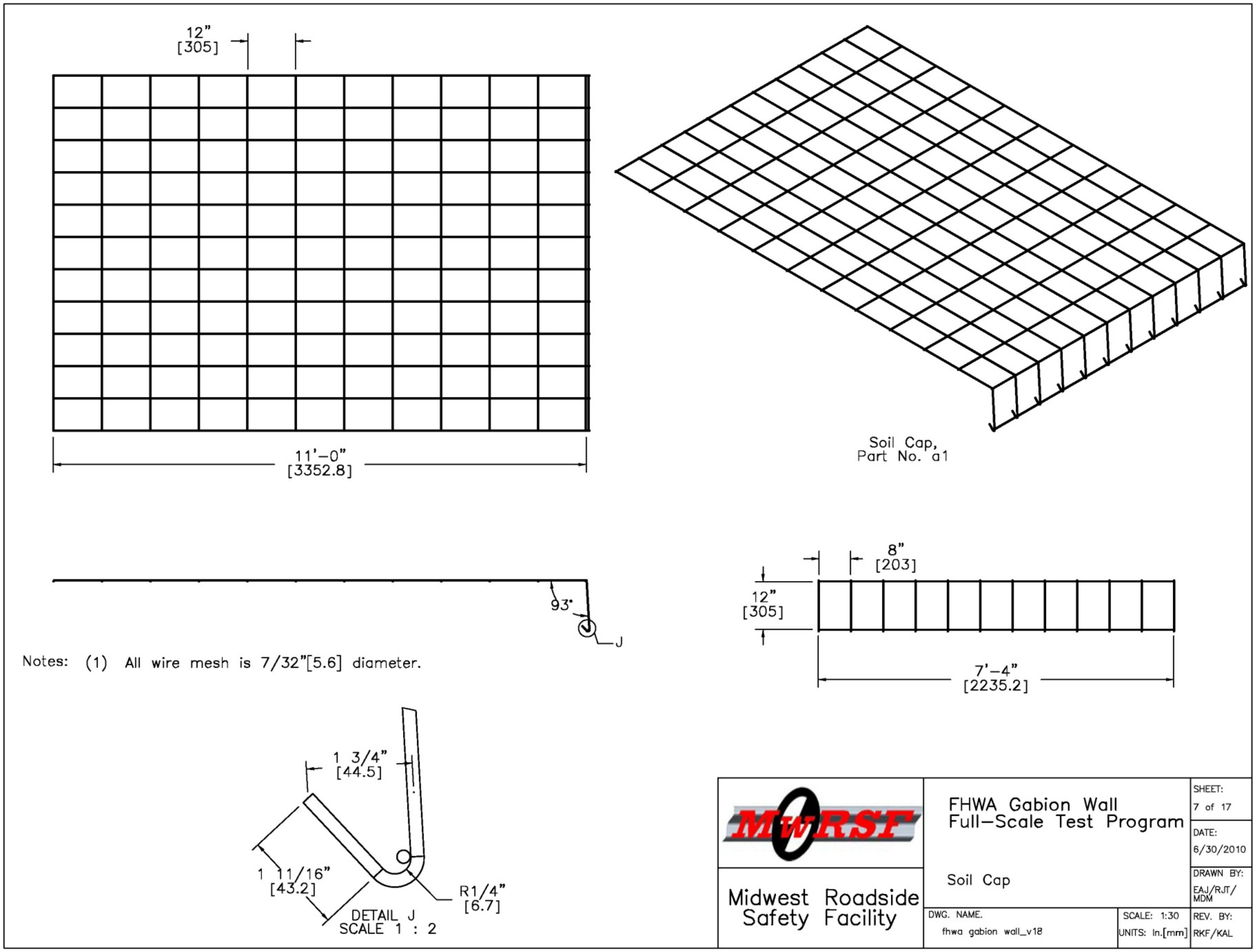


Figure 20. Schematic. Soil Cap, Test Nos. MGSGW-1 and MGSGW-2.

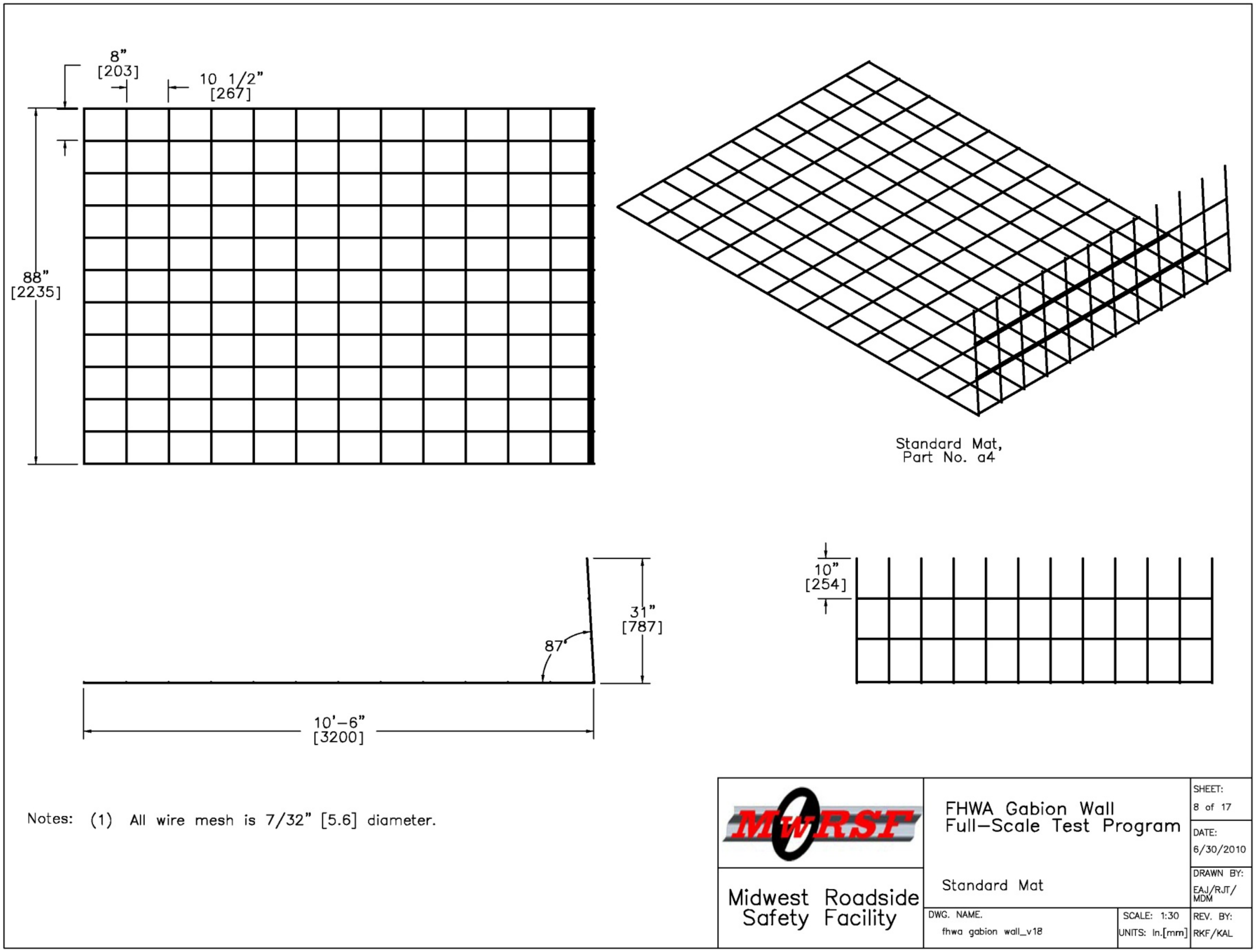


Figure 21. Schematic. Standard Mat, Test Nos. MGSGW-1 and MGSGW-2.

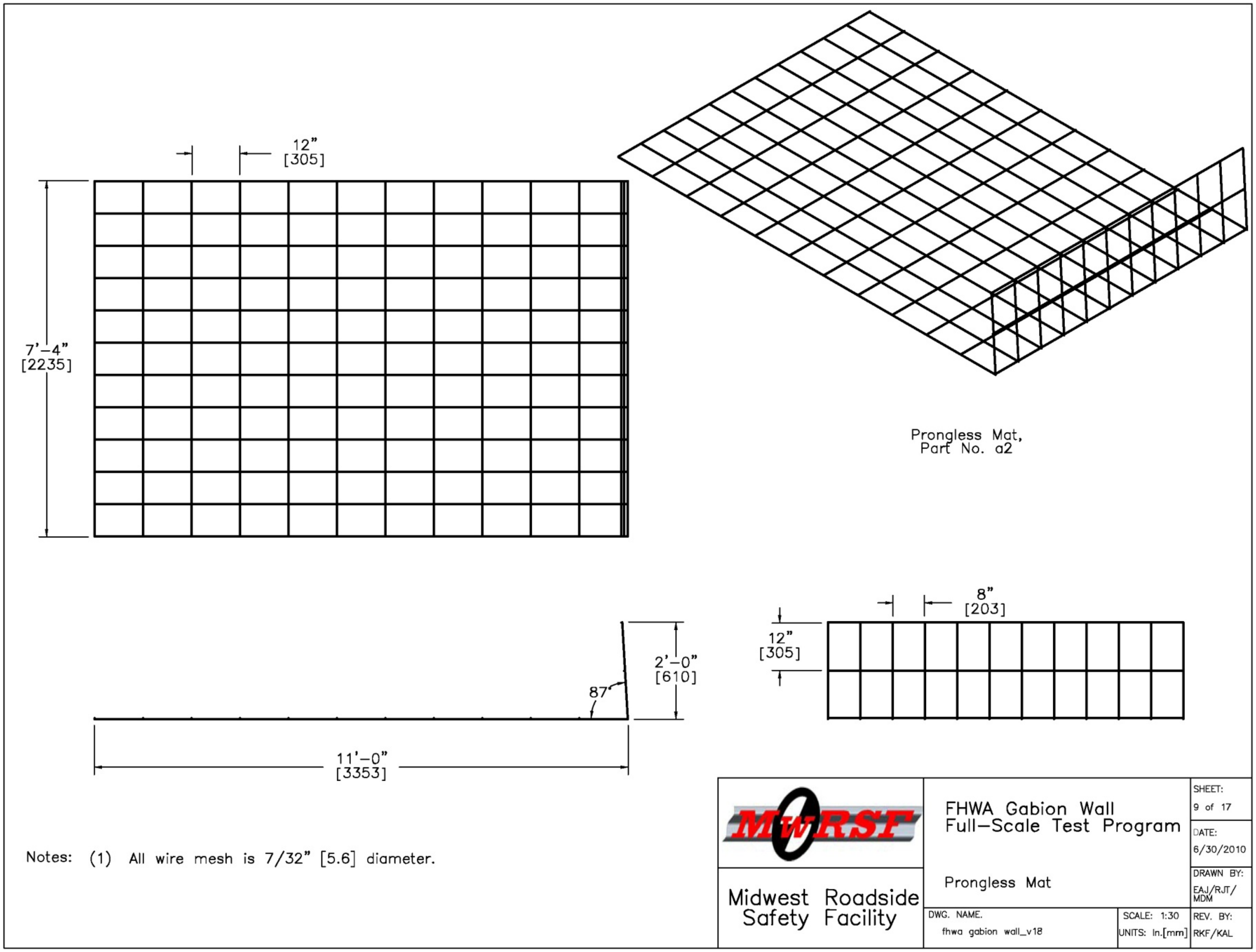


Figure 22. Schematic. Prongless Mat, Test Nos. MGSGW-1 and MGSGW-2.

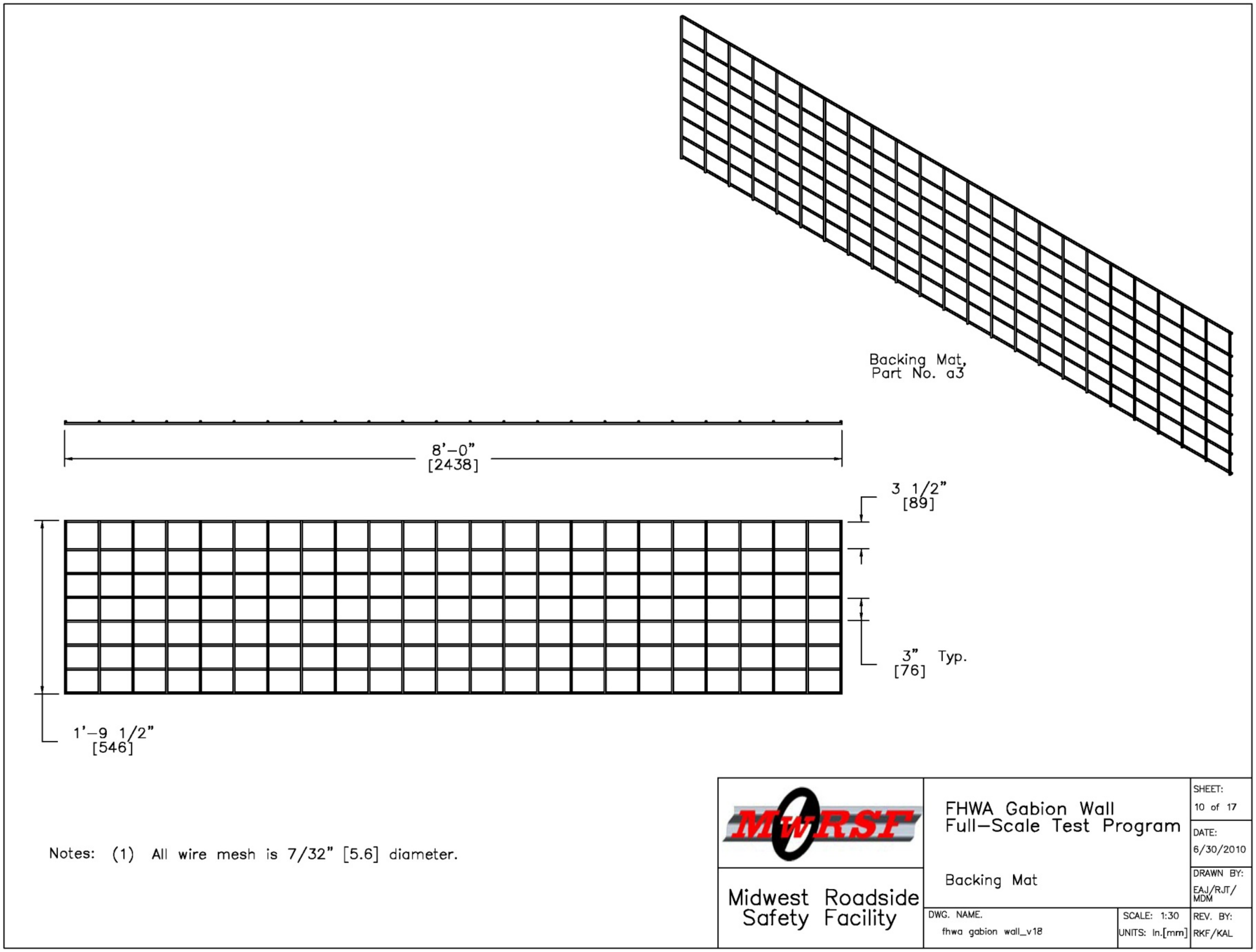


Figure 23. Schematic. Backing Mat, Test Nos. MGSGW-1 and MGSGW-2.

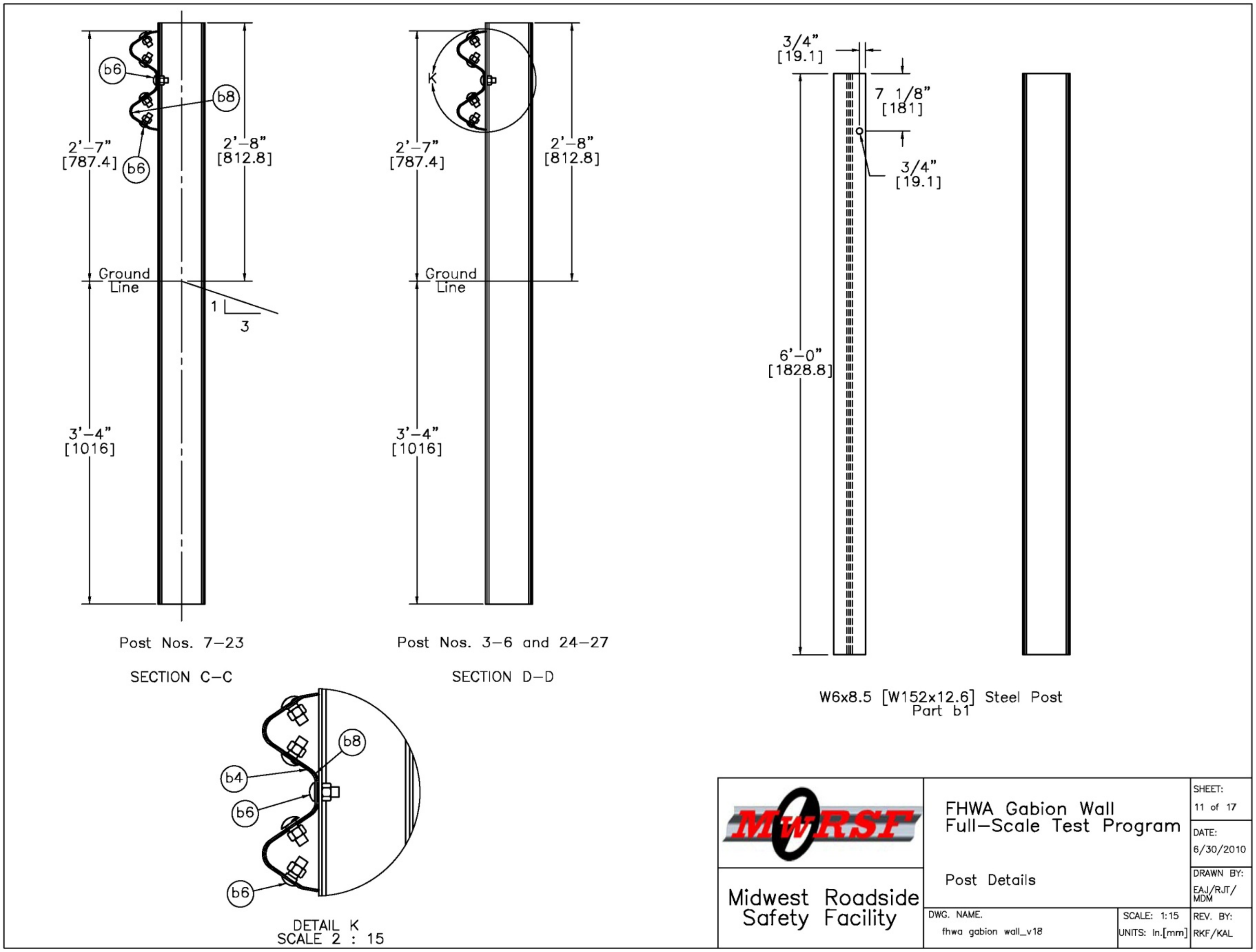


Figure 24. Schematic. Post Details, Test Nos. MGSGW-1 and MGSGW-2.

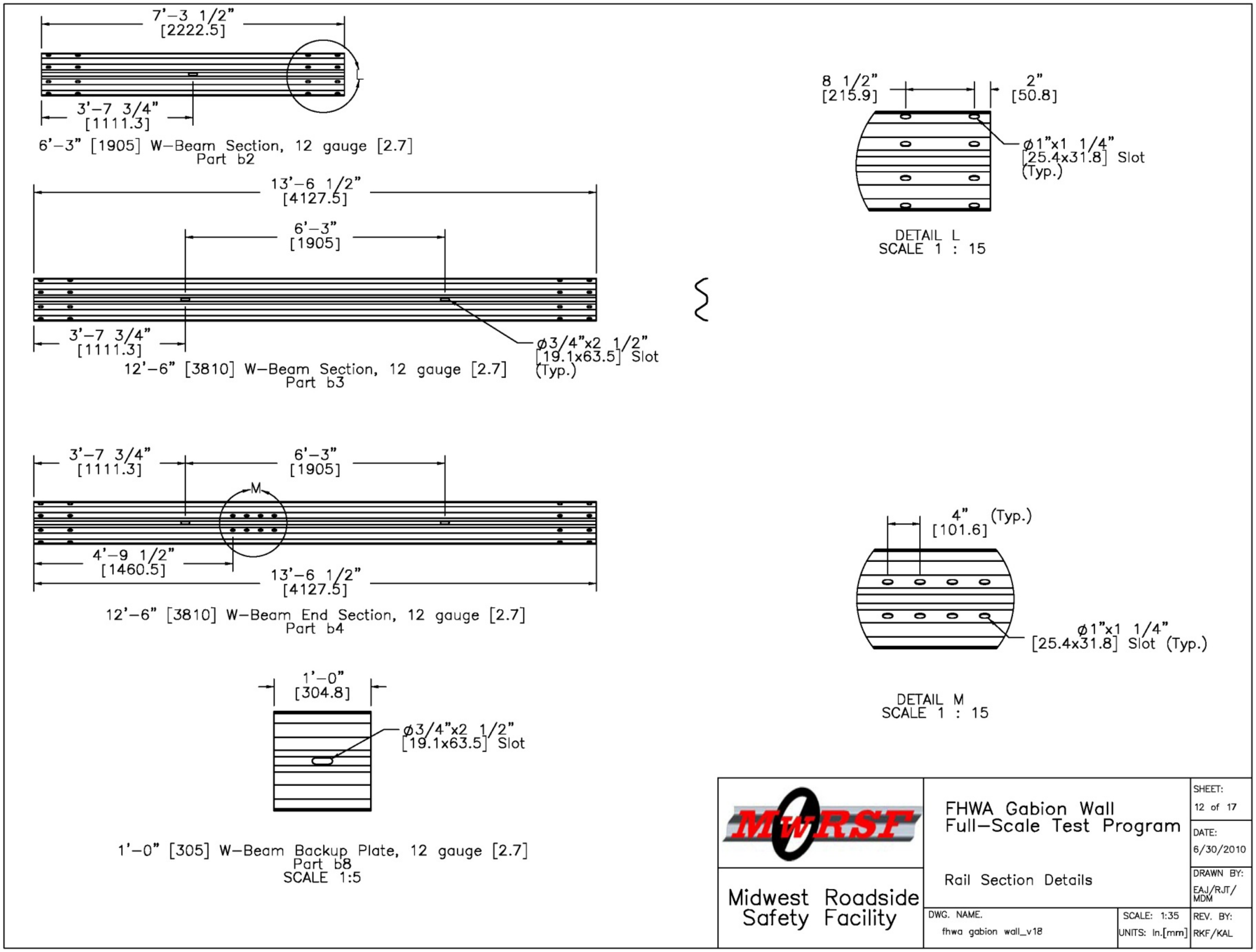


Figure 25. Schematic. Rail Section Details, Test Nos. MGSGW-1 and MGSGW-2.

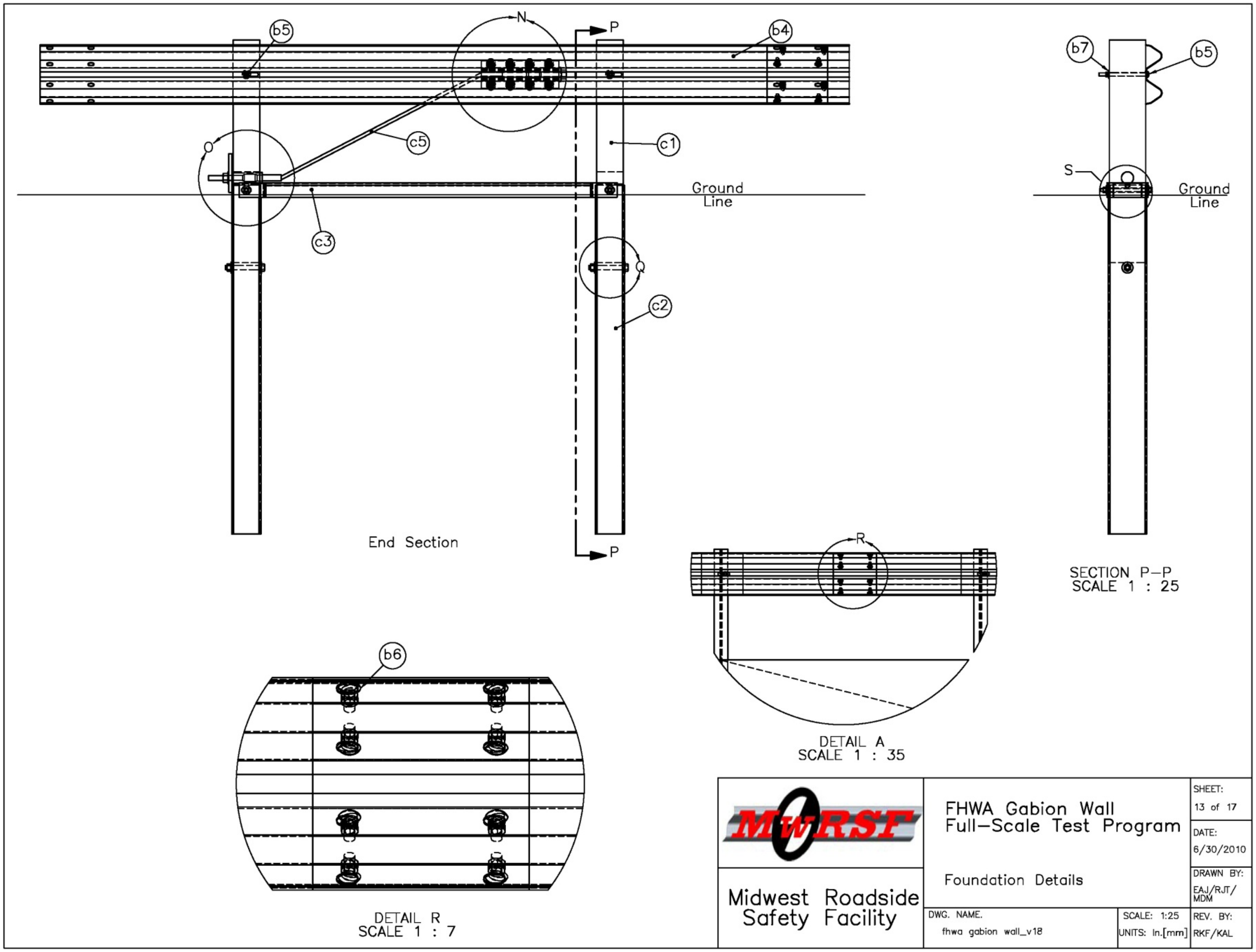


Figure 26. Schematic. Foundation Details, Test Nos. MGSGW-1 and MGSGW-2.

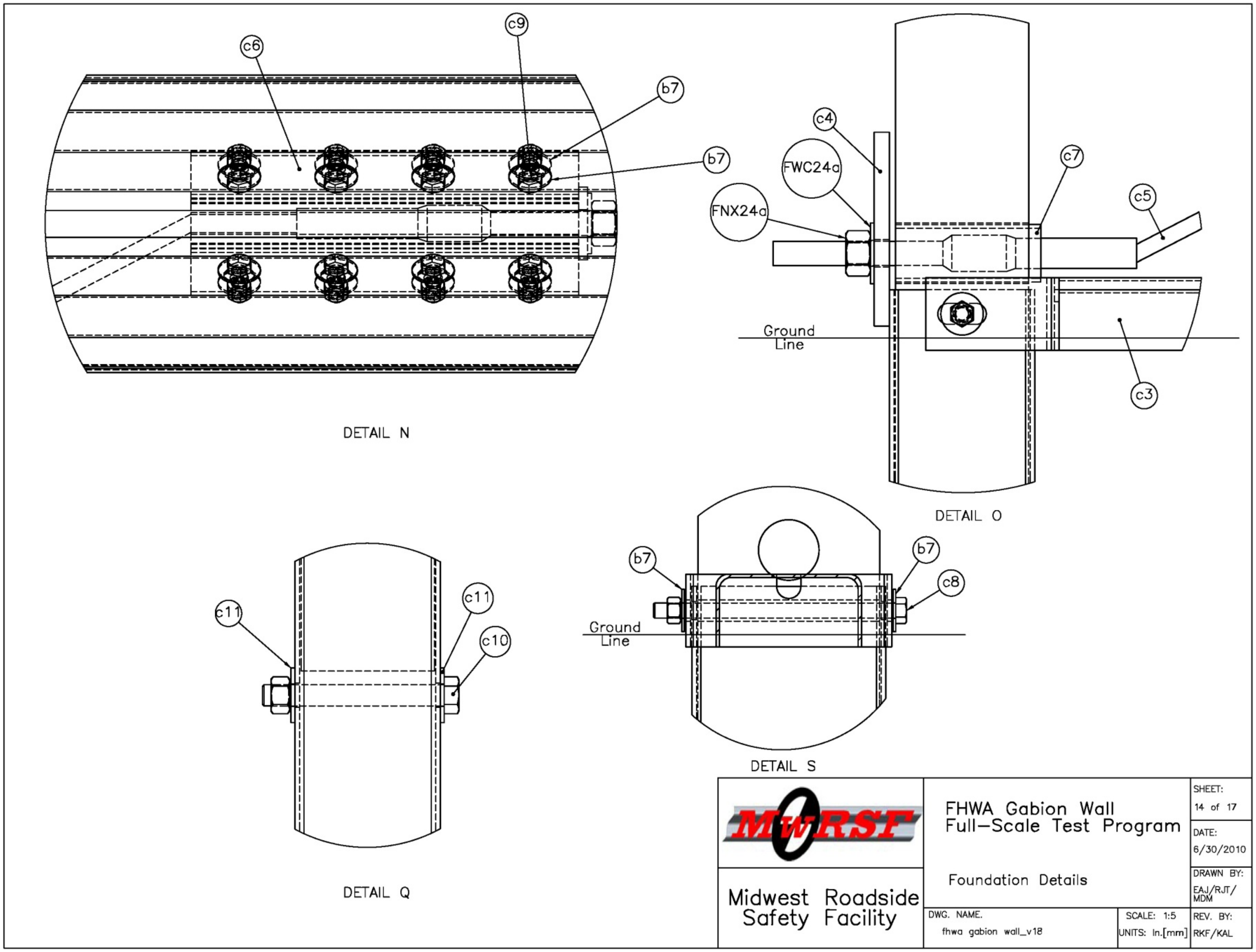


Figure 27. Schematic. Foundation Details, Test Nos. MGSGW-1 and MGSGW-2.

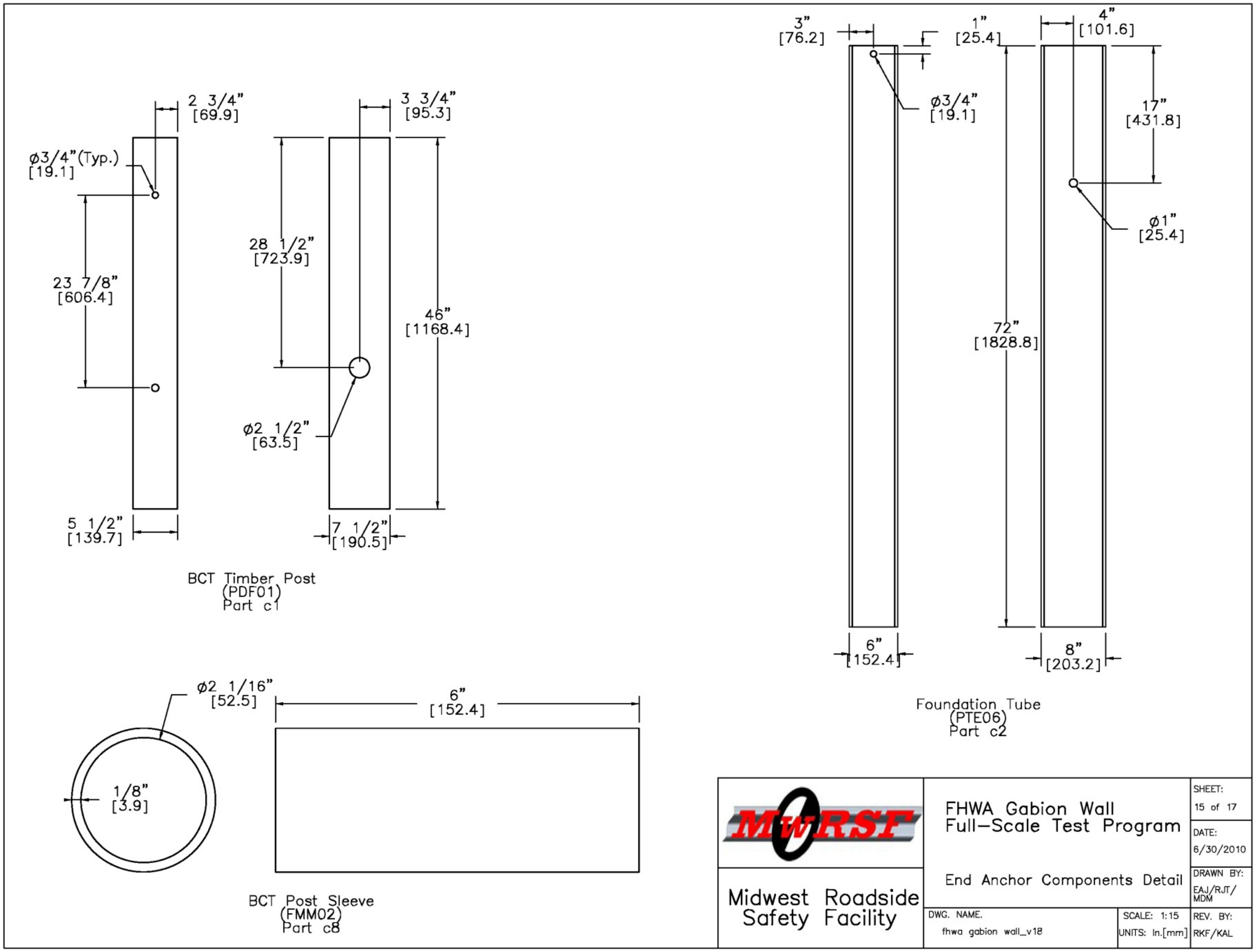


Figure 28. Schematic. End Anchor Components Details, Test Nos. MGSGW-1 and MGSGW-2.

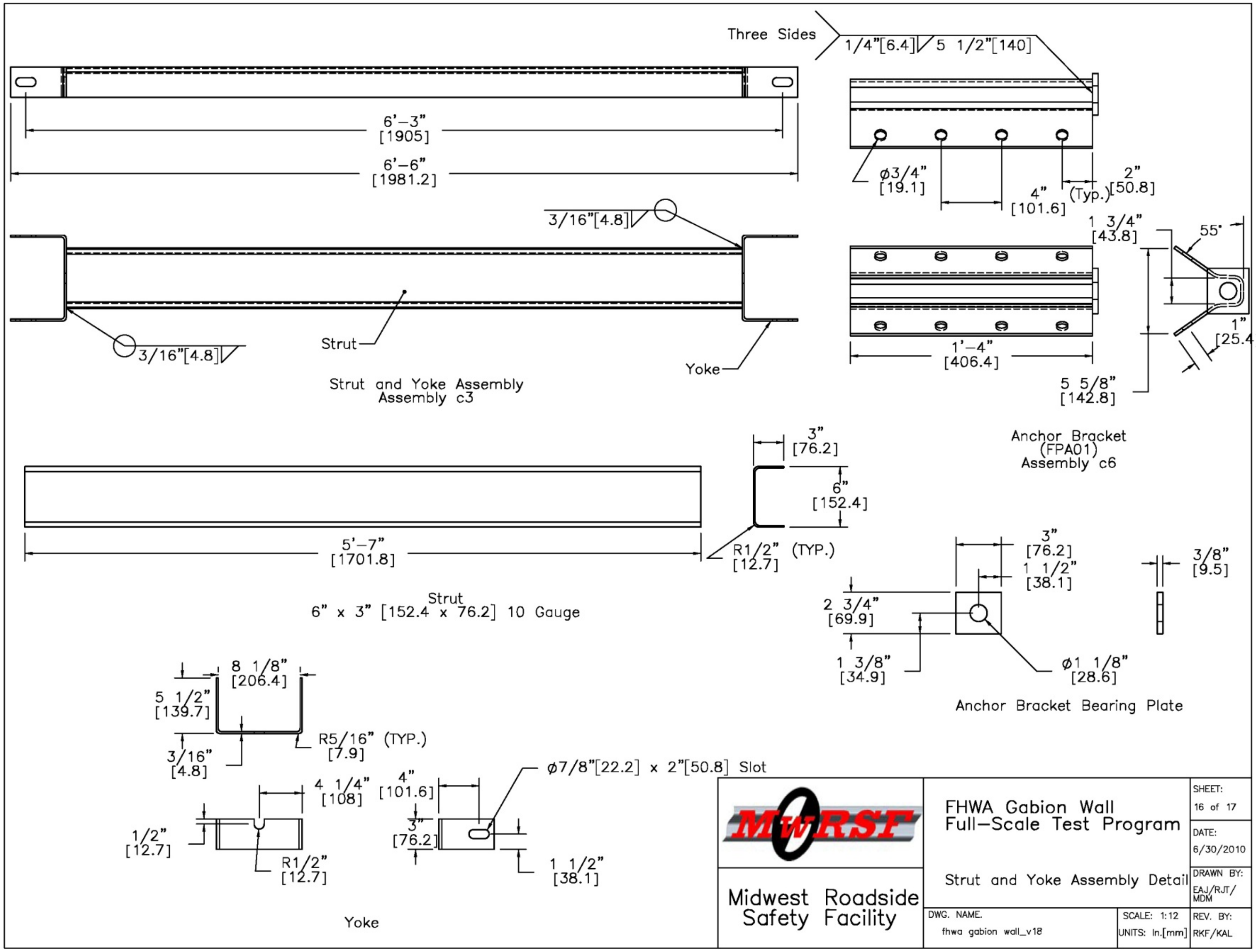


Figure 29. Schematic. Strut and Yoke Assembly Details, Test Nos. MGSGW-1 and MGSGW-2.

Item No.	QTY.	Description	Material Specifications and/or Grade	Vendor	Hardware Guide
–	–	Wall Facing Fill	Wall Face Aggregate, 4–6 in. Rock		–
a1	11	Cap Mat	8" x 12" [203 x 305] Steel Mesh, 3 Gauge		–
a2	10	Prongless Mat	8" x 12" [203 x 305] Steel Mesh, 3 Gauge		–
a3	20	Backing Mat	4" x 3" [102 x 76] Steel Mesh, 3 Gauge		–
a4	10	Standard Mat	8" x 10.5" [203 x 267] Steel Mesh, 3 Gauge		–
a5	180	Hog Rings	–		–
a6	–	Filter Fabric	–		–
b1	25	W6x8.5 x 6' long [W152x12.6, 1829 long] Steel Post	ASTM A36 [248 MPa]		–
b2	1	6'–3" [1905] W–Beam Section	12 ga. [2.7] AASHTO M180		RWM01a
b3	14	12'–6" [3810] W–Beam MGS Section	12 ga. [2.7] AASHTO M180		RWM04a
b4	2	12'–6" [3810] W–Beam MGS End Section	12 ga. [2.7] AASHTO M180		–
b5	4	5/8" [15.9] Dia. x 10" [254] long Guardrail Bolt and Nut	ASTM A307		FBB03
b6	137	5/8" [15.9] Dia. x 1 1/2" [38] Guardrail Bolt and Nut	ASTM A307		FBB01
b7	44	5/8" [15.9] Dia. Flat Washer	ASTM A153		FWC16a
b8	25	W–Beam Backup Plate	12 ga. [2.7] AASHTO M180		RWB01a
c1	4	BCT Timber Post – MGS Height	SYP Grade No. 1 or better		PDF01
c2	4	72" [1829] Foundation Tube	ASTM A53 Grade B		PTE06
c3	2	Strut and Yoke Assembly	ASTM A36 Steel Galvanized		PFP01
c4	2	5x8x5/8" [127x203x15.9] Anchor Bearing Plate	ASTM A36 Steel		FPB01
c5	2	BCT Anchor Cable Assembly	ϕ3/4" [19] 6x19 IWRC IPS Galvanized Wire Rope		FCA01–02
c6	2	Anchor Bracket Assembly	ASTM A36 Steel		FPA01
c7	2	2 3/8" [60] O.D. x 6" [152] Long BCT Post Sleeve	ASTM A53 Grade B Schedule 40		FMM02
c8	4	5/8" [15.9] Dia. x 10" [254] Long Hex Head Bolt and Nut	ASTM A307		FBX16a
c9	16	5/8" [15.9] Dia. x 1 1/2" [38] Long Hex Head Bolt and Nut	ASTM A307		FBX16a
c10	4	7/8" [22.2] Dia. x 7 1/2" [191] Long Hex Head Bolt and Nut	ASTM A307		FBX22a
c11	8	7/8" [22.2] Dia. Flat Washer	ASTM A153		FWC22a

MwRSF

Midwest Roadside
Safety Facility

FHWA Gabion Wall
Full–Scale Test Program

Bill of Materials

SHEET: 17 of 17
DATE: 6/30/2010
DRAWN BY: EAJ/RJT/MDM
DWG. NAME. fhwa gabion wall_v18
SCALE: None
UNITS: In.[mm]
REV. BY: RKF/KAL

Figure 30. Schematic. Bill of Materials, Test Nos. MGSGW-1 and MGSGW-2.

a. MSE Wall, Pit Base Layer

c. MSE Wall, First Fill Layer, Upstream View

b. MSE Wall, First Fill Layer, Rear View

d. MSE Wall, First Fill Layer, Downstream View

Figure 31. Photo. Construction of Wire-Faced, MSE Wall.

a. Filter Fabric Held by Posts

c. Filter Fabric Positioned

b. Fiber Filter Positioned, Ready for Course Aggregate

d. Wall Face Aggregate Filled by Hand

Figure 32. Photo. Construction of Wire-Faced, MSE Wall. (continued.)

a. Second Layer Wire Mat Inastalled

c. Wire Mat Final Allignment Before Filter Fabric

b. Rolling Out Fiber Filter

d. Second Layer Wire Mat Installed, Upstream End

Figure 33. Photo. Construction of Wire-Faced, MSE Wall. (continued.)

a. MSE Wall, Second Layer, Uncompacted

c. MSE Wall, Second Layer, Leveling

b. MSE Wall, Second Layer With Fiber Filter

d. Second Layer Fiber Filter Positioning

Figure 34. Photo. Construction of Wire-Faced, MSE Wall. (continued.)

a. MSE Wall, Upstream View

c. MSE Wall Stone Face

b. MSE Wall, Downstream View

d. MSE Wall. Back View

Figure 35. Photo. Construction of Wire-Faced, MSE Wall. (continued.)

a. Non-Blocked MGS System Installation

c. Non-Blocked MGS System, Initial Rail Attachment

b. Non-Blocked MGS Installation, Leveling Rail

d. Non-Blocked MGS Installation, Driving Posts-1

Figure 36. Photo. Construction of Midwest Guardrail System (MGS) on MSE Wall.

a. Non-Blocked MGS Installation, Driving Post No. 2

b. Non-Blocked MGS Installation, Driving Post No. 3

c. Non-Blocked MGS Installation, Driving Post No. 4

d. Non-Blocked MGS Installation, Driving Post No. 5

Figure 37. Photo. Construction of Midwest Guardrail System (MGS) on MSE Wall. (continued.)

a. MGS on MSE Wall, Upstream Quarter View

b. MGS on MSE Wall, Rear Quarter View

c. MGS on MSE Wall, Downstream Quarter View

d. MGS on MSE Wall, Upstream Quarter View

Figure 38. Photo. Test Installation – MGS on MSE Wall.

a. MGS on MSE Wall, Rear Quarter View

c. MGS on MSE Wall, Front View

b. MGS on MSE Wall, Upstream Rear Quarter View

d. MGS on MSE Wall, Downstream Rear View

Figure 39. Photo. Test Installation – MGS on MSE Wall. (continued.)

a. MSE Wall

c. MSE Wall, Near Impact

b. MSE Wall, Downstream End

d. MSE Wall, Course Aggregate Close-up

Figure 40. Photo. Test Installation – Wire-Mesh and Wall Facing Rock.

a. Upstream Inline View

c. Downstream Inline View

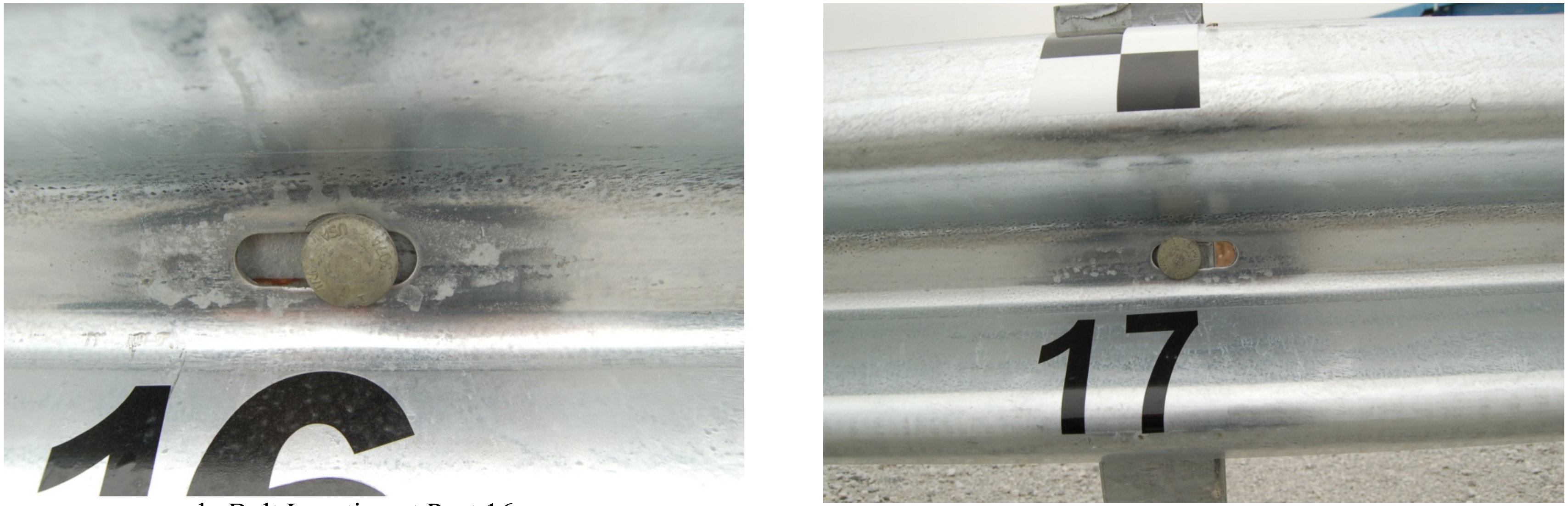
b. Rear View of Downstream Anchor

d. Front View of Upstream Anchor

Figure 41. Photo. Test Installation – End Anchorage System.

a. Bolt Location at Post 14

c. Bolt Location at Post 15



b. Bolt Location at Post 16

d. Bolt Location at Post 17

Figure 42. Photo. W-Beam Backup Plate and Post Bolt Locations, Test No. MGSGW-1.

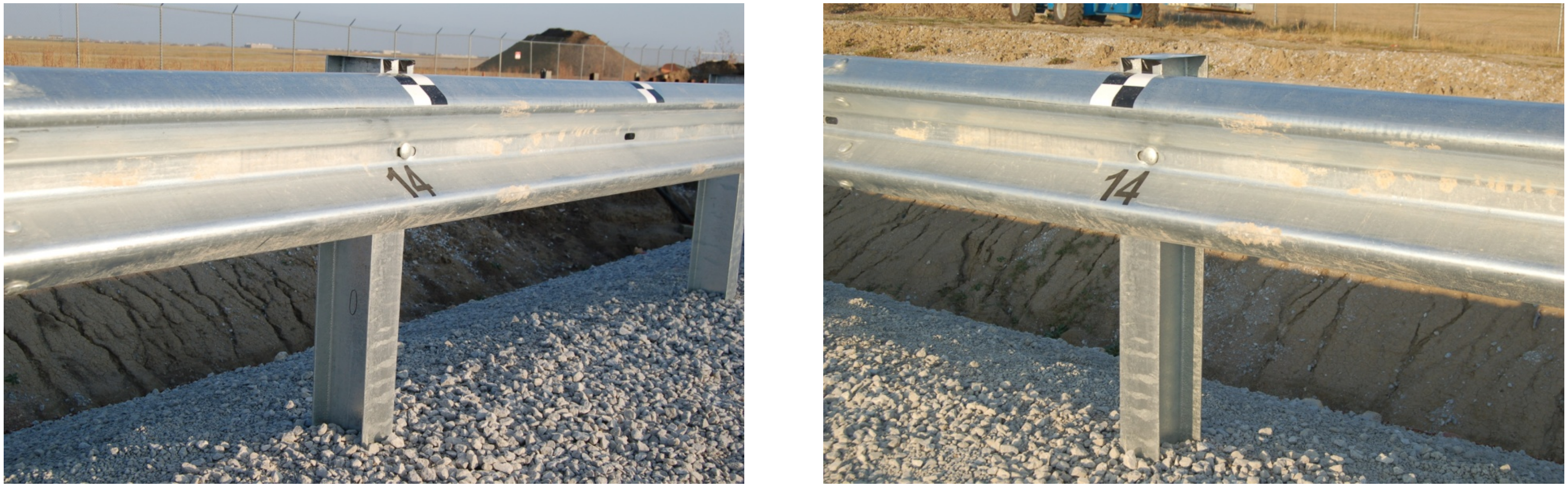
a. Downstream View of Post 12

c. Upstream View of Post 12

b. Downstream View of Post 13

d. Upstream View of Post 13

Figure 43. Photo. Post Bolt Locations at Post Nos. 12 and 13, Test No. MGSGW-2.



a. Downstream View of Post 14

c. Upstream View of Post 14

b. Downstream View of Post 15

d. Upstream View of Post 15

Figure 44. Photo. Post Bolt Locations at Post Nos. 14 and 15, Test No. MGSGW-2.

a. Downstream View of Post 16

c. Upstream View of Post 16

b. Downstream View of Post 17

d. Upstream View of Post 17

Figure 45. Photo. Post Bolt Locations at Post Nos. 16 and 17, Test No. MGSGW-2.

CHAPTER 7. TEST REQUIREMENTS AND EVALUATION CRITERIA

7.1 TEST REQUIREMENTS

Longitudinal barriers, such as W-beam guardrails, must satisfy impact safety standards in order to be accepted by the Federal Highway Administration (FHWA) for use on the National Highway System (NHS) for new 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.[25] However, NCHRP Project 22-14(2) generated revised testing procedures and guidelines for use in the evaluation of roadside safety appurtenances and are provided in MASH.[14] According to Test Level 3 (TL-3) of MASH, longitudinal barrier systems must be subjected to two full-scale vehicle crash tests. The two full-scale crash tests are noted below.

1. Test Designation No. 3-10 consists of a 2,425-lb (1,100-kg) passenger car impacting the system at a nominal speed and angle of 62 mph (100 km/h) and 25 degrees, respectively.
2. Test Designation No. 3-11 consists of a 5,000-lb (2,268-kg) pickup truck impacting the system at a nominal speed and angle of 62 mph (100 km/h) and 25 degrees, respectively.

The test conditions of TL-3 longitudinal barriers are summarized in Table 8.

Table 8. MASH TL-3 Crash Test Conditions.

Test Article	Test Designation No.	Test Vehicle	Impact Conditions			Evaluation Criteria[1]
			Speed		Angle (deg)	
			mph	km/h		
Longitudinal Barrier	3-10	1100C	62	100	25	A,D,F,H,I
	3-11	2270P	62	100	25	A,D,F,H,I

[1] - Evaluation criteria explained in Table 9.

7.2 EVALUATION CRITERIA

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 guardrail to contain and redirect impacting vehicles. In addition, controlled lateral deflection of the test article is acceptable. 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 result in multi-vehicle accidents. This criterion also indicates the potential for safety hazard for the occupants of other vehicles or occupants of the crash vehicle when subjected to secondary collisions with other fixed objects. These three evaluation criteria are described in greater detail in MASH and are summarized in Table 9. Finally, the full-scale vehicle crash tests were conducted and reported in accordance with the procedures provided in MASH.

In addition to the standard occupant risk measures, the Post-Impact Head Deceleration (PHD), the Theoretical Head Impact Velocity (THIV), and the Acceleration Severity Index (ASI) were determined and reported on the test summary sheets. Additional discussion on PHD, THIV, and ASI is provided in Reference 14.

Table 9. MASH Evaluation Criteria for Longitudinal Barriers.

<table>
<tr><td>Structural Adequacy</td><td colspan="3">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.</td></tr>
<tr><td rowspan="10">Occupant Risk</td><td colspan="3">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 MASH.</td></tr>
<tr><td colspan="3">F. The vehicle should remain upright during and after collision. The maximum roll and pitch angles are not to exceed 75 degrees.</td></tr>
<tr><td colspan="3">H. Occupant Impact Velocity (OIV) (see Appendix A, Section A5.3 of MASH for calculation procedure) should satisfy the following limits:</td></tr>
<tr><td colspan="3">Occupant Impact Velocity Limits</td></tr>
<tr><td>Component</td><td>Preferred</td><td>Maximum</td></tr>
<tr><td>Longitudinal and Lateral</td><td>30 ft/s
(9.1 m/s)</td><td>40 ft/s
(12.2 m/s)</td></tr>
<tr><td colspan="3">I. The Occupant Ridedown Acceleration (ORA) (see Appendix A, Section A5.3 of MASH for calculation procedure) should satisfy the following limits:</td></tr>
<tr><td colspan="3">Occupant Ridedown Acceleration Limits</td></tr>
<tr><td>Component</td><td>Preferred</td><td>Maximum</td></tr>
<tr><td>Longitudinal and Lateral</td><td>15.0 g’s</td><td>20.49 g’s</td></tr>
</table>

7.3 SOIL STRENGTH REQUIREMENTS

In order to limit the variation of soil strength among testing agencies, the foundation soil must satisfy the recommended performance characteristics set forth in Chapter 3 and Appendix B of MASH. Testing facilities must first subject the baseline soil material to a dynamic post test to demonstrate a minimum dynamic load of 7.5 kips (33.4 kN) at deflections between 5 and 20 in. (127 and 508 mm). If satisfactory results are observed, a static test is conducted using an identical test installation. The results from this static test become the baseline requirement for soil strength in future full-scale crash testing. On the day of the full-scale crash test, an additional steel post is to be statically tested in the same manner as used for the baseline static test. If the static test results reveal a post-soil resistance equal to or greater than 90 percent of the baseline test result at deflections of 5, 10, and 15 in. (127, 254, and 381 mm), the full-scale crash test can be conducted. Otherwise, the crash test must be postponed until the soil demonstrates adequate post-soil strength. However, the soil strength tests were not conducted for this crash testing program since a special soil material was required and placed with a roller-compactor in a region where the guardrail posts were driven.

CHAPTER 8. TEST CONDITIONS

8.1 TEST FACILITY

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

8.2 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 increased the accuracy of the test vehicle impact speed.

A vehicle guidance system developed by Hinch was used to steer the test vehicle.[27] A guide-flag, attached to the left-front wheel and the guide cable, was sheared off before impact with the barrier system. The ⅜-in. (9.5-mm) diameter guide cable was tensioned to approximately 3,500 lb (15.6 kN) and supported both laterally and vertically every 100 ft (30.48 m) 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.

8.3 TEST VEHICLES

For test no. MGSGW-1, a 2003 Kia Rio Sedan was used as the test vehicle. The curb, test inertial, and gross static vehicle weights were 2,302 lb (1,044 kg), 2,427 lb (1,101 kg), and 2,596 lb (1,178 kg), respectively. The test vehicle is shown in Figure 46, and vehicle dimensions are shown in Figure 47.

For test no. MGSGW-2, a 2003 Dodge Ram Quad Cab pickup truck was used as the test vehicle. The curb, test inertial, and gross static vehicle weights were 5,081 lb (2,305 kg), 4,999 lb (2,268 kg), and 5,169 lb (2,345 kg), respectively. The test vehicle is shown in Figure 48, and vehicle dimensions are shown in Figure 49.

The longitudinal component of the center of gravity (c.g.) was determined using the measured axle weights for both the small car and pickup truck. The Suspension Method was used to determine the vertical component of the c.g. for the pickup truck.[28] 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 c.g. location for the test inertial condition. The c.g. height of the 1100C vehicle was estimated based on historical c.g. height measurements. The location of the final c.g. for each vehicle is shown in Figures 47 and 49 through 51. Data used to calculate the final location of the c.g. is shown in Appendix C.


a. Rear Quarter View


b. Non-Impact Side


c. Front View

Figure 46. Photo. Test Vehicle, Test No. MGSGW-1.

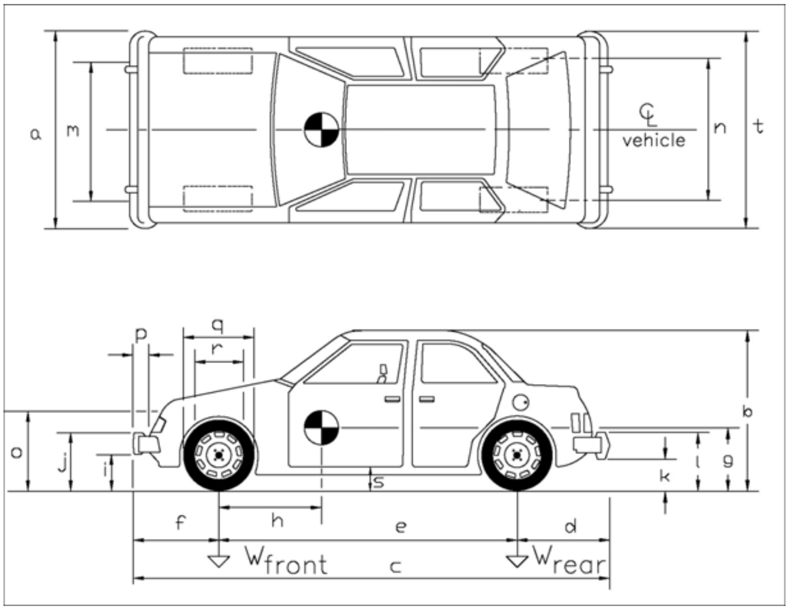
Date: 10/20/2009 **Test Number:** MGSGW-1 **Model:** Rio Sedan (1100C)

Make: Kia **Vehicle I.D.#:** KNADC125336269907

Tire Size: 175/65 R14 **Year:** 2003 **Odometer:** 36304

Tire Inflation Pressure: 29 psi

***(All Measurements Refer to Impacting Side)**



Vehicle Geometry -- in. (mm)

a	64	(1626)	b	55.75	(1416)
c	166.75	(4235)	d	38.3	(973)
e	95.25	(2419)	f	33.25	(845)
g	21.75	(552)	h	39.28	(998)
i	9.75	(248)	j	22	(559)
k	10.25	(260)	l	21.75	(552)
m	56.5	(1435)	n	56.75	(1441)
o	28	(711)	p	3	(76)
q	22.5	(572)	r	15.5	(394)
s	11.75	(298)	t	63	(1600)

Wheel Center Height Front	10.75	(273)
Wheel Center Height Rear	11	(279)
Wheel Well Clearance (F)	24.5	(622)
Wheel Well Clearance (R)	24	(610)
Frame Height (F)	10.75	(273)
Frame Height (R)	16	(406)
Engine Type	4 cyl.	
Engine Size	1.6 Liter	

Transmition Type:

Automatic [✓ Manual]

[✓ FWD] RWD 4WD

Mass Distribution

Gross Static	LF	734	RF	755
	LR	515	RR	592

Weights lb (kg)	Curb	Test Inertial	Gross Static
W-front	1412 (640)	1407 (638)	1489 (675)
W-rear	890 (404)	1020 (463)	1107 (502)
W-total	2302 (1044)	2427 (1101)	2596 (1178)

GVWR Ratings

Front 1808

Rear 1742

Total 3315

Dummy Data

Type: Hybrid 2

Mass: 170 lb

Seat Position: Passenger

Note any damage prior to test: none

Figure 47. Schematic. Vehicle Dimensions, Test No. MGSGW-1.

a. Non-Impact Side

b. Front Quarter View

Figure 48. Photo. Test Vehicle, Test No. MGSGW-2

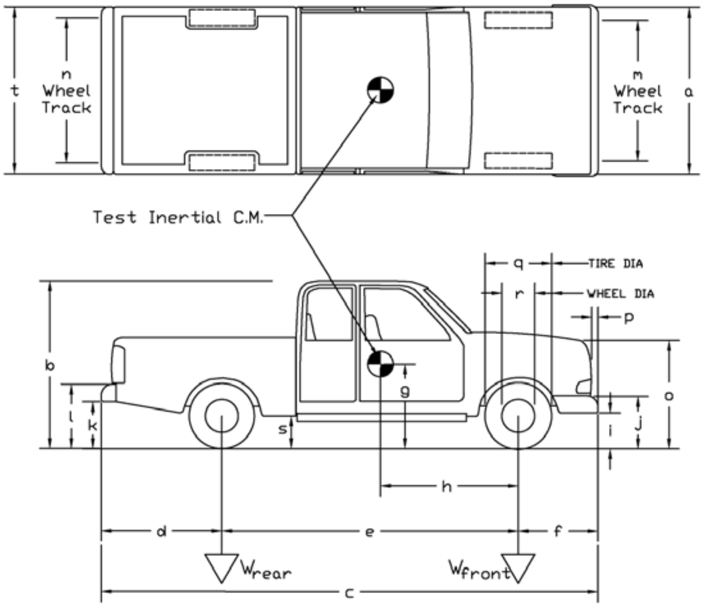
Date: 11/20/2009 **Test Number:** MGSGW-2 **Model:** 2270P (RAM 1500)

Make: Dodge **Vehicle I.D.#:** 1D7HA18N13S298692

Tire Size: 265/70 R17 **Year:** 2003 **Odometer:** 224685

Tire Inflation Pressure: 35psi

***(All Measurements Refer to Impacting Side)**



Vehicle Geometry -- in. (mm)

a	78 (1981)	b	76.25 (1937)
c	227 (5766)	d	46.5 (1181)
e	140.5 (3569)	f	40 (1016)
g	28.32 (719)	h	62.00 (1575)
i	15.25 (387)	j	27.25 (692)
k	21.75 (552)	l	29.875 (759)
m	68.5 (1740)	n	68 (1727)
o	44.25 (1124)	p	3 (76)
q	31.5 (800)	r	21.625 (549)
s	16.125 (410)	t	75.5 (1918)

Wheel Center Height Front 15.25 (387)
Wheel Center Height Rear 15.25 (387)
Wheel Well Clearance (F) 35.5 (902)
Wheel Well Clearance (R) 38.5 (978)
Frame Height (F) 18.125 (460)
Frame Height (R) 26.25 (667)
Engine Type Gas V-8
Engine Size 4.7L
Transmition Type:
[✓ Automatic] Manual
FWD [✓ RWD] 4WD

Mass Distribution

Gross Static	**LF** 1456		**RF** 1417
	LR 1154		**RR** 1142

Weights lb (kg)	**Curb**	**Test Inertial**	**Gross Static**
W-front	2865 (1300)	2787 (1264)	2873 (1303)
W-rear	2216 (1005)	2212 (1003)	2296 (1041)
W-total	5081 (2305)	4999 (2268)	5169 (2345)

GVWR Ratings

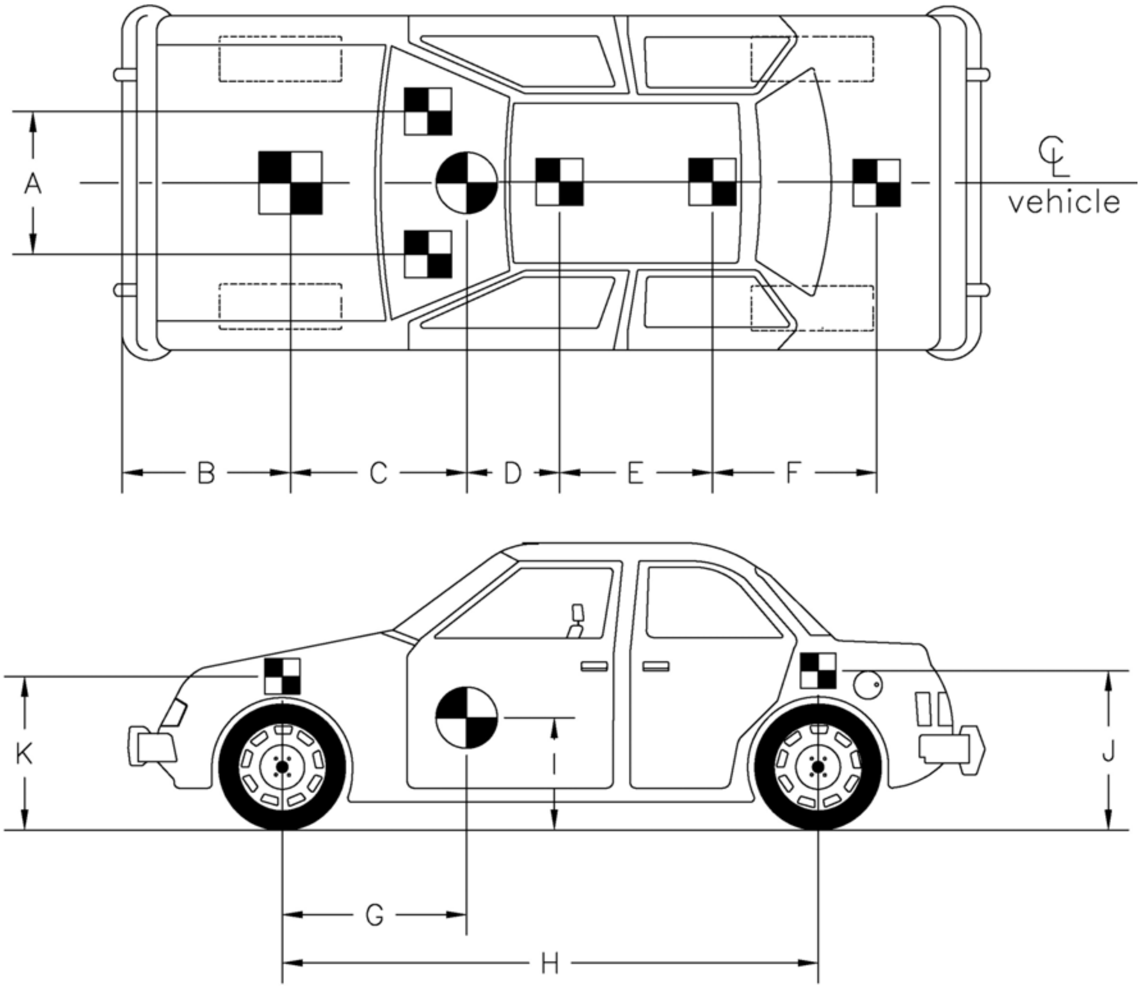
Front 3650
Rear 3900
Total 6650

Dummy Data

Type: Hybrid II
Mass: 170 lb
Seat Position: Passenger

Note any damage prior to test: None

Figure 49. Schematic. Vehicle Dimensions, Test No. MGSGW-2.

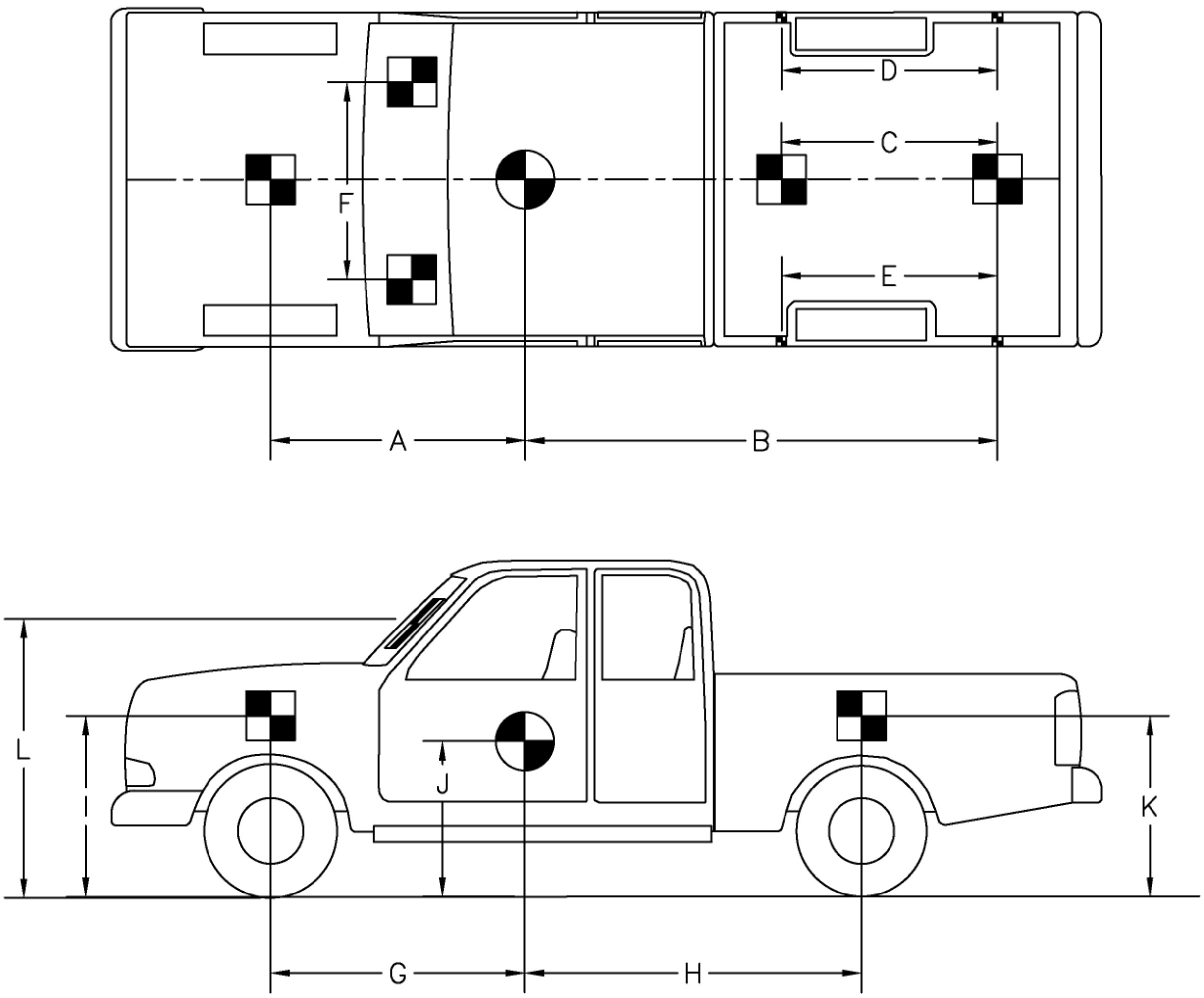


TEST #: MGSGW-1

TARGET GEOMETRY-- in. (mm)

A	**28**	**(711)**	**E**	**34.5**	**(876)**	**I**	**21.75**	**(552)**
B	**23.25**	**(591)**	**F**	**37.25**	**(946)**	**J**	**28**	**(711)**
C	**48.5**	**(1232)**	**G**	**39.25**	**(997)**	**K**	**28.5**	**(724)**
D	**11**	**(279)**	**H**	**95.25**	**(2419)**			

Figure 50. Schematic. Target Geometry, Test No. MGSGW-1.



TEST #: MGSGW-2

TARGET GEOMETRY-- in. (mm)

A	**63.75**	**(1619)**	**E**	**63.875**	**(1622)**	**I**	**40**	**(1016)**
B	**99.5**	**(2527)**	**F**	**42.625**	**(1083)**	**J**	**29.5**	**(749)**
C	**42.875**	**(1089)**	**G**	**63.75**	**(1619)**	**K**	**43.25**	**(1099)**
D	**64**	**(1626)**	**H**	**76.25**	**(1937)**	**L**	**61**	**(1549)**

Figure 51. Schematic. Target Geometry, Test No. MGSGW-2.

Square black- and white-checkered targets were placed on the vehicles to aid in the analysis of the high-speed digital videos, as shown in Figures 50 and 51. Round, checkered targets were placed on the center of gravity on the left-side door, the right-side door, and the roof of the vehicles. The remaining targets were located for references so they could be viewed from the high-speed cameras for video analysis.

The front wheels of the test vehicles 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 under the left-side windshield wiper and was fired by a pressure tape switch mounted at the impact corner of the bumper. The flash bulb was fired upon initial impact with the test article to create a visual indicator of the precise time of impact on the high-speed digital videos. A remote controlled brake system was installed in the test vehicles so the vehicles could be brought safely to a stop after the test.

8.4 SIMULATED OCCUPANT

For test nos. MGSGW-1 and MGSGW-2, A Hybrid II 50th Percentile Adult Male Dummy, equipped with clothing and footware, was placed in the right-front seat of the test vehicle with the seat belt fastened. The dummy, which had a final weight of 170 lb (77 kg), was represented by model no. 572, serial no. 451, and was manufactured by Android Systems of Carson, California. As recommended by MASH, the dummy was not included in calculating the c.g location.

8.5 DATA ACQUISITION SYSTEMS

8.5.1 Accelerometers

Two environmental shock and vibration sensor/recorder systems were used to measure the accelerations in the longitudinal, lateral, and vertical directions. All of the accelerometers were mounted near the center of gravity of the test vehicles.

The first accelerometer system was a two-arm piezoresistive accelerometer system manufactured by Endevco of San Juan Capistrano, California. Three accelerometers were used to measure each of the longitudinal, lateral, and vertical accelerations independently at a sample rate of 10,000 Hz. Two additional accelerometers were used to measure the longitudinal and lateral accelerations independently at the same sample rate. The accelerometers were configured and controlled using a system developed and manufactured by Diversified Technical Systems, Inc. (DTS) of Seal Beach, California. More specifically, data was collected using a DTS Sensor Input Module (SIM), Model TDAS3-SIM-16M. 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 was configured with isolated power/event/communications, 10BaseT Ethernet and RS232 communication, and an internal backup battery. Both the SIM and module rack were crashworthy. The “DTS TDAS Control” computer software program and a customized Microsoft Excel worksheet were used to analyze and plot the accelerometer data.

The second system, Model EDR-3, was a triaxial piezoresistive accelerometer system developed by Instrumented Sensor Technology (IST) of Okemos, Michigan. The EDR-3 was configured with 256 kB of RAM memory, a range of ±200 g's, a sample rate of 3,200 Hz, and a 1,120 Hz lowpass filter. The computer software program "DynaMax 1 (DM-1)" and a customized Microsoft Excel worksheet were used to analyze and plot the accelerometer data.

8.5.2 Rate Transducers

An angle rate sensor, the ARS-1500, with a range of 1,500 degrees/sec in each of the three directions (roll, pitch, and yaw) was used to measure the rates of rotation of the test vehicles. The angular rate sensor was mounted on an aluminum block inside the test vehicles near 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. The computer software program "DTS TDAS Control" and a customized Microsoft Excel worksheet were used to analyze and plot the angular rate sensor data.

8.5.3 Pressure Tape Switches

For test nos. MGSGW-1 and MGSGW-2, five pressure-activated tape switches, spaced at approximately 6.56-ft (2-m) intervals, were used to determine the speed of the vehicles before impact. Each tape switch fired a strobe light which sent an electronic timing signal to the data acquisition system as the right-front tire of the test vehicle passed over it. Test vehicle speeds were determined from electronic timing mark data recorded using TestPoint and LabVIEW computer software programs. Strobe lights and high-speed video analysis are used only as a backup in the event that vehicle speed cannot be determined from the electronic data. However, due to technical difficulties, the strobe data was not collected with the LabVIEW computer software program for test no. MGSGW-1.

8.5.4 High-Speed Photography

Two high-speed AOS VITcam digital video cameras, three high-speed AOS X-PRI digital video cameras, four JVC digital video cameras, and two Canon digital video cameras were utilized to film both tests. Camera details, camera operating speeds, lens information, and a schematic of the camera locations relative to the system for both tests are shown in Figures 52 and 53. The high-speed digital videos were analyzed using the ImageExpress MotionPlus and Redlake MotionScope software. Actual camera speed and camera divergence factors were considered in the analysis of the high-speed digital videos. A Nikon D50 digital still camera was also used to document pre-test and post-test conditions for both tests.

	No.	Type	Operating Speed (frames/sec)	Lens	Lens Setting
High-Speed Video	2	AOS Vitcam CTM	500	Cosmicar 12.5mm fixed	--
	4	AOS Vitcam CTM	500	Nikkor Fixed 20mm	--
	5	AOS X-PRI	500	Sigma 24-135	100
	6	AOS X-PRI	500	Fujinon 50mm Fixed	--
	7	AOS X-PRI	500	Sigma 50mm Fixed	--
Digital Video	1	JVC – GZ-MC500 (Everio)	29.97		
	2	JVC – GZ-MG27u (Everio)	29.97		
	3	JVC – GZ-MG27u (Everio)	29.97		
	4	JVC – GZ-MG27u (Everio)	29.97		
	1	Canon ZR90	29.97		
	2	Canon ZR10	29.97		

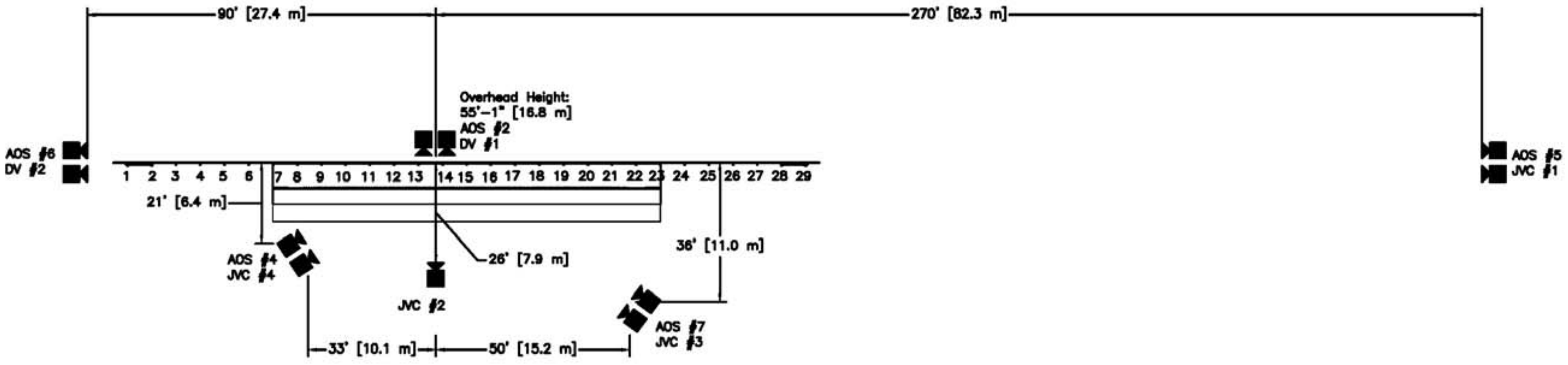


Figure 52. Schematic. Camera Locations, Speeds, and Lens Settings, Test No. MGSGW-1.

	No.	Type	Operating Speed (frames/sec)	Lens	Lens Setting
High-Speed Video	2	AOS Vitcam CTM	500	Cosmicar 12.5mm fixed	--
	3	AOS Vitcam CTM	500	Canon TV Lens 17-102mm	20 mm
	5	AOS X-PRI Gigabit	500	Telesar 135 mm Fixed	--
	6	AOS X-PRI Gigabit	500	Sigma 50mm Fixed	--
	7	AOS X-PRI Gigabit	500	Fujinon 50mm Fixed	--
Digital Video	1	JVC – GZ-MC500 (Everio)	29.97		
	2	JVC – GZ-MG27u (Everio)	29.97		
	3	JVC – GZ-MG27u (Everio)	29.97		
	4	JVC – GZ-MG27u (Everio)	29.97		
	1	Canon ZR90	29.97		
	2	Canon ZR10	29.97		

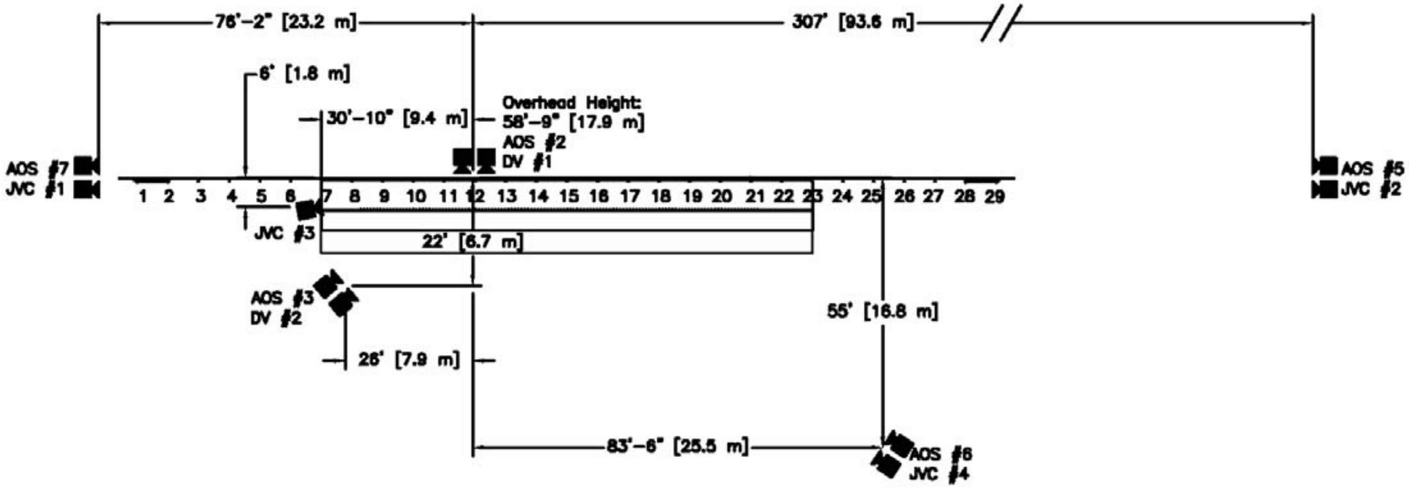


Figure 53. Schematic. Camera Locations, Speeds, and Lens Settings, Test No. MGSGW-2.

CHAPTER 9. FULL-SCALE CRASH TEST NO. MGSGW-1

9.1 TEST NO. MGSGW-1

The 2,596-lb (1,178-kg) small car with a simulated occupant seated in the right-front seat, impacted the non-blocked MGS placed at the slope break point of the 3H:1V fill slope on top of a wire-faced, MSE wall at a speed of 61.0 mph (98.2 km/h) and at an angle of 25.3 degrees. A summary of the test results and sequential photographs are shown in Figure 54. Additional sequential photographs are shown in Figures 55 and 56. Documentary photographs of the crash test are shown in Figures 57 and 58.

9.2 WEATHER CONDITIONS

Test no. MGSGW-1 was conducted on October 20, 2009 at approximately 1:30 pm. The weather conditions as per the National Oceanic and Atmospheric Administration (station 14939/LNK) were documented and are shown in Table 10.

Table 10. Weather Conditions, Test No. MGSGW-1.

Temperature	63° F
Humidity	75%
Wind Speed	7 mph
Wind Direction	70° from True North
Sky Conditions	Overcast
Visibility	10 Statute Miles
Pavement Surface	Dry
Previous 3-Day Precipitation	0.00 in.
Previous 7-Day Precipitation	0.21 in.

9.3 TEST DESCRIPTION

Initial vehicle impact was to occur 4 ft - 9½ in. (1.5 m) upstream of the splice between post nos. 14 and 15, as shown in Figure 59. The actual point of impact was 4½ in. (114 mm) downstream from the target impact location, or 4 ft – 5 in. (1.3 m) upstream from the centerline of the splice between post nos. 14 and 15. A sequential description of the impact events is shown in Table 11. The vehicle came to rest 31 ft - 1 in. (9.5 m) downstream from impact and 11 ft – 3 in. (3.4 m) laterally in front of the traffic-side face of the barrier and oriented with its front end facing upstream. The vehicle trajectory and final position are shown in Figures 54 and 60.

Table 11. Sequential Description of Impact Events, Test No. MGSGW-1.

TIME (sec)	EVENT
0.000	The vehicle impacted the system.
0.018	The right-front bumper of the vehicle underrode the rail.
0.022	The right-front tire contacted the front-upstream flange of post no. 14.
0.03	The rail disengaged from post no. 14.
0.044	The engine block contacted the rail at splice between post nos. 14 and 15.
0.058	The vehicle rolled away from the barrier.
0.068	The center of the front bumper contacted the upstream side of post No. 15.
0.070	The right-front tire deflated.
0.074	The rail disengaged from post no. 15, which twisted downstream.
0.078	The right-front tire became airborne.
0.112	The surrogate occupant’s head contacted the right-front side window, causing the window to shatter.
0.116	The right-rear tire became airborne.
0.128	The front bumper overrode post no. 15.
0.158	The center-front bumper contacted the front-upstream flange of post no. 16.
0.174	The rail separated from post no. 16.
0.188	The left-front tire deflated.
0.272	A buckle formed in bottom rail corrugation just downstream of post no. 16.
0.276	The front bumper contacted post no. 17, which twisted upstream.
0.282	The vehicle pitched downward.
0.306	The rail disengaged from post no. 17.
0.322	The right-front tire contacted the ground.
0.328	The vehicle yawed toward the barrier.
0.726	The right-front corner of the engine hood lost contact with the rail at post no. 18, and the vehicle exited the system at an angle of 58.3 degrees with a velocity of 10.2 mph (16.3 km/h).
0.826	Left front of vehicle yaws toward barrier.
1.346	Front of vehicle continues to yaw toward barrier.

9.4 BARRIER DAMAGE

Damage to the barrier was moderate, as shown in Figures 61 through 66. Barrier damage consisted of contact marks on and deformation to the guardrail posts and W-beam rail. The length of vehicle contact along the barrier was approximately 24 ft – 2 in. (7.4 m) extending from 53 in. (1,346 mm) upstream of the centerline of the splice between post nos. 14 and 15 to 26 in. (660 mm) upstream of post no. 18.

Damage to the W-beam rail occurred between posts nos. 13 and 18. Minor buckling was found just upstream of post no. 13. Sheet metal from the vehicle body was wedged in the guardrail slot near post no. 14. A ¼-in. (6-mm) gap was found at the splice between post nos. 14 and 15. General deformation and flattening in the rail splice between posts nos. 16 and 17. Between posts nos. 16 and 17, the splice bolt holes encountered a ⅛-in. (3-mm) gap. At post no. 17, the bottom of the backup plate was crushed upward with a 1-in. (25-mm) tear on the upstream side. The guardrail bolt and backup plate were still attached to post no. 17, while the slot in the guardrail was folded with a ½-in. (13-mm) tear. Minor buckling occurred at post nos. 17 and 18.

A 2½-in. (64-mm) soil gap was found at the front of post no. 13. Post nos. 14 and 15 twisted and bent downstream. The front flange of post no. 14 was bent and sustained contact marks. A 4-in. (102-mm) soil gap was found at the front of post no 14. The guardrail bolt tore through the flange of post no. 14. The guardrail bolt tore through the flange at post nos. 14 through 16. Posts nos. 16 and 17 were completely removed from the ground, with the wire mesh being exposed at the bottom of the hole at post no. 16. The front flange of post no. 16 was deformed due to contact with the vehicle. Post no. 17 was bent at the groundline and at the location of vehicle contact, and it was severely twisted. Post no. 18 twisted upstream, and its front flange buckled due to vehicle contact. An ⅛-in. (3-mm) gap was found at the front of post no. 18.

The permanent set of the barrier system is shown in Figure 61. The maximum lateral permanent set rail and post deflections were 17⅜ in. (441 mm) at the midspan between post nos. 15 and 16 and 20⅛ in. (511 mm) at post no. 14, respectively, as measured in the field. The maximum lateral dynamic rail and post deflections were 27.4 in (696 mm) at the midspan between post nos. 15 and 16 and 26.2 in. (665 mm) at post no. 14, respectively, as determined from high-speed digital video analysis. The working width of the system was found to be 35.7 in. (907 mm).

9.5 VEHICLE DAMAGE

The damage to the vehicle was moderate, as shown in Figures 67 through 70. The maximum occupant compartment deformations are shown in Table 12 with the deformation limits established in MASH for various regions of the occupant compartment. It should be noted that the MASH-established deformation limits were not violated. Complete interior occupant compartment deformations as well as other vehicle deformations, along with the corresponding locations, are provided in Appendix D.

The majority of the damage was concentrated on the right-front corner and right side of the vehicle where the impact occurred. The front bumper was completely detached and fractured. The front frame was deformed inward toward the engine compartment and fractured on the right side. The metal headlight assembly frame was deformed inward, and the headlight was disengaged from the vehicle. The right-front A-arm assembly was disengaged from the frame. The right-front fender was torn back to approximately the midpoint of the wheel and became detached. The engine support bowed downward and backward. Both front tires were deflated. Two gouge marks were found along the right side, measuring 27¼ in. (692 mm) and 19 in. (483 mm) in length. The hood and radiator were crushed inward at the right bumper corner. The right-front window was fractured, and the glass removed. A 7-in. (178-mm) scratch was found on the underside of the fender. Severe folding occurred on the right-front quarter panel. Minor denting was found along the bottom of the right-front door. The right-front wheel was deformed. The right-front side of the interior floor panel was deformed inward and upward. Both right-side doors were partially detached at the hinge.

Table 12. Maximum Occupant Compartment Deformation by Location, Test No. MGSGW-1.

LOCATION	MAXIMUM DEFORMATION in. (mm)	MASH ALLOWABLE DEFORMATION in. (mm)
Wheel Well & Toe Pan	1¼ (32)	≤ 9 (229)
Floor Pan & Transmission Tunnel	¼ (6)	≤ 12 (305)
Side Front Panel (in Front of A-Pillar)	¼ (6)	≤ 12 (305)
Side Door (Above Seat)	¾ (19)	≤ 9 (229)
Side Door (Below Seat)	1¼ (32)	≤ 12 (305)
Roof	NA	≤ 4 (102)
Windshield	NA	≤ 3 (76)

9.6 OCCUPANT RISK

The calculated occupant impact velocities (OIVs) and maximum 0.010-sec occupant ridedown accelerations (ORAs) in both the longitudinal and lateral directions are shown in Table 13. It is noted that the OIVs and ORAs were within the suggested limits provided in MASH. The calculated THIV, PHD, and ASI values are also shown in Table 13. The results of the occupant risk analysis, as determined from the accelerometer data, are summarized in Figure 54. The recorded data from the accelerometers and the rate transducers are shown graphically in Appendix E.

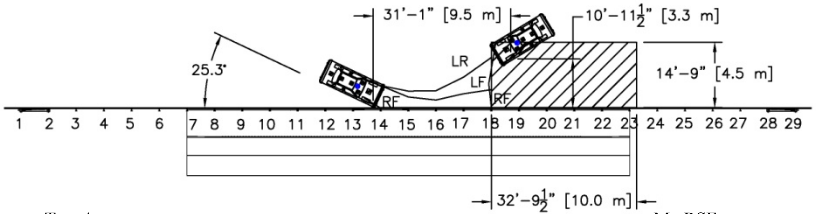
Table 13. Summary of OIV, ORA, THIV, PHD, and ASI Values, Test No. MGSGW-1.

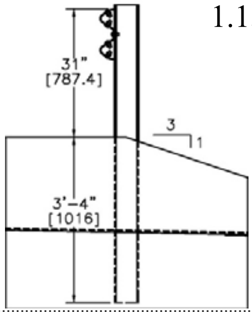
Evaluation Criteria		Transducer			MASH Limits
		EDR-3	DTS set 1	DTS set 2	
OIV ft/s (m/s)	Longitudinal	-22.62 (-6.89)	-25.87 (-7.89)	-22.45 (-6.84)	≤ 40 (12.2)
	Lateral	-16.51 (-5.03)	-17.07 (-5.20)	-16.53 (-5.04)	≤40 (12.2)
ORA g's	Longitudinal	-9.94	-13.78	-10.25	≤ 20.49
	Lateral	-6.54	-7.81	-7.40	≤ 20.49
THIV ft/s (m/s)		NA	30.08 (9.17)	NA	not required
PHD g's		NA	14.55	NA	not required
ASI		0.74	0.92	0.78	not required

9.7 DISCUSSION

The analysis of the test results for test no. MGSGW-1 showed that the non-blocked MGS placed at the slope break point of the 3H:1V fill slope on top of a wire-faced, MSE wall adequately contained and redirected the 1100C vehicle with controlled lateral displacements of the barrier. 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 and remained upright during and after the collision. Vehicle roll, pitch, and yaw angular displacements were deemed acceptable because they did not adversely influence occupant risk safety criteria nor cause rollover. After impact, the vehicle exited the barrier at an angle of 58.3 degrees as it spun-out. The vehicle's trajectory violated the bounds of the exit box. However, the exit box criterion is preferable and not a requirement. Therefore, test no. MGSGW-1 (test designation no. 3-10) was determined to be acceptable according to the TL-3 MASH safety performance criteria.

0.000 sec 0.112 sec 0.238 sec 0.622 sec 1.154 sec



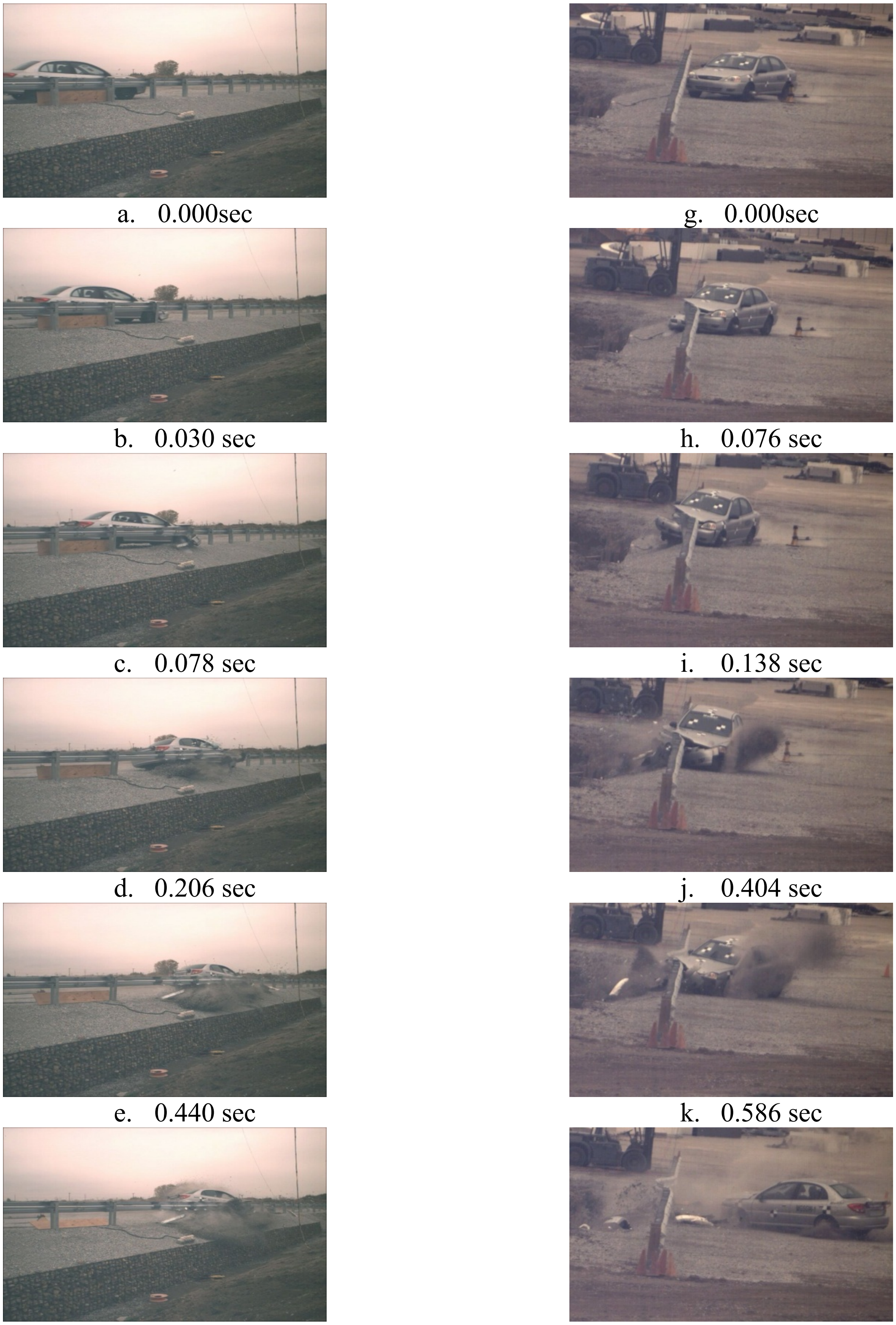


• Test Agency	MwRSF
• Test Number	MGSGW-1
• Date	10/20/2009
• MASH Test Designation	3-10
• Test Article	MGS without blockouts on MSE wall with a 3:1 slope
• Total Length	175 ft (53.4 m)
• Key Component – Steel W-Beam	
Thickness	12 gauge (2.66 mm)
Top Mounting Height	31 in. (787 mm)
• Key Component – Steel Posts	
Post nos. 3-27	W6x8.5 (W152x12.6) by 6 ft (1.8 m) long
Post Location	Centerline of posts at slope break point
Spacing	6 ft-3 in. (1.9-m)
Blockout	None
• Key Component – Wood Posts	
Post nos. 1-2, 28-29	5½ by 7½ by 46 in. (140x191x1,168 mm)
• Key Component – Foundation Tube	6 ft (1.8 m) long
• Soil Type	NCHRP No. 350 Strong Soil
• Vehicle Model	2003 Kia Rio Sedan
Curb	2,302 lb (1,044 kg)
Test Inertial	2,427 lb (1,101 kg)
Gross Static	2,596 lb (1,178 kg)
• Impact Conditions	
Speed	61.0 mph (98.2 km/h)
Angle	25.3 deg
Impact Location	4 ft - 5 in. (1.3 m) US of splice btwn posts 14 and 15
• Exit Conditions	
Speed	10.2 mph (16.3 km/h)
Angle	58.3 deg
• Exit Box	Fail (Not required)
• Vehicle Stability	Satisfactory
• Vehicle Stopping Distance	31 ft - 1 in. downstream
	11 ft - 3 in. (3.4 m) laterally from traffic-side face

• Vehicle Damage	Moderate
VDS[29]	1-FR-5
CDC[30]	01-FZEW4
Maximum Interior Deformation	1¼ in. (32 mm) Right Toe Pan
• Test Article Damage	Moderate
• Test Article Deflections	
Permanent Set	20⅛ in. (511 mm)
Dynamic	27.4 in. (696 mm)
Working Width	35.7 in. (906 mm)
• Maximum Angular Displacements (DTS)	
Roll	-11.2° < 75°
Pitch	-5.4° < 75°
Yaw	126.0°
• IS	58.97 kip-ft (80 kJ)
• Transducer Data	

Evaluation Criteria		Transducer			MASH Limit
		EDR-3	DTS set 1	DTS set 2	
OIV ft/s (m/s)	Longitudinal	-22.62 (-6.89)	-25.87 (-7.89)	-22.45 (-6.84)	≤ 40 (12.2)
	Lateral	-16.51 (-5.03)	-17.07 (-5.20)	-16.53 (-5.04)	≤ 40 (12.2)
ORA g's	Longitudinal	-9.94	-13.78	-10.25	≤ 20.49
	Lateral	-6.54	-7.81	-7.40	≤ 20.49
THIV – ft/s (m/s)		NA	30.10 (9.17)	NA	not required
PHD – g's		NA	14.55	NA	not required
ASI		0.74	0.92	0.78	not required

Figure 54. Schematic. Test Results and Sequential Photographs, Test No. MGSGW-1.



a. 0.000sec

b. 0.030 sec

c. 0.078 sec

d. 0.206 sec

e. 0.440 sec

f. 0.572 sec

g. 0.000sec

h. 0.076 sec

i. 0.138 sec

j. 0.404 sec

k. 0.586 sec

l. 1.092 sec

Figure 55. Photo. Additional Sequential Photographs, Test No. MGSGW-1.

a. 0.000sec

g. 0.000sec

b. 0.126 sec

h. 0.120 sec

c. 0.204 sec

i. 0.158 sec

d. 0.372 sec

j. 0.256 sec

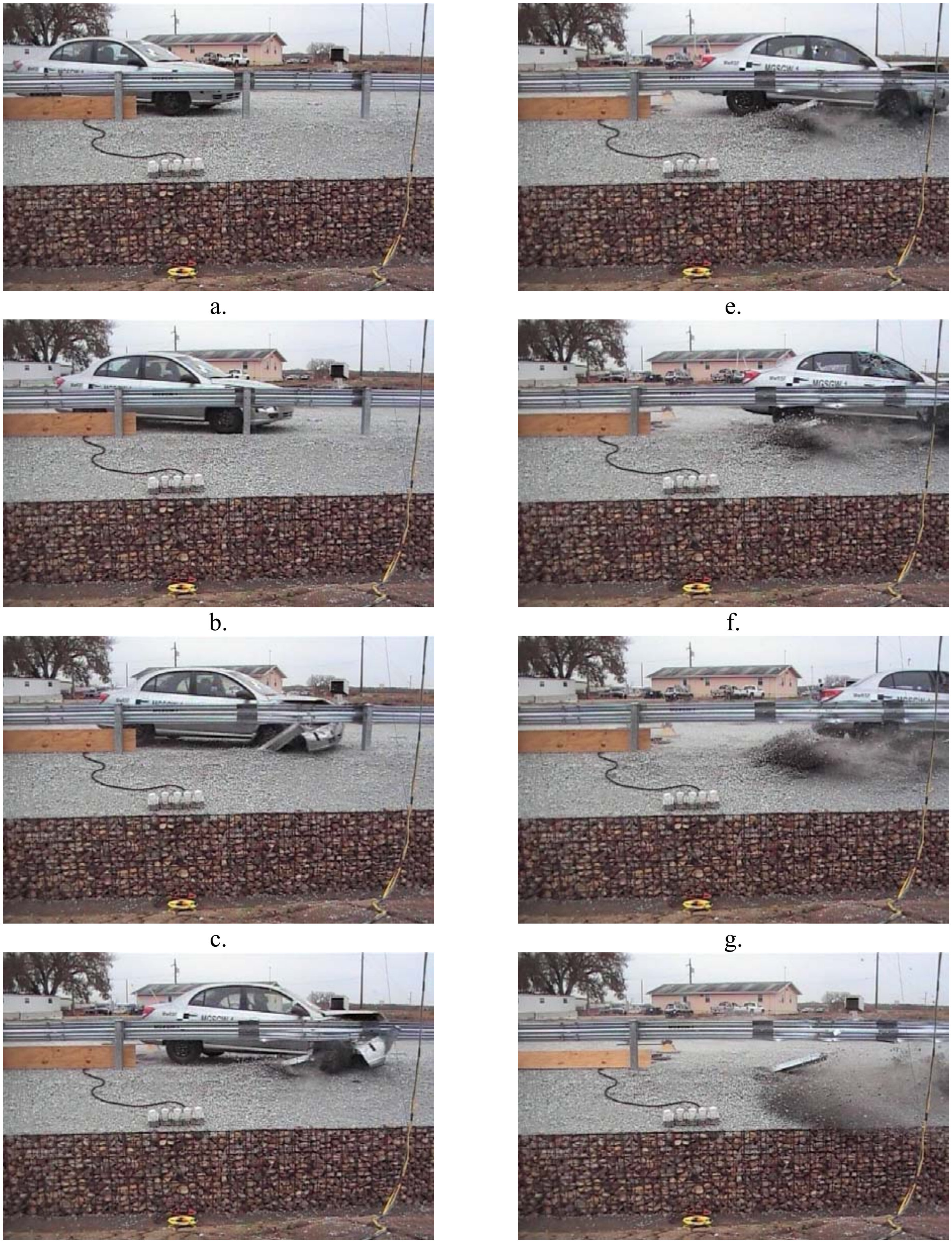
e. 0.574 sec

k. 0.306 sec

f. 1.252 sec

l. 0.492 sec

Figure 56. Photo. Additional Sequential Photographs, Test No. MGSGW-1.



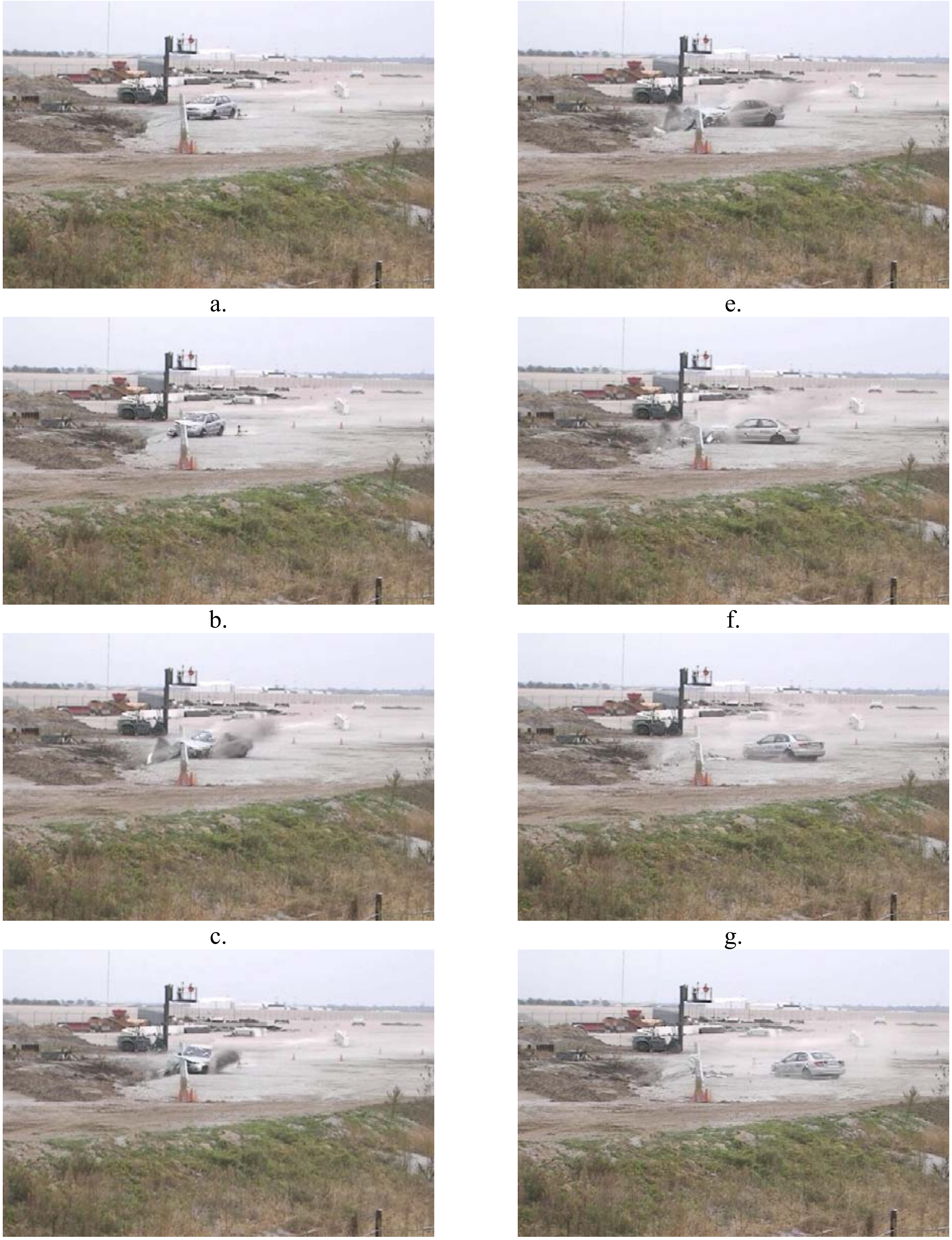
a. e.

b. f.

c. g.

d. h.

Figure 57. Photo. Documentary Photographs, Test No. MGSGW-1.



a.

b.

c.

d.

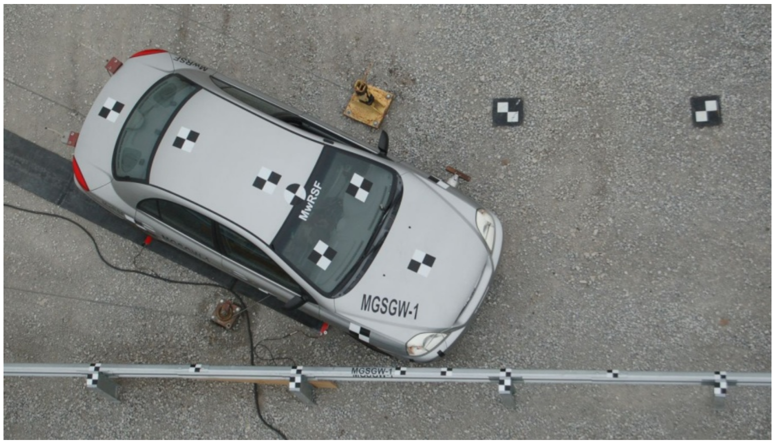
e.

f.

g.

h.

Figure 58. Photo. Documentary Photographs, Test No. MGSGW-1.



a. Impact Location, Overhead

b. Impact Location Upstream

c. Impact Location, Close-up

Figure 59. Photo. Impact Location, Test No. MGSGW-1.

a. Vehicle Final Position, Profile View

b. Vehicle Trajectory Marks

Figure 60. Photo. Vehicle Final Position and Trajectory Marks, Test No. MGSGW-1.

a. Vehicle Path View

b. Exit Trajectory View

c. Downstream View

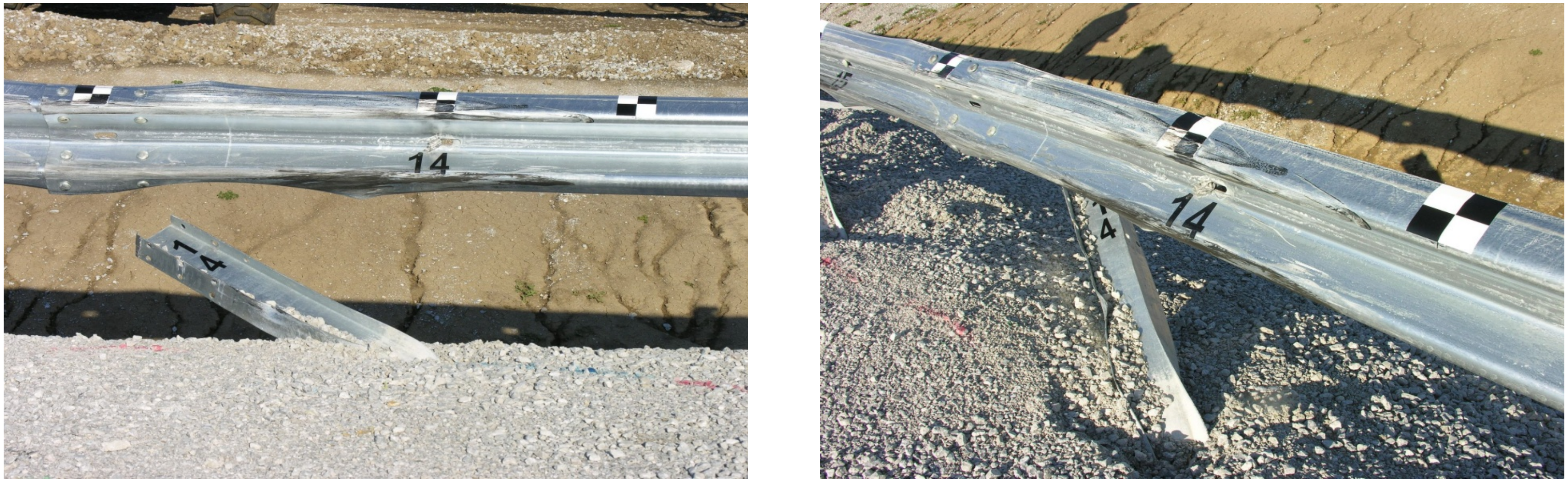
Figure 61. Photo. System Damage, Test No. MGSGW-1.

a. Permenant Set Deflection

b. Front Side

c. Back Side

Figure 62. Photo. System Damage, Test No. MGSGW-1.



a. Rail at Post No. 14, Front View

c. Rail at Post No. 14 Upstream Quarter View

b. Rail at Post No. Back View

d. Backing Plate at Post No. 14

Figure 63. Photo. System Damage, Test No. MGSGW-1.

a. Post No. 13, Front Side

c. Post No. 13, Upstream View

b. Post No. 14, Front Side

d. Post No. 14, Post Bolt Hole Tear

Figure 64. Photo. Post Nos. 13 and 14 Damage, Test No. MGSGW-1.

a. Post No. 15, Front View

c. Post No. 15, Rear View

b. Post No. 16, Downstream View

d. Post Nos. 15 and 16, Upstream View

Figure 65. Photo. Post Nos. 15 and 16 Damage, Test No. MGSGW-1.

a. Post Nos 17, Top Portion

c. Post No. 17, Entire Length

b. Post No. 18, Front View

d. Post No. 18, Rear View

Figure 66. Photo. Post Nos. 17 and 18 Damage, Test No. MGSGW-1.

a. Left Side

c. Right Side

b. Front

d. RearMGSGW-1

Figure 67. Photo. Vehicle Damage, Test No. MGSGW-1.

a. Impact Side Quarter View

b. Rail Interlock

c. Impact Side Wheel

Figure 68. Photo. Vehicle Damage, Test No. MGSGW-1.

a. Impact Side Suspension

b. Axel/Transmission Connection

c. Impact Side

Figure 69. Photo. Vehicle Undercarriage Damage, Test No. MGSGW-1.

a. Impact Side Firewall

b. Impact Side Tunnel

Figure 70. Photo. Vehicle Occupant Compartment Damage, Test No. MGSGW-1.

CHAPTER 10. FULL-SCALE CRASH TEST NO. MGSGW-2

10.1 TEST NO. MGSGW-2

The 5,169-lb (2,345-kg) pickup truck with a simulated occupant seated in the right fron seat, impacted the non-blocked MGS placed at the slope break point of the 3H:1V fill slope on top of a wire-faced, MSE wall at a speed of 65.3 mph (105.0 km/h) and at an angle of 25.1 degrees. A summary of the test results and sequential photographs are shown in Figure 71. Additional sequential photographs are shown in Figures 72 and 73. Documentary photographs of the crash test are shown in Figures 74 through 76.

10.2 WEATHER CONDITIONS

Test no. MGSGW-2 was conducted on November 20, 2009 at approximately 2:20 pm. The weather conditions as per the National Oceanic and Atmospheric Administration (station 14939/LNK) were reported and are shown in Table 14.

Table 14. Weather Conditions, Test No. MGSGW-2.

Temperature	53° F
Humidity	43%
Wind Speed	0 mph
Wind Direction	0° from True North
Sky Conditions	Sunny
Visibility	10 Statute Miles
Pavement Surface	Dry
Previous 3-Day Precipitation	0.00 in.
Previous 7-Day Precipitation	0.06 in.

10.3 TEST DESCRIPTION

Initial vehicle impact was to occur 16 ft (4.9 m) upstream of the splice between post nos. 14 and 15, as shown in Figure 77. The actual point of impact occurred at the target impact point. A sequential description of the impact events is shown in Table 15. The vehicle came to rest 103 ft - 4½ in. (31.5 m) downstream from impact and 16 ft - 3 in. (4.9 m) laterally in front of the barrier. The vehicle trajectory and final position are shown in Figures 71 and 78.

Table 15. Sequential Description of Impact Events, Test No. MGSGW-2.

TIME (sec)	EVENT
0.000	The right-front corner of the vehicle impacted the guardrail.
0.070	The rail separated from post no. 13. The vehicle rolled toward the barrier.
0.078	The right-front tire contacted post no. 13.
0.084	The vehicle began to redirect.
0.104	The right-rear tire contacted the guardrail at the target impact location.
0.108	The right-front door of the vehicle became ajar. The bolt on post no. 14 pulled through rail.
0.148	The right-front tire ruptured.
0.152	The front-right tire contacted post no. 14.
0.184	The left-rear tire became airborne.
0.190	The left-front tire became airborne.
0.230	The vehicle became parallel to the system with a velocity of 46.7 mph (75.2 km/h). The vehicle continued to yaw in the negative direction.
0.248	The right-front tire struck post no. 15.
0.252	The rail separated from post no. 15. The right-front wheel was disengaged from the vehicle.
0.398	The vehicle yawed back in the positive direction.
0.404	The right-rear tire contacted post no. 15 and became airborne.
0.452	The right side of the rear bumper lost contact with the rail at the midpoint between post nos. 14 and 15, and the vehicle exited the system at an angle of 20.4 degrees and a velocity of 43.8 mph (70.5 km/h).
0.700	The driveshaft made contact with the ground, and the vehicle continued to yaw in the negative direction.
0.748	The driveshaft folded and detached from the vehicle.
0.756	The left-front tire contacted the ground.
0.988	The left-front tire became airborne again.
1.168	The left-front tire contacted the ground again.
1.190	The left-rear tire contacted the ground.

10.4 BARRIER DAMAGE

Damage to the barrier was moderate, as shown in Figures 79 through 84. Barrier damage consisted of deformed guardrail posts, contact marks on the W-beam rail and guardrail posts, and deformed W-beam rail. The length of vehicle contact along the barrier was approximately 25 ft – 9½ in. (7.9 m), extending from 5 in. (127 mm) upstream of post no. 12 to 4½ in. (114 mm) downstream of post no. 16.

Contact marks were found on the W-beam rail between the impact location at 16 ft upstream of the splice between post nos. 14 and 15 through 4½ in. downstream of post no. 16. A buckle formed in the rail at 3 in. (76 mm) upstream of post no. 11. Flattening of the lower corrugation occurred from 4 in. (102 mm) downstream of post no. 12 through 20 in. (508 mm) upstream of post no. 14. The bottom of the rail folded from post no. 14 through 19 in. (483 mm) downstream of post no. 15. The rail disengaged from post nos. 13 through 16. Two tears were found in the bottom of the guardrail slots at post nos. 13 through 15, measuring 1½ in. (38 mm), 2¾ in. (70 mm), and 1¼ in. (32 mm), respectively. The splices between post nos. 12 and 13 and 14 and 15 were stretched ¼ in. (6.4 mm) and $^1/_{16}$ in. (1.6 mm), respectively.

Post nos. 3 through 10 twisted slightly downstream. Post no. 11 twisted downstream and rotated backward forming a 1-in. (25-mm) soil gap at the front face of the post. Post no. 12 rotated backward, and soil gaps of 4½ in. (114 mm) and 2 in. (51 mm) were found at the front and back faces of the post, respectively. Post no. 13 twisted and bent downstream. The upstream edge of the front flange of post no. 13 encountered local deformation and contact marks, and a sharp kink was found on the back flange. Post no. 14 was bent downstream, and its front flange encountered deformations and contact marks. Post no. 15 was bent downstream and had a 5-in. (127-mm) soil gap at its front flange. The tire of the vehicle came to rest on top of post no. 15. Post no. 16 rotated slightly upstream and had a 2¼-in. (57 mm) soil gap at its front face, and its front flange was slightly deformed near the top. The backup plate at post nos. 13 and 14 disengaged from the system. The remaining posts sustained no damage.

The permanent set of the barrier system is shown in Figure 79. The maximum lateral permanent set rail and post deflections were 22¼ in. (565 mm) at post no. 14 and 26¼ in. (667 mm) at post no. 13, respectively, as measured in the field. The maximum lateral dynamic rail and post deflections were 35.7 in (907 mm) at the midpoint of post nos. 13 and 14 and 35.7 in. (907 mm) at post no. 14, respectively, as determined from high-speed digital video analysis. The working width of the system was found to be 45.2 in. (1,148 mm).

10.5 VEHICLE DAMAGE

The damage to the vehicle was moderate, as shown in Figures 85 through 88. The maximum occupant compartment deformations as well as the deformation limits established in MASH for various regions of the occupant compartment are shown in Table 16. It should be noted that the MASH-established deformation limits were not violated. Complete interior occupant compartment deformations as well as other vehicle deformations, along with the corresponding locations, are provided in Appendix D.

The majority of the damage was concentrated on the right-front corner and the right side of the vehicle. The right-front wheel was detached, and the brake lines were cut. The right control arm was sheared off, and the upper A-arm was bent downward. Denting occurred to the inner right-front wheel well. The lower-right side of the front bumper was crushed upward, and the bumper sustained contact marks. The right-front quarter panel was crushed slightly inward, and the right headlight was fractured. The hood was slightly ajar, and cracking occurred along the right side of the grill. The right-front door was crushed inward at the lower hinge and slightly ajar. Crushing and scraping occurred along the entire lower length of the vehicle. The right-rear quarter panel and the bumper encountered denting and folding. The driveshaft was removed from the vehicle. The right-rear taillight was displaced, and the right side of the tailgate was slightly ajar. The left-rear wheel was detached. A 3-in. (76-mm) diameter bulge was found in the sidewall of the right-rear tire.

Table 16. Maximum Occupant Compartment Deformation by Location, Test No. MGSGW-2.

LOCATION	MAXIMUM DEFORMATION in. (mm)	MASH ALLOWABLE DEFORMATION in. (mm)
Wheel Well & Toe Pan	1 (25)	≤ 9 (229)
Floor Pan & Transmission Tunnel	¼ (6)	≤ 12 (305)
Side Front Panel (in Front of A-Pillar)	¼ (6)	≤ 12 (305)
Side Door (Above Seat)	1½ (38)	≤ 9 (229)
Side Door (Below Seat)	½ (13)	≤ 12 (305)
Roof	NA	≤ 4 (102)
Windshield	NA	≤ 3 (76)

10.6 OCCUPANT RISK

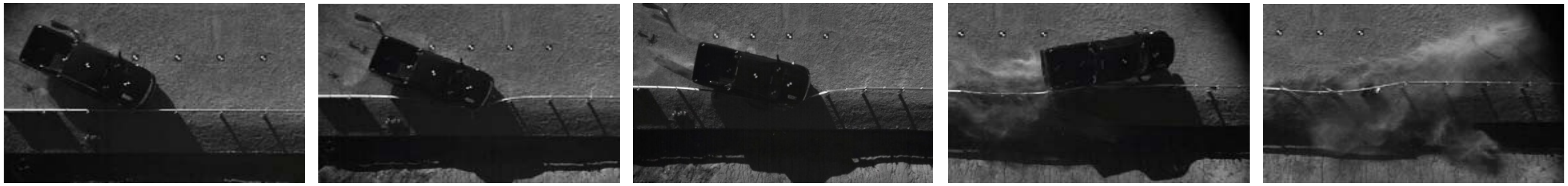
The calculated occupant impact velocities (OIVs) and maximum 0.010-sec occupant ridedown accelerations (ORAs) in both the longitudinal and lateral directions are shown in Table 17. It is noted that the OIVs and ORAs were within the suggested limits provided in MASH. The calculated THIV, PHD, and ASI values are also shown in Table 17. The results of the occupant risk analysis, as determined from the accelerometer data, are summarized in Figure 71. The recorded data from the accelerometers and the rate transducers are shown graphically in Appendix F.

Table 17. Summary of OIV, ORA, THIV, PHD, and ASI Values, Test No. MGSGW-2.

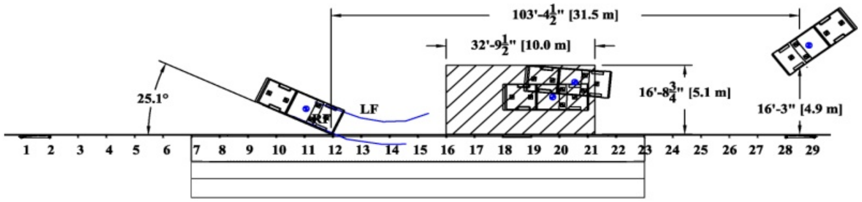
Evaluation Criteria		Transducer			MASH Limits
		EDR-3	DTS set 1	DTS set 2	
OIV ft/s (m/s)	Longitudinal	-17.25 (-5.26)	-17.85 (-5.44)	-16.91 (-5.15)	≤ 40 (12.2)
	Lateral	-17.71 (-5.40)	-18.26 (-5.57)	-17.56 (-5.35)	≤ 40 (12.2)
ORA g's	Longitudinal	-11.15	-11.99	-10.98	≤ 20.49
	Lateral	-8.76	-8.91	-10.37	≤ 20.49
THIV ft/s (m/s)		NA	24.1 (7.35)	NA	not required
PHD g's		NA	12.73	NA	not required
ASI		0.76	0.81	0.84	not required

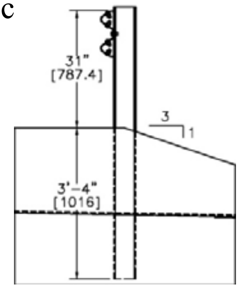
10.7 DISCUSSION

The analysis of the test results for test no. MGSGW-2 showed that the non-blocked MGS placed at the slope break point of the 3H:1V fill slope on top of a wire-faced, MSE wall adequately contained and redirected the 2270P vehicle with controlled lateral displacements of the barrier. 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 and remained upright during and after the collision. Vehicle roll, pitch, and yaw angular displacements were deemed acceptable because they did not adversely influence occupant risk safety criteria nor cause rollover. After impact, the vehicle exited the barrier at an angle of 20.4 degrees. The vehicle's trajectory violated the bounds of the exit box as it spun-out. However, the exit box criterion is preferable and not a requirement. Therefore, test no. MGSGW-2 (test designation no. 3-11) was determined to be acceptable according to the TL-3 MASH safety performance criteria.



0.000 sec 0.078 sec 0.152 sec 0.486 sec 0.92 sec





- Test Agency .... MwRSF
- Test Number MGSGW-2
- Date 11/20/2009
- MASH Test Designation 3-11
- Test Article .... MGS without blockouts on MSE wall with a 3:1 slope
- Total Length .... 175 ft (53.4 m)
- Key Component – Steel W-Beam
    - Thickness .... 12-gauge (2.66 mm)
    - Top Mounting Height .... 31 in. (787 mm)
- Key Component – Steel Posts
    - Post nos. 3-27 .... W6x8.5 (W152x12.6) by 6 ft (1.8 m) long
    - Post Location .... Centerline of posts at slope break point
    - Spacing .... 6 ft - 3 in. (1.9 m)
    - Blockouts .... None
- Key Component – Wood Posts
    - Post nos. 1-2, 28-29 .... 5½ by 7½ by 46 in. long (140x191x1,186 mm)
- Key Component – Foundation Tube .... 6 ft (1.8 m) long
- Soil Type .... NCHRP No. 350 Strong Soil
- Vehicle Model .... 2003 Dodge Ram 1500 Quad Cab
    - Curb .... 5,081 lb (2,305 kg)
    - Test Inertial .... 4,999 lb (2,268 kg)
    - Gross Static .... 5,169 lb (2,345 kg)
- Impact Conditions
    - Speed .... 65.3 mph (105.0 km/h)
    - Angle .... 25.1 deg
    - Impact Location .... 16 ft (4.9 m) US of splice btwn posts 14 and 15
- Exit Conditions
    - Speed .... 43.8 mph (70.5 km/h)
    - Angle .... 20.4 deg
    - Exit Box Criteria .... Fail (Not required)
- Vehicle Stability .... Satisfactory
- Vehicle Stopping Distance .... 103 ft - 4 ½ in.(31.5 m) downstream
  16 ft - 3 in. (4.9 m) laterally in front of traffic-side face
- Vehicle Damage .... Moderate
    - VDS[29] 1-RFQ-3
    - CDC[30] 01-RDEW2
    - Maximum Interior Deformation .... 1 1/4 in. (32 mm) right toe pan
- Test Article Damage .... Moderate
- Test Article Deflections
    - Permanent Set .... 26¼ in. (667 mm)
    - Dynamic .... 35.7 in. (907 mm)
    - Working Width .... 45.2 in. (1,148 mm)
- Maximum Angular Displacements (DTS)
    - Roll .... 16.4 deg <75º
    - Pitch .... -15.7 deg <75º
    - Yaw .... 38.0 deg
- IS .... 132.3 kip-ft (180 kJ)
- Transducer Data

Evaluation Criteria		Transducer			MASH Limit
		EDR-3	DTS set 1	DTS set 2	
OIV ft/s (m/s)	Longitudinal	-17.25 (-5.26)	-17.85 (-5.44)	-16.91 (-5.15)	≤ 40 (12.2)
	Lateral	-17.71 (-5.40)	-18.26 (-5.57)	-17.56 (-5.35)	≤ 40 (12.2)
ORA g's	Longitudinal	-11.15	-11.99	-10.98	≤ 20.49
	Lateral	-8.76	-8.91	-10.37	≤ 20.49
THIV – ft/s (m/s)		NA	24.1 (7.35)	NA	Not required
PHD – g's		NA	12.73	NA	Not required
ASI		0.76	0.81	0.84	Not required

Figure 71. Schematic. Test Results and Sequential Photographs, Test No. MGSGW-2.

a. 0.000 sec

b. 0.048 sec

c. 0.086 sec

d. 0.152 sec

e. 0.276 sec

f. 0.576 sec

g. 0.000 sec

h. 0.054 sec

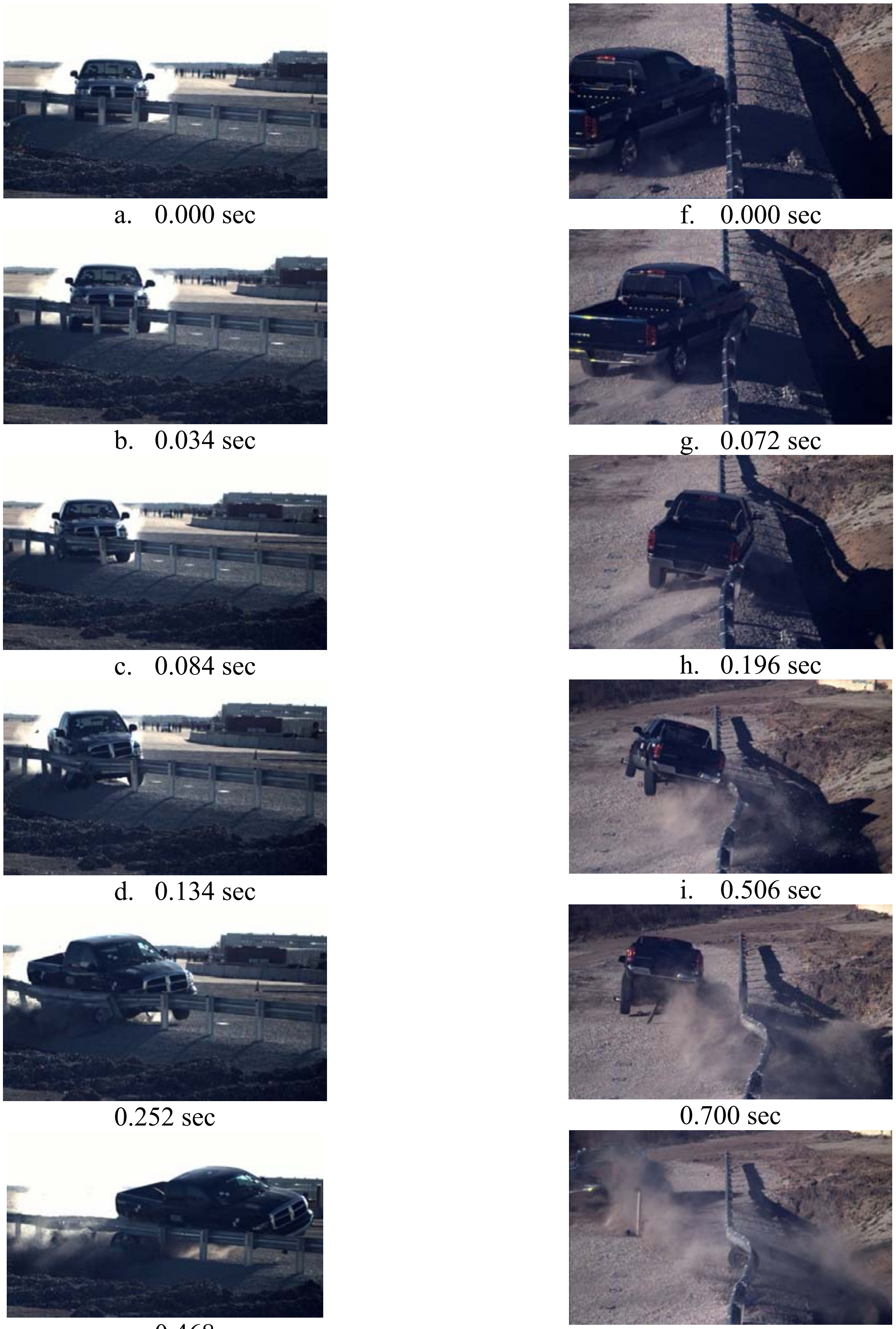
i. 0.152 sec

j. 0.248 sec

k. 0.756 sec

l. 0.826 sec

Figure 72. Photo. Additional Sequential Photographs, Test No. MGSGW-2.



a. 0.000 sec

b. 0.034 sec

c. 0.084 sec

d. 0.134 sec

0.252 sec

e. 0.468 sec

f. 0.000 sec

g. 0.072 sec

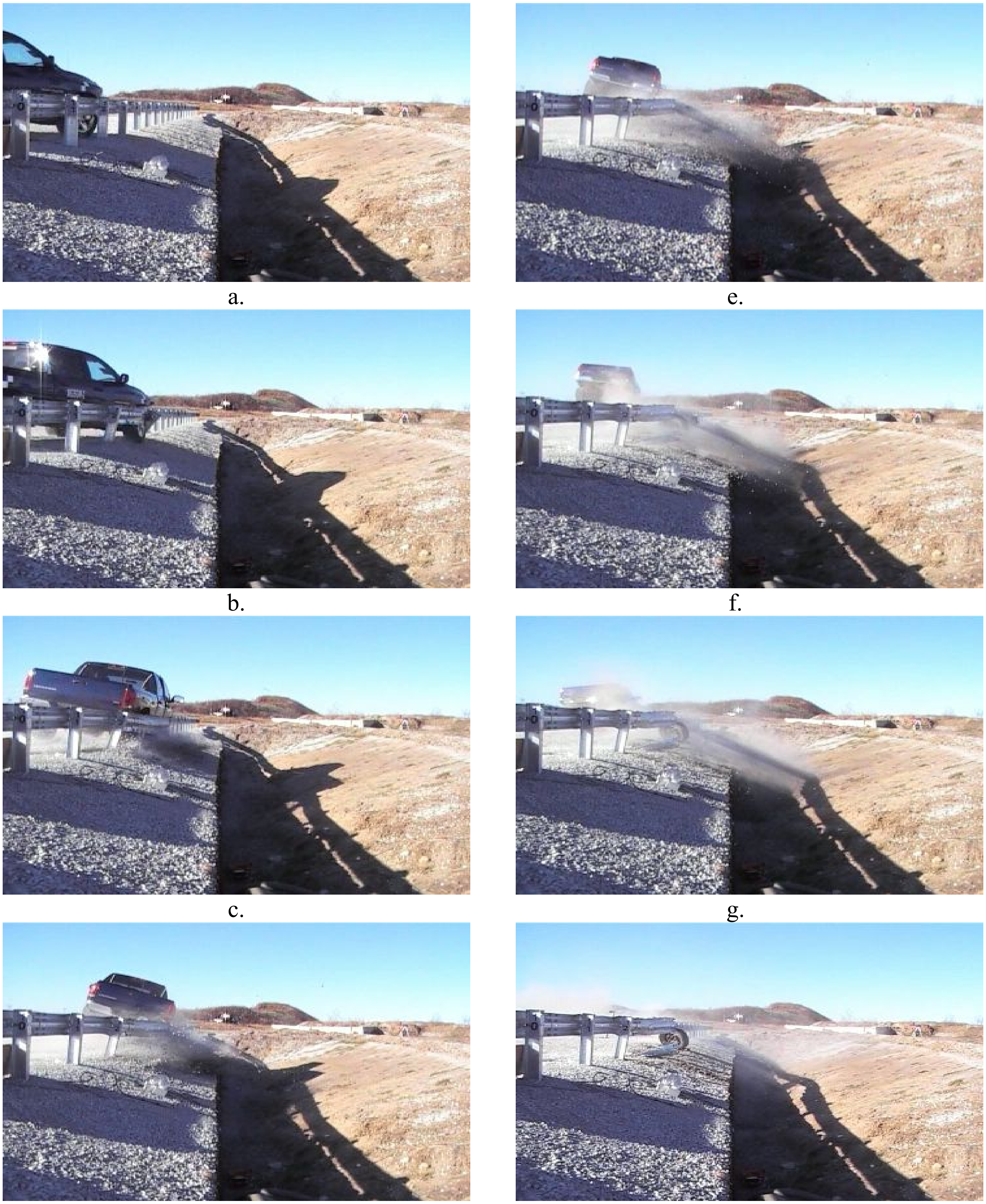
h. 0.196 sec

i. 0.506 sec

0.700 sec

j. 1.190 sec

Figure 73. Photo. Additional Sequential Photographs, Test No. MGSGW-2.



a. e.

b. f.

c. g.

d. h.

Figure 74. Photo. Documentary Photographs, Test No. MGSGW-2.

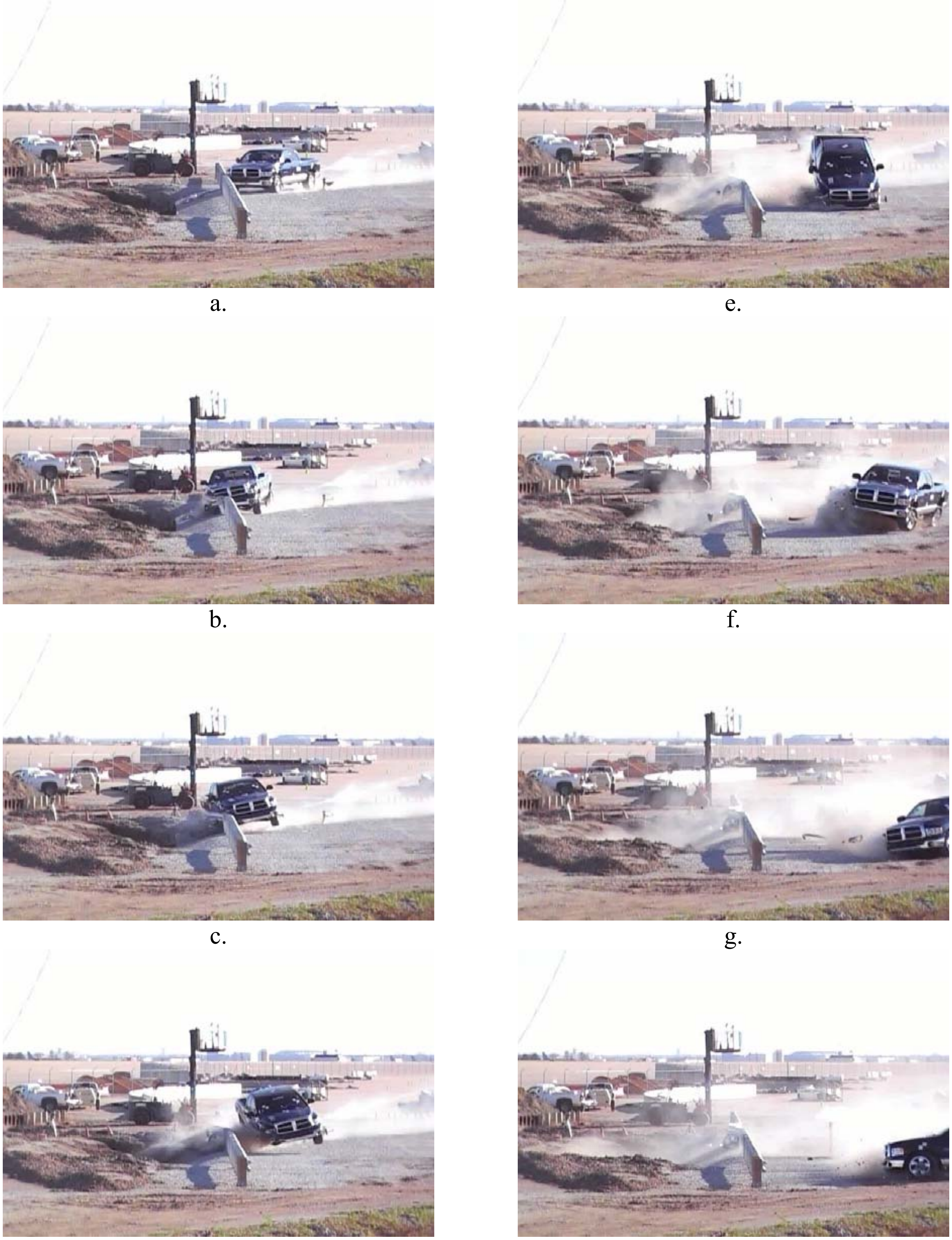
a. e.

b. f.

c. g.

d. h.

Figure 75. Photo. Documentary Photographs, Test No. MGSGW-2.



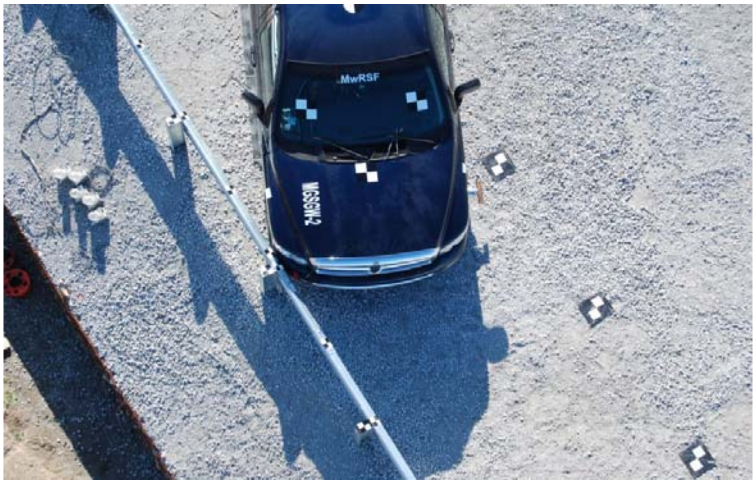
a. e.

b. f.

c. g.

d. h.

Figure 76. Photo. Documentary Photographs, Test No. MGSGW-2.



a. Overhead

b. Upstream View

c. Closeup View

Figure 77. Photo. Impact Location, Test No. MGSGW-2.

a. Vehicle Final Position

b. Broad View

Figure 78. Photo. Vehicle Final Position and Trajectory Marks, Test No. MGSGW-2.

a. Downstream Inline View

b. Upstream Inline View

c. Front View

Figure 79. Photo. System Damage, Test No. MGSGW-2.

a. Impacted Rail

c. Impacted Rail, Front Quarter View

b. Impacted Rail Rear View

d. Wheel Lodged Under Rail

Figure 80. Photo. System Damage, Test No. MGSGW-2.

a. Post No. 11 Top View

c. Post No. 11 Rear View

b. Post No. 12 Upstream View

d. Post No. 12 Downstream View

Figure 81. Photo. Post Nos. 11 and 12 Damage, Test No. MGSGW-2.

a. Post No. 13 Front View

c. Post No. 13 Rear View

b. Post No. 14 Front View

d. Post No. 14 Rear View

Figure 82. Photo. Post Nos. 13 and 14 Damage, Test No. MGSGW-2.

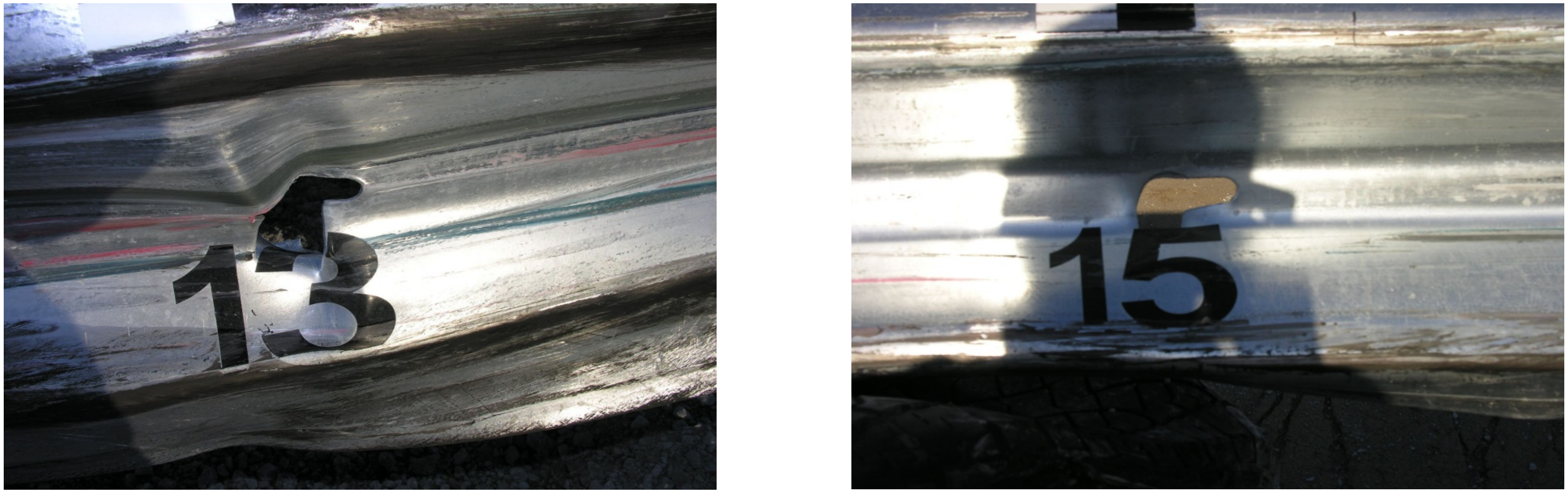
a. Post No. 15 Upstream View

c. Post No. 15 Front View

b. Post No. 16 Rear View

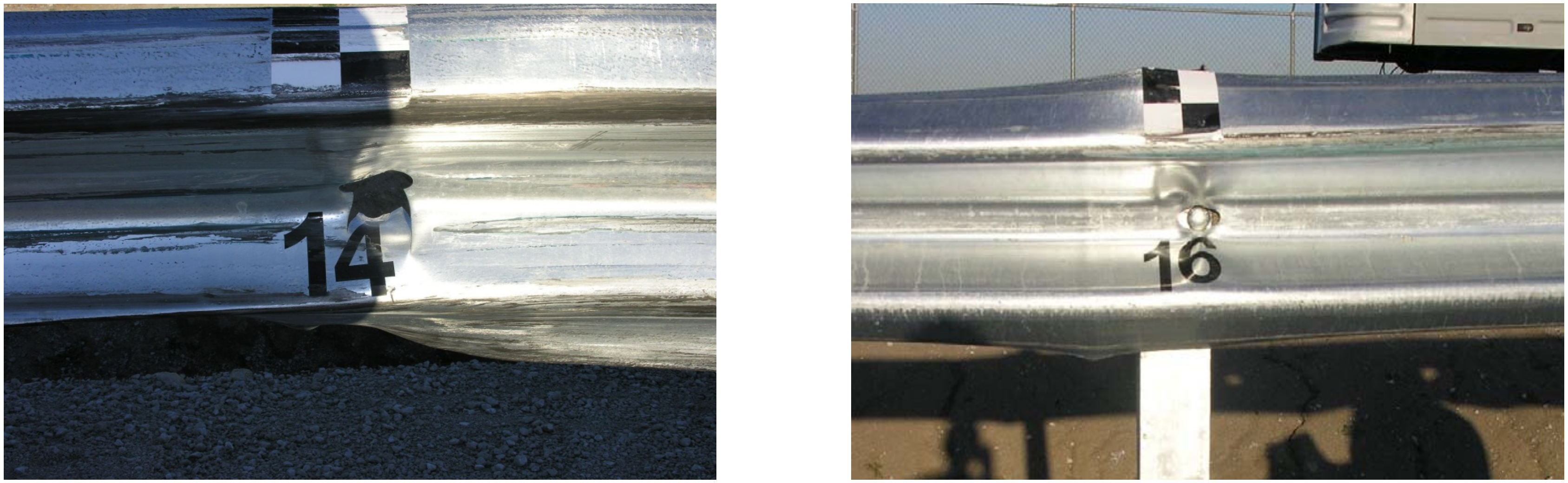
d. Post No. 16 Upstream View

Figure 83. Photo. Post Nos. 15 and 16 Damage, Test No. MGSGW-2.



a. Post No. 13

c. Post No. 15



b. Post No. 14

d. Post No. 16

Figure 84. Photo. Post Bolt Location Rail Damage Photographs, Test Nos. MGSGW-2.

a. Right Side

c. Left Side

b. Front

d. Rear

Figure 85. Photo. Vehicle Damage, Test No. MGSGW-2.

a. Right Side Bumper and Wheel Well

b. Right Side Rear Quarter

c. Left Quarter

Figure 86. Photo. Vehicle Damage, Test No. MGSGW-2.

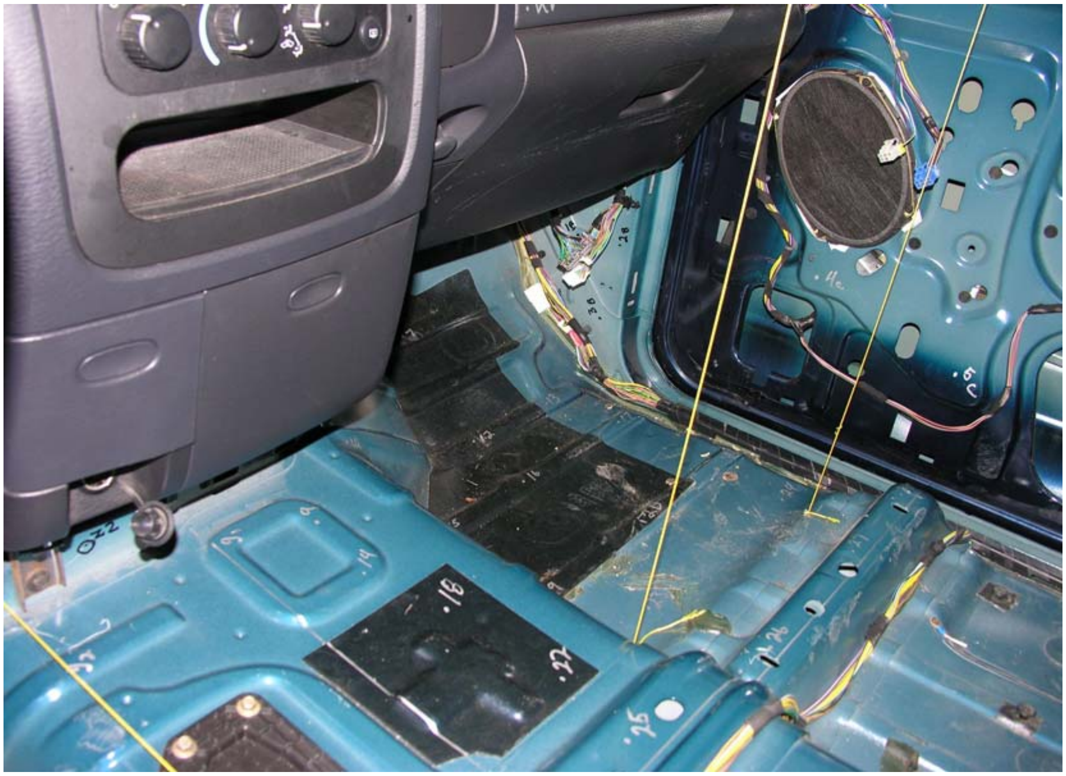
a. Rear Axle/Suspension

b. Drive Shaft

c. Right Side Suspension

Figure 87. Photo. Vehicle Undercarriage Damage, Test No. MGSGW-2.

a. Impact Side Floorboard



b. Impact Side Door

Figure 88. Photo. Vehicle Occupant Compartment Damage, Test No. MGSGW-2.

CHAPTER 11. SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

A design review, cost comparison, and evaluation was performed on selected barrier concepts for consideration in protecting hazardous conditions that arise from the construction of wire-faced, MSE wall systems. After eliminating general concepts that utilized deeply-embedded reinforced concrete foundations and long, sloped tension elements, five barrier concepts remained for further investigation and analysis. During the evaluation process, a cost comparison was made between different barrier types as well as on the effect of their use in the construction of wire-faced, MSE walls. From this effort, a non-blocked MGS with steel posts placed at the slope break point of a 3H:1V fill slope (Concept no. 4) was found to provide the greatest net cost reduction, or $158/ft, when compared to the baseline configuration of standard MGS with steel posts and a 2-ft (610-mm) lateral offset to the slope break point (Concept no. 1). Based on the cost analysis and system comparison, the CFLHD-MwRSF project team selected Concept no. 4 for further development and consideration for protecting vertical drop-offs associated with wire-faced, MSE walls.

During this study, a significant dynamic bogie testing program was conducted to determine the post-soil behavior of steel and wood posts embedded in level and/or sloped terrain using a compacted soil material similar to that used for the construction of wire-faced, MSE walls. This post testing program was also used to evaluate different post placement methods, such as the auger, backfill, and tamp method versus driven posts, as well as to select the appropriate post length, determine the preferred post material, and evaluate the propensity for damage to occur to wire-faced, MSE walls during vehicular impacts into the barrier system. A total of 26 dynamic bogie tests were performed and are described in detail in an MwRSF research report.[23] From this effort, a 6-ft (1.8-m) long steel guardrail post with a 40-in. (1,016-mm) embedment depth was selected for use in the MGS when located at the slope break point of a 3H:1V fill slope. A 6-ft (1.8-m) long steel guardrail post embedded into a roller-compacted, special MSE wall fill material, driven through the upper wire-mesh layer, and placed at the slope break point, was found to provide adequate post-soil resistance for use in the MGS. In addition, dynamic component testing of steel posts driven at the slope break point did not reveal any concerns for damage to the wire-faced, MSE wall system.

Following the dynamic component testing effort, a non-blocked version of the MGS was developed for use with a wire-faced, MSE wall system. The modified MGS utilized 6-ft (1.8-m) long steel posts spaced on 75 in. (1,905 mm) centers, a top mounting height of 31 in. (787 mm) for the W-beam rail, and steel W-beam backup plates at the steel post locations. The 12-in. (305-mm) deep wood spacer or offset blocks were not utilized in this barrier system.

The non-blocked MGS was successfully crash tested using both the 1100C small car and 2270P pickup truck vehicles according to TL-3 safety performance guidelines provided in MASH, as shown in Table 18. After the first full-scale crash test, the deformed posts were removed from the wire-faced, MSE wall. Subsequently, the soil region surrounding the locations of the damaged posts were filled with soil and recompacted. Then, new steel posts were driven into the wire-faced, MSE wall at the slope break point in order to repair the MGS and for use in the second full-scale crash test. **Following both crash tests, no damage was observed in the wire-**

Table 18. Summary of Safety Performance Evaluation Results.

<table>
<tr><th>Evaluation Factors</th><th colspan="2">Evaluation Criteria</th><th>Test No. MGSGW-1 (1100C Test)</th><th>Test No. MGSGW-2 (2270P Test)</th></tr>
<tr><td>Structural Adequacy</td><td>A.</td><td>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.</td><td>S</td><td>S</td></tr>
<tr><td rowspan="4">Occupant Risk</td><td>D.</td><td>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 MASH.</td><td>S</td><td>S</td></tr>
<tr><td>F.</td><td>The vehicle should remain upright during and after collision. The maximum roll and pitch angles are not to exceed 75 degrees.</td><td>S</td><td>S</td></tr>
<tr><td>H.</td><td>Occupant Impact Velocity (OIV) (see Appendix A, Section A5.3 of MASH for calculation procedure) should satisfy the following limits:
<table>
<tr><th colspan="3">Occupant Impact Velocity Limits, ft/s (m/s)</th></tr>
<tr><th>Component</th><th>Preferred</th><th>Maximum</th></tr>
<tr><td>Longitudinal and Lateral</td><td>30 ft/s (9.1 m/s)</td><td>40 ft/s (12.2 m/s)</td></tr>
</table></td><td>S</td><td>S</td></tr>
<tr><td>I.</td><td>The Occupant Ridedown Acceleration (ORA) (see Appendix A, Section A5.3 of MASH for calculation procedure) should satisfy the following limits:
<table>
<tr><th colspan="3">Occupant Ridedown Acceleration Limits (g’s)</th></tr>
<tr><th>Component</th><th>Preferred</th><th>Maximum</th></tr>
<tr><td>Longitudinal and Lateral</td><td>15.0 g’s</td><td>20.49 g’s</td></tr>
</table></td><td>S</td><td>S</td></tr>
</table>

S – Satisfactory U – Unsatisfactory NA - Not Applicable

faced, MSE wall system for the backside of the steel posts positioned 5 ft – 9 in. (1.75 m) away from the MSE wall's outer face.

Based on the research program described herein, the non-blocked MGS (Concept no. 4) is recommended for use on top of wire-faced, MSE walls when the centerline of the steel posts are placed at the slope break point of a 3H:1V fill slope. Under this scenario and as previously shown in Figure 10, the face of the W-beam rail would be positioned approximately 6 ft – 6¼ in. (1.99 m) away from the outer edge of the wire-faced, MSE wall when assuming a 2-ft (0.6 m) fill height – 1 ft (0.3 m) normal layer thickness of select wall backfill and 1 ft (0.3 m) thick combined layer for wearing surface and road base material. The current FHLD accepted practice, as depicted in Figure 3, is to install the face of conventional, wood-post W-beam guardrail 9 ft – 7¼ in. (2.93 m) away from the exterior face of the MSE wall when assuming a 2-ft (0.6–m) level surface behind the posts, an adjacent 3H:1V fill slope, and a 2-ft (0.6-m) fill height for the road base and wearing surface. Therefore, the implementation of the new TL-3 barrier system would provide at least a 3 ft - 1 in. (0.94 m) reduction in the required width of the wire-face, MSE wall. Thus, the non-blocked, steel post MGS provides (1) an economical and practical barrier alternative for use on wire-faced, MSE walls, (2) satisfactory vehicle containment under the TL-3 MASH impact conditions, (3) reduces the required width of the wire-faced, MSE wall structure with the elimination of a timber blockout and removal of the 2-ft (0.6-m) wide level terrain behind the posts, and (4) results in decreased construction and material costs for the overall wire-faced, MSE wall and barrier systems.

As noted above, the non-blocked MGS was successfully crash tested with the back side of the steel posts positioned approximately 2 ft – 9 in. (0.84 m) away from the inside edge of the wall facing fill or 5 ft – 9 in. (1.75 m) away from the outer edge of the wire-faced, MSE wall. For this baseline configuration, the steel posts were driven into the select wall backfill. During the 2270P crash test (test no. MGSGW-2), the maximum dynamic barrier deflection was observed to be 35.7 in. (907 mm). In addition, no damage was observed in the MSE wall structure during either of the MASH crash tests. Following the successful crash testing program on the finalized configuration (Concept No. 4), as shown in Figure 10, the researchers believed that the non-blocked MGS should be capable of safely containing and redirecting the 2270P pickup truck under TL-3 impact conditions when positioned closer than the 5-ft 9-in. (1.75-m) lateral offset to the outer edge of the MSE wall.

Due to the presence of the special compaction zone consisting of larger rocks (i.e., wall facing fill), it is impossible to drive steel posts 3 ft (0.91 m) laterally away from the outer MSE wall edge. This assertion comes from field results obtained from the post-soil testing program as well as a general concern for mitigating damage to the MSE wall. Therefore, it was deemed necessary to establish a minimum lateral offset between the backside of the steel posts and the rock boundary (i.e., inside edge of the wall facing fill) to address these concerns. Further, any minimum design guidelines should consider the situation where the wall facing fill width may slightly exceed 3 ft (0.91 m).

Recall, the non-blocked, steel post MGS performed in an acceptable manner when backside face was positioned 2-ft 9 in. (0.84 m) laterally away from the inside face of the wall facing fill. When possible, it would seem reasonable to accommodate this lateral barrier offset. However, special scenarios will occur in actual field installations in which this lateral barrier offset will not be available. Therefore, the recommended minimum lateral barrier offset should be 1 ft (0.3 m) between the back side of post to inside edge of the wall facing fill or 4 ft (1.22 m) between back side of post to outer edge of the MSE wall, whichever results in greater lateral offset between the post and exterior wall surface. For high-energy, vehicular impact events, this minimum lateral placement recommendation would provide the most economical barrier system and MSE wall configuration, assure adequate safety performance, and mitigate concerns for damage to the MSE wall structure.

For this minimum placement recommendation, the lateral offset between the rail face and outer edge of the MSE wall would be 4 ft - 9¼ in. (1.45 m). For varying thicknesses of select wall backfill and different widths for the 3H:1V fill slope, three different configurations were prepared to demonstrate the recommended minimum lateral barrier offset for the steel posts, as shown in Figures 89 through 91. When the non-blocked, steel-post MGS is installed using the minimum lateral barrier offset, the maximum width reduction for the wire-faced, MSE wall would increase from 3 ft - 1 in. (0.94 m) to 4 ft - 10 in. (1.47 m) if compared to the current FLHD guidance, thus providing even greater economic benefit at the TL-3 impact conditions.

As noted above and for TL-3 applications, the non-blocked, steel post MGS was constructed, tested, and evaluated with the front face of the W-beam rail positioned approximately 6 ft – 6¼ in. (1.99 m) away from the outer edge of the wire-faced, MSE wall. Based on the successful safety performance evaluations of the two crash tests, the observed dynamic barrier deflections, and the configuration of the MSE wall, the non-blocked MGS can also be installed with the rail face approximately 4 ft - 9¼ in. (1.45 m) away from the outer edge of the MSE wall system and still meet TL-3 impact safety standards.

Under TL-2 impact conditions, dynamic rail deflections for the non-blocked MGS would be reduced from those observed under TL-3 impact conditions. As such, the recommended barrier placement for TL-2 conditions could conservatively utilize the minimum lateral barrier offset of 4 ft – 9¼ in. (1.45 m) which was noted for TL-3 conditions. However, TL-2 post deflections near the ground line may be smaller than those deflections observed during comparable TL-3 impact events. As a result and under TL-2 impact conditions, a 6-in. (152-mm) lateral barrier shift toward the outer MSE wall edge may be considered. Under this more aggressive scenario, the rail face would be positioned approximately 4 ft – 3¼ in. (1.30 m) away from the wire-faced, MSE wall. Of course, this modified TL-2 barrier placement could result in increased risk for damage to the MSE wall structure as well as reduced constructability in driving steel posts if the wall facing fill (i.e., layer of larger stones) extends beyond the common width of 3 ft (0.91 m).

The roller-compacted soil fill material and mesh reinforcement within the wire-faced, MSE wall system provided a stiff foundation for the driven, steel guardrail posts. This finding was made upon review of the post-soil responses observed in selected dynamic bogie tests as well as from the barrier deflections and working widths observed during the full-scale crash testing program reported herein. From the successful MASH crash testing program reported herein, it is the researcher's opinion that a non-blocked MGS would also perform satisfactorily when installed in standard soil placed on level terrain. However, the safety performance of a non-blocked MGS installed on level terrain can only be verified through full-scale crash testing.

Previously, it has been demonstrated that wood blockouts used in combination with the MGS greatly increases barrier capacity, reduces occupant risk, and improves the vehicle post-impact trajectory. Thus, the researchers recommend that 12-in. (305-mm) deep wood spacer blocks, or acceptable alternatives, be used with the MGS when the roadside geometry can accommodate a guardrail system with increased width.

Concrete curbs or asphalt dikes often provide drainage control at the edge of roadway or shoulder. Occasionally, curbs and vehicular barrier systems are both required along the roadside. For these circumstances, it is necessary to ensure that the combination curb and guardrail system meets current impact safety standards. Therefore, if curbs are required on MSE wall structures, it is recommended that the steel post MGS be installed with wood blockouts, or other acceptable alternatives.

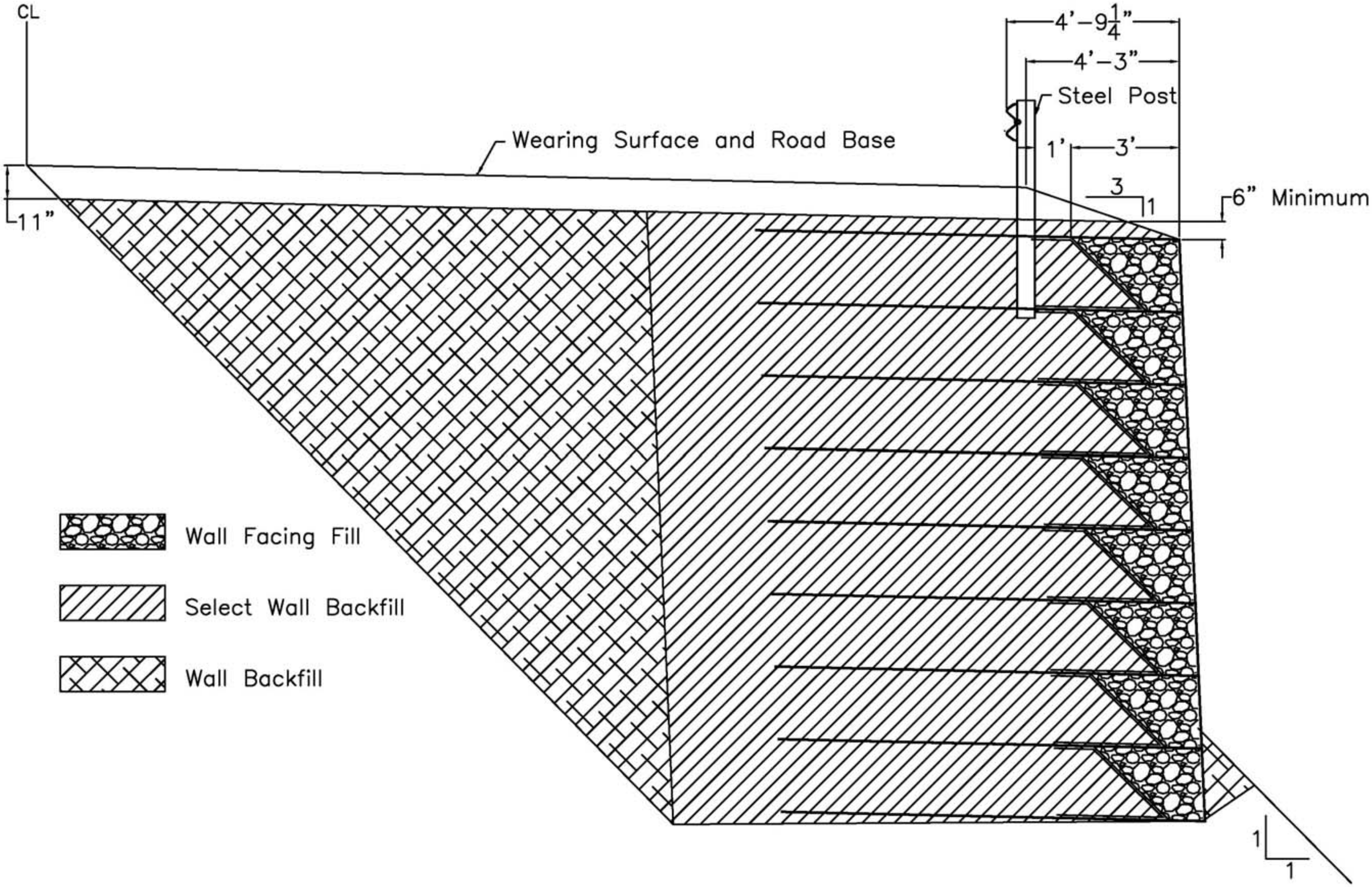


Figure 89. Schematic. Non-Blocked, Steel-Post MGS Centered at Slope Break Point with Minimum Lateral Offset.

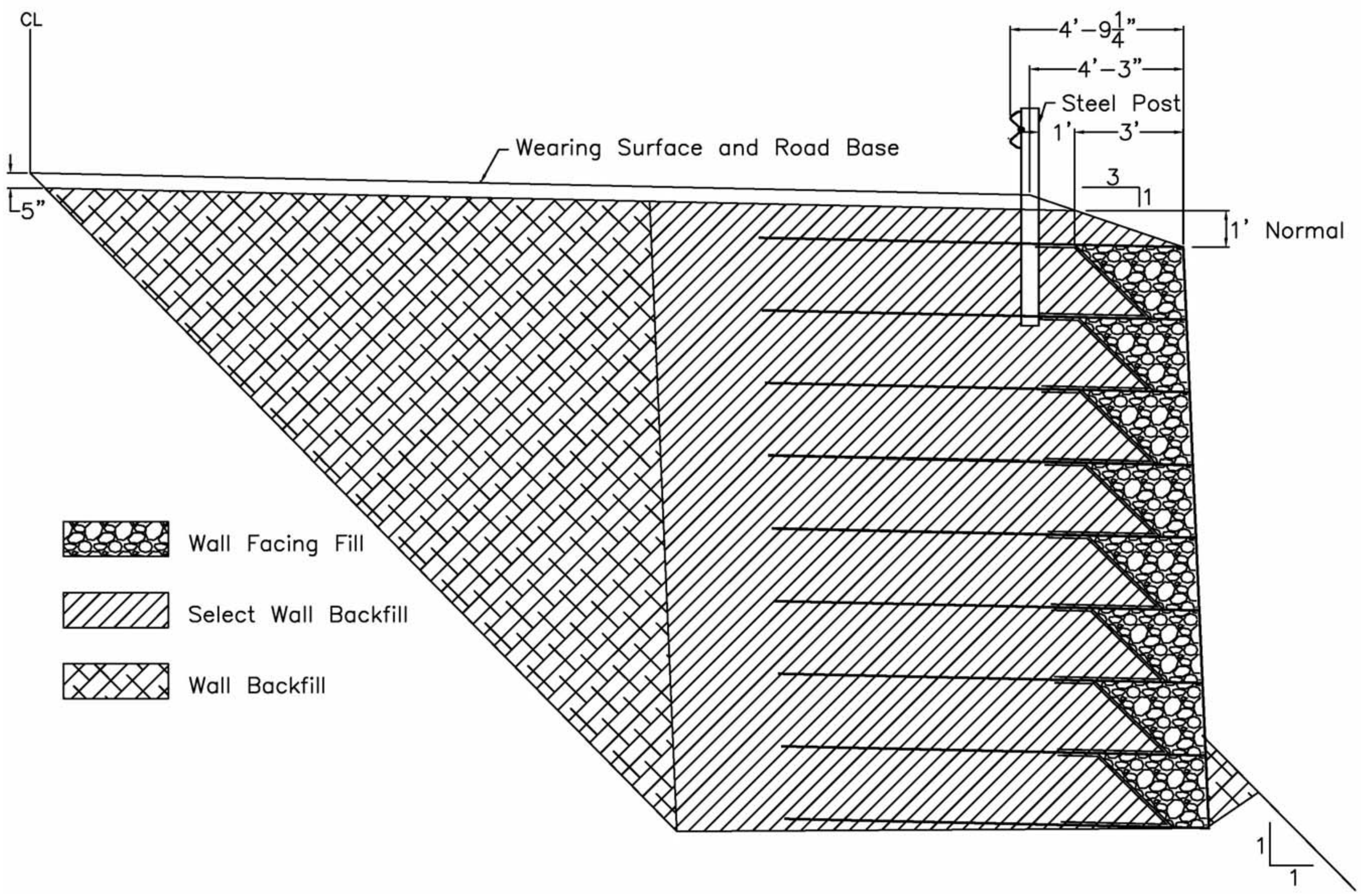


Figure 90. Schematic. Non-Blocked, Steel-Post MGS Centered at Slope Break Point with Minimum Lateral Offset.

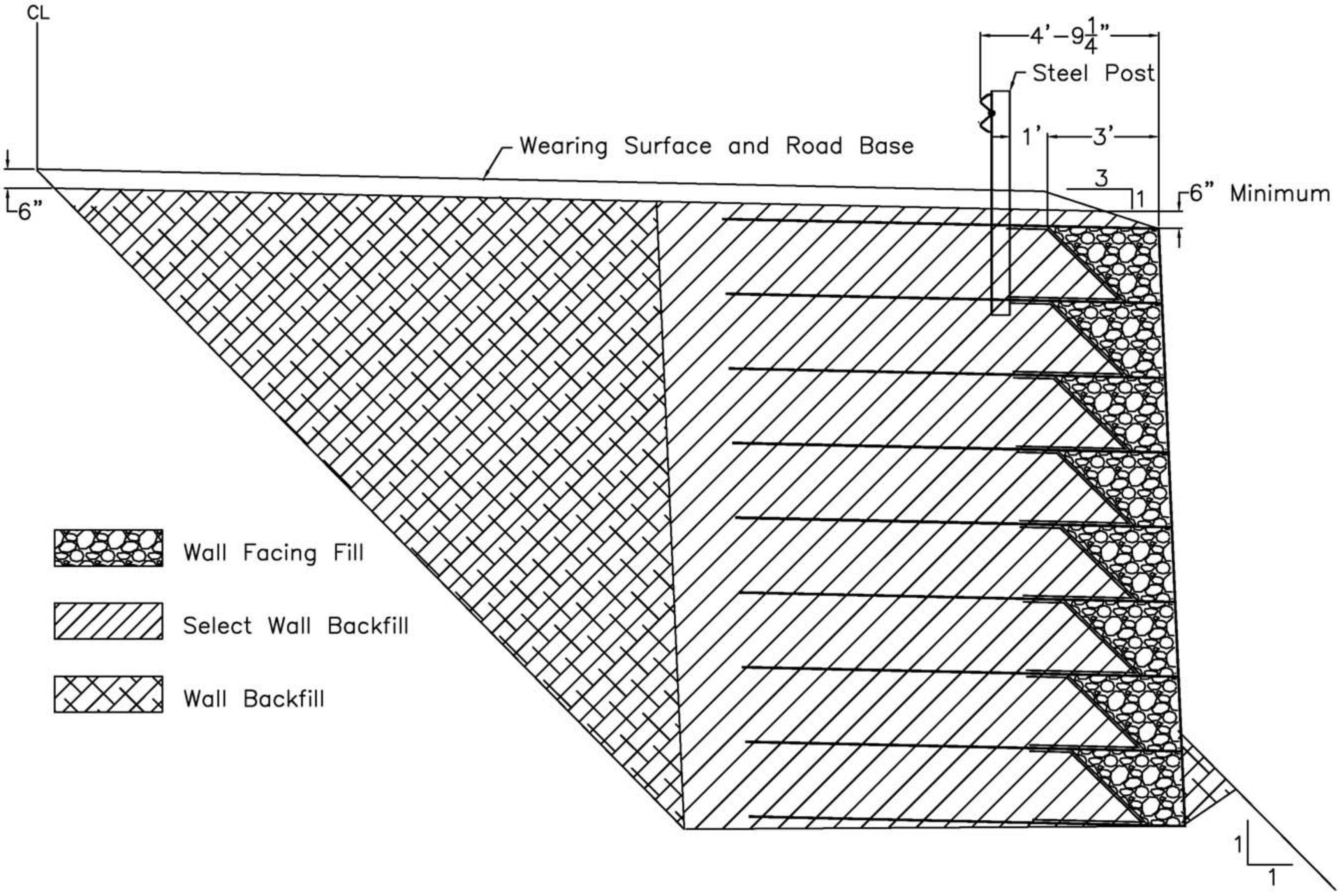


Figure 91. Schematic. Non-Blocked, Steel-Post MGS with Minimum Lateral Offset.

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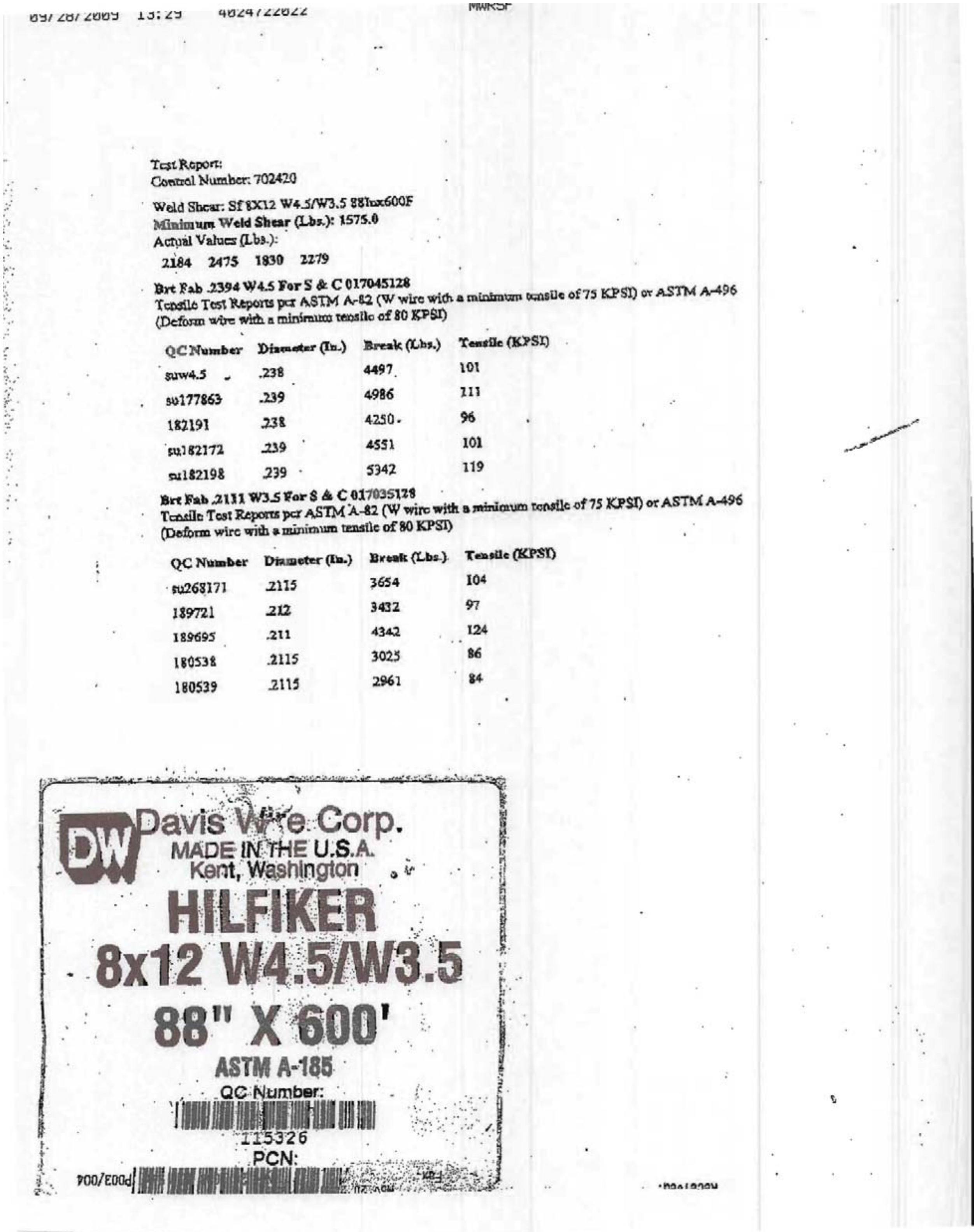
APPENDIX A. MATERIAL SPECIFICATIONS

The material specifications for the critical components in the system are contained in this appendix.

Item No.	QT Y.	Description	Material Specifications and/or Grade	heat #	Hardware Guide
-	-	Wall Facing Fill	Wall Face Aggregate, 4-6 in. Rock	10843/11046	-
a1	11	Cap Mat	8 x 12" Steel Mesh, 3 Gauge	737960	-
a2	10	Prongless Mat	8 x 12" Steel Mesh, 3 Gauge	737960	-
a3	20	Backing Mat	8 x 3" Steel Mesh, 3 Gauge	737960	-
a4	10	Standard Mat	8 x 10" Steel Mesh, 3 Gauge	737960	-
a5	180	Hog Rings	-	na	-
a6	-	Filter Fabric	-	na	-
b1	25	W6x8.5 x 6' long [W152x12.6, 2134 long] Steel Post	ASTM A36 [36 ksi] (W6x9 A992 [50 ksi])	Posts 2-6(Uncert), Posts 7-27(002)	-
b2	1	6'-3" [1905] W-Beam Section	12 ga. [2.7] AASHTO M180	111813	RWM01a
b3	14	12'-6" [3810] W-Beam MGS Section	12 ga. [2.7] AASHTO M180	4614	RWM04a
b4	2	12'-6" [3810] W-Beam MGS End Section	12 ga. [2.7] AASHTO M180	4614	-
b5	4	5/8" [15.9] Dia. x 10" [254] long Guardrail Bolt and Nut	ASTM A307	7261611/545770	FBB03
b6	137	5/8" [15.9] Dia. x 1 1/2" [38] Guardrail Bolt and Nut	ASTM A307	7366484/545770	FBB01
b7	44	5/8" [15.9] Dia. Flat Washer	ASTM A153	COC	FWC16a
b8	25	W-Beam Backup Plate	12 ga. [2.7] AASHTO M180	4614, 3390	RWB01a
c1	4	BCT Timber Post - MGS Height	SYP Grade No. 1 or better	9999	PDF01
c2	4	72" [1829] Foundation Tube	ASTM A53 Grade B	Y85912	PTE06
c3	2	Strut and Yoke Assembly	ASTM A36 Steel Galvanized	COC	-
c4	2	5x8x5/8" [127x203x15.9] Anchor Bearing Plate	ASTM A36 Steel	6106195	FPB01
c5	2	BCT Anchor Cable Assembly	n0.75" 6x19 IWRC IPS Galvanized Wire Rope	43073	FCA01-02
c6	2	Anchor Bracket Assembly	ASTM A36 Steel	4153095	FPA01
c7	2	2 3/8" [60] O.D. x 6" [152] Long BCT Post Sleeve	ASTM A53 Grade B Schedule 40	280638	FMM02
c8	4	5/8" [15.9] Dia. x 10" [254] Long Hex Head Bolt and Nut	ASTM A307	COC	FBX16a
c9	16	5/8" [15.9] Dia. x 1 1/2" [38] Long Hex Head Bolt and Nut	ASTM A307	443270/15100302	FBX16a
c10	4	7/8" [22.2] Dia. x 7 1/2" [191] Long Hex Head Bolt and Nut	ASTM A307	Head Markings	FBX22a
c11	8	7/8" [22.2] Dia. Flat Washer	ASTM A153	na	FWC22a

Figure 92. Chart. List of Heat/Lot Numbers.



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Test Report:
Control Number: 702420

Weld Shear: Sf 8X12 W4.5/W3.5 88Inx600F
Minimum Weld Shear (Lbs.): 1575.0
Actual Values (Lbs.):
2184 2475 1830 2279

Brt Fab .2394 W4.5 For S & C 017045128
Tensile Test Reports per ASTM A-82 (W wire with a minimum tensile of 75 KPSI) or ASTM A-496 (Deform wire with a minimum tensile of 80 KPSI)

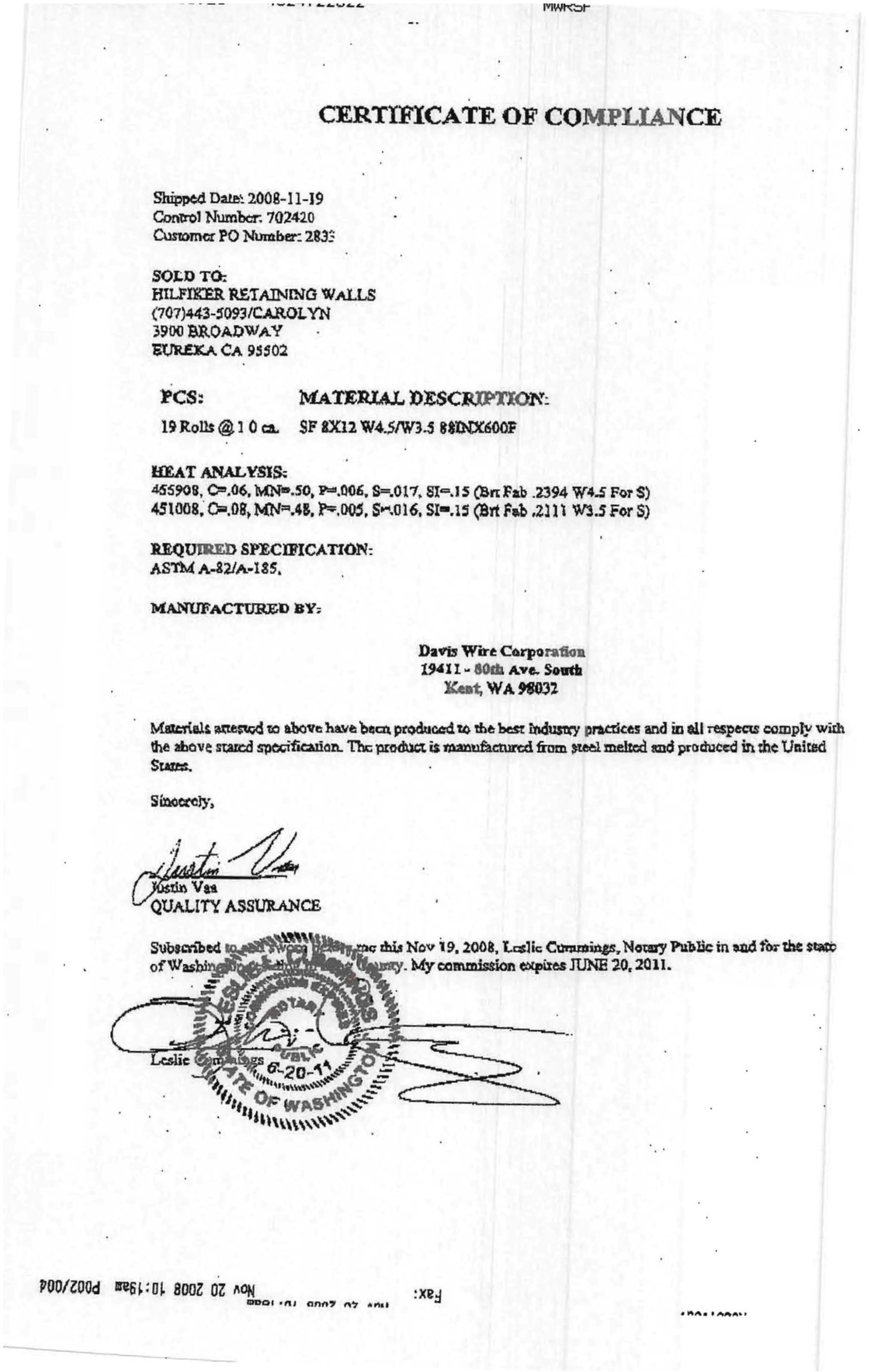
QC Number	Diameter (In.)	Break (Lbs.)	Tensile (KPSI)
suw4.5	.238	4497	101
su177863	.239	4986	111
182191	.238	4250	96
su182172	.239	4551	101
su182198	.239	5342	119

Brt Fab .2131 W3.5 For S & C 017035128
Tensile Test Reports per ASTM A-82 (W wire with a minimum tensile of 75 KPSI) or ASTM A-496 (Deform wire with a minimum tensile of 80 KPSI)

QC Number	Diameter (In.)	Break (Lbs.)	Tensile (KPSI)
su268171	.2115	3654	104
189721	.212	3432	97
189695	.211	4342	124
180538	.2115	3025	86
180539	.2115	2961	84

DW Davis Wire Corp.
MADE IN THE U.S.A.
Kent, Washington
HILFIKER
8x12 W4.5/W3.5
88" X 600'
ASTM A-185
QC Number:
115326
PCN:

Figure 93. Photo. Cap Mat and Prongless Mat, Material Specification.



CERTIFICATE OF COMPLIANCE

Shipped Date: 2008-11-19
Control Number: 702420
Customer PO Number: 2833

SOLD TO:
HILFIKER RETAINING WALLS
(707)443-5093/CAROLYN
3900 BROADWAY
EUREKA CA 95502

PCS:	MATERIAL DESCRIPTION:
19 Rolls @ 1 0 ea.	SF 8X12 W4.5/W3.5 88INX600F

HEAT ANALYSIS:
455908, C=.06, MN=.50, P=.006, S=.017, SI=.15 (Brt Fab .2394 W4.5 For S)
451008, C=.08, MN=.48, P=.005, S=.016, SI=.15 (Brt Fab .2111 W3.5 For S)

REQUIRED SPECIFICATION:
ASTM A-82/A-185.

MANUFACTURED BY:

Davis Wire Corporation
19411 - 80th Ave. South
Kent, WA 98032

Materials attested to above have been produced to the best industry practices and in all respects comply with the above stated specification. The product is manufactured from steel melted and produced in the United States.

Sincerely,

Justin Vaa
QUALITY ASSURANCE

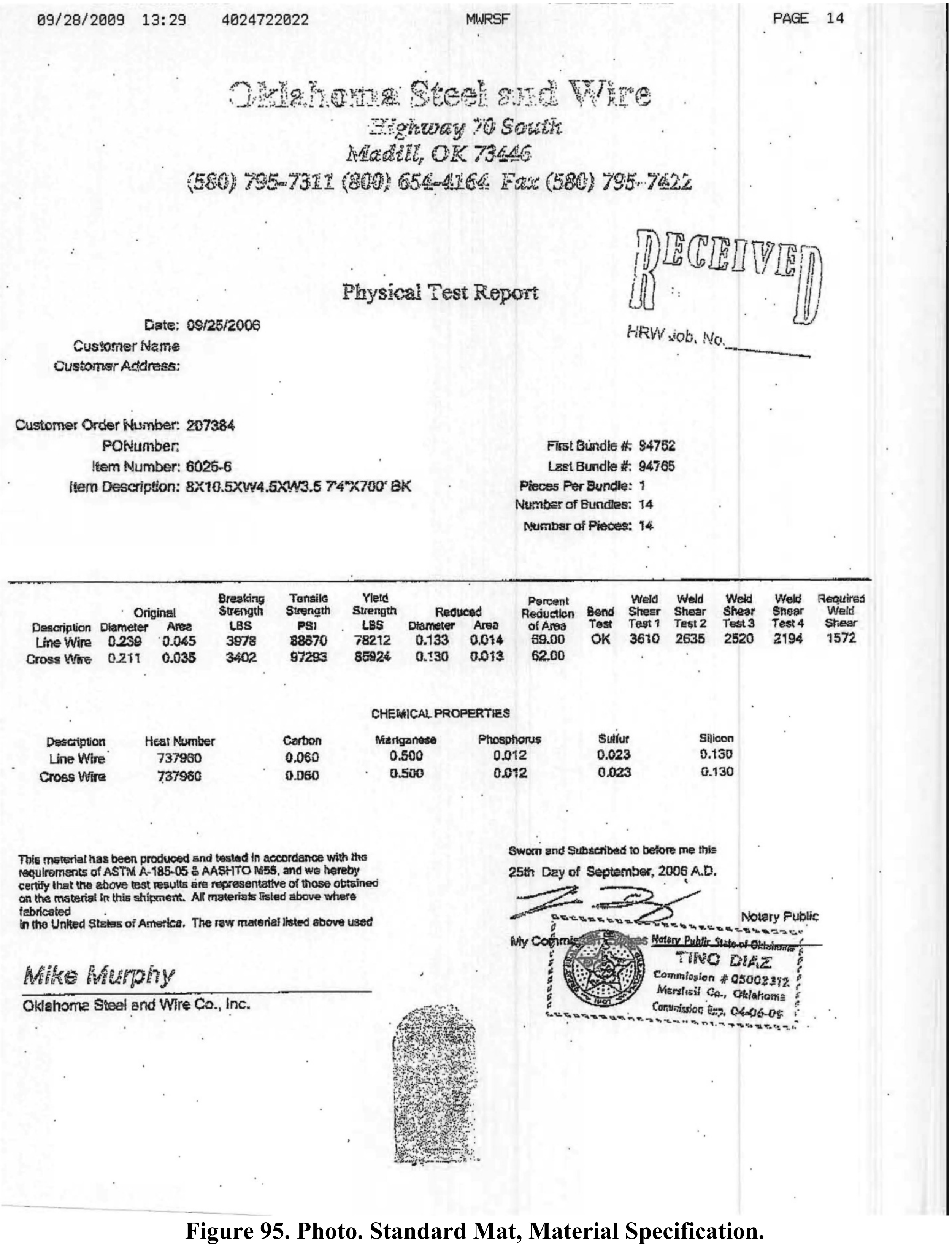
Subscribed to and sworn before me this Nov 19, 2008, Leslie Cummings, Notary Public in and for the state of Washington residing in [illegible] County. My commission expires JUNE 20, 2011.

Leslie Cummings

6-20-11

Nov 20 2008 10:19am P002/004

Figure 94. Photo. Cap Mat and Prongless Mat, Certificate of Compliance.



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Oklahoma Steel and Wire
Highway 70 South
Madill, OK 73446
(580) 795-7311 (800) 654-4164 Fax (580) 795-7422

RECEIVED
HRW Job. No.

Physical Test Report

Date: 09/25/2006
Customer Name
Customer Address:

Customer Order Number: 207384
PONumber:
Item Number: 6025-6
Item Description: 8X10.5XW4.5XW3.5 7'4"X700' BK

First Bundle #: 94752
Last Bundle #: 94765
Pieces Per Bundle: 1
Number of Bundles: 14
Number of Pieces: 14

Description	Original Diameter	Original Area	Breaking Strength LBS	Tensile Strength PSI	Yield Strength LBS	Reduced Diameter	Reduced Area	Percent Reduction of Area	Bend Test	Weld Shear Test 1	Weld Shear Test 2	Weld Shear Test 3	Weld Shear Test 4	Required Weld Shear
Line Wire	0.239	0.045	3978	88670	78212	0.133	0.014	69.00	OK	3610	2635	2520	2194	1572
Cross Wire	0.211	0.035	3402	97293	85924	0.130	0.013	62.00						

CHEMICAL PROPERTIES

Description	Heat Number	Carbon	Manganese	Phosphorus	Sulfur	Silicon
Line Wire	737960	0.060	0.500	0.012	0.023	0.130
Cross Wire	737960	0.060	0.500	0.012	0.023	0.130

This material has been produced and tested in accordance with the requirements of ASTM A-185-05 & AASHTO M55, and we hereby certify that the above test results are representative of those obtained on the material in this shipment. All materials listed above where fabricated
in the United States of America. The raw material listed above used

Mike Murphy
Oklahoma Steel and Wire Co., Inc.

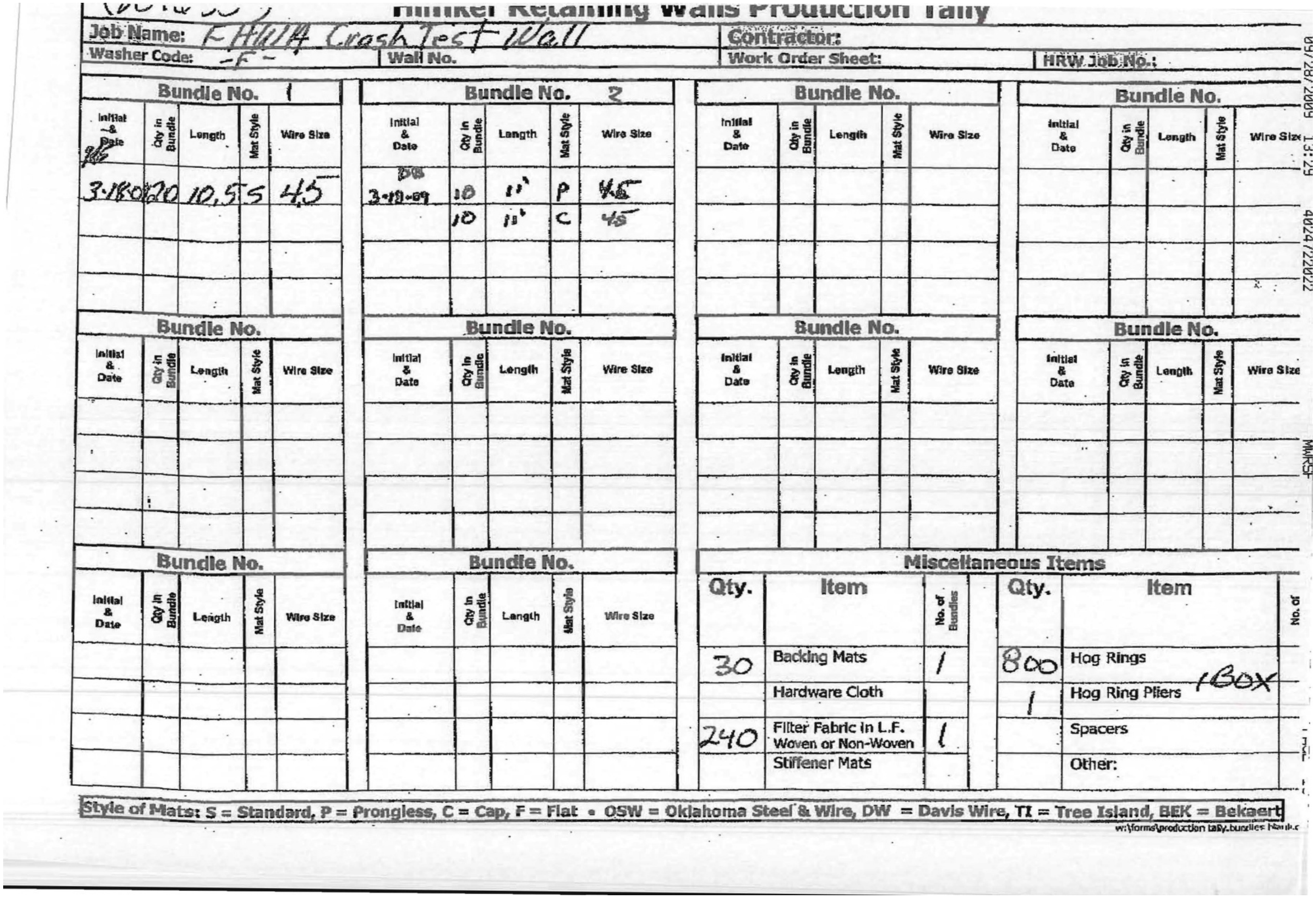
Sworn and Subscribed to before me this
25th Day of September, 2006 A.D.

Notary Public

My Commission Expires

Notary Public State of Oklahoma
TINO DIAZ
Commission # 05002312
Marshall Co., Oklahoma
Commission Exp. 04-06-09

Figure 95. Photo. Standard Mat, Material Specification.



Retaining Walls Production Tally

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Job Name: FHWA Crash Test Wall
Contractor:
Washer Code: -F-
Wall No.
Work Order Sheet:
HRW Job No.:

Bundle No. 1

Initial & Date	Qty in Bundle	Length	Mat Style	Wire Size
3·18·0	20	10.5	S	4.5

Bundle No. 2

Initial & Date	Qty in Bundle	Length	Mat Style	Wire Size
DB 3-19-09	10	11'	P	4.5
	10	11'	C	45

Bundle No.

Initial & Date	Qty in Bundle	Length	Mat Style	Wire Size

Bundle No.

Initial & Date	Qty in Bundle	Length	Mat Style	Wire Size

Bundle No.

Initial & Date	Qty in Bundle	Length	Mat Style	Wire Size

Bundle No.

Initial & Date	Qty in Bundle	Length	Mat Style	Wire Size

Bundle No.

Initial & Date	Qty in Bundle	Length	Mat Style	Wire Size

Bundle No.

Initial & Date	Qty in Bundle	Length	Mat Style	Wire Size

Bundle No.

Initial & Date	Qty in Bundle	Length	Mat Style	Wire Size

Bundle No.

Initial & Date	Qty in Bundle	Length	Mat Style	Wire Size

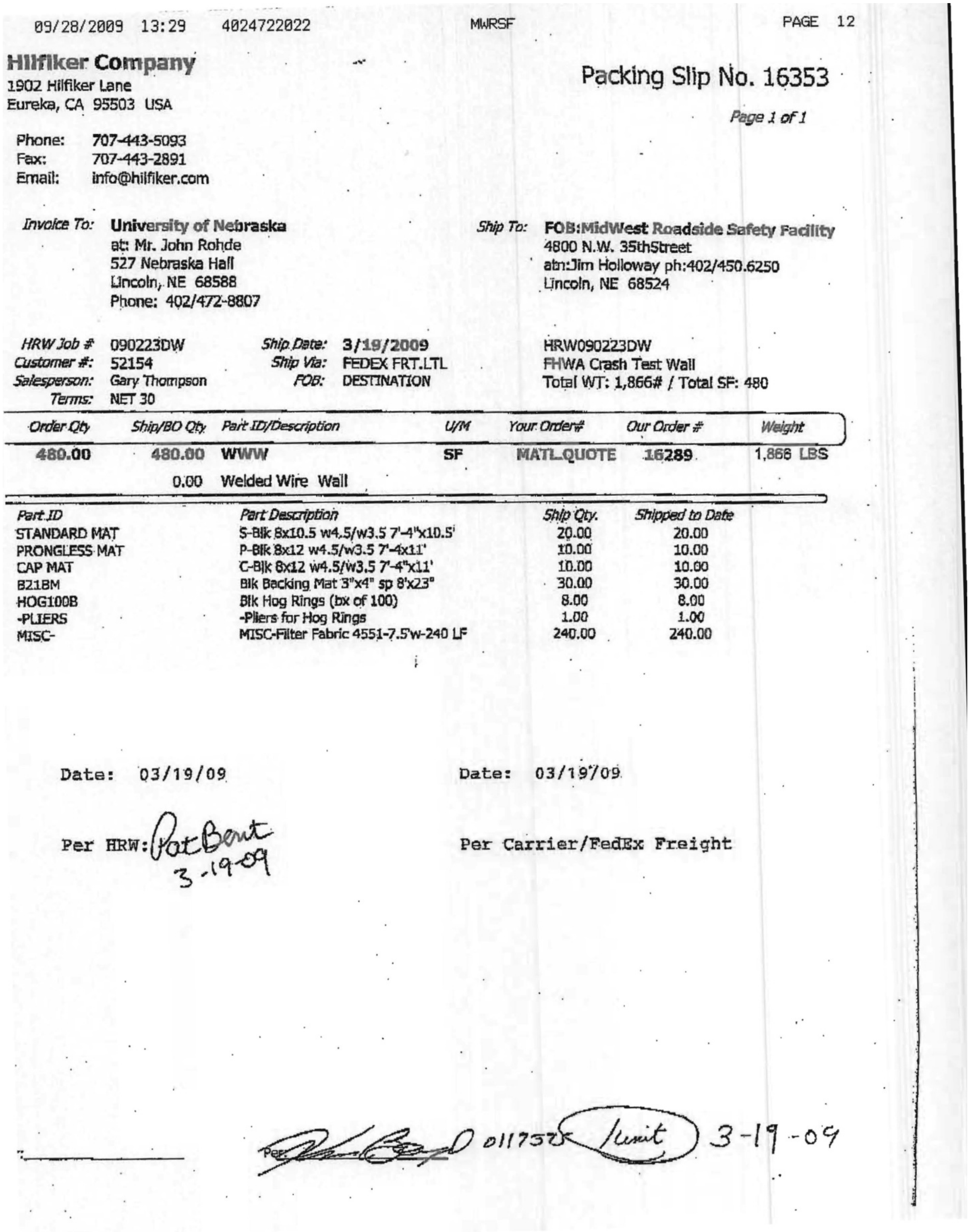
Miscellaneous Items

Qty.	Item	No. of Bundles	Qty.	Item	No. of
30	Backing Mats	1	800	Hog Rings	
	Hardware Cloth		1	Hog Ring Pliers 1 BOX	
240	Filter Fabric in L.F. Woven or Non-Woven	1		Spacers	
	Stiffener Mats			Other:	

Style of Mats: S = Standard, P = Prongless, C = Cap, F = Flat • OSW = Oklahoma Steel & Wire, DW = Davis Wire, TI = Tree Island, BEK = Bekaert

w:\forms\production tally.bundles blank.c

Figure 96. Photo. Hog Rings and Filter Fabric, Materials Specification.



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Hilfiker Company
1902 Hilfiker Lane
Eureka, CA 95503 USA

Packing Slip No. 16353

Page 1 of 1

Phone: 707-443-5093
Fax: 707-443-2891
Email: info@hilfiker.com

Invoice To: **University of Nebraska**
at: Mr. John Rohde
527 Nebraska Hall
Lincoln, NE 68588
Phone: 402/472-8807

Ship To: **FOB:MidWest Roadside Safety Facility**
4800 N.W. 35thStreet
atn:Jim Holloway ph:402/450.6250
Lincoln, NE 68524

HRW Job # 090223DW
Customer #: 52154
Salesperson: Gary Thompson
Terms: NET 30

Ship Date: 3/19/2009
Ship Via: FEDEX FRT.LTL
FOB: DESTINATION

HRW090223DW
FHWA Crash Test Wall
Total WT: 1,866# / Total SF: 480

Order Qty	*Ship/BO Qty*	*Part ID/Description*	*U/M*	*Your Order#*	*Our Order #*	*Weight*
480.00	480.00	WWW	SF	MATL QUOTE	16289	1,866 LBS
	0.00	Welded Wire Wall				

Part ID	*Part Description*	*Ship Qty.*	*Shipped to Date*
STANDARD MAT	S-Blk 8x10.5 w4.5/w3.5 7'-4"x10.5'	20.00	20.00
PRONGLESS MAT	P-Blk 8x12 w4.5/w3.5 7'-4x11'	10.00	10.00
CAP MAT	C-Blk 8x12 w4.5/w3.5 7'-4"x11'	10.00	10.00
B21BM	Blk Backing Mat 3"x4" sp 8'x23"	30.00	30.00
HOG100B	Blk Hog Rings (bx of 100)	8.00	8.00
-PLIERS	-Pliers for Hog Rings	1.00	1.00
MISC-	MISC-Filter Fabric 4551-7.5'w-240 LF	240.00	240.00

Date: 03/19/09

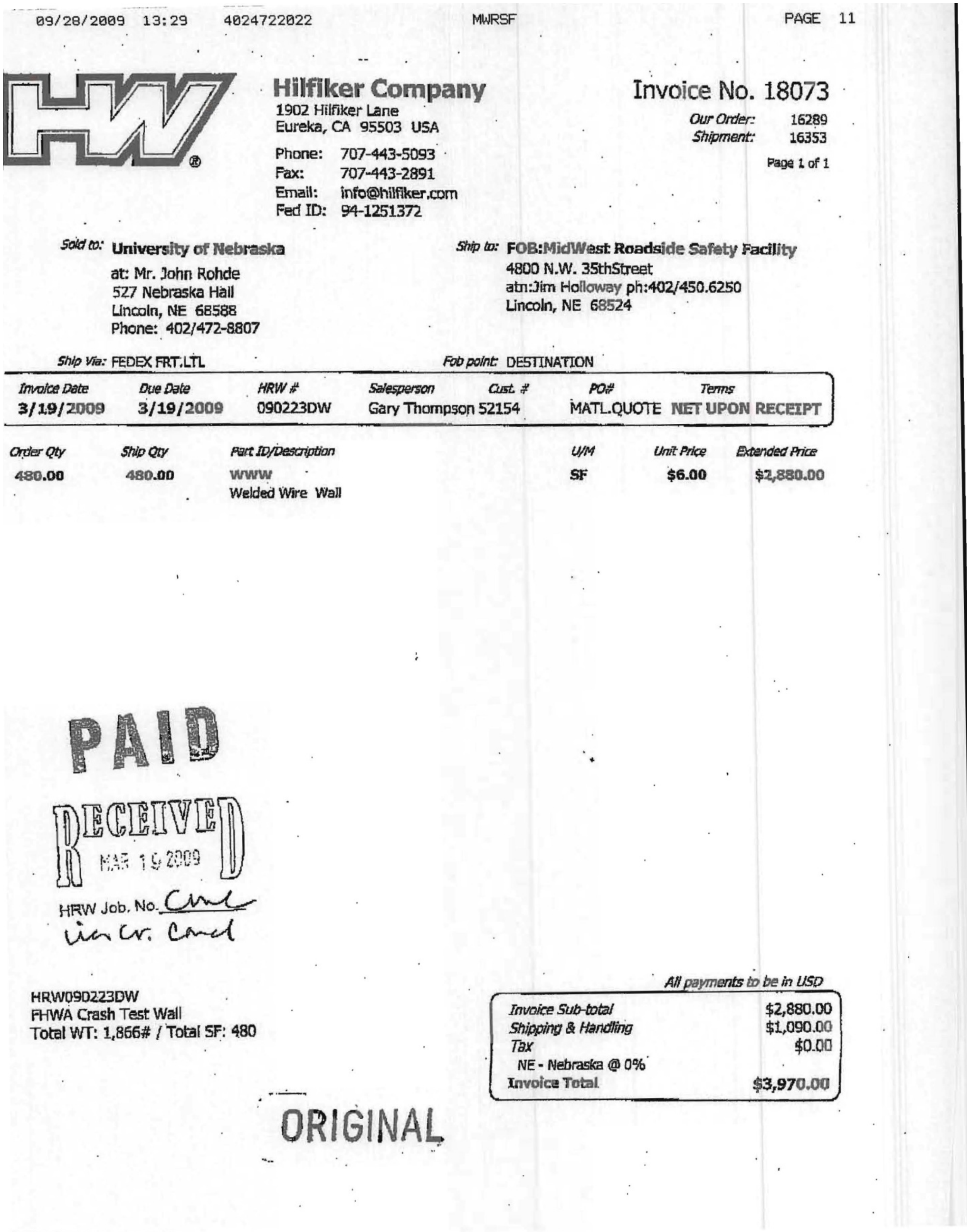
Per HRW: Pat Bent
3-19-09

Date: 03/19/09

Per Carrier/FedEx Freight

Per: 011752 /unit 3-19-09

Figure 97. Photo. Hog Rings and Backing Mat, Material Specification. (continued.)



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Hilfiker Company
1902 Hilfiker Lane
Eureka, CA 95503 USA

Phone: 707-443-5093
Fax: 707-443-2891
Email: info@hilfiker.com
Fed ID: 94-1251372

Invoice No. 18073

Our Order:	16289
Shipment:	16353

Page 1 of 1

Sold to: **University of Nebraska**
at: Mr. John Rohde
527 Nebraska Hall
Lincoln, NE 68588
Phone: 402/472-8807

Ship to: **FOB:MidWest Roadside Safety Facility**
4800 N.W. 35thStreet
atn:Jim Holloway ph:402/450.6250
Lincoln, NE 68524

Ship Via: FEDEX FRT.LTL

Fob point: DESTINATION

Invoice Date	*Due Date*	*HRW #*	*Salesperson*	*Cust. #*	*PO#*	*Terms*
3/19/2009	**3/19/2009**	090223DW	Gary Thompson	52154	MATL.QUOTE	**NET UPON RECEIPT**

Order Qty	*Ship Qty*	*Part ID/Description*	*U/M*	*Unit Price*	*Extended Price*
480.00	**480.00**	WWW Welded Wire Wall	**SF**	**$6.00**	**$2,880.00**

PAID

RECEIVED
MAR 19 2009

HRW Job. No. Cml
via Cr. Card

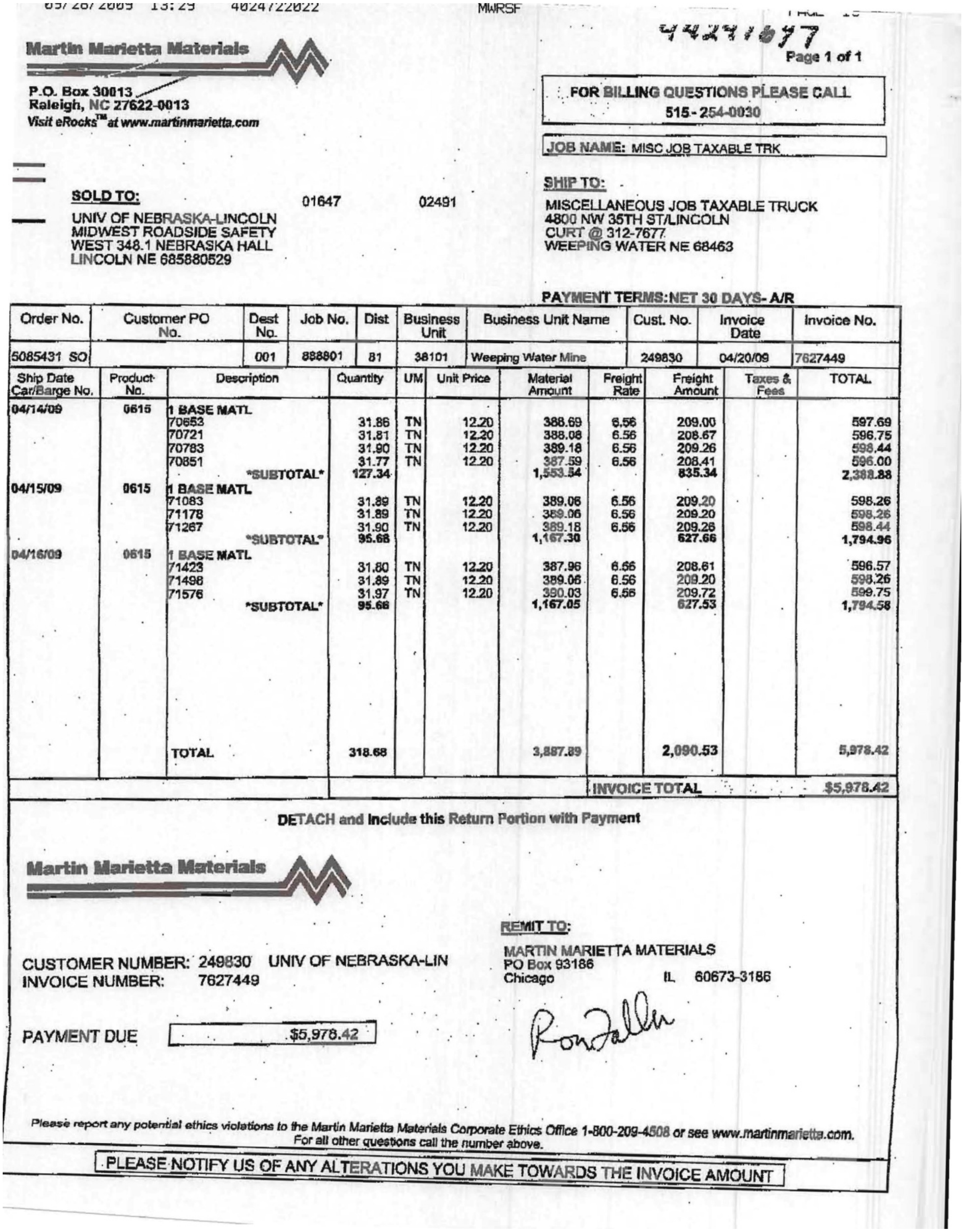
HRW090223DW
FHWA Crash Test Wall
Total WT: 1,866# / Total SF: 480

All payments to be in USD

Invoice Sub-total	$2,880.00
Shipping & Handling	$1,090.00
Tax	$0.00
NE - Nebraska @ 0%	
Invoice Total	**$3,970.00**

ORIGINAL

Figure 98. Photo. Cap Mat, Backing Mat, Standard Mat, & Prongless Mat, Material Specification.



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Page 1 of 1

Martin Marietta Materials

P.O. Box 30013
Raleigh, NC 27622-0013
Visit eRocks™ at www.martinmarietta.com

FOR BILLING QUESTIONS PLEASE CALL
515-254-0030

JOB NAME: MISC JOB TAXABLE TRK

SOLD TO: 01647 02491
UNIV OF NEBRASKA-LINCOLN
MIDWEST ROADSIDE SAFETY
WEST 348.1 NEBRASKA HALL
LINCOLN NE 685880529

SHIP TO:
MISCELLANEOUS JOB TAXABLE TRUCK
4800 NW 35TH ST/LINCOLN
CURT @ 312-7677
WEEPING WATER NE 68463

PAYMENT TERMS: NET 30 DAYS- A/R

Order No.	Customer PO No.	Dest No.	Job No.	Dist	Business Unit	Business Unit Name	Cust. No.	Invoice Date	Invoice No.
5085431 SO		001	888801	81	38101	Weeping Water Mine	249830	04/20/09	7627449

Ship Date Car/Barge No.	Product No.	Description	Quantity	UM	Unit Price	Material Amount	Freight Rate	Freight Amount	Taxes & Fees	TOTAL
04/14/09	0615	1 BASE MATL								
		70653	31.86	TN	12.20	388.69	6.56	209.00		597.69
		70721	31.81	TN	12.20	388.08	6.56	208.67		596.75
		70783	31.90	TN	12.20	389.18	6.56	209.26		598.44
		70851	31.77	TN	12.20	387.59	6.56	208.41		596.00
		SUBTOTAL	127.34			1,553.54		835.34		2,388.88
04/15/09	0615	1 BASE MATL								
		71083	31.89	TN	12.20	389.06	6.56	209.20		598.26
		71178	31.89	TN	12.20	389.06	6.56	209.20		598.26
		71267	31.90	TN	12.20	389.18	6.56	209.26		598.44
		SUBTOTAL	95.68			1,167.30		627.66		1,794.96
04/16/09	0615	1 BASE MATL								
		71423	31.80	TN	12.20	387.96	6.56	208.61		596.57
		71498	31.89	TN	12.20	389.06	6.56	209.20		598.26
		71576	31.97	TN	12.20	390.03	6.56	209.72		599.75
		SUBTOTAL	95.66			1,167.05		627.53		1,794.58
		TOTAL	318.68			3,887.89		2,090.53		5,978.42

INVOICE TOTAL $5,978.42

DETACH and Include this Return Portion with Payment

Martin Marietta Materials

CUSTOMER NUMBER: 249830 UNIV OF NEBRASKA-LIN
INVOICE NUMBER: 7627449

REMIT TO:
MARTIN MARIETTA MATERIALS
PO Box 93186
Chicago IL 60673-3186

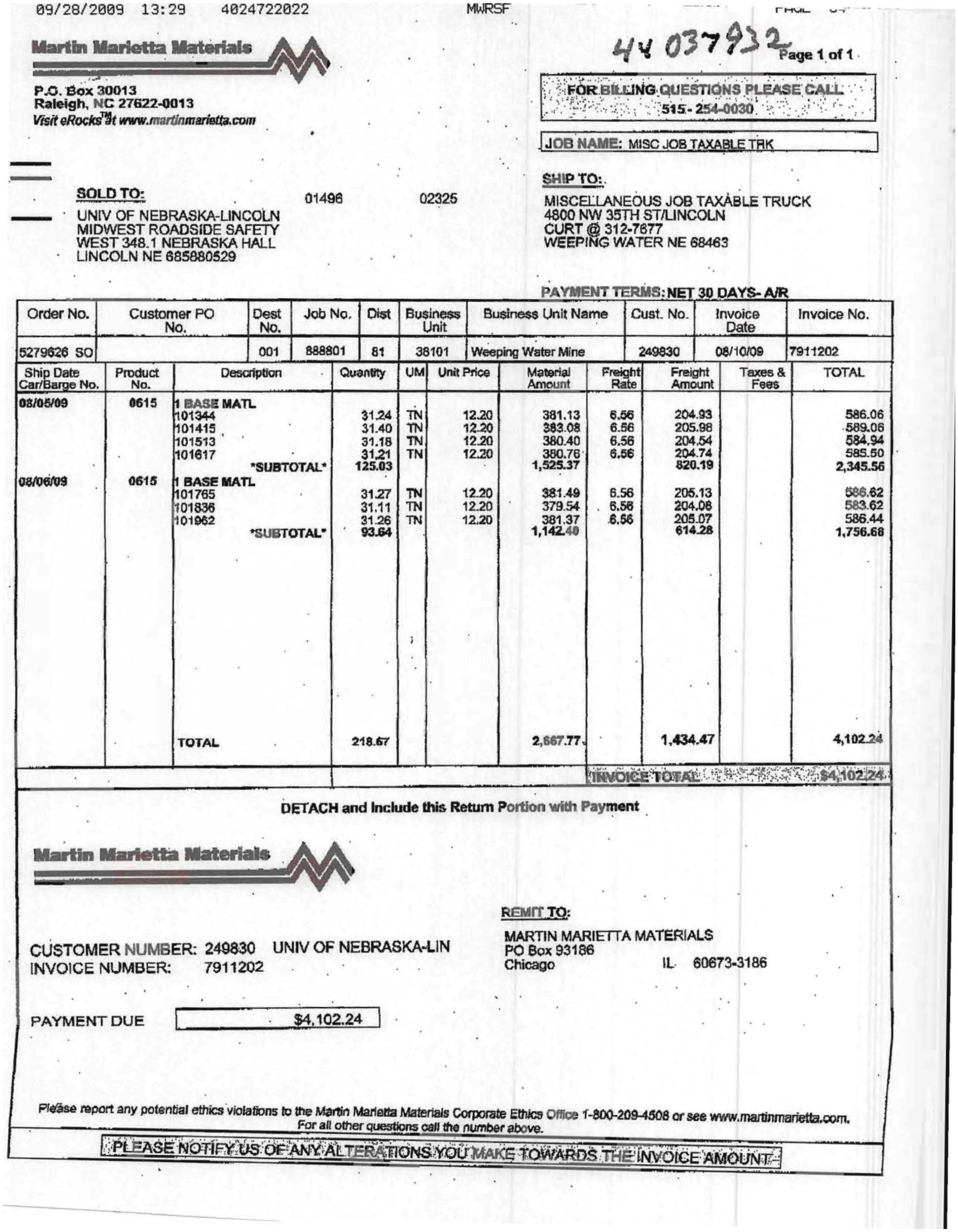
PAYMENT DUE $5,978.42

Ron Faller

Please report any potential ethics violations to the Martin Marietta Materials Corporate Ethics Office 1-800-209-4508 or see www.martinmarietta.com.
For all other questions call the number above.

PLEASE NOTIFY US OF ANY ALTERATIONS YOU MAKE TOWARDS THE INVOICE AMOUNT

Figure 99. Photo. Fill Material, Material Specification.



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Martin Marietta Materials

P.O. Box 30013
Raleigh, NC 27622-0013
Visit eRocks™ at www.martinmarietta.com

4V 037932

Page 1 of 1

FOR BILLING QUESTIONS PLEASE CALL
515-254-0030

JOB NAME: MISC JOB TAXABLE TRK

SOLD TO: 01496 02325
UNIV OF NEBRASKA-LINCOLN
MIDWEST ROADSIDE SAFETY
WEST 348.1 NEBRASKA HALL
LINCOLN NE 685880529

SHIP TO:
MISCELLANEOUS JOB TAXABLE TRUCK
4800 NW 35TH ST/LINCOLN
CURT @ 312-7677
WEEPING WATER NE 68463

PAYMENT TERMS: NET 30 DAYS- A/R

Order No.	Customer PO No.	Dest No.	Job No.	Dist	Business Unit	Business Unit Name	Cust. No.	Invoice Date	Invoice No.
5279626 SO		001	888801	81	38101	Weeping Water Mine	249830	08/10/09	7911202

Ship Date Car/Barge No.	Product No.	Description	Quantity	UM	Unit Price	Material Amount	Freight Rate	Freight Amount	Taxes & Fees	TOTAL
08/05/09	0615	1 BASE MATL								
		101344	31.24	TN	12.20	381.13	6.56	204.93		586.06
		101415	31.40	TN	12.20	383.08	6.56	205.98		589.06
		101513	31.18	TN	12.20	380.40	6.56	204.54		584.94
		101617	31.21	TN	12.20	380.76	6.56	204.74		585.50
		SUBTOTAL	125.03			1,525.37		820.19		2,345.56
08/06/09	0615	1 BASE MATL								
		101765	31.27	TN	12.20	381.49	6.56	205.13		586.62
		101836	31.11	TN	12.20	379.54	6.56	204.08		583.62
		101962	31.26	TN	12.20	381.37	6.56	205.07		586.44
		SUBTOTAL	93.64			1,142.40		614.28		1,756.68
		TOTAL	218.67			2,667.77		1,434.47		4,102.24

INVOICE TOTAL $4,102.24

DETACH and Include this Return Portion with Payment

Martin Marietta Materials

REMIT TO:
MARTIN MARIETTA MATERIALS
PO Box 93186
Chicago IL 60673-3186

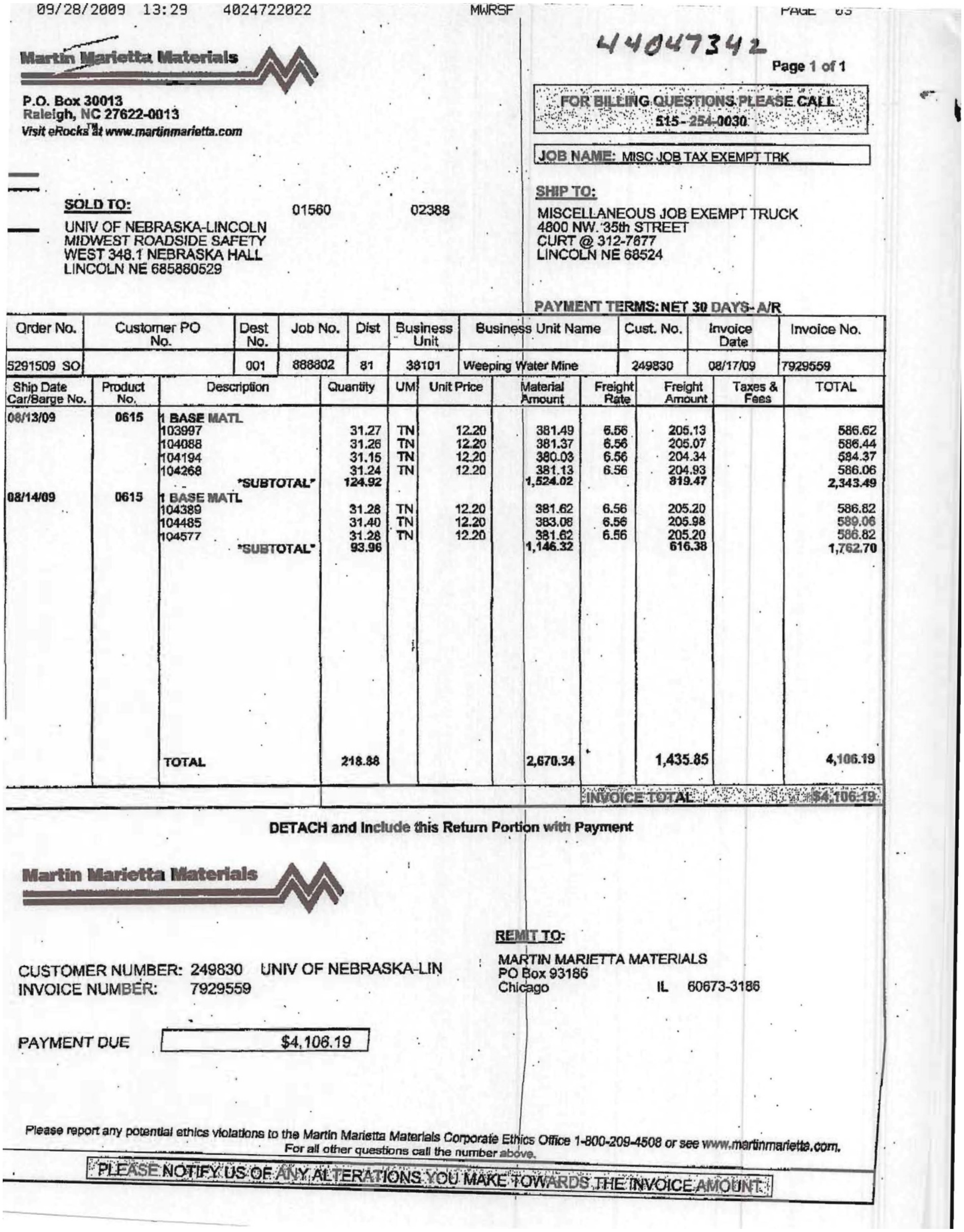
CUSTOMER NUMBER: 249830 UNIV OF NEBRASKA-LIN
INVOICE NUMBER: 7911202

PAYMENT DUE $4,102.24

Please report any potential ethics violations to the Martin Marietta Materials Corporate Ethics Office 1-800-209-4508 or see www.martinmarietta.com.
For all other questions call the number above.

PLEASE NOTIFY US OF ANY ALTERATIONS YOU MAKE TOWARDS THE INVOICE AMOUNT

Figure 100. Photo. Fill Material, Material Specification.



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Martin Marietta Materials

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Raleigh, NC 27622-0013
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Page 1 of 1

FOR BILLING QUESTIONS PLEASE CALL
515-254-0030

JOB NAME: MISC JOB TAX EXEMPT TRK

SOLD TO: 01560 02388
UNIV OF NEBRASKA-LINCOLN
MIDWEST ROADSIDE SAFETY
WEST 348.1 NEBRASKA HALL
LINCOLN NE 685880529

SHIP TO:
MISCELLANEOUS JOB EXEMPT TRUCK
4800 NW. 35th STREET
CURT @ 312-7677
LINCOLN NE 68524

PAYMENT TERMS: NET 30 DAYS- A/R

Order No.	Customer PO No.	Dest No.	Job No.	Dist	Business Unit	Business Unit Name	Cust. No.	Invoice Date	Invoice No.
5291509 SO		001	888802	81	38101	Weeping Water Mine	249830	08/17/09	7929559

Ship Date Car/Barge No.	Product No.	Description	Quantity	UM	Unit Price	Material Amount	Freight Rate	Freight Amount	Taxes & Fees	TOTAL
08/13/09	0615	1 BASE MATL								
		103997	31.27	TN	12.20	381.49	6.56	205.13		586.62
		104088	31.26	TN	12.20	381.37	6.56	205.07		586.44
		104194	31.15	TN	12.20	380.03	6.56	204.34		584.37
		104268	31.24	TN	12.20	381.13	6.56	204.93		586.06
		SUBTOTAL	124.92			1,524.02		819.47		2,343.49
08/14/09	0615	1 BASE MATL								
		104389	31.28	TN	12.20	381.62	6.56	205.20		586.82
		104485	31.40	TN	12.20	383.08	6.56	205.98		589.06
		104577	31.28	TN	12.20	381.62	6.56	205.20		586.82
		SUBTOTAL	93.96			1,146.32		616.38		1,762.70
		TOTAL	218.88			2,670.34		1,435.85		4,106.19

INVOICE TOTAL $4,106.19

DETACH and Include this Return Portion with Payment

Martin Marietta Materials

CUSTOMER NUMBER: 249830 UNIV OF NEBRASKA-LIN
INVOICE NUMBER: 7929559

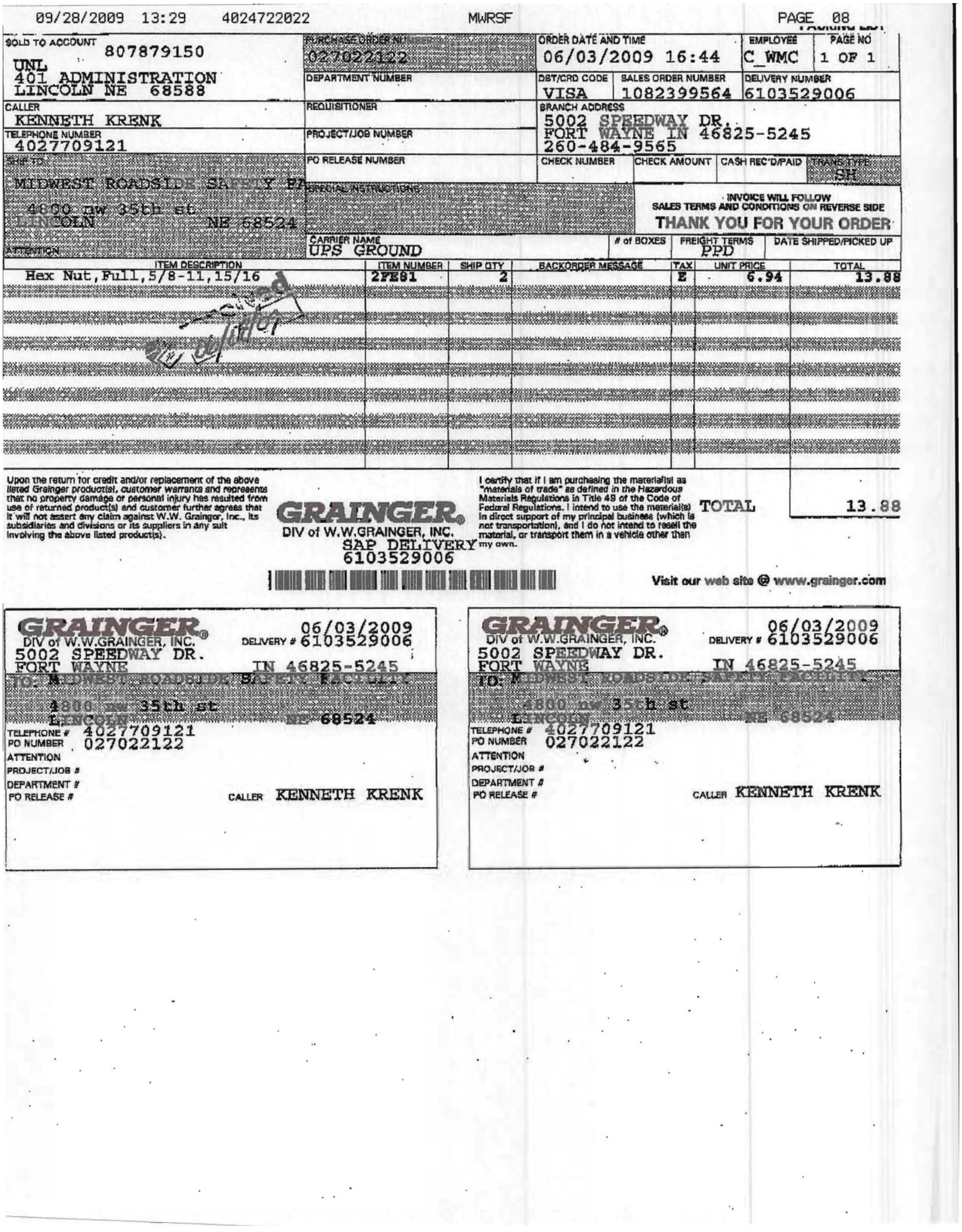
PAYMENT DUE $4,106.19

REMIT TO:
MARTIN MARIETTA MATERIALS
PO Box 93186
Chicago IL 60673-3186

Please report any potential ethics violations to the Martin Marietta Materials Corporate Ethics Office 1-800-209-4508 or see www.martinmarietta.com.
For all other questions call the number above.

PLEASE NOTIFY US OF ANY ALTERATIONS YOU MAKE TOWARDS THE INVOICE AMOUNT.

Figure 101. Photo. Fill Material, Material Specification.



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SOLD TO ACCOUNT 807879150
UNL
401 ADMINISTRATION
LINCOLN NE 68588

CALLER KENNETH KRENK

TELEPHONE NUMBER 4027709121

SHIP TO
MIDWEST ROADSIDE SAFETY FA
4800 nw 35th st
LINCOLN NE 68524

ATTENTION

PURCHASE ORDER NUMBER 027022122

DEPARTMENT NUMBER

REQUISITIONER

PROJECT/JOB NUMBER

PO RELEASE NUMBER

SPECIAL INSTRUCTIONS

CARRIER NAME UPS GROUND

ORDER DATE AND TIME 06/03/2009 16:44

EMPLOYEE C_WMC

PAGE NO 1 OF 1

DST/CRD CODE VISA

SALES ORDER NUMBER 1082399564

DELIVERY NUMBER 6103529006

BRANCH ADDRESS
5002 SPEEDWAY DR.
FORT WAYNE IN 46825-5245
260-484-9565

CHECK NUMBER

CHECK AMOUNT

CASH REC'D/PAID

TRANS TYPE SH

INVOICE WILL FOLLOW
SALES TERMS AND CONDITIONS ON REVERSE SIDE
THANK YOU FOR YOUR ORDER

# of BOXES

FREIGHT TERMS PPD

DATE SHIPPED/PICKED UP

ITEM DESCRIPTION	ITEM NUMBER	SHIP QTY	BACKORDER MESSAGE	TAX	UNIT PRICE	TOTAL
Hex Nut,Full,5/8-11,15/16	2FE81	2		E	6.94	13.88

Upon the return for credit and/or replacement of the above listed Grainger product(s), customer warrants and represents that no property damage or personal injury has resulted from use of returned product(s) and customer further agrees that it will not assert any claim against W.W. Grainger, Inc., its subsidiaries and divisions or its suppliers in any suit involving the above listed product(s).

GRAINGER®
DIV of W.W.GRAINGER, INC.
SAP DELIVERY
6103529006

I certify that if I am purchasing the material(s) as "materials of trade" as defined in the Hazardous Materials Regulations in Title 49 of the Code of Federal Regulations. I intend to use the material(s) in direct support of my principal business (which is not transportation), and I do not intend to resell the material, or transport them in a vehicle other than my own.

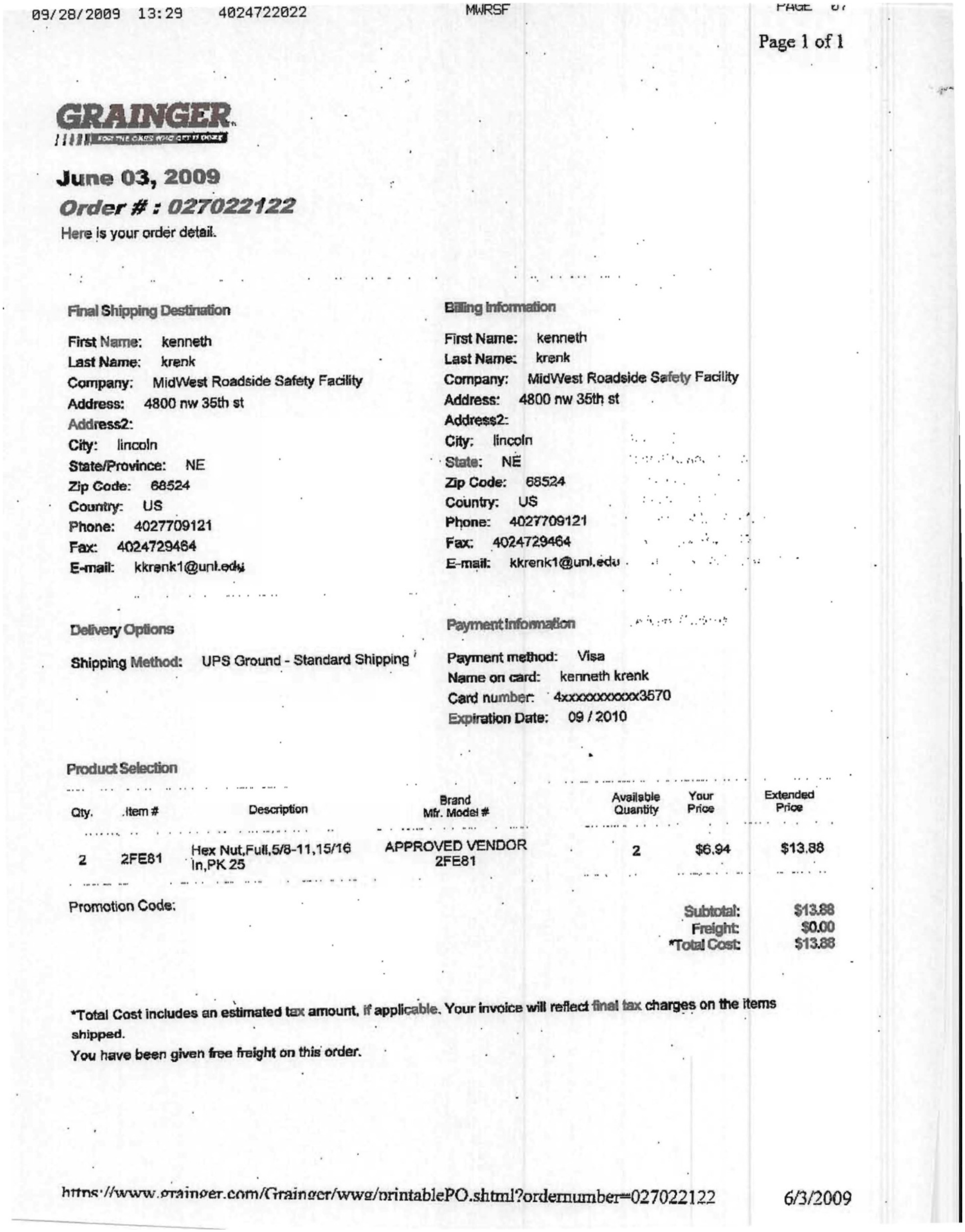
TOTAL 13.88

Visit our web site @ www.grainger.com

GRAINGER®
DIV of W.W.GRAINGER, INC.
5002 SPEEDWAY DR.
FORT WAYNE IN 46825-5245
06/03/2009
DELIVERY # 6103529006
TO: MIDWEST ROADSIDE SAFETY FACILITY
4800 nw 35th st
LINCOLN NE 68524
TELEPHONE # 4027709121
PO NUMBER 027022122
ATTENTION
PROJECT/JOB #
DEPARTMENT #
PO RELEASE #
CALLER KENNETH KRENK

GRAINGER®
DIV of W.W.GRAINGER, INC.
5002 SPEEDWAY DR.
FORT WAYNE IN 46825-5245
06/03/2009
DELIVERY # 6103529006
TO: MIDWEST ROADSIDE SAFETY FACILITY
4800 nw 35th st
LINCOLN NE 68524
TELEPHONE # 4027709121
PO NUMBER 027022122
ATTENTION
PROJECT/JOB #
DEPARTMENT #
PO RELEASE #
CALLER KENNETH KRENK

Figure 102. Photo. ⅝-in. (15.9 mm) x 10 in. (254 mm) Hex Nut, Material Specification.



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Page 1 of 1

GRAINGER

June 03, 2009

Order # : 027022122

Here is your order detail.

Final Shipping Destination

First Name: kenneth
Last Name: krenk
Company: MidWest Roadside Safety Facility
Address: 4800 nw 35th st
Address2:
City: lincoln
State/Province: NE
Zip Code: 68524
Country: US
Phone: 4027709121
Fax: 4024729464
E-mail: kkrenk1@unl.edu

Billing Information

First Name: kenneth
Last Name: krenk
Company: MidWest Roadside Safety Facility
Address: 4800 nw 35th st
Address2:
City: lincoln
State: NE
Zip Code: 68524
Country: US
Phone: 4027709121
Fax: 4024729464
E-mail: kkrenk1@unl.edu

Delivery Options

Shipping Method: UPS Ground - Standard Shipping

Payment Information

Payment method: Visa
Name on card: kenneth krenk
Card number: 4xxxxxxxxxxx3570
Expiration Date: 09 / 2010

Product Selection

Qty.	Item #	Description	Brand Mfr. Model #	Available Quantity	Your Price	Extended Price
2	2FE81	Hex Nut,Full,5/8-11,15/16 In,PK 25	APPROVED VENDOR 2FE81	2	$6.94	$13.88

Promotion Code:

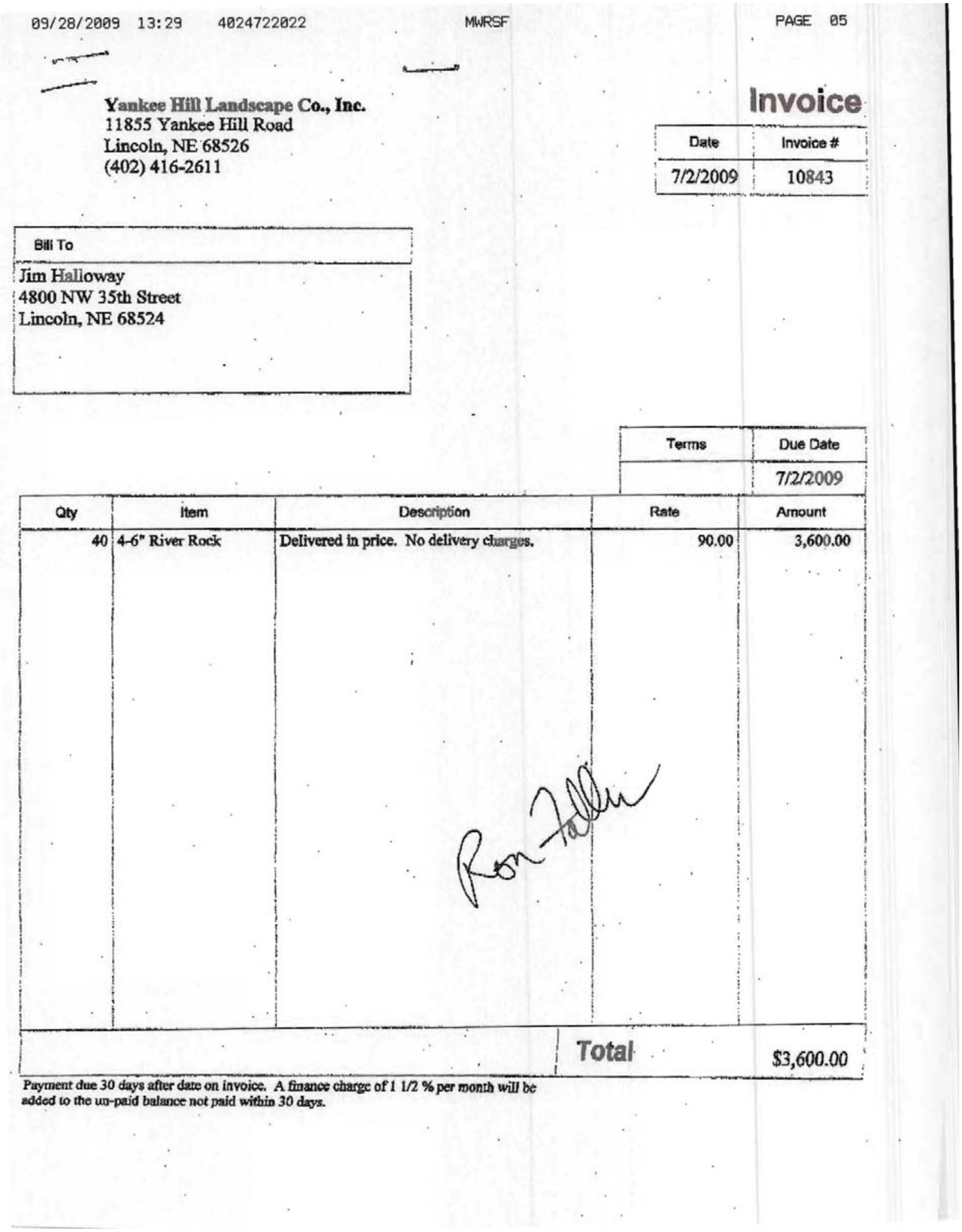
Subtotal:	$13.88
Freight:	$0.00
*Total Cost:	$13.88

*Total Cost includes an estimated tax amount, if applicable. Your invoice will reflect final tax charges on the items shipped.

You have been given free freight on this order.

https://www.grainger.com/Grainger/wwg/printablePO.shtml?ordernumber=027022122 6/3/2009

Figure 103. Photo. ⅝-in. (15.9 mm) x 10 in. (254 mm) Hex Nut, Material Specification. (continued.)



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Yankee Hill Landscape Co., Inc.
11855 Yankee Hill Road
Lincoln, NE 68526
(402) 416-2611

Invoice

Date	Invoice #
7/2/2009	10843

Bill To

Jim Halloway
4800 NW 35th Street
Lincoln, NE 68524

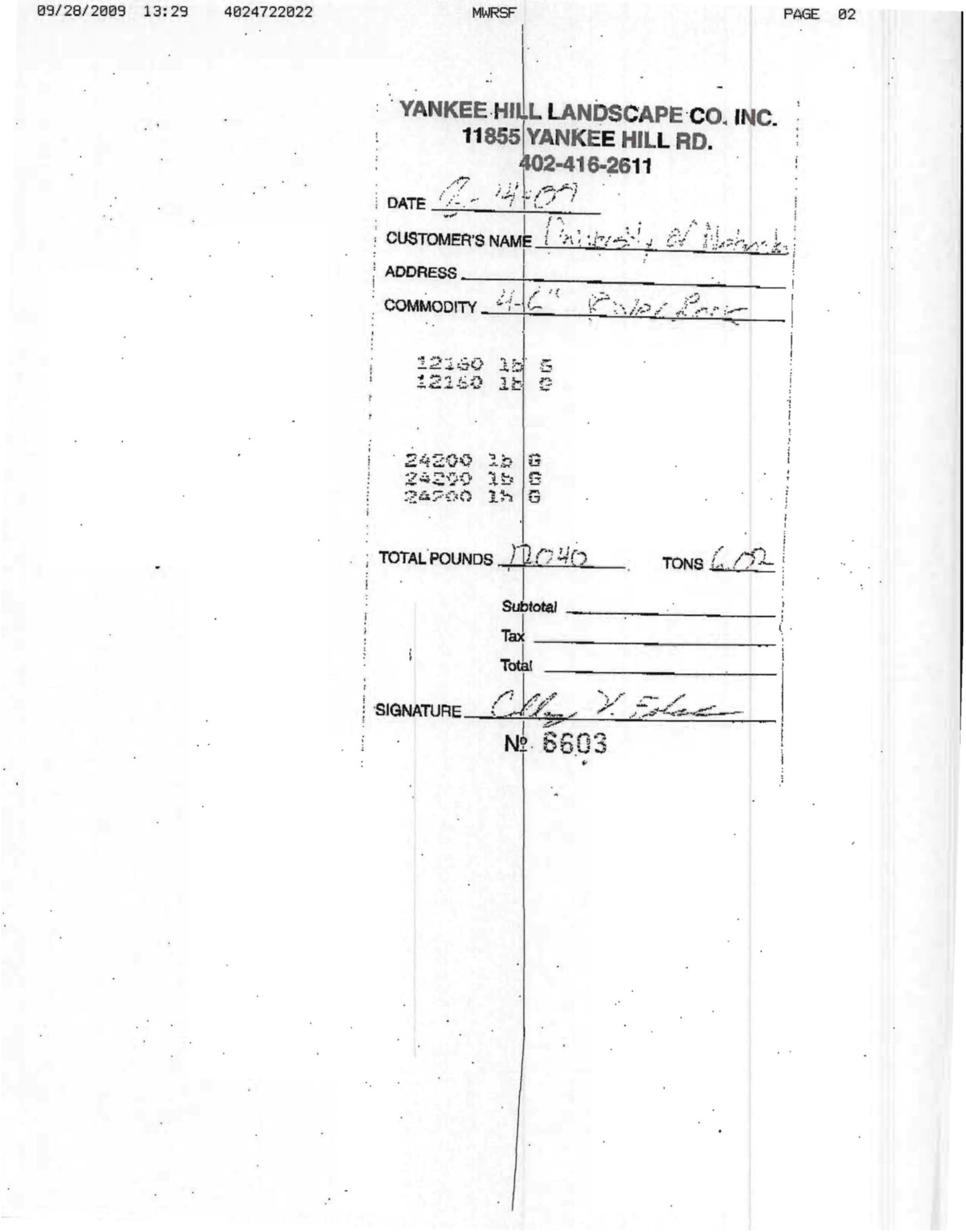
Terms	Due Date
	7/2/2009

Qty	Item	Description	Rate	Amount
40	4-6" River Rock	Delivered in price. No delivery charges.	90.00	3,600.00
			Total	$3,600.00

Ron Faller

Payment due 30 days after date on invoice. A finance charge of 1 1/2 % per month will be added to the un-paid balance not paid within 30 days.

Figure 104. Photo. Wall Facing Fill, Material Specification.



09/28/2009 13:29 4024722022 MWRSF PAGE 02

YANKEE HILL LANDSCAPE CO. INC.
11855 YANKEE HILL RD.
402-416-2611

DATE 9-14-09

CUSTOMER'S NAME University of Nebraska

ADDRESS

COMMODITY 4-6" River Rock

```
12160 lb G
12160 lb G


24200 lb G
24200 lb G
24200 lb G
```

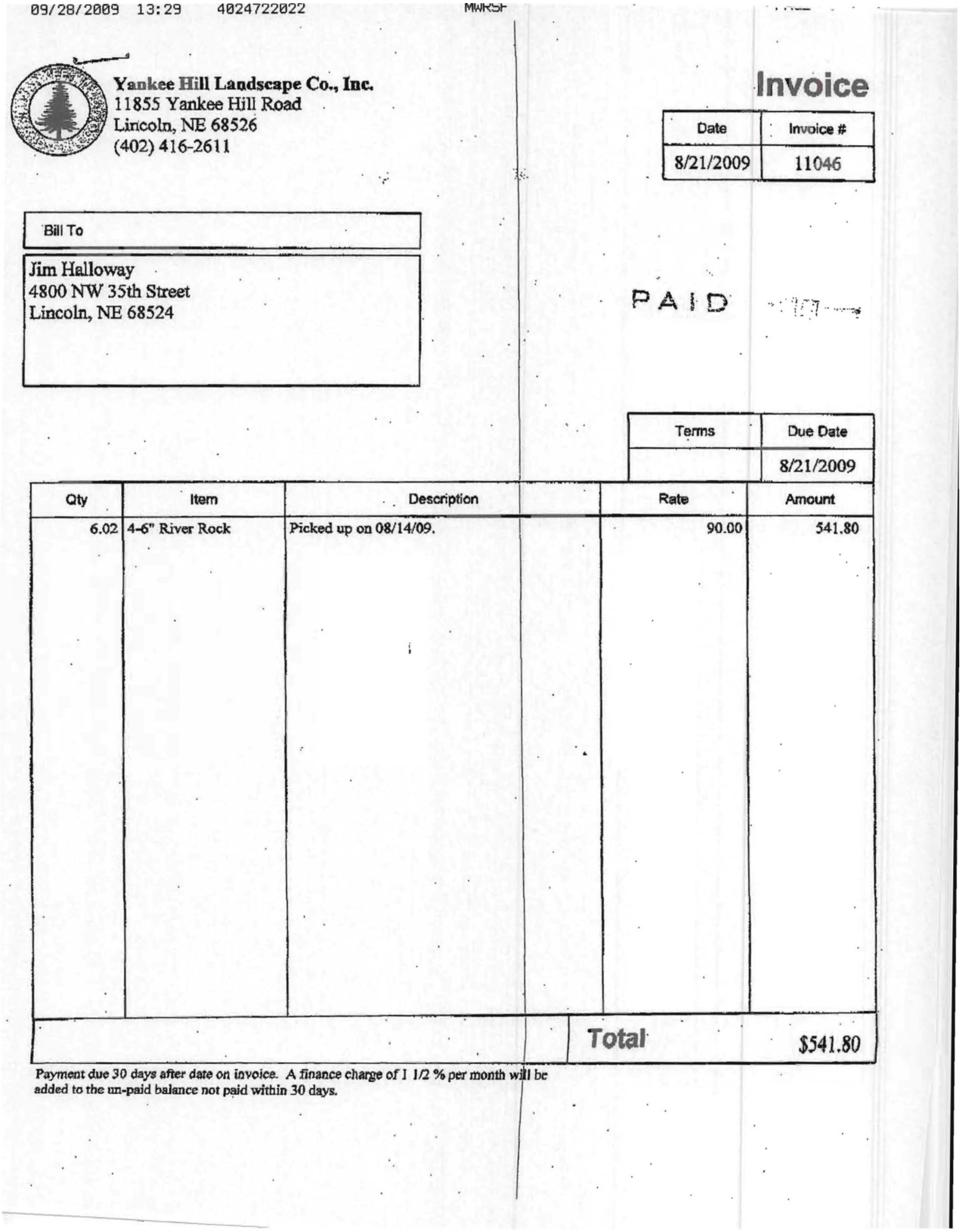
TOTAL POUNDS 12040 TONS 6.02

Subtotal
Tax
Total

SIGNATURE

№ 6603

Figure 105. Photo. Wall Facing Fill, Material Specification.



09/28/2009 13:29 4024722022 MWRSF

Yankee Hill Landscape Co., Inc.
11855 Yankee Hill Road
Lincoln, NE 68526
(402) 416-2611

Invoice

Date	Invoice #
8/21/2009	11046

Bill To

Jim Halloway
4800 NW 35th Street
Lincoln, NE 68524

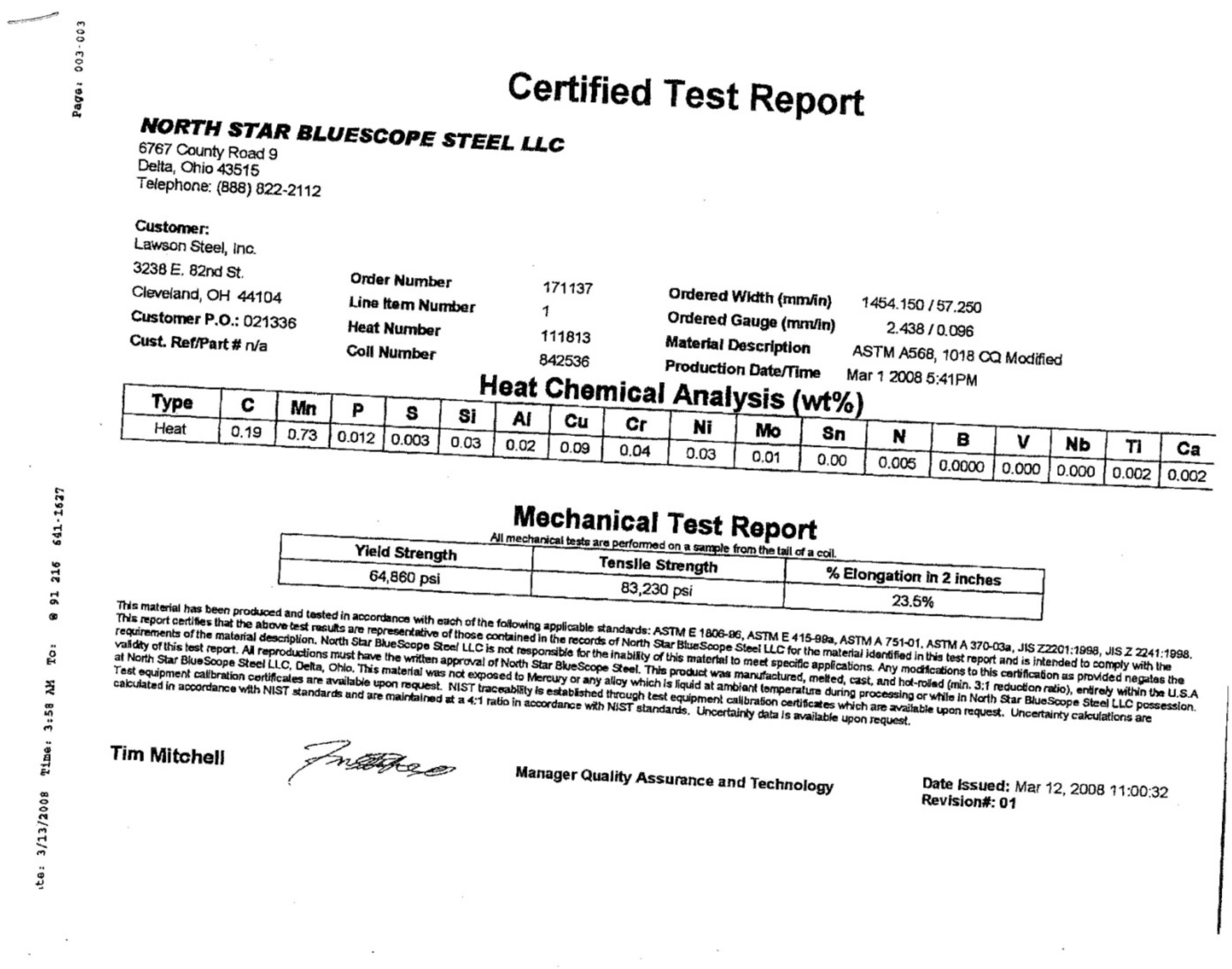
PAID

Terms	Due Date
	8/21/2009

Qty	Item	Description	Rate	Amount
6.02	4-6" River Rock	Picked up on 08/14/09.	90.00	541.80
			Total	$541.80

Payment due 30 days after date on invoice. A finance charge of 1 1/2 % per month will be added to the un-paid balance not paid within 30 days.

Figure 106. Photo. Wall Facing Fill, Material Specification.



te: 3/13/2008 Time: 3:58 AM To: @ 91 216 641-1627 Page: 003-003

Certified Test Report

NORTH STAR BLUESCOPE STEEL LLC
6767 County Road 9
Delta, Ohio 43515
Telephone: (888) 822-2112

Customer:
Lawson Steel, Inc.
3238 E. 82nd St.
Cleveland, OH 44104
Customer P.O.: 021336
Cust. Ref/Part # n/a

Order Number 171137
Line Item Number 1
Heat Number 111813
Coil Number 842536

Ordered Width (mm/in) 1454.150 / 57.250
Ordered Gauge (mm/in) 2.438 / 0.096
Material Description ASTM A568, 1018 CQ Modified
Production Date/Time Mar 1 2008 5:41PM

Heat Chemical Analysis (wt%)

Type	C	Mn	P	S	Si	Al	Cu	Cr	Ni	Mo	Sn	N	B	V	Nb	Ti	Ca
Heat	0.19	0.73	0.012	0.003	0.03	0.02	0.09	0.04	0.03	0.01	0.00	0.005	0.0000	0.000	0.000	0.002	0.002

Mechanical Test Report

All mechanical tests are performed on a sample from the tail of a coil.

Yield Strength	Tensile Strength	% Elongation in 2 inches
64,860 psi	83,230 psi	23.5%

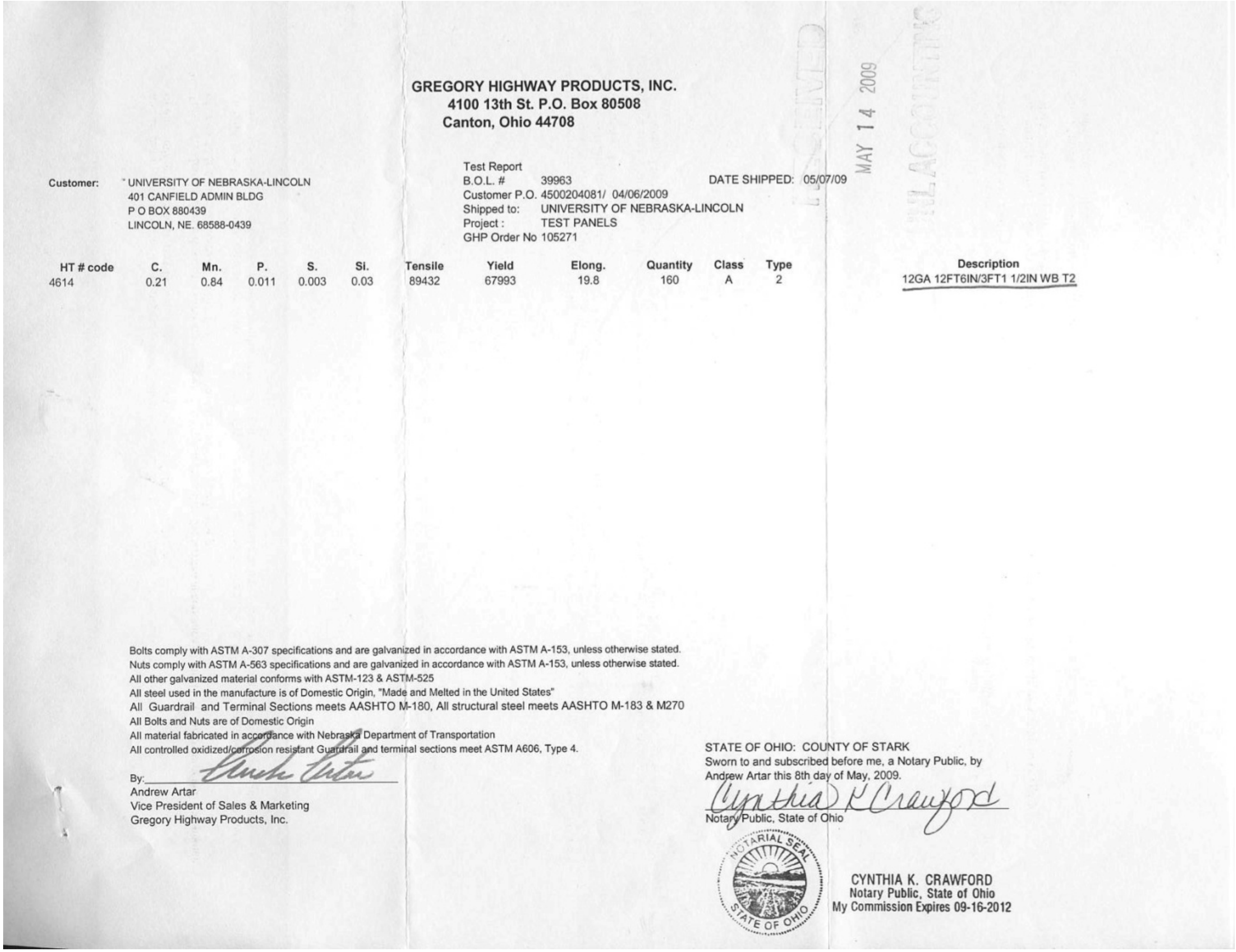
This material has been produced and tested in accordance with each of the following applicable standards: ASTM E 1806-96, ASTM E 415-99a, ASTM A 751-01, ASTM A 370-03a, JIS Z2201:1998, JIS Z 2241:1998. This report certifies that the above test results are representative of those contained in the records of North Star BlueScope Steel LLC for the material identified in this test report and is intended to comply with the requirements of the material description. North Star BlueScope Steel LLC is not responsible for the inability of this material to meet specific applications. Any modifications to this certification as provided negates the validity of this test report. All reproductions must have the written approval of North Star BlueScope Steel. This product was manufactured, melted, cast, and hot-rolled (min. 3:1 reduction ratio), entirely within the U.S.A at North Star BlueScope Steel LLC, Delta, Ohio. This material was not exposed to Mercury or any alloy which is liquid at ambient temperature during processing or while in North Star BlueScope Steel LLC possession. Test equipment calibration certificates are available upon request. NIST traceability is established through test equipment calibration certificates which are available upon request. Uncertainty calculations are calculated in accordance with NIST standards and are maintained at a 4:1 ratio in accordance with NIST standards. Uncertainty data is available upon request.

Tim Mitchell

Manager Quality Assurance and Technology

Date Issued: Mar 12, 2008 11:00:32
Revision#: 01

Figure 107. Photo. 6-ft 3-in. (1,905-mm) W-Beam Section, Material Specification.



GREGORY HIGHWAY PRODUCTS, INC.
4100 13th St. P.O. Box 80508
Canton, Ohio 44708

Customer: UNIVERSITY OF NEBRASKA-LINCOLN
401 CANFIELD ADMIN BLDG
P O BOX 880439
LINCOLN, NE. 68588-0439

Test Report
B.O.L. # 39963
DATE SHIPPED: 05/07/09
Customer P.O. 4500204081/ 04/06/2009
Shipped to: UNIVERSITY OF NEBRASKA-LINCOLN
Project : TEST PANELS
GHP Order No 105271

HT # code	C.	Mn.	P.	S.	Si.	Tensile	Yield	Elong.	Quantity	Class	Type	Description
4614	0.21	0.84	0.011	0.003	0.03	89432	67993	19.8	160	A	2	12GA 12FT6IN/3FT1 1/2IN WB T2

Bolts comply with ASTM A-307 specifications and are galvanized in accordance with ASTM A-153, unless otherwise stated.
Nuts comply with ASTM A-563 specifications and are galvanized in accordance with ASTM A-153, unless otherwise stated.
All other galvanized material conforms with ASTM-123 & ASTM-525
All steel used in the manufacture is of Domestic Origin, "Made and Melted in the United States"
All Guardrail and Terminal Sections meets AASHTO M-180, All structural steel meets AASHTO M-183 & M270
All Bolts and Nuts are of Domestic Origin
All material fabricated in accordance with Nebraska Department of Transportation
All controlled oxidized/corrosion resistant Guardrail and terminal sections meet ASTM A606, Type 4.

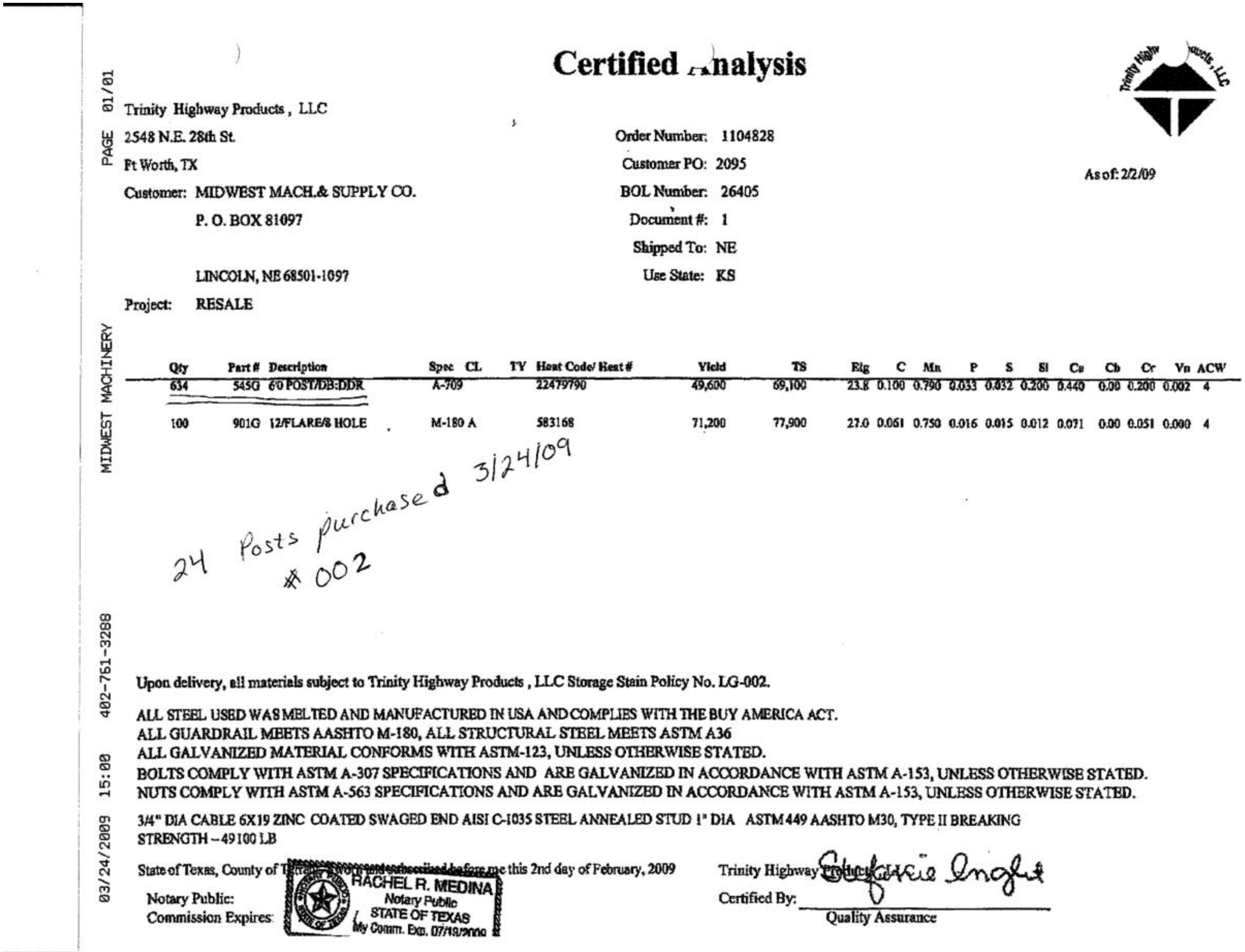
By:
Andrew Artar
Vice President of Sales & Marketing
Gregory Highway Products, Inc.

STATE OF OHIO: COUNTY OF STARK
Sworn to and subscribed before me, a Notary Public, by Andrew Artar this 8th day of May, 2009.

Cynthia K Crawford
Notary Public, State of Ohio

CYNTHIA K. CRAWFORD
Notary Public, State of Ohio
My Commission Expires 09-16-2012

Figure 108. Photo. 12-ft 6-in. (3,810-mm) W-Beam and Backup Plate, Material Specification.



03/24/2009 15:00 402-761-3288 MIDWEST MACHINERY PAGE 01/01

Certified Analysis

Trinity Highway Products, LLC
2548 N.E. 28th St.
Ft Worth, TX
Customer: MIDWEST MACH.& SUPPLY CO.
P. O. BOX 81097

LINCOLN, NE 68501-1097

Project: RESALE

Order Number: 1104828
Customer PO: 2095
BOL Number: 26405
Document #: 1
Shipped To: NE
Use State: KS

As of: 2/2/09

Qty	Part #	Description	Spec	CL	TY	Heat Code/ Heat #	Yield	TS	Elg	C	Mn	P	S	Si	Cu	Cb	Cr	Vn	ACW
634	545G	6'0 POST/DB:DDR	A-709			22479790	49,600	69,100	23.8	0.100	0.790	0.033	0.032	0.200	0.440	0.00	0.200	0.002	4
100	901G	12/FLARE/8 HOLE	M-180 A			583168	71,200	77,900	27.0	0.061	0.750	0.016	0.015	0.012	0.071	0.00	0.051	0.000	4

24 Posts purchased 3/24/09
#002

Upon delivery, all materials subject to Trinity Highway Products, LLC Storage Stain Policy No. LG-002.

ALL STEEL USED WAS MELTED AND MANUFACTURED IN USA AND COMPLIES WITH THE BUY AMERICA ACT.
ALL GUARDRAIL MEETS AASHTO M-180, ALL STRUCTURAL STEEL MEETS ASTM A36
ALL GALVANIZED MATERIAL CONFORMS WITH ASTM-123, UNLESS OTHERWISE STATED.
BOLTS COMPLY WITH ASTM A-307 SPECIFICATIONS AND ARE GALVANIZED IN ACCORDANCE WITH ASTM A-153, UNLESS OTHERWISE STATED.
NUTS COMPLY WITH ASTM A-563 SPECIFICATIONS AND ARE GALVANIZED IN ACCORDANCE WITH ASTM A-153, UNLESS OTHERWISE STATED.

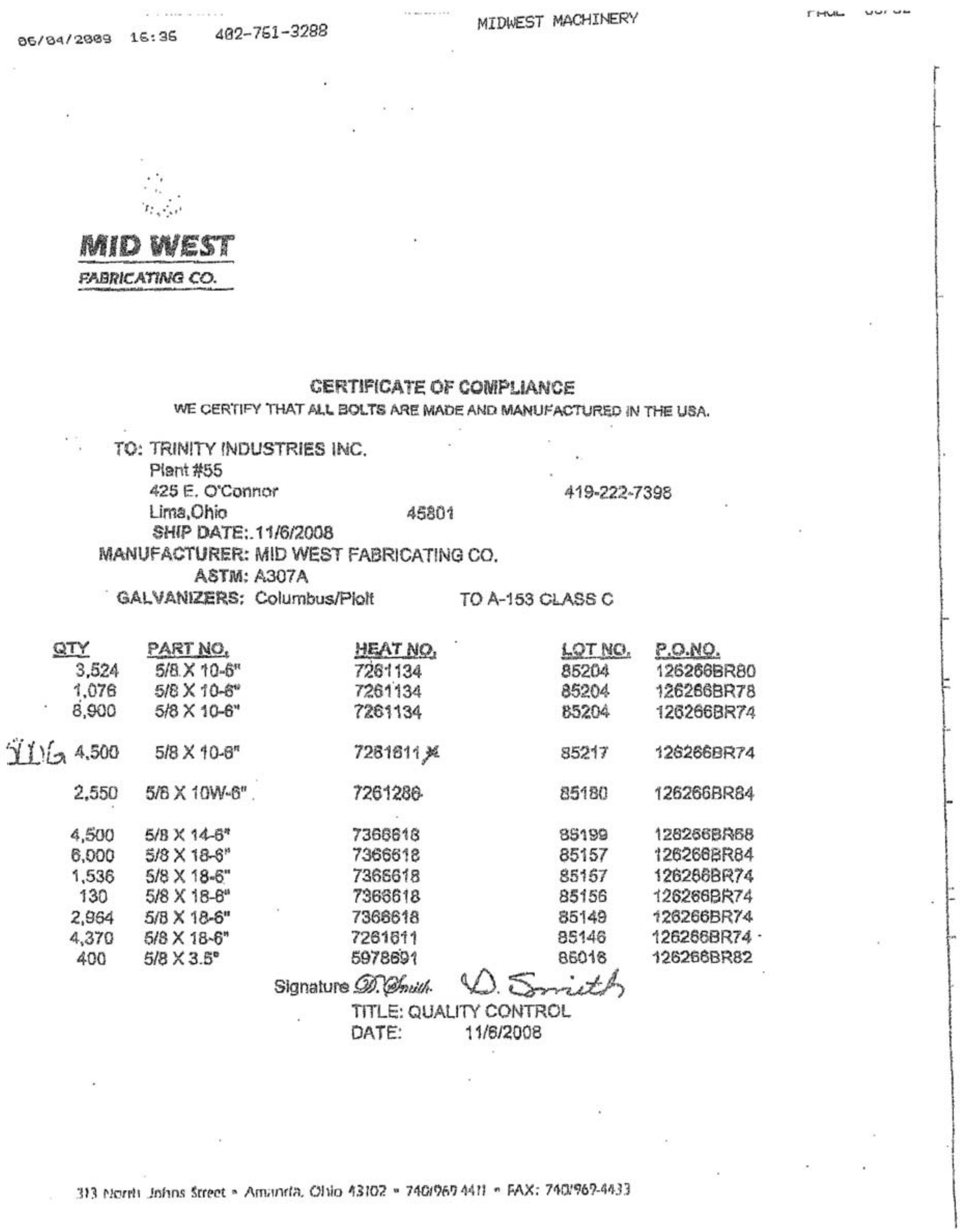
3/4" DIA CABLE 6X19 ZINC COATED SWAGED END AISI C-1035 STEEL ANNEALED STUD 1" DIA ASTM 449 AASHTO M30, TYPE II BREAKING STRENGTH – 49100 LB

State of Texas, County of T[illegible] [illegible] subscribed before me this 2nd day of February, 2009
Notary Public:
Commission Expires:

RACHEL R. MEDINA
Notary Public
STATE OF TEXAS
My Comm. Exp. 07/19/2009

Trinity Highway Products, LLC
Certified By:
Quality Assurance

Figure 109. Photo. W6x8.5 (W152x12.6) Steel Posts, Material Specification.



06/04/2009 16:36 402-761-3288 MIDWEST MACHINERY

MID WEST
FABRICATING CO.

CERTIFICATE OF COMPLIANCE

WE CERTIFY THAT ALL BOLTS ARE MADE AND MANUFACTURED IN THE USA.

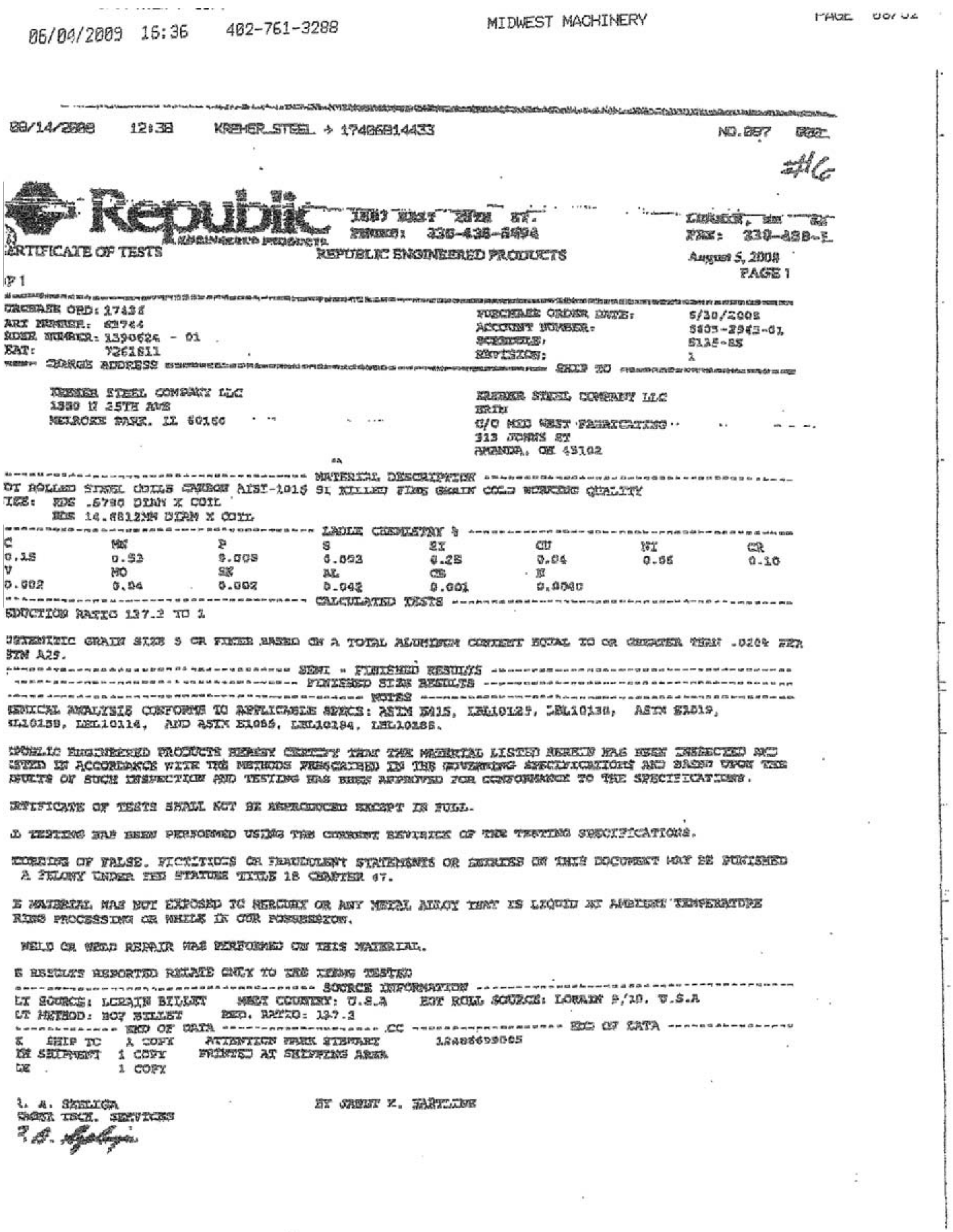
TO: TRINITY INDUSTRIES INC.
Plant #55
425 E. O'Connor 419-222-7398
Lima,Ohio 45801
SHIP DATE:.11/6/2008
MANUFACTURER: MID WEST FABRICATING CO.
ASTM: A307A
GALVANIZERS: Columbus/Piolt TO A-153 CLASS C

QTY	PART NO.	HEAT NO.	LOT NO.	P.O.NO.
3,524	5/8 X 10-6"	7261134	85204	126266BR80
1,076	5/8 X 10-6"	7261134	85204	126266BR78
8,900	5/8 X 10-6"	7261134	85204	126266BR74
YDG 4,500	5/8 X 10-6"	7261611	85217	126266BR74
2,550	5/8 X 10W-6"	7261286	85180	126266BR84
4,500	5/8 X 14-6"	7366618	85199	128266BR68
6,000	5/8 X 18-6"	7366618	85157	126266BR84
1,536	5/8 X 18-6"	7366618	85157	126266BR74
130	5/8 X 18-6"	7366618	85156	126266BR74
2,964	5/8 X 18-6"	7366618	85149	126266BR74
4,370	5/8 X 18-6"	7261611	85146	126266BR74
400	5/8 X 3.5"	5978691	85016	126266BR82

Signature D. Smith D. Smith
TITLE: QUALITY CONTROL
DATE: 11/6/2008

313 North Johns Street • Amanda, Ohio 43102 • 740/969-4411 • FAX: 740/969-4433

Figure 110. Photo. ⅝-in. (15.9-mm) Guardrail Bolts, Material Specification.



06/04/2009 16:36 402-761-3288 MIDWEST MACHINERY PAGE 08/02

08/14/2008 12:38 KREHER_STEEL → 17406814433 NO.087 002

#6

Republic ENGINEERED PRODUCTS

1807 EAST 28TH ST. LORAIN, OH

PHONE: 330-438-5494 FAX: 330-438-

ERTIFICATE OF TESTS

REPUBLIC ENGINEERED PRODUCTS

August 5, 2008
PAGE 1

P 1

URCHASE ORD: 17436
ART NUMBER: 62744
RDER NUMBER: 1390626 - 01
EAT: 7261811

PURCHASE ORDER DATE: 5/30/2008
ACCOUNT NUMBER: 5605-2943-01
SCHEDULE: 5135-85
REVISION: 1

CHARGE ADDRESS

KREHER STEEL COMPANY LLC
1550 N 25TH AVE
MELROSE PARK, IL 60160

SHIP TO

KREHER STEEL COMPANY LLC
BRIAN
C/O MID WEST FABRICATING
313 JOHNS ST
AMANDA, OH 43102

MATERIAL DESCRIPTION

OT ROLLED STEEL COILS CARBON AISI-1018 SI KILLED FINE GRAIN COLD WORKING QUALITY
IZE: RDS .5780 DIAM X COIL
RDS 14.6812MM DIAM X COIL

LADLE CHEMISTRY %

C	MN	P	S	SI	CU	NI	CR
0.15	0.52	0.008	0.003	0.25	0.04	0.06	0.10
V	MO	SN	AL	CB	N		
0.002	0.04	0.002	0.042	0.001	0.0040		

CALCULATED TESTS

EDUCTION RATIO 137.2 TO 1

USTENITIC GRAIN SIZE 5 OR FINER BASED ON A TOTAL ALUMINUM CONTENT EQUAL TO OR GREATER THAN .020% PER STM A29.

SEMI - FINISHED RESULTS

FINISHED SIZE RESULTS

NOTES

HEMICAL ANALYSIS CONFORMS TO APPLICABLE SPECS: ASTM E415, LEL10129, LEL10138, ASTM E1019, LL10159, LEL10114, AND ASTM E1086, LEL10194, LEL10188.

EPUBLIC ENGINEERED PRODUCTS HEREBY CERTIFY THAT THE MATERIAL LISTED HEREIN HAS BEEN INSPECTED AND ESTED IN ACCORDANCE WITH THE METHODS PRESCRIBED IN THE GOVERNING SPECIFICATIONS AND BASED UPON THE ESULTS OF SUCH INSPECTION AND TESTING HAS BEEN APPROVED FOR CONFORMANCE TO THE SPECIFICATIONS.

ERTIFICATE OF TESTS SHALL NOT BE REPRODUCED EXCEPT IN FULL.

LL TESTING HAS BEEN PERFORMED USING THE CURRENT REVISION OF THE TESTING SPECIFICATIONS.

ECORDING OF FALSE, FICTITIOUS OR FRAUDULENT STATEMENTS OR ENTRIES ON THIS DOCUMENT MAY BE PUNISHED A FELONY UNDER FED STATUTE TITLE 18 CHAPTER 47.

E MATERIAL WAS NOT EXPOSED TO MERCURY OR ANY METAL ALLOY THAT IS LIQUID AT AMBIENT TEMPERATURE RING PROCESSING OR WHILE IN OUR POSSESSION.

WELD OR WELD REPAIR WAS PERFORMED ON THIS MATERIAL.

E RESULTS REPORTED RELATE ONLY TO THE ITEMS TESTED

SOURCE INFORMATION

LT SOURCE: LORAIN BILLET MELT COUNTRY: U.S.A HOT ROLL SOURCE: LORAIN 9/10, U.S.A
LT METHOD: BOF BILLET RED. RATIO: 137.2

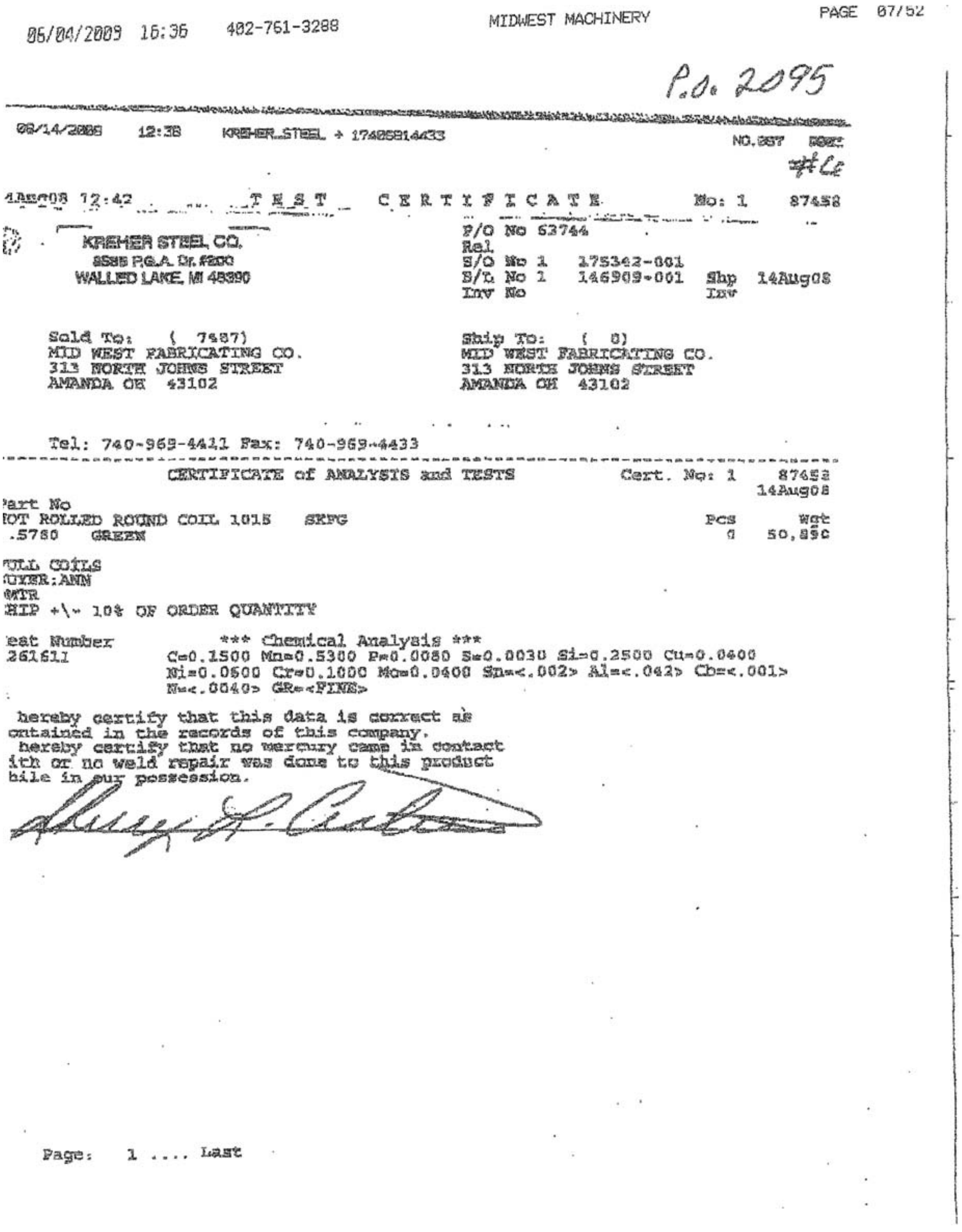
END OF DATA .CC END OF DATA

S SHIP TO 1 COPY ATTENTION MARK STEWART 12486699005
TH SHIPMENT 1 COPY PRINTED AT SHIPPING AREA
DE 1 COPY

R. A. SKELIGA
MGR. TECH. SERVICES
R. A. Skeliga

BY GRANT K. HARTLINE

Figure 111. Photo. ⅝-in. (15.9-mm) Guardrail Bolts, Material Specification. (continued.)



06/04/2009 16:36 402-761-3288 MIDWEST MACHINERY PAGE 07/52

P.O. 2095

08/14/2008 12:38 KREHER_STEEL + 17406914433 NO.887

#6

14Aug08 12:42 TEST CERTIFICATE No: 1 87458

KREHER STEEL CO.
8585 P.G.A. Dr. #200
WALLED LAKE, MI 48390

P/O No 63744
Rel
S/O No 1 175342-001
B/L No 1 146909-001 Shp 14Aug08
Inv No Inv

Sold To: (7487)
MID WEST FABRICATING CO.
313 NORTH JOHNS STREET
AMANDA OH 43102

Ship To: (0)
MID WEST FABRICATING CO.
313 NORTH JOHNS STREET
AMANDA OH 43102

Tel: 740-969-4411 Fax: 740-969-4433

CERTIFICATE of ANALYSIS and TESTS Cert. No: 1 87458
14Aug08

art No
OT ROLLED ROUND COIL 1015 SKFG
.5780 GREEN

	Pcs	Wgt
	0	50,890

ULL COILS
UYER:ANN
MTR
HIP +\- 10% OF ORDER QUANTITY

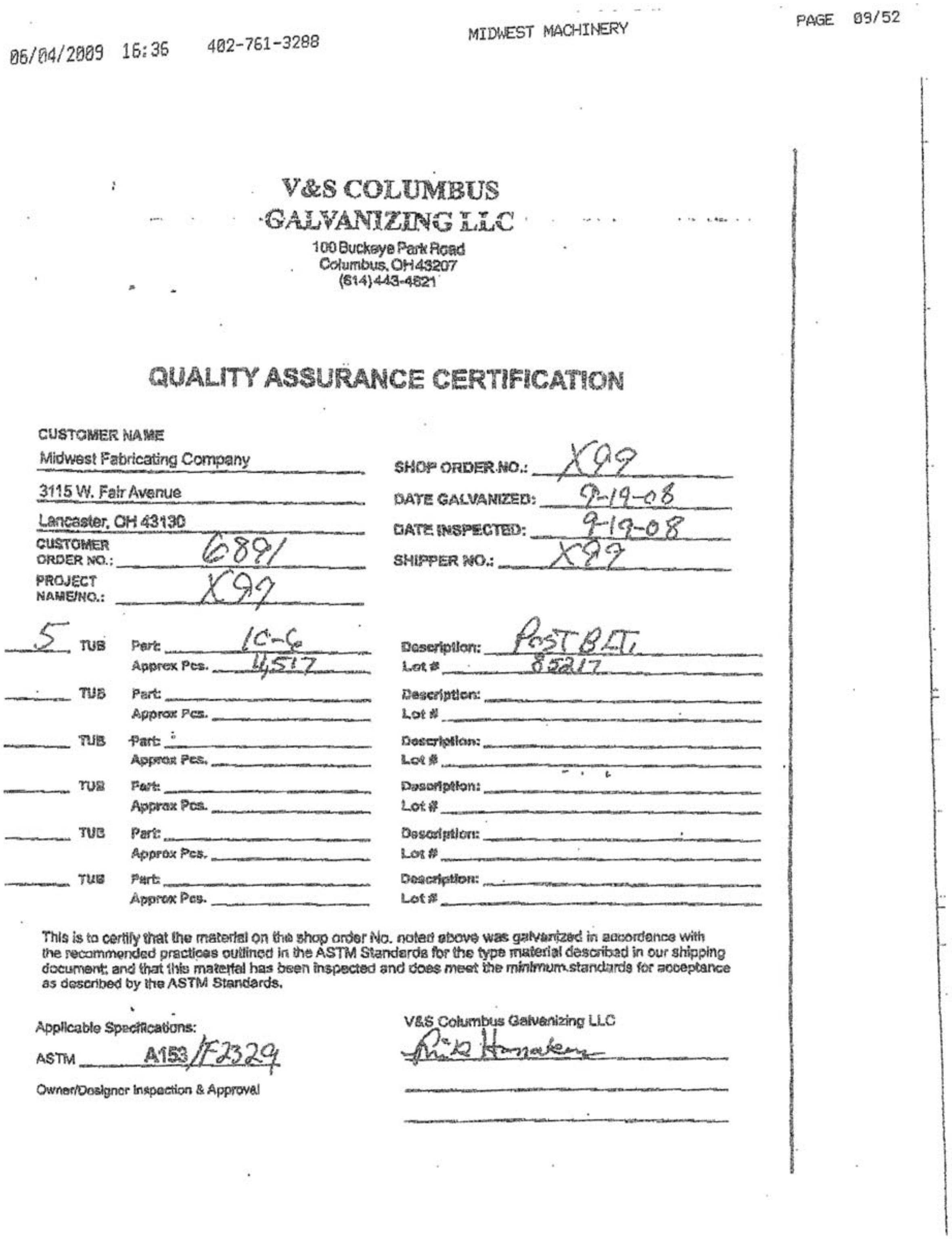
eat Number
261611

*** Chemical Analysis ***
C=0.1500 Mn=0.5300 P=0.0080 S=0.0030 Si=0.2500 Cu=0.0400
Ni=0.0600 Cr=0.1000 Mo=0.0400 Sn=<.002> Al=<.042> Cb=<.001>
N=<.0040> GR=<FINE>

hereby certify that this data is correct as
ontained in the records of this company.
hereby certify that no mercury came in contact
ith or no weld repair was done to this product
hile in our possession.

Page: 1 .... Last

Figure 112. Photo. ⅝-in. (15.9-mm) Guardrail Bolts, Material Specification. (continued.)



06/04/2009 16:36 402-761-3288 MIDWEST MACHINERY PAGE 09/52

V&S COLUMBUS GALVANIZING LLC

100 Buckeye Park Road
Columbus, OH 43207
(614) 443-4621

QUALITY ASSURANCE CERTIFICATION

CUSTOMER NAME
Midwest Fabricating Company
3115 W. Fair Avenue
Lancaster, OH 43130

CUSTOMER ORDER NO.: 6891
PROJECT NAME/NO.: X99

SHOP ORDER NO.: X99
DATE GALVANIZED: 9-19-08
DATE INSPECTED: 9-19-08
SHIPPER NO.: X99

5 TUB Part: 10-6 Description: POST BLT.
Approx Pcs. 4,517 Lot # 85217

TUB Part: Description:
Approx Pcs. Lot #

TUB Part: Description:
Approx Pcs. Lot #

TUB Part: Description:
Approx Pcs. Lot #

TUB Part: Description:
Approx Pcs. Lot #

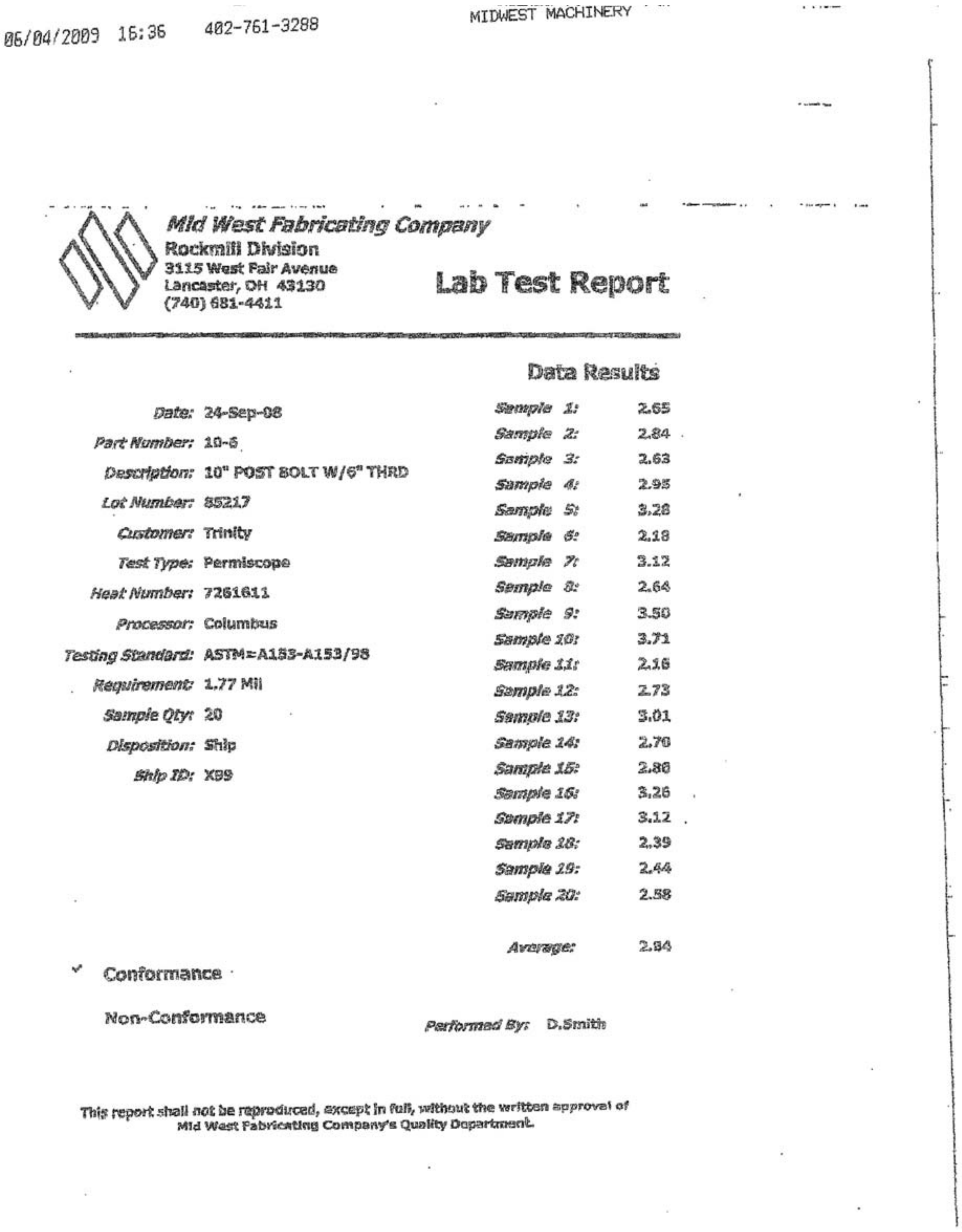
TUB Part: Description:
Approx Pcs. Lot #

This is to certify that the material on the shop order No. noted above was galvanized in accordance with the recommended practices outlined in the ASTM Standards for the type material described in our shipping document; and that this material has been inspected and does meet the minimum standards for acceptance as described by the ASTM Standards.

Applicable Specifications:
ASTM A153/F2329
Owner/Designer Inspection & Approval

V&S Columbus Galvanizing LLC
Rick Honaker

Figure 113. Photo. ⅝-in. (15.9-mm) Guardrail Bolts, Material Specification. (continued.)



06/04/2009 16:36 402-761-3288 MIDWEST MACHINERY

Mid West Fabricating Company
Rockmill Division
3115 West Fair Avenue
Lancaster, OH 43130
(740) 681-4411

Lab Test Report

Date:	24-Sep-08
Part Number:	10-6
Description:	10" POST BOLT W/6" THRD
Lot Number:	85217
Customer:	Trinity
Test Type:	Permiscope
Heat Number:	7261611
Processor:	Columbus
Testing Standard:	ASTM=A153-A153/98
Requirement:	1.77 Mil
Sample Qty:	20
Disposition:	Ship
Ship ID:	X99

Data Results

Sample 1:	2.65
Sample 2:	2.84
Sample 3:	2.63
Sample 4:	2.95
Sample 5:	3.28
Sample 6:	2.18
Sample 7:	3.12
Sample 8:	2.64
Sample 9:	3.50
Sample 10:	3.71
Sample 11:	2.16
Sample 12:	2.73
Sample 13:	3.01
Sample 14:	2.70
Sample 15:	2.86
Sample 16:	3.26
Sample 17:	3.12
Sample 18:	2.39
Sample 19:	2.44
Sample 20:	2.58
Average:	2.84

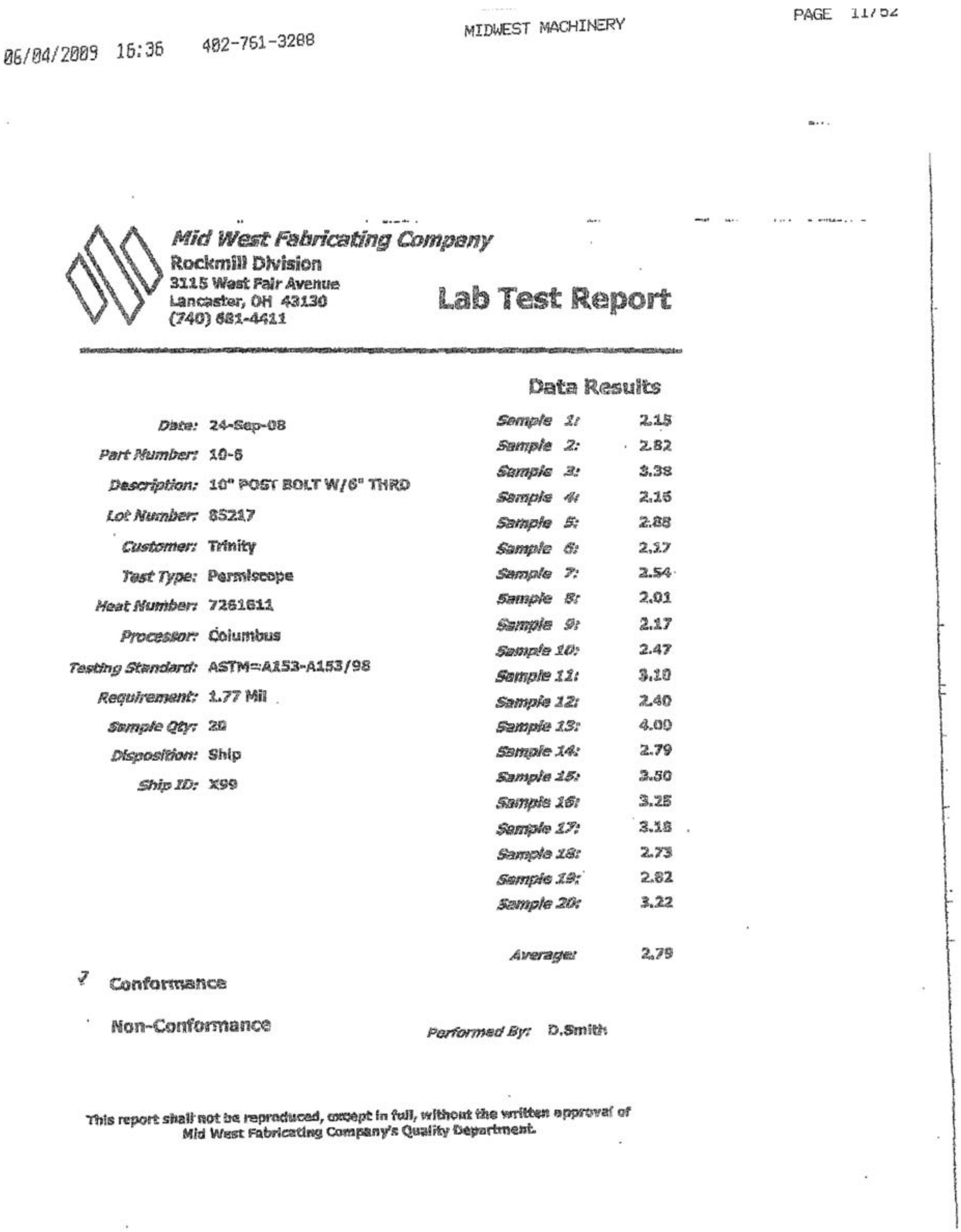
✓ Conformance

Non-Conformance

Performed By: D.Smith

This report shall not be reproduced, except in full, without the written approval of Mid West Fabricating Company's Quality Department.

Figure 114. Photo. ⅝-in. (15.9-mm) Guardrail Bolts, Material Specification. (continued.)



06/04/2009 16:36 402-761-3288 MIDWEST MACHINERY PAGE 11/52

Mid West Fabricating Company
Rockmill Division
3115 West Fair Avenue
Lancaster, OH 43130
(740) 681-4411

Lab Test Report

Date: 24-Sep-08
Part Number: 10-6
Description: 10" POST BOLT W/6" THRD
Lot Number: 85217
Customer: Trinity
Test Type: Permiscope
Heat Number: 7261611
Processor: Columbus
Testing Standard: ASTM=A153-A153/98
Requirement: 1.77 Mil
Sample Qty: 20
Disposition: Ship
Ship ID: X99

Data Results

Sample 1:	2.15
Sample 2:	2.82
Sample 3:	3.38
Sample 4:	2.16
Sample 5:	2.88
Sample 6:	2.17
Sample 7:	2.54
Sample 8:	2.01
Sample 9:	2.17
Sample 10:	2.47
Sample 11:	3.10
Sample 12:	2.40
Sample 13:	4.00
Sample 14:	2.79
Sample 15:	3.50
Sample 16:	3.25
Sample 17:	3.18
Sample 18:	2.73
Sample 19:	2.82
Sample 20:	3.22
Average:	2.79

[✓ Conformance]

Non-Conformance

Performed By: D.Smith

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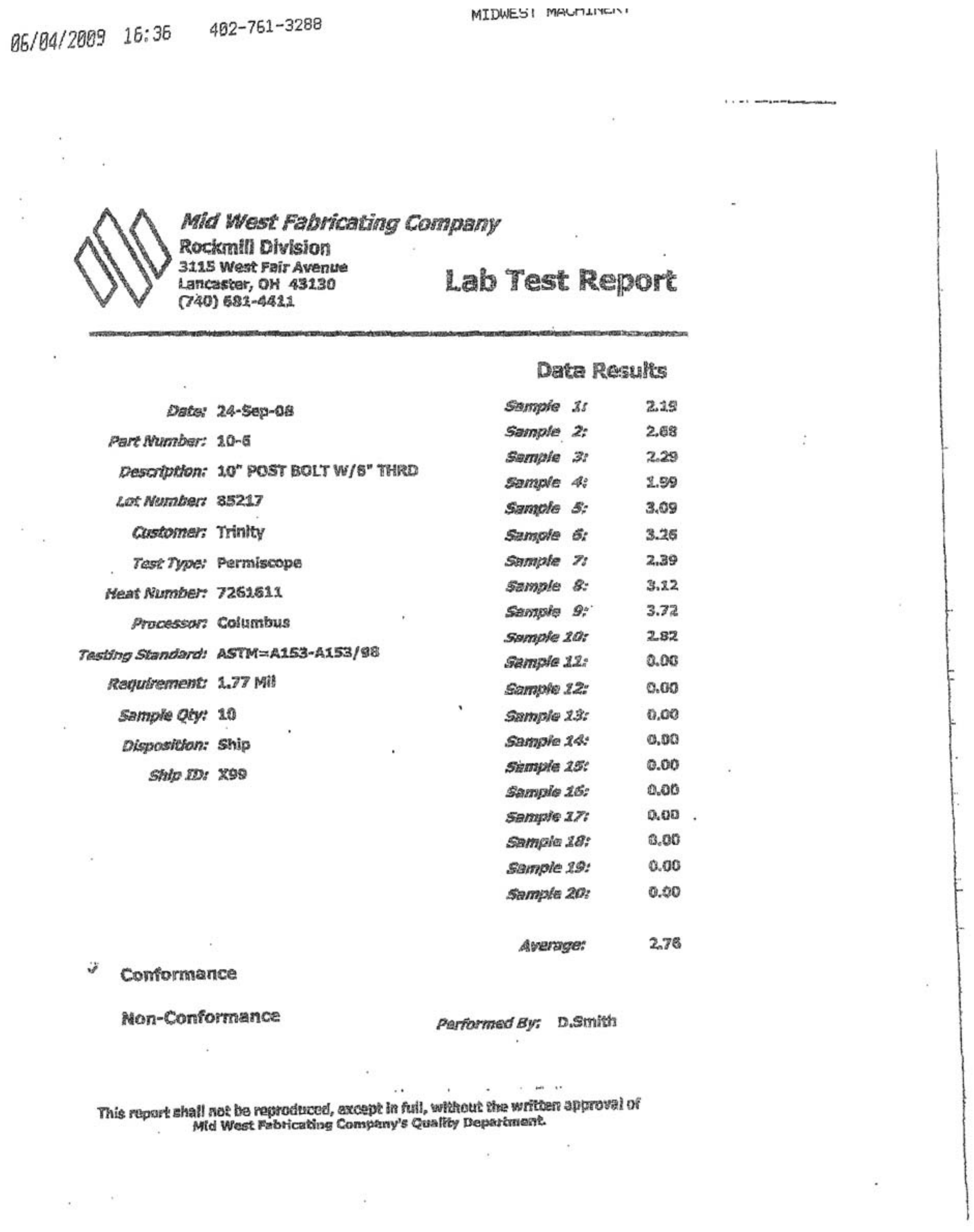
Figure 115. Photo. ⅝-in. (15.9-mm) Guardrail Bolts, Material Specification. (continued.)



06/04/2009 16:36 402-761-3288 MIDWEST MACHINERY

Mid West Fabricating Company
Rockmill Division
3115 West Fair Avenue
Lancaster, OH 43130
(740) 681-4411

Lab Test Report

Date: 24-Sep-08
Part Number: 10-6
Description: 10" POST BOLT W/6" THRD
Lot Number: 85217
Customer: Trinity
Test Type: Permiscope
Heat Number: 7261611
Processor: Columbus
Testing Standard: ASTM=A153-A153/98
Requirement: 1.77 Mil
Sample Qty: 10
Disposition: Ship
Ship ID: X99

Data Results

Sample 1:	2.19
Sample 2:	2.68
Sample 3:	2.29
Sample 4:	1.99
Sample 5:	3.09
Sample 6:	3.26
Sample 7:	2.39
Sample 8:	3.12
Sample 9:	3.72
Sample 10:	2.82
Sample 11:	0.00
Sample 12:	0.00
Sample 13:	0.00
Sample 14:	0.00
Sample 15:	0.00
Sample 16:	0.00
Sample 17:	0.00
Sample 18:	0.00
Sample 19:	0.00
Sample 20:	0.00
Average:	2.76

✓ Conformance

Non-Conformance

Performed By: D.Smith

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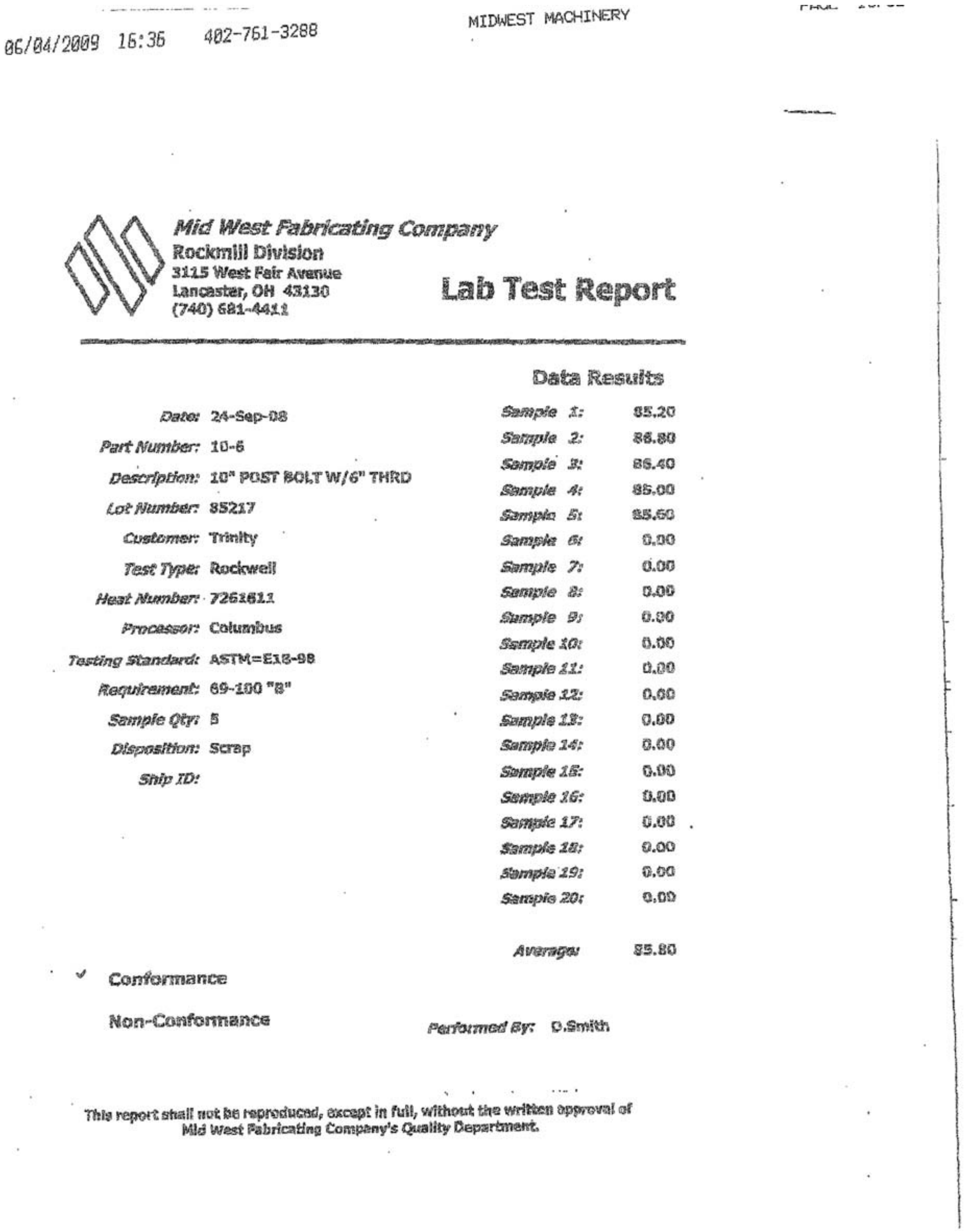
Figure 116. Photo. ⅝-in. (15.9-mm) Guardrail Bolts, Material Specification. (continued.)



06/04/2009 16:36 402-761-3288 MIDWEST MACHINERY

Mid West Fabricating Company
Rockmill Division
3115 West Fair Avenue
Lancaster, OH 43130
(740) 681-4411

Lab Test Report

Date: 24-Sep-08
Part Number: 10-6
Description: 10" POST BOLT W/6" THRD
Lot Number: 85217
Customer: Trinity
Test Type: Rockwell
Heat Number: 7261611
Processor: Columbus
Testing Standard: ASTM=E18-98
Requirement: 69-100 "B"
Sample Qty: 5
Disposition: Scrap
Ship ID:

Data Results

Sample 1:	85.20
Sample 2:	86.80
Sample 3:	86.40
Sample 4:	85.00
Sample 5:	85.60
Sample 6:	0.00
Sample 7:	0.00
Sample 8:	0.00
Sample 9:	0.00
Sample 10:	0.00
Sample 11:	0.00
Sample 12:	0.00
Sample 13:	0.00
Sample 14:	0.00
Sample 15:	0.00
Sample 16:	0.00
Sample 17:	0.00
Sample 18:	0.00
Sample 19:	0.00
Sample 20:	0.00
Average:	85.80

✓ Conformance

Non-Conformance

Performed By: D.Smith

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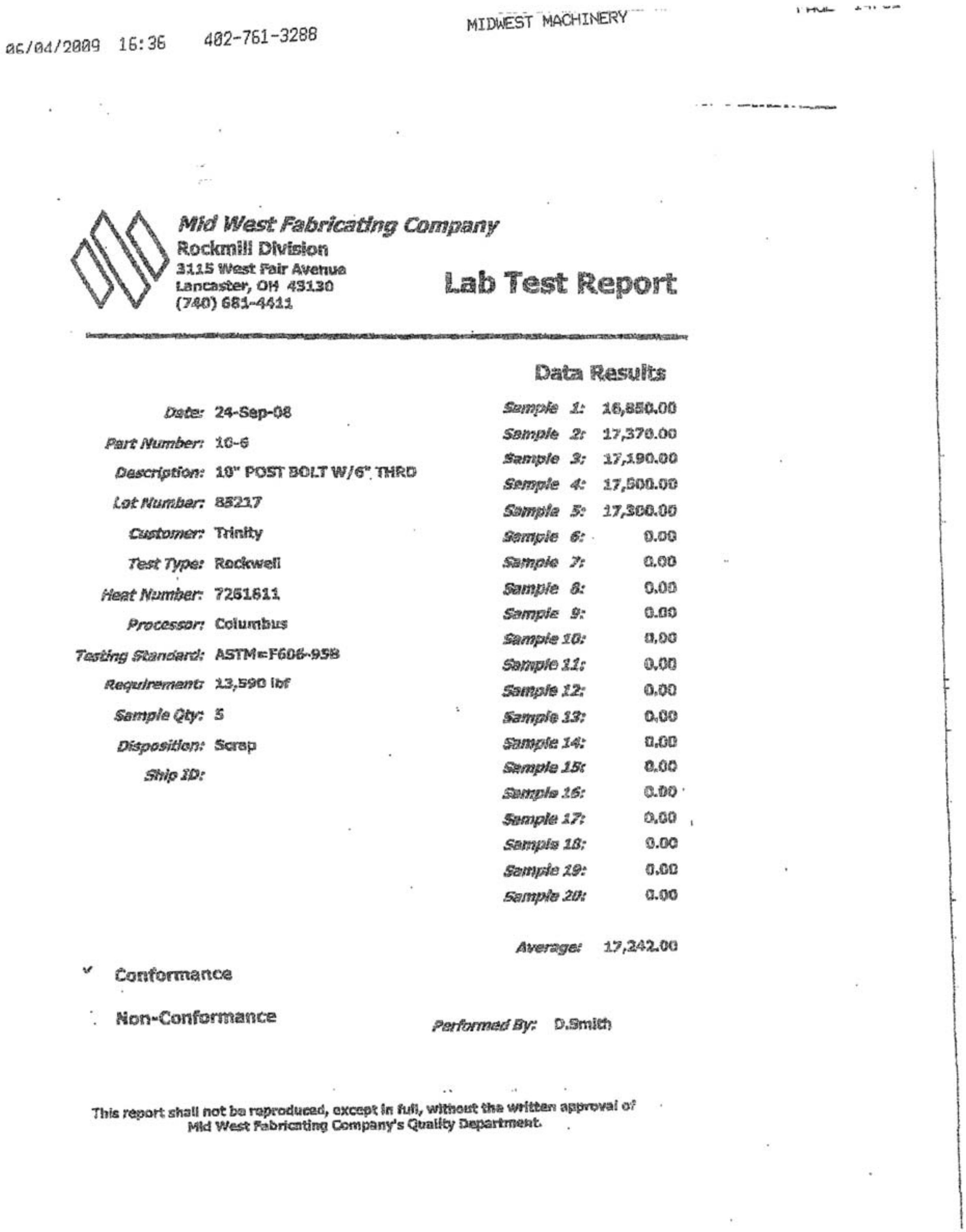
Figure 117. Photo. ⅝-in. (15.9-mm) Guardrail Bolts, Material Specification. (continued.)



06/04/2009 16:36 402-761-3288 MIDWEST MACHINERY

Mid West Fabricating Company
Rockmill Division
3115 West Fair Avenue
Lancaster, OH 43130
(740) 681-4411

Lab Test Report

Date: 24-Sep-08
Part Number: 10-6
Description: 10" POST BOLT W/6" THRD
Lot Number: 88217
Customer: Trinity
Test Type: Rockwell
Heat Number: 7261611
Processor: Columbus
Testing Standard: ASTM=F606-95B
Requirement: 13,590 lbf
Sample Qty: 5
Disposition: Scrap
Ship ID:

Data Results

Sample 1:	16,850.00
Sample 2:	17,370.00
Sample 3:	17,190.00
Sample 4:	17,500.00
Sample 5:	17,300.00
Sample 6:	0.00
Sample 7:	0.00
Sample 8:	0.00
Sample 9:	0.00
Sample 10:	0.00
Sample 11:	0.00
Sample 12:	0.00
Sample 13:	0.00
Sample 14:	0.00
Sample 15:	0.00
Sample 16:	0.00
Sample 17:	0.00
Sample 18:	0.00
Sample 19:	0.00
Sample 20:	0.00
Average:	17,242.00

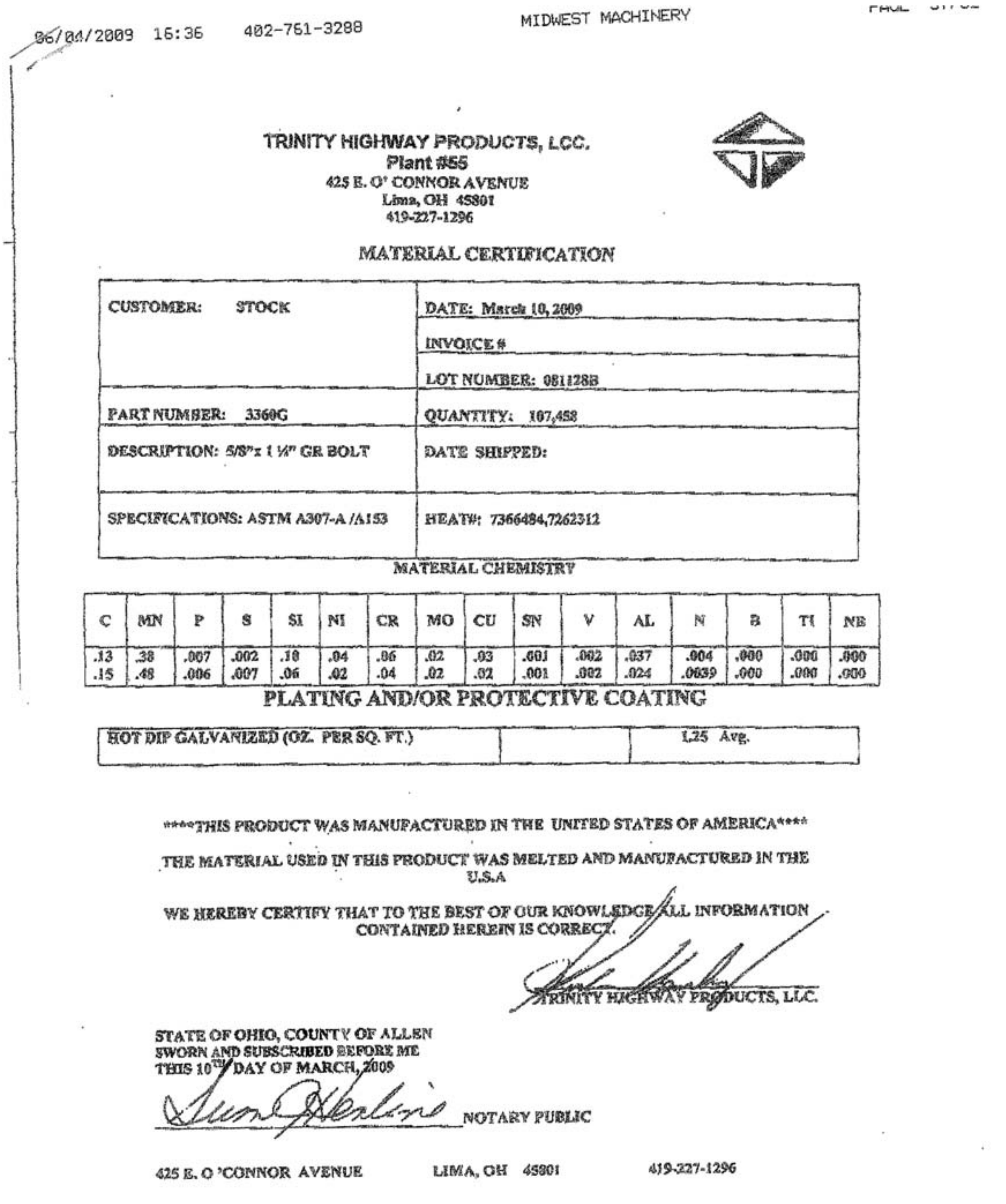
✓ Conformance

Non-Conformance

Performed By: D.Smith

This report shall not be reproduced, except in full, without the written approval of Mid West Fabricating Company's Quality Department.

Figure 118. Photo. ⅝-in. (15.9-mm) Guardrail Bolts, Material Specification. (continued.)



06/04/2009 16:36 402-761-3288 MIDWEST MACHINERY

TRINITY HIGHWAY PRODUCTS, LCC.
Plant #55
425 E. O' CONNOR AVENUE
Lima, OH 45801
419-227-1296

MATERIAL CERTIFICATION

CUSTOMER: STOCK	DATE: March 10, 2009
	INVOICE #
	LOT NUMBER: 081128B
PART NUMBER: 3360G	QUANTITY: 107,458
DESCRIPTION: 5/8"x 1 ½" GR BOLT	DATE SHIPPED:
SPECIFICATIONS: ASTM A307-A /A153	HEAT#: 7366484,7262312

MATERIAL CHEMISTRY

C	MN	P	S	SI	NI	CR	MO	CU	SN	V	AL	N	B	TI	NB
.13	.38	.007	.002	.18	.04	.06	.02	.03	.001	.002	.037	.004	.000	.000	.000
.15	.48	.006	.007	.06	.02	.04	.02	.02	.001	.002	.024	.0039	.000	.000	.000

PLATING AND/OR PROTECTIVE COATING

HOT DIP GALVANIZED (OZ. PER SQ. FT.)		1.25 Avg.

****THIS PRODUCT WAS MANUFACTURED IN THE UNITED STATES OF AMERICA****

THE MATERIAL USED IN THIS PRODUCT WAS MELTED AND MANUFACTURED IN THE U.S.A

WE HEREBY CERTIFY THAT TO THE BEST OF OUR KNOWLEDGE ALL INFORMATION CONTAINED HEREIN IS CORRECT.

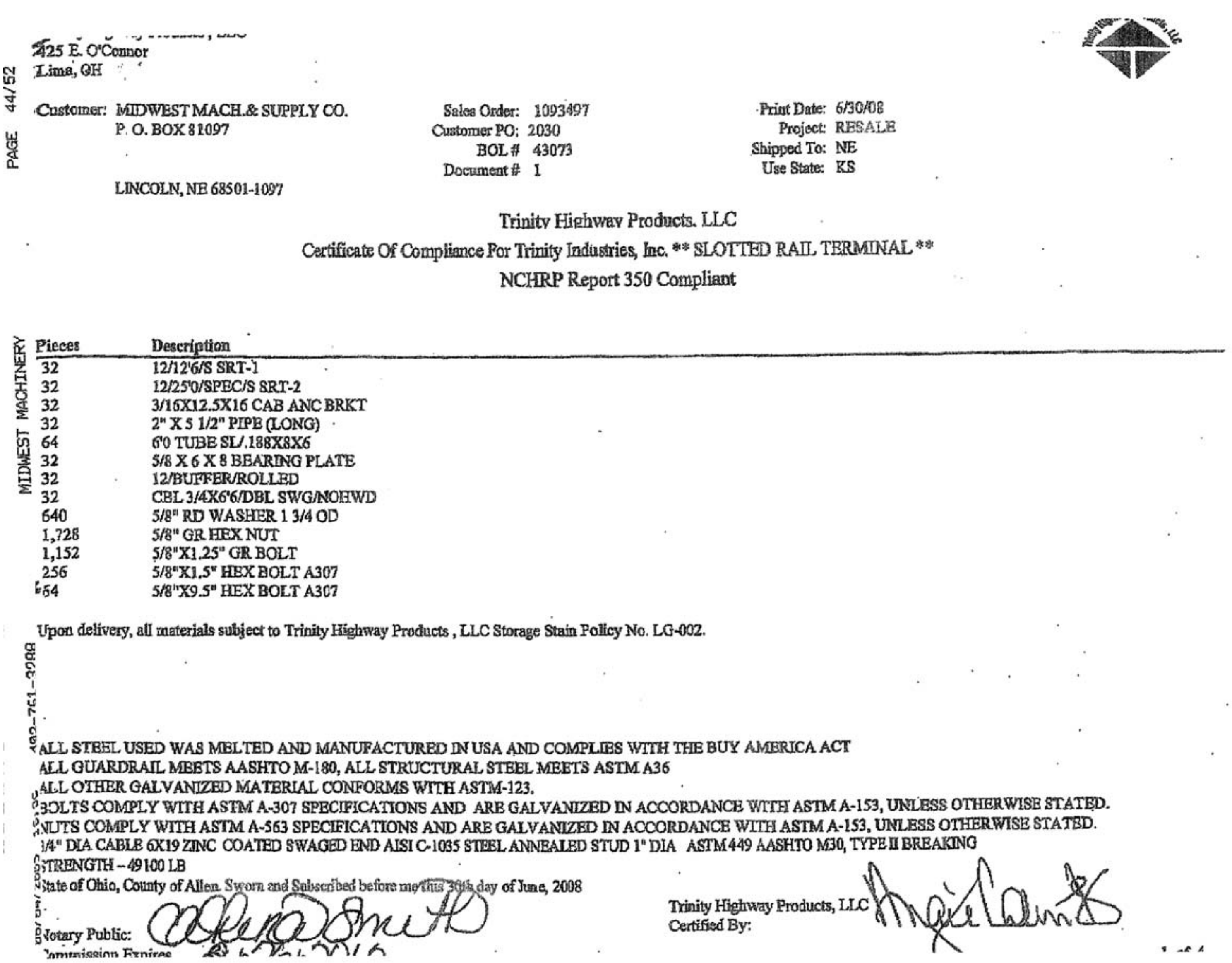
TRINITY HIGHWAY PRODUCTS, LLC.

STATE OF OHIO, COUNTY OF ALLEN
SWORN AND SUBSCRIBED BEFORE ME
THIS 10TH DAY OF MARCH, 2009

NOTARY PUBLIC

425 E. O 'CONNOR AVENUE LIMA, OH 45801 419-227-1296

Figure 119. Photo. ⅝-in. x 1½-in (15.9x38-mm) Splicebolts, Material Specification.



PAGE 44/52

425 E. O'Connor
Lima, OH

Customer: MIDWEST MACH.& SUPPLY CO.
P. O. BOX 81097

LINCOLN, NE 68501-1097

Sales Order: 1093497
Customer PO: 2030
BOL # 43073
Document # 1

Print Date: 6/30/08
Project: RESALE
Shipped To: NE
Use State: KS

Trinity Highway Products, LLC

Certificate Of Compliance For Trinity Industries, Inc. ** SLOTTED RAIL TERMINAL **

NCHRP Report 350 Compliant

MIDWEST MACHINERY

Pieces	Description
32	12/12'6/S SRT-1
32	12/25'0/SPEC/S SRT-2
32	3/16X12.5X16 CAB ANC BRKT
32	2" X 5 1/2" PIPE (LONG)
64	6'0 TUBE SL/.188X8X6
32	5/8 X 6 X 8 BEARING PLATE
32	12/BUFFER/ROLLED
32	CBL 3/4X6'6/DBL SWG/NOHWD
640	5/8" RD WASHER 1 3/4 OD
1,728	5/8" GR HEX NUT
1,152	5/8"X1.25" GR BOLT
256	5/8"X1.5" HEX BOLT A307
64	5/8"X9.5" HEX BOLT A307

Upon delivery, all materials subject to Trinity Highway Products, LLC Storage Stain Policy No. LG-002.

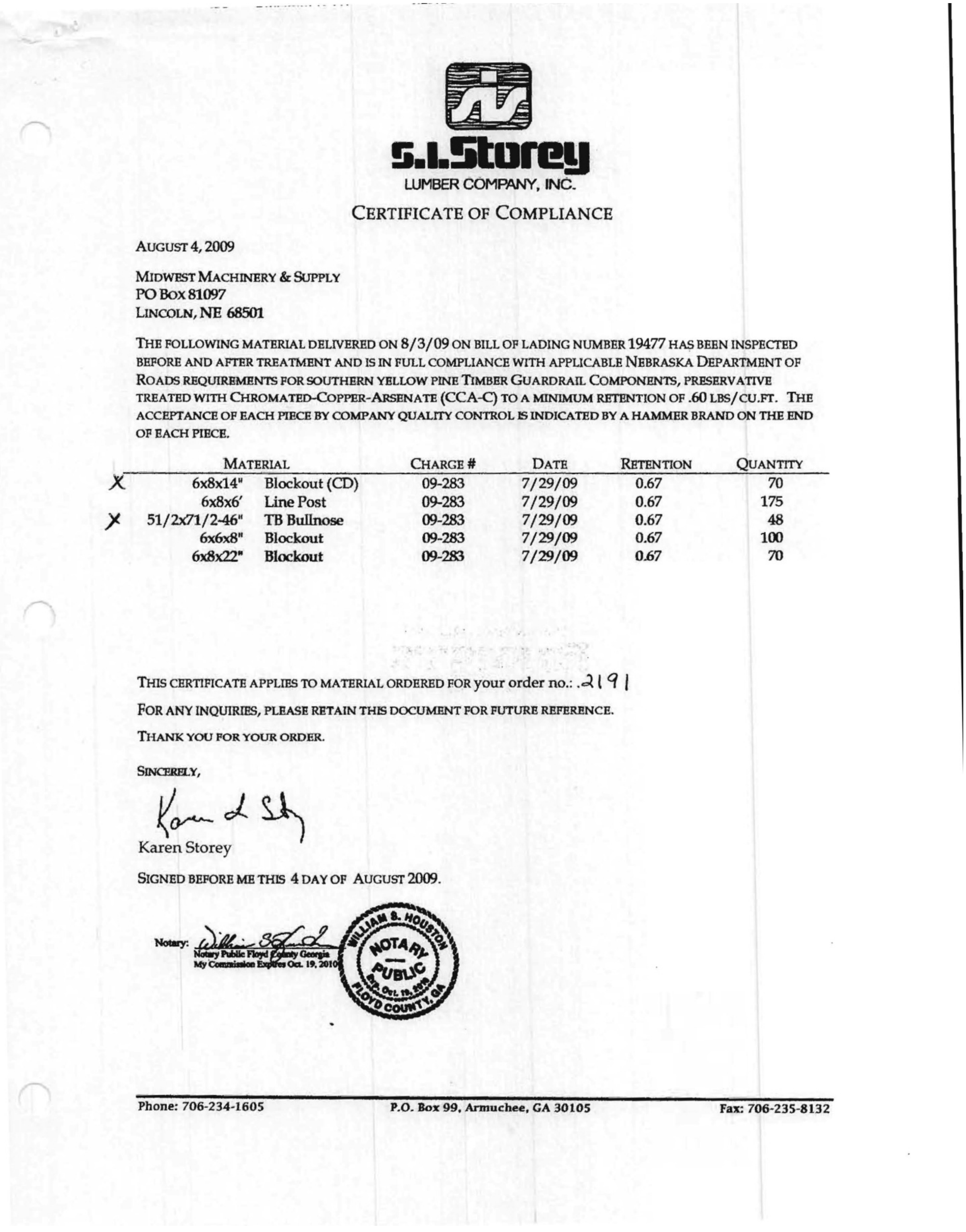
ALL STEEL USED WAS MELTED AND MANUFACTURED IN USA AND COMPLIES WITH THE BUY AMERICA ACT
ALL GUARDRAIL MEETS AASHTO M-180, ALL STRUCTURAL STEEL MEETS ASTM A36
ALL OTHER GALVANIZED MATERIAL CONFORMS WITH ASTM-123.
BOLTS COMPLY WITH ASTM A-307 SPECIFICATIONS AND ARE GALVANIZED IN ACCORDANCE WITH ASTM A-153, UNLESS OTHERWISE STATED.
NUTS COMPLY WITH ASTM A-563 SPECIFICATIONS AND ARE GALVANIZED IN ACCORDANCE WITH ASTM A-153, UNLESS OTHERWISE STATED.
3/4" DIA CABLE 6X19 ZINC COATED SWAGED END AISI C-1035 STEEL ANNEALED STUD 1" DIA ASTM449 AASHTO M30, TYPE II BREAKING STRENGTH – 49100 LB

State of Ohio, County of Allen. Sworn and Subscribed before me this 30th day of June, 2008

Notary Public:
Commission Expires

Trinity Highway Products, LLC
Certified By:

Figure 120. Photo. ⅝-in. (15.9-mm) Washers, Certificate of Compliance.



S.I.Storey
LUMBER COMPANY, INC.

CERTIFICATE OF COMPLIANCE

AUGUST 4, 2009

MIDWEST MACHINERY & SUPPLY
PO BOX 81097
LINCOLN, NE 68501

THE FOLLOWING MATERIAL DELIVERED ON 8/3/09 ON BILL OF LADING NUMBER 19477 HAS BEEN INSPECTED BEFORE AND AFTER TREATMENT AND IS IN FULL COMPLIANCE WITH APPLICABLE NEBRASKA DEPARTMENT OF ROADS REQUIREMENTS FOR SOUTHERN YELLOW PINE TIMBER GUARDRAIL COMPONENTS, PRESERVATIVE TREATED WITH CHROMATED-COPPER-ARSENATE (CCA-C) TO A MINIMUM RETENTION OF .60 LBS/CU.FT. THE ACCEPTANCE OF EACH PIECE BY COMPANY QUALITY CONTROL IS INDICATED BY A HAMMER BRAND ON THE END OF EACH PIECE.

	MATERIAL		CHARGE #	DATE	RETENTION	QUANTITY
X	6x8x14"	Blockout (CD)	09-283	7/29/09	0.67	70
	6x8x6'	Line Post	09-283	7/29/09	0.67	175
X	51/2x71/2-46"	TB Bullnose	09-283	7/29/09	0.67	48
	6x6x8"	Blockout	09-283	7/29/09	0.67	100
	6x8x22"	Blockout	09-283	7/29/09	0.67	70

THIS CERTIFICATE APPLIES TO MATERIAL ORDERED FOR your order no.: .2191

FOR ANY INQUIRIES, PLEASE RETAIN THIS DOCUMENT FOR FUTURE REFERENCE.

THANK YOU FOR YOUR ORDER.

SINCERELY,

Karen Storey

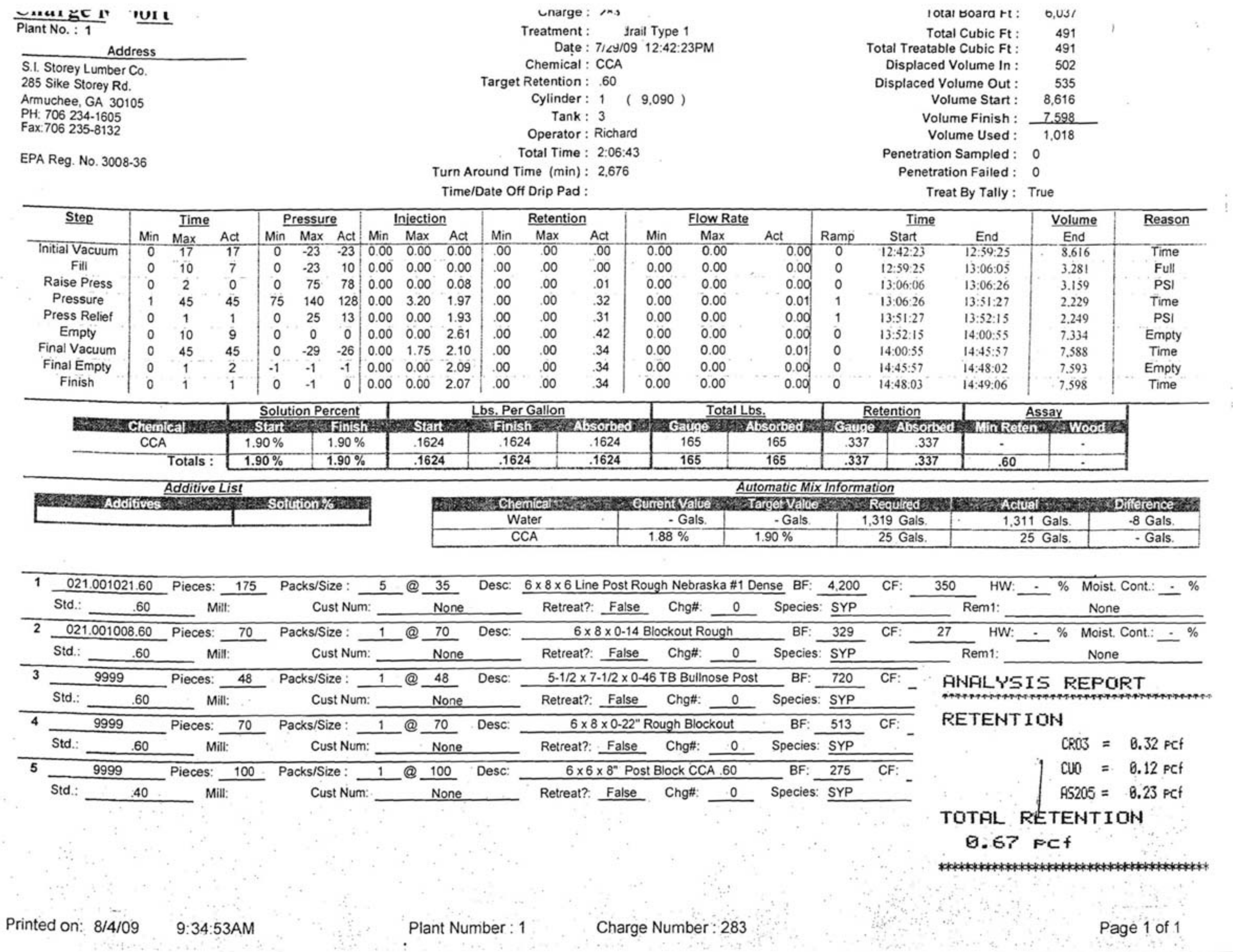
SIGNED BEFORE ME THIS 4 DAY OF AUGUST 2009.

Notary:
Notary Public Floyd County Georgia
My Commission Expires Oct. 19, 2010

WILLIAM S. HOUSTON
EXP. OCT. 19, 2010

Phone: 706-234-1605 P.O. Box 99, Armuchee, GA 30105 Fax: 706-235-8132

Figure 121. Photo. BCT Timber Posts, Certificate of Compliance.



Charge R ort
Plant No. : 1

Address
S.I. Storey Lumber Co.
285 Sike Storey Rd.
Armuchee, GA 30105
PH: 706 234-1605
Fax:706 235-8132

EPA Reg. No. 3008-36

Charge : 283
Treatment : drail Type 1
Date : 7/29/09 12:42:23PM
Chemical : CCA
Target Retention : .60
Cylinder : 1 (9,090)
Tank : 3
Operator : Richard
Total Time : 2:06:43
Turn Around Time (min) : 2,676
Time/Date Off Drip Pad :

Total Board Ft : 6,037
Total Cubic Ft : 491
Total Treatable Cubic Ft : 491
Displaced Volume In : 502
Displaced Volume Out : 535
Volume Start : 8,616
Volume Finish : 7,598
Volume Used : 1,018
Penetration Sampled : 0
Penetration Failed : 0
Treat By Tally : True

Step	Time			Pressure			Injection			Retention			Flow Rate			Time			Volume	Reason
	Min	Max	Act	Min	Max	Act	Min	Max	Act	Min	Max	Act	Min	Max	Act	Ramp	Start	End	End	
Initial Vacuum	0	17	17	0	-23	-23	0.00	0.00	0.00	.00	.00	.00	0.00	0.00	0.00	0	12:42:23	12:59:25	8,616	Time
Fill	0	10	7	0	-23	10	0.00	0.00	0.00	.00	.00	.00	0.00	0.00	0.00	0	12:59:25	13:06:05	3,281	Full
Raise Press	0	2	0	0	75	78	0.00	0.00	0.08	.00	.00	.01	0.00	0.00	0.00	0	13:06:06	13:06:26	3,159	PSI
Pressure	1	45	45	75	140	128	0.00	3.20	1.97	.00	.00	.32	0.00	0.00	0.01	1	13:06:26	13:51:27	2,229	Time
Press Relief	0	1	1	0	25	13	0.00	0.00	1.93	.00	.00	.31	0.00	0.00	0.00	1	13:51:27	13:52:15	2,249	PSI
Empty	0	10	9	0	0	0	0.00	0.00	2.61	.00	.00	.42	0.00	0.00	0.00	0	13:52:15	14:00:55	7,334	Empty
Final Vacuum	0	45	45	0	-29	-26	0.00	1.75	2.10	.00	.00	.34	0.00	0.00	0.01	0	14:00:55	14:45:57	7,588	Time
Final Empty	0	1	2	-1	-1	-1	0.00	0.00	2.09	.00	.00	.34	0.00	0.00	0.00	0	14:45:57	14:48:02	7,593	Empty
Finish	0	1	1	0	-1	0	0.00	0.00	2.07	.00	.00	.34	0.00	0.00	0.00	0	14:48:03	14:49:06	7,598	Time

	Solution Percent		Lbs. Per Gallon			Total Lbs.		Retention		Assay	
Chemical	Start	Finish	Start	Finish	Absorbed	Gauge	Absorbed	Gauge	Absorbed	Min Reten	Wood
CCA	1.90 %	1.90 %	.1624	.1624	.1624	165	165	.337	.337	-	-
Totals :	1.90 %	1.90 %	.1624	.1624	.1624	165	165	.337	.337	.60	-

Additive List

Additives	Solution %

Automatic Mix Information

Chemical	Current Value	Target Value	Required	Actual	Difference
Water	- Gals.	- Gals.	1,319 Gals.	1,311 Gals.	-8 Gals.
CCA	1.88 %	1.90 %	25 Gals.	25 Gals.	- Gals.

1 021.001021.60 Pieces: 175 Packs/Size : 5 @ 35 Desc: 6 x 8 x 6 Line Post Rough Nebraska #1 Dense BF: 4,200 CF: 350 HW: - % Moist. Cont.: - %
Std.: .60 Mill: Cust Num: None Retreat?: False Chg#: 0 Species: SYP Rem1: None

2 021.001008.60 Pieces: 70 Packs/Size : 1 @ 70 Desc: 6 x 8 x 0-14 Blockout Rough BF: 329 CF: 27 HW: - % Moist. Cont.: - %
Std.: .60 Mill: Cust Num: None Retreat?: False Chg#: 0 Species: SYP Rem1: None

3 9999 Pieces: 48 Packs/Size : 1 @ 48 Desc: 5-1/2 x 7-1/2 x 0-46 TB Bullnose Post BF: 720 CF: -
Std.: .60 Mill: Cust Num: None Retreat?: False Chg#: 0 Species: SYP

4 9999 Pieces: 70 Packs/Size : 1 @ 70 Desc: 6 x 8 x 0-22" Rough Blockout BF: 513 CF: -
Std.: .60 Mill: Cust Num: None Retreat?: False Chg#: 0 Species: SYP

5 9999 Pieces: 100 Packs/Size : 1 @ 100 Desc: 6 x 6 x 8" Post Block CCA .60 BF: 275 CF: -
Std.: .40 Mill: Cust Num: None Retreat?: False Chg#: 0 Species: SYP

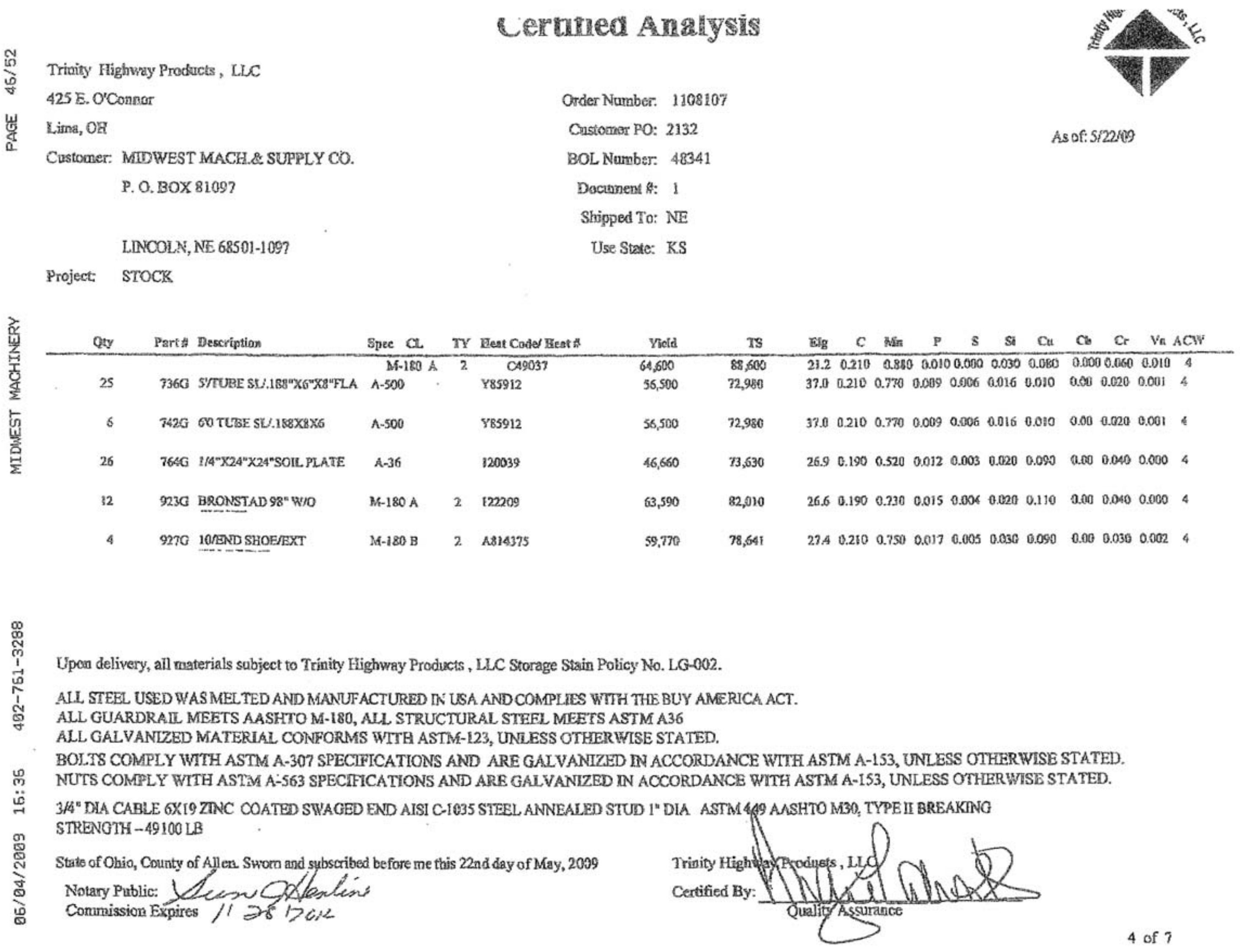
ANALYSIS REPORT
****

RETENTION
CR03 = 0.32 pcf
CU0 = 0.12 pcf
AS205 = 0.23 pcf

TOTAL RETENTION
0.67 pcf
****

Printed on: 8/4/09 9:34:53AM Plant Number : 1 Charge Number : 283 Page 1 of 1

Figure 122. Photo. BCT Timber Posts, Material Specification.



06/04/2009 16:35 402-761-3288 MIDWEST MACHINERY PAGE 46/52

Certified Analysis

Trinity Highway Products , LLC
425 E. O'Connor
Lima, OH
Customer: MIDWEST MACH.& SUPPLY CO.
P. O. BOX 81097

LINCOLN, NE 68501-1097
Project: STOCK

Order Number: 1108107
Customer PO: 2132
BOL Number: 48341
Document #: 1
Shipped To: NE
Use State: KS

As of: 5/22/09

Qty	Part #	Description	Spec	CL	TY	Heat Code/ Heat #	Yield	TS	Elg	C	Mn	P	S	Si	Cu	Cb	Cr	Vn	ACW
			M-180	A	2	C49037	64,600	88,600	21.2	0.210	0.880	0.010	0.000	0.030	0.080	0.000	0.060	0.010	4
25	736G	5'/TUBE SL/.188"X6"X8"FLA	A-500			Y85912	56,500	72,980	37.0	0.210	0.770	0.009	0.006	0.016	0.010	0.00	0.020	0.001	4
6	742G	6'0 TUBE SL/.188X8X6	A-500			Y85912	56,500	72,980	37.0	0.210	0.770	0.009	0.006	0.016	0.010	0.00	0.020	0.001	4
26	764G	1/4"X24"X24"SOIL PLATE	A-36			120039	46,660	73,630	26.9	0.190	0.520	0.012	0.003	0.020	0.090	0.00	0.040	0.000	4
12	923G	BRONSTAD 98" W/O	M-180	A	2	122209	63,590	82,010	26.6	0.190	0.730	0.015	0.004	0.020	0.110	0.00	0.040	0.000	4
4	927G	10/END SHOE/EXT	M-180	B	2	A814375	59,770	78,641	27.4	0.210	0.750	0.017	0.005	0.030	0.090	0.00	0.030	0.002	4

Upon delivery, all materials subject to Trinity Highway Products , LLC Storage Stain Policy No. LG-002.

ALL STEEL USED WAS MELTED AND MANUFACTURED IN USA AND COMPLIES WITH THE BUY AMERICA ACT.
ALL GUARDRAIL MEETS AASHTO M-180, ALL STRUCTURAL STEEL MEETS ASTM A36
ALL GALVANIZED MATERIAL CONFORMS WITH ASTM-123, UNLESS OTHERWISE STATED.
BOLTS COMPLY WITH ASTM A-307 SPECIFICATIONS AND ARE GALVANIZED IN ACCORDANCE WITH ASTM A-153, UNLESS OTHERWISE STATED.
NUTS COMPLY WITH ASTM A-563 SPECIFICATIONS AND ARE GALVANIZED IN ACCORDANCE WITH ASTM A-153, UNLESS OTHERWISE STATED.

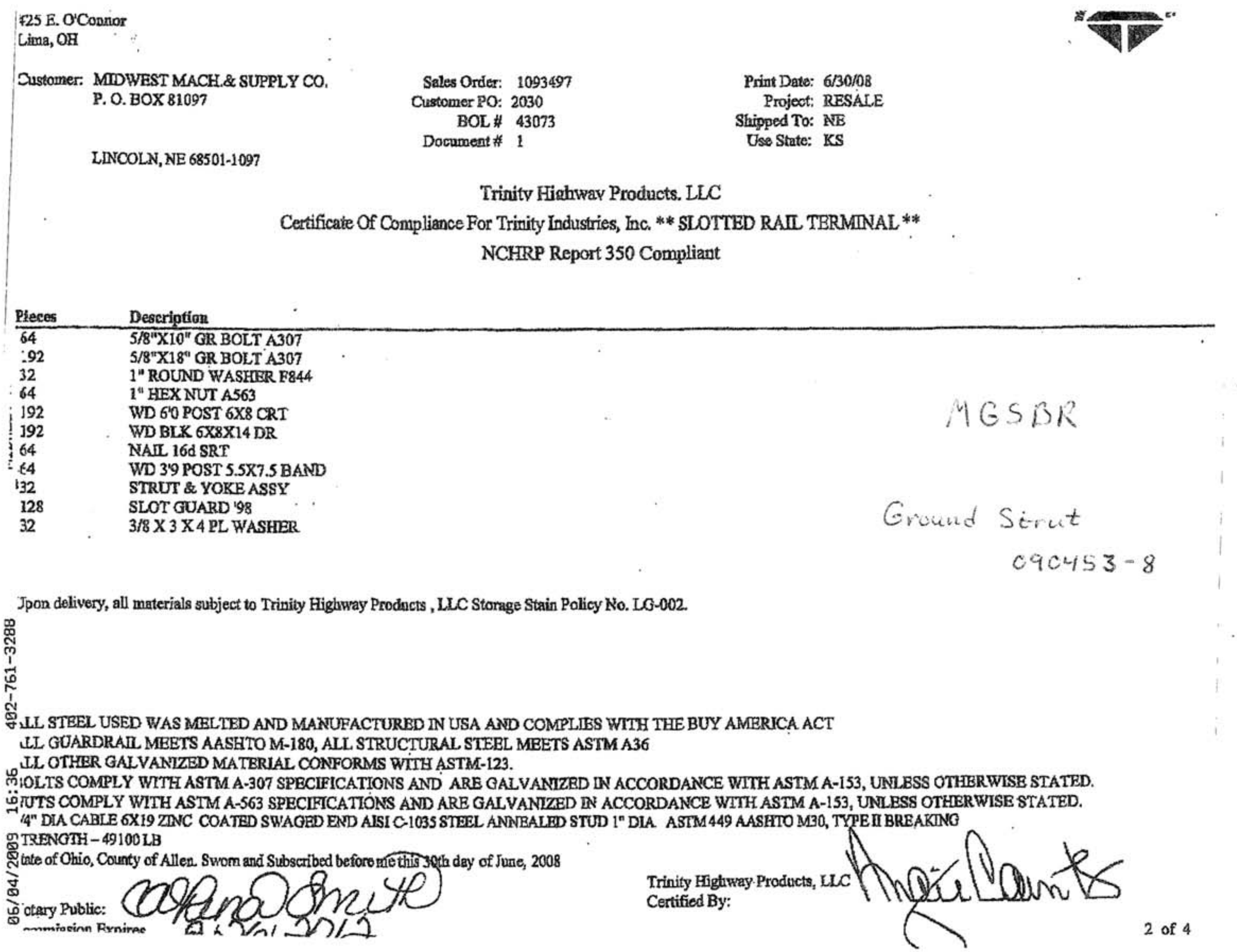
3/4" DIA CABLE 6X19 ZINC COATED SWAGED END AISI C-1035 STEEL ANNEALED STUD 1" DIA ASTM 449 AASHTO M30, TYPE II BREAKING STRENGTH – 49100 LB

State of Ohio, County of Allen. Sworn and subscribed before me this 22nd day of May, 2009
Notary Public:
Commission Expires 11 28 2012

Trinity Highway Products , LLC
Certified By:
Quality Assurance

4 of 7

Figure 123. Photo. 6-ft (1.8-m) Foundation Tube, Material Specification.



425 E. O'Connor
Lima, OH

Customer: MIDWEST MACH.& SUPPLY CO.
P. O. BOX 81097

LINCOLN, NE 68501-1097

Sales Order: 1093497
Customer PO: 2030
BOL # 43073
Document # 1

Print Date: 6/30/08
Project: RESALE
Shipped To: NE
Use State: KS

Trinity Highway Products, LLC

Certificate Of Compliance For Trinity Industries, Inc. ** SLOTTED RAIL TERMINAL **

NCHRP Report 350 Compliant

Pieces	Description
64	5/8"X10" GR BOLT A307
192	5/8"X18" GR BOLT A307
32	1" ROUND WASHER F844
64	1" HEX NUT A563
192	WD 6'0 POST 6X8 CRT
192	WD BLK 6X8X14 DR
64	NAIL 16d SRT
64	WD 3'9 POST 5.5X7.5 BAND
32	STRUT & YOKE ASSY
128	SLOT GUARD '98
32	3/8 X 3 X 4 PL WASHER

MGSBR

Ground Strut

090453-8

Jpon delivery, all materials subject to Trinity Highway Products , LLC Storage Stain Policy No. LG-002.

05/04/2009 16:36 402-761-3288

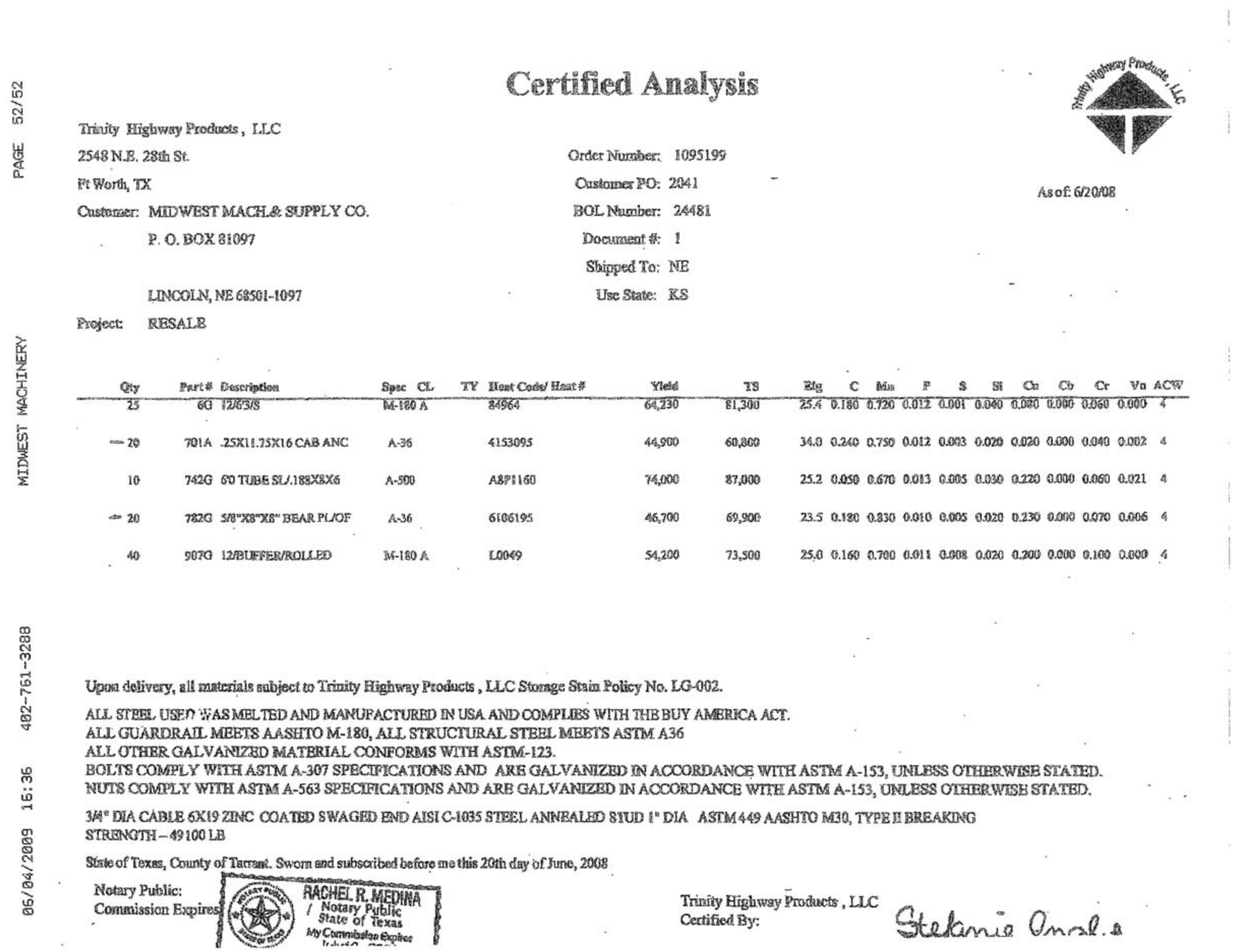
LL STEEL USED WAS MELTED AND MANUFACTURED IN USA AND COMPLIES WITH THE BUY AMERICA ACT
LL GUARDRAIL MEETS AASHTO M-180, ALL STRUCTURAL STEEL MEETS ASTM A36
LL OTHER GALVANIZED MATERIAL CONFORMS WITH ASTM-123.
IOLTS COMPLY WITH ASTM A-307 SPECIFICATIONS AND ARE GALVANIZED IN ACCORDANCE WITH ASTM A-153, UNLESS OTHERWISE STATED.
UTS COMPLY WITH ASTM A-563 SPECIFICATIONS AND ARE GALVANIZED IN ACCORDANCE WITH ASTM A-153, UNLESS OTHERWISE STATED.
/4" DIA CABLE 6X19 ZINC COATED SWAGED END AISI C-1035 STEEL ANNEALED STUD 1" DIA ASTM 449 AASHTO M30, TYPE II BREAKING
TRENGTH – 49100 LB
tate of Ohio, County of Allen. Sworn and Subscribed before me this 30th day of June, 2008

otary Public:
ommission Expires

Trinity Highway Products, LLC
Certified By:

2 of 4

Figure 124. Photo. Strut and Yoke Assembly, Certificate of Compliance.



06/04/2009 16:35 402-761-3288 MIDWEST MACHINERY PAGE 52/52

Certified Analysis

Trinity Highway Products , LLC
2548 N.E. 28th St.
Ft Worth, TX

Customer: MIDWEST MACH.& SUPPLY CO.
P. O. BOX 81097

LINCOLN, NE 68501-1097

Project: RESALE

Order Number: 1095199
Customer PO: 2041
BOL Number: 24481
Document #: 1
Shipped To: NE
Use State: KS

As of: 6/20/08

Qty	Part#	Description	Spec	CL	TY	Heat Code/ Heat #	Yield	TS	Elg	C	Mn	P	S	Si	Cu	Cb	Cr	Vn	ACW
25	6G	12/6'3/S	M-180	A		84964	64,230	81,300	25.4	0.180	0.720	0.012	0.001	0.040	0.080	0.000	0.060	0.000	4
20	701A	.25X11.75X16 CAB ANC	A-36			4153095	44,900	60,800	34.0	0.240	0.750	0.012	0.003	0.020	0.020	0.000	0.040	0.002	4
10	742G	6'0 TUBE SL/.188X8X6	A-500			A8P1160	74,000	87,000	25.2	0.050	0.670	0.013	0.005	0.030	0.220	0.000	0.060	0.021	4
20	782G	5/8"X8"X8" BEAR PL/OF	A-36			6106195	46,700	69,900	23.5	0.180	0.830	0.010	0.005	0.020	0.230	0.000	0.070	0.006	4
40	907G	12/BUFFER/ROLLED	M-180	A		L0049	54,200	73,500	25.0	0.160	0.700	0.011	0.008	0.020	0.200	0.000	0.100	0.000	4

Upon delivery, all materials subject to Trinity Highway Products , LLC Storage Stain Policy No. LG-002.

ALL STEEL USED WAS MELTED AND MANUFACTURED IN USA AND COMPLIES WITH THE BUY AMERICA ACT.
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BOLTS COMPLY WITH ASTM A-307 SPECIFICATIONS AND ARE GALVANIZED IN ACCORDANCE WITH ASTM A-153, UNLESS OTHERWISE STATED.
NUTS COMPLY WITH ASTM A-563 SPECIFICATIONS AND ARE GALVANIZED IN ACCORDANCE WITH ASTM A-153, UNLESS OTHERWISE STATED.

3/4" DIA CABLE 6X19 ZINC COATED SWAGED END AISI C-1035 STEEL ANNEALED STUD 1" DIA ASTM 449 AASHTO M30, TYPE II BREAKING STRENGTH – 49100 LB

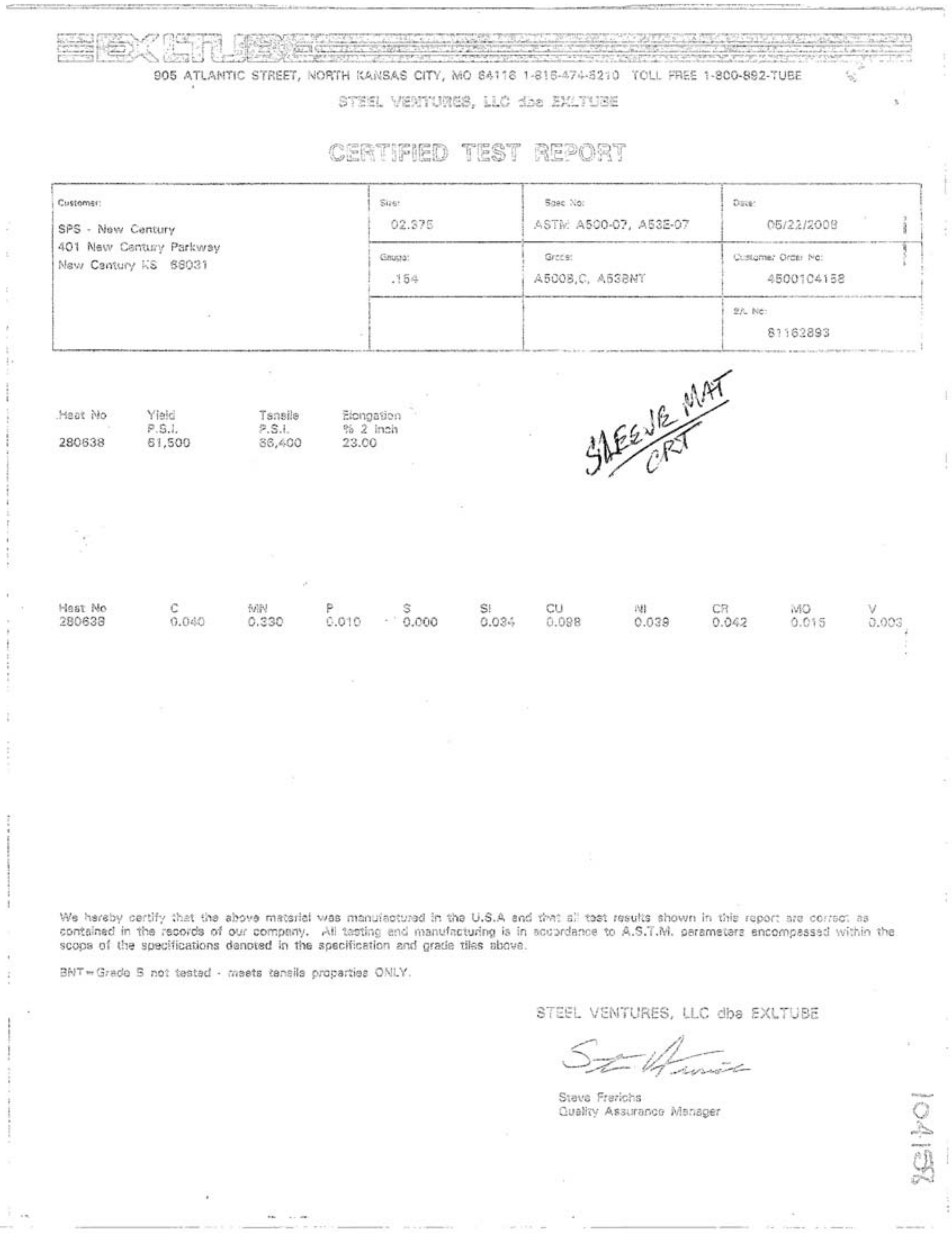
State of Texas, County of Tarrant. Sworn and subscribed before me this 20th day of June, 2008

Notary Public:
Commission Expires

RACHEL R. MEDINA
Notary Public
State of Texas
My Commission Expires

Trinity Highway Products , LLC
Certified By: Stefanie Ornel.s

Figure 125. Photo. BCT Anchor Plate and Anchor Bracket Assembly, Material Specification.



EXLTUBE

905 ATLANTIC STREET, NORTH KANSAS CITY, MO 64116 1-816-474-5210 TOLL FREE 1-800-892-TUBE

STEEL VENTURES, LLC dba EXLTUBE

CERTIFIED TEST REPORT

Customer:
SPS - New Century
401 New Century Parkway
New Century KS 66031

Size: 02.375

Spec No: ASTM A500-07, A53E-07

Date: 05/22/2008

Gauge: .154

Grade: A500B,C, A53BNT

Customer Order No: 4500104158

S/L No: 81162893

Heat No	Yield P.S.I.	Tensile P.S.I.	Elongation % 2 Inch
280638	61,500	86,400	23.00

SLEEVE MAT
CRT

Heat No	C	MN	P	S	SI	CU	NI	CR	MO	V
280638	0.040	0.330	0.010	0.000	0.034	0.098	0.039	0.042	0.015	0.003

We hereby certify that the above material was manufactured in the U.S.A and that all test results shown in this report are correct as contained in the records of our company. All testing and manufacturing is in accordance to A.S.T.M. parameters encompassed within the scope of the specifications denoted in the specification and grade tiles above.

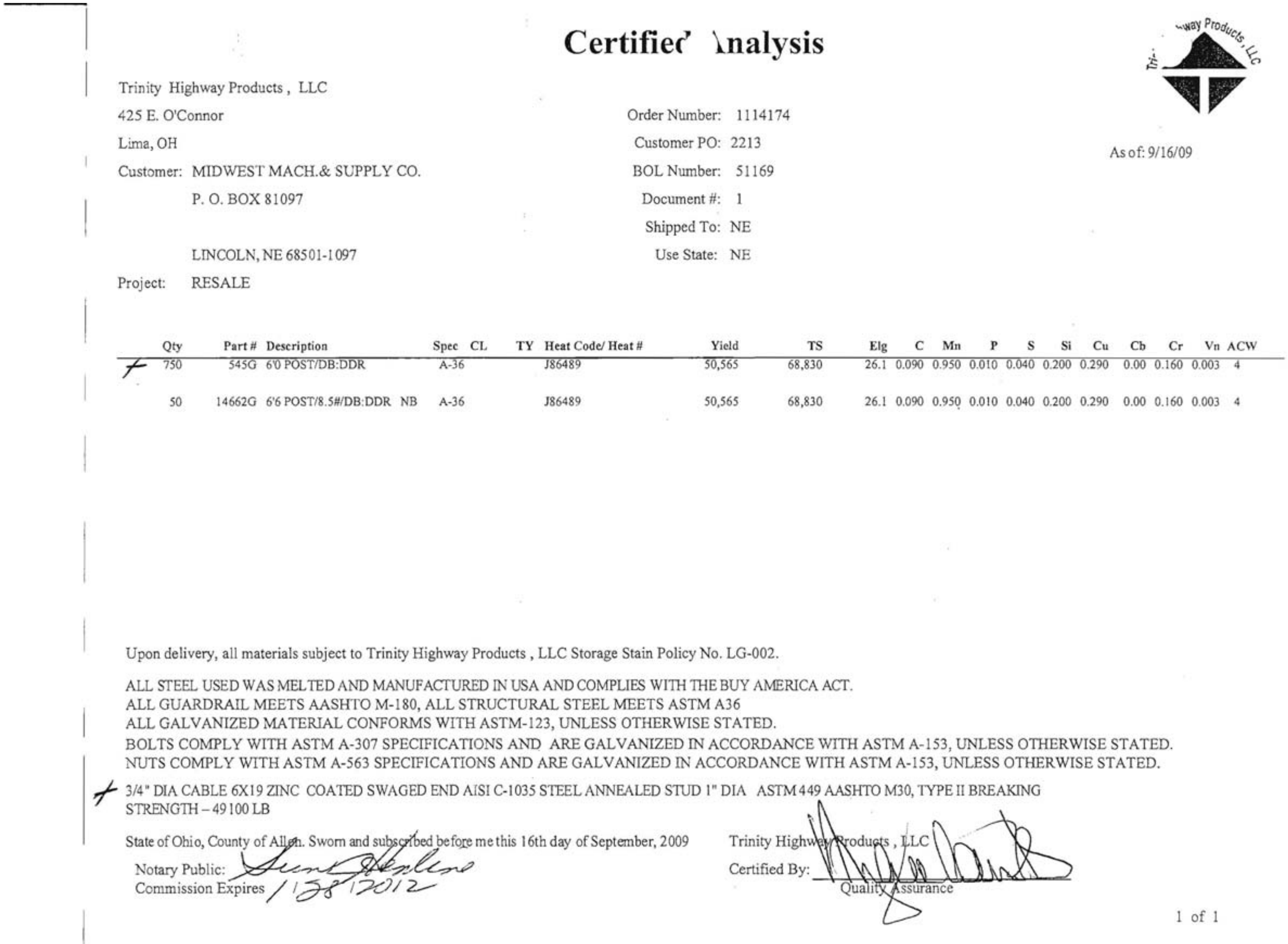
BNT=Grade B not tested - meets tensile properties ONLY.

STEEL VENTURES, LLC dba EXLTUBE

Steve Frerichs
Quality Assurance Manager

104158

Figure 126. Photo. 2⅜-in. x 6-in. (60x152-mm) BCT Post Sleeve, Material Specification.



Certifie' ‌\nalysis

Trinity Highway Products , LLC
425 E. O'Connor
Lima, OH
Customer: MIDWEST MACH.& SUPPLY CO.
P. O. BOX 81097

LINCOLN, NE 68501-1097
Project: RESALE

Order Number: 1114174
Customer PO: 2213
BOL Number: 51169
Document #: 1
Shipped To: NE
Use State: NE

As of: 9/16/09

Qty	Part #	Description	Spec	CL	TY	Heat Code/ Heat #	Yield	TS	Elg	C	Mn	P	S	Si	Cu	Cb	Cr	Vn	ACW
750	545G	6'0 POST/DB:DDR	A-36			J86489	50,565	68,830	26.1	0.090	0.950	0.010	0.040	0.200	0.290	0.00	0.160	0.003	4
50	14662G	6'6 POST/8.5#/DB:DDR NB	A-36			J86489	50,565	68,830	26.1	0.090	0.950	0.010	0.040	0.200	0.290	0.00	0.160	0.003	4

Upon delivery, all materials subject to Trinity Highway Products , LLC Storage Stain Policy No. LG-002.

ALL STEEL USED WAS MELTED AND MANUFACTURED IN USA AND COMPLIES WITH THE BUY AMERICA ACT.
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ALL GALVANIZED MATERIAL CONFORMS WITH ASTM-123, UNLESS OTHERWISE STATED.
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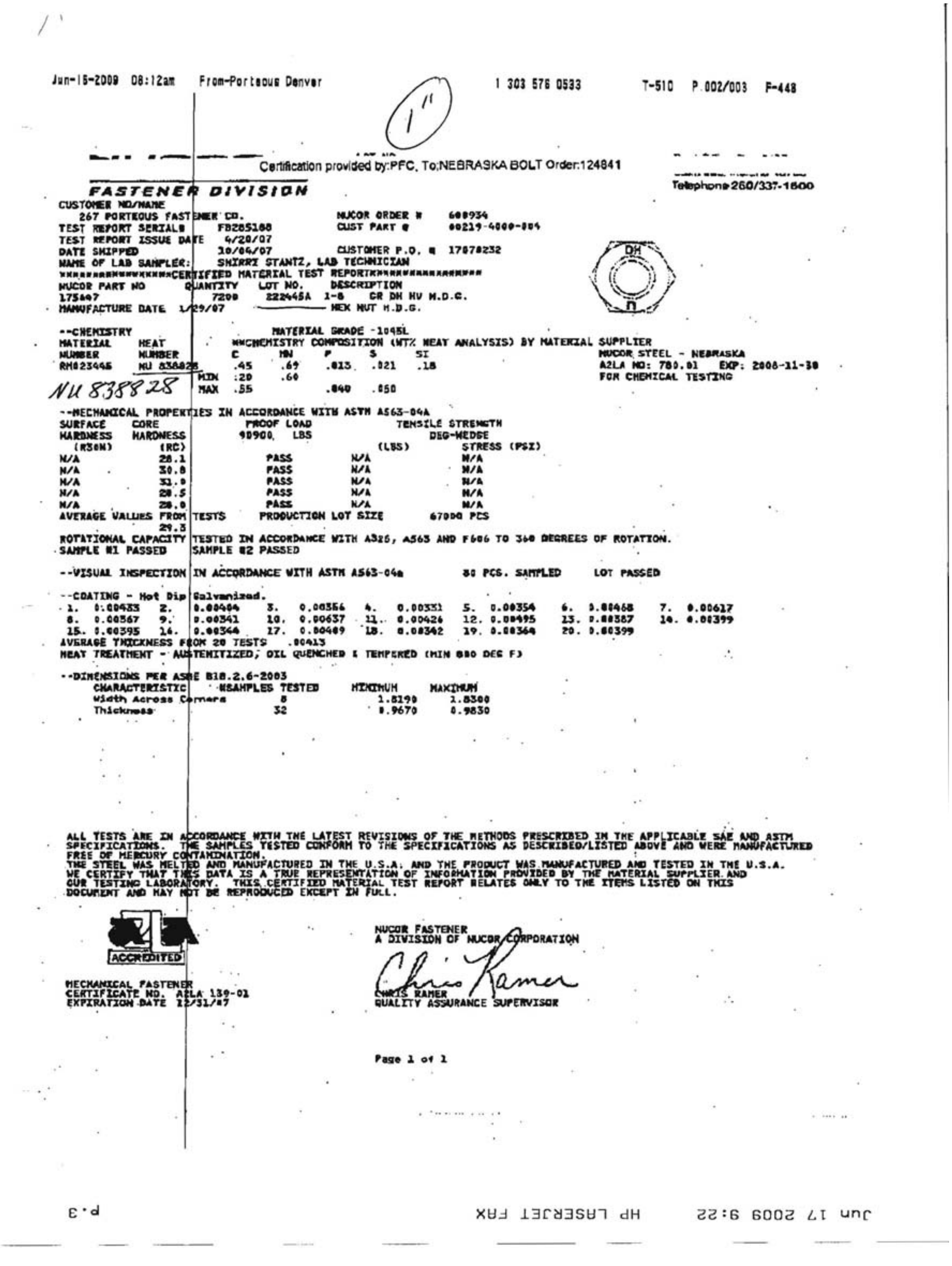
3/4" DIA CABLE 6X19 ZINC COATED SWAGED END AISI C-1035 STEEL ANNEALED STUD 1" DIA ASTM 449 AASHTO M30, TYPE II BREAKING STRENGTH – 49100 LB

State of Ohio, County of Allen. Sworn and subscribed before me this 16th day of September, 2009
Notary Public:
Commission Expires 1/28/2012

Trinity Highway Products , LLC
Certified By:
Quality Assurance

1 of 1

Figure 127. Photo. BCT Anchor Cable Assembly, Material Specification.



Jun-15-2009 08:12am From-Porteous Denver 1 303 576 0533 T-510 P.002/003 F-448

1"

Certification provided by:PFC, To:NEBRASKA BOLT Order:124841

FASTENER DIVISION

Telephone 260/337-1600

CUSTOMER NO/NAME
267 PORTEOUS FASTENER CO.
TEST REPORT SERIAL# FB285188
TEST REPORT ISSUE DATE 4/20/07
DATE SHIPPED 10/04/07
NAME OF LAB SAMPLER: SHIRRI STANTZ, LAB TECHNICIAN
NUCOR ORDER # 600934
CUST PART # 00219-4000-004
CUSTOMER P.O. # 17078232

******************CERTIFIED MATERIAL TEST REPORT******************

NUCOR PART NO	QUANTITY	LOT NO.	DESCRIPTION
175407	7200	222445A	1-8 GR DH HV H.D.G. HEX NUT H.D.G.

MANUFACTURE DATE 1/29/07

DH

--CHEMISTRY MATERIAL GRADE -1045L

**CHEMISTRY COMPOSITION (WT% HEAT ANALYSIS) BY MATERIAL SUPPLIER

MATERIAL NUMBER	HEAT NUMBER		C	MN	P	S	SI
RM023446	NU 838828		.45	.69	.013	.021	.18
		MIN	:20	.60			
		MAX	.55		.040	.050	

NU 838828

NUCOR STEEL - NEBRASKA
A2LA NO: 780.01 EXP: 2008-11-30
FOR CHEMICAL TESTING

--MECHANICAL PROPERTIES IN ACCORDANCE WITH ASTM A563-04A

SURFACE HARDNESS (R30N)	CORE HARDNESS (RC)	PROOF LOAD 90900 LBS	TENSILE STRENGTH DEG-WEDGE (LBS)	STRESS (PSI)
N/A	28.1	PASS	N/A	N/A
N/A	30.8	PASS	N/A	N/A
N/A	31.0	PASS	N/A	N/A
N/A	28.5	PASS	N/A	N/A
N/A	28.0	PASS	N/A	N/A

AVERAGE VALUES FROM TESTS PRODUCTION LOT SIZE 67000 PCS
29.3

ROTATIONAL CAPACITY TESTED IN ACCORDANCE WITH A325, A563 AND F606 TO 360 DEGREES OF ROTATION.
SAMPLE #1 PASSED SAMPLE #2 PASSED

--VISUAL INSPECTION IN ACCORDANCE WITH ASTM A563-04a 80 PCS. SAMPLED LOT PASSED

--COATING - Hot Dip Galvanized.

1.	0.00433	2.	0.00404	3.	0.00356	4.	0.00331	5.	0.00354	6.	0.00468	7.	0.00617
8.	0.00567	9.	0.00341	10.	0.00637	11.	0.00426	12.	0.00495	13.	0.00387	14.	0.00399
15.	0.00395	16.	0.00344	17.	0.00409	18.	0.00342	19.	0.00364	20.	0.00399		

AVERAGE THICKNESS FROM 20 TESTS .00413
HEAT TREATMENT - AUSTENITIZED, OIL QUENCHED & TEMPERED (MIN 800 DEG F)

--DIMENSIONS PER ASME B18.2.6-2003

CHARACTERISTIC	#SAMPLES TESTED	MINIMUM	MAXIMUM
Width Across Corners	8	1.8190	1.8300
Thickness	32	0.9670	0.9830

ALL TESTS ARE IN ACCORDANCE WITH THE LATEST REVISIONS OF THE METHODS PRESCRIBED IN THE APPLICABLE SAE AND ASTM SPECIFICATIONS. THE SAMPLES TESTED CONFORM TO THE SPECIFICATIONS AS DESCRIBED/LISTED ABOVE AND WERE MANUFACTURED FREE OF MERCURY CONTAMINATION.
THE STEEL WAS MELTED AND MANUFACTURED IN THE U.S.A. AND THE PRODUCT WAS MANUFACTURED AND TESTED IN THE U.S.A.
WE CERTIFY THAT THIS DATA IS A TRUE REPRESENTATION OF INFORMATION PROVIDED BY THE MATERIAL SUPPLIER AND OUR TESTING LABORATORY. THIS CERTIFIED MATERIAL TEST REPORT RELATES ONLY TO THE ITEMS LISTED ON THIS DOCUMENT AND MAY NOT BE REPRODUCED EXCEPT IN FULL.

ACCREDITED

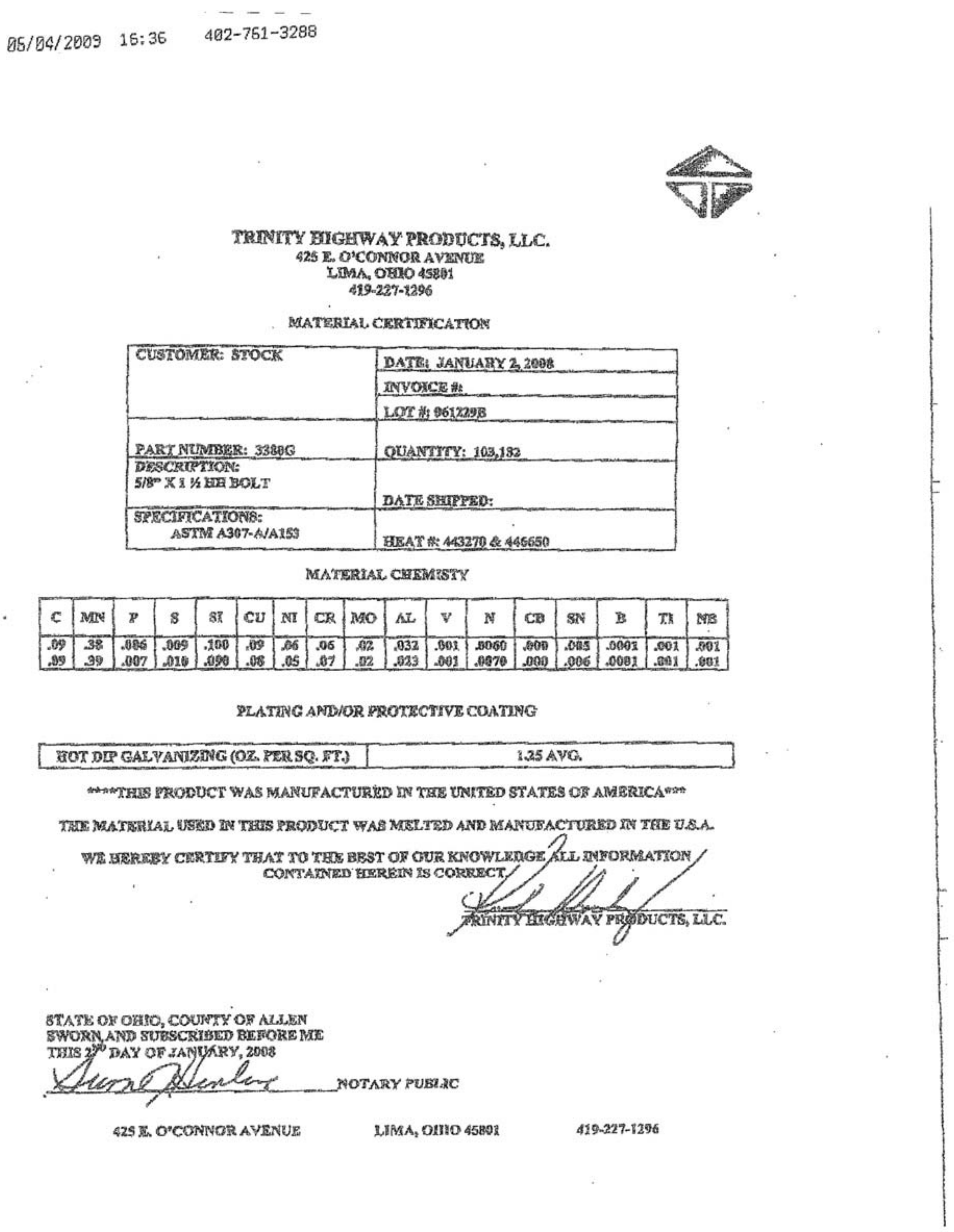
MECHANICAL FASTENER
CERTIFICATE NO. A2LA 139-01
EXPIRATION DATE 12/31/07

NUCOR FASTENER
A DIVISION OF NUCOR CORPORATION

Chris Ramer
CHRIS RAMER
QUALITY ASSURANCE SUPERVISOR

Page 1 of 1

Figure 128. Photo. BCT Anchor Cable Assembly, Material Specification.



05/04/2009 16:36 402-761-3288

TRINITY HIGHWAY PRODUCTS, LLC.
425 E. O'CONNOR AVENUE
LIMA, OHIO 45801
419-227-1296

MATERIAL CERTIFICATION

CUSTOMER: STOCK	DATE: JANUARY 2, 2008 INVOICE #: LOT #: 961229B
PART NUMBER: 3380G	QUANTITY: 103,182
DESCRIPTION: 5/8" X 1 ½ HH BOLT	DATE SHIPPED:
SPECIFICATIONS: ASTM A307-A/A153	HEAT #: 443270 & 446650

MATERIAL CHEMISTY

C	MN	P	S	SI	CU	NI	CR	MO	AL	V	N	CB	SN	B	TI	NB
.09	.38	.086	.009	.100	.09	.06	.06	.02	.032	.001	.0060	.000	.005	.0001	.001	.001
.09	.39	.007	.010	.090	.06	.05	.07	.02	.023	.001	.0070	.000	.006	.0001	.001	.001

PLATING AND/OR PROTECTIVE COATING

HOT DIP GALVANIZING (OZ. PER SQ. FT.)	1.25 AVG.

****THIS PRODUCT WAS MANUFACTURED IN THE UNITED STATES OF AMERICA***

THE MATERIAL USED IN THIS PRODUCT WAS MELTED AND MANUFACTURED IN THE U.S.A.

WE HEREBY CERTIFY THAT TO THE BEST OF OUR KNOWLEDGE ALL INFORMATION CONTAINED HEREIN IS CORRECT.

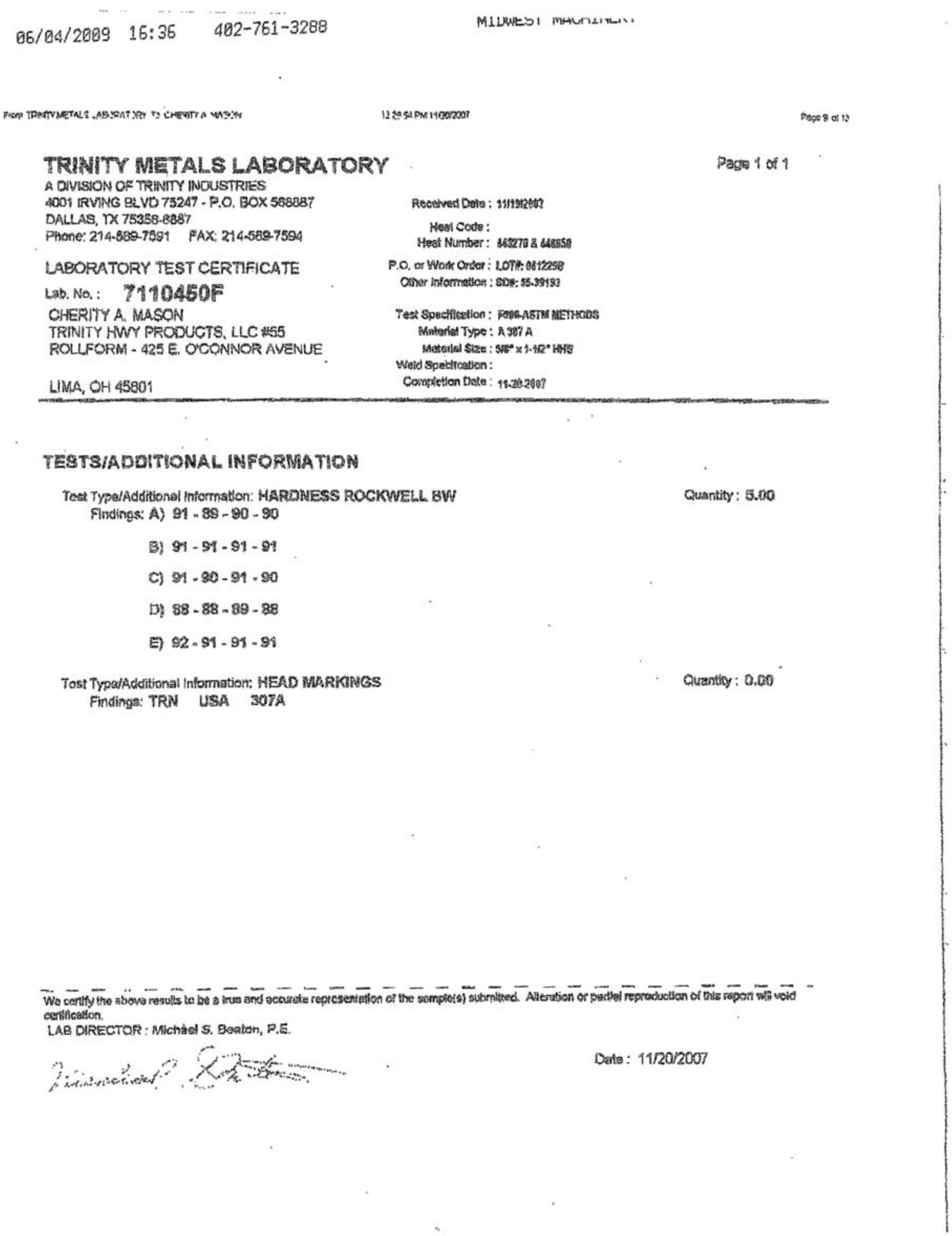
TRINITY HIGHWAY PRODUCTS, LLC.

STATE OF OHIO, COUNTY OF ALLEN
SWORN AND SUBSCRIBED BEFORE ME
THIS 2nd DAY OF JANUARY, 2008

NOTARY PUBLIC

425 E. O'CONNOR AVENUE LIMA, OHIO 45801 419-227-1296

Figure 129. Photo. ⅝-in. x 1½-in. (15.9x38-mm) Hex Bolt and Nut, Material Specification.



06/04/2009 16:36 402-761-3288 MIDWEST MACHINERY

From TRINITY METALS LABORATORY TO CHERITY A MASON 12:29:54 PM 11/20/2007 Page 9 of 12

TRINITY METALS LABORATORY

Page 1 of 1

A DIVISION OF TRINITY INDUSTRIES
4001 IRVING BLVD 75247 - P.O. BOX 568887
DALLAS, TX 75356-8887
Phone: 214-589-7591 FAX: 214-589-7594

LABORATORY TEST CERTIFICATE

Lab. No.: **7110450F**

CHERITY A. MASON
TRINITY HWY PRODUCTS, LLC #55
ROLLFORM - 425 E. O'CONNOR AVENUE

LIMA, OH 45801

Received Date : 11/19/2007
Heat Code :
Heat Number : 843270 & 448550
P.O. or Work Order : LOT#: 0612258
Other Information : SO#: 55-39193
Test Specification : F606-ASTM METHODS
Material Type : A 307 A
Material Size : 5/8" x 1-1/2" HHS
Weld Specification :
Completion Date : 11-20-2007

TESTS/ADDITIONAL INFORMATION

Test Type/Additional Information: HARDNESS ROCKWELL BW — Quantity : 5.00

Findings: A) 91 - 89 - 90 - 90

B) 91 - 91 - 91 - 91

C) 91 - 90 - 91 - 90

D) 88 - 88 - 89 - 88

E) 92 - 91 - 91 - 91

Test Type/Additional Information: HEAD MARKINGS — Quantity : 0.00

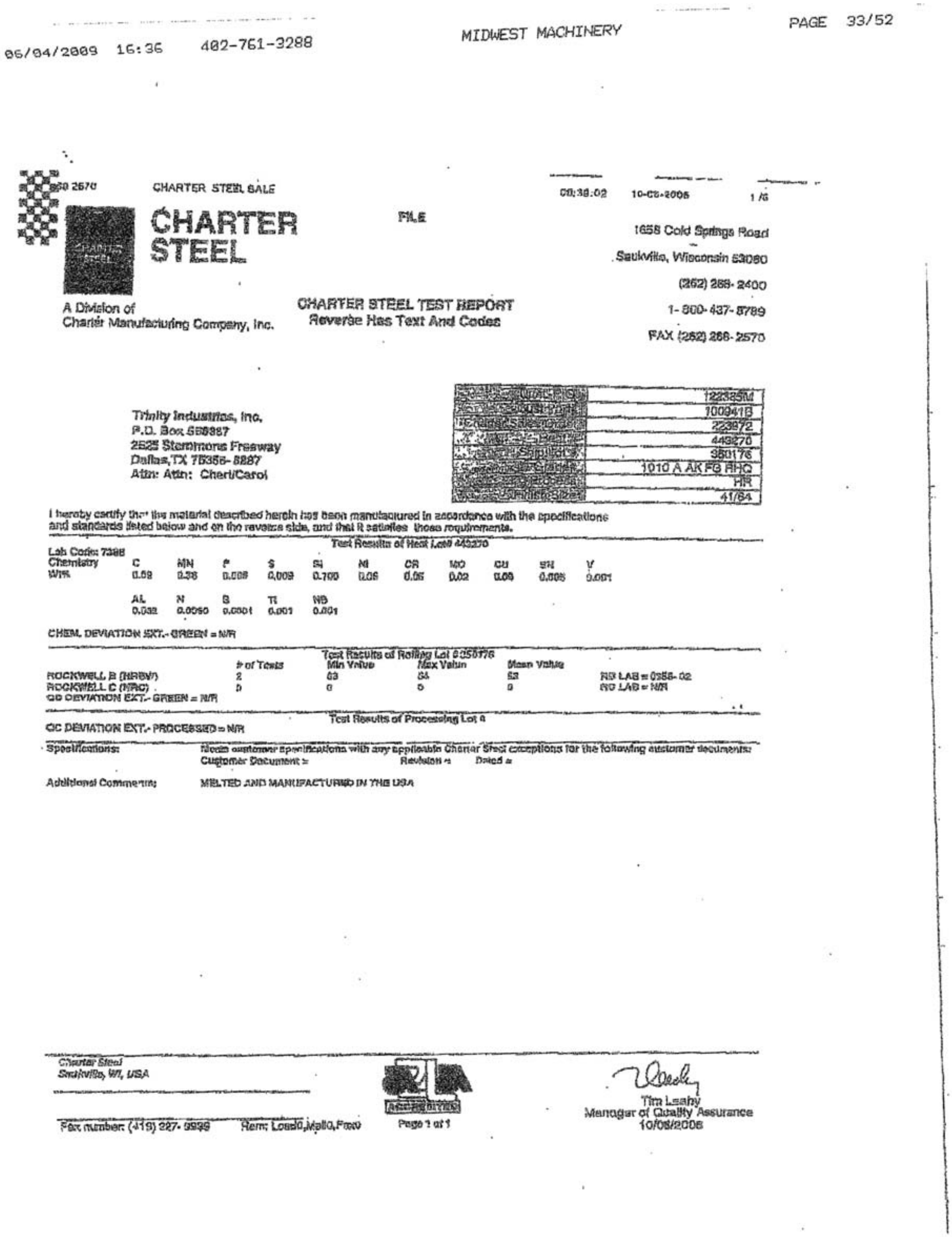
Findings: TRN USA 307A

We certify the above results to be a true and accurate representation of the sample(s) submitted. Alteration or partial reproduction of this report will void certification.

LAB DIRECTOR : Michael S. Beaton, P.E.

Date : 11/20/2007

Figure 130. Photo. ⅝-in. x 1½-in. (15.9x38-mm) Hex Bolt and Nut, Material Specification. (continued.)



06/04/2009 16:36 402-761-3288 MIDWEST MACHINERY PAGE 33/52

260 2570 CHARTER STEEL SALE 08:38:02 10-06-2006 1 /6

CHARTER STEEL

FILE

A Division of
Charter Manufacturing Company, Inc.

CHARTER STEEL TEST REPORT
Reverse Has Text And Codes

1658 Cold Springs Road
Saukville, Wisconsin 53080
(262) 268- 2400
1- 800- 437- 8789
FAX (262) 268- 2570

Trinity Industries, Inc.
P.O. Box 568887
2525 Stemmons Freeway
Dallas,TX 75356- 8887
Attn: Attn: Cheri/Carol

Cust P.O.	122385M
Cust Part	100941B
Charter Sales Order	223872
Heat / Batch	449270
Ship Lot #	350176
Grade	1010 A AK FG RHQ
Process	HR
Finish Size	41/64

I hereby certify that the material described herein has been manufactured in accordance with the specifications and standards listed below and on the reverse side, and that it satisfies those requirements.

Test Results of Heat Lot# 449270

Lab Code: 7388

Chemistry	C	MN	P	S	SI	NI	CR	MO	CU	SN	V
Wt%	0.09	0.38	0.008	0.009	0.100	0.06	0.05	0.02	0.09	0.008	0.001
	AL	N	B	TI	NB						
	0.032	0.0060	0.0001	0.001	0.001						

CHEM. DEVIATION EXT.- GREEN = N/R

Test Results of Rolling Lot 8350176

	# of Tests	Min Value	Max Value	Mean Value	
ROCKWELL B (HRBW)	2	63	64	63	RB LAB = 0358- 02
ROCKWELL C (HRC)	0	0	0	0	RC LAB = N/R

QD DEVIATION EXT.- GREEN = N/R

Test Results of Processing Lot 0

QC DEVIATION EXT.- PROCESSED = N/R

Specifications: Meets customer specifications with any applicable Charter Steel exceptions for the following customer documents:
Customer Document = Revision = Dated =

Additional Comments: MELTED AND MANUFACTURED IN THE USA

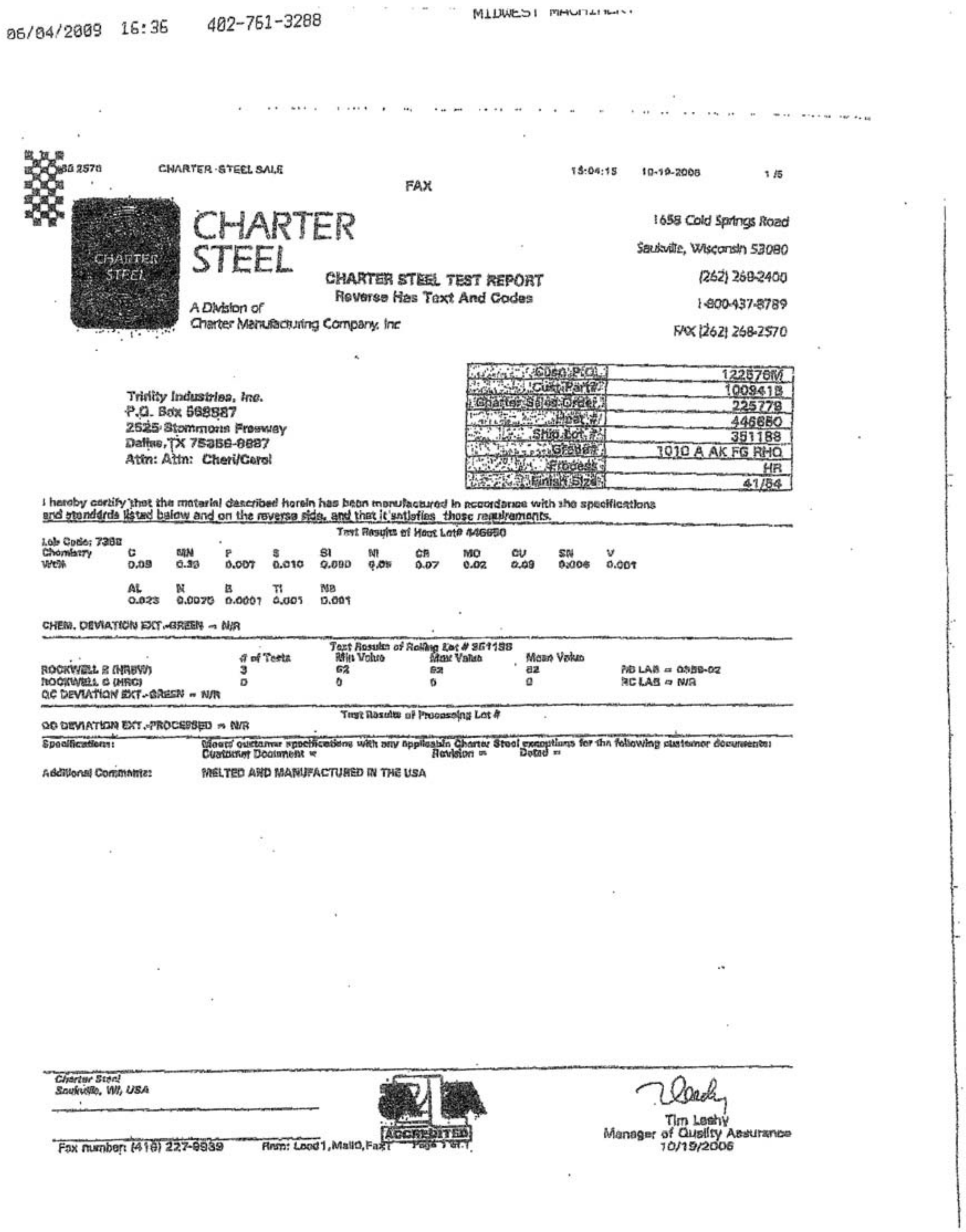
Charter Steel
Saukville, WI, USA

Fax number: (419) 227- 9939 Rem: Losell,Mallo,Faxo

A2LA ACCREDITED
Page 1 of 1

Tim Leahy
Manager of Quality Assurance
10/06/2006

Figure 131. Photo. ⅝-in. x 1½-in. (15.9x38-mm) Hex Bolt and Nut, Material Specification. (continued.)



06/04/2009 16:36 402-761-3288 MIDWEST MACHINERY

262 2570 CHARTER STEEL SALE 15:04:15 10-19-2006 1 /5

FAX

CHARTER
STEEL

A Division of
Charter Manufacturing Company, Inc

CHARTER STEEL TEST REPORT
Reverse Has Text And Codes

1658 Cold Springs Road
Saukville, Wisconsin 53080
(262) 268-2400
1-800-437-8789
FAX (262) 268-2570

Trinity Industries, Inc.
P.O. Box 568887
2525 Stemmons Freeway
Dallas, TX 75356-8887
Attn: Attn: Cheri/Carol

Cust P.O.	122576M
Cust Part #	1009418
Charter Sales Order	225779
Heat #	446650
Ship Lot #	351188
Grade	1010 A AK FG RHQ
Process	HR
Finish Size	41/64

I hereby certify that the material described herein has been manufactured in accordance with the specifications and standards listed below and on the reverse side, and that it satisfies those requirements.

Test Results of Heat Lot# 446650

Lab Code: 7388

Chemistry	C	MN	P	S	SI	NI	CR	MO	CU	SN	V
Wt%	0.09	0.39	0.007	0.010	0.090	0.05	0.07	0.02	0.09	0.006	0.001

AL	N	B	TI	NB
0.023	0.0070	0.0001	0.001	0.001

CHEM. DEVIATION EXT.-GREEN = N/R

Test Results of Rolling Lot # 351188

	# of Tests	Min Value	Max Value	Mean Value	
ROCKWELL B (HRBW)	3	62	62	62	RB LAB = 0359-02
ROCKWELL C (HRC)	0	0	0	0	RC LAB = N/R

QC DEVIATION EXT.-GREEN = N/R

Test Results of Processing Lot #

QC DEVIATION EXT.-PROCESSED = N/R

Specifications: Meets customer specifications with any applicable Charter Steel exceptions for the following customer documents:
Customer Document = Revision = Dated =

Additional Comments: MELTED AND MANUFACTURED IN THE USA

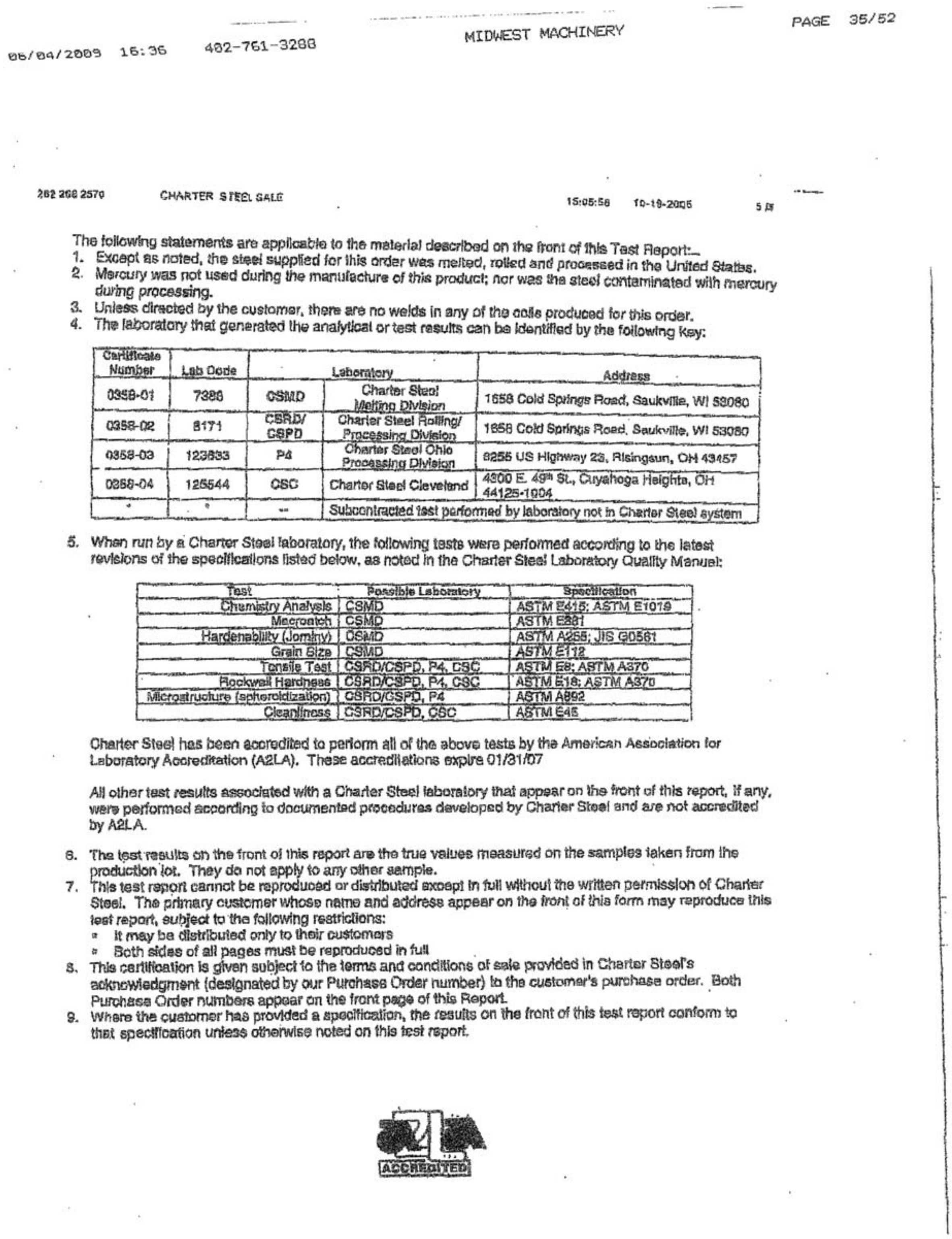
Charter Steel
Saukville, WI, USA

Fax number: (419) 227-9939 Rnm: Lod1,Mail0,Fax1 Page 1 of 1

ACCREDITED

Tim Leahy
Manager of Quality Assurance
10/19/2006

Figure 132. Photo. ⅝-in. x 1½-in. (15.9x38-mm) Hex Bolt and Nut, Material Specification. (continued.)



06/04/2009 16:36 402-761-3288 MIDWEST MACHINERY PAGE 35/52

262 268 2570 CHARTER STEEL SALE 15:05:56 10-19-2006 5 /8

The following statements are applicable to the material described on the front of this Test Report:

1. Except as noted, the steel supplied for this order was melted, rolled and processed in the United States.
2. Mercury was not used during the manufacture of this product; nor was the steel contaminated with mercury during processing.
3. Unless directed by the customer, there are no welds in any of the coils produced for this order.
4. The laboratory that generated the analytical or test results can be identified by the following key:

Certificate Number	Lab Code	Laboratory		Address
0358-01	7386	CSMD	Charter Steel Melting Division	1658 Cold Springs Road, Saukville, WI 53080
0358-02	8171	CSRD/ CSPD	Charter Steel Rolling/ Processing Division	1658 Cold Springs Road, Saukville, WI 53080
0358-03	123833	P4	Charter Steel Ohio Processing Division	6255 US Highway 23, Risingsun, OH 43457
0358-04	125544	CSC	Charter Steel Cleveland	4300 E. 49th St., Cuyahoga Heights, OH 44125-1004
*	*	--	Subcontracted test performed by laboratory not in Charter Steel system	

5. When run by a Charter Steel laboratory, the following tests were performed according to the latest revisions of the specifications listed below, as noted in the Charter Steel Laboratory Quality Manual:

Test	Possible Laboratory	Specification
Chemistry Analysis	CSMD	ASTM E415; ASTM E1019
Macroetch	CSMD	ASTM E381
Hardenability (Jominy)	CSMD	ASTM A255; JIS G0561
Grain Size	CSMD	ASTM E112
Tensile Test	CSRD/CSPD, P4, CSC	ASTM E8; ASTM A370
Rockwell Hardness	CSRD/CSPD, P4, CSC	ASTM E18; ASTM A370
Microstructure (spheroidization)	CSRD/CSPD, P4	ASTM A892
Cleanliness	CSRD/CSPD, CSC	ASTM E45

Charter Steel has been accredited to perform all of the above tests by the American Association for Laboratory Accreditation (A2LA). These accreditations expire 01/31/07

All other test results associated with a Charter Steel laboratory that appear on the front of this report, if any, were performed according to documented procedures developed by Charter Steel and are not accredited by A2LA.

6. The test results on the front of this report are the true values measured on the samples taken from the production lot. They do not apply to any other sample.
7. This test report cannot be reproduced or distributed except in full without the written permission of Charter Steel. The primary customer whose name and address appear on the front of this form may reproduce this test report, subject to the following restrictions:
   - It may be distributed only to their customers
   - Both sides of all pages must be reproduced in full
8. This certification is given subject to the terms and conditions of sale provided in Charter Steel's acknowledgment (designated by our Purchase Order number) to the customer's purchase order. Both Purchase Order numbers appear on the front page of this Report.
9. Where the customer has provided a specification, the results on the front of this test report conform to that specification unless otherwise noted on this test report.

Figure 133. Photo. ⅝-in. x 1½-in. (15.9x38-mm) Hex Bolt and Nut, Material Specification. (continued.)

APPENDIX B. INSTALLATION GUIDE

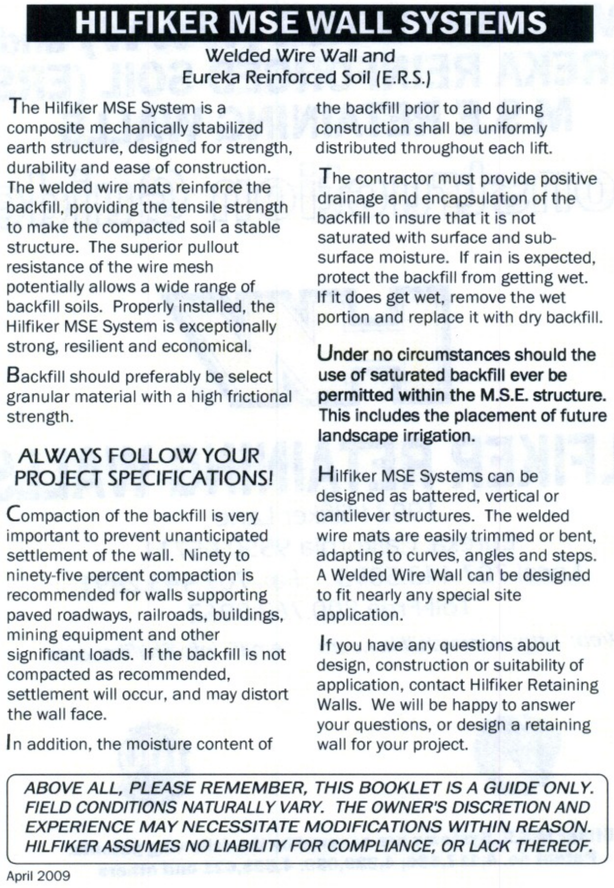
The MSE wall installation guide obtained is contained in this appendix.

WELDED WIRE (WWW) and EUREKA REINFORCED SOIL (ERS) M.S.E RETAINING WALLS

Construction Guide

HILFIKER RETAINING WALLS
1902 Hilfiker Lane
Eureka, California 95503-5711
Local 707.443.5093 Fax 707.443.2891
Toll-Free 800.762.8962
Web: http://www.hilfiker.com *email: info@hilfiker.com*

**Hilfiker M.S.E. Systems are covered by the following patents:
Patent no. 4,117,686; 4,329,089; 4,505,621 and others**



HILFIKER MSE WALL SYSTEMS

Welded Wire Wall and
Eureka Reinforced Soil (E.R.S.)

The Hilfiker MSE System is a composite mechanically stabilized earth structure, designed for strength, durability and ease of construction. The welded wire mats reinforce the backfill, providing the tensile strength to make the compacted soil a stable structure. The superior pullout resistance of the wire mesh potentially allows a wide range of backfill soils. Properly installed, the Hilfiker MSE System is exceptionally strong, resilient and economical.

Backfill should preferably be select granular material with a high frictional strength.

ALWAYS FOLLOW YOUR PROJECT SPECIFICATIONS!

Compaction of the backfill is very important to prevent unanticipated settlement of the wall. Ninety to ninety-five percent compaction is recommended for walls supporting paved roadways, railroads, buildings, mining equipment and other significant loads. If the backfill is not compacted as recommended, settlement will occur, and may distort the wall face.

In addition, the moisture content of the backfill prior to and during construction shall be uniformly distributed throughout each lift.

The contractor must provide positive drainage and encapsulation of the backfill to insure that it is not saturated with surface and sub-surface moisture. If rain is expected, protect the backfill from getting wet. If it does get wet, remove the wet portion and replace it with dry backfill.

Under no circumstances should the use of saturated backfill ever be permitted within the M.S.E. structure. This includes the placement of future landscape irrigation.

Hilfiker MSE Systems can be designed as battered, vertical or cantilever structures. The welded wire mats are easily trimmed or bent, adapting to curves, angles and steps. A Welded Wire Wall can be designed to fit nearly any special site application.

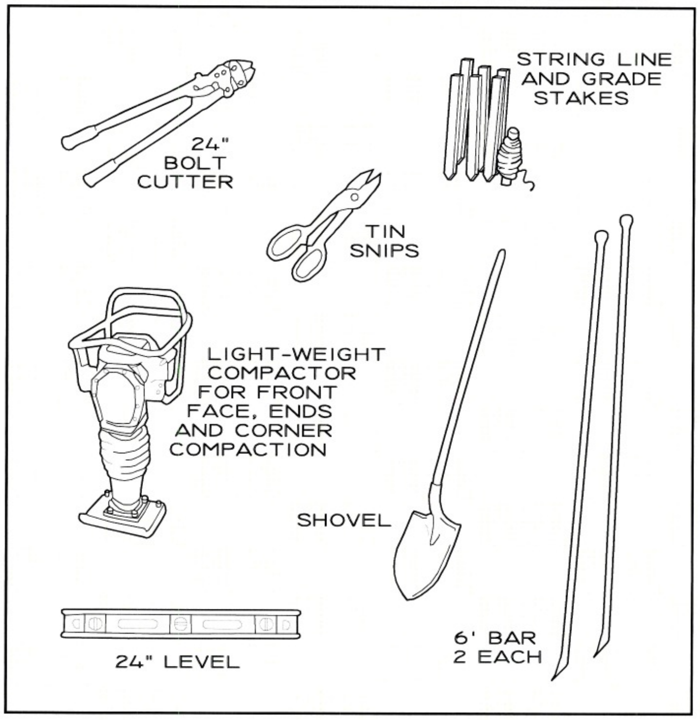
If you have any questions about design, construction or suitability of application, contact Hilfiker Retaining Walls. We will be happy to answer your questions, or design a retaining wall for your project.

ABOVE ALL, PLEASE REMEMBER, THIS BOOKLET IS A GUIDE ONLY. FIELD CONDITIONS NATURALLY VARY. THE OWNER'S DISCRETION AND EXPERIENCE MAY NECESSITATE MODIFICATIONS WITHIN REASON. HILFIKER ASSUMES NO LIABILITY FOR COMPLIANCE, OR LACK THEREOF.

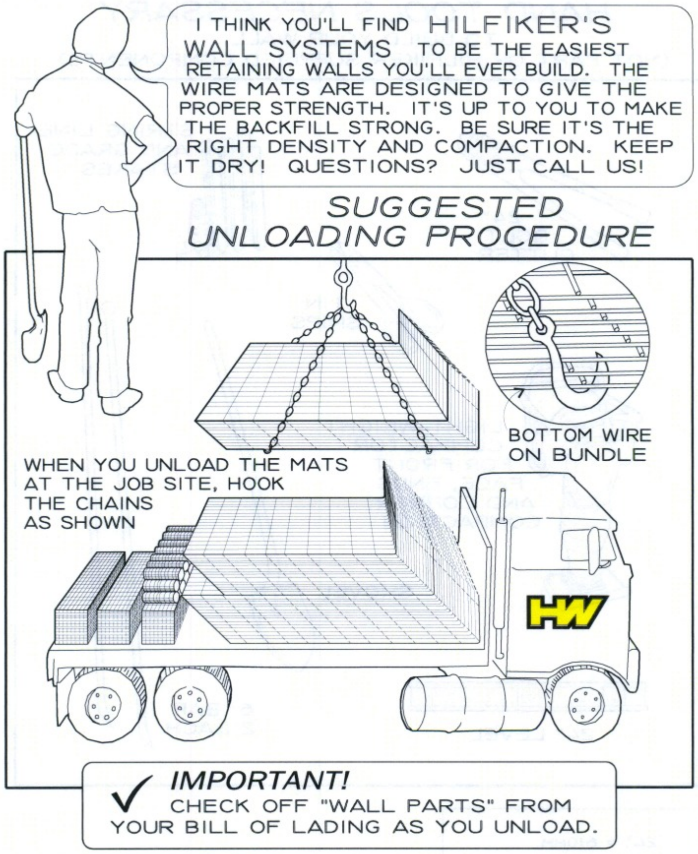
April 2009

HAND TOOLS NECESSARY

TO BUILD YOUR WALL
(NOT PART OF HILFIKER SUPPLIED COMPONENTS)



24" = 610MM
6' = 1.83 M

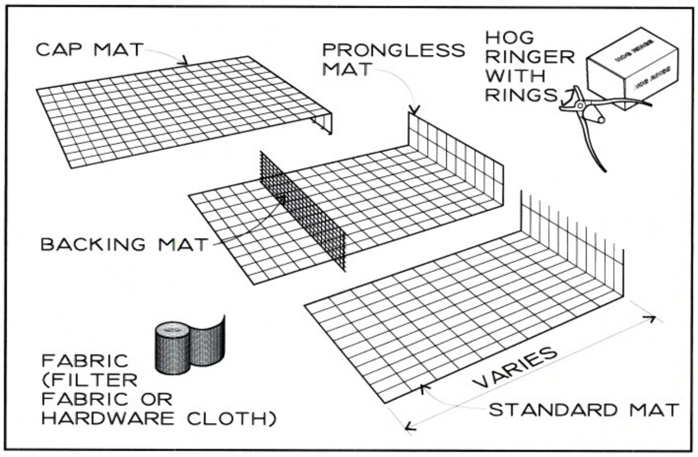


SUGGESTED UNLOADING PROCEDURE

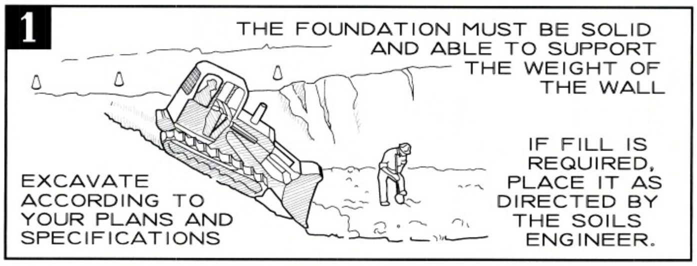
WHEN YOU UNLOAD THE MATS AT THE JOB SITE, HOOK THE CHAINS AS SHOWN

✓ **IMPORTANT!**
CHECK OFF "WALL PARTS" FROM YOUR BILL OF LADING AS YOU UNLOAD.

SUPPLIED WALL PARTS



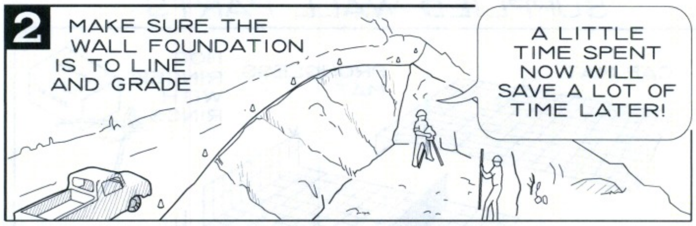
EXCAVATION

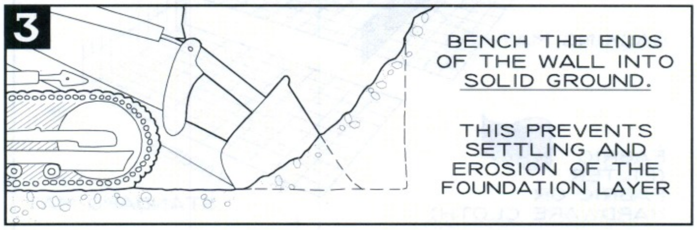


THE FOUNDATION MUST BE SOLID AND ABLE TO SUPPORT THE WEIGHT OF THE WALL

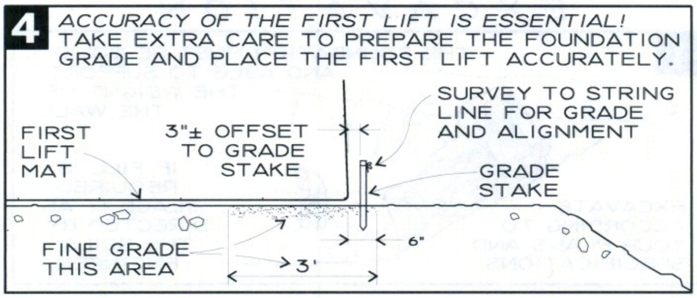
IF FILL IS REQUIRED, PLACE IT AS DIRECTED BY THE SOILS ENGINEER.

EXCAVATE ACCORDING TO YOUR PLANS AND SPECIFICATIONS

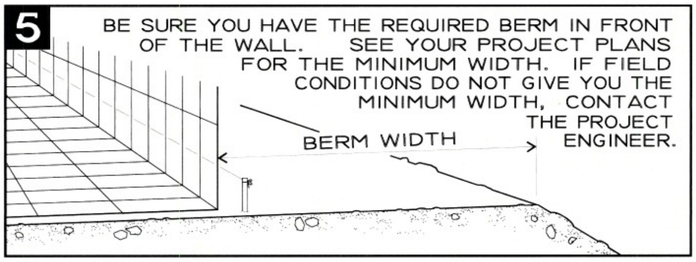




START YOUR WALL!

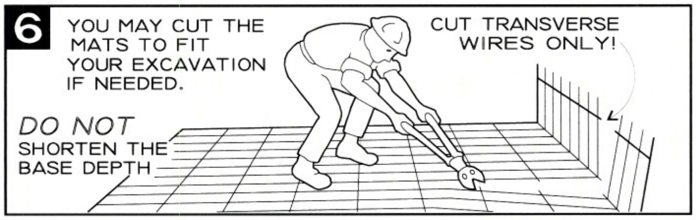


3" = 76MM
6"=152MM
3' = 914MM



5

BE SURE YOU HAVE THE REQUIRED BERM IN FRONT OF THE WALL. SEE YOUR PROJECT PLANS FOR THE MINIMUM WIDTH. IF FIELD CONDITIONS DO NOT GIVE YOU THE MINIMUM WIDTH, CONTACT THE PROJECT ENGINEER.

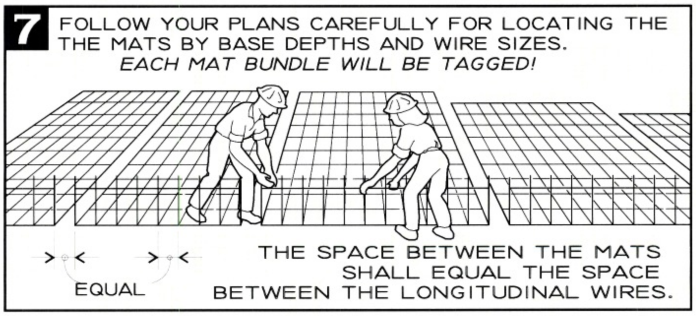


6

YOU MAY CUT THE MATS TO FIT YOUR EXCAVATION IF NEEDED.

DO NOT SHORTEN THE BASE DEPTH

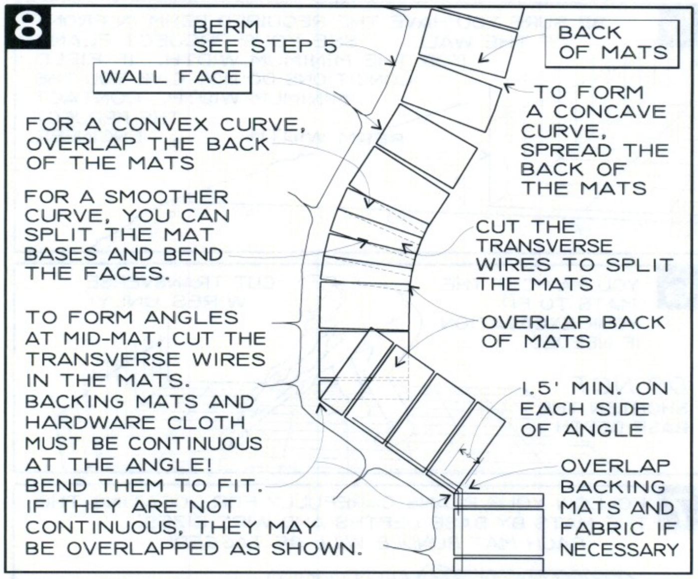
CUT TRANSVERSE WIRES ONLY!



7

FOLLOW YOUR PLANS CAREFULLY FOR LOCATING THE THE MATS BY BASE DEPTHS AND WIRE SIZES.
EACH MAT BUNDLE WILL BE TAGGED!

THE SPACE BETWEEN THE MATS SHALL EQUAL THE SPACE BETWEEN THE LONGITUDINAL WIRES.



8

FOR A CONVEX CURVE, OVERLAP THE BACK OF THE MATS

FOR A SMOOTHER CURVE, YOU CAN SPLIT THE MAT BASES AND BEND THE FACES.

TO FORM ANGLES AT MID-MAT, CUT THE TRANSVERSE WIRES IN THE MATS. BACKING MATS AND HARDWARE CLOTH MUST BE CONTINUOUS AT THE ANGLE! BEND THEM TO FIT. IF THEY ARE NOT CONTINUOUS, THEY MAY BE OVERLAPPED AS SHOWN.

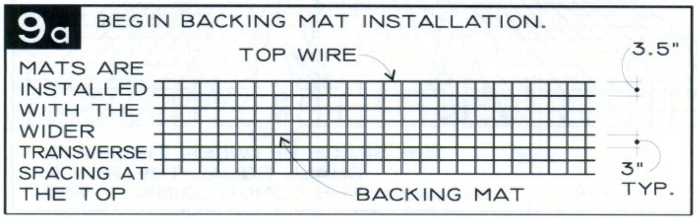
TO FORM A CONCAVE CURVE, SPREAD THE BACK OF THE MATS

CUT THE TRANSVERSE WIRES TO SPLIT THE MATS

OVERLAP BACK OF MATS

1.5' MIN. ON EACH SIDE OF ANGLE

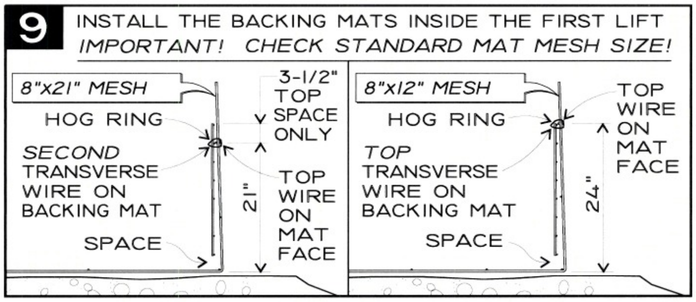
OVERLAP BACKING MATS AND FABRIC IF NECESSARY



9a BEGIN BACKING MAT INSTALLATION.

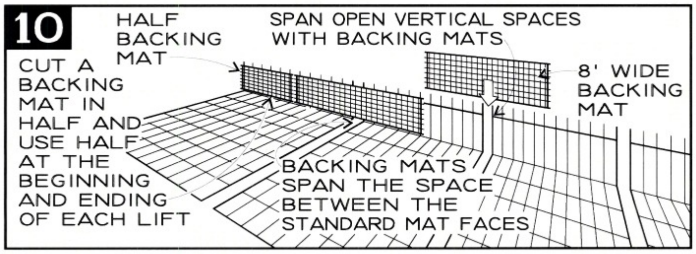
MATS ARE INSTALLED WITH THE WIDER TRANSVERSE SPACING AT THE TOP

3" = 76MM
$3\frac{1}{2}$" = 89MM

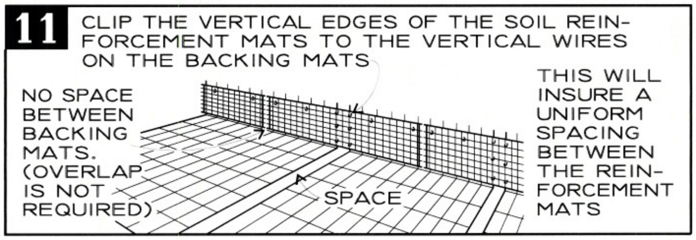


9 INSTALL THE BACKING MATS INSIDE THE FIRST LIFT

IMPORTANT! CHECK STANDARD MAT MESH SIZE!



10



11 CLIP THE VERTICAL EDGES OF THE SOIL REINFORCEMENT MATS TO THE VERTICAL WIRES ON THE BACKING MATS

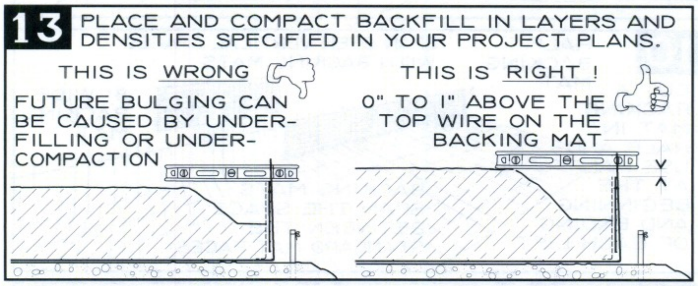
3½" = 89MM
12" = 305MM
8" = 203MM
24" = 610MM
8' = 2.438M

7

12

UNROLL THE FABRIC AGAINST THE BACKING MATS. KEEP IT AS TIGHT AS POSSIBLE.

CLIP WITH HOG RINGS ABOUT 16" APART



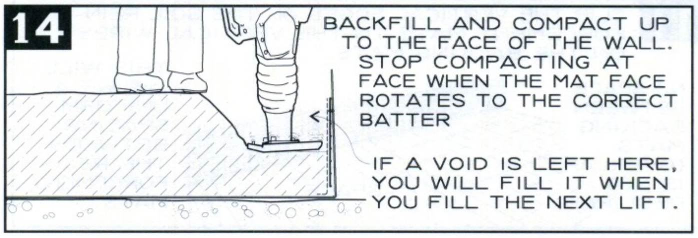
13 PLACE AND COMPACT BACKFILL IN LAYERS AND DENSITIES SPECIFIED IN YOUR PROJECT PLANS.

THIS IS WRONG

FUTURE BULGING CAN BE CAUSED BY UNDER-FILLING OR UNDER-COMPACTION

THIS IS RIGHT !

0" TO 1" ABOVE THE TOP WIRE ON THE BACKING MAT



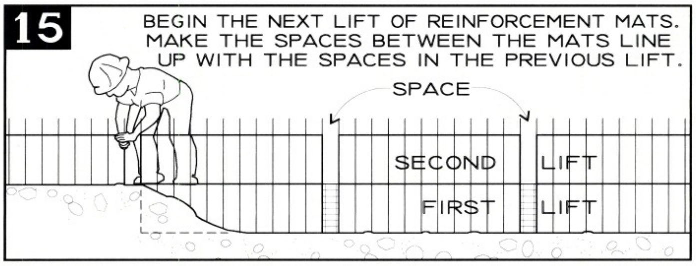
14

BACKFILL AND COMPACT UP TO THE FACE OF THE WALL. STOP COMPACTING AT FACE WHEN THE MAT FACE ROTATES TO THE CORRECT BATTER

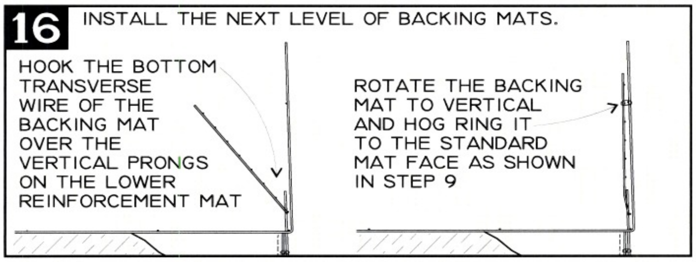
IF A VOID IS LEFT HERE, YOU WILL FILL IT WHEN YOU FILL THE NEXT LIFT.

16" = 406MM
1" = 25MM

15


BEGIN THE NEXT LIFT OF REINFORCEMENT MATS. MAKE THE SPACES BETWEEN THE MATS LINE UP WITH THE SPACES IN THE PREVIOUS LIFT.

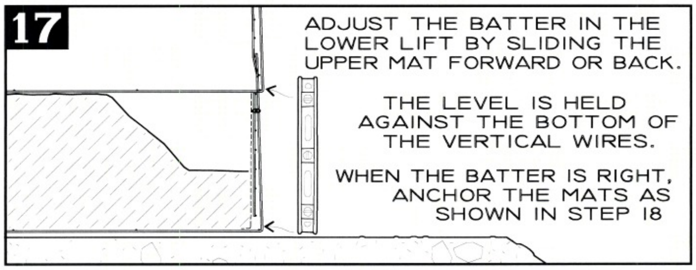
16


INSTALL THE NEXT LEVEL OF BACKING MATS.

HOOK THE BOTTOM TRANSVERSE WIRE OF THE BACKING MAT OVER THE VERTICAL PRONGS ON THE LOWER REINFORCEMENT MAT

ROTATE THE BACKING MAT TO VERTICAL AND HOG RING IT TO THE STANDARD MAT FACE AS SHOWN IN STEP 9

17

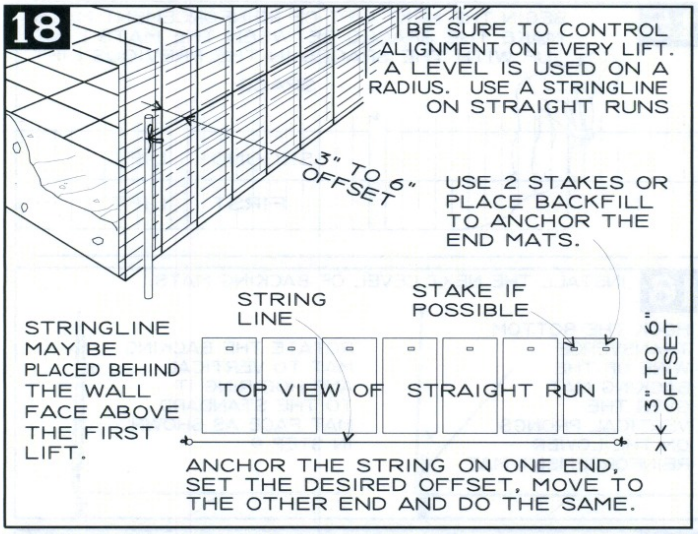

ADJUST THE BATTER IN THE LOWER LIFT BY SLIDING THE UPPER MAT FORWARD OR BACK.

THE LEVEL IS HELD AGAINST THE BOTTOM OF THE VERTICAL WIRES.

WHEN THE BATTER IS RIGHT, ANCHOR THE MATS AS SHOWN IN STEP 18

1:48 = 1/4 INCH PER VERTICAL FOOT
1:10 = 1.2 INCH PER VERTICAL FOOT
1:6 = 2 INCHES PER VERTICAL FOOT

18



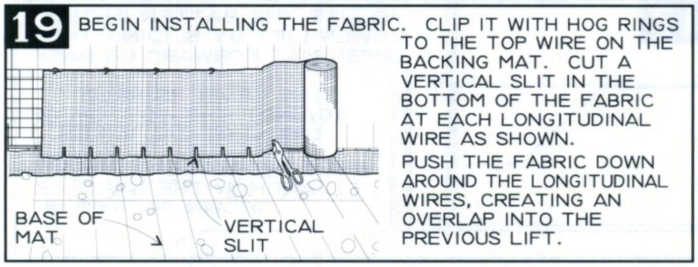
BE SURE TO CONTROL ALIGNMENT ON EVERY LIFT. A LEVEL IS USED ON A RADIUS. USE A STRINGLINE ON STRAIGHT RUNS

USE 2 STAKES OR PLACE BACKFILL TO ANCHOR THE END MATS.

STRINGLINE MAY BE PLACED BEHIND THE WALL FACE ABOVE THE FIRST LIFT.

ANCHOR THE STRING ON ONE END, SET THE DESIRED OFFSET, MOVE TO THE OTHER END AND DO THE SAME.

19

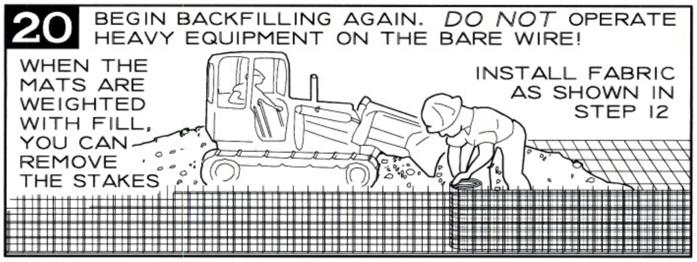


BEGIN INSTALLING THE FABRIC. CLIP IT WITH HOG RINGS TO THE TOP WIRE ON THE BACKING MAT. CUT A VERTICAL SLIT IN THE BOTTOM OF THE FABRIC AT EACH LONGITUDINAL WIRE AS SHOWN.

PUSH THE FABRIC DOWN AROUND THE LONGITUDINAL WIRES, CREATING AN OVERLAP INTO THE PREVIOUS LIFT.

3" TO 6" = 76MM TO 152MM

20

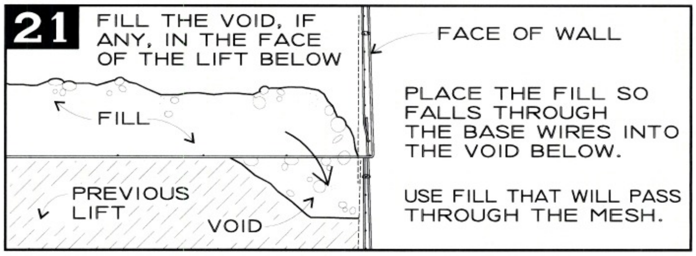


BEGIN BACKFILLING AGAIN. *DO NOT* OPERATE HEAVY EQUIPMENT ON THE BARE WIRE!

WHEN THE MATS ARE WEIGHTED WITH FILL, YOU CAN REMOVE THE STAKES

INSTALL FABRIC AS SHOWN IN STEP 12

21

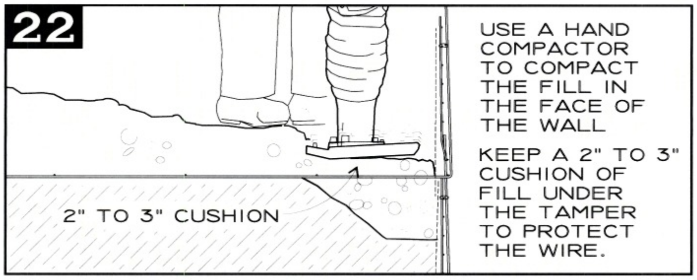


FILL THE VOID, IF ANY, IN THE FACE OF THE LIFT BELOW

PLACE THE FILL SO FALLS THROUGH THE BASE WIRES INTO THE VOID BELOW.

USE FILL THAT WILL PASS THROUGH THE MESH.

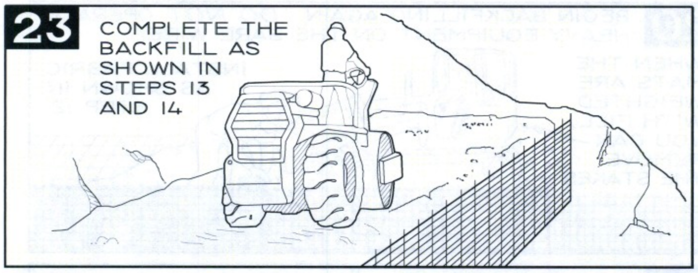
22



USE A HAND COMPACTOR TO COMPACT THE FILL IN THE FACE OF THE WALL

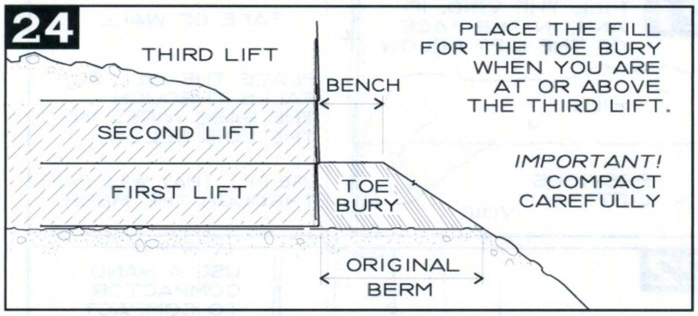
KEEP A 2" TO 3" CUSHION OF FILL UNDER THE TAMPER TO PROTECT THE WIRE.

2"TO 3" = 51MM TO 76MM



23

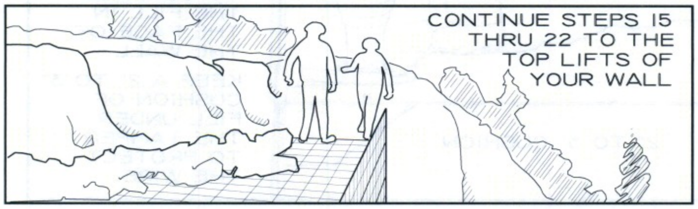
COMPLETE THE BACKFILL AS SHOWN IN STEPS 13 AND 14



24

PLACE THE FILL FOR THE TOE BURY WHEN YOU ARE AT OR ABOVE THE THIRD LIFT.

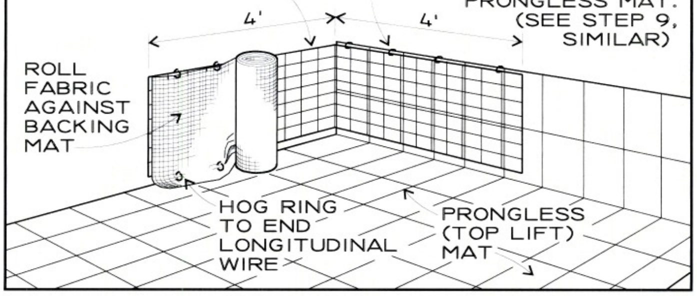
IMPORTANT! COMPACT CAREFULLY



CONTINUE STEPS 15 THRU 22 TO THE TOP LIFTS OF YOUR WALL

TOP OF WALL DETAILS

25 THE ENDS OF THE TOP LIFTS NEED RETURN BACKING MATS TO CONTAIN THE FILL.



MAKE A RETURN BACKING MAT BY BENDING AN 8' BACKING MAT IN HALF AS SHOWN.

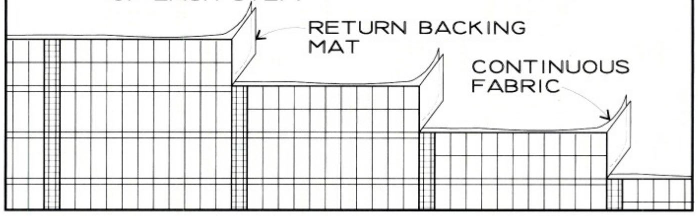
IMPORTANT! IN THE 8"X12" LIFTS ONLY, HOG RING THE *TOP* WIRE ON THE BACKING MAT TO THE *TOP* WIRE ON THE PRONGLESS MAT. (SEE STEP 9, SIMILAR)

ROLL FABRIC AGAINST BACKING MAT

HOG RING TO END LONGITUDINAL WIRE

PRONGLESS (TOP LIFT) MAT

26 IF YOUR WALL STEPS AT THE TOP, USE A RETURN BACKING MAT TO CLOSE THE END OF EACH STEP.

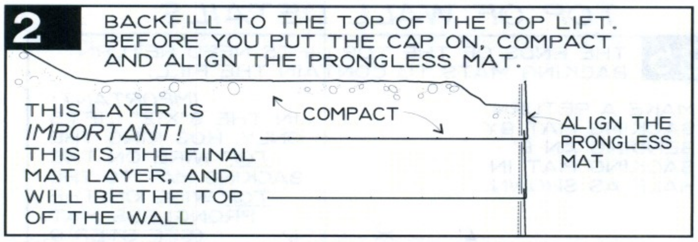


RETURN BACKING MAT

CONTINUOUS FABRIC

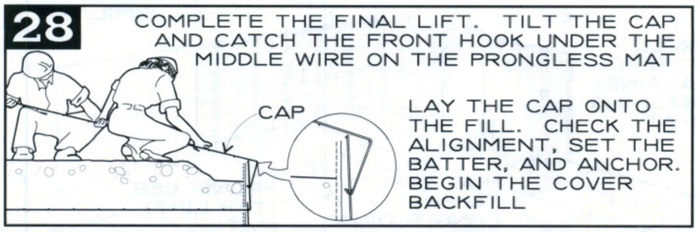
8" = 203MM   4' = 1.22M
12" = 305MM   8' = 2.44M

2 BACKFILL TO THE TOP OF THE TOP LIFT. BEFORE YOU PUT THE CAP ON, COMPACT AND ALIGN THE PRONGLESS MAT.



28 COMPLETE THE FINAL LIFT. TILT THE CAP AND CATCH THE FRONT HOOK UNDER THE MIDDLE WIRE ON THE PRONGLESS MAT

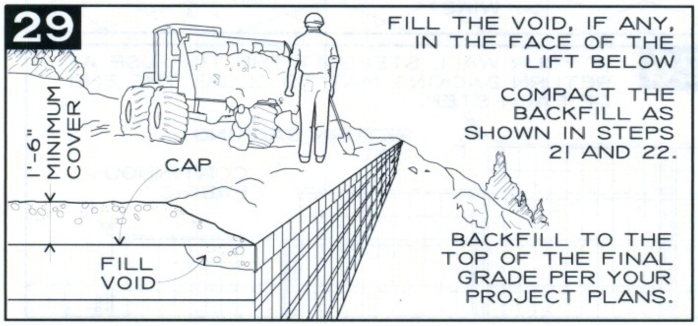
LAY THE CAP ONTO THE FILL. CHECK THE ALIGNMENT, SET THE BATTER, AND ANCHOR. BEGIN THE COVER BACKFILL



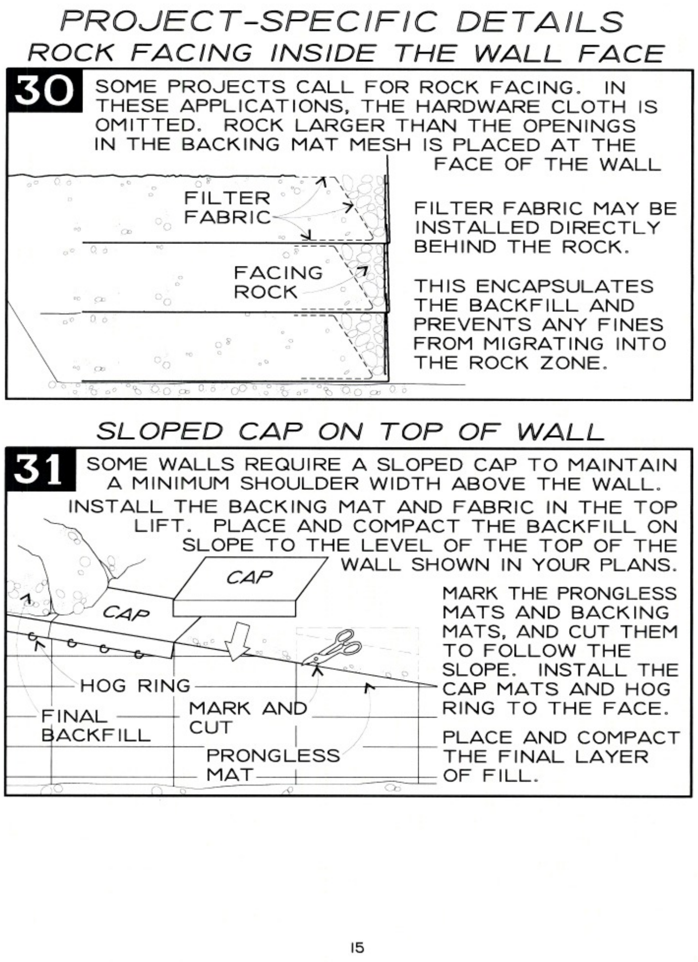
29 FILL THE VOID, IF ANY, IN THE FACE OF THE LIFT BELOW

COMPACT THE BACKFILL AS SHOWN IN STEPS 21 AND 22.

BACKFILL TO THE TOP OF THE FINAL GRADE PER YOUR PROJECT PLANS.



1'-6" = 457MM



PROJECT-SPECIFIC DETAILS

ROCK FACING INSIDE THE WALL FACE

30 SOME PROJECTS CALL FOR ROCK FACING. IN THESE APPLICATIONS, THE HARDWARE CLOTH IS OMITTED. ROCK LARGER THAN THE OPENINGS IN THE BACKING MAT MESH IS PLACED AT THE FACE OF THE WALL

FILTER FABRIC MAY BE INSTALLED DIRECTLY BEHIND THE ROCK.

THIS ENCAPSULATES THE BACKFILL AND PREVENTS ANY FINES FROM MIGRATING INTO THE ROCK ZONE.

SLOPED CAP ON TOP OF WALL

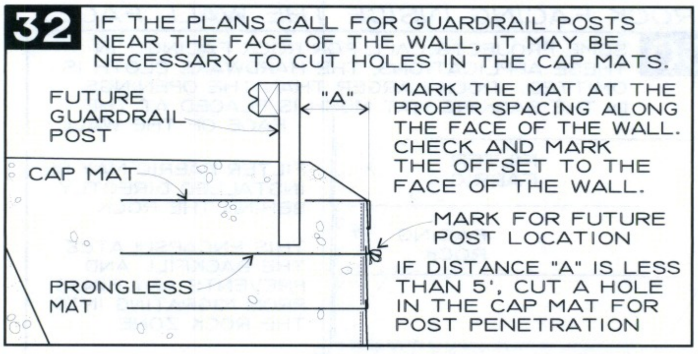
31 SOME WALLS REQUIRE A SLOPED CAP TO MAINTAIN A MINIMUM SHOULDER WIDTH ABOVE THE WALL. INSTALL THE BACKING MAT AND FABRIC IN THE TOP LIFT. PLACE AND COMPACT THE BACKFILL ON SLOPE TO THE LEVEL OF THE TOP OF THE WALL SHOWN IN YOUR PLANS.

MARK THE PRONGLESS MATS AND BACKING MATS, AND CUT THEM TO FOLLOW THE SLOPE. INSTALL THE CAP MATS AND HOG RING TO THE FACE.

PLACE AND COMPACT THE FINAL LAYER OF FILL.

15

WOOD GUARDRAIL PENETRATION



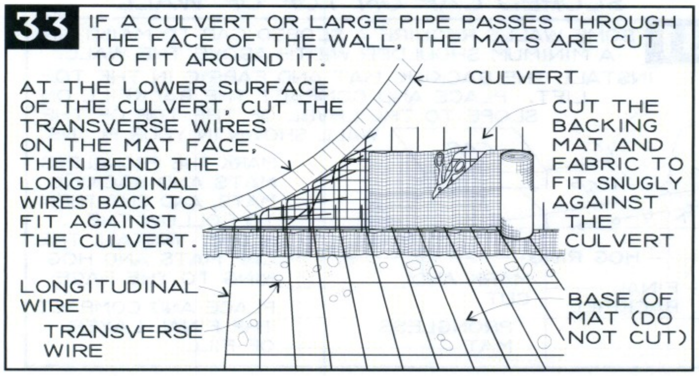
32 IF THE PLANS CALL FOR GUARDRAIL POSTS NEAR THE FACE OF THE WALL, IT MAY BE NECESSARY TO CUT HOLES IN THE CAP MATS.

MARK THE MAT AT THE PROPER SPACING ALONG THE FACE OF THE WALL. CHECK AND MARK THE OFFSET TO THE FACE OF THE WALL.

MARK FOR FUTURE POST LOCATION

IF DISTANCE "A" IS LESS THAN 5', CUT A HOLE IN THE CAP MAT FOR POST PENETRATION

CULVERT THROUGH WALL



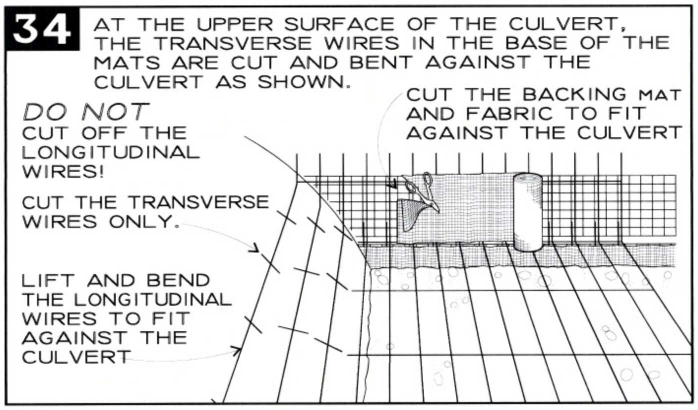
33 IF A CULVERT OR LARGE PIPE PASSES THROUGH THE FACE OF THE WALL, THE MATS ARE CUT TO FIT AROUND IT.

AT THE LOWER SURFACE OF THE CULVERT, CUT THE TRANSVERSE WIRES ON THE MAT FACE, THEN BEND THE LONGITUDINAL WIRES BACK TO FIT AGAINST THE CULVERT.

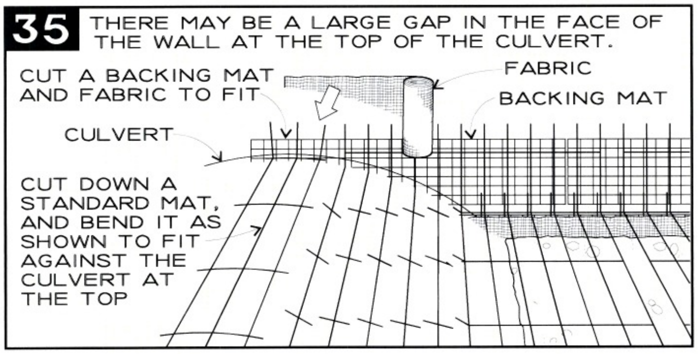
CUT THE BACKING MAT AND FABRIC TO FIT SNUGLY AGAINST THE CULVERT

5'= 1.524M

CULVERT THROUGH WALL (CONTINUED)



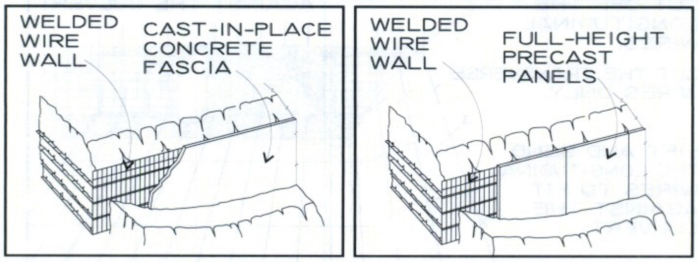
34 AT THE UPPER SURFACE OF THE CULVERT, THE TRANSVERSE WIRES IN THE BASE OF THE MATS ARE CUT AND BENT AGAINST THE CULVERT AS SHOWN.



35 THERE MAY BE A LARGE GAP IN THE FACE OF THE WALL AT THE TOP OF THE CULVERT.

EUREKA REINFORCED SOIL M.S.E. WALL DETAILS

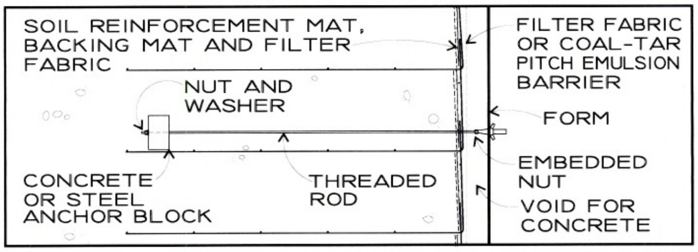
THE HILFIKER E.R.S. WALL BEGINS AS A WELDED WIRE WALL. AFTER COMPLETION AND ANY POTENTIAL SETTLEMENT, PERMANENT FACING IS INSTALLED. THIS MAY CONSIST OF CAST-IN-PLACE CONCRETE, OR FULL-HEIGHT PRECAST CONCRETE PANELS. THE PROJECT CONSTRUCTION PLANS WILL GIVE MORE SPECIFIC DETAILS.



A LEVELING COURSE IS CAST AGAINST THE TOE OF THE WELDED WIRE WALL. THIS WILL SERVE TO SUPPORT AND ALIGN THE FORMS FOR THE C.I.P. FACING, OR WILL HAVE A KEYWAY FOR ALIGNMENT AND CONTROL OF THE TOE OF THE PRECAST FULL-HEIGHT PANELS.

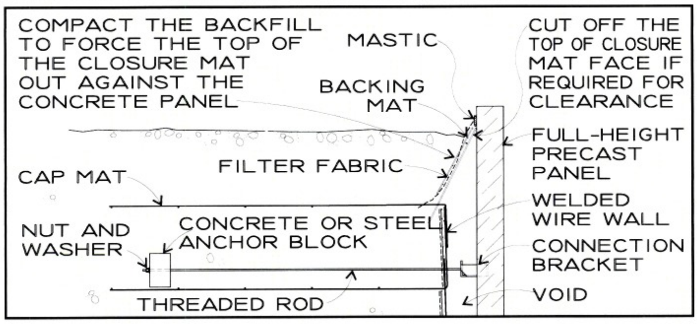
ANCHORS FOR C.I.P. FORMS

ANCHORAGE BOLTS ARE INSTALLED AS THE WELDED WIRE WALL IS BUILT. THE DESIGN MAY VARY FROM THAT SHOWN HERE. SPACING, SIZE AND PROJECT-SPECIFIC DETAILS OF THE ANCHORS WILL BE SHOWN IN THE CONSTRUCTION PLANS.



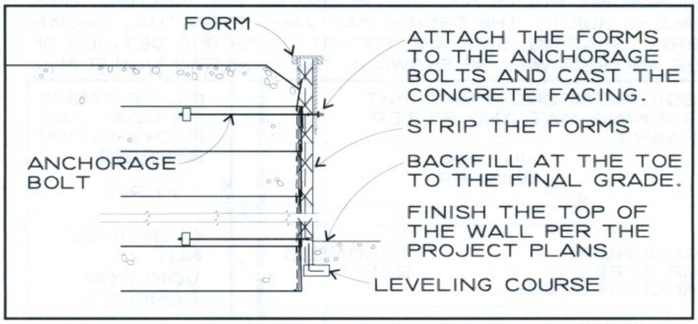
ANCHORS FOR FULL-HEIGHT PRECAST PANELS

ANCHORAGE BOLTS ARE INSTALLED ONLY NEAR THE TOP OF THE WALL. THE DESIGN MAY VARY FROM THAT SHOWN HERE. SPACING, SIZE AND PROJECT-SPECIFIC DETAILS OF THE ANCHORS WILL BE SHOWN IN THE CONSTRUCTION PLANS.



19

FINISHING THE E.R.S. C.I.P. FACING



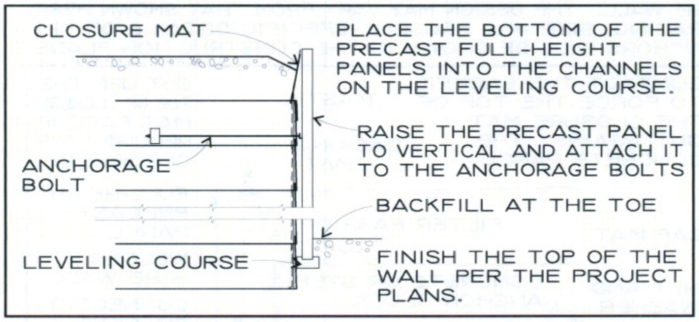
ATTACH THE FORMS TO THE ANCHORAGE BOLTS AND CAST THE CONCRETE FACING.

STRIP THE FORMS

BACKFILL AT THE TOE TO THE FINAL GRADE.

FINISH THE TOP OF THE WALL PER THE PROJECT PLANS

FINISHING THE E.R.S. PRECAST FACING



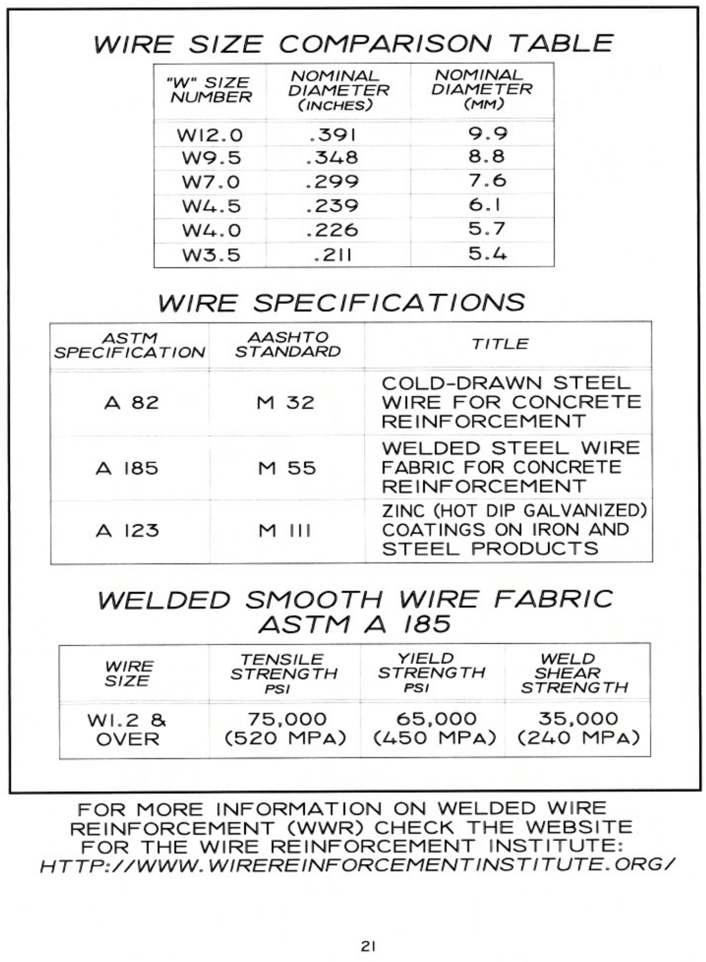
PLACE THE BOTTOM OF THE PRECAST FULL-HEIGHT PANELS INTO THE CHANNELS ON THE LEVELING COURSE.

RAISE THE PRECAST PANEL TO VERTICAL AND ATTACH IT TO THE ANCHORAGE BOLTS

BACKFILL AT THE TOE

FINISH THE TOP OF THE WALL PER THE PROJECT PLANS.

STAND BACK AND ADMIRE YOUR WORK OF ART! SEND PHOTOGRAPHS TO HILFIKER RETAINING WALLS FOR POTENTIAL PUBLICATION (WITH YOUR APPROVAL, OF COURSE!)



WIRE SIZE COMPARISON TABLE

"W" SIZE NUMBER	NOMINAL DIAMETER (INCHES)	NOMINAL DIAMETER (MM)
W12.0	.391	9.9
W9.5	.348	8.8
W7.0	.299	7.6
W4.5	.239	6.1
W4.0	.226	5.7
W3.5	.211	5.4

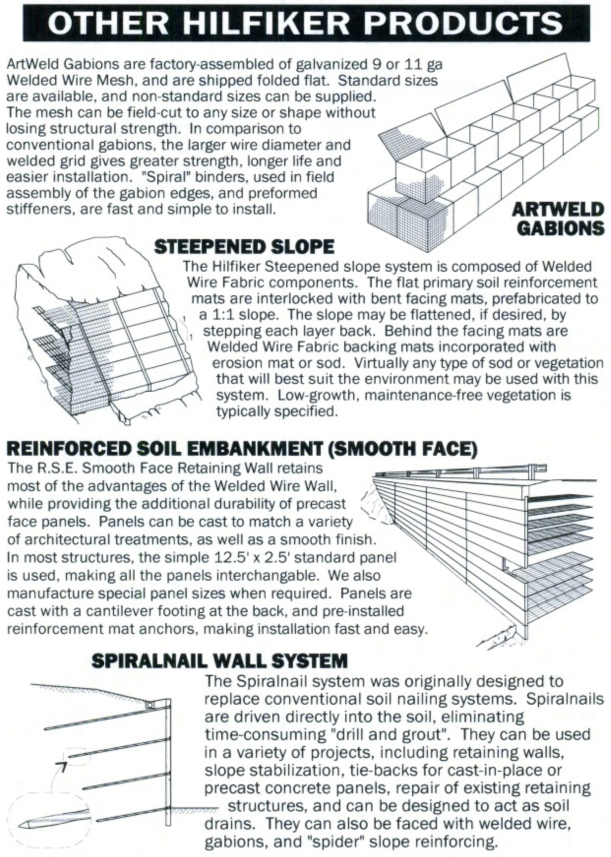
WIRE SPECIFICATIONS

ASTM SPECIFICATION	AASHTO STANDARD	TITLE
A 82	M 32	COLD-DRAWN STEEL WIRE FOR CONCRETE REINFORCEMENT
A 185	M 55	WELDED STEEL WIRE FABRIC FOR CONCRETE REINFORCEMENT
A 123	M 111	ZINC (HOT DIP GALVANIZED) COATINGS ON IRON AND STEEL PRODUCTS

WELDED SMOOTH WIRE FABRIC
ASTM A 185

WIRE SIZE	TENSILE STRENGTH PSI	YIELD STRENGTH PSI	WELD SHEAR STRENGTH
W1.2 & OVER	75,000 (520 MPA)	65,000 (450 MPA)	35,000 (240 MPA)

FOR MORE INFORMATION ON WELDED WIRE REINFORCEMENT (WWR) CHECK THE WEBSITE FOR THE WIRE REINFORCEMENT INSTITUTE:
HTTP://WWW.WIREREINFORCEMENTINSTITUTE.ORG/



OTHER HILFIKER PRODUCTS

ArtWeld Gabions are factory-assembled of galvanized 9 or 11 ga Welded Wire Mesh, and are shipped folded flat. Standard sizes are available, and non-standard sizes can be supplied. The mesh can be field-cut to any size or shape without losing structural strength. In comparison to conventional gabions, the larger wire diameter and welded grid gives greater strength, longer life and easier installation. "Spiral" binders, used in field assembly of the gabion edges, and preformed stiffeners, are fast and simple to install.

ARTWELD GABIONS

STEEPENED SLOPE

The Hilfiker Steepened slope system is composed of Welded Wire Fabric components. The flat primary soil reinforcement mats are interlocked with bent facing mats, prefabricated to a 1:1 slope. The slope may be flattened, if desired, by stepping each layer back. Behind the facing mats are Welded Wire Fabric backing mats incorporated with erosion mat or sod. Virtually any type of sod or vegetation that will best suit the environment may be used with this system. Low-growth, maintenance-free vegetation is typically specified.

REINFORCED SOIL EMBANKMENT (SMOOTH FACE)

The R.S.E. Smooth Face Retaining Wall retains most of the advantages of the Welded Wire Wall, while providing the additional durability of precast face panels. Panels can be cast to match a variety of architectural treatments, as well as a smooth finish. In most structures, the simple 12.5' x 2.5' standard panel is used, making all the panels interchangable. We also manufacture special panel sizes when required. Panels are cast with a cantilever footing at the back, and pre-installed reinforcement mat anchors, making installation fast and easy.

SPIRALNAIL WALL SYSTEM

The Spiralnail system was originally designed to replace conventional soil nailing systems. Spiralnails are driven directly into the soil, eliminating time-consuming "drill and grout". They can be used in a variety of projects, including retaining walls, slope stabilization, tie-backs for cast-in-place or precast concrete panels, repair of existing retaining structures, and can be designed to act as soil drains. They can also be faced with welded wire, gabions, and "spider" slope reinforcing.

APPENDIX C. VEHICLE CENTER OF GRAVITY DETERMINATION

The information used to determine the center of gravity of each vehicle and documentation of the ballast placed in each vehicle is shown in this appendix.

Test: **MGSGW-1** Vehicle: **Rio Sedan (1110C)**

Vehicle CG Determination

VEHICLE	Equipment	Weight	Long CG	HOR M
+	Unbalasted Car	2302	36.92	84995
+	Brake receivers/wires	6	130	780
+	Brake Frame	4	62	248
+	Brake Cylinder	22	31	682
+	Strobe Battery	4	59	236
+	Hub	17	0	0
+	CG Plate (EDRs)	11	47	517
+	DTS	22	62	1364
-	Battery	-34	-9	306
-	Oil	-5	-8	40
-	Interior	-40	39	-1560
-	Fuel	-41	75	-3075
-	Coolant	-9	-19	171
-	Washer fluid	-6	-16	96
BALLAST	Water	98	75	7350
	Misc.			0
	Misc.	33	45	1485
				93635
	TOTAL WEIGHT	2384	lb	39.27643

wheel base 95.5

MASH targets		CURRENT	Difference
Test Inertial Weight	2420 (+/-)55	2384	-36.0
Long CG	39 (+/-)4	39.28	0.27643

Note, Long. CG is measured from front axle of test vehicle

Dummy = 170lb

Curb Weight	Left	Right
Front	727	685
Rear	435	455
FRONT	1412	
REAR	890	
TOTAL	2302	

Actual test inertial weight (from scales)	Left	Right
Front	719	688
Rear	488	532
FRONT	1407	
REAR	1020	
TOTAL	2427	

Figure 134. Chart. Vehicle Mass Distribution, Test No. MGSGW-1.

Test: MGSGW-2 Vehicle: 2270P (RAM 1500)

Vehicle CG Determination

VEHICLE	Equipment	Weight (lb)	Long CG (in.)	Lat CG (in.)	Vert CG (in.)	Long M (lb-in.)	Lat M (lb-in.)	Vert M (lb-in.)
+	Unbalasted Truck(Curb)	5041	61.17853	-1.06281	28.3556	308401	-5357.62	142940.6
+	Brake receivers/wires	6	109	0	52.5	654	0	315
+	Brake Frame	5	33.5	-18.5	26	167.5	-92.5	130
+	Brake Cylinder (Nitrogen)	28	71	21	27.5	1988	770	770
+	Strobe/Brake Battery	6	79	-2.5	31	474	186	186
+	Hub	27	0	-41	15.25	0	-1107	411.75
+	CG Plate (EDRs)	8	54.5	0	32	436	0	256
-	Battery	-44	-7.5	-25	39	330	1100	-1716
-	Oil	-7	8.5	0	17	-59.5	0	-119
-	Interior	-75	52	0	22	-3900	0	-1650
-	Fuel	-165	112	-11	20	-18480	1815	-3300
-	Coolant	-9	-26	0	36	234	0	-324
-	Washer fluid	-3	-26	17	33	78	-51	-99
BALLAST	Water	162	112	-11	20	18144	-1782	3240
	DTS Rack	18	79	-19.75	27	1422	-355.5	486
	Misc.					0	0	0
						309889	-4874.62	141527.3
	TOTAL WEIGHT	4998	lb		CG location (in.)	62.00259	-0.97532	28.31679

wheel base 140.25

Calculated Test Inertial Weight

MASH Targets	Targets	CURRENT	Difference
Test Inertial Weight (lb)	5000 ± 110	4998	-2.0
Long CG (in.)	63 ± 4	62.00	-0.99741
Lat CG (in.)	NA	-0.98	NA
Vert CG (in.)	28 min.	28.32	0.31679

Note: Long. CG is measured from front axle of test vehicle

Note: Lateral CG measured from centerline - positive to vehicle right (passenger) side

Curb Weight (lb)

	Left	Right
Front	1473	1372
Rear	1126	1070

FRONT	2845	lb
REAR	2196	lb
TOTAL	5041	lb

Actual test inertial weight (lb)
(from scales)

	Left	Right
Front	1413	1374
Rear	1112	1100

FRONT	2787	lb
REAR	2212	lb
TOTAL	4999	lb

Figure 135. Chart. Vehicle Mass Distribution, Test No. MGSGW-2.

APPENDIX D. VEHICLE DEFORMATION RECORDS

The vehicle deformation records for each test are contained in this appendix.

VEHICLE PRE/POST CRUSH
FLOORPAN - SET 1

TEST: MGSGW-1
VEHICLE: Rio Sedan (1100C)

Note: If impact is on driver side need to enter negative number for Y

POINT	X	Y	Z	X'	Y'	Z'	DEL X	DEL Y	DEL Z
1	29	8.5	-2.75	28.75	9	-2.75	-0.25	0.5	0
2	31	11.5	-2.25	30.75	11.25	-2.5	-0.25	-0.25	-0.25
3	31	15.25	-1.25	30.5	15.25	-1.25	-0.5	0	0
4	28.5	20.25	0	27.75	21.25	0	-0.75	1	0
5	24	7.25	-6.5	24	7	-6.25	0	-0.25	0.25
6	28.25	12.5	-5	28.25	12	-5.25	0	-0.5	-0.25
7	28.75	18.5	-4	28.5	18.25	-4	-0.25	-0.25	0
8	26	24	-2.5	25.25	23.75	-2.25	-0.75	-0.25	0.25
9	23.5	8.5	-8.75	23.5	8.5	-8.75	0	0	0
10	25.25	13.25	-7.75	25.25	13	-7.75	0	-0.25	0
11	25.75	18.5	-7	25.75	18	-7	0	-0.5	0
12	23.5	23.5	-6.5	23.5	23.75	-6.75	0	0.25	-0.25
13	17.75	7.75	-8.75	17.75	7.5	-8.75	0	-0.25	0
14	19	13.25	-8.5	19	13	-8.5	0	-0.25	0
15	19.25	19	-7.5	19	19.5	-7.75	-0.25	0.5	-0.25
16	10.75	3.5	-4.5	10.5	3.5	-4.5	-0.25	0	0
17	12.75	11.25	-8.5	12.75	11	-8.5	0	-0.25	0
18	13	18.25	-7.5	13	18.25	-7.5	0	0	0
19	13.25	26	-7	13.25	26.25	-7	0	0.25	0
20	5	4.25	-4.25	5	4	-4.25	0	-0.25	0
21	5.5	11	-8.25	5.5	11	-8.25	0	0	0
22	5.75	18.25	-7.25	5.75	18	-7.25	0	-0.25	0
23	5.5	26	-6.75	5.75	26.5	-6.75	0.25	0.5	0
24	0.25	4.75	-3.5	0.25	4.75	-3.5	0	0	0
25	0.5	9.5	-5	0.5	9.5	-5	0	0	0
26	0.25	13.75	-5	0.25	13.75	-5	0	0	0
27	0	20.25	-4.5	0	20.25	-4.5	0	0	0
28	0.25	24.5	-3.25	0.25	24.5	-3.25	0	0	0
29							0	0	0
30							0	0	0
31							0	0	0

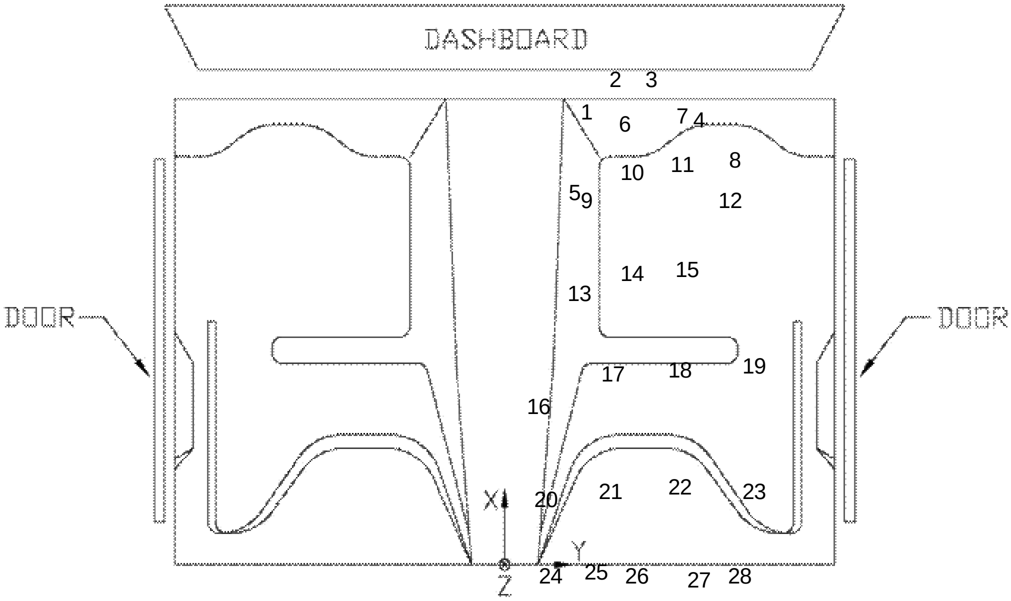


Figure 136. Chart. Floor Pan Deformation Data – Set 1, Test No. MGSGW-1.

VEHICLE PRE/POST CRUSH
FLOORPAN - SET 2

TEST: MGSGW-1
VEHICLE: Rio Sedan (1110C)

Note: If impact is on driver side need to enter negative number for Y

POINT	X	Y	Z	X'	Y'	Z'	DEL X	DEL Y	DEL Z
1	48.75	9.25	-2.5	48.5	9.25	-2.5	-0.25	0	0
2	50.75	12.5	-2	50.5	12.25	-2.25	-0.25	-0.25	-0.25
3	50.75	16.5	-1.25	50.75	16.25	-1	0	-0.25	0.25
4	48	22	0	47.25	22.75	0	-0.75	0.75	0
5	44.25	8.25	-6	44	8	-6	-0.25	-0.25	0
6	48.25	13.25	-4.75	48.25	13.25	-4.75	0	0	0
7	48.5	19.75	-4	48.5	19.5	-4	0	-0.25	0
8	45.75	25.25	-2.5	45.25	25	-2.5	-0.5	-0.25	0
9	44	10.25	-8.5	43.75	9.5	-8.25	-0.25	-0.75	0.25
10	45.75	15.25	-7.5	45.5	15.25	-7.5	-0.25	0	0
11	46	19.75	-6.75	46	19.75	-7	0	0	-0.25
12	43.75	25	-6.75	43.75	25	-7	0	0	-0.25
13	38	8.25	-8.5	38	8.75	-8.5	0	0.5	0
14	39.5	14.25	-8.25	39.5	14.5	-8.25	0	0.25	0
15	39.5	20.5	-7.5	39.5	20.75	-7.75	0	0.25	-0.25
16	30.75	5	-3.75	30.75	4.75	-3.75	0	-0.25	0
17	33.25	12.5	-8	33.25	12.25	-8.25	0	-0.25	-0.25
18	33.75	19.75	-7.75	33.5	19	-7.5	-0.25	-0.75	0.25
19	33.75	27.5	-7	33.5	27.25	-7.25	-0.25	-0.25	-0.25
20	25	5.5	-3.75	25	5.5	-3.75	0	0	0
21	25.25	12.5	-7.75	25.5	12.25	-7.75	0.25	-0.25	0
22	26	19.25	-7	26	19.25	-7.25	0	0	-0.25
23	26	27.5	-6.75	26	27.25	-6.75	0	-0.25	0
24	20.25	5.75	-2.75	20.25	5.75	-2.75	0	0	0
25	20.75	10.75	-4.5	20.75	10.5	-4.5	0	-0.25	0
26	20.75	15	-4.75	21	14.75	-4.75	0.25	-0.25	0
27	20.5	21.25	-4.5	20.5	21.25	-4.5	0	0	0
28	20.75	25.75	-3.25	20.5	25.75	-3.25	-0.25	0	0
29							0	0	0
30							0	0	0
31							0	0	0

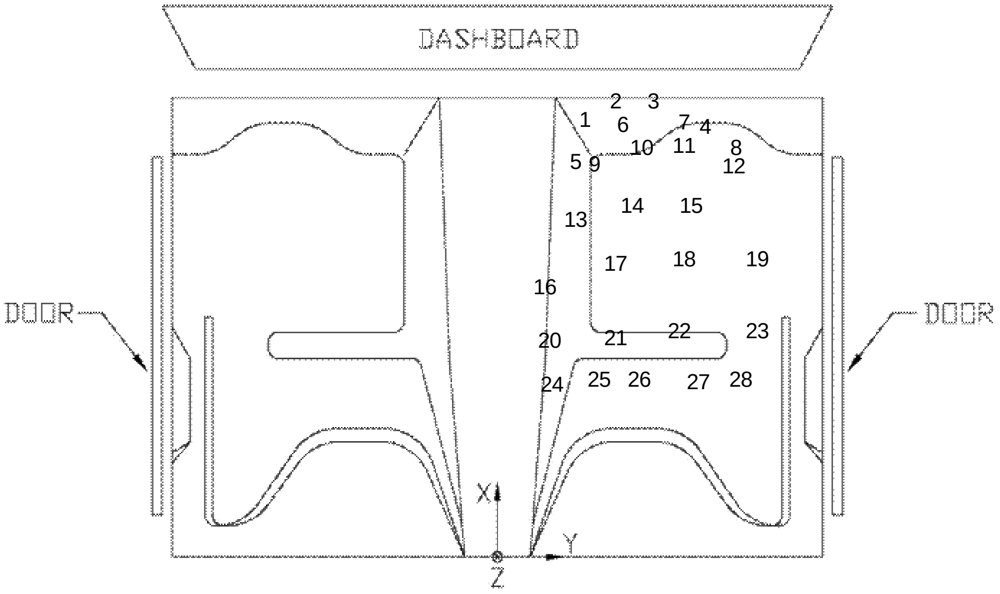


Figure 137. Chart. Floor Pan Deformation Data – Set 2, Test No. MGSGW-1.

VEHICLE PRE/POST CRUSH
INTERIOR CRUSH - SET 1

TEST: MGSGW-1
VEHICLE: Rio Sedan (1100C)

Note: If impact is on driver side need to enter negative number for Y

	POINT	X	Y	Z	X'	Y'	Z'	DEL X	DEL Y	DEL Z
DASH	A1	28.75	11	19.75	28.25	11.25	19.75	-0.5	0.25	0
	A2	31	21.25	20.25	31	21	20.25	0	-0.25	0
	A3	29.25	30	20.75	29	29.75	21	-0.25	-0.25	0.25
	A4	27.75	15.25	13.5	27	15	13.5	-0.75	-0.25	0
	A5	27.75	22	14.25	27	22	14.5	-0.75	0	0.25
	A6	27.75	32	10.5	27.5	32	10.5	-0.25	0	0
SIDE PANEL	B1	36.75	35.75	3	36.75	35.5	2.75	0	-0.25	-0.25
	B2	33.75	35.75	1.5	33.75	35.5	1.5	0	-0.25	0
	B3	33	35.75	-1	33	35.5	-1.25	0	-0.25	-0.25
IMPACT SIDE DOOR	C1	24.75	36.25	18	24.5	36.75	18	-0.25	0.5	0
	C2	16.75	36.25	18.75	16.75	36.75	19.25	0	0.5	0.5
	C3	1.5	36.25	17.75	0.75	37	18.25	-0.75	0.75	0.5
	C4	22.25	36.75	-0.25	21.75	36.75	-0.25	-0.5	0	0
	C5	22	36.5	5	21.5	36.75	5	-0.5	0.25	0
	C6	2.5	36.75	5.5	2	36.75	5.75	-0.5	0	0.25
ROOF	D1							0	0	0
	D2							0	0	0
	D3							0	0	0
	D4							0	0	0
	D5							0	0	0
	D6							0	0	0
	D7							0	0	0
	D8							0	0	0
	D9							0	0	0
	D10							0	0	0
	D11							0	0	0
	D12							0	0	0
	D13							0	0	0
	D14							0	0	0
	D15							0	0	0

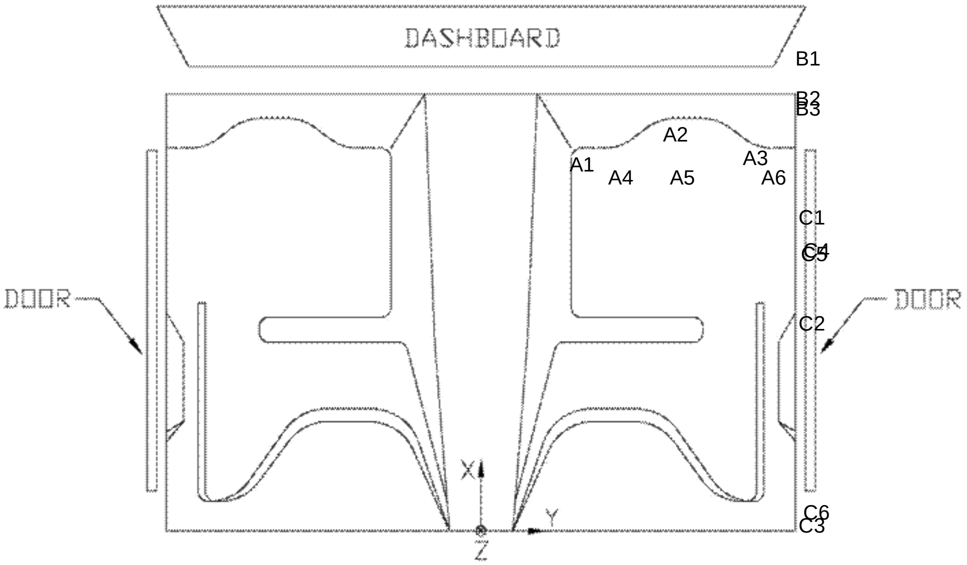


Figure 138. Chart. Occupant Compartment Deformation Data – Set 1, Test No. MGSGW-1.

VEHICLE PRE/POST CRUSH
INTERIOR CRUSH - SET 2

TEST: MGSGW-1
VEHICLE: Rio Sedan (1100C)

Note: If impact is on driver side need to enter negative number for Y

	POINT	X	Y	Z	X'	Y'	Z'	DEL X	DEL Y	DEL Z
DASH	A1	43	25.75	20.25	43.5	25.25	20	0.5	-0.5	-0.25
	A2	43.75	34	20.5	43.5	34	20.5	-0.25	0	0
	A3	43.5	43.75	20.75	43.5	43.25	20.75	0	-0.5	0
	A4	40.25	28.75	14	40	28.75	14	-0.25	0	0
	A5	40.25	35.5	14.5	40	35.5	14.75	-0.25	0	0.25
	A6	41	44	10.25	40.75	44	10.5	-0.25	0	0.25
SIDE PANEL	B1	50.5	48	2.75	50.25	48.25	3	-0.25	0.25	0.25
	B2	47.75	48	1.5	47.5	48.25	1.5	-0.25	0.25	0
	B3	47	48	-1.25	47	48.25	-1.5	0	0.25	-0.25
IMPACT SIDE DOOR	C1	37.75	49.5	17.75	37.5	50.25	17.75	-0.25	0.75	0
	C2	29.5	49.5	18.5	29.5	50.25	18.25	0	0.75	-0.25
	C3	14.25	49.5	17.5	14.25	50	17.75	0	0.5	0.25
	C4	36	49	-0.5	36	49	-0.5	0	0	0
	C5	35.75	49	4.75	35.25	50.25	4.75	-0.5	1.25	0
	C6	16.25	49	5.5	15.5	50.25	5.5	-0.75	1.25	0
ROOF	D1							0	0	0
	D2							0	0	0
	D3							0	0	0
	D4							0	0	0
	D5							0	0	0
	D6							0	0	0
	D7							0	0	0
	D8							0	0	0
	D9							0	0	0
	D10							0	0	0
	D11							0	0	0
	D12							0	0	0
	D13							0	0	0
	D14							0	0	0
	D15							0	0	0

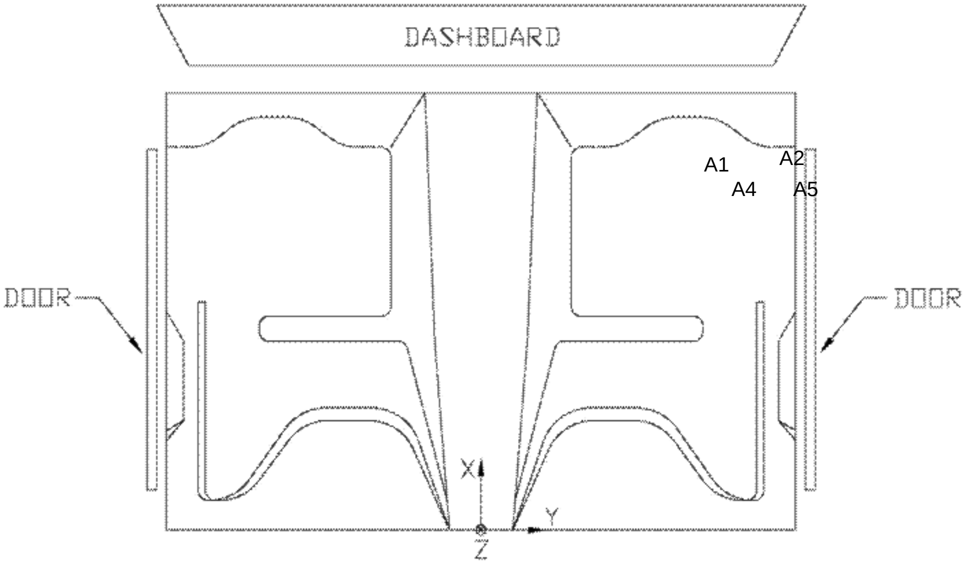
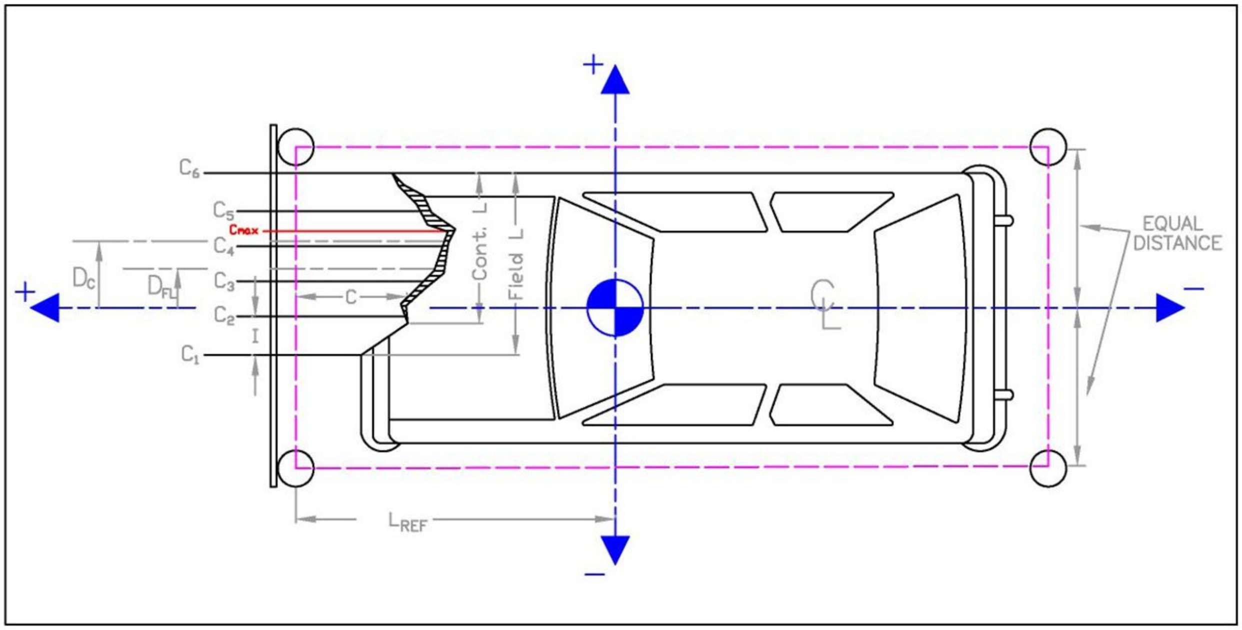


Figure 139. Chart. Occupant Compartment Deformation Data – Set 2, Test No. MGSGW-1.

Date: 11/3/2009 **Test Number:** MGSGW-1

Make: Kia **Model:** Rio Sedan (1100C) **Year:** 2003



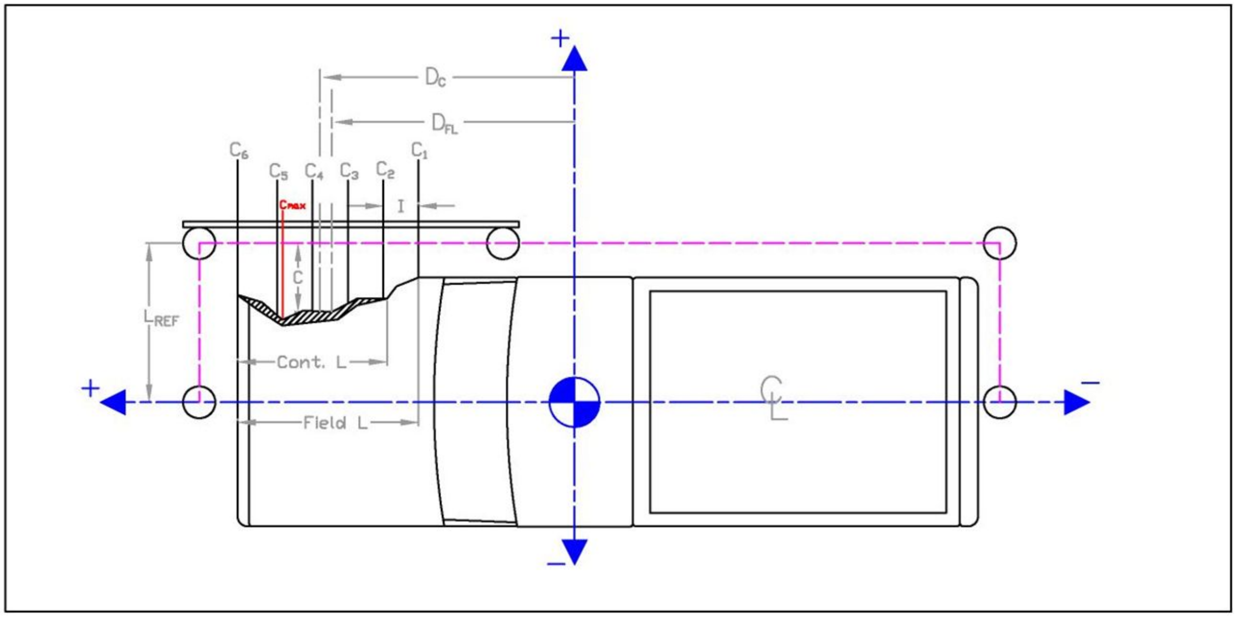
	in.	(mm)
Distance from C.G. to reference line - L_{REF}:	77	(1956)
Width of contact and induced crush - Field L:	64	(1626)
Crush measurement spacing interval (L/5) - I:	12.8	(325)
Distance from center of vehicle to center of Field L - D_{FL}:	0	()
Width of Contact Damage:	32	(813)
Distance from center of vehicle to center of contect damage - D_C:	16	(406)

	Crush Measurement		Lateral Location		Original Profile Measurement		Dist. Between Ref. Lines		Actual Crush	
	in.	(mm)	in.	(mm)	in.	(mm)	in.	(mm)	in.	(mm)
C_1	NA	######	-32	-(813)	30.625	(778)	-5.026	-(128)	######	######
C_2	23.25	(591)	-19.2	-(488)	10.016	(254)			18.261	(464)
C_3	17	(432)	-6.4	-(163)	7.75	(197)			14.276	(363)
C_4	18.5	(470)	6.4	(163)	7.75	(197)			15.776	(401)
C_5	20	(508)	19.2	(488)	9.9375	(252)			15.089	(383)
C_6	31.5	(800)	32	(813)	30.625	(778)			5.9014	(150)
C_{MAX}	27.5	(699)	23.5	(597)	13.25	(337)			19.276	(490)

Figure 140. Chart. Exterior Vehicle Crush (NASS) - Front, Test No. MGSGW-1.

Date: 11/23/2009 **Test Number:** MGSGW-2

Make: Dodge **Model:** 2270P (RAM 1500) **Year:** 2003



	in.	(mm)
Distance from centerline to reference line - L_{REF}:	46.5	(1181)
Width of contact and induced crush - Field L:	227	(5766)
Crush measurement spacing interval (L/5) - I:	45.4	(1153)
Distance from vehicle c.g. to center of Field L - D_{FL}:	-11.5	-(292)
Width of Contact Damage:	227	(5766)
Distance from vehicle c.g. to center of contect damage - D_C:	11.5	(292)

NOTE: Enter "NA" for crush measurement if distance can not be measured (i.e., front of vehicle has been pushed inward or tire has been remeoved)

	Crush Measurement		**Longitudinal Location**		**Original Profile Measurement**		**Dist. Between Ref. Lines**		**Actual**	**Crush**
	in.	(mm)	in.	(mm)	in.	(mm)	in.	(mm)	in.	(mm)
C_1	Na	#######	-125	-(3175)	15.0625	(383)	-3.5	-(89)	#######	#VALUE!
C_2	8.75	(222)	-79.6	-(2022)	10.5	(267)			1.75	(44)
C_3	7.75	(197)	-34.2	-(869)	11.6042	(295)			-0.3542	-(9)
C_4	8.25	(210)	11.2	(284)	11.25	(286)			0.5	(13)
C_5	NA	#######	56.6	(1438)	10.5	(267)			#######	#VALUE!
C_6	NA	#######	102	(2591)	36.125	(918)			#######	#VALUE!
C_{MAX}	13.25	(337)	81	(2057)	11.25	(286)			5.5	(140)

Figure 141. Chart. Exterior Vehicle Crush (NASS) – Side, Test No. MGSGW-1.

VEHICLE PRE/POST CRUSH
FLOORPAN - SET 1

TEST: MGSGW-2
VEHICLE: 2270P (RAM 1500)

Note: If impact is on driver side need to enter negative number for Y

POINT	X (in.)	Y (in.)	Z (in.)	X' (in.)	Y' (in.)	Z' (in.)	ΔX (in.)	ΔY (in.)	ΔZ (in.)
1	27.25	11.5	0.75	26.75	12	0.625	-0.5	0.5	-0.125
2	31.75	19.5	3.375	31.5	19.25	3.5	-0.25	-0.25	0.125
3	31.5	25.5	3.125	31.25	25.25	3.75	-0.25	-0.25	0.625
4	30.25	30	1.75	29	29	2.25	-1.25	-1	0.5
5	24.75	10.5	1.125	24.25	11.5	1.125	-0.5	1	0
6	25.25	15.5	4.25	25	15.75	4	-0.25	0.25	-0.25
7	26.25	21.25	7.75	26.25	21.25	7.75	0	0	0
8	26.5	29.75	7.25	26.25	29.25	7.5	-0.25	-0.5	0.25
9	14.25	3.5	3	14.25	3.5	3	0	0	0
10	17.5	8	3.5	17.25	7.875	3.5	-0.25	-0.125	0
11	19	13.75	7.125	19	13.5	7.25	0	-0.25	0.125
12	20.5	19.75	10.875	20.25	20.25	11	-0.25	0.5	0.125
13	20.5	25.75	11.375	20.25	26	11.5	-0.25	0.25	0.125
14	11.5	3	3.25	11.5	2.875	3.25	0	-0.125	0
15	16.5	13.25	10.125	16.5	13.5	10	0	0.25	-0.125
16	16.75	18.75	11	16.75	19.25	11.125	0	0.5	0.125
17	16.75	27.25	11.625	16.75	27.5	11.75	0	0.25	0.125
18	8.5	4	3.75	8.5	4	3.875	0	0	0.125
19	10.5	12.75	10.5	10.25	13.25	10.625	-0.25	0.5	0.125
20	10.5	20.5	11.125	10.5	21	11.25	0	0.5	0.125
21	10.75	28.5	11.75	10.5	29	11.875	-0.25	0.5	0.125
22	4	4.5	4.375	4	4.5	4.375	0	0	0
23	7.25	15.75	11.125	6.75	16.25	11.25	-0.5	0.5	0.125
24	7	27.5	11.875	6.5	28.25	12	-0.5	0.75	0.125
25	1	3.25	3.625	1	3.125	3.625	0	-0.125	0
26	0.5	13	6.875	0.5	13	7	0	0	0.125
27	0.5	20.75	7.375	0.5	21	7.5	0	0.25	0.125
28	0.5	26.5	7.75	0.5	27	7.875	0	0.5	0.125
29							0	0	0
30							0	0	0
31							0	0	0

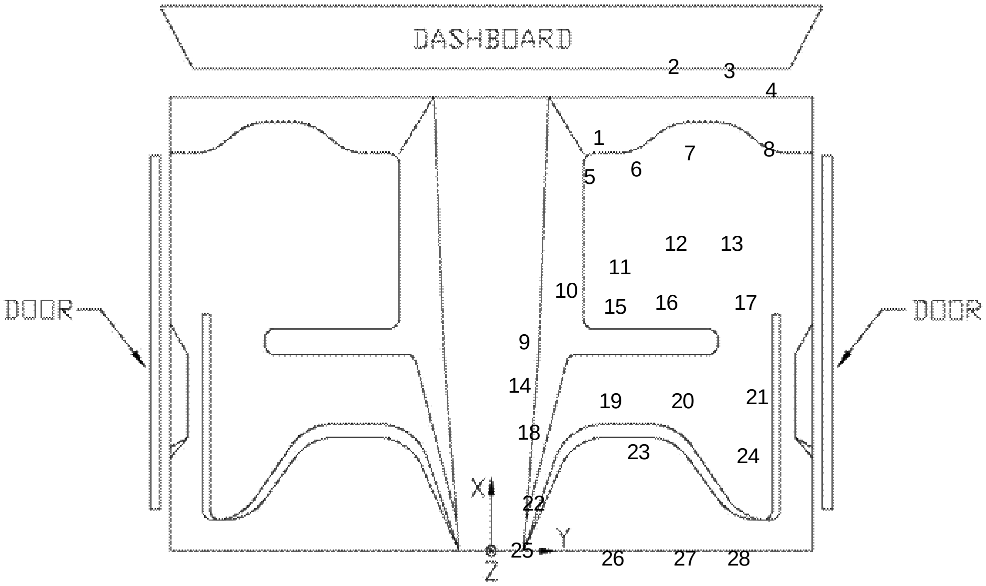


Figure 142. Chart. Floor Pan Deformation Data – Set 1, Test No. MGSGW-2.

VEHICLE PRE/POST CRUSH
FLOORPAN - SET 2

TEST: MGSGW-2
VEHICLE: 2270P (RAM 1500)

Note: If impact is on driver side need to enter negative number for Y

POINT	X (in.)	Y (in.)	Z (in.)	X' (in.)	Y' (in.)	Z' (in.)	ΔX (in.)	ΔY (in.)	ΔZ (in.)
1	49.5	18	0	49.5	19.5	0	0	1.5	0
2	54.25	26.75	3.125	54.5	25.75	3.25	0.25	-1	0.125
3	54.125	32.5	3.25	54.125	32.25	3.125	0	-0.25	-0.125
4	52.25	36.75	2.5	52.25	36.5	2.75	0	-0.25	0.25
5	47	18.25	0.5	47	18.5	0.5	0	0.25	0
6	47.875	22.5	3.75	47.75	22.5	3.5	-0.125	0	-0.25
7	49.125	28	7.5	49.5	28	7.5	0.375	0	0
8	49.625	36.5	7.625	49.5	36.75	7.5	-0.125	0.25	-0.125
9	37	10.25	1.625	37	10.5	1.75	0	0.25	0.125
10	40.125	15	2.5	40.125	14.875	2.625	0	-0.125	0.125
11	41.75	20.5	6.375	41.875	20.5	6.5	0.125	0	0.125
12	43	26.25	10.5	43	27.25	10.625	0	1	0.125
13	43	32.25	11.125	43.25	33	11.25	0.25	0.75	0.125
14	34.125	9.75	1.875	34.25	10	2	0.125	0.25	0.125
15	39	19.75	9.375	39.25	20.25	9.5	0.25	0.5	0.125
16	39.25	25.75	10.5	39.5	26.25	10.625	0.25	0.5	0.125
17	39.5	33.75	11.5	39.5	34.5	11.625	0	0.75	0.125
18	31.375	10.75	2.375	31.375	11	2.5	0	0.25	0.125
19	33.375	19.5	9.625	33.375	19.75	9.75	0	0.25	0.125
20	33.25	27	10.5	33.375	27.75	10.75	0.125	0.75	0.25
21	33.375	35.25	11.5	33.5	36	11.5	0.125	0.75	0
22	26.875	11.5	2.875	26.875	11.5	3	0	0	0.125
23	29.75	22.25	10.25	29.75	22.875	10.25	0	0.625	0
24	29.25	34.25	11.625	29.5	35.125	11.75	0.25	0.875	0.125
25	23.75	10	2.125	23.75	10	2	0	0	-0.125
26	23.25	19.75	5.75	23.5	19.75	5.875	0.25	0	0.125
27	23.25	27.75	6.625	23.5	27.75	6.75	0.25	0	0.125
28	23.5	33.75	7.25	23.375	33.5	7.375	-0.125	-0.25	0.125
29							0	0	0
30							0	0	0
31							0	0	0

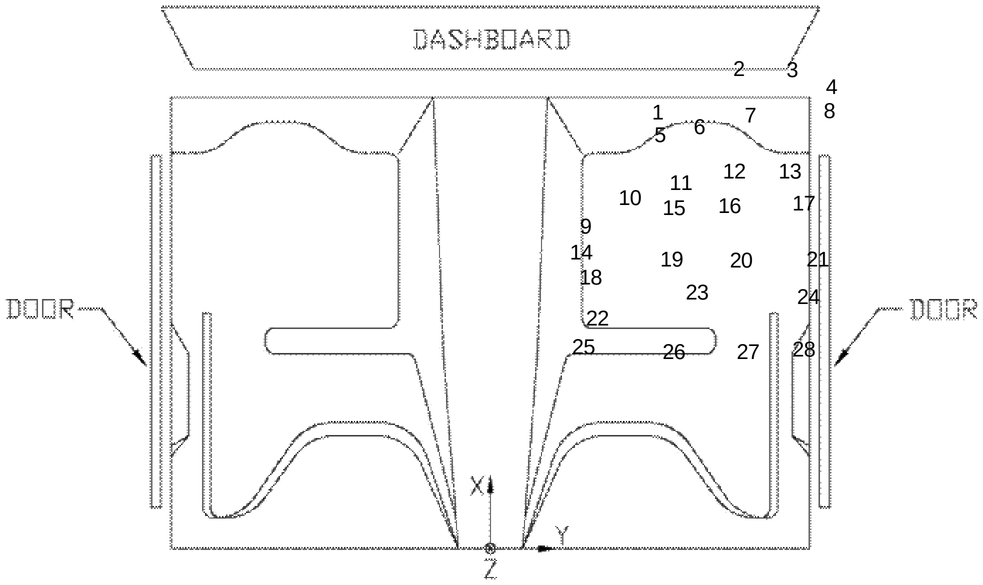


Figure 143. Chart. Floor Pan Deformation Data – Set 2, Test No. MGSGW-2.

VEHICLE PRE/POST CRUSH
INTERIOR CRUSH - Comparitive

TEST: MGSGW-2
VEHICLE: 2270P (RAM 1500)

Note: If impact is on driver side need to enter negative number for Y

		Ref. vehicle			Post test GW-2					
	POINT	X (in.)	Y (in.)	Z (in.)	X' (in.)	Y' (in.)	Z' (in.)	ΔX (in.)	ΔY (in.)	ΔZ (in.)
DASH	A1	33.75	46.25	31.25	33.75	46	31.25	0	-0.25	0
	A2	33.75	54.25	31	33.75	54.25	31.25	0	0	0.25
	A3	33.5	65.25	30.5	33.5	65	30.5	0	-0.25	0
	A4	31.75	41.75	24.75	31.75	41.25	24.75	0	-0.5	0
	A5	31.5	49.75	25	31.5	50	24.75	0	0.25	-0.25
	A6	32	62	25.25	32	61.75	25	0	-0.25	-0.25
SIDE PANEL	B1	40.25	28.5	0	40.25	28.5	0	0	0	0
	B2	36.25	27.75	-0.75	36.25	27.5	-0.5	0	-0.25	0.25
	B3	37	28.25	-5.25	37	28.25	-5.5	0	0	-0.25
IMPACT SIDE DOOR	C1	24.5	39	27	25	39.75	26.75	0.5	0.75	-0.25
	C2	15.75	39.25	27	16	40	27	0.25	0.75	0
	C3	4.25	40	27.5	4.5	41.5	27.5	0.25	1.5	0
	C4	25.5	34.25	10.5	25.5	34	10.5	0	-0.25	0
	C5	17.25	33.75	8.25	17.75	34	8	0.5	0.25	-0.25
	C6	1.5	34	8	1.5	35	8	0	1	0
ROOF	D1							0	0	0
	D2							0	0	0
	D3							0	0	0
	D4	Not needed due to low probability of damge						#VALUE!	0	0
	D5							0	0	0
	D6							0	0	0
	D7							0	0	0
	D8							0	0	0
	D9							0	0	0
	D10							0	0	0
	D11							0	0	0
	D12							0	0	0
	D13							0	0	0
	D14							0	0	0
	D15							0	0	0

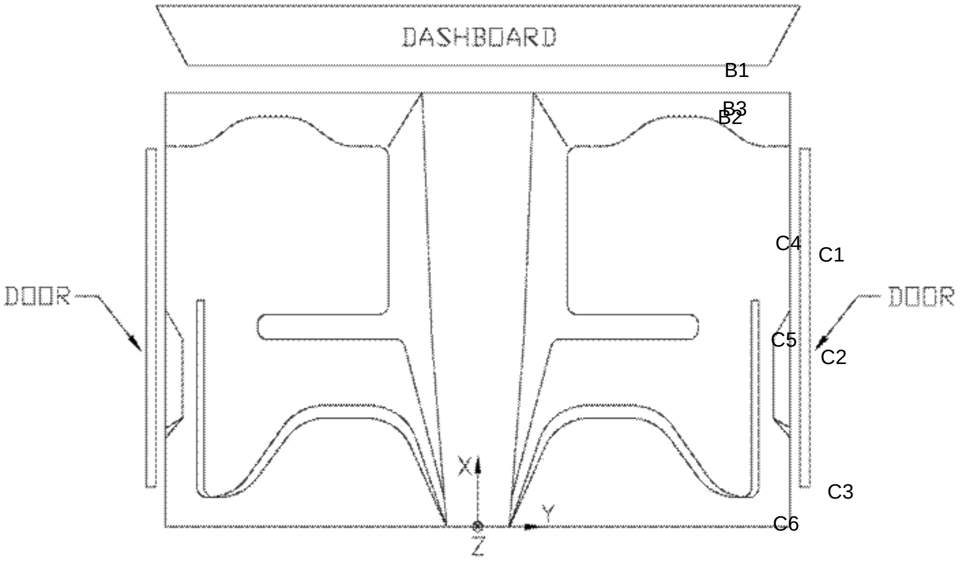
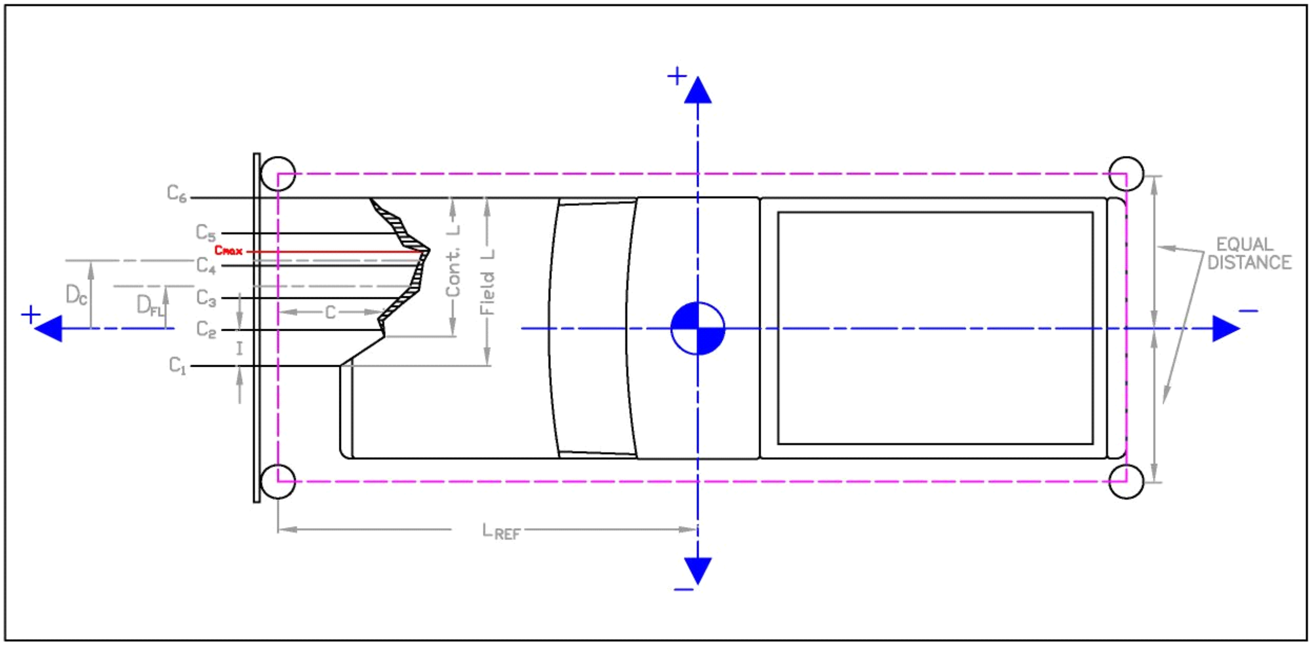


Figure 144. Chart. Occupant Compartment Deformation Data, Test No. MGSGW-2.

Date: 11/23/2009 **Test Number:** MGSGW-2

Make: Dodge **Model:** 2270P (RAM 1500) **Year:** 2003



	in.	(mm)
Distance from C.G. to reference line - L_{REF}:	113	(2870)
Width of contact and induced crush - Field L:	39	(991)
Crush measurement spacing interval (L/5) - I:	7.8	(198)
Distance from center of vehicle to center of Field L - D_{FL}:	19.5	(495)
Width of Contact Damage:	18	(457)
Distance from center of vehicle to center of contect damage - D_C:	28.5	(724)

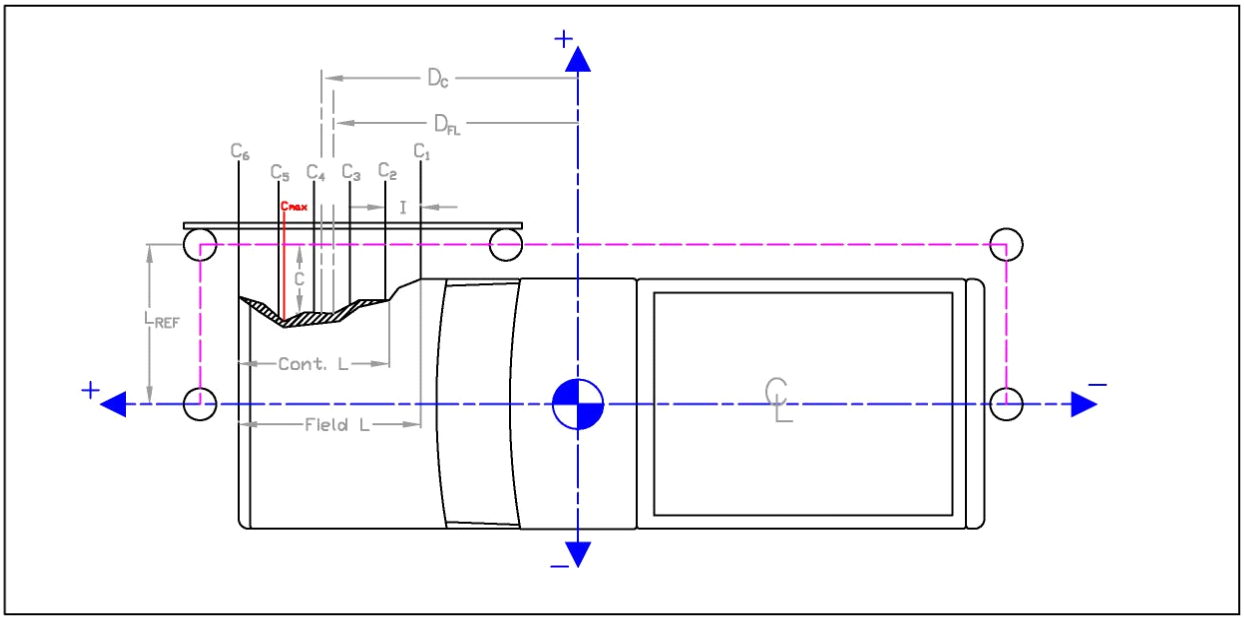
NOTE: Enter "NA" for crush measurement if distance can not be measured (i.e., side of vehicle has been pushed inward)

	Crush Measurement		Lateral Location		Original Profile Measurement		Dist. Between Ref. Lines		Actual	Crush
	in.	(mm)	in.	(mm)	in.	(mm)	in.	(mm)	in.	(mm)
C_1	10	(254)	0	()	10.25	(260)	1.49741	(38)	-1.74741	-(44)
C_2	10.5	(267)	7.8	(198)	10.484	(266)			-1.48178	-(38)
C_3	11.5	(292)	15.6	(396)	11.656	(296)			-1.65366	-(42)
C_4	16.5	(419)	23.4	(594)	13.391	(340)			1.61197	(41)
C_5	24.75	(629)	31.2	(792)	16.813	(427)			6.44009	(164)
C_6	NA	#######	39	(991)	29	(737)			#######	#VALUE!
C_{MAX}	24	(610)	29	(737)	15.688	(398)			6.81509	(173)

Figure 145. Chart. Exterior Vehicle Crush (NASS) - Front, Test No. MGSGW-2.

Date: 11/23/2009 **Test Number:** MGSGW-2

Make: Dodge **Model:** 2270P (RAM 1500) **Year:** 2003



	in.	(mm)
Distance from centerline to reference line - L_{REF}:	46.5	(1181)
Width of contact and induced crush - Field L:	227	(5766)
Crush measurement spacing interval (L/5) - I:	45.4	(1153)
Distance from vehicle c.g. to center of Field L - D_{FL}:	-11.5	-(292)
Width of Contact Damage:	227	(5766)
Distance from vehicle c.g. to center of contect damage - D_C:	11.5	(292)

NOTE: Enter "NA" for crush measurement if distance can not be measured (i.e., front of vehicle has been pushed inward or tire has been remeoved)

	Crush Measurement		Longitudinal Location		Original Profile Measurement		Dist. Between Ref. Lines		Actual	Crush
	in.	(mm)	in.	(mm)	in.	(mm)	in.	(mm)	in.	(mm)
C_1	Na	#######	-125	-(3175)	15.0625	(383)	-3.5	-(89)	#######	#VALUE!
C_2	8.75	(222)	-79.6	-(2022)	10.5	(267)			1.75	(44)
C_3	7.75	(197)	-34.2	-(869)	11.6042	(295)			-0.3542	-(9)
C_4	8.25	(210)	11.2	(284)	11.25	(286)			0.5	(13)
C_5	NA	#######	56.6	(1438)	10.5	(267)			#######	#VALUE!
C_6	NA	#######	102	(2591)	36.125	(918)			#######	#VALUE!
C_{MAX}	13.25	(337)	81	(2057)	11.25	(286)			5.5	(140)

Figure 146. Chart. Exterior Vehicle Crush (NASS) - Side, Test No. MGSGW-2.

APPENDIX E. ACCELEROMETER AND RATE TRANSDUCER DATA PLOTS, TEST NO. MGSGW-1

The plots from each data acquisition system for test no. MGSGW-1 is contained in this appendix.

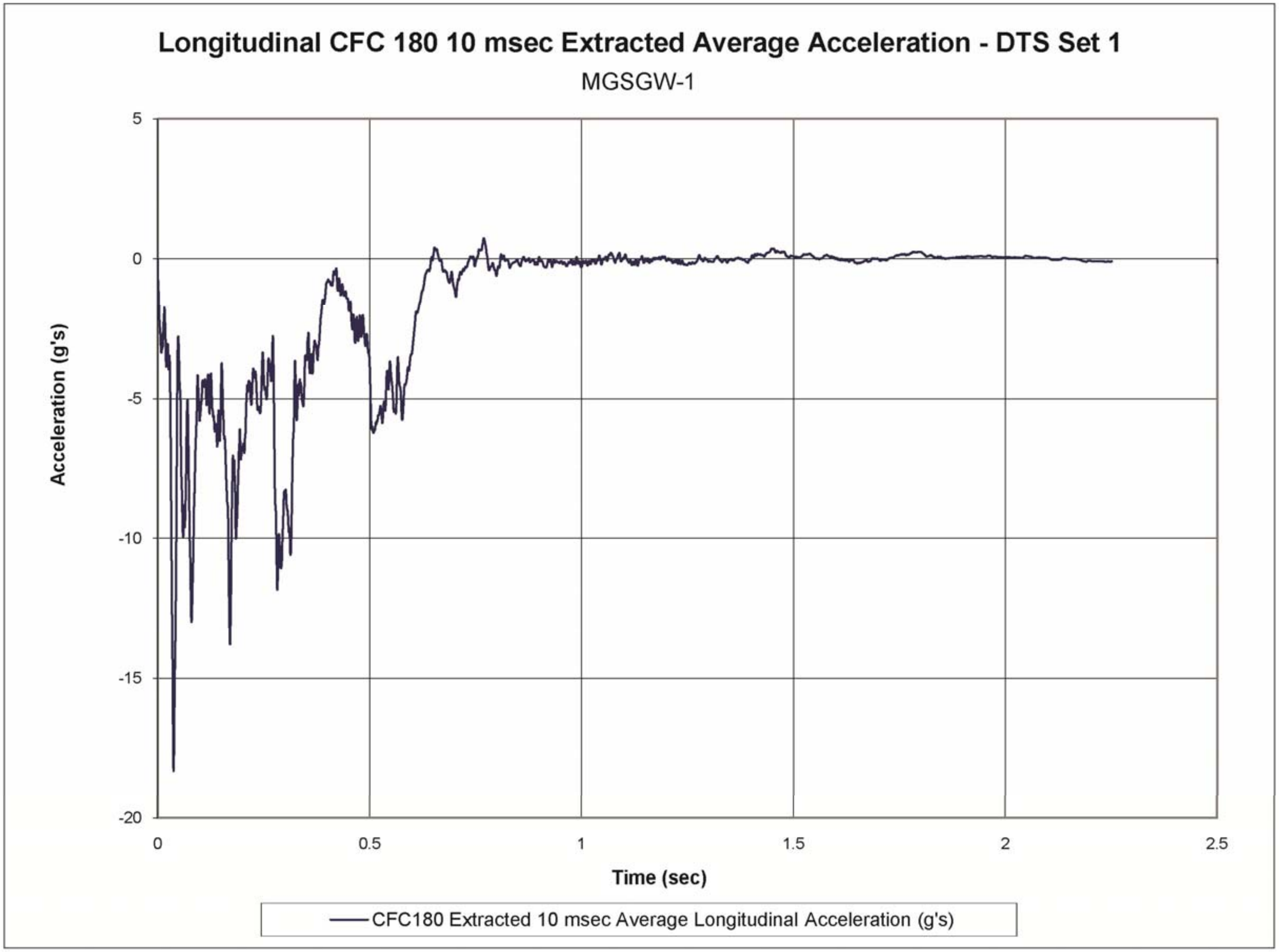


Figure 147. Graph. 10-ms Average Longitudinal Deceleration (DTS Set 1), Test No. MGSGW-1.

Figure 148. Graph. Longitudinal Occupant Impact Velocity (DTS Set 1), Test No. MGSGW-1.

Figure 149. Graph. Longitudinal Occupant Displacement (DTS Set 1), Test No. MGSGW-1.

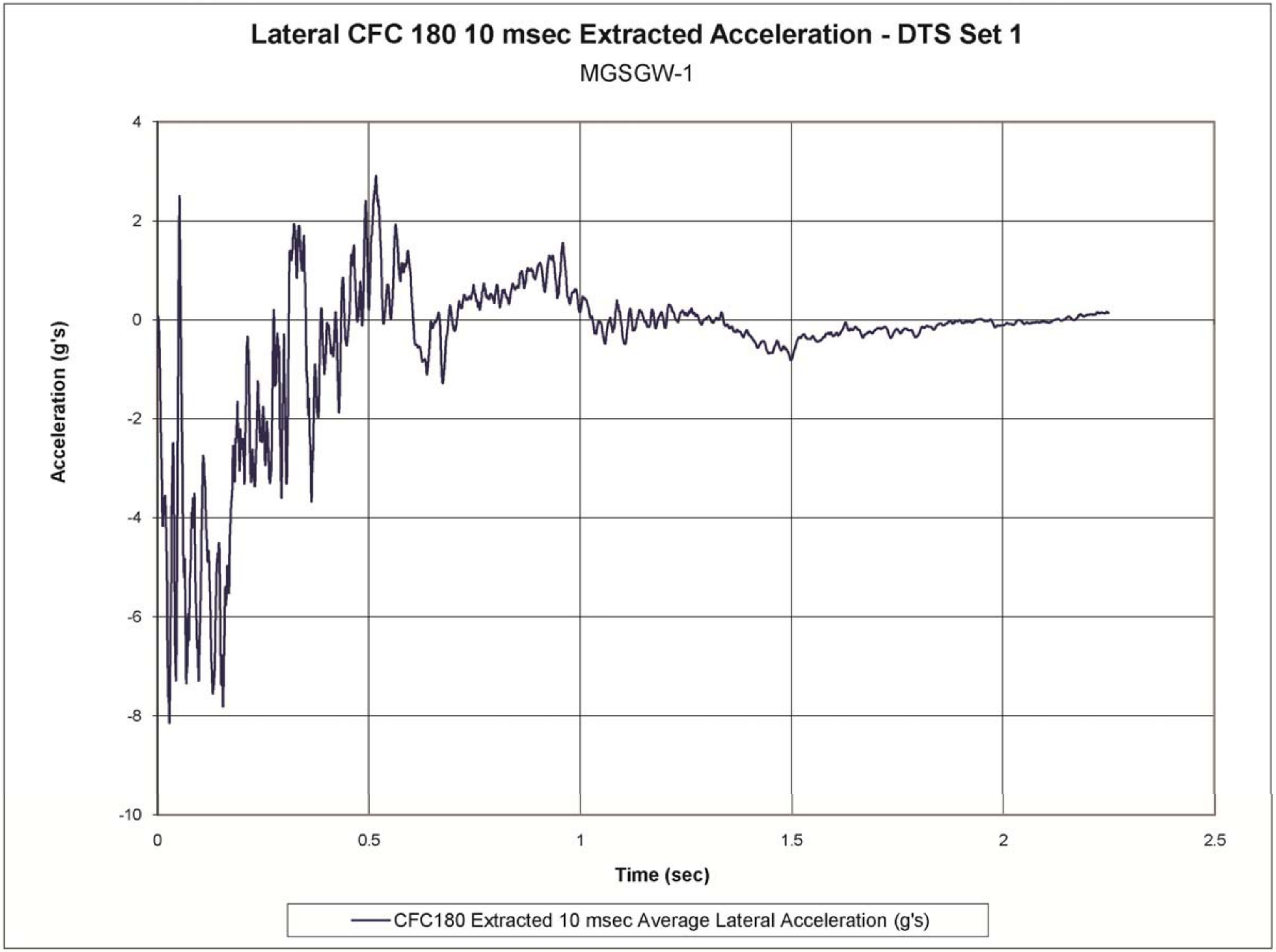


Figure 150. Graph. 10-ms Average Lateral Deceleration (DTS Set 1), Test No. MGSGW-1.

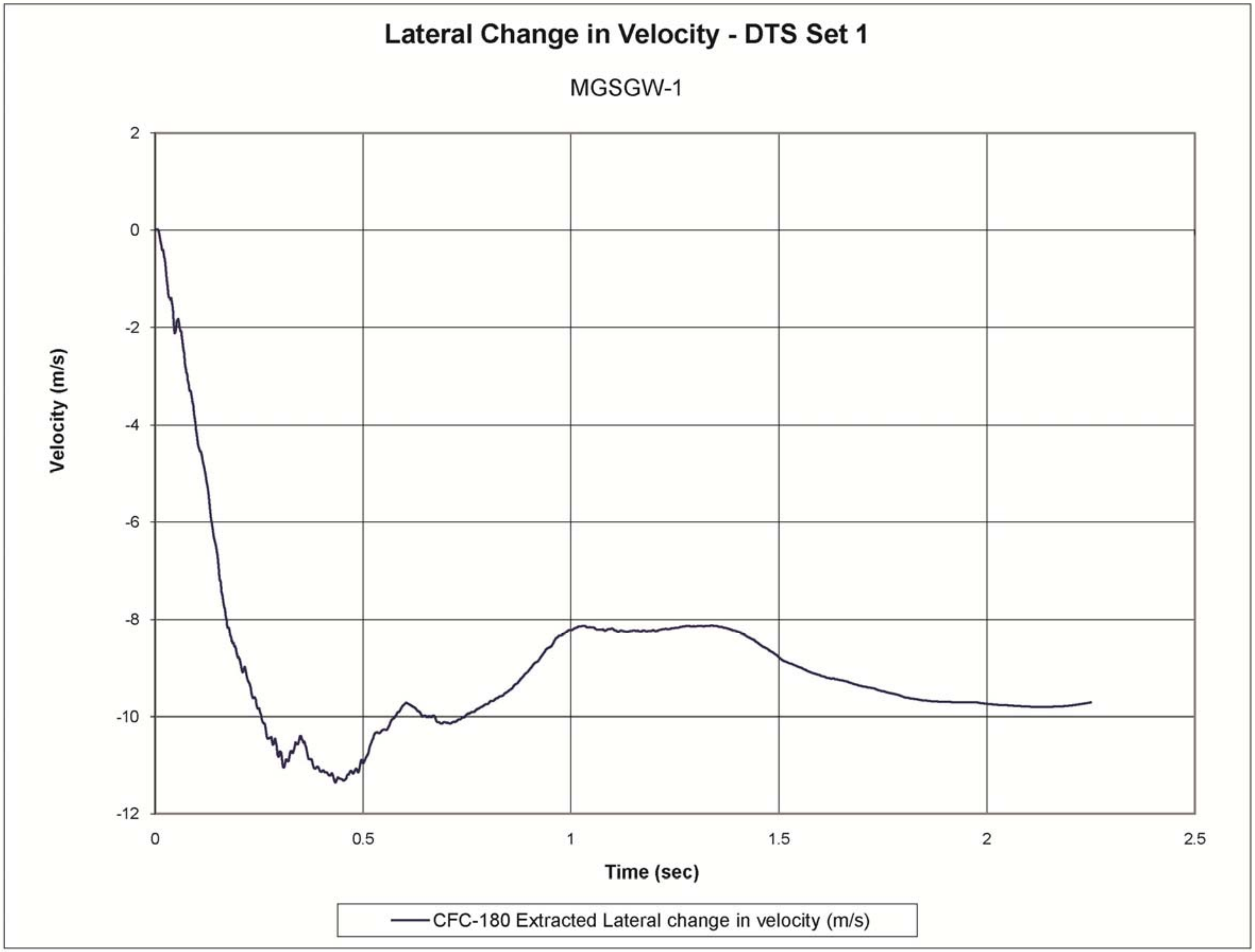


Figure 151. Graph. Lateral Occupant Impact Velocity (DTS Set 1), Test No. MGSGW-1.

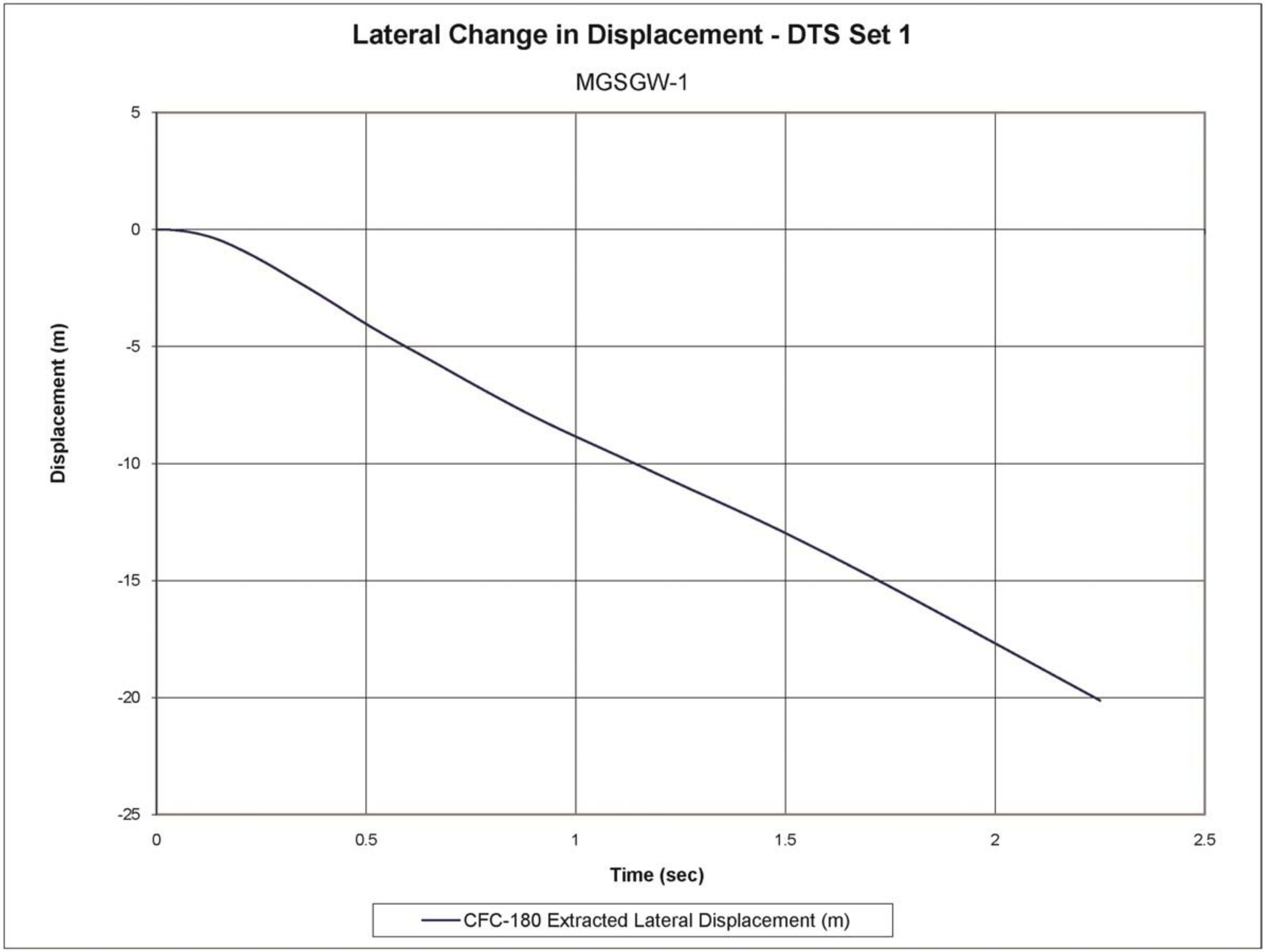


Figure 152. Graph. Lateral Occupant Displacement (DTS Set 1), Test No. MGSGW-1.

Figure 153. Graph. Vehicle Angular Displacements (DTS Set 1), Test No. MGSGW-1.

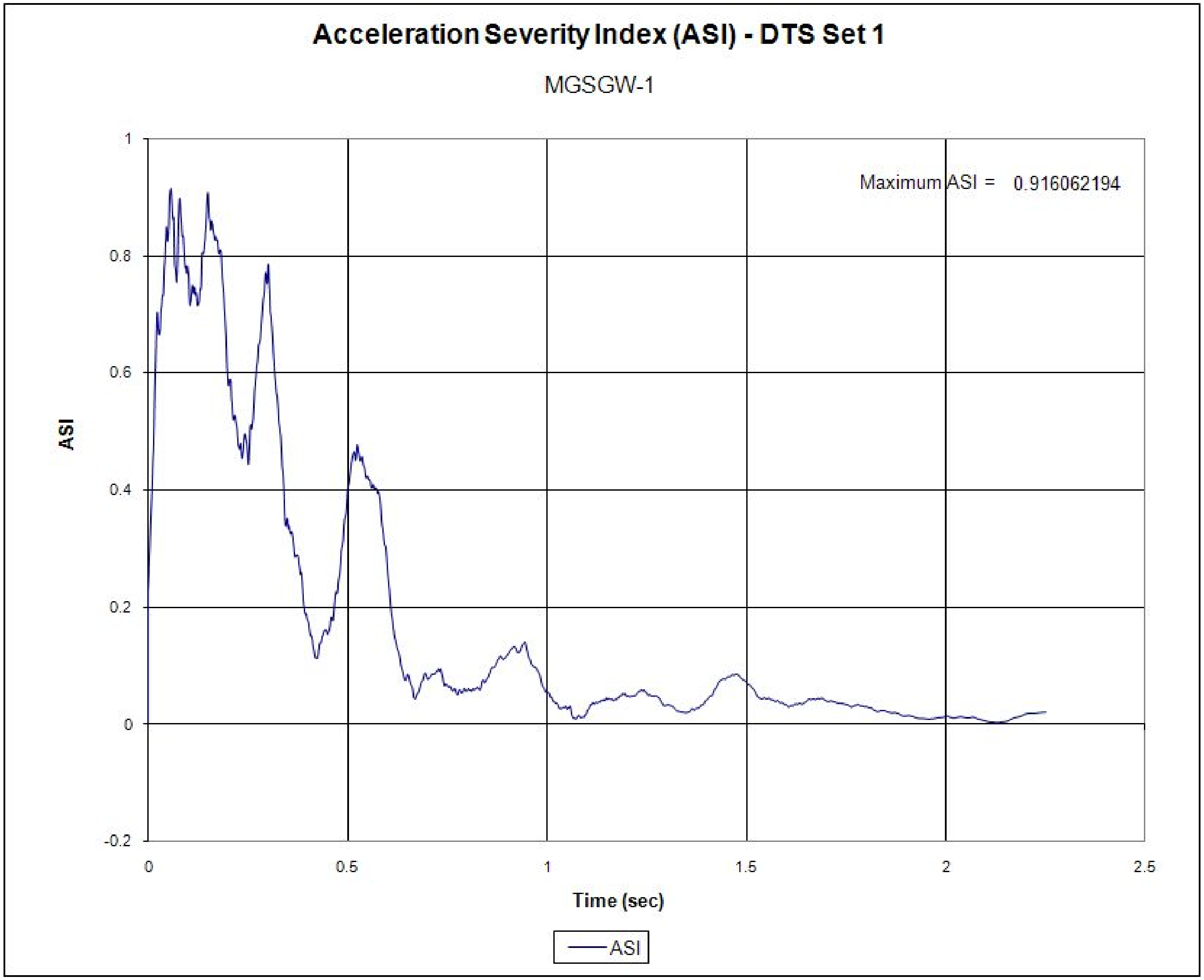


Figure 154. Graph. Acceleration Severity Index (DTS Set 1), Test No. MGSGW-1.

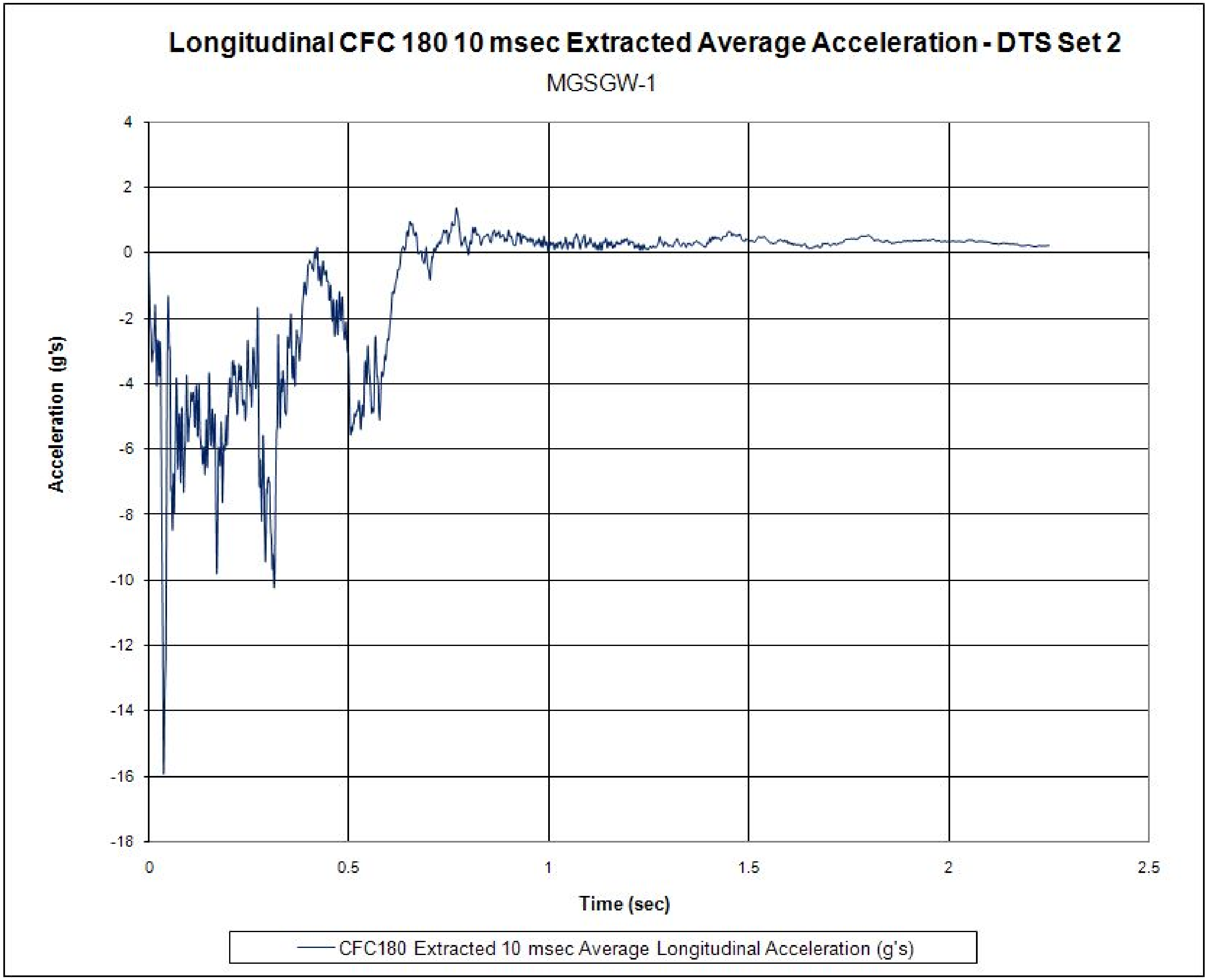


Figure 155. Graph. 10-ms Average Longitudinal Deceleration (DTS Set 2), Test No. MGSGW-1.

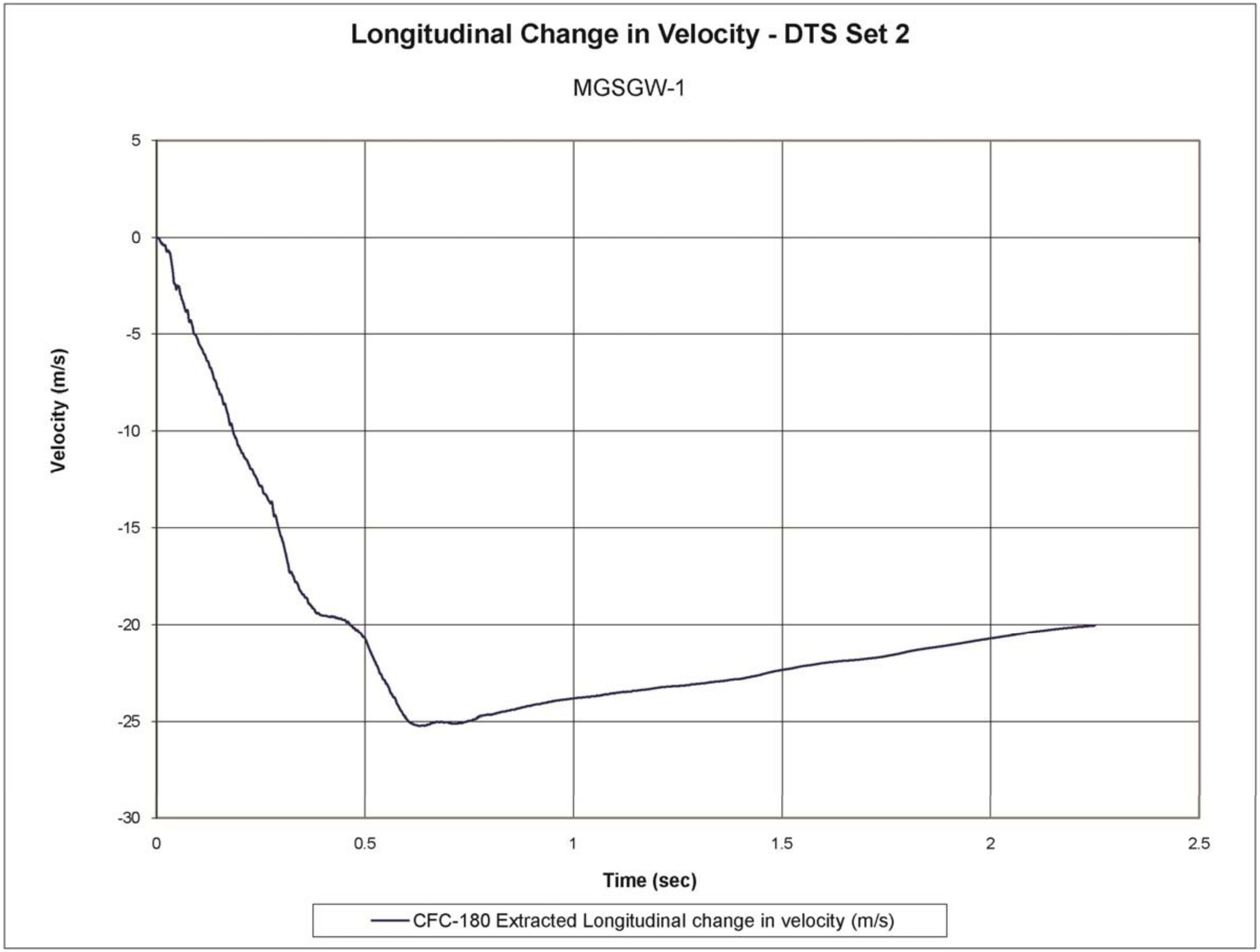


Figure 156. Graph. Longitudinal Occupant Impact Velocity (DTS Set 2), Test No. MGSGW-1.

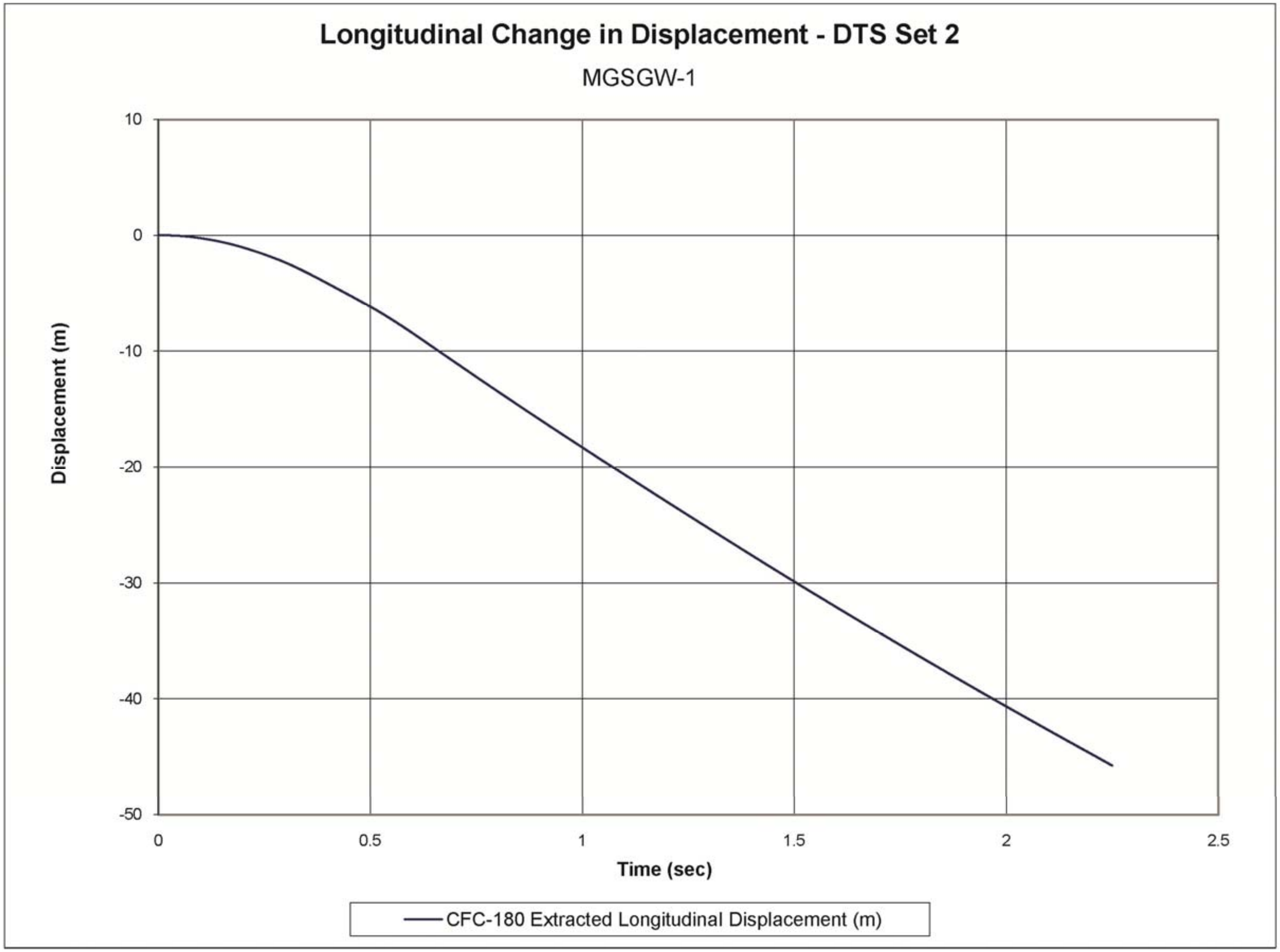


Figure 157. Graph. Longitudinal Occupant Displacement (DTS Set 2), Test No. MGSGW-1.

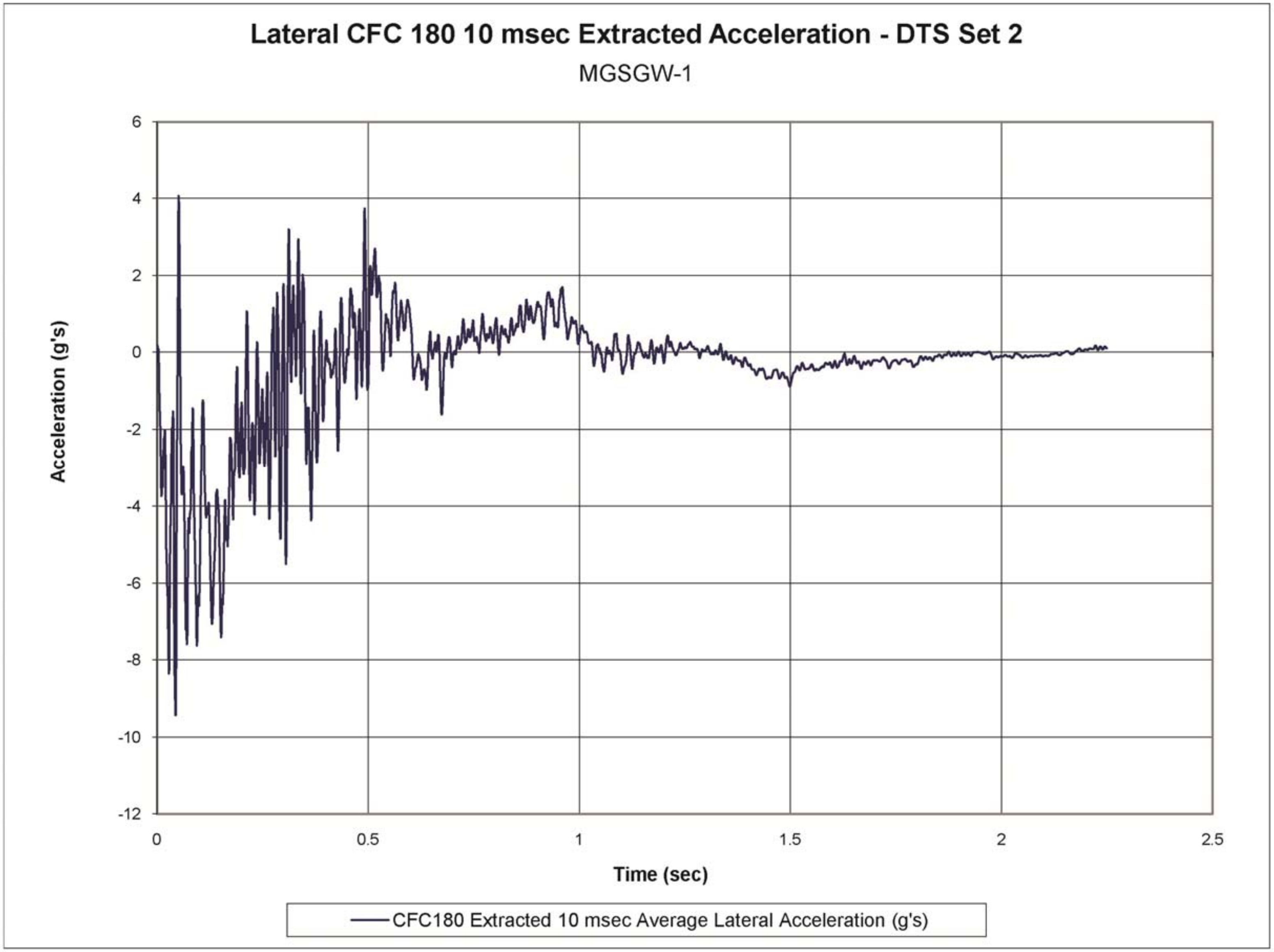


Figure 158. Graph. 10-ms Average Lateral Deceleration (DTS Set 2), Test No. MGSGW-1.

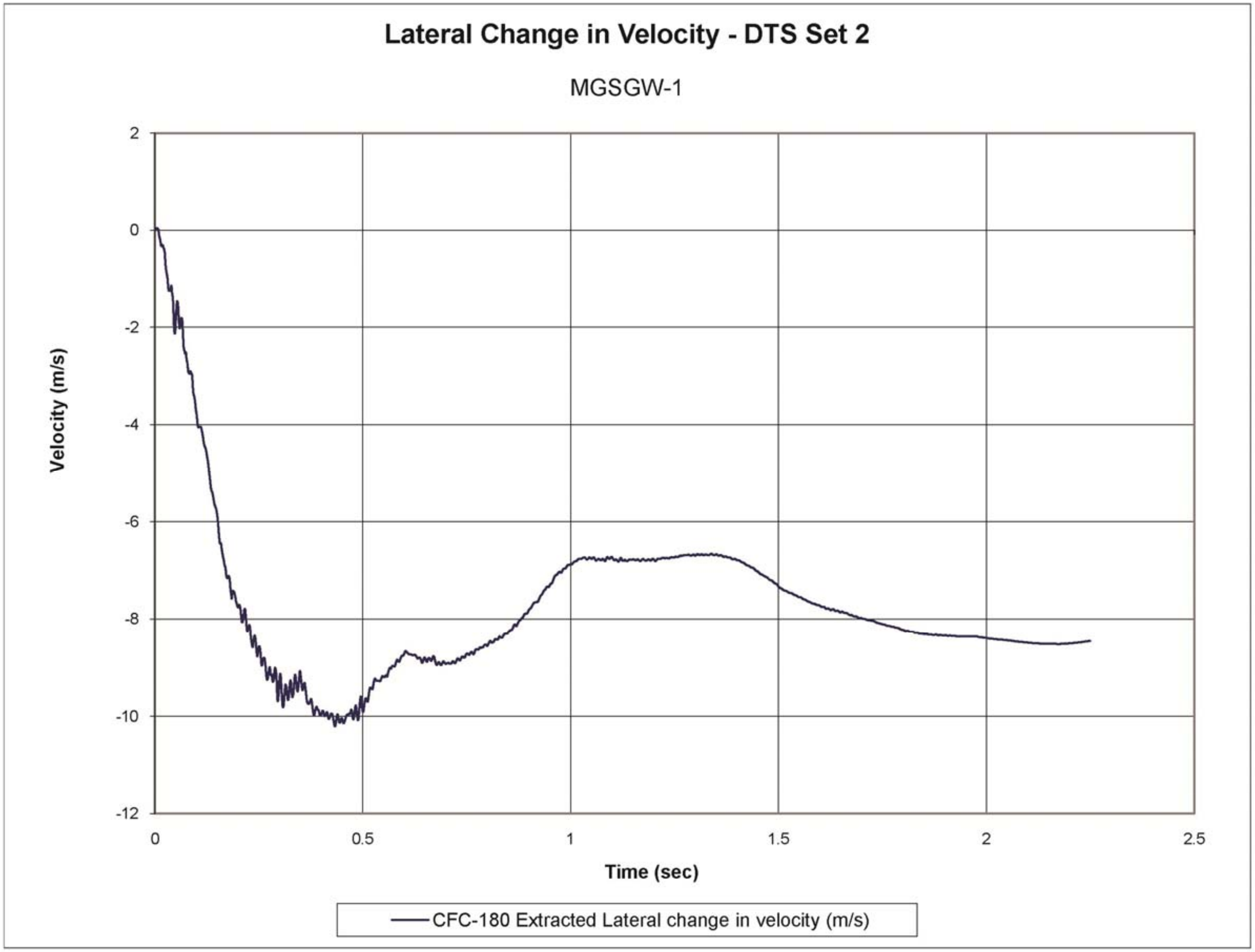


Figure 159. Graph. Lateral Occupant Impact Velocity (DTS Set 2), Test No. MGSGW-1.

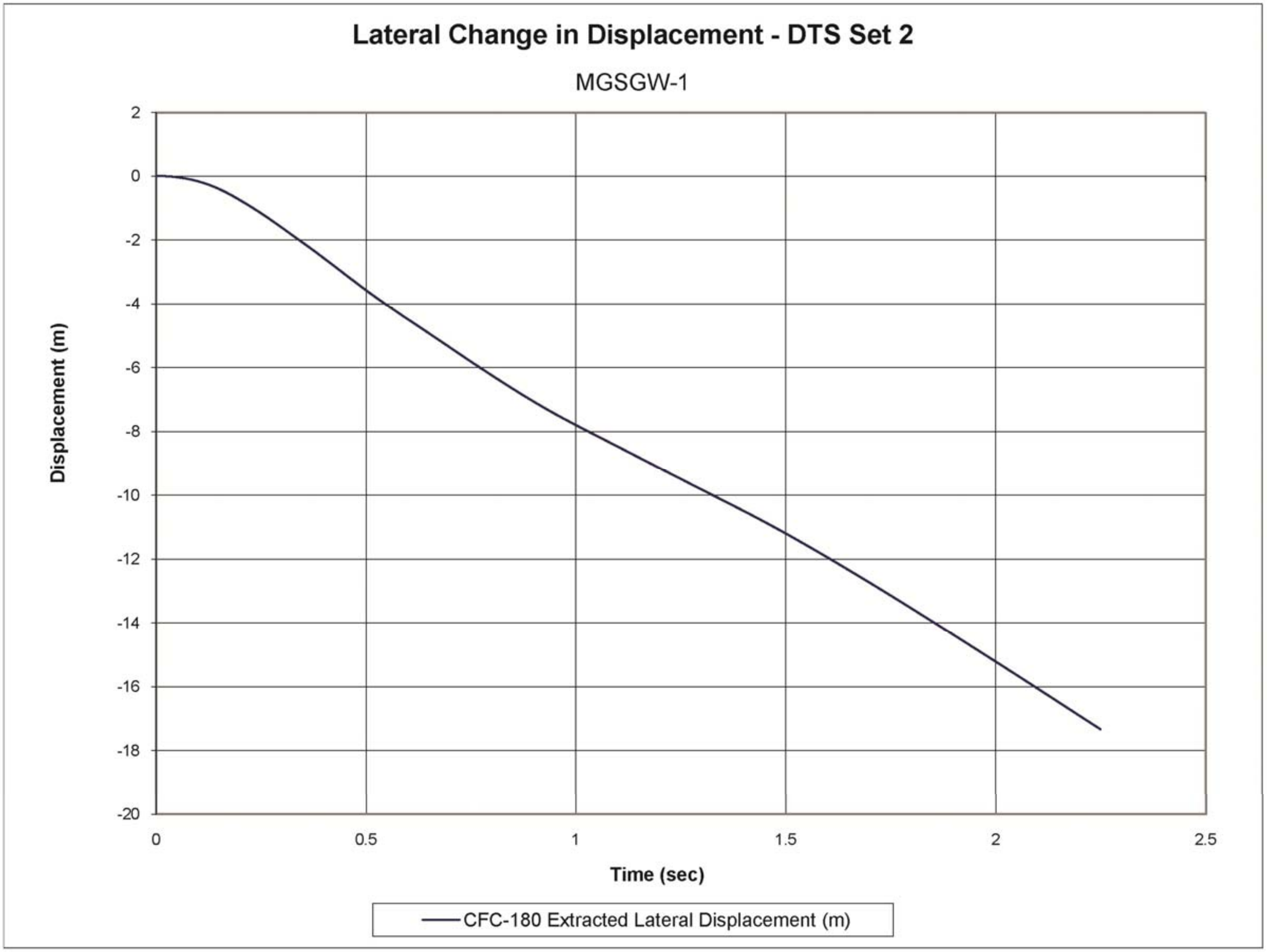


Figure 160. Graph. Lateral Occupant Displacement (DTS Set 2), Test No. MGSGW-1.

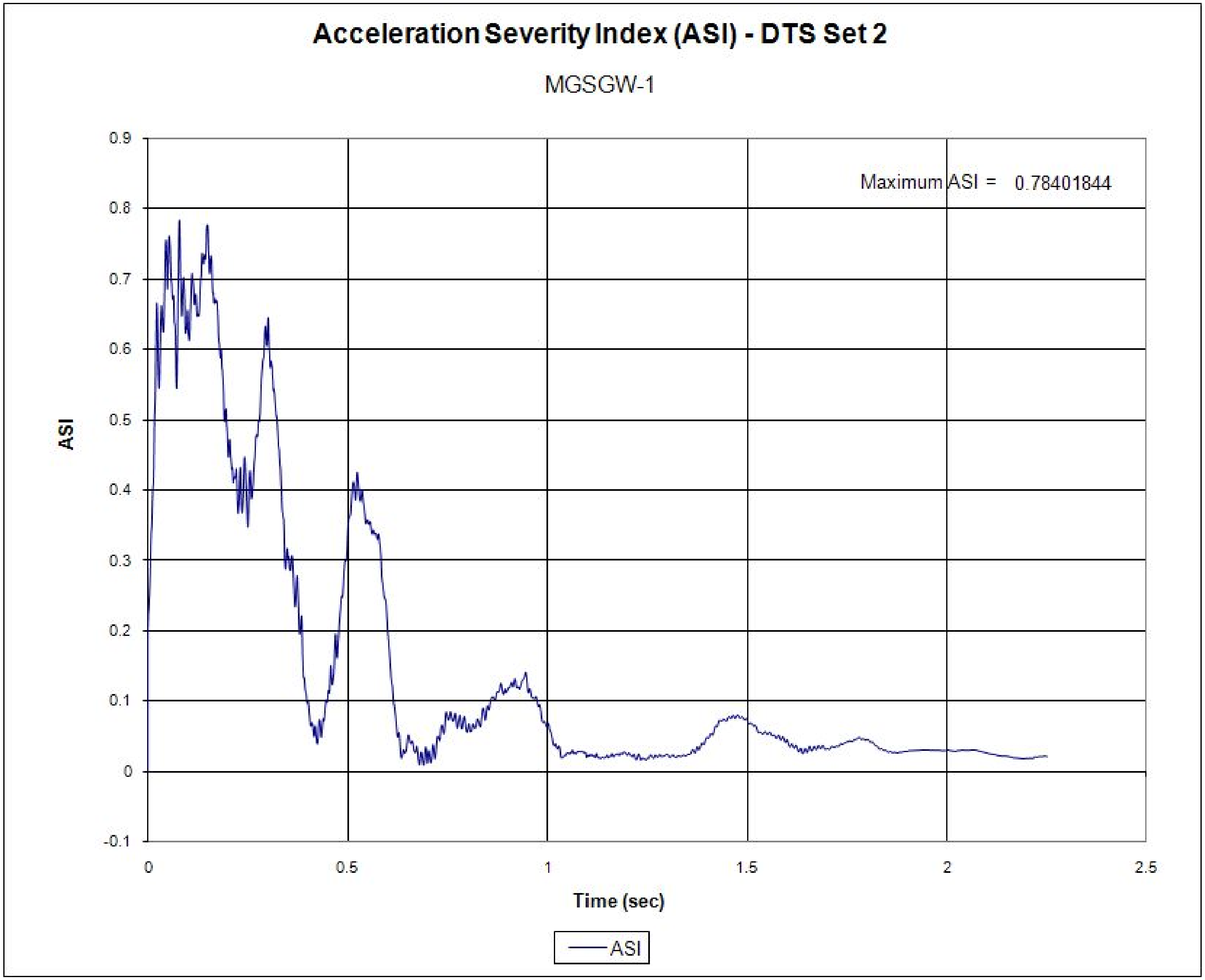


Figure 161. Graph. Acceleration Severity Index (DTS Set 2), Test No. MGSGW-1.

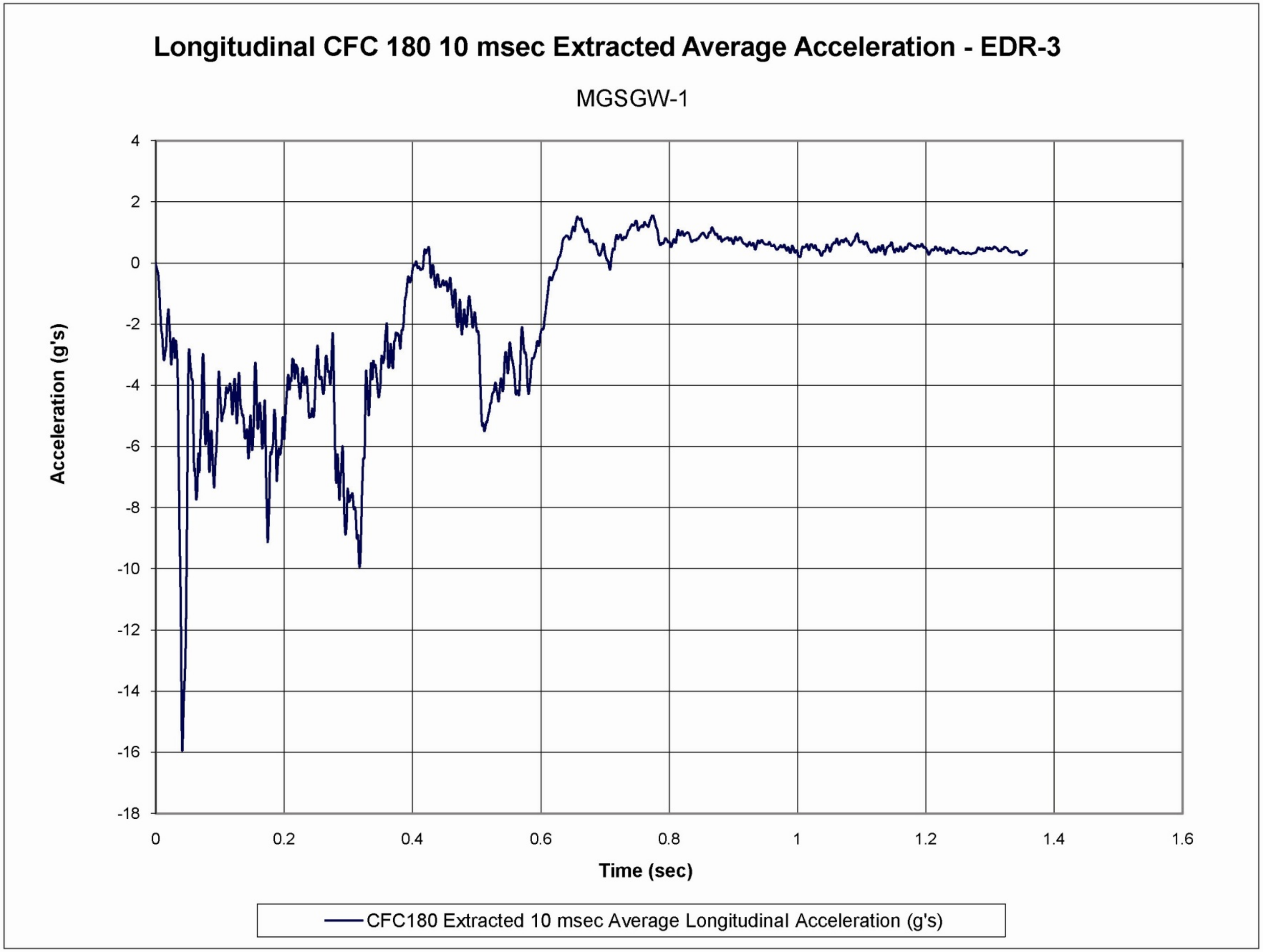


Figure 162. Graph. 10-ms Average Longitudinal Deceleration (EDR-3), Test No. MGSGW-1.

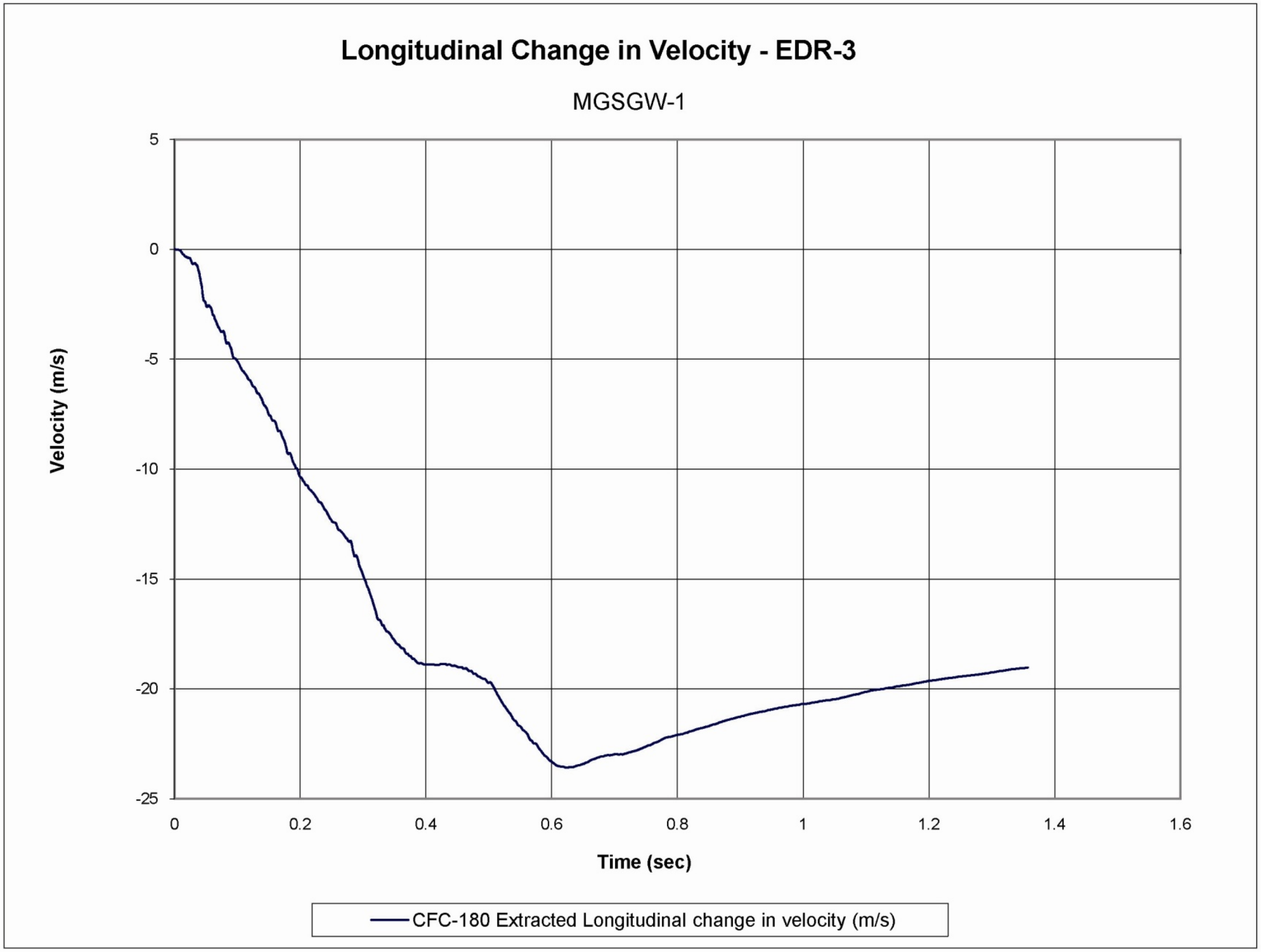


Figure 163. Graph. Longitudinal Occupant Impact Velocity (EDR-3), Test No. MGSGW-1.

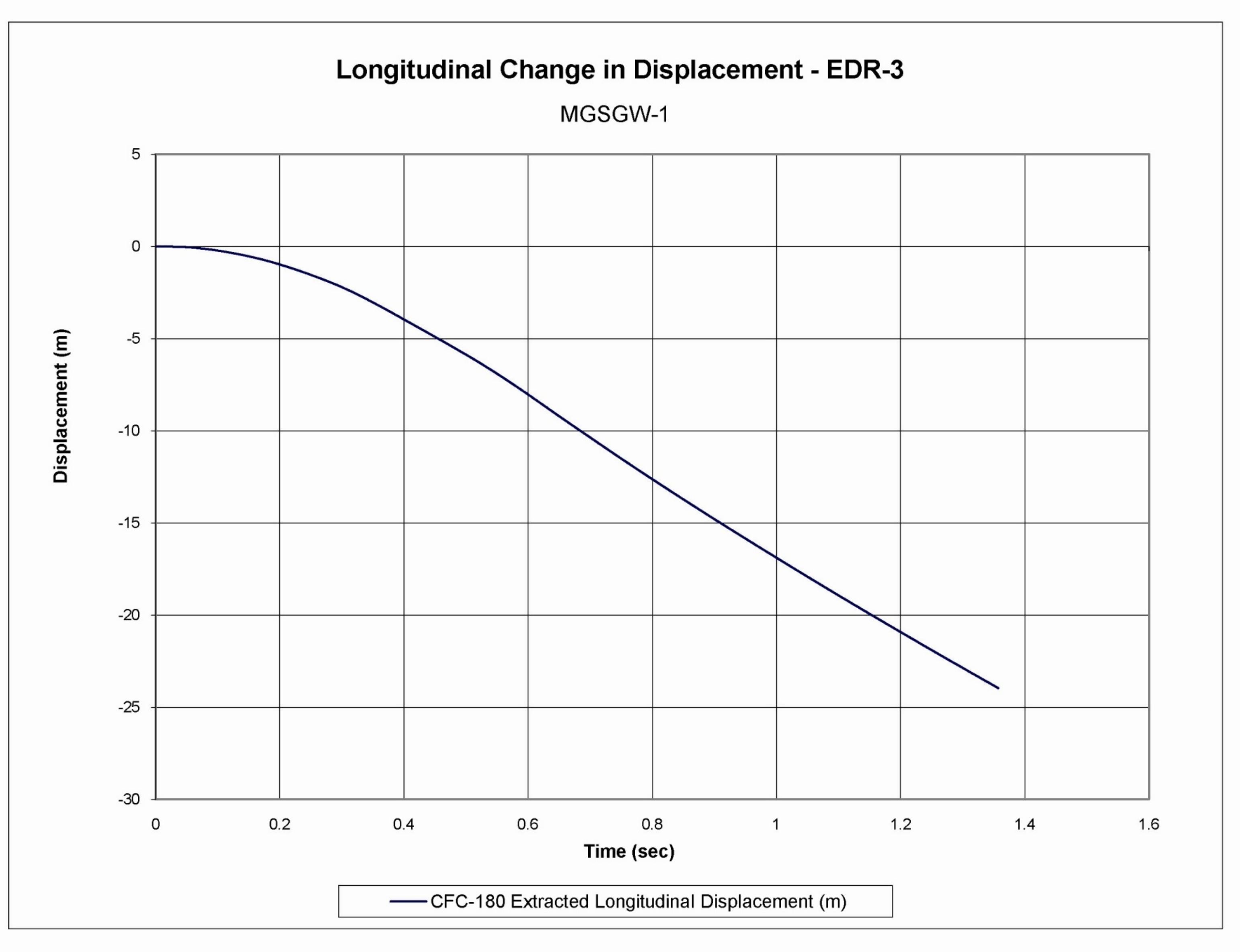


Figure 164. Graph. Longitudinal Occupant Displacement (EDR-3), Test No. MGSGW-1.

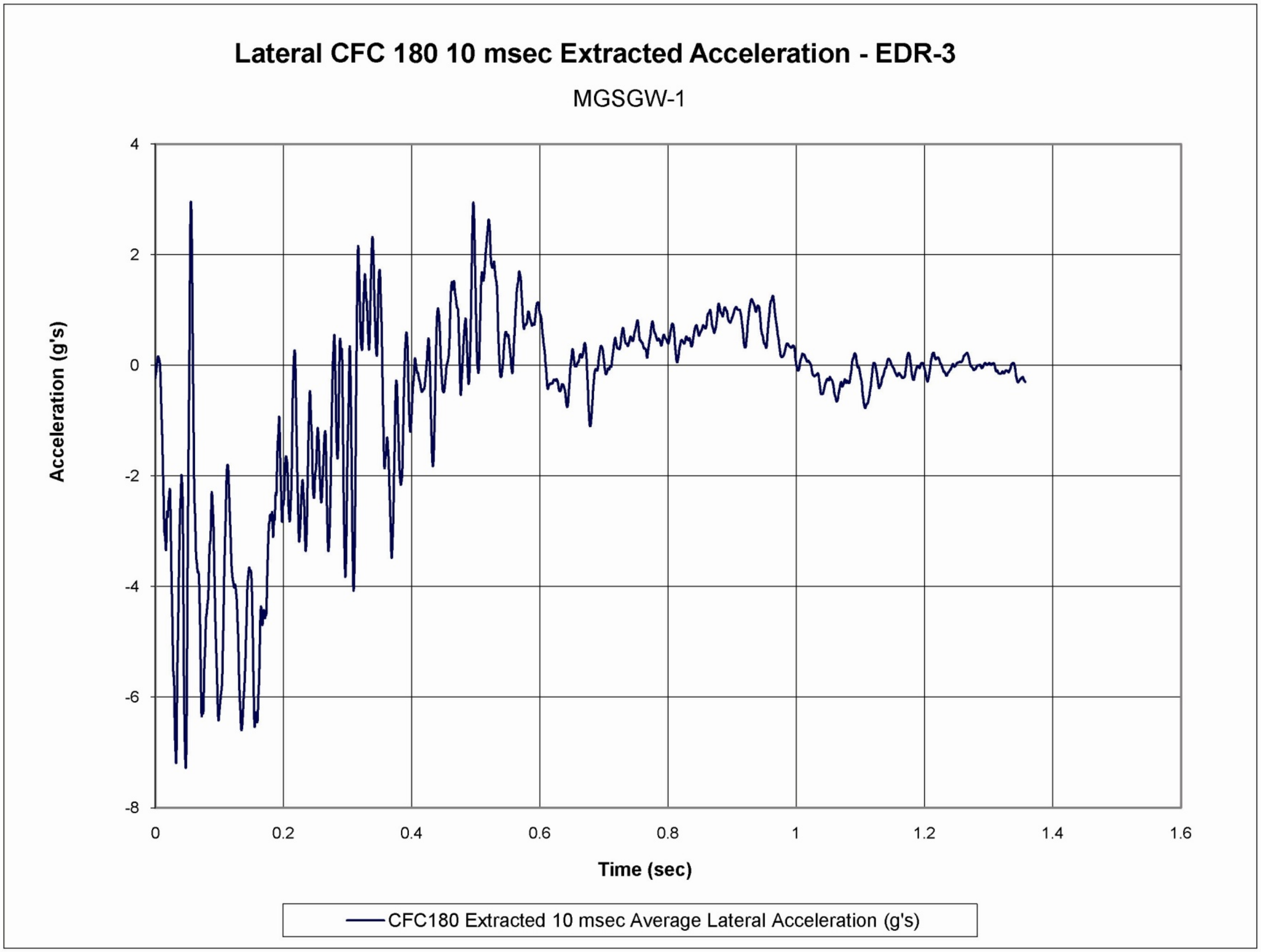


Figure 165. Graph. 10-ms Average Lateral Deceleration (EDR-3), Test No. MGSGW-1.

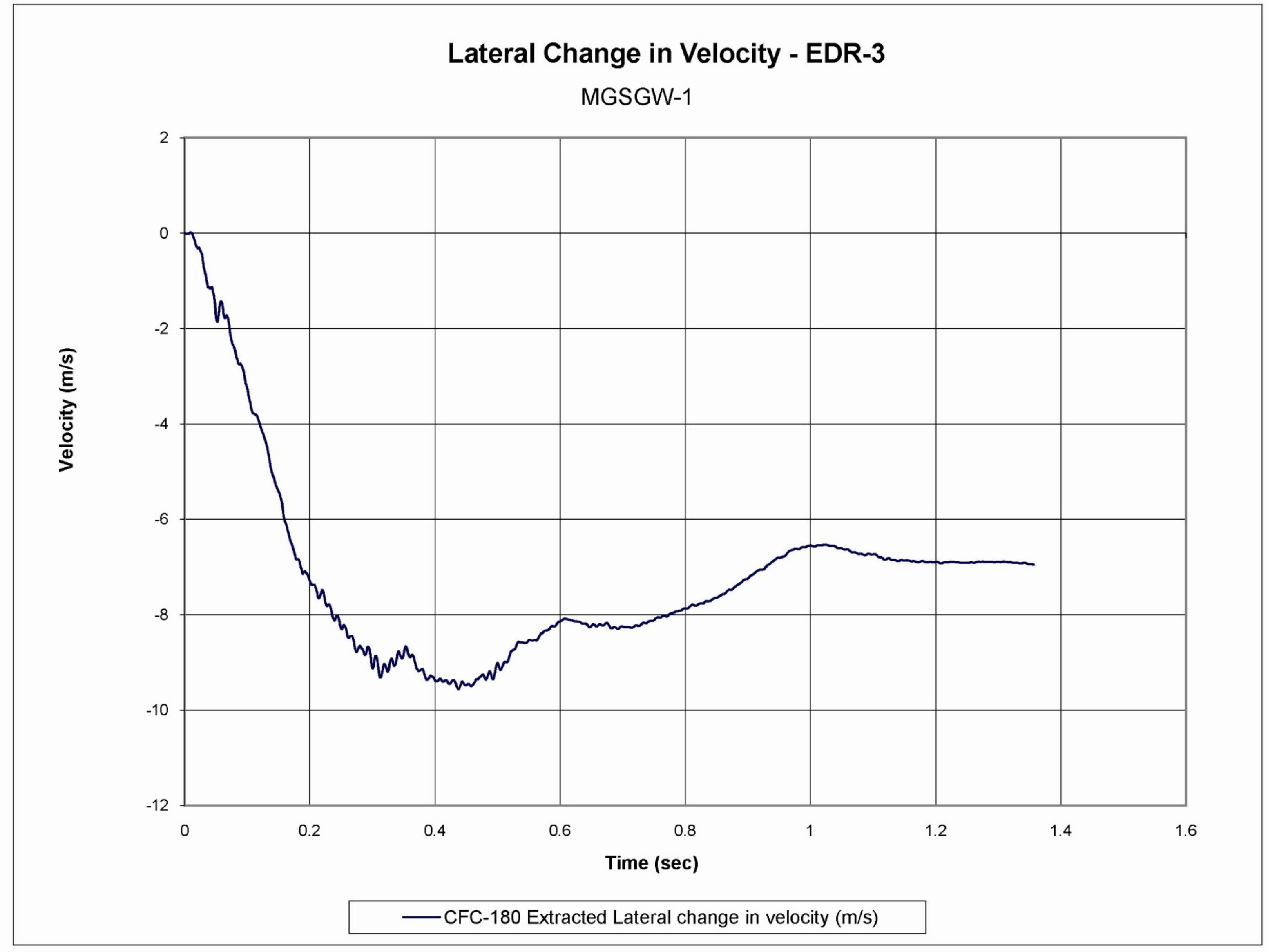


Figure 166. Graph. Lateral Occupant Impact Velocity (EDR-3), Test No. MGSGW-1.

Figure 167. Graph. Lateral Occupant Displacement (EDR-3), Test No. MGSGW-1.

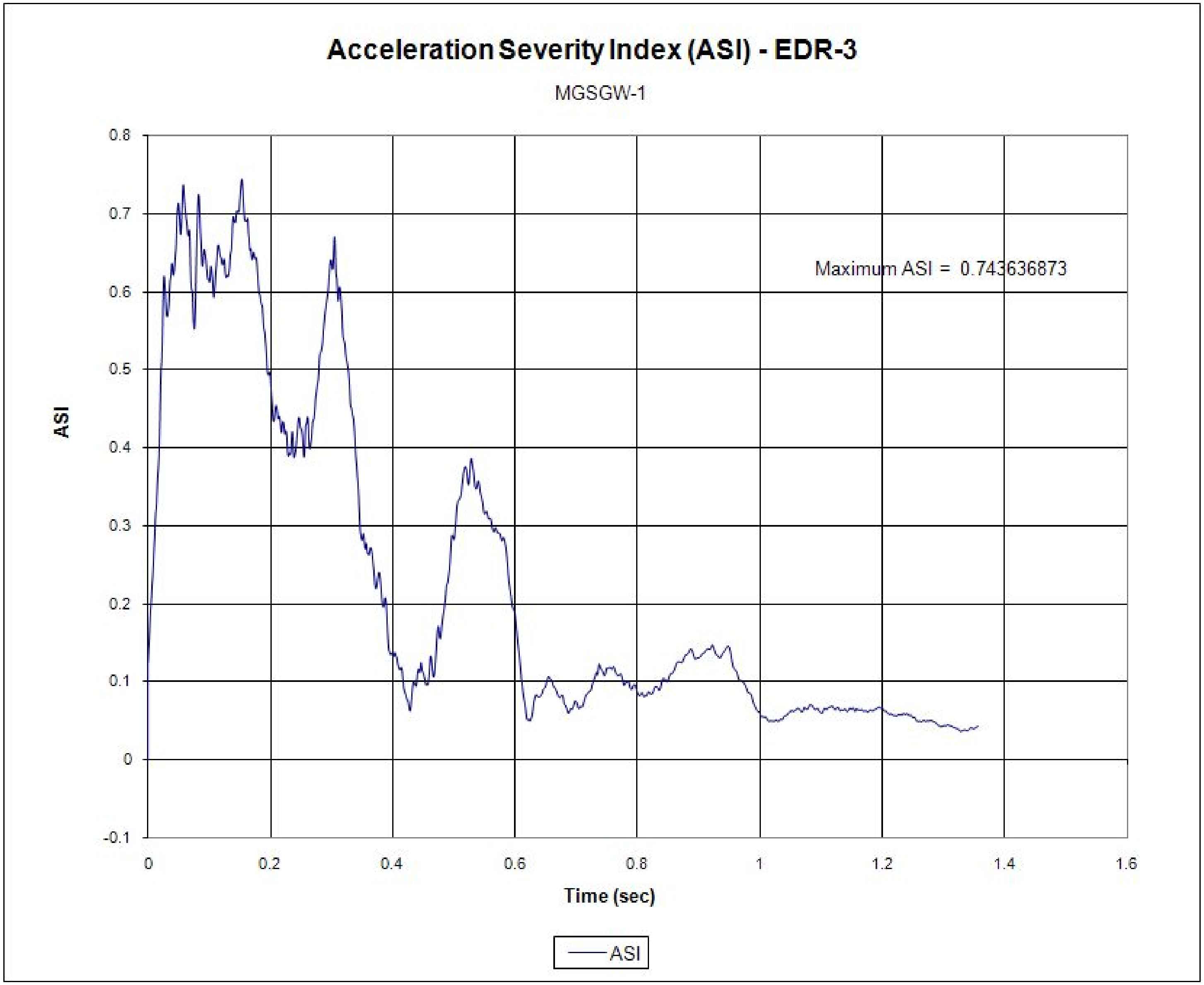


Figure 168. Graph. Acceleration Severity Index (EDR-3), Test No. MGSGW-1.

APPENDIX F. ACCELEROMETER AND RATE TRANSDUCER DATA PLOTS, TEST NO. MGSGW-2

The plots from each data acquisition system for test no. MGSGW-2 is contained in this appendix.

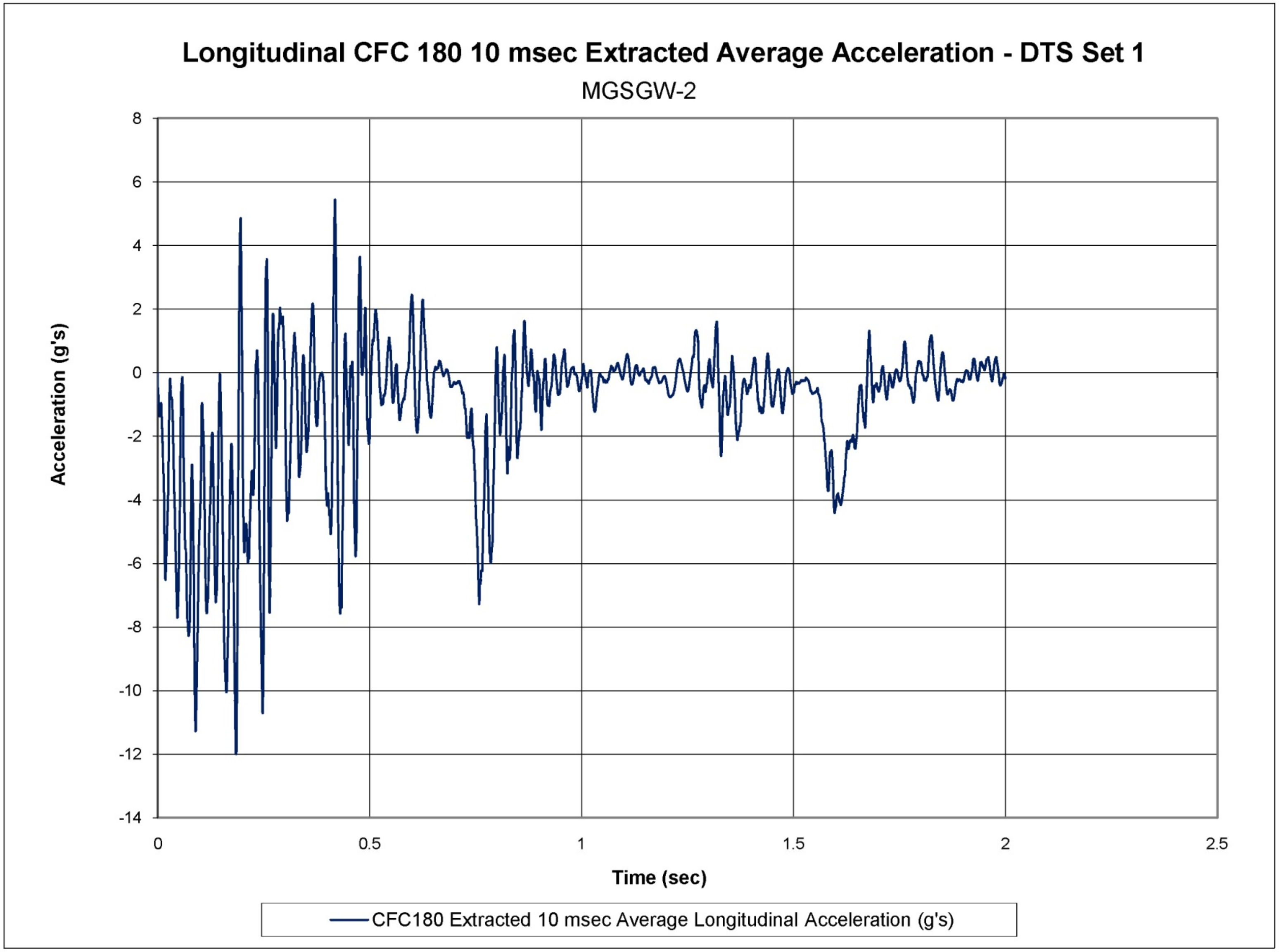


Figure 169. Graph. 10-ms Average Longitudinal Deceleration (DTS Set 1), Test No. MGSGW-2.

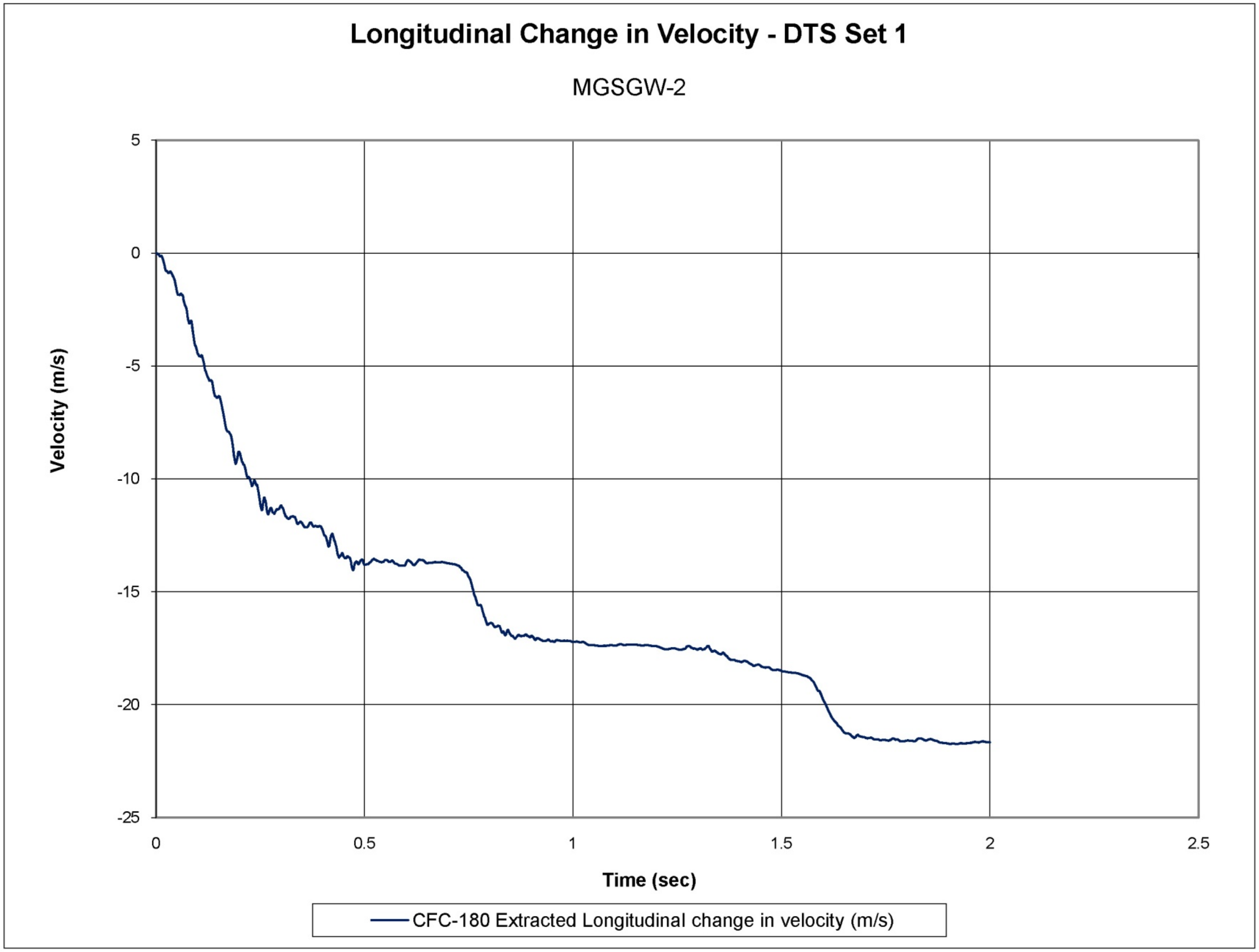


Figure 170. Graph. Longitudinal Occupant Impact Velocity (DTS Set 1), Test No. MGSGW-2.

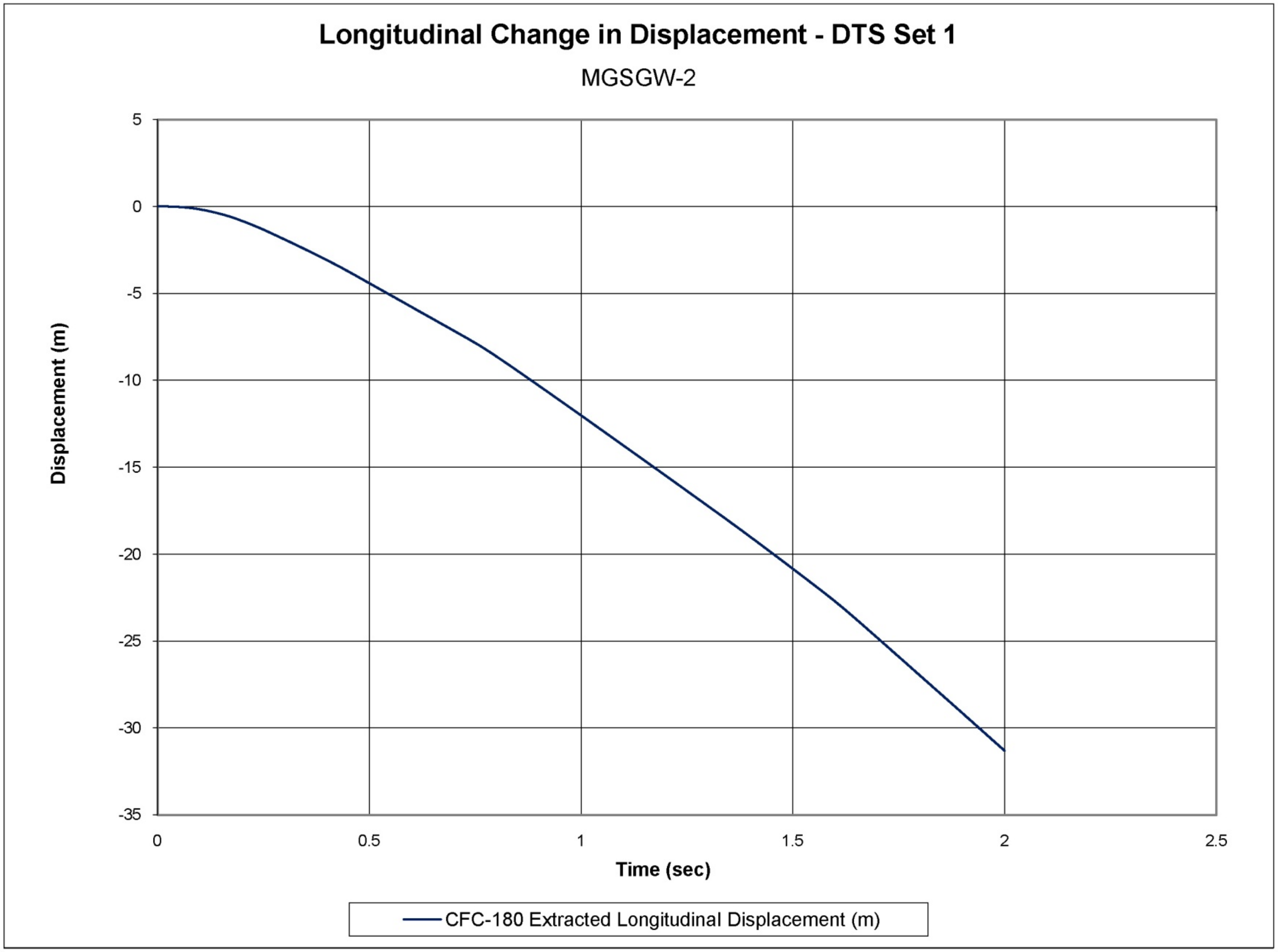


Figure 171. Graph. Longitudinal Occupant Displacement (DTS Set 1), Test No. MGSGW-2.

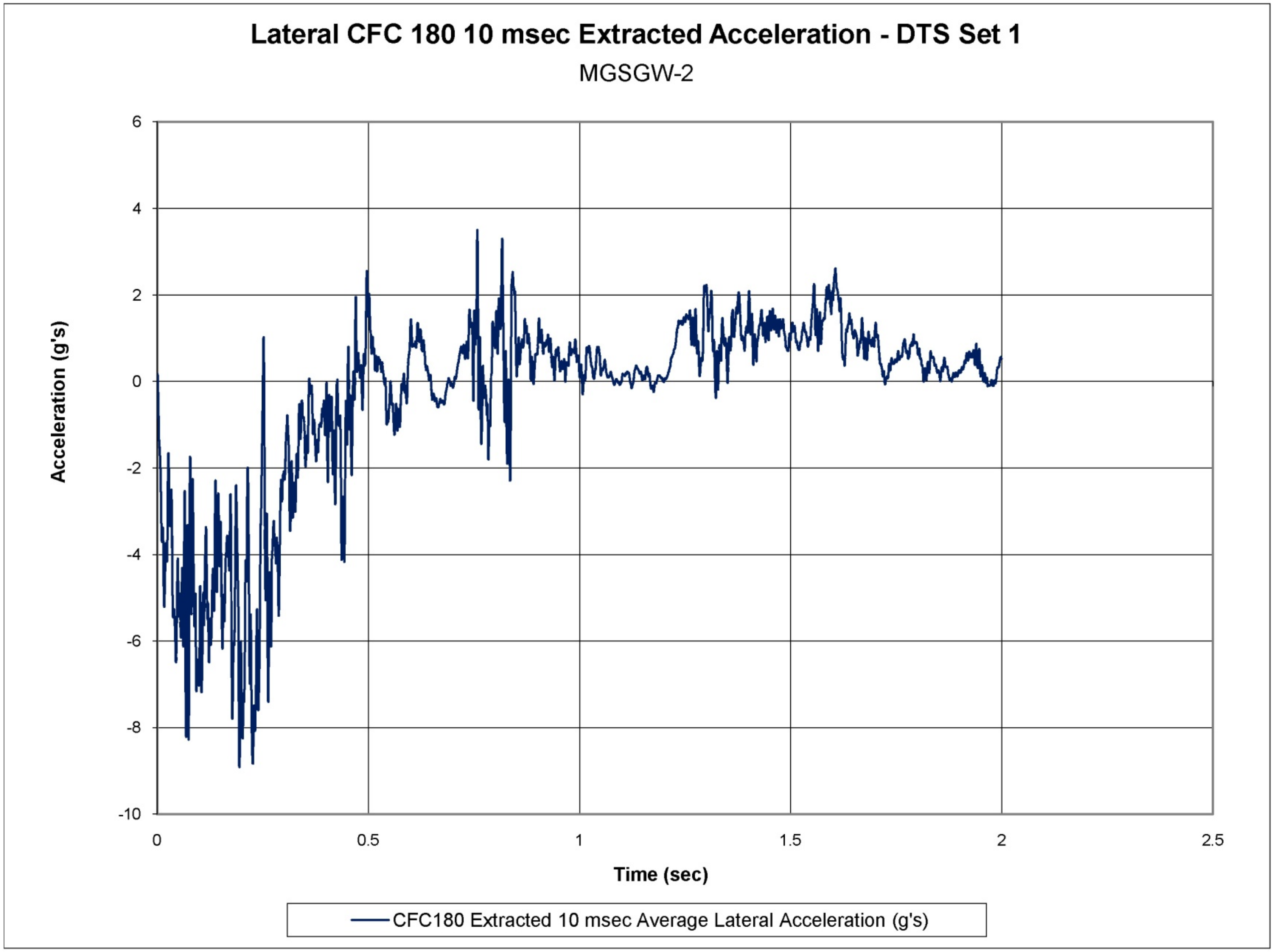


Figure 172. Graph. 10-ms Average Lateral Deceleration (DTS Set 1), Test No. MGSGW-2.

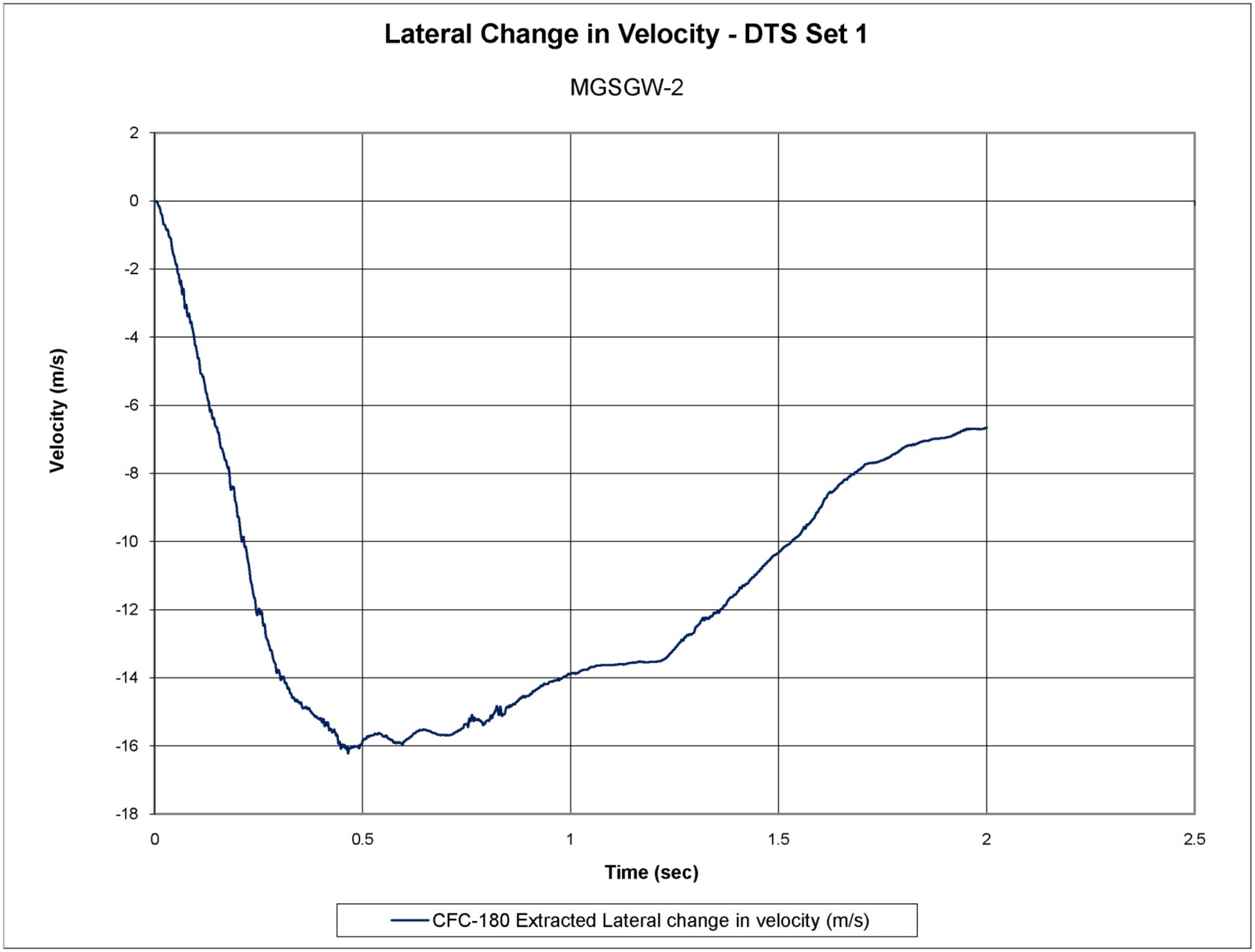


Figure 173. Graph. Lateral Occupant Impact Velocity (DTS Set 1), Test No. MGSGW-2.

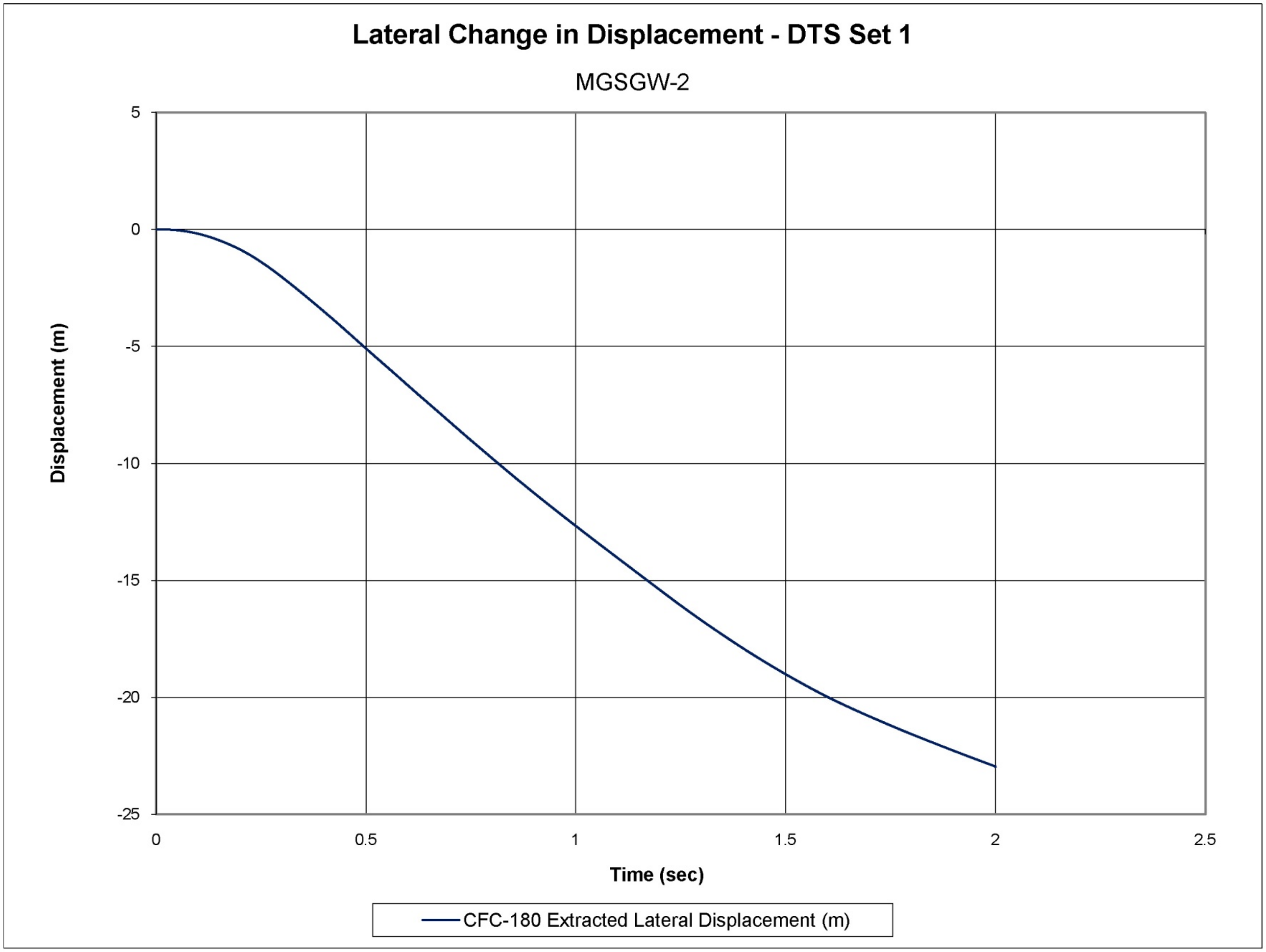


Figure 174. Graph. Lateral Occupant Displacement (DTS Set 1), Test No. MGSGW-2.

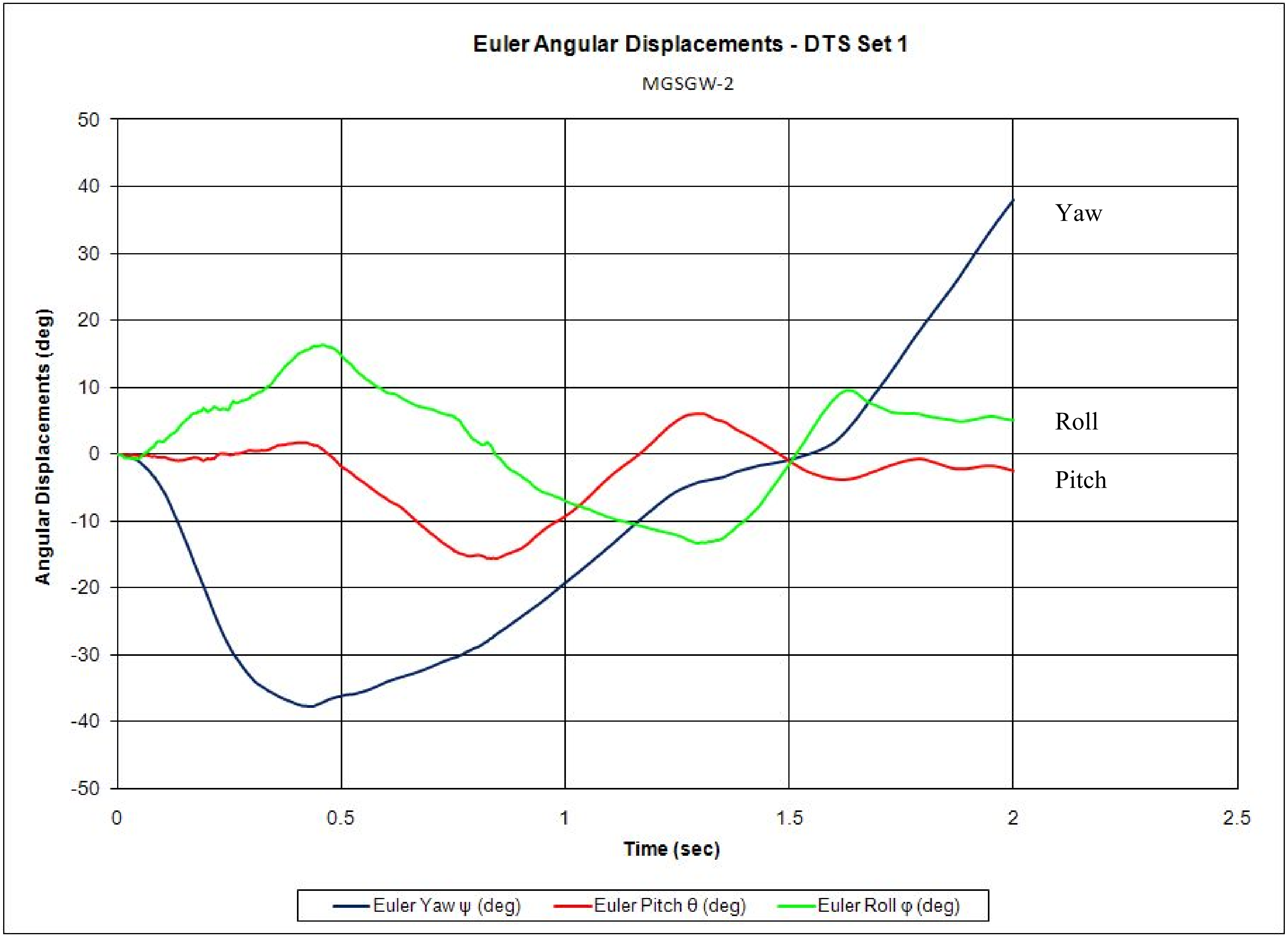


Figure 175. Graph. Vehicle Angular Displacements (DTS Set 1), Test No. MGSGW-2.

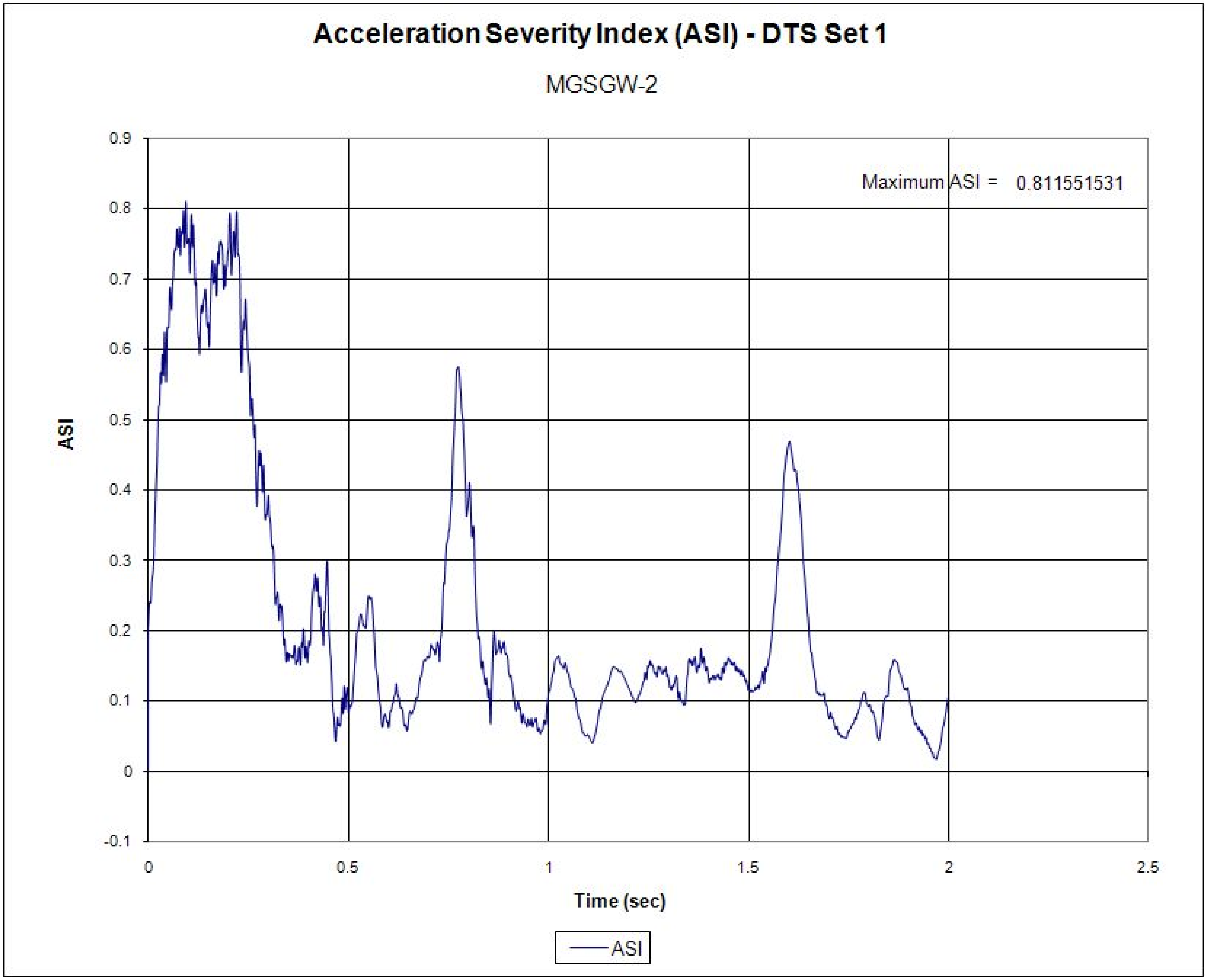


Figure 176. Graph. Acceleration Severity Index (DTS Set 1), Test No. MGSGW-2.

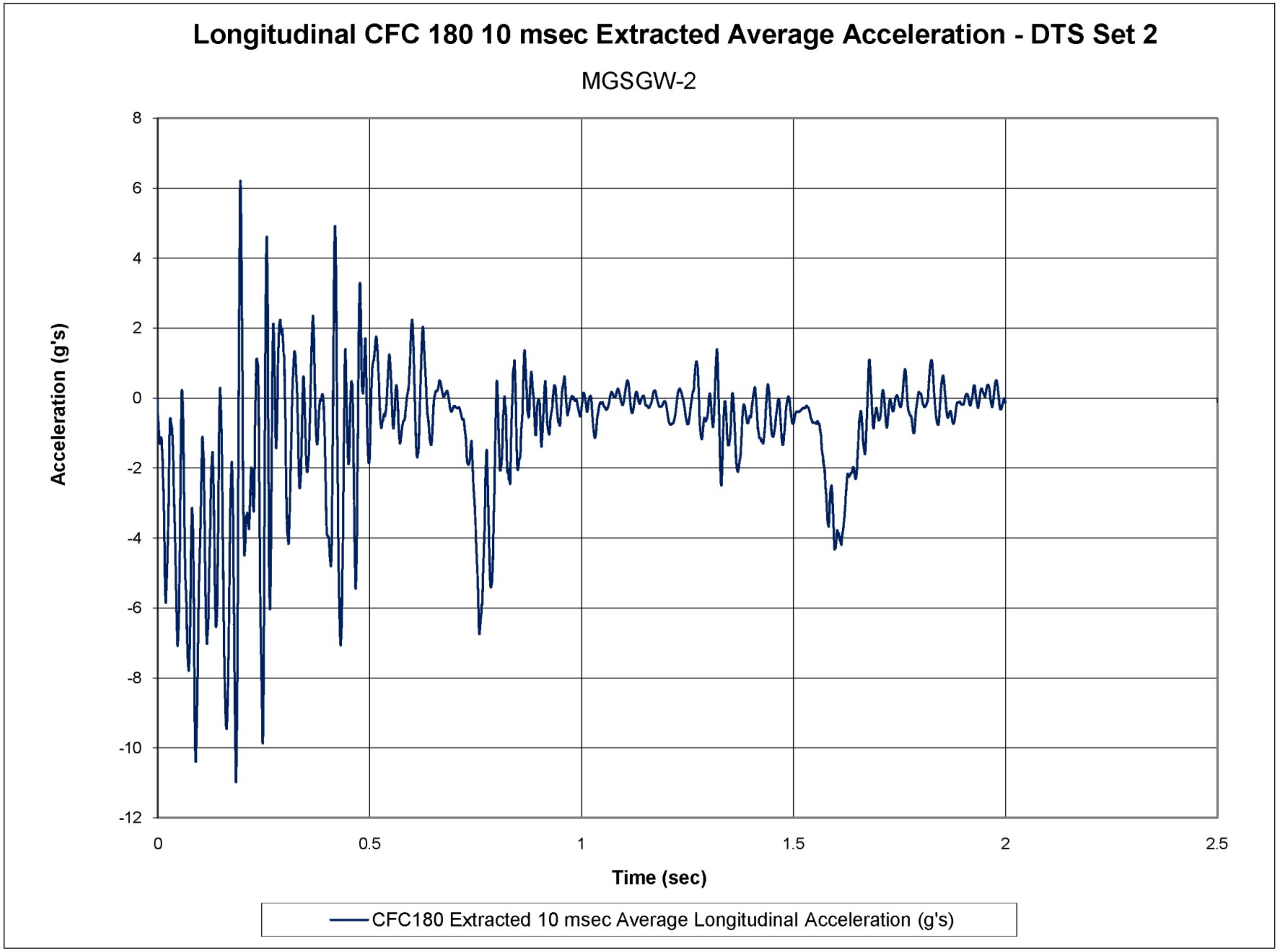


Figure 177. Graph. 10-ms Average Longitudinal Deceleration (DTS Set 2), Test No. MGSGW-2.

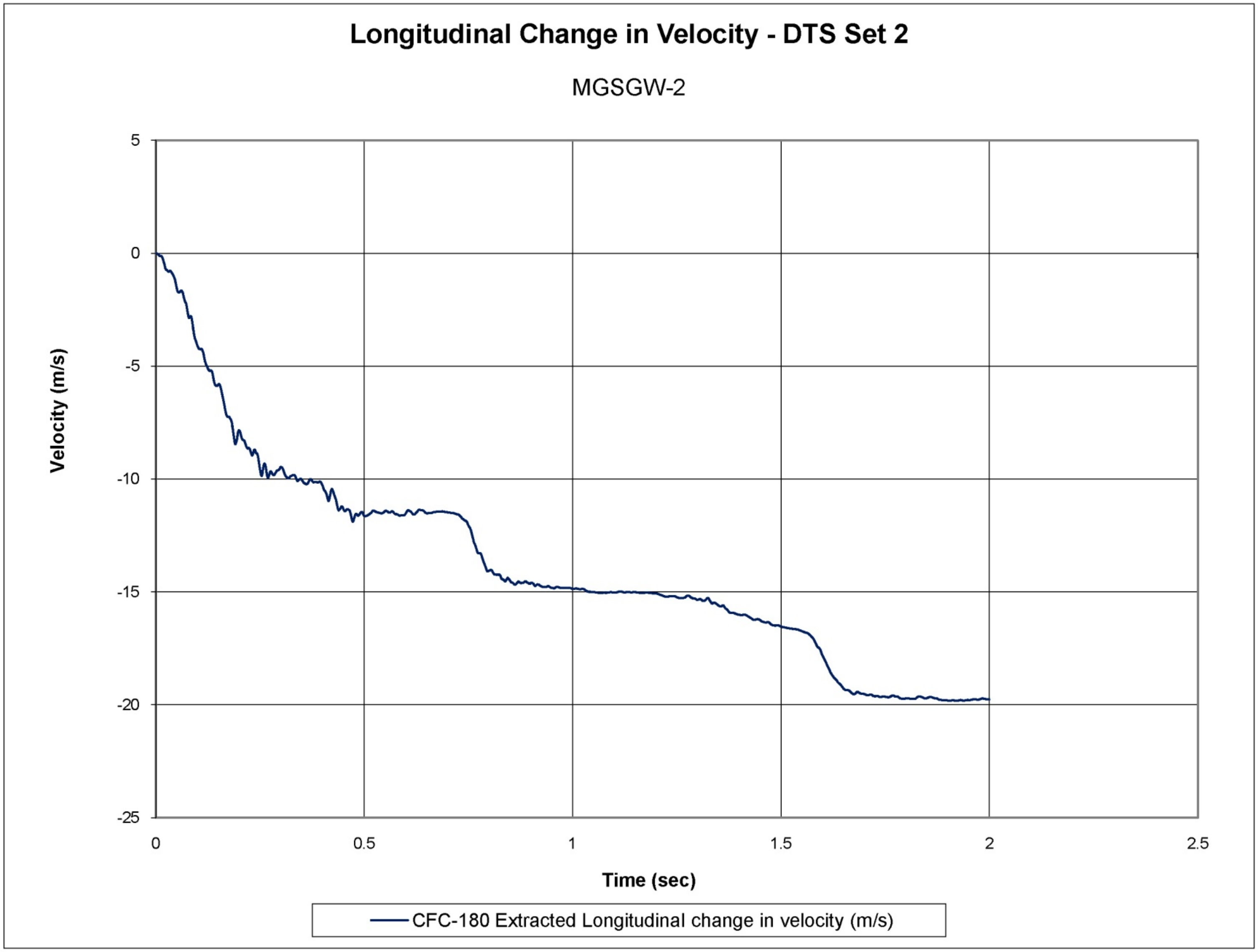


Figure 178. Graph. Longitudinal Occupant Impact Velocity (DTS Set 2), Test No. MGSGW-2.

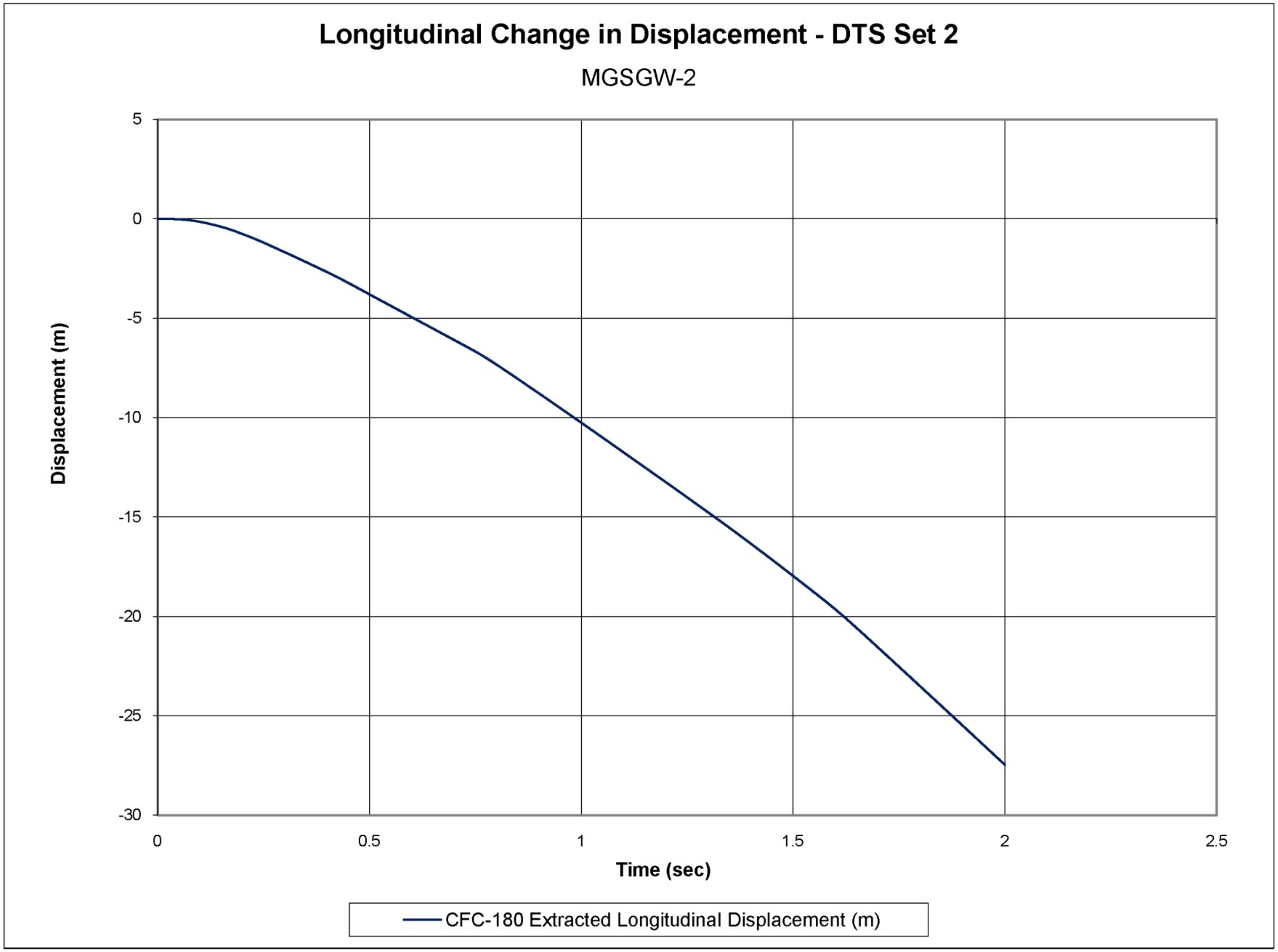


Figure 179. Graph. Longitudinal Occupant Displacement (DTS Set 2), Test No. MGSGW-2.

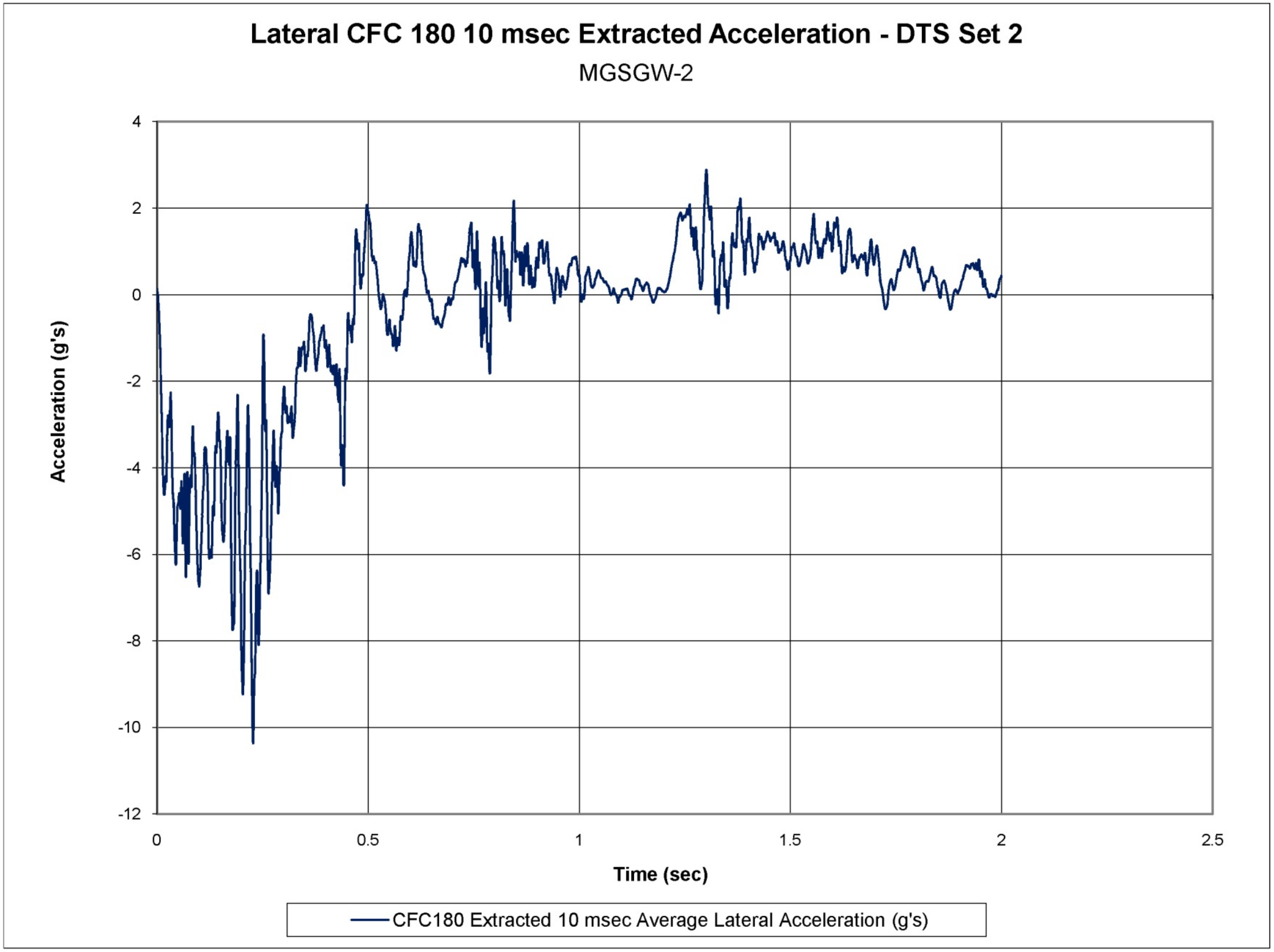


Figure 180. Graph. 10-ms Average Lateral Deceleration (DTS Set 2), Test No. MGSGW-2.

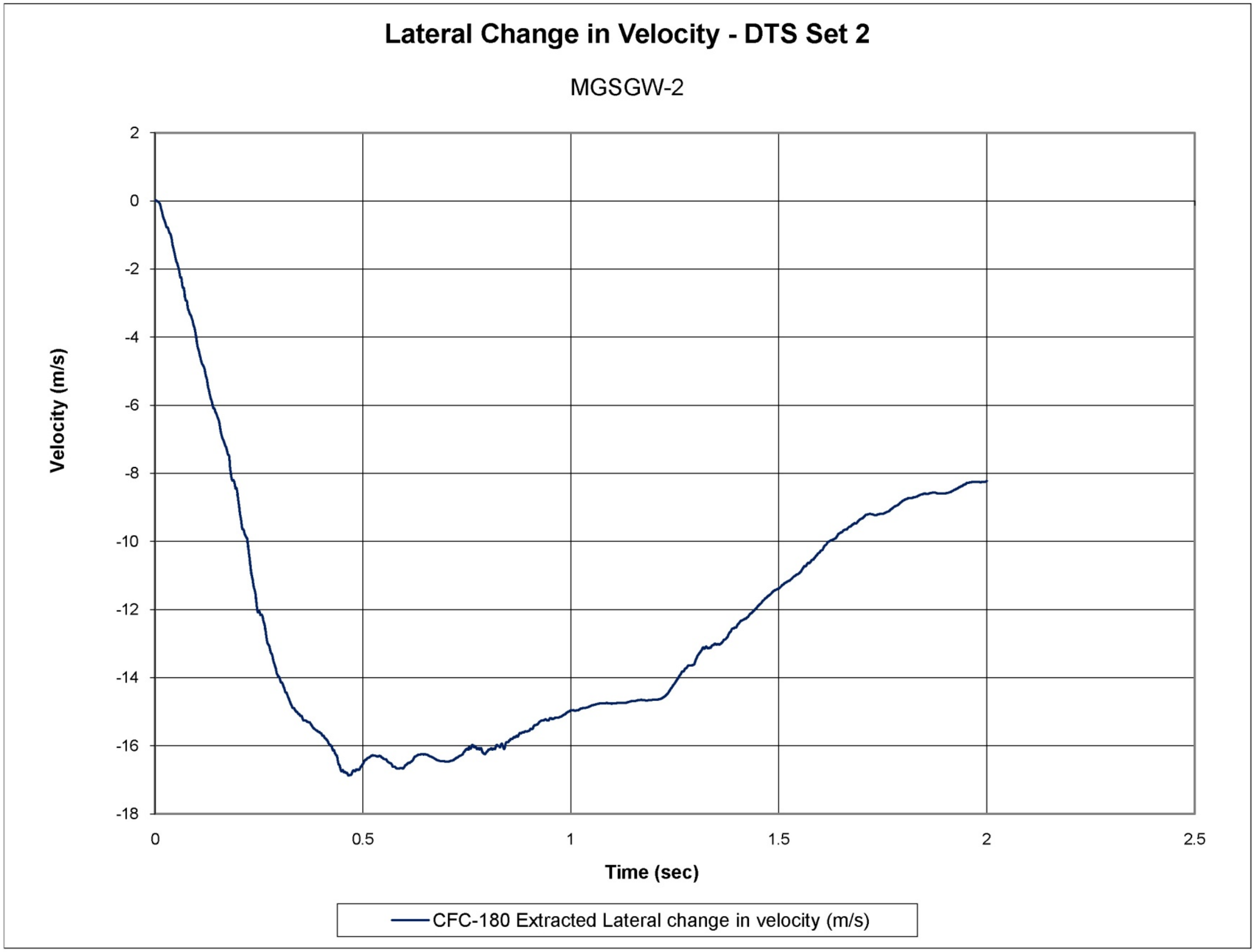


Figure 181. Graph. Lateral Occupant Impact Velocity (DTS Set 2), Test No. MGSGW-2.

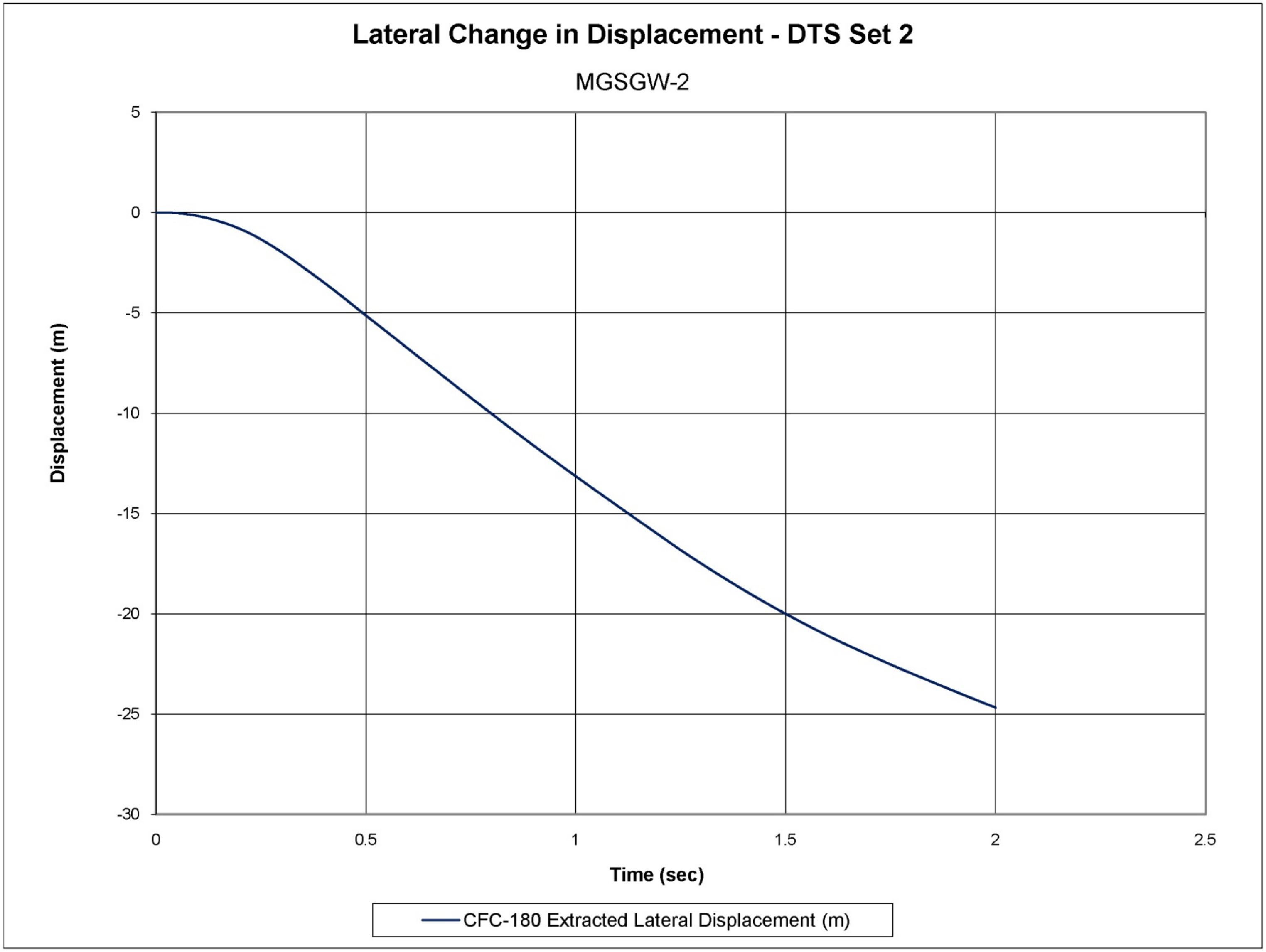


Figure 182. Graph. Lateral Occupant Displacement (DTS Set 2), Test No. MGSGW-2.

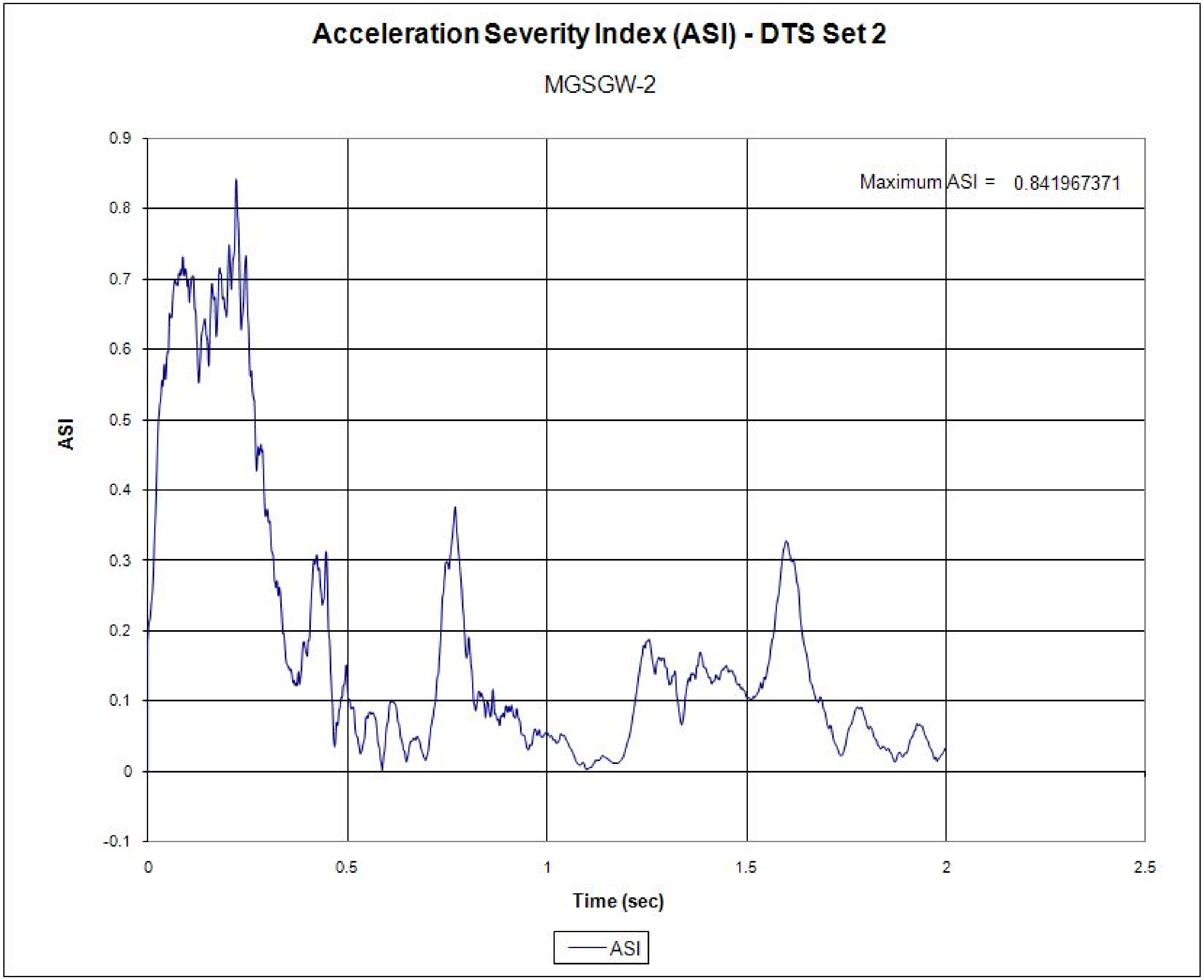


Figure 183. Graph. Acceleration Severity Index (DTS set 2), Test No. MGSGW-2.

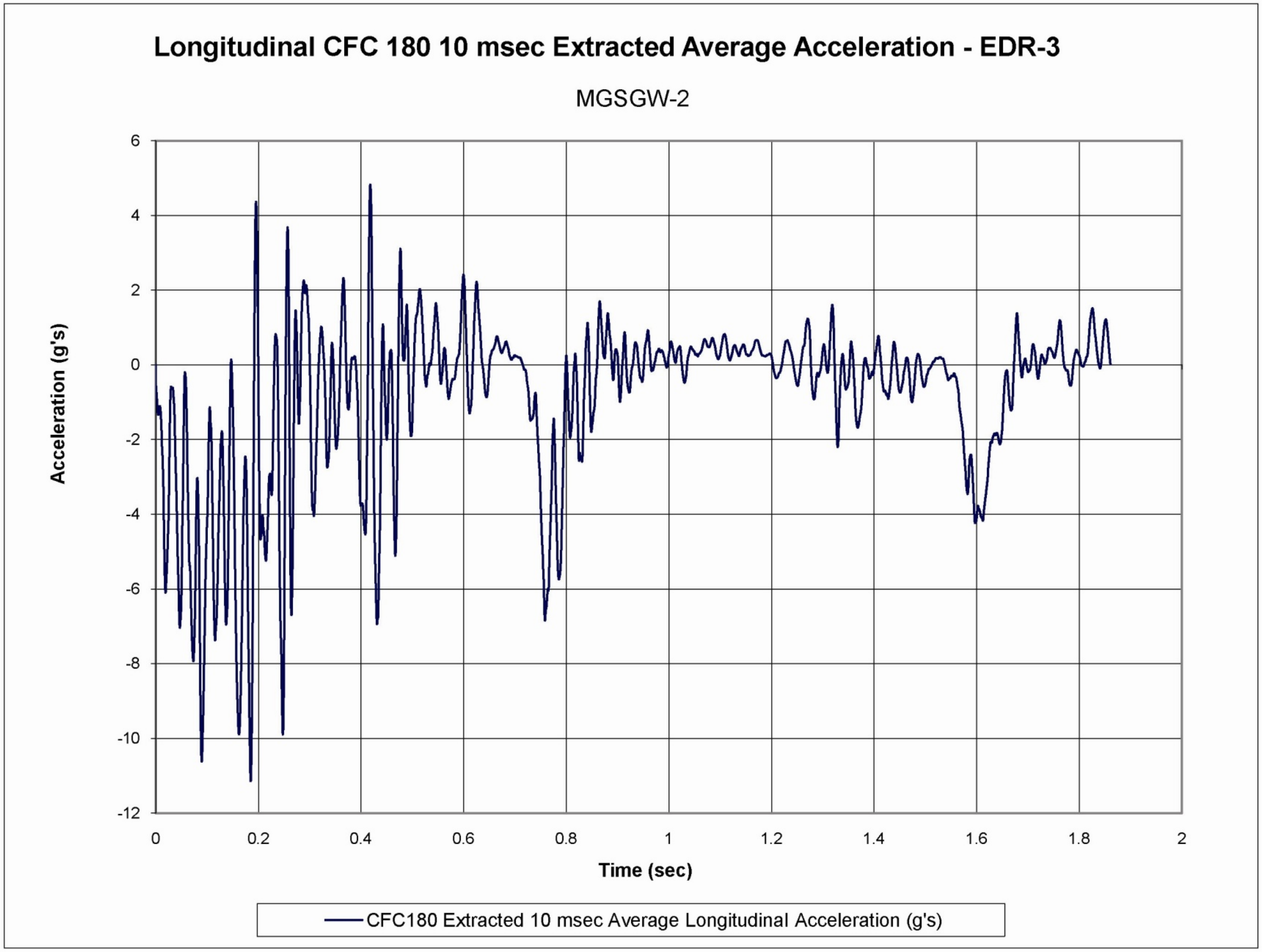


Figure 184. Graph. 10-ms Average Longitudinal Deceleration (EDR-3), Test No. MGSGW-2.

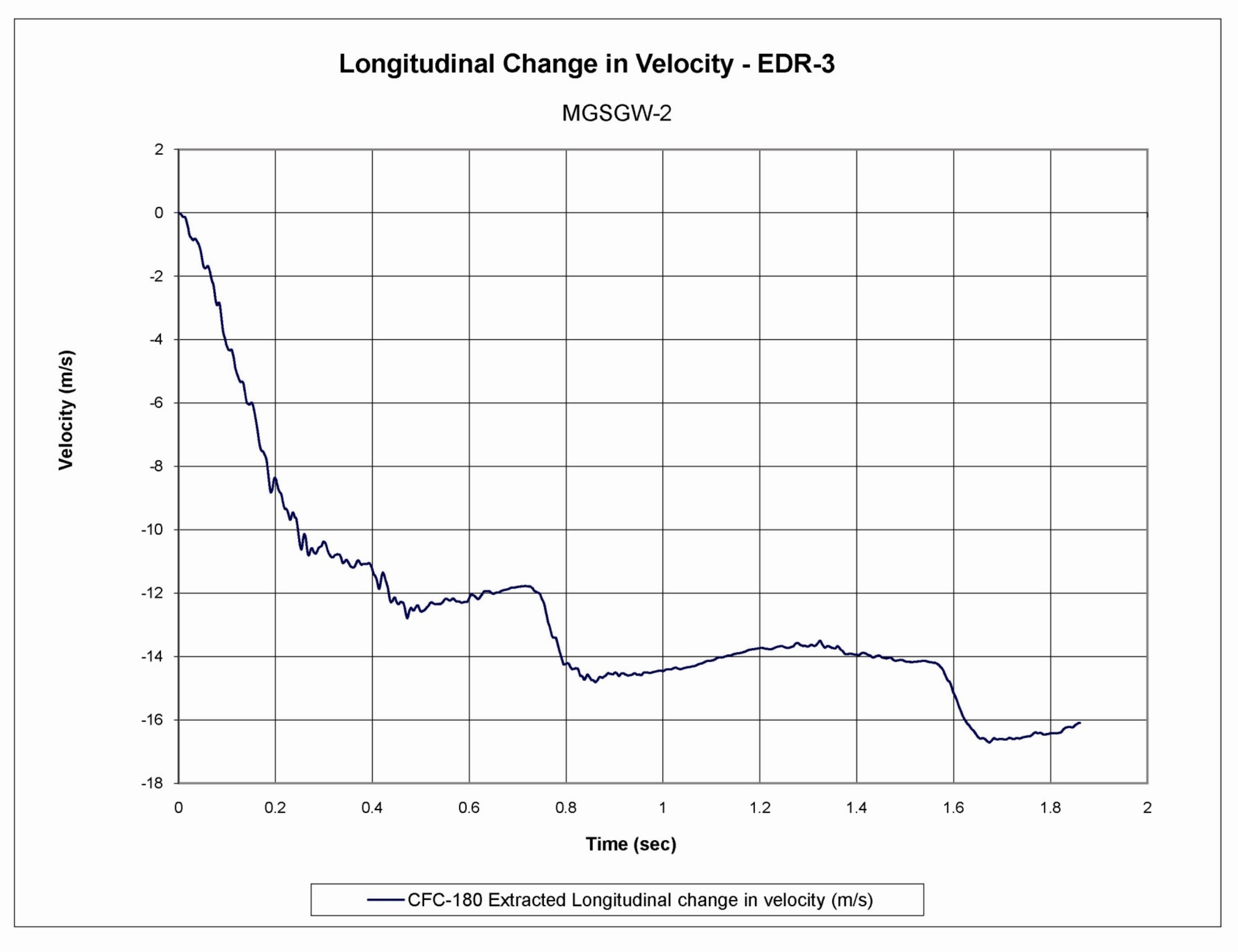


Figure 185. Graph. Longitudinal Occupant Impact Velocity (EDR-3), Test No. MGSGW-2.

Figure 186. Graph. Longitudinal Occupant Displacement (EDR-3), Test No. MGSGW-2.

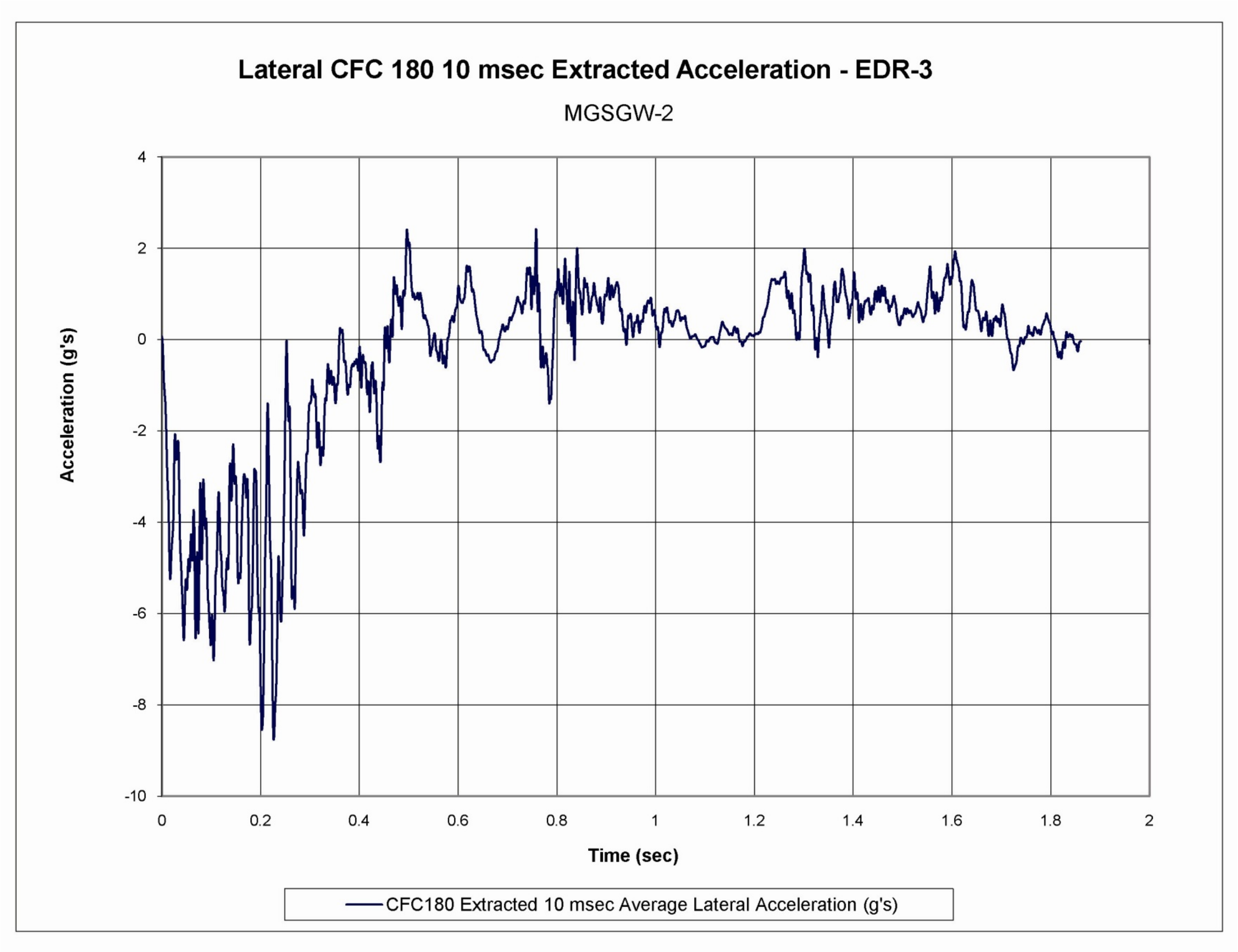


Figure 187. Graph. 10-ms Average Lateral Deceleration (EDR-3), Test No. MGSGW-2.

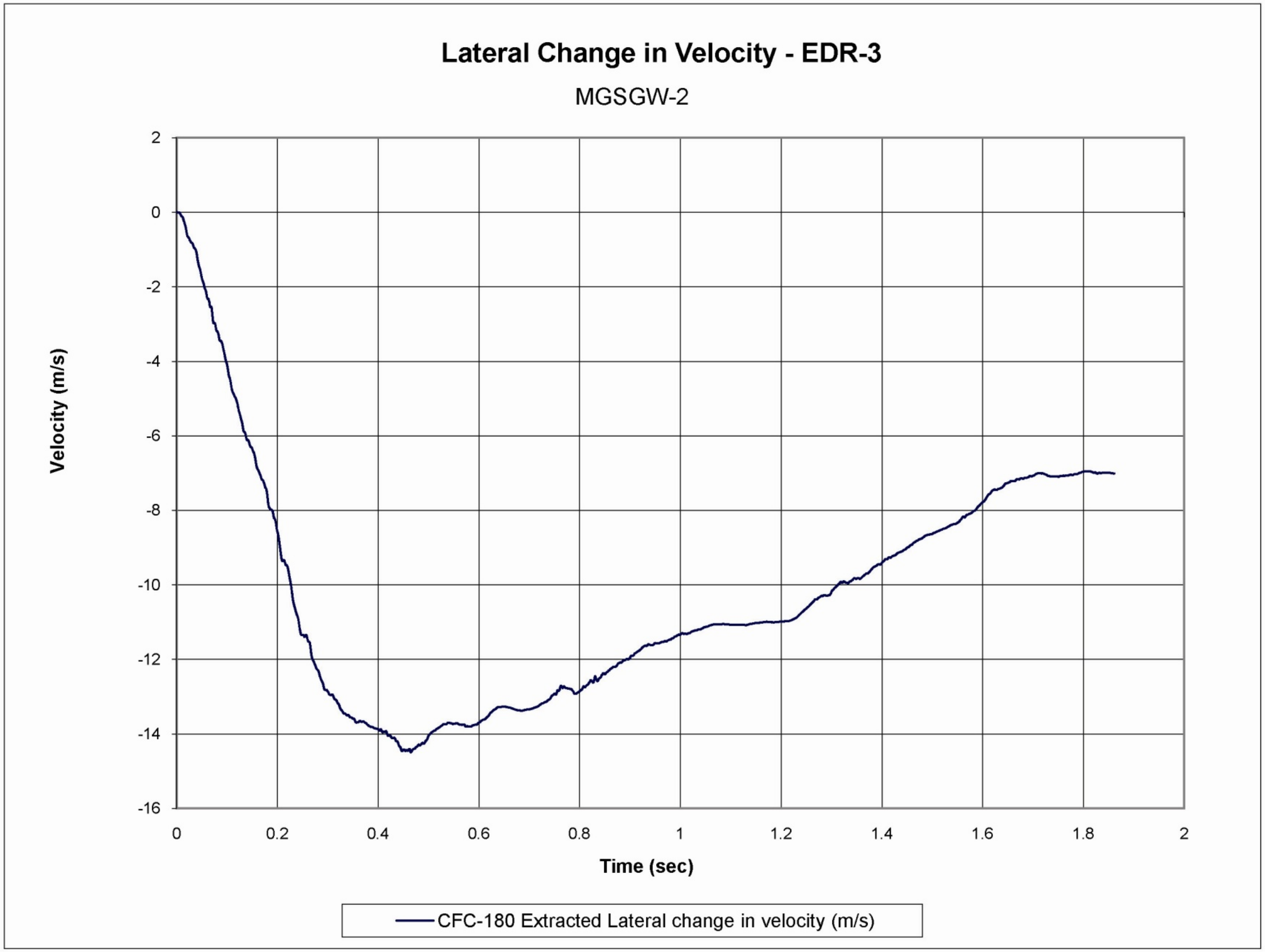


Figure 188. Graph. Lateral Occupant Impact Velocity (EDR-3), Test No. MGSGW-2.

Figure 189. Graph. Lateral Occupant Displacement (EDR-3), Test No. MGSGW-2.

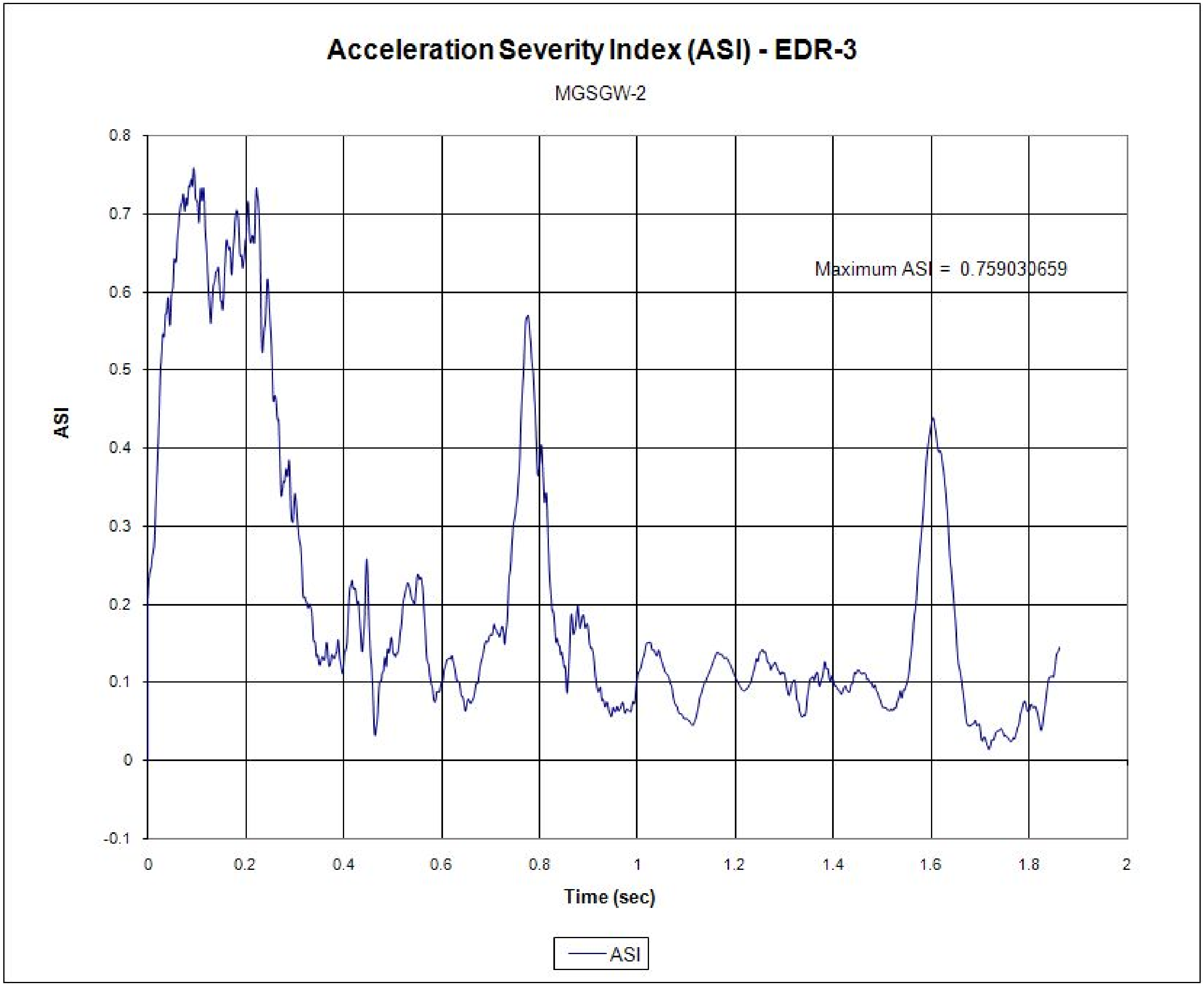


Figure 190. Graph. Acceleration Severity Index (EDR-3), Test No. MGSGW-2.

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