DESIGN AND EVALUATION OF MINNESOTA'S TIMBER RUB-RAIL FOR NOISE BARRIERS

Submitted by

Karla A. Polivka, M.S.M.E., E.I.T.
Research Associate Engineer

John R. Rohde, Ph.D., P.E.
Associate Professor

Ronald K. Faller, Ph.D., P.E.
Research Assistant Professor

James C. Holloway, M.S.C.E., E.I.T.
Research Associate Engineer

Dean L. Sicking, Ph.D., P.E.
Professor and MwRSF Director

MIDWEST ROADSIDE SAFETY FACILITY
University of Nebraska-Lincoln
527 Nebraska Hall
Lincoln, Nebraska 68588-0529
(402) 472-6864

Submitted to

MINNESOTA DEPARTMENT OF TRANSPORTATION
395 John Ireland Boulevard
M.S.696
St. Paul, Minnesota 55155

MwRSF Research Report No. TRP-03-156-05

March 8, 2005

Technical Report Documentation Page

1. Report No.	2.	3. Recipient's Accession No.
TRP-03-156-05		

4. Title and Subtitle	5. Report Date
Design and Evaluation of Minnesota's Timber Rub-Rail for Noise Barriers	March 8, 2005
	6.
7. Author(s) Polivka, K.A., Rohde, J.R., Faller, R.K., Holloway, J.C., and Sicking, D.L.	8. Performing Organization Report No. TRP-03-156-05
9. Performing Organization Name and Address Midwest Roadside Safety Facility (MwRSF) University of Nebraska-Lincoln 527 Nebraska Hall Lincoln, NE 68588-0529	10. Project/Task/Work Unit No. 11. Contract © or Grant (G) No.
12. Sponsoring Organization Name and Address Minnesota Department of Transportation 395 John Ireland Boulevard M.S.696 St. Paul, Minnesota 55155	13. Type of Report and Period Covered Final Report 2003-2005 14. Sponsoring Agency Code

15. Supplementary Notes

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

16. Abstract (Limit: 200 words)

The Minnesota Department of Transportation's (Mn/DOT's) glue-laminated timber rub rail for noise barriers was developed for situations where a noise barrier will be located within the clear zone and when other types of protection are not considered desirable. The rub rail is intended to prevent an errant vehicle from snagging on the support posts of the noise barrier or on any portions of the noise wall itself. The test installation consisted of 24.86-m (81-ft) of timber rail sections supported by eleven concrete posts.

One full-scale crash test, a 1,989-kg (4,386-lb) pickup truck impacting at a speed of 99.4 km/h (61.8 mph) and at an angle of 25.3 degrees, was conducted and reported in accordance with the requirements specified in the National Cooperative Highway Research Program (NCHRP) Report No. 350, *Recommended Procedures for the Safety Performance Evaluation of Highway Features*. The safety performance of the timber rub rail was determined to be acceptable according to the TL-3 evaluation criteria specified in NCHRP Report No. 350.

17. Document Analysis/Descriptors	18. Availability Statement
Highway Safety, Noise Barrier, Sound Wall, Timber Rail, Rub Rail, Roadside Appurtenances, Crash Test, Compliance Test	No restrictions. Document available from: National Technical Information Services, Springfield, Virginia 22161

19. Security Class (this report)	20. Security Class (this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	98	

DISCLAIMER STATEMENT

The contents of this report reflect the views of the authors who are responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official views nor policies of the Minnesota Department of Transportation nor the Federal Highway Administration. This report does not constitute a standard, specification, or regulation.

ACKNOWLEDGMENTS

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

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

Midwest Roadside Safety Facility

J. D. Reid, Ph.D., Professor
R.W. Bielenberg, M.S.M.E., E.I.T., Research Associate Engineer
A.T. Russell, B.S.B.A., Laboratory Mechanic II
C.L. Meyer, B.S.M.E., E.I.T., Research Engineer II
Undergraduate and Graduate Assistants

Minnesota Department of Transportation

Jim Klessig, Implementation Liaison
Mohammad Dehdashti, P.E., Design Standards Engineer
Bruce Westby, P.E., Assistant Design Standards Engineer
Andrew Halverson, P.E., Former Assistant Design Standards Engineer

Dunlap Photography

James Dunlap, President and Owner

TABLE OF CONTENTS

Page

List of Figures

Page

List of Tables

Page

1 INTRODUCTION

1.1 Background and Problem Statement

The Minnesota Department of Transportation's (Mn/DOT's) glue-laminated timber rub rail was developed for situations where a noise barrier will be located within the clear zone and when other types of protection are not considered desirable. The rub rail is intended to prevent an errant vehicle from snagging on the support posts of the noise barrier or on any portions of the noise wall itself. The rub rail is normally not placed as a structural element of the noise barrier. The decision to use a rub rail is sometimes influenced by a desire to keep the traffic-related barrier element farther away from the traffic by affixing it to the noise barrier in lieu of placing a free-standing barrier in front of the noise barrier wall. Therefore, a need existed to evaluate the rub rail design according to the safety performance criteria of the National Cooperative Highway Research Program (NCHRP) Report No. 350, *Recommended Procedures for the Safety Performance Evaluation of Highway Features* (1).

Within the evaluation criteria, all beam and post longitudinal barriers must be capable of developing significant tensile loads and/or flexural loads. Further, adequate anchorage must be provided at the end of the railing system in order for the barrier to perform adequately when struck near the end. Therefore, prior to the evaluation of the system's safety performance, it was necessary to analyze and design the glue-laminated timber rail for use in the noise barrier system.

1.2 Objective

The objective of the research project was to develop and evaluate the safety performance of a new Mn/DOT timber rub rail for noise barriers. The timber rub rail was to be evaluated according to the Test Level 3 (TL-3) safety performance criteria set forth in the National Cooperative Highway

Research Program (NCHRP) Report No. 350, *Recommended Procedures for the Safety Performance Evaluation of Highway Features* (1).

1.3 Scope

The research objective was achieved by performing several tasks. First, an analysis phase was conducted in order to design a timber rub rail. After the final design was completed, the timber rub rail for noise barrier system was fabricated and constructed at the Midwest Roadside Safety Facility's (MwRSF's) outdoor test facility. Following the fabrication of the rub-rail system, a full-scale vehicle crash test was performed using a ¾-ton pickup truck, weighing approximately 2,000 kg (4,409 lbs), with a target impact speed and an angle of 100.0 km/h (62.1 mph) and 25 degrees, respectively. Finally, the test results were analyzed, evaluated, and documented. Conclusions and recommendations were then made that pertain to the safety performance of the timber rub rail system.

2 TEST REQUIREMENTS AND EVALUATION CRITERIA

2.1 Test Requirements

Longitudinal barriers, such as timber rub rails, must satisfy the requirements provided in NCHRP Report No. 350 to be accepted for use on National Highway System (NHS) construction projects or as a replacement for existing systems not meeting current safety standards. According to TL-3 of NCHRP Report No. 350, the barrier system must be subjected to two full-scale vehicle crash tests. The two crash tests are as follows:

1. Test Designation 3-10. An 820-kg (1,808-lb) small car impacting the rub rail system at a nominal speed and angle of 100.0 km/h (62.1 mph) and 20 degrees, respectively.

2. Test Designation 3-11. A 2,000-kg (4,409-lb) pickup truck impacting the rub rail system at a nominal speed and angle of 100.0 km/h (62.1 mph) and 25 degrees, respectively.

However, during the design phase of the barrier system, special attention was given to prevent geometric features that would cause the small car test to fail due to excessive snagging or overturning. Therefore, due to the low bottom-height of the rail element and the significant distance that the front of the rail is blocked out away from the concrete posts, the 820-kg small car crash test was deemed unnecessary for this project. The test conditions for TL-3 longitudinal barriers are summarized in Table 1.

2.2 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 barrier to contain, redirect, or allow controlled vehicle penetration in a predictable manner. Occupant risk evaluates the degree of hazard to occupants in the impacting vehicle. Vehicle trajectory after collision is a measure of the potential for the post-impact trajectory of the vehicle to cause subsequent multi-vehicle accidents. This criterion also indicates the potential safety hazard for the occupants of other vehicles or the occupants of the impacting vehicle when subjected to secondary collisions with other fixed objects. These three evaluation criteria are defined in Table 2. The full-scale vehicle crash test was conducted and reported in accordance with the procedures provided in NCHRP Report No. 350.

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

Test Article	Test Designation	Test Vehicle	Impact Conditions			Evaluation Criteria [1]
			Speed		Angle (degrees)	
			(km/h)	(mph)		
Longitudinal Barrier	3-10	820C	100	62.1	20	A,D,F,H,I,K,M
	3-11	2000P	100	62.1	25	A,D,F,K,L,M

[1] Evaluation criteria explained in Table 2.

Table 2. NCHRP Report No. 350 Evaluation Criteria for Crash Tests (1)

Structural Adequacy	A.	Test article should contain and redirect the vehicle; the vehicle should not penetrate, underride, or override the installation although controlled lateral deflection of the test article is acceptable.
Occupant Risk	D.	Detached elements, fragments or other debris from the test article should not penetrate or show potential for penetrating the occupant compartment, or present an undue hazard to other traffic, pedestrians, or personnel in a work zone. Deformations of, or intrusions into, the occupant compartment that could cause serious injuries should not be permitted.
	F.	The vehicle should remain upright during and after collision although moderate roll, pitching, and yawing are acceptable.
	H.	Longitudinal and lateral occupant impact velocities should fall below the preferred value of 9 m/s (29.53 ft/s), or at least below the maximum allowable value of 12 m/s (39.37 ft/s).
	I.	Longitudinal and lateral occupant ridedown accelerations should fall below the preferred value of 15 g's, or at least below the maximum allowable value of 20 g's.
Vehicle Trajectory	K.	After collision it is preferable that the vehicle's trajectory not intrude into adjacent traffic lanes.
	L.	The occupant impact velocity in the longitudinal direction should not exceed 12 m/sec (39.37 ft/sec), and the occupant ridedown acceleration in the longitudinal direction should not exceed 20 G's.
	M.	The exit angle from the test article preferably should be less than 60 percent of test impact angle measured at time of vehicle loss of contact with test device.

3 DESIGN DETAILS

3.1 Design Criteria

In order to limit the scope of the noise barriers considered under this study, several assumptions were made. First, the evaluation would be limited to the systems configured with concrete columns. Second, a minimum embedment depth would be selected and then the existing Mn/DOT sound wall design standard would be modified for those systems containing shorter embedment depths. Third, the rub rail system would utilize one size of glulam rail section for all systems. Finally, for those systems utilizing the rub rail, the noise wall panels would be mounted on the back side of the posts.

3.2 Rub Rail for Noise Barriers

The test installation consisted of 24.86-m (81-ft) of timber rail sections supported by concrete posts, as shown in Figure 1. Design details are shown in Figures 1 through 11. The corresponding English-unit drawings are shown in Appendix A. Photographs of the test installation are shown in Figures 12 through 17.

The glulam timber for the rail members and spacer blocks was fabricated with Combination No. 48 Southern Pine material, as specified in AASHTO's *LRFD Bridge Design Specifications*, and it was treated with pentachlorophenol in heavy oil to a minimum net retention of 9.61 kg/m^3 (0.6 lb/ft^3) as specified in AWPA Standard C14 (2). The rail members were 343-mm (13 ½-in.) wide by 222-mm (8 ¾-in.) deep with a 762-mm (30-in.) top mounting height, as measured from the top of the soil surface to the top of the rub rail. Five rail splice plates were required on the rub rail to attain the total rail length. The splice plates consisted of two ASTM A36 steel plates measuring 343-mm wide x 743-mm long x 9.5-mm thick (13 ½-in. x 29 ¼-in. x ⅜-in.) and one ASTM A36 steel plate

343-mm wide x 203-mm long x 9.5-mm thick (13 ½-in. x 8-in. x ⅜-in.), as shown in Figures 10 and 15. The rub rail was offset away from the posts with spacer blocks measuring 229-mm wide x 152-mm deep x 343-mm long (9-in. x 6-in. x 13 ½-in.), as shown in Figures 2, 3, 13, and 16. The rub rail and spacer blocks were attached to the posts with two 19-mm (¾-in.) diameter by 406-mm (16-in.) long, Grade 2 galvanized dome head bolts without lugs. At all rail splice locations, eight 32-mm (1 ¼-in.) diameter by 305-mm (12-in.) long, ASTM Grade 2 galvanized dome head bolts without lugs and with a 32-mm (1 ¼-in.) diameter Type A flat washer and a 32-mm (1 ¼-in.) diameter finished hex nut were used to attach to rail sections to the splice plates, as shown in Figures 1, 2, 10, and 15. Each cable bracket was attached to the rail section with eight 32-mm (1 ¼-in.) diameter by 305-mm (12-in.) long, ASTM Grade 2 galvanized dome head bolts with lugs and with a 32-mm (1 ¼-in.) diameter Type A flat washer and a 32-mm (1 ¼-in.) diameter finished hex nut.

The entire system was constructed with eleven prestressed concrete posts, as shown in Figures 1, 2, 12, and 13. All eleven posts were concrete sections measuring 305-mm wide x 457-mm deep x 4,877-mm long (12-in. x 18-in. x 16-ft), as shown in Figure 8. The concrete posts were spaced 2,438 mm (8 ft) on centers along the length of the system with a soil embedment depth of 1,829 mm (6 ft), as shown in Figure 1. The posts were placed in a compacted course, crushed limestone material that met Grading B of AASHTO M147-65 (1990) as found in NCHRP Report No. 350.

The concrete used for the prestressed concrete posts consisted of a Minnesota Type 3 mix, with a minimum compressive strength of 38 MPa (5,512 psi). A minimum concrete cover of 51 mm (2 in.) was used for all the rebar and strands placed within the posts. The precast concrete posts can either contain standard reinforcement or prestressing longitudinal reinforcement. Therefore, all steel reinforcement in the post was either Grade 420 epoxy-coated rebar or 270 LO-LAX prestressing strand. The post reinforcement details are shown in Figures 8 through 9 and A-12.

The steel reinforcement details for standard reinforced concrete posts consist of No. 4 bars for the longitudinal bars and No. 3 bars for the loop bars, as shown in Figures 8 and 9. Each of the six longitudinal rebar was 4,775-mm (15-ft 8-in.) long. The loop bars were 1,270-mm (50-in.) long and were bent into a rectangular shape. The loop bar spacings were 451-mm (17 ¾-in.) on centers, except for the last spacing which was 257-mm (10 ⅛-in.) on center, as shown in Figures 8 and 9.

The steel reinforcement details for prestressing longitudinal reinforced concrete posts consist of 270 LO-LAX prestress strands for the longitudinal bars and No. 3 bars for the loop bars, as shown in Figure A-12. Each of the four longitudinal strands was 4,775-mm (15-ft 8-in.) long. The loop bars were 1,270-mm (50-in.) long and were bent into a rectangular shape. The loop bar spacings were 457-mm (18in.) on centers. The concrete posts contained in the test installation were configured with the prestressing longitudinal reinforcement details, as shown in Figure A-12.

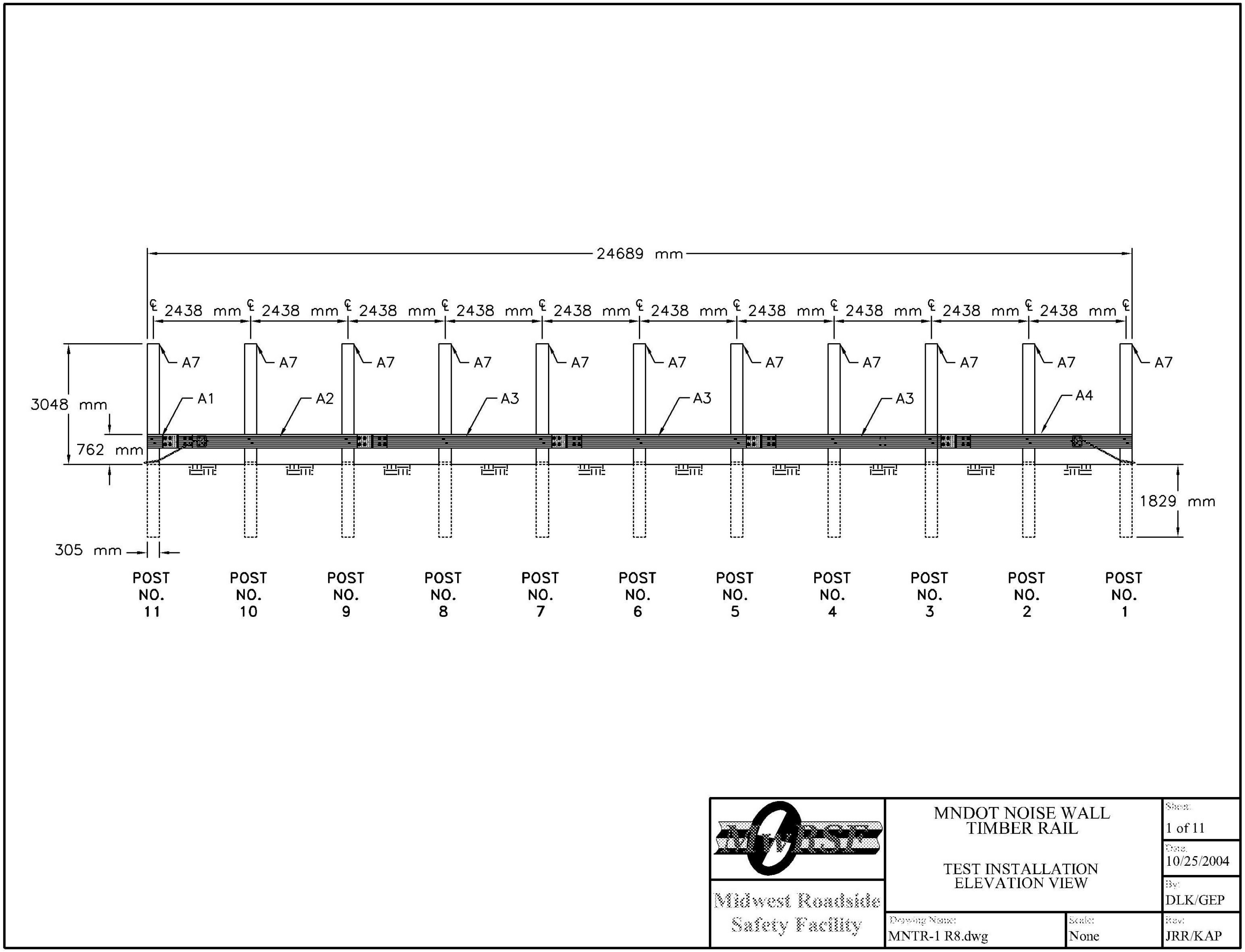


Figure 1. Layout for Mn/DOT's Timber Rub Rail for Noise Barriers – Elevation View

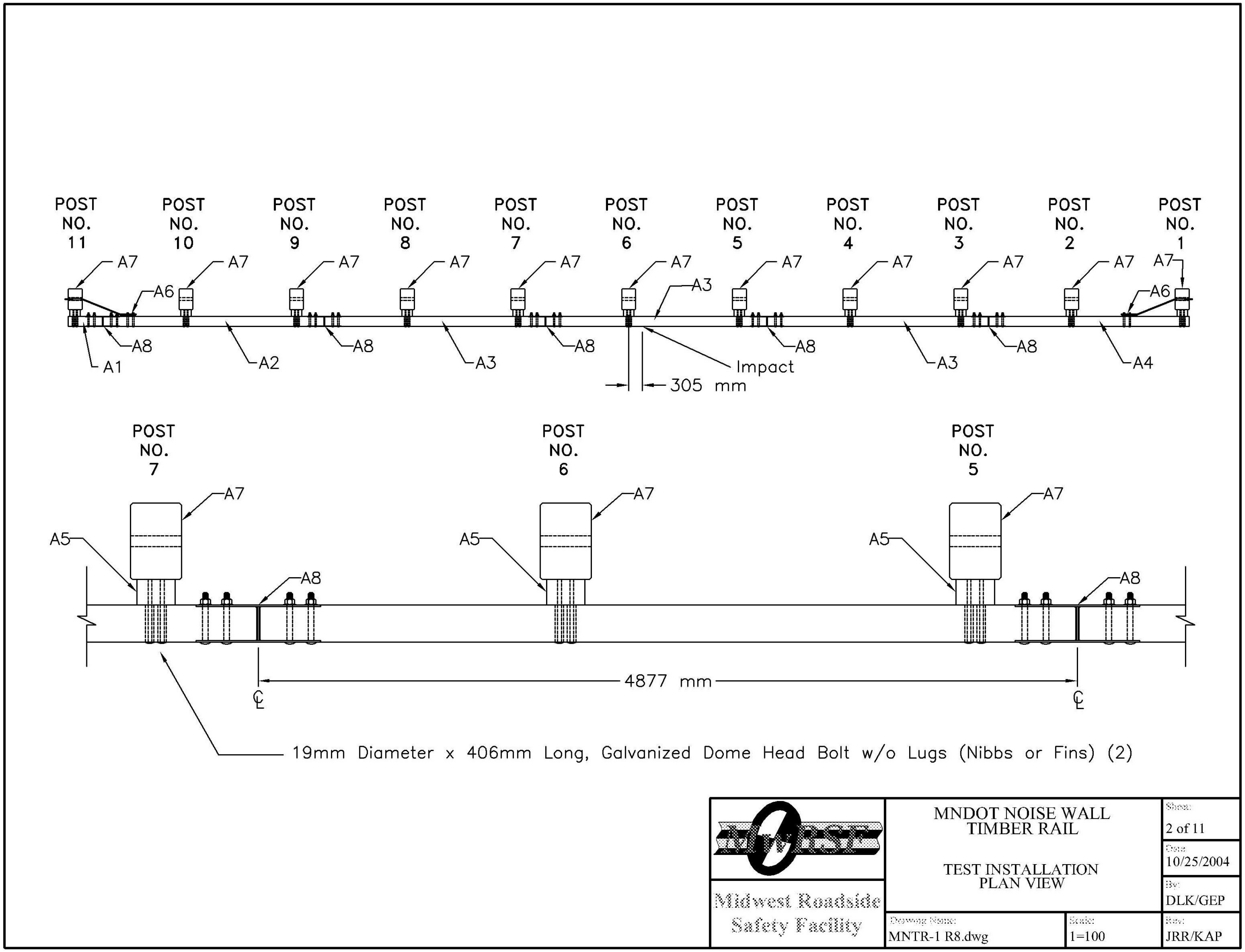


Figure 2. Layout for Mn/DOT's Timber Rub Rail for Noise Barrier – Plan View

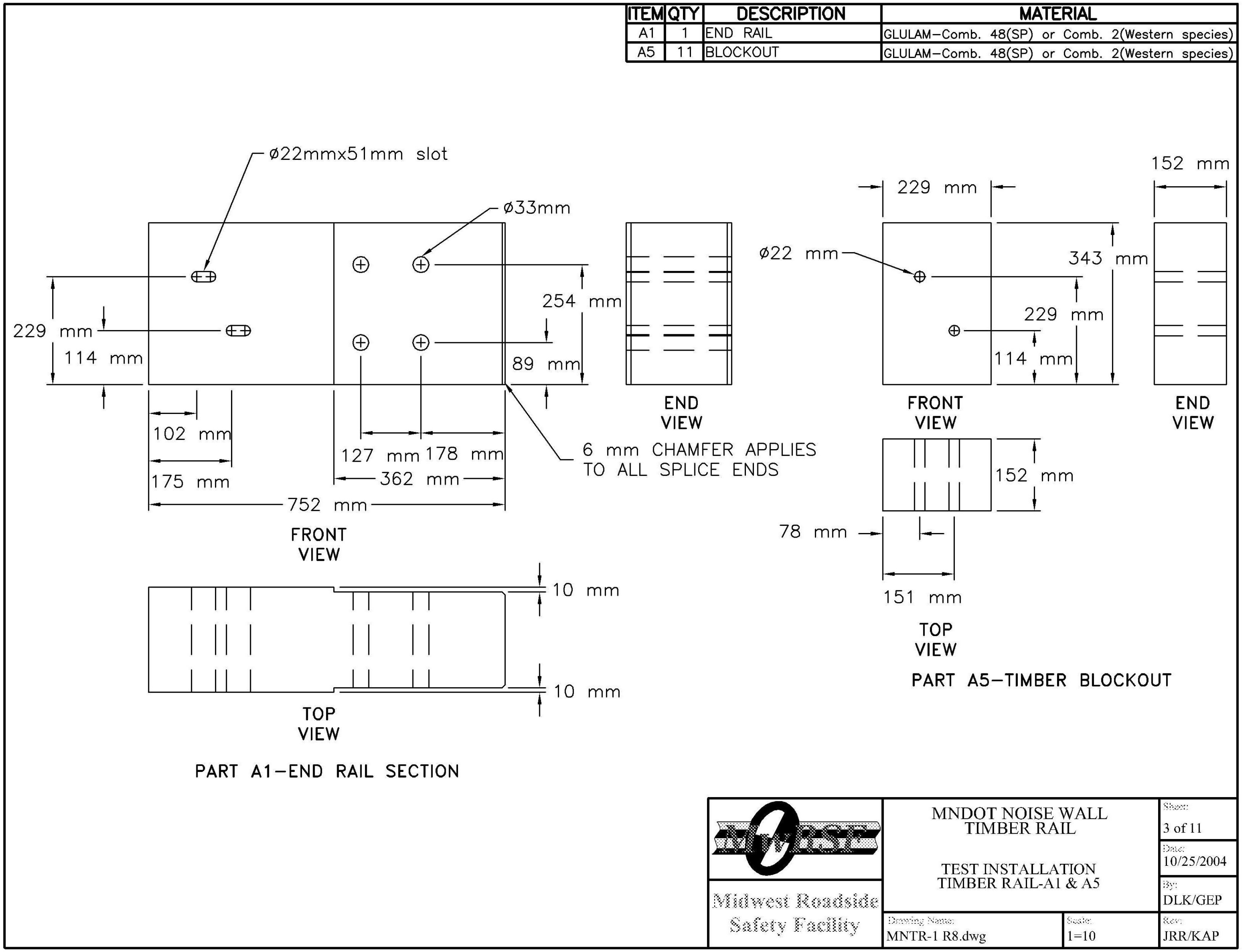


Figure 3. Mn/DOT's Timber Rub Rail Design Rail and Timber Blockout Details

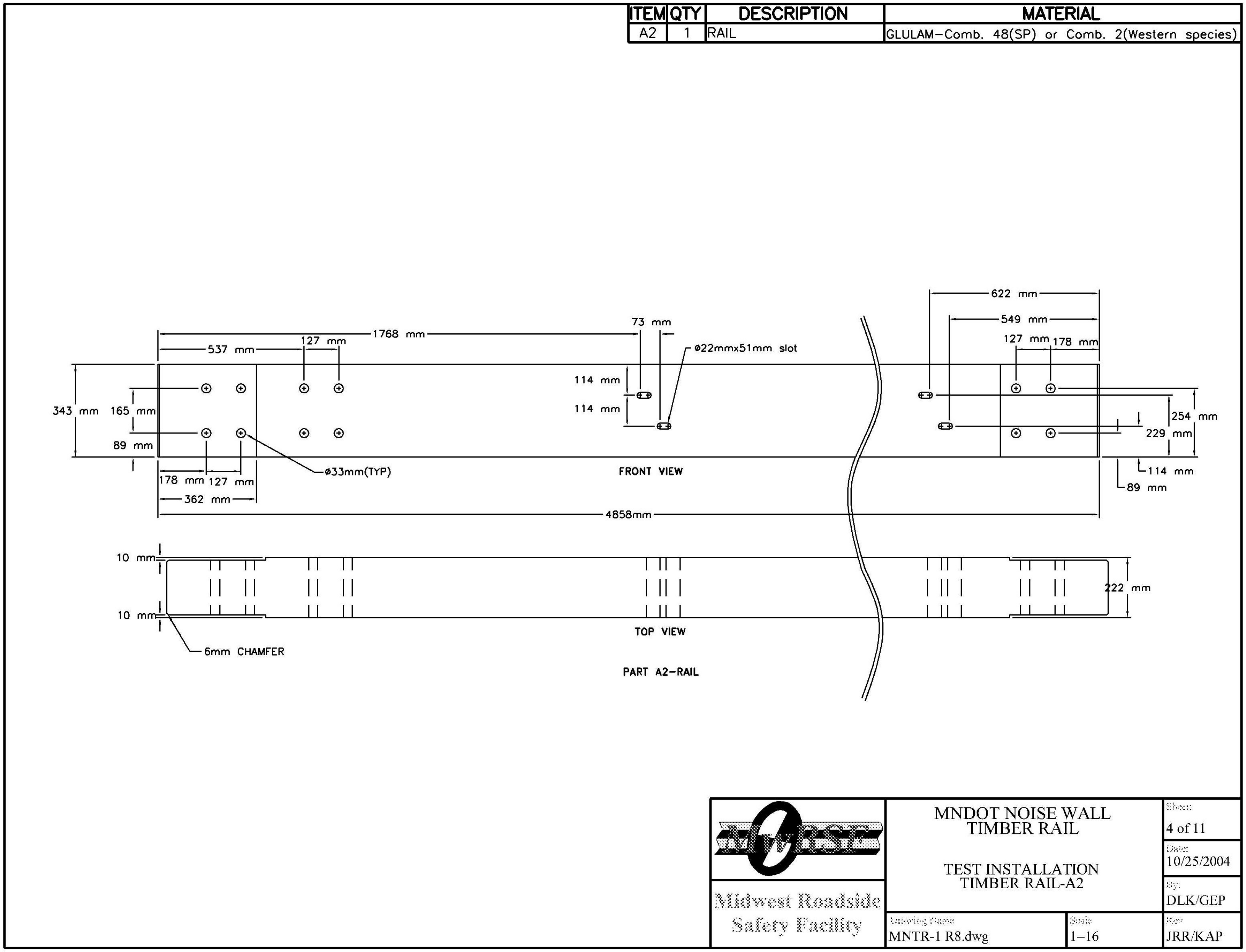


Figure 4. Mn/DOT's Timber Rub Rail Design Rail Details

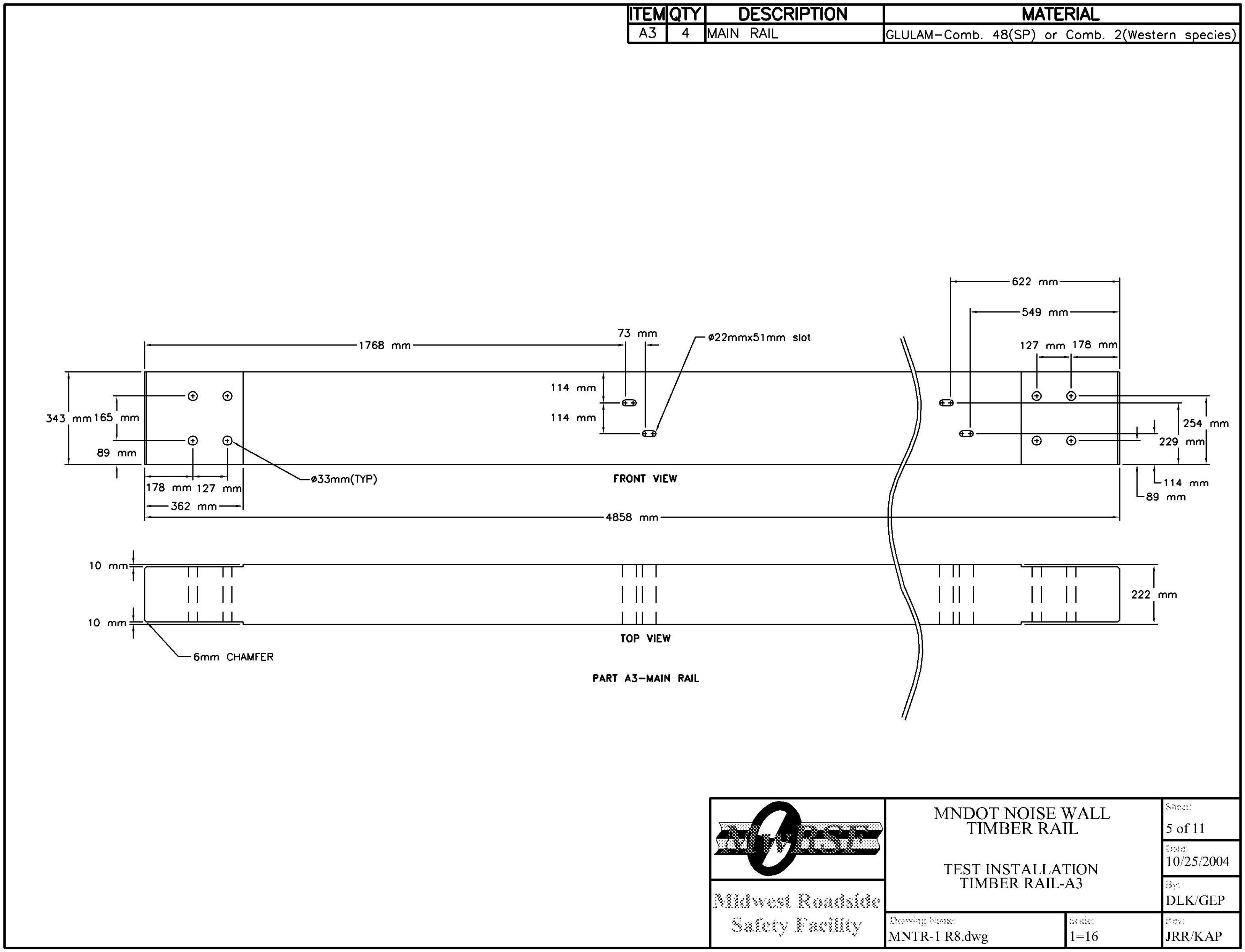


Figure 5. Mn/DOT’s Timber Rub Rail Design Main Rail Details

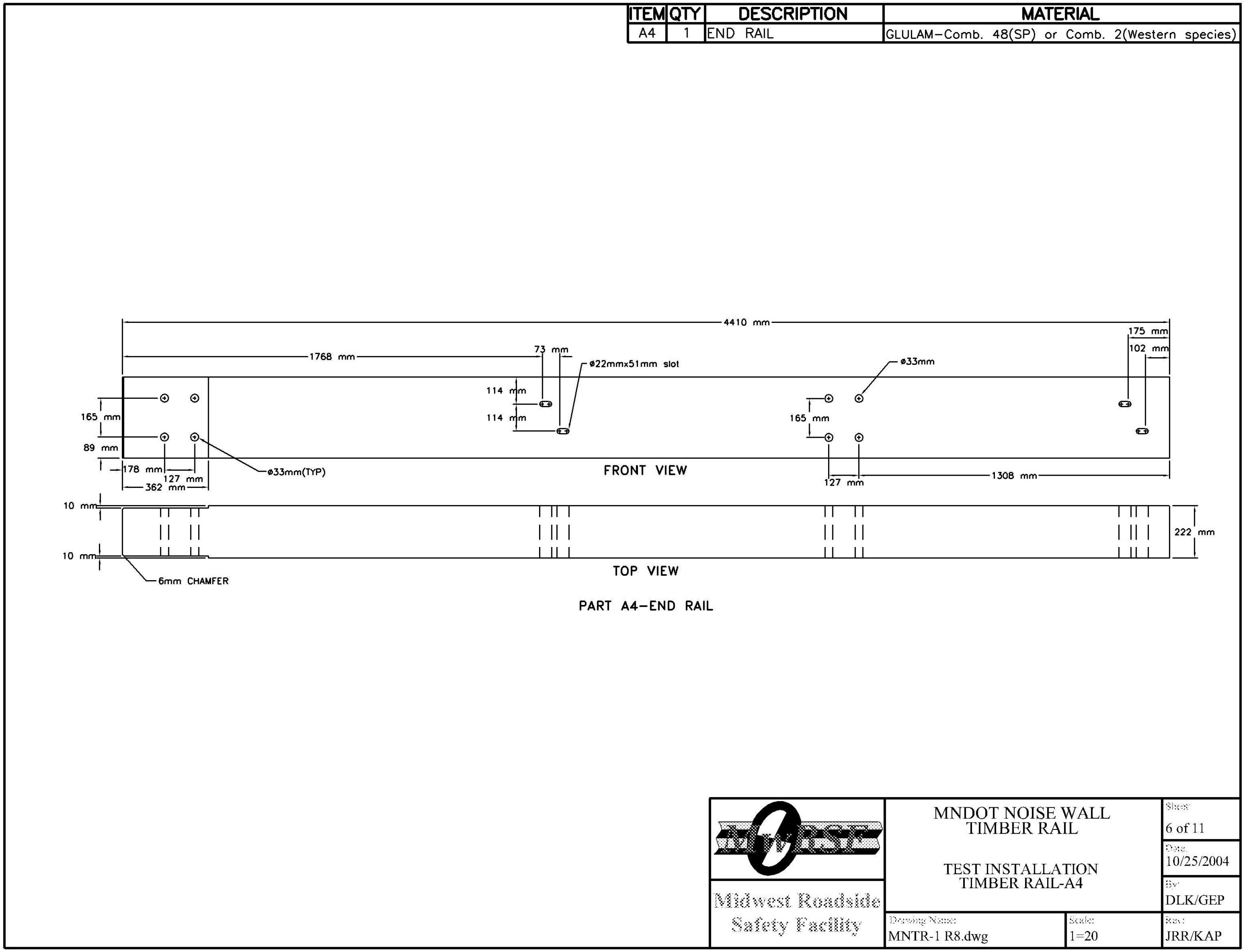


Figure 6. Mn/DOT's Timber Rub Rail Design End Rail Details

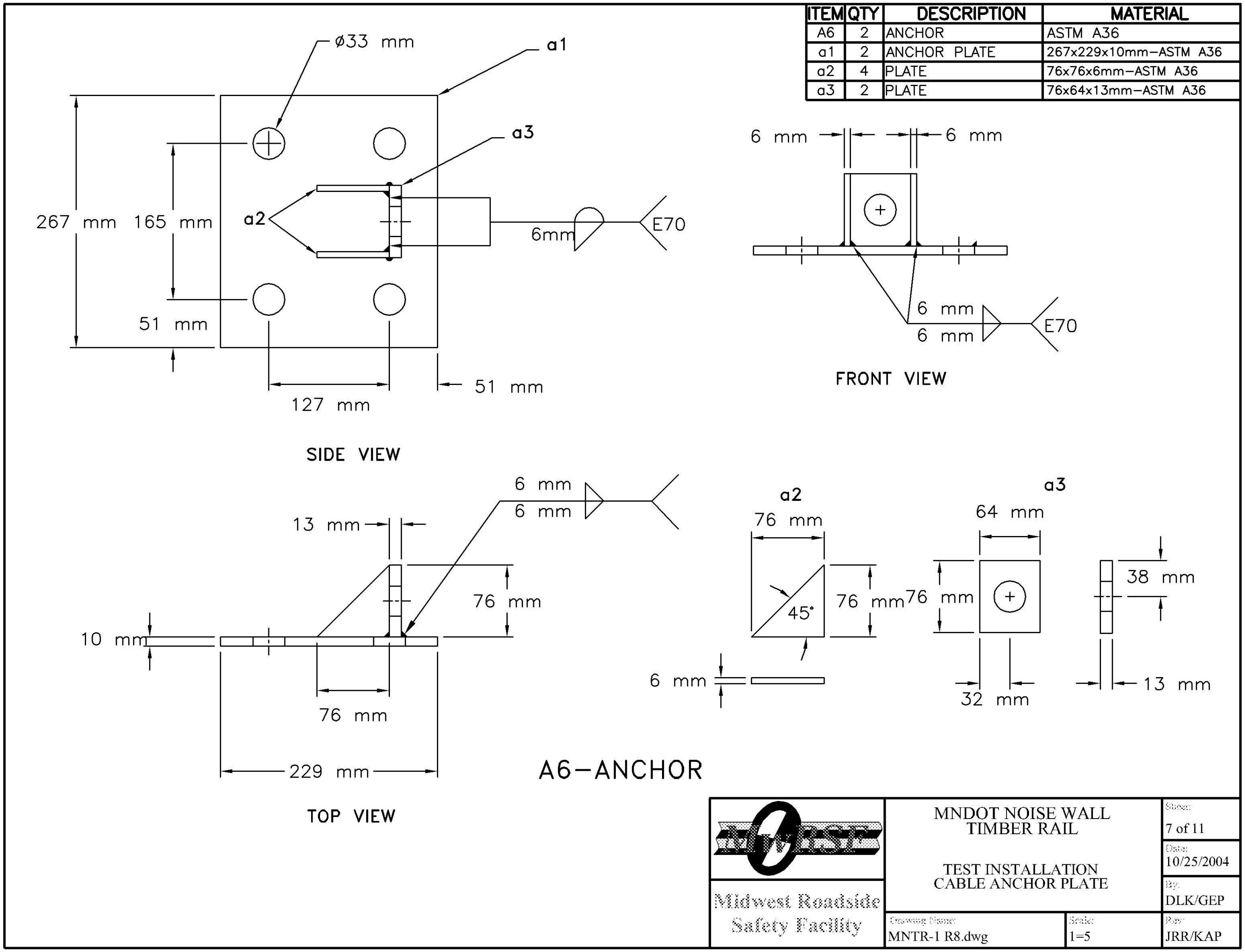


Figure 7. Mn/DOT's Timber Rub Rail Design Cable Anchor Plate Details

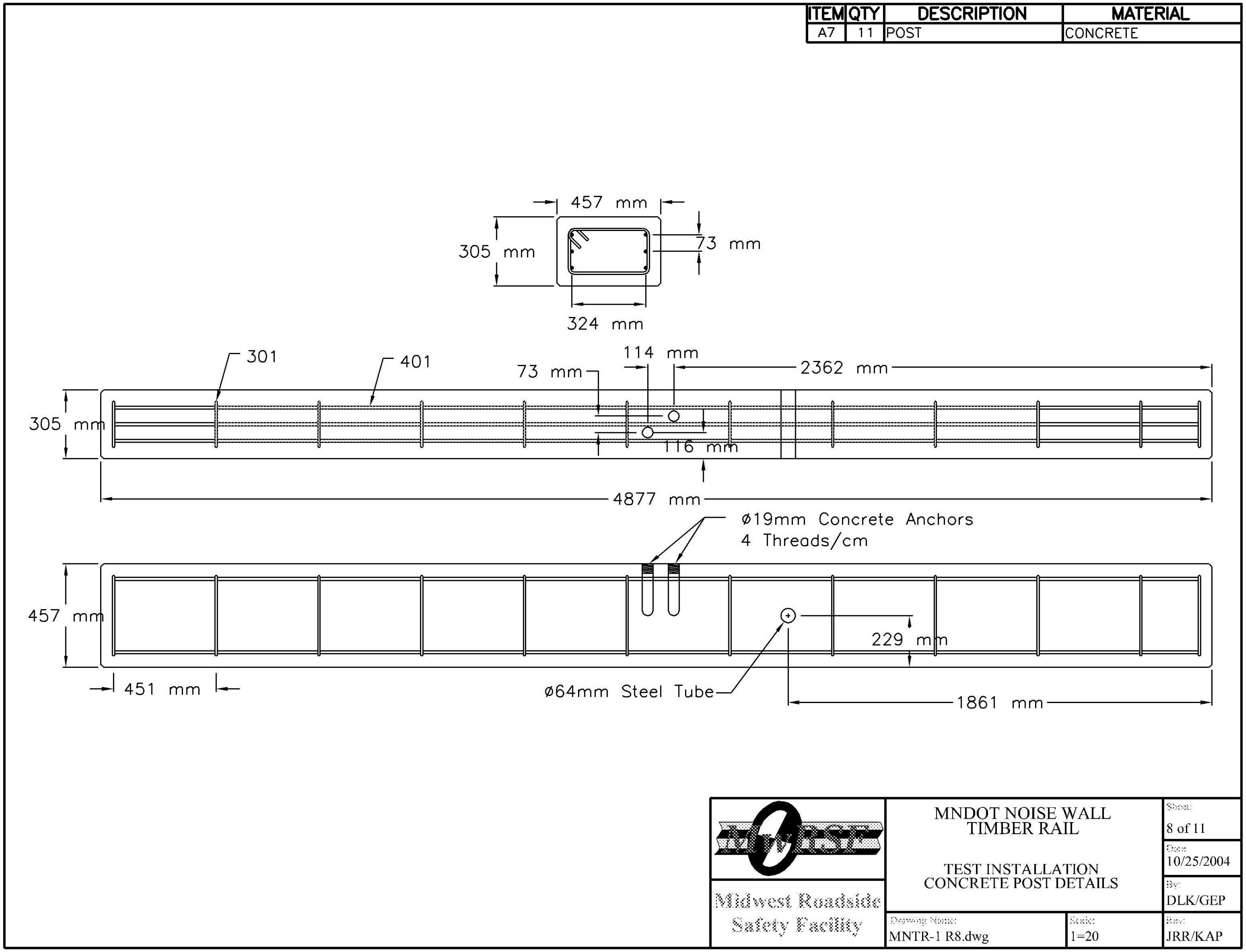
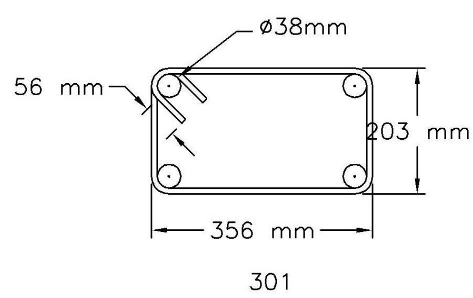
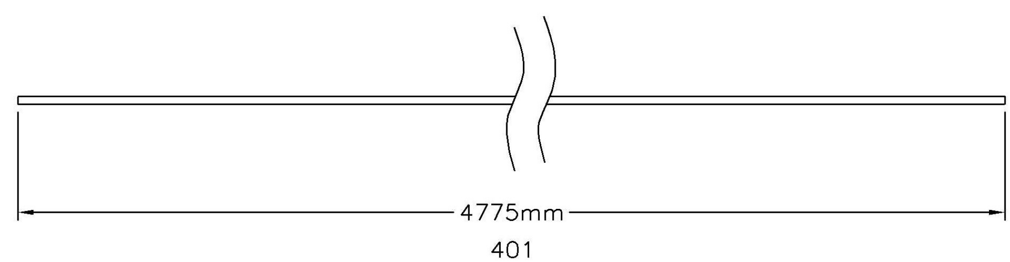


Figure 8. Mn/DOT's Timber Rub Rail Design Concrete Post Details



Shape	Bar Number	Quantity Per Post	Length
301	3	12	1270mm
401	4	6	4775mm



Midwest Roadside Safety Facility

MNDOT NOISE WALL
TIMBER RAIL

TEST INSTALLATION
BILL OF REINFORCING STEEL

Sheet: 9 of 11
Date: 10/25/2004
By: DLK/GEP
Drawing Name: MNTR-1 R8.dwg
Scale: 1=10
Rev: JRR/KAP

Figure 9. Mn/DOT's Timber Rub Rail Design Reinforcement Details

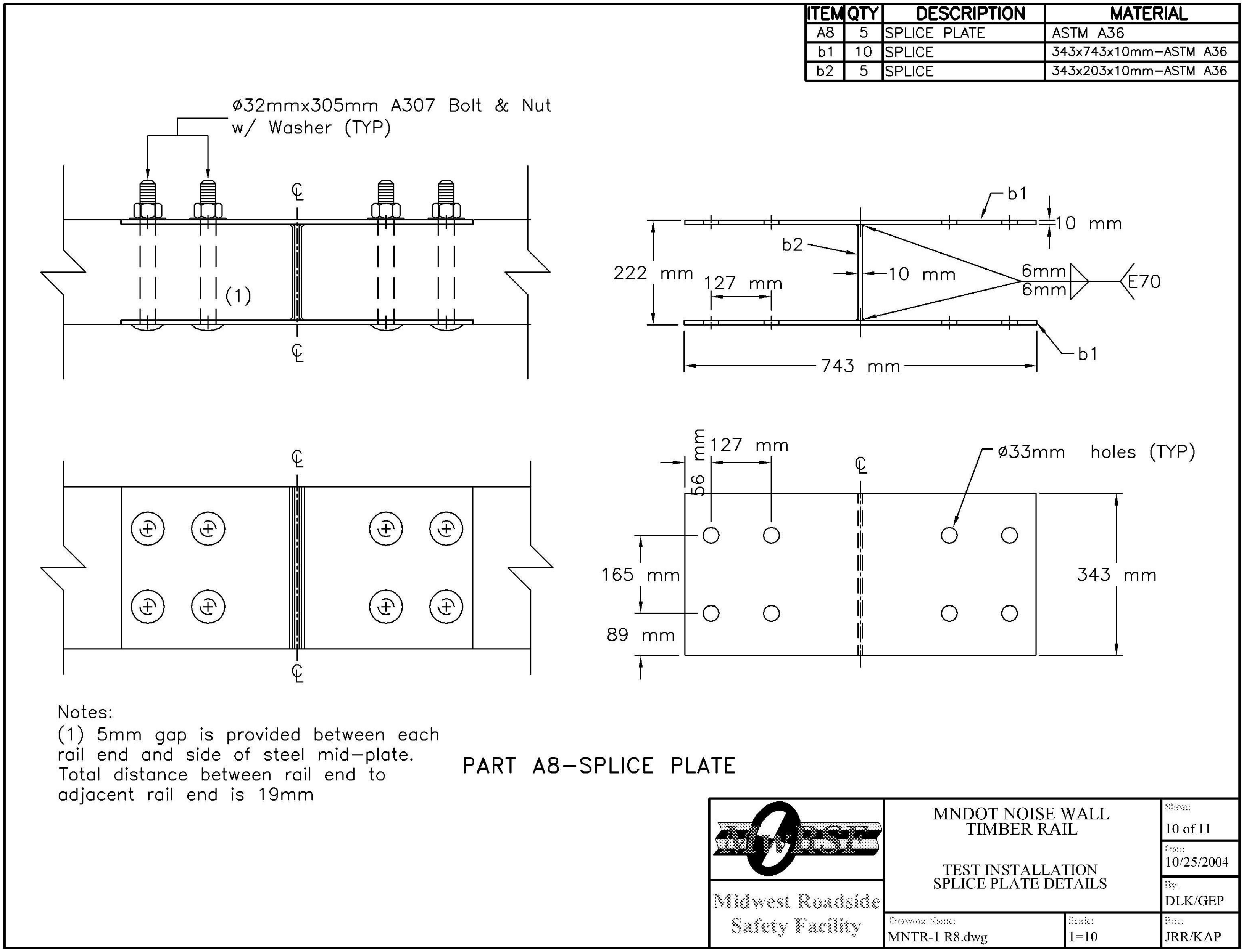


Figure 10. Mn/DOT's Timber Rub Rail Design Splice Plate Details

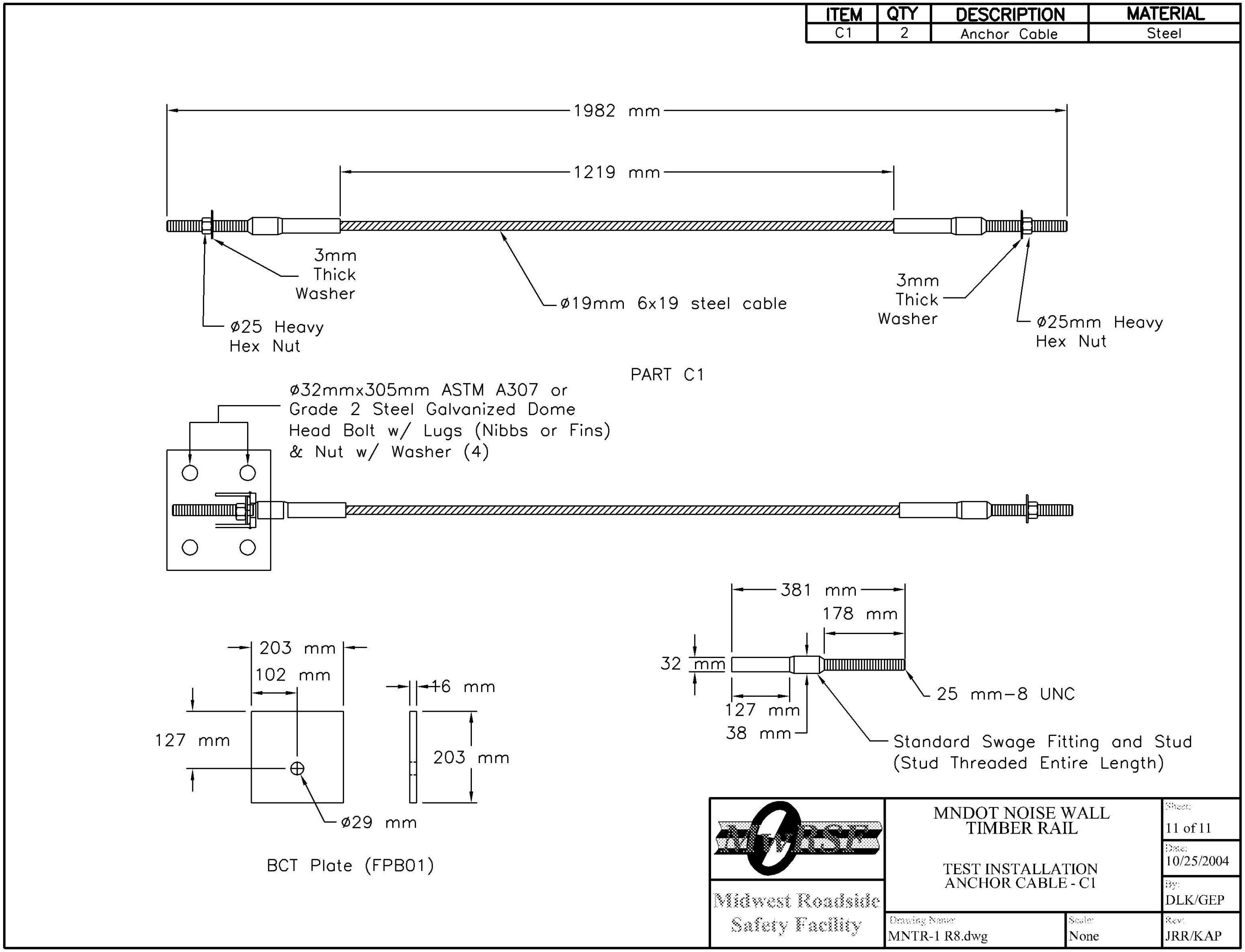


Figure 11. Mn/DOT's Timber Rub Rail Design Anchor Cable Details

Figure 12. Mn/DOT's Timber Rub Rail Design for Noise Barriers

Figure 13. Mn/DOT’s Timber Rub Rail for Noise Barriers

Figure 14. Mn/DOT’s Timber Rub Rail Design for Noise Barriers

Figure 15. Mn/DOT's Timber Rub Rail for Noise Barriers

Figure 16. Mn/DOT's Timber Rub Rail Design for Noise Barriers

Figure 17. Mn/DOT's Timber Rub Rail Design for Noise Barriers

4 TEST CONDITIONS

4.1 Test Facility

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

4.2 Vehicle Tow and Guidance System

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

A vehicle guidance system developed by Hinch (3) was used to steer the test vehicle. A guide-flag, attached to the front-right wheel and the guide cable, was sheared off before impact with the barrier system. The 9.5-mm (0.375-in.) diameter guide cable was tensioned to approximately 15.6 kN (3,500 lbf), and supported laterally and vertically every 30.48 m (100 ft) by hinged stanchions. The hinged stanchions stood upright while holding up the guide cable, but as the vehicle was towed down the line, the guide-flag struck and knocked each stanchion to the ground. For test MNTR-1, the vehicle guidance system was 305-m (1,000-ft) long.

4.3 Test Vehicles

For test MNTR-1, a 1999 GMC 2500 ¾-ton pickup truck was used as the test vehicle. The test inertial and gross static weights were 1,989 kg (4,386 lbs). The test vehicle is shown in Figure 18, and vehicle dimensions are shown in Figure 19.

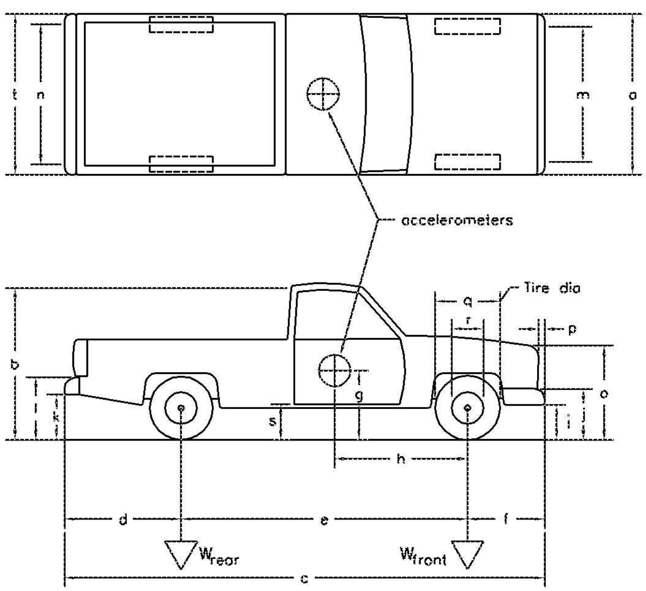
Figure 18. Test Vehicle, Test MNTR-1

Date: 7/16/04 Test Number: MNTR-1 Model: 2000P

Make: GMC Vehicle I.D.#: 1GDGC24R6XF085889

Tire Size: LT245/75/R16 Year: 1999 Odometer: 218664

*(All Measurements Refer to Impacting Side)



Vehicle Geometry – mm (in.)

a	1880 (74.0)	b	1835 (72.25)
c	5537 (218.0)	d	1283 (50.5)
e	3334 (131.25)	f	921 (36.25)
g	667 (26.25)	h	1413 (55.625)
i	470 (18.5)	j	679 (26.75)
k	597 (23.5)	l	775 (30.5)
m	1588 (62.5)	n	1626 (64.0)
o	1041 (41.0)	p	89 (3.5)
q	756 (29.75)	r	445 (17.5)
s	502 (19.75)	t	1829 (72.0)

Wheel Center Height Front 368 (14.5)

Wheel Center Height Rear 371 (14.625)

Wheel Well Clearance (FR) 918 (36.125)

Wheel Well Clearance (RR) 959 (37.75)

Frame Height (FR) 419 (16.5)

Frame Height (RR) 683 (26.875)

Engine Type 8 CYL. GAS

Engine Size 5.7 L 350 CID

Transmission Type:

(Automatic) or Manual

FWD or (RWD) or 4WD

Weights kg (lbs)	Curb	Test Inertial	Gross Static
W_{front}	1139 (2511)	1146 (2527)	1146 (2527)
W_{rear}	842 (1856)	843 (1859)	843 (1859)
W_{total}	1987 (4367)	1989 (4386)	1989 (4386)

Note any damage prior to test: None

Figure 19. Vehicle Dimensions, Test MNTR-1

The longitudinal component of the center of gravity was determined using the measured axle weights. The location of the final centers of gravity are shown in Figures 18 and 19.

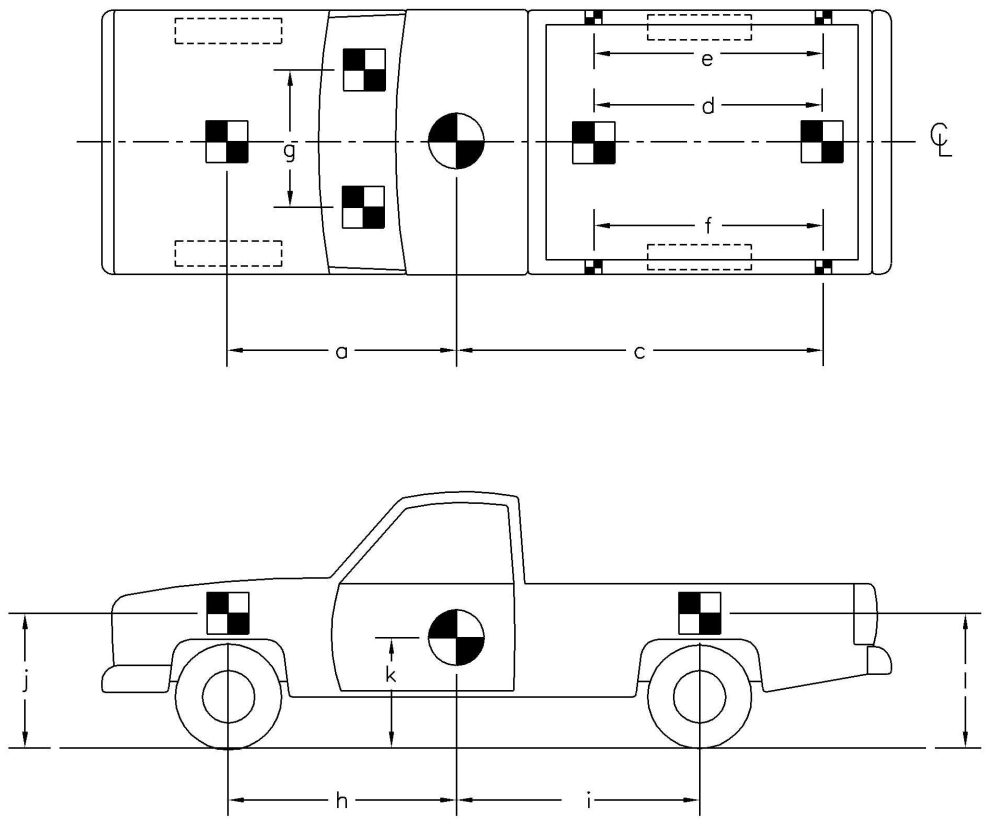
Square black and white-checkered targets were placed on the vehicle to aid in the analysis of the high-speed film and E/cam and Photron video, as shown in Figure 20. Round, checkered targets were placed on the center of gravity, on the driver's side door, on the passenger's side door, and on the roof of the vehicle. The remaining targets were located for reference so that they could be viewed from the high-speed cameras for film analysis.

The front wheels of the test vehicle were aligned for camber, caster, and toe-in values of zero so that the vehicle would track properly along the guide cable. Two 5B flash bulbs were mounted on both the hood and roof of the vehicle to pinpoint the time of impact with the barrier on the high-speed film, E/cam video, and Photron video. The flash bulbs were fired by a pressure tape switch mounted on the front face of the bumper. A remote-controlled brake system was installed in the test vehicle so the vehicle could be brought safely to a stop after the test.

4.4 Data Acquisition Systems

4.4.1 Accelerometers

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



TEST #: MNTR-1

TARGET GEOMETRY -- mm (in.)

a 1645 (64.75)	d 1867 (73.5)	g 972 (38.25)	j 1019 (40.125)
b –	e 2153 (84.75)	h 1413 (55.625)	k 667 (26.25)
c 2692 (106)	f 2153 (84.75)	i 1921 (75.625)	l 1057 (41.625)

Figure 20. Vehicle Target Locations, Test MNTR-1

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

4.4.2 Rate Transducers

A Humphrey 3-axis rate transducer with a range of 360 deg/sec in each of the three directions (pitch, roll, and yaw) was used to measure the rates of motion of the test vehicle. The rate transducer was rigidly attached to the vehicle near the center of gravity of the test vehicle. Rate transducer signals, excited by a 28-volt DC power source, were received through the three single-ended channels located externally on the EDR-4M6 and stored in the internal memory. The raw data measurements were then downloaded for analysis and plotted. Computer software, "DynaMax 1 (DM-1)" and "DADiSP", was used to analyze and plot the rate transducer data.

4.4.3 High-Speed Photography

For test MNTR-1, one high-speed 16-mm Red Lake Locam camera, with operating speed of approximately 500 frames/sec, was used to film the crash test. Two Photron high-speed video camera and four high-speed Red Lake E/cam video cameras, all with operating speeds of 500 frames/sec, were also used to film the crash test. Six Canon digital video cameras, with a standard operating speed of 29.97 frames/sec, were also used to film the crash test. A Locam (with a wide-angle 12.5-mm lens), a high-speed Photron video camera (with a 12.5-mm lens), and one Canon digital video camera were placed above the test installation to provide a field of view perpendicular to the ground. A high-speed E/cam video camera, a Canon digital video camera, and a Nikon digital 35-mm camera were placed downstream from the impact point and had a field of view parallel to the barrier. A high-speed E/cam video camera was placed downstream from the impact point and behind the barrier. A high-speed E/cam video camera and a Canon digital video camera were placed upstream from the impact point and had a field of view parallel to the barrier. A high-speed E/cam video camera and a Canon digital video camera was placed upstream from the point of impact and behind the barrier. A high-speed Photron video camera was placed upstream from the point of impact and behind the barrier. A Cannon digital video camera was placed on upstream from the point of impact and behind the barrier and was focus on the upstream cable anchor. A Canon digital video camera, with a panning view, was placed on the traffic side of the barrier and had a field of view perpendicular to the barrier. A schematic of all fourteen camera locations for test MNTR-1 is shown in Figure 21. The Locam films, Photron videos, and E/cam videos were analyzed using the Vanguard Motion Analyzer, ImageExpress MotionPlus software, and Redlake Motion Scope software, respectively. Actual camera speed and camera divergence factors were considered in the analysis of the high-speed film.

4.4.4 Pressure Tape Switches

For test MNTR-1, five pressure-activated tape switches, spaced at 2-m (6.56-ft) intervals, were used to determine the speed of the vehicle before impact. Each tape switch fired a strobe light which sent an electronic timing signal to the data acquisition system as the right-front tire of the test vehicle passed over it. Test vehicle speed was determined from electronic timing mark data recorded using the "Test Point" software. Strobe lights and high-speed film analysis are used only as a backup in the event that vehicle speed cannot be determined from the electronic data.

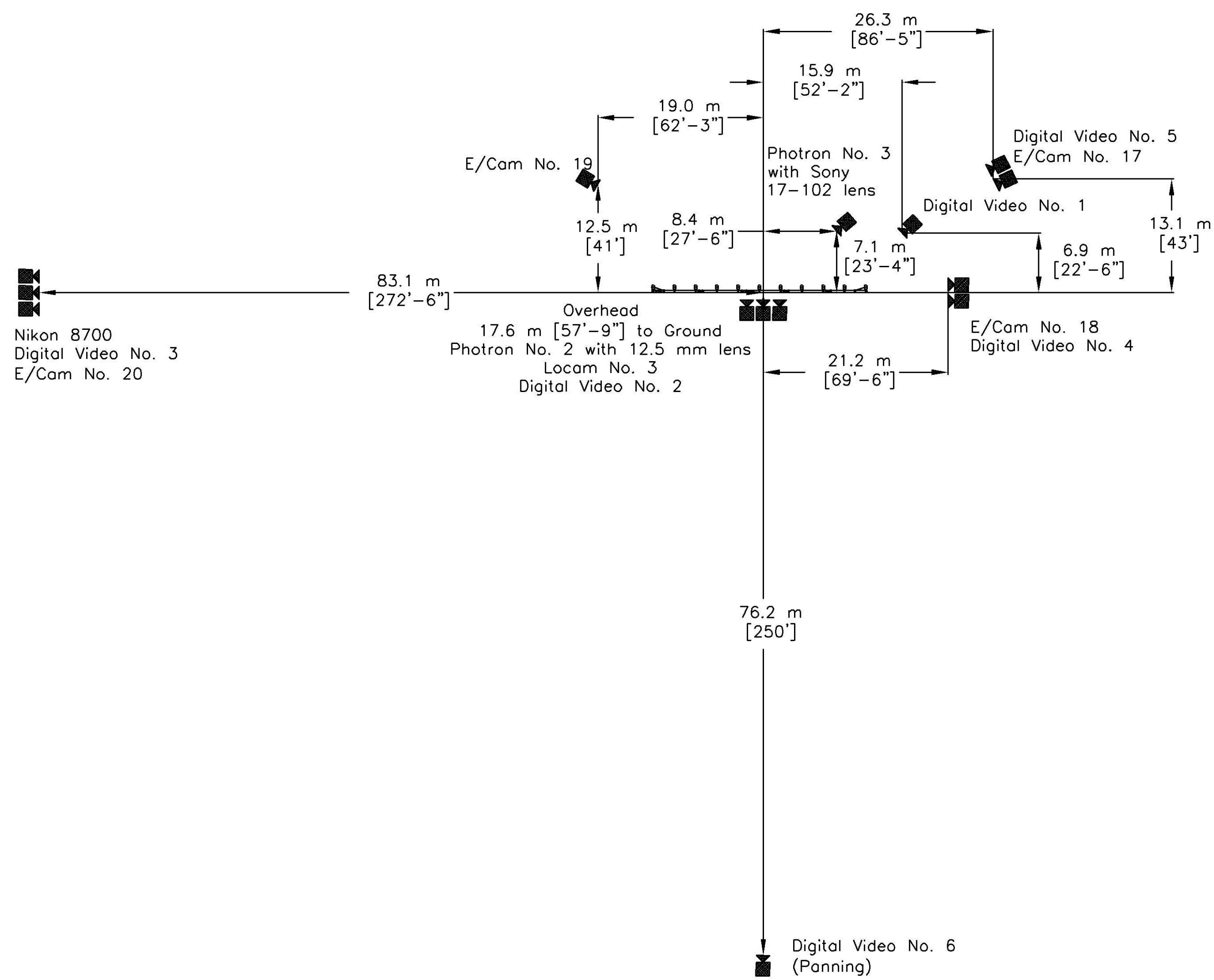


Figure 21. Location of High-Speed Cameras, Test MNTR-1

5 CRASH TEST NO. 1

5.1 Test MNTR-1

The 1,989-kg (4,386-lb) pickup truck impacted the timber rub rail for noise barriers at a speed of 99.4 km/h (61.8 mph) and at an angle of 25.3 degrees. A summary of the test results and sequential photographs are shown in Figure 22. The summary of the test results and sequential photographs in English units are shown in Appendix B. Additional sequential photographs are shown in Figures 23 through 27. Documentary photographs of the crash test are shown in Figures 28 and 29.

5.2 Test Description

Initial vehicle impact was to occur 305-mm (12-in.) upstream from the centerline of post no. 6 in order to generate a critical impact for the splice in the next span (i.e., ¾-point) and also a potential for engine hood snag on the upstream side of post no. 7, as shown in Figure 30. Actual vehicle impact occurred 254-mm (10-in.) upstream from the centerline of post no. 6. At 0.014 sec after initial impact, the right-front corner of the vehicle crushed inward as the right-front tire contacted the rail. At 0.034 sec, the right-front corner of the hood protruded over the timber rail. At 0.054 sec, post no. 6 deflected backward and soil movement occurred. At this same time, the right-front quarter panel of the vehicle was in contact with the timber rail, and the hood continued to protrude over the rail. At 0.062 sec, sheet metal rippling was visible on the right-side door. At 0.074 sec, the right-side door was ajar, and visible gaps formed between the hood and the front quarter panels. At this same time, post no. 6 continued to deflect, and post no. 7 began to deflect backward. It appears that the vehicle began to redirect about this same time. Also around this time, the rail splice deflected toward the back side of the system. At 0.098 sec, the right-front corner of the vehicle contacted post no. 7. At 0.118 sec, the vehicle remained in contact with post no. 7 and the right-front corner of the hood was deformed under and inward. At 0.138 sec, the hood rotated clockwise (CW) toward the right side of the vehicle as the gap between the left-side quarter panel and hood increased. At this same time, extensive damage to the lower portion of the right-side door had occurred, and the vehicle rolled slightly toward the system. At 0.158 sec, the right-front corner of the vehicle was no longer in contact with post no. 7. At 0.168 sec, the rear of the vehicle pitched upward, and the right-rear tire became airborne. At 0.176 sec, both left-side tires were airborne. At 0.198 sec, the vehicle continued to be redirected while the right side of the vehicle's cab was in contact with the timber rail. At this same time, the grill disengaged from the vehicle, and lines appeared across the windshield, potentially the result of hood contact with the windshield. Also at this same time, post nos. 6 and 7 rebounded back toward the traffic side of the barrier. At 0.236 sec, the hood continued to deflect upward as the front latch fractured. At 0.254 sec, the entire right side of the vehicle was in contact with the timber rail with the right-front corner located near post no. 8. At 0.272 sec, the right-rear tire contacted the rail splice between post nos. 6 and 7. At 0.292 sec, the right-rear tire moved up the rail and was positioned with approximately half of it above the rail. At this same time, the left-front tire contacted the ground. At 0.328 sec after impact, the vehicle became parallel to the barrier with a resultant velocity of 54.4 km/h (33.8 mph). At 0.352 sec, the rear of the vehicle continued to pitched upward. At 0.430 sec, the vehicle exited the barrier at an angle of 4.1 degrees and a resultant velocity of 57.4 km/h (35.7 mph). At 0.466 sec, the rear of the vehicle pitched upward significantly. At 0.516 sec, the pitch of the vehicle was so significant that the front bumper almost contacted the ground. At 0.716 sec, the vehicle began to be redirected back toward the system. By 0.990 sec after impact, both rear tires had regained contact with the ground. The vehicle came to rest 39.75 m (130 ft - 5 in.) downstream from impact and 1.47 m (4 ft - 10 in.) laterally behind a line projected parallel to the traffic-side face of the timber rub rail. The trajectory and final position of the pickup truck are shown in Figures 22 and 31.

5.3 Barrier Damage

Damage to the timber rub rail for noise barriers was minimal, as shown in Figures 32 through 39. Barrier damage consisted of contact and gouge marks on a timber rail section, contact marks on posts, a damaged wooden blockout, and deformed bolts. The length of vehicle contact along the timber rub rail was approximately 5 m (16.5 ft), which spanned from 254 mm (10 in.) upstream from the centerline of post no. 6 through the upstream edge of post no. 8.

Significant gouging occurred to the top and front faces of the timber rail between post nos. 6 and 8. Contact marks were also found on the top and front faces of the timber rail between post nos. 6 and 8. Black contact marks and scratches were found on the splice plate between post nos. 6 and 7 and bolts within this splice. No significant timber rail damage occurred upstream of post no. 6 nor downstream of post no. 9.

A 64 mm x 114 mm (2.5 in. x 4.5 in.) gouge was found on the front-downstream corner of post no. 7. A vertical contact mark, 133-mm wide x 343-mm long (5.25-in. x 13.5-in.), was found on the upstream-side face of post no. 7. Another vertical contact mark, 38-mm wide x 152-mm long (1.5-in. x 6-in.), was found on the upstream-side face of post no. 7. A 13-mm wide x 216-mm long (0.5-in. x 8.5-in.) contact mark was found across the front face of post no. 7. Another contact mark, 13-mm wide x 305-mm long (0.5-in. x 12-in.), was found across the front face of post no. 7. A third contact mark, 38-mm wide x 305-mm long (1.5-in. x 12-in.), was found across the front face of post no. 7. A 152-mm (6-in.) long contact mark was found across the front face of post no. 8. Contact marks and scrape marks were also found on the blockout at post no. 7. The post bolt heads at post nos. 6 and 7 were bent toward the downstream end of the system, thus protruding away from the rail approximately 19 mm (0.75 in.), as shown in Figures 35 and 37. All four of these bolts also encountered black tire contact marks and scrape marks.

The permanent set of the timber rub rail and concrete posts was visible between post nos. 6 and 9 as shown in Figures 32, 38, and 39. The maximum lateral permanent set rail and post deflections were approximately 55 mm (2.2 in.) at the centerline of the top of the timber rail at post no. 7 and 121 mm (4.75 in.) at the centerline of the top of post no. 7, respectively, as determined from high-speed digital video analysis. The maximum lateral dynamic rail and post deflections were 92 mm (3.6 in.) at the rail midspan between post nos. 6 and 7 (top of timber rail) and 301 mm (11.85 in.) at the centerline of the top of post no. 7, respectively, as determined from high-speed digital video analysis. The working width of the system was found to be 1,133 mm (44.6 in.).

5.4 Vehicle Damage

Exterior vehicle damage was moderate, as shown in Figures 40 through 45. Occupant compartment deformations to the right side and center of the floorboard, as shown in Figure 45, were judged insufficient to cause serious injury to the vehicle occupants. Maximum longitudinal deflections of 89 mm (3 ½ in.) were located near the left-front corner of the right-side floor pan. Maximum lateral deflections of 159 mm (6 ¼ in.) and 190.5 mm (7 ½ in.) were located near the right-front corner and front-center of the right-side floor pan, respectively. Maximum vertical deflections of 95 mm (3 ¾ in.) were located near the right-front corner and left-front corner of the right-side floor pan. Complete occupant compartment deformations and the corresponding locations are provided in Appendix C.

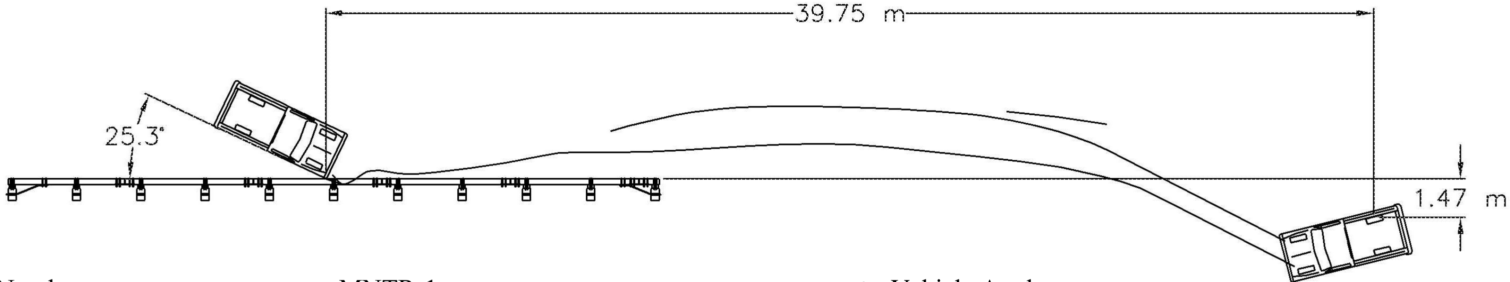
Damage was concentrated on the right-front corner of the vehicle. The right-front quarter panel was crushed inward and downward. The left-front quarter panel was dented near the front of the left-side door. The right side of the front bumper was flattened and bent back toward the engine compartment. The right-rear fender was deformed upward behind the wheel well. The box encountered numerous dents along the entire right side. The cab portion of the vehicle was shifted to the left. Rubber contact marks were found on the left rear of the truck box. Severe sheet metal tearing was found on the lower portion of the right-side door. The lower rear of the right-side door encountered dents. The top of the left door was ajar. The hood was buckled and jarred open. The grill was fractured and completely disengaged from the rest of the vehicle. Both the right-side and left-side headlights were fractured. The right-front wheel assembly deformed and crushed inward toward the engine compartment with severe frame damage occurring at the right-front wheel assembly. The right side of the frame was bent and deformed, and a buckle point was found on the lower flange at the center of the right-side door. A tear was found in the frame at the right-front spring attachment. The right-side tie rod and control arm were bent. The right-front suspension sustained severe damage and included the fracturing of the bolt at the frame-suspension attachment. The right-front and right-rear steel rims were deformed and dented. The both the right-front and right-rear tires' seals were broken, and the tires deflated. The drive shaft fractured. The right side of the roof buckled. The windshield encountered severe cracking on the right side, while the left side only sustained minor cracking. The rear of the vehicle and all window glass except for the windshield remained undamaged.

5.5 Occupant Risk Values

The longitudinal and lateral occupant impact velocities were determined to be 8.97 m/sec (29.42 ft/sec) and 6.81 m/sec (22.33 ft/sec), respectively. The maximum 0.010-sec average occupant ridedown decelerations in the longitudinal and lateral directions were 8.45 g's and 9.76 g's, respectively. It is noted that the occupant impact velocities (OIV's) and occupant ridedown decelerations (ORD's) were within the suggested limits provided in NCHRP Report No. 350. The results of the occupant risk, as determined from the accelerometer data, are summarized in Figure 22. Results are shown graphically in Appendix D. Roll and yaw data were collected from film analysis and are shown graphically in Appendix D.

5.6 Discussion

The analysis of the test results for test no. MNTR-1 showed that the timber rub rail for noise barriers adequately contained and redirected the vehicle with controlled lateral displacements of the rub rail system. There were no detached elements nor fragments which showed potential for penetrating the occupant compartment nor presented undue hazard to other traffic. Deformations of, or intrusion into, the occupant compartment that could have caused serious injury did not occur. The test vehicle did not penetrate nor ride over the rub rail system and remained upright during and after the collision. Vehicle roll, pitch, and yaw angular displacements were noted, but they were deemed acceptable because they did not adversely influence occupant risk safety criteria nor cause rollover. After collision, the vehicle's trajectory did not intrude into adjacent traffic lanes. In addition, the vehicle's exit angle was less than 60 percent of the impact angle. Therefore, test no. MNTR-1 conducted on the timber rub rail for noise barriers was determined to be acceptable according to the TL-3 safety performance criteria found in NCHRP Report No. 350.



- Test Number MNTR-1
- Date 7/16/04
- Appurtenance . . . . Minnesota's Timber Rub Rail for Noise Barriers
- Total Length . . . . 24.86 m
- Glulam Wood Rail
  - Material . . . . Southern Pine, Combination No. 48
  - Dimensions . . . . 343 mm x 222 mm by 24.86 m long
  - Top Mounting Height . . . . 762 mm
- Post Nos. 1-11
  - Material . . . . Concrete
  - Dimensions . . . . 305 mm x 457 mm by 4,877 mm long
  - Embedment Depth . . . . 1,829 mm
  - Spacing . . . . 2,438 mm
- Wood Spacer Blocks Nos. 1-11
  - Material . . . . Southern Pine, Combination No. 48
  - Dimensions . . . . 229 mm x 152 mm by 343 mm long
- Vehicle Model . . . . 1999 GMC 2500 ¾-ton pickup
  - Curb . . . . 1,981 kg
  - Test Inertial . . . . 1,989 kg
  - Gross Static . . . . 1,989 kg
- Vehicle Speed
  - Impact . . . . 99.4 km/h
  - Exit . . . . 57.4 km/h
- Vehicle Angle
  - Impact . . . . 25.3 deg
  - Exit . . . . 4.1 deg
- Vehicle Snagging . . . . Minor
- Vehicle Pocketing . . . . None
- Vehicle Stability . . . . Satisfactory
- Occupant Ridedown Deceleration (10 msec avg.)
  - Longitudinal . . . . 8.45 g's < 20 g's
  - Lateral (not required) . . . . 9.76 g's
- Occupant Impact Velocity
  - Longitudinal . . . . 8.97 m/s < 12 m/s
  - Lateral (not required) . . . . 6.81 m/s
- PHD . . . . 10.27 g's
- THIV . . . . 11.59 m/s
- Vehicle Damage . . . . Moderate
  - TAD[4] 1-RFQ-6
  - SAE[5] 1-FZEW5
- Vehicle Stopping Distance . . . . 39.75 m downstream
  1.47 m laterally behind
- Barrier Damage . . . . Minimal
- Maximum Rail Deflections
  - Permanent Set . . . . 55 mm
  - Dynamic . . . . 92 mm
- Working Width . . . . 1,133 mm

Figure 22. Summary of Test Results and Sequential Photographs, Test MNTR-1

0.000 sec

0.086 sec

0.176 sec

0.276 sec

0.416 sec

0.566 sec

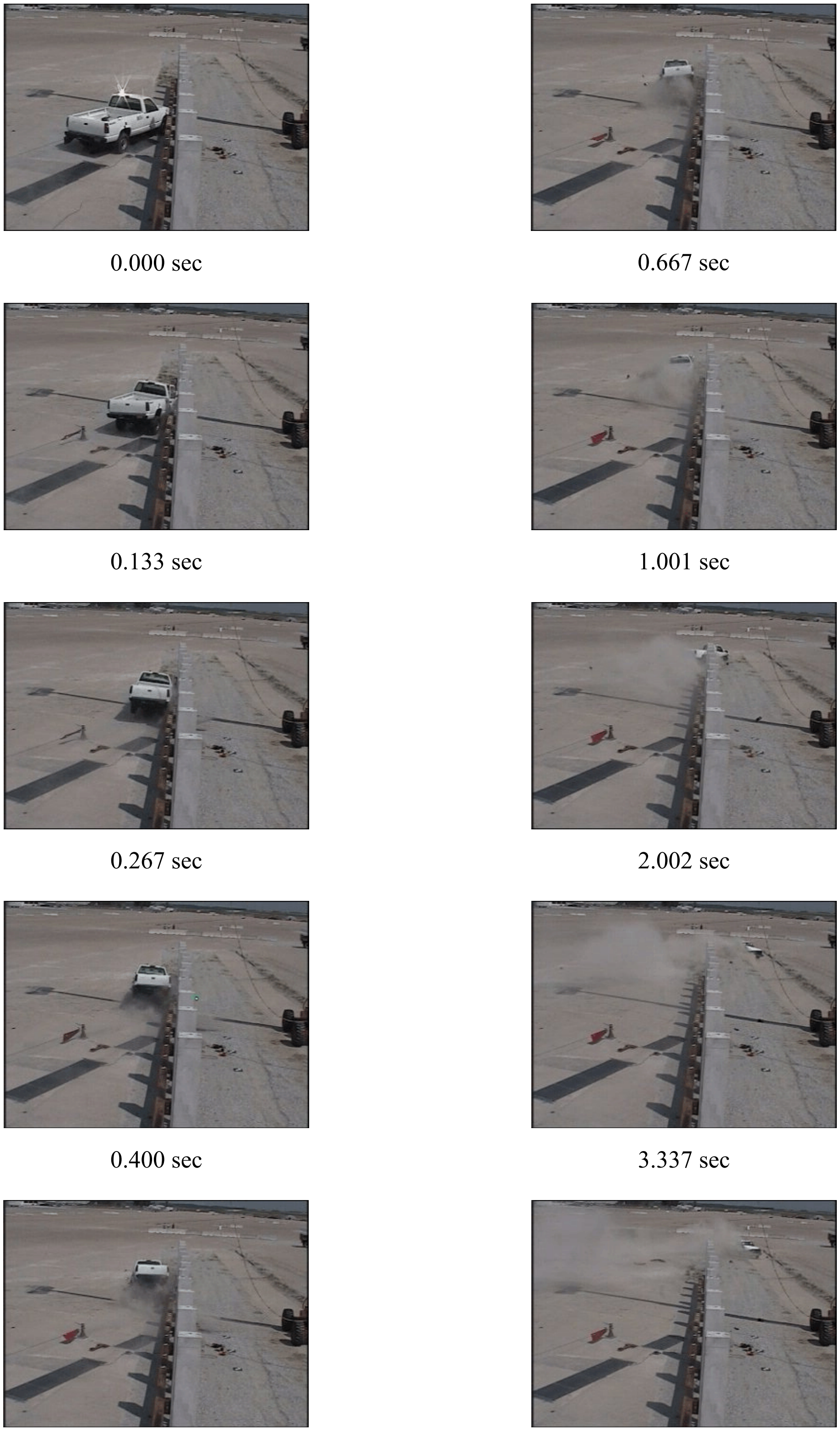
0.816 sec

1.216 sec

1.616 sec

2.016 sec

Figure 23. Additional Sequential Photographs, Test MNTR-1



0.000 sec

0.133 sec

0.267 sec

0.400 sec

0.534 sec

0.667 sec

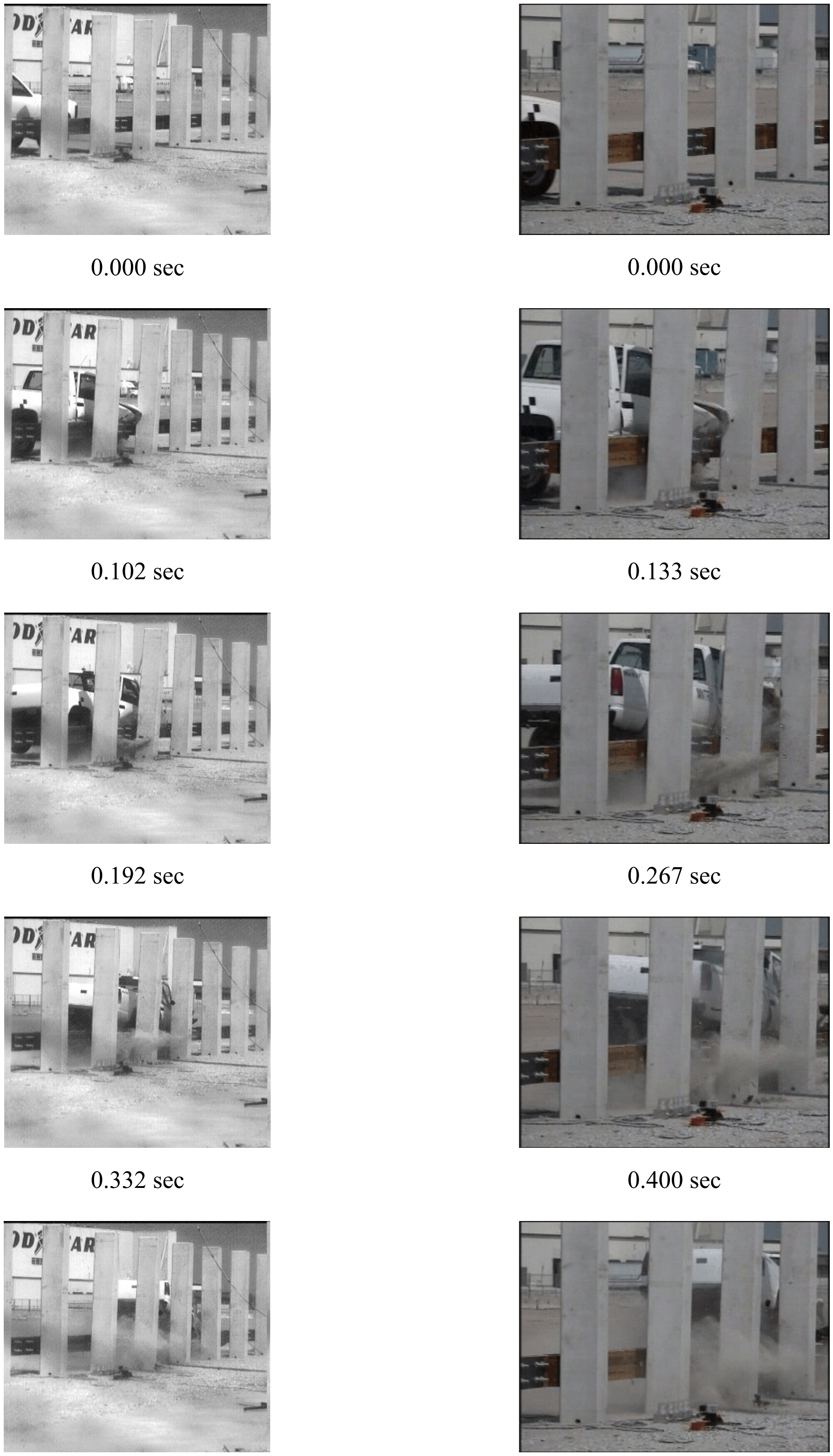
1.001 sec

2.002 sec

3.337 sec

5.005 sec

Figure 24. Additional Sequential Photographs, Test MNTR-1



0.000 sec | 0.000 sec
0.102 sec | 0.133 sec
0.192 sec | 0.267 sec
0.332 sec | 0.400 sec
0.542 sec | 0.534 sec

Figure 25. Additional Sequential Photographs, Test MNTR-1

0.000 sec

0.000 sec

0.054 sec

0.060 sec

0.104 sec

0.094 sec

0.205 sec

0.108 sec

0.274 sec

0.148 sec

0.394 sec

0.172 sec

Figure 26. Additional Sequential Photographs, Test MNTR-1

0.000 sec

0.133 sec

0.234 sec

0.434 sec

0.667 sec

0.934 sec

1.268 sec

1.768 sec

Figure 27. Additional Sequential Photographs, Test MNTR-1

Figure 28. Documentary Photographs, Test MNTR-1

Figure 29. Documentary Photographs, Test MNTR-1

Figure 30. Impact Location, Test MNTR-1

Figure 31. Vehicle Final Position, Test MNTR-1

Figure 32. System Damage, Test MNTR-1

Figure 33. System Damage, Test MNTR-1

Figure 34. System Damage, Test MNTR-1

Figure 35. System Damage at Post No. 6, Test MNTR-1

Figure 36. System Damage Between Post Nos. 6 and 7, Test MNTR-1

Figure 37. Traffic-side Face System Damage between Post Nos. 6 and 7, Test MNTR-1

Figure 38. Post Damage and Movement at Post Nos. 6 through 8, Test MNTR-1

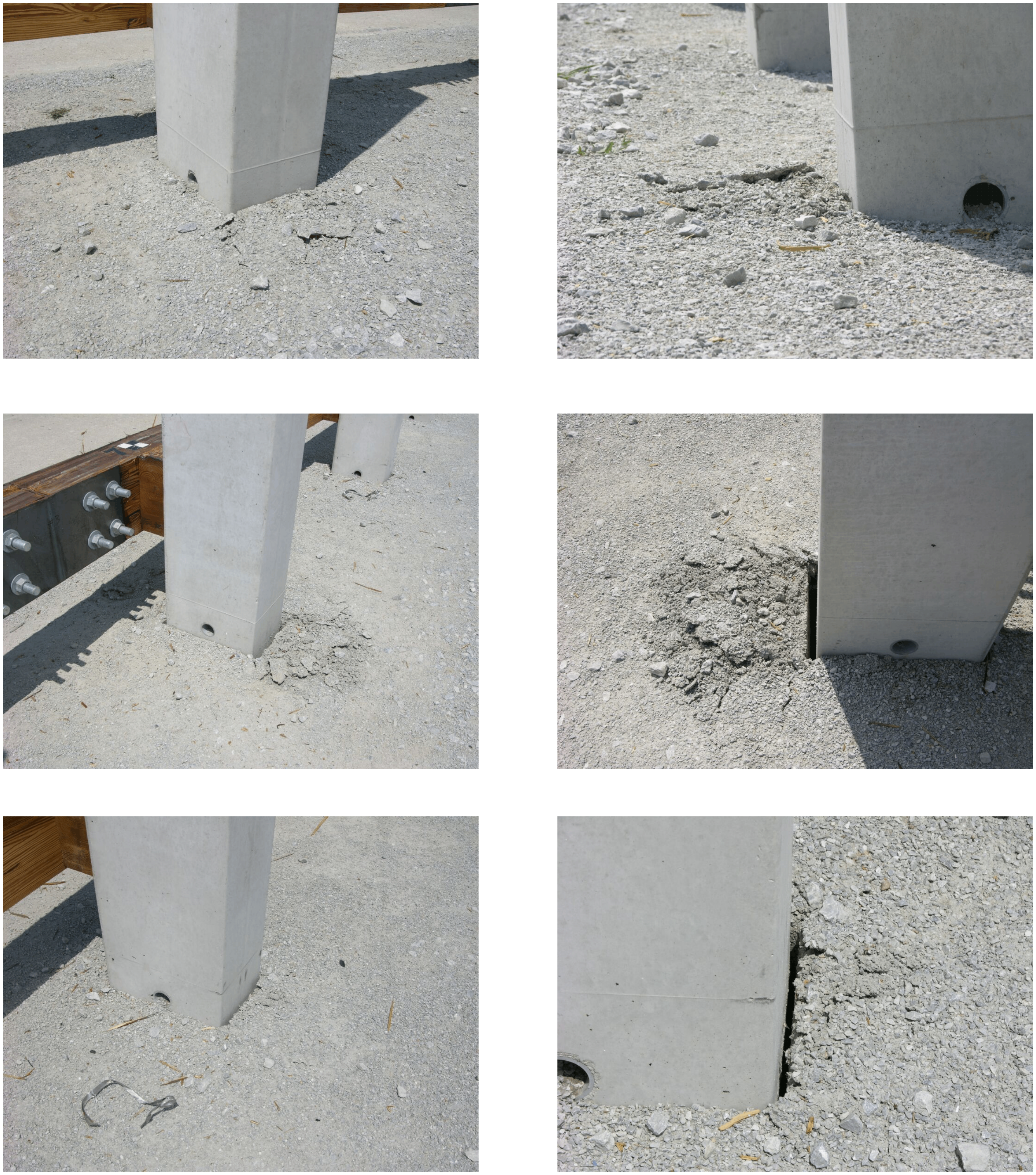


Figure 39. Soil Failure at Post Nos. 6 through 8, Test MNTR-1

Figure 40. Vehicle Damage, Test MNTR-1

Figure 41. Vehicle Damage, Test MNTR-1

Figure 42. Vehicle Damage, Test MNTR-1

Figure 43. Vehicle Windshield Damage, Test MNTR-1

Figure 44. Vehicle Undercarriage Damage, Test MNTR-1

Figure 45. Occupant Compartment Damage, Test MNTR-1

6 SUMMARY AND CONCLUSIONS

A timber rub rail for use with noise barriers was designed, constructed, and full-scale vehicle crash tested. A full-scale vehicle crash test was performed with a ¾-ton pickup on the timber rub rail system and was determined to be acceptable according to the TL-3 safety performance criteria presented in NCHRP Report No. 350. The rub rail system safely redirected the pickup truck with minimal barrier deflections. A summary of the safety performance evaluation is provided in Table 3.

Table 3. Summary of Safety Performance Evaluation Results

Evaluation Factors	Evaluation Criteria		Test MNTR-1
Structural Adequacy	A.	Test article should contain and redirect the vehicle; the vehicle should not penetrate, underride, or override the installation although controlled lateral deflections of the test article is acceptable.	S
Occupant Risk	D.	Detached elements, fragments or other debris from the test article should not penetrate or show potential for penetrating the occupant compartment, or present an undue hazard to other traffic, pedestrians, or personnel in a work zone. Deformations of, or intrusions into, the occupant compartment that could cause serious injuries should not be permitted.	S
	F.	The vehicle should remain upright during and after collision although moderate roll, pitching, and yawing are acceptable.	S
Vehicle Trajectory	K.	After collision it is preferable that the vehicle's trajectory not intrude into adjacent traffic lanes.	S
	L.	The occupant impact velocity in the longitudinal direction should not exceed 12 m/sec (39.37 ft/sec), and the occupant ridedown acceleration in the longitudinal direction should not exceed 20 G's.	S
	M.	The exit angle from the test article preferably should be less than 60 percent of test impact angle measured at time of vehicle loss of contact with test device.	S

S - Satisfactory
M - Marginal
U - Unsatisfactory
NA - Not Available

7 RECOMMENDATIONS

A timber rub rail for noise barriers, as described in this report, was designed and successfully crash tested according to the TL-3 criteria found in NCHRP Report No. 350. The results of this test indicate that this design is a suitable design for use on Federal-aid highways. However, any design modifications made to the barrier system can only be verified through the use of full-scale crash testing.

Following a review of the test results, it was apparent that improved barrier performance could be achieved through the use of several minor design changes. These individual design changes are discussed below.

It is suggested that a through-bolt design, in lieu of the current threaded insert design, be utilized for attaching the glulam timber rail to the front face of the concrete support posts. With this change, multiple benefits likely would be observed. First, a through-bolt design would allow for a nut and washer combination to be placed on the end of the dome head bolt (i.e., on the back side of the post), thus providing increased constructability as well as a greater potential for tightening each bolt. Increased bolt tightening would also allow the dome head to be pulled farther into the outer surface of the wood rail, thus largely eliminating the exposed edge of the dome head as well as eliminating any propensity for vehicle snag. If a through-bolt design is utilized, lugs should be incorporated into the underside of the dome head bolt. In addition, pre-positioned conduit or thin-walled tubes would allow for easy installation of the through holes in the concrete posts.

Other alternatives exist for reducing vehicle snag on the edge of the dome head bolts that are used to attach the timber rail to the posts. One option would be to countersink a 3.2 to 4.8 mm (1/8 to 3/16 in.) hole in the rail for the dome bolt head so that the bolt head's outer edge would be less likely to snag a vehicle's door or steel rim. Currently, slotted holes have also been placed in the timber rail at post locations in order to improve constructability when posts are not exactly spaced on 2.44-m (8-ft) centers. However, when several bolt heads were snagged during the crash test, the extra longitudinal void space adjacent to the bolt shaft allowed the shaft to bend, thus further accentuating the bolt head's exposure above the timber rail surface. Therefore, if it is not possible to either incorporate a through-bolt design or countersink the bolt heads, it would be recommended that the length of the longitudinal slot be reduced in order to decrease bolt bending and any raising of the head above the rail surface.

8 REFERENCES

1. Ross, H.E., Sicking, D.L., Zimmer, R.A., and Michie, J.D., *Recommended Procedures for the Safety Performance Evaluation of Highway Features*, National Cooperative Research Program (NCHRP) Report No. 350, Transportation Research Board, Washington, D.C., 1993.

2. *American Wood-Preservers' Association Book of Standards*, American Wood-Preservers' Association, Woodstock, MD, 1991.

3. Hinch, J., Yang, T.L., and Owings, R., *Guidance Systems for Vehicle Testing*, ENSCO, Inc., Springfield, VA, 1986.

4. *Vehicle Damage Scale for Traffic Investigators*, Second Edition, Technical Bulletin No. 1, Traffic Accident Data (TAD) Project, National Safety Council, Chicago, Illinois, 1971.

5. *Collision Deformation Classification - Recommended Practice J224 March 1980*, Handbook Volume 4, Society of Automotive Engineers (SAE), Warrendale, Pennsylvania, 1985.

9 APPENDICES

APPENDIX A

English-Unit System Drawings

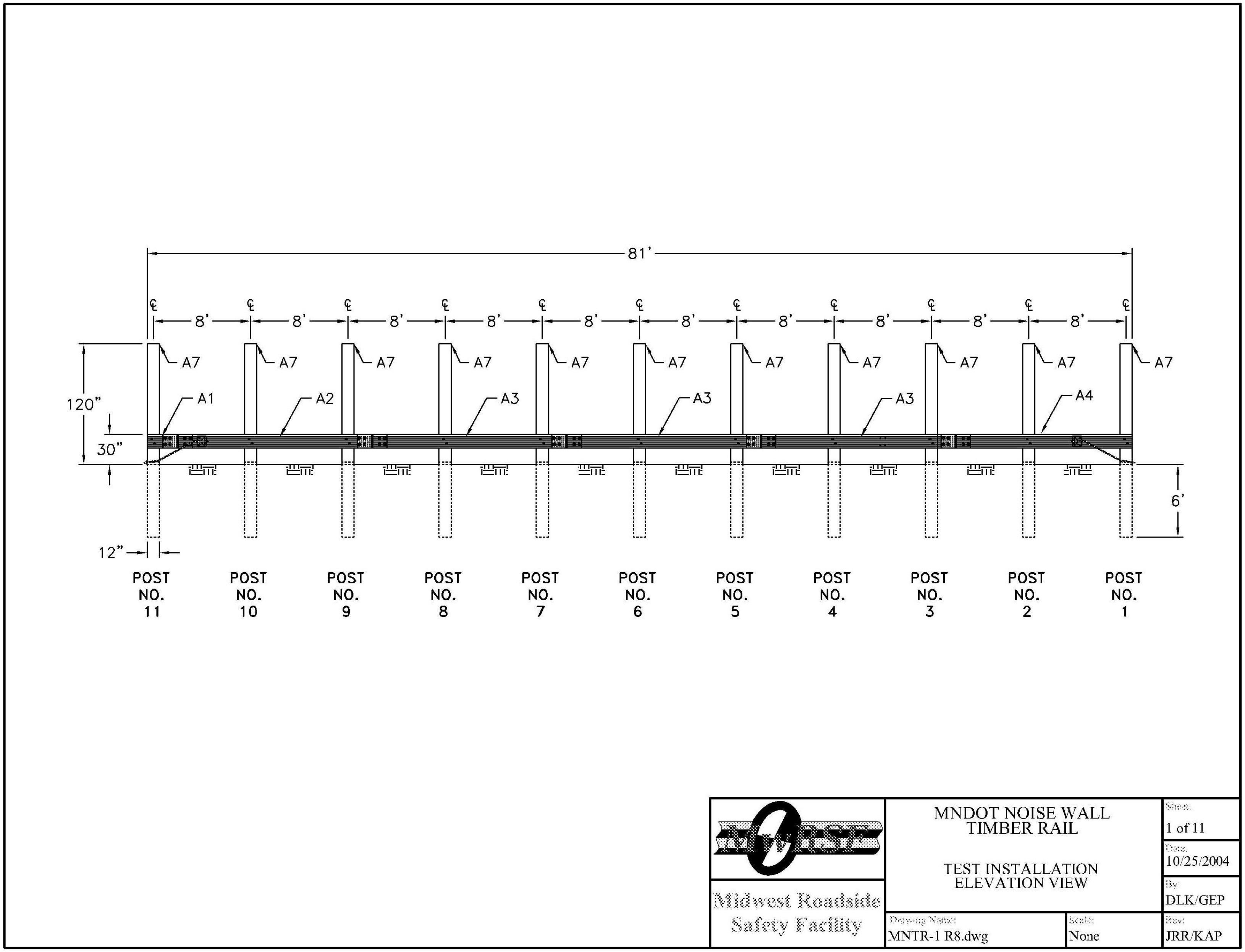


Figure A-1. Layout for Mn/DOT's Timber Rub Rail for Noise Barriers - Elevation View (English)

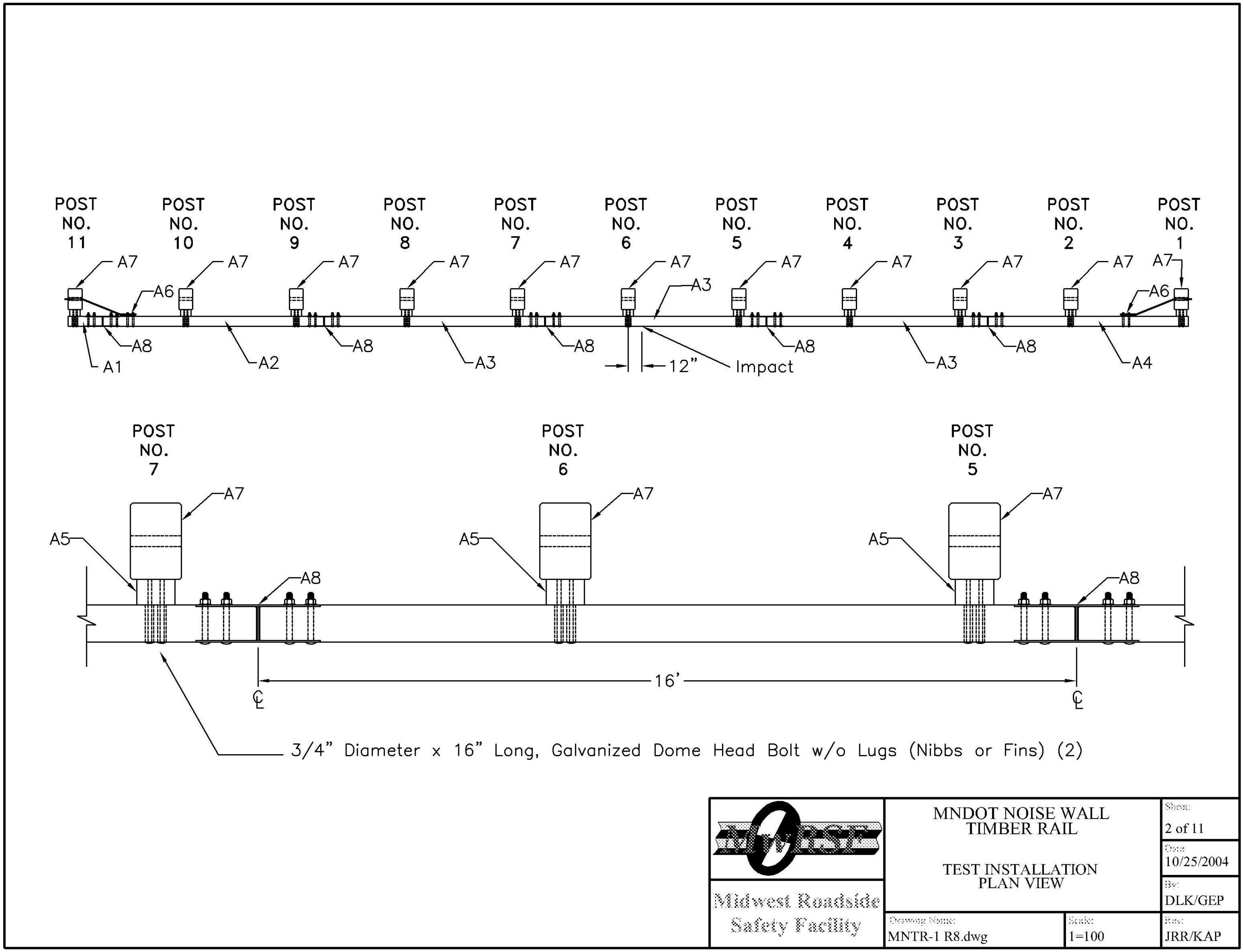


Figure A-2. Layout for Mn/DOT's Timber Rub Rail for Noise Barriers - Plan View (English)

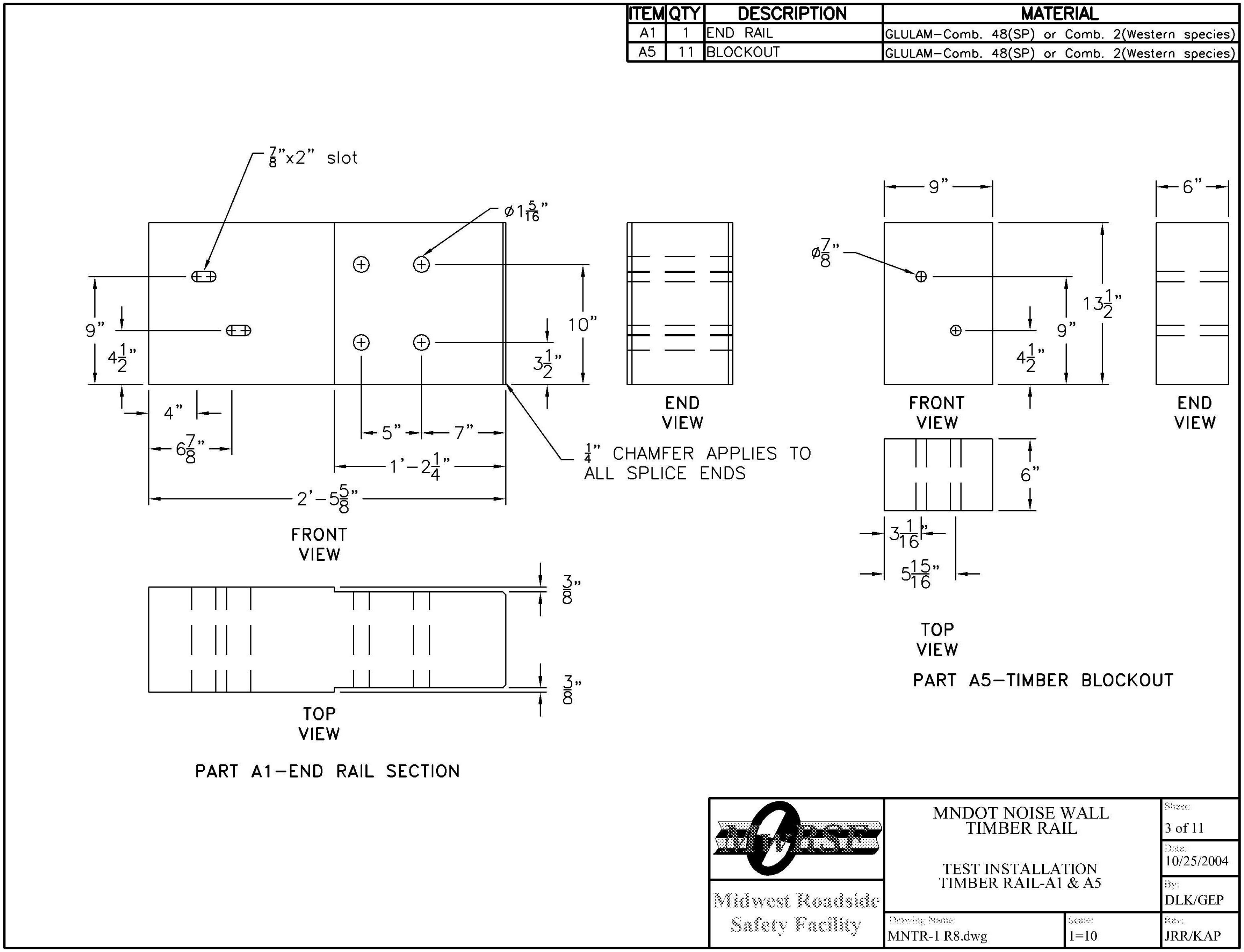
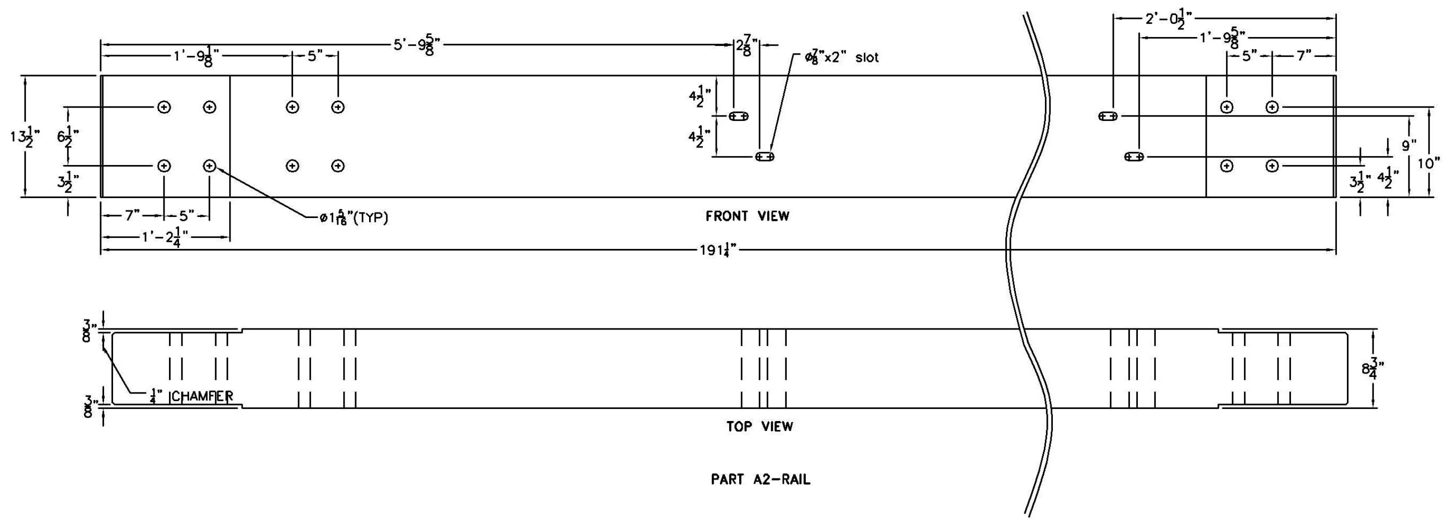


Figure A-3. Mn/DOT's Timber Rub Rail Design Rail and Timber Blockout Details (English)

ITEM	QTY	DESCRIPTION	MATERIAL
A2	1	RAIL	GLULAM–Comb. 48(SP) or Comb. 2(Western species)



Midwest Roadside Safety Facility	MNDOT NOISE WALL TIMBER RAIL TEST INSTALLATION TIMBER RAIL-A2	Sheet: 4 of 11
		Date: 10/25/2004
		By: DLK/GEP
	Drawing Name: MNTR-1 R8.dwg / Scale: 1=16	Rev: JRR/KAP

Figure A-4. Mn/DOT’s Timber Rub Rail Design Rail Details (English)

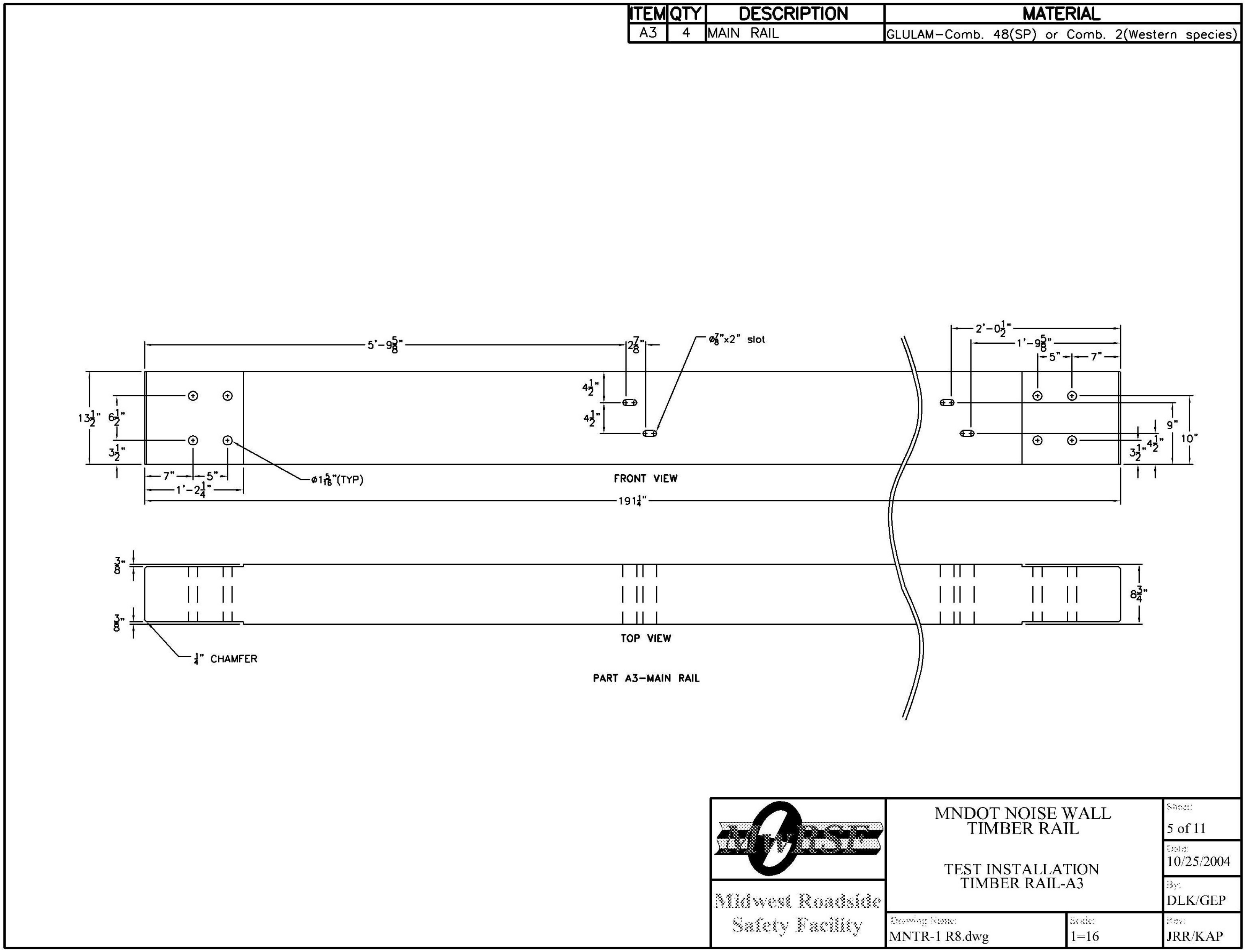
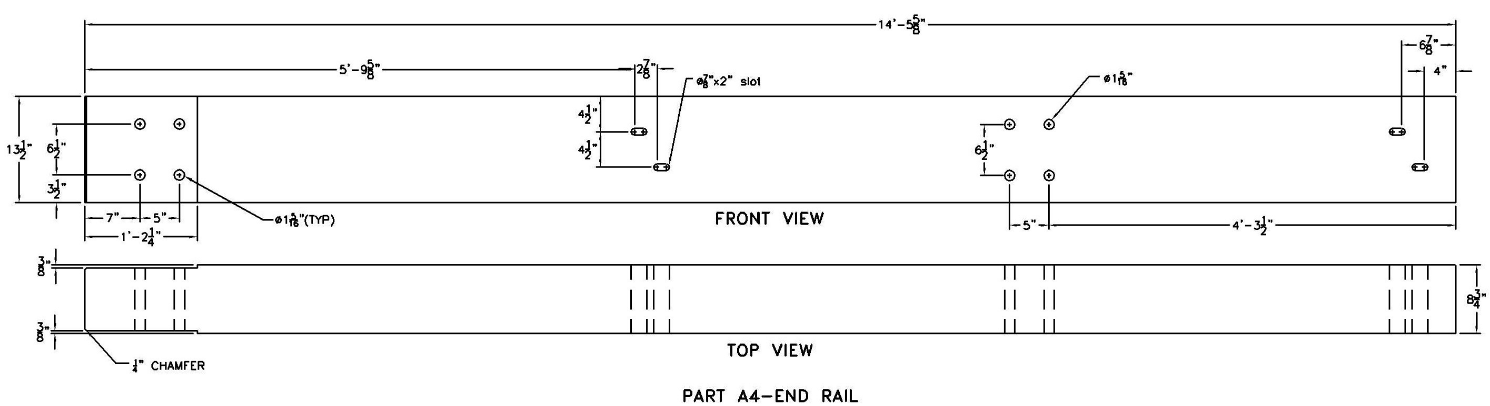


Figure A-5. Mn/DOT's Timber Rub Rail Design Main Rail Details (English)

ITEM	QTY	DESCRIPTION	MATERIAL
A4	1	END RAIL	GLULAM–Comb. 48(SP) or Comb. 2(Western species)



Midwest Roadside Safety Facility	MNDOT NOISE WALL TIMBER RAIL TEST INSTALLATION TIMBER RAIL-A4		Sheet: 6 of 11
			Date: 10/25/2004
			By: DLK/GEP
	Drawing Name: MNTR-1 R8.dwg	Scale: 1=20	Rev: JRR/KAP

Figure A-6. Mn/DOT’s Timber Rub Rail Design End Rail Details (English)

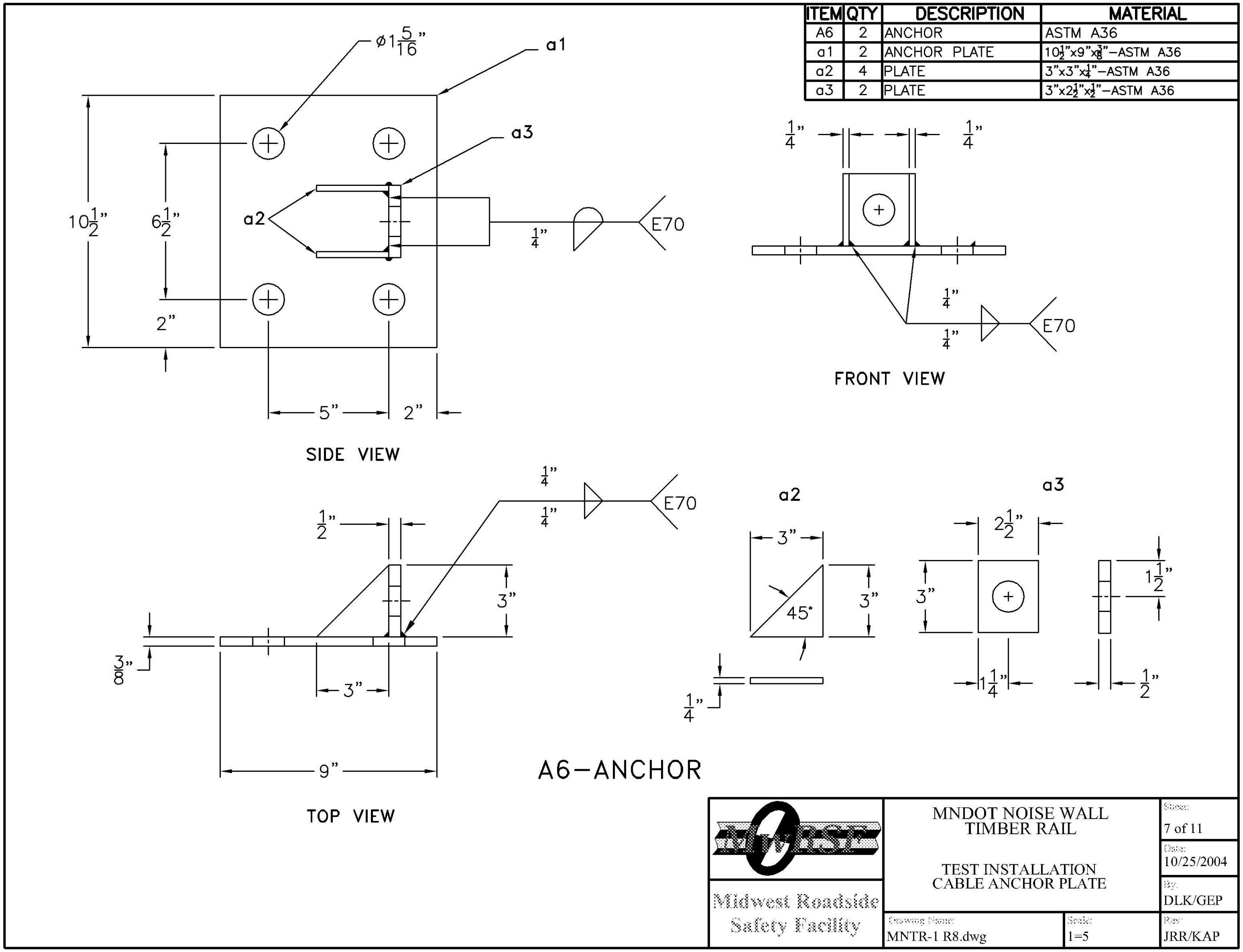


Figure A-7. Mn/DOT's Timber Rub Rail Design Cable Anchor Plate Details (English)

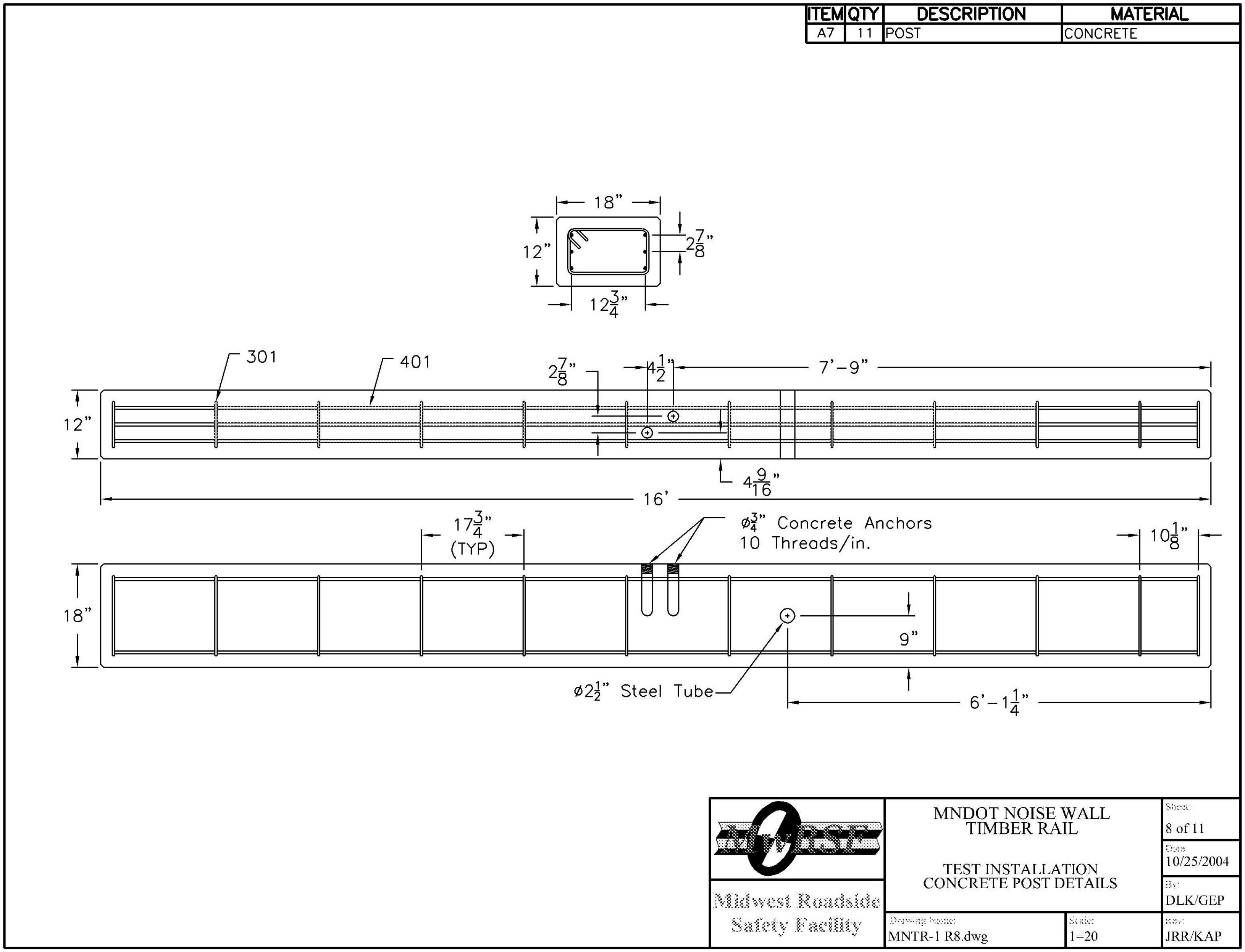
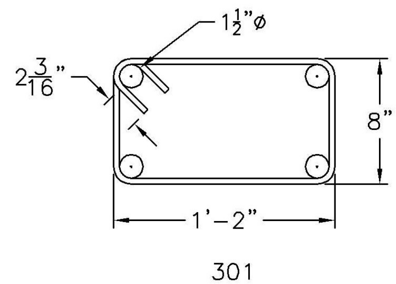
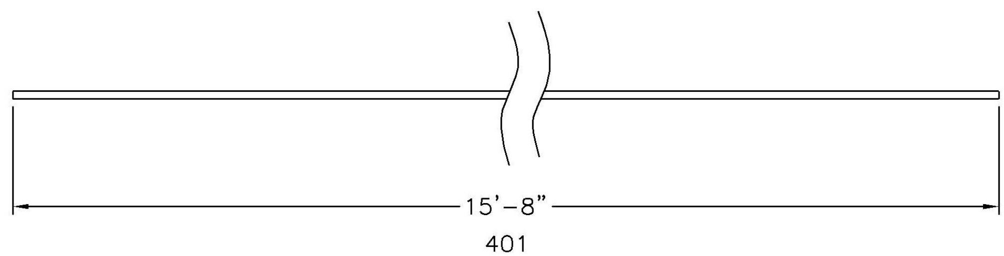


Figure A-8. Mn/DOT's Timber Rub Rail Design Concrete Post Details (English)



Shape	Bar Number	Quantity Per Post	Length
301	3	12	50"
401	4	6	15'-8"



Midwest Roadside Safety Facility

MNDOT NOISE WALL
TIMBER RAIL

TEST INSTALLATION
BILL OF REINFORCING STEEL

Sheet: 9 of 11	Date: 10/25/2004	By: DLK/GEP	Rev: JRR/KAP
Drawing Name: MNTR-1 R8.dwg	Scale: 1=10		

Figure A-9. Mn/DOT's Timber Rub Rail Design Reinforcement Details (English)

ITEM	QTY	DESCRIPTION	MATERIAL
A8	5	SPLICE PLATE	ASTM A36
b1	10	SPLICE	13½"x29¼"x⅜"–ASTM A36
b2	5	SPLICE	13½"x8"x⅜"–ASTM A36

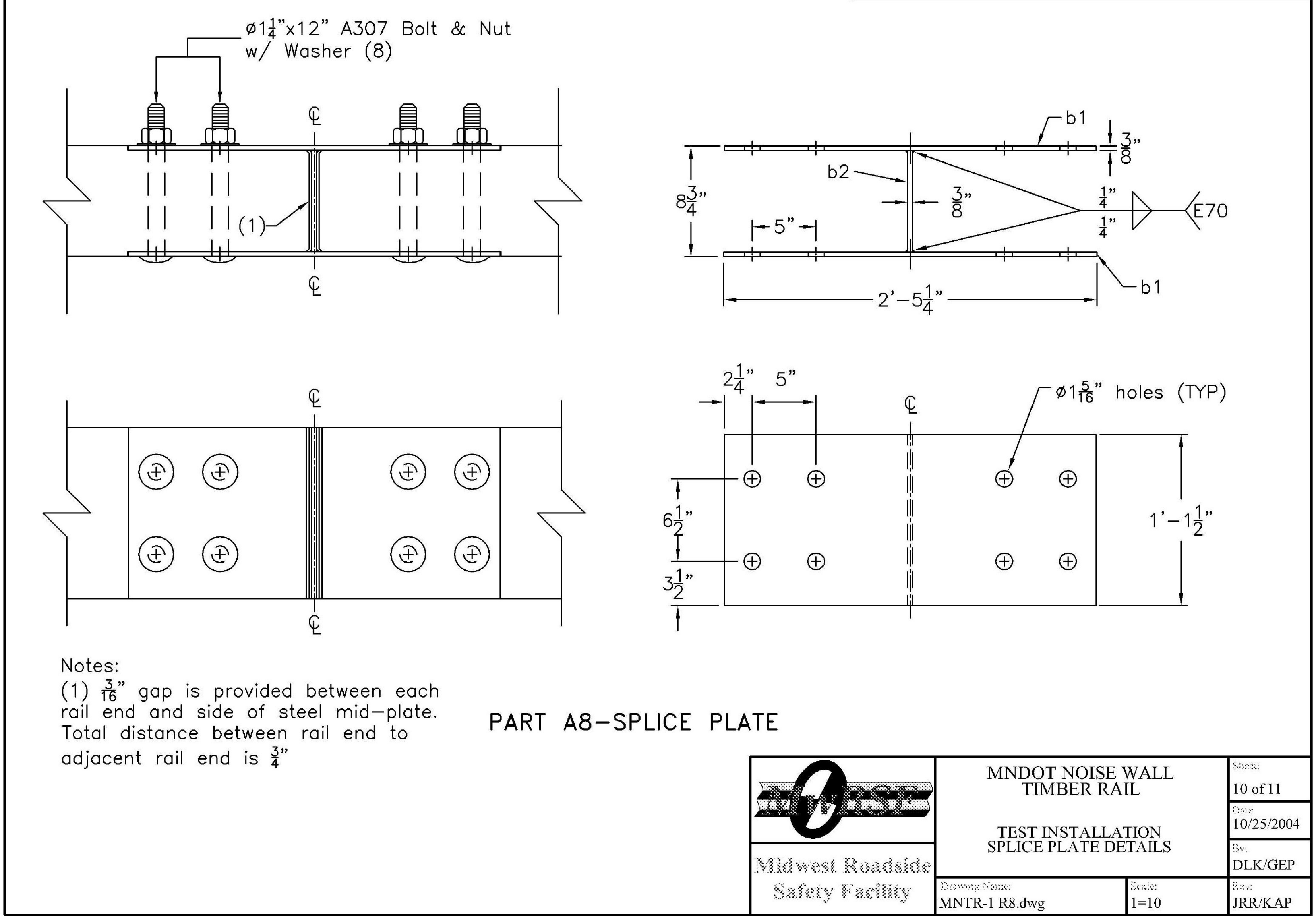


Figure A-10. Mn/DOT's Timber Rub Rail Design Splice Plate Details (English)

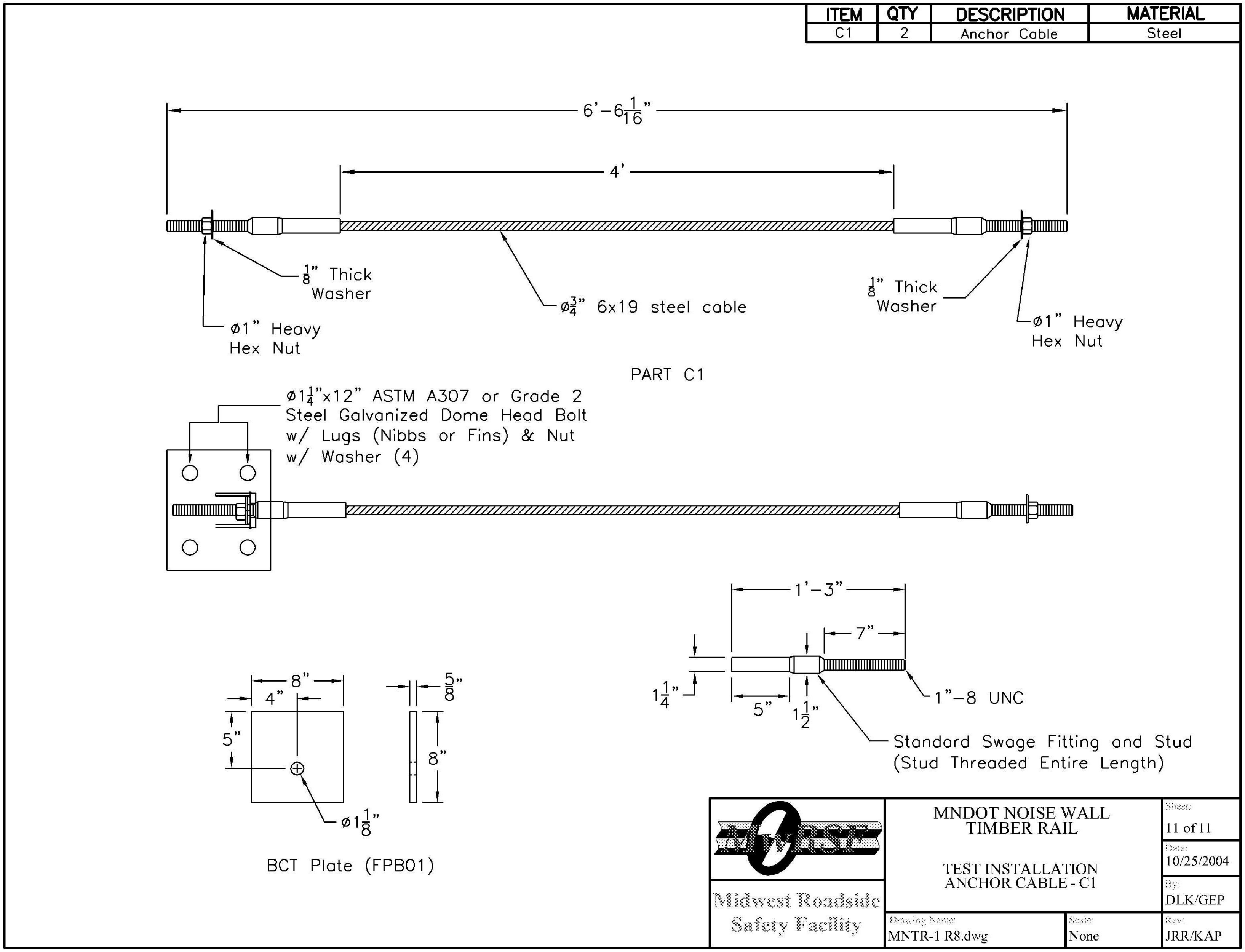


Figure A-11. Mn/DOT's Timber Rub Rail Design Anchor Cable Details (English)

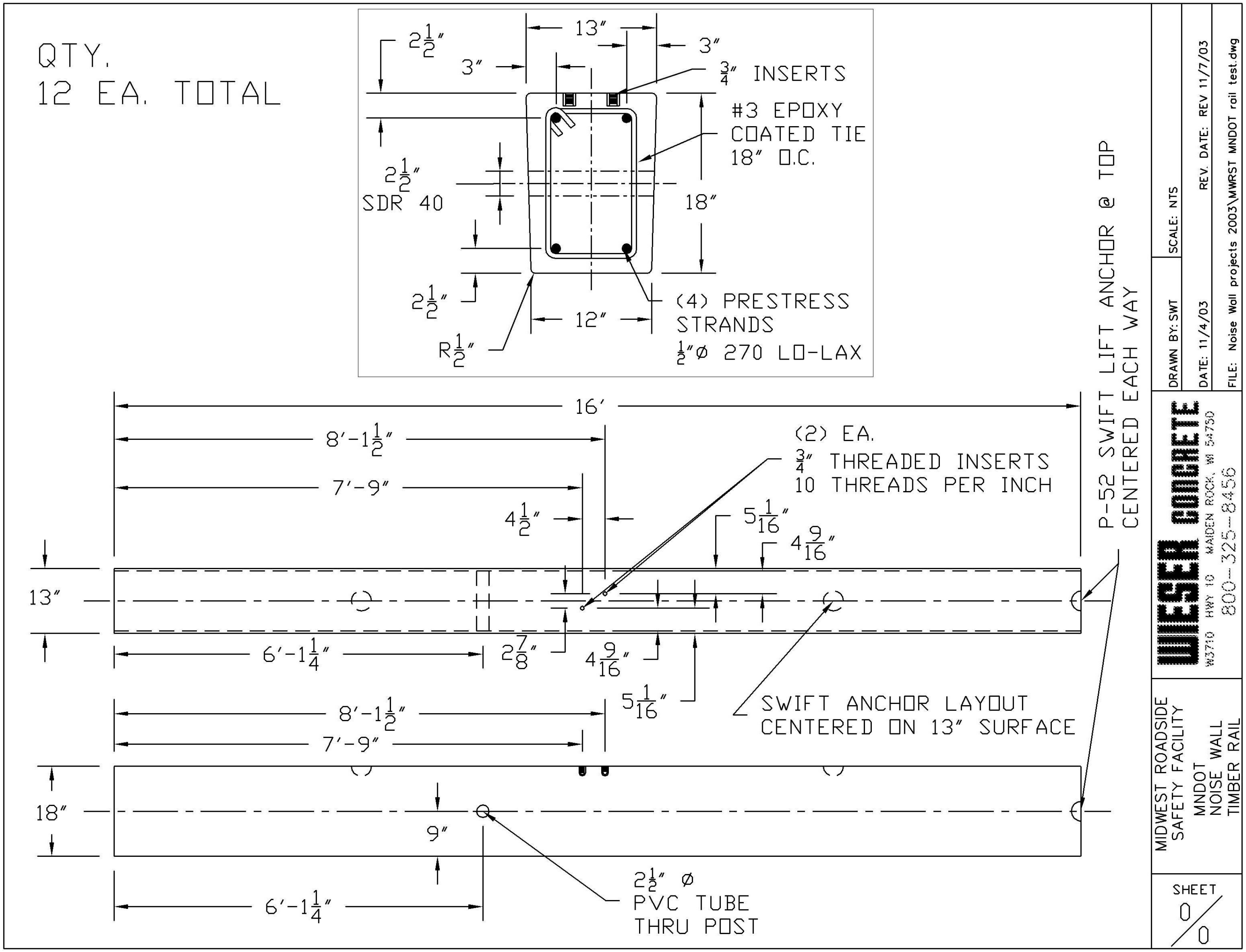


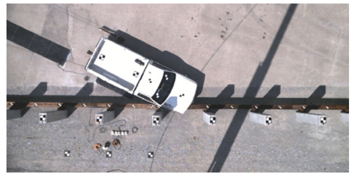
Figure A-12. Wieser Concrete's Concrete Post Details (English)

APPENDIX B

Test Summary Sheet in English Units, Test MNTR-1

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

0.000 sec

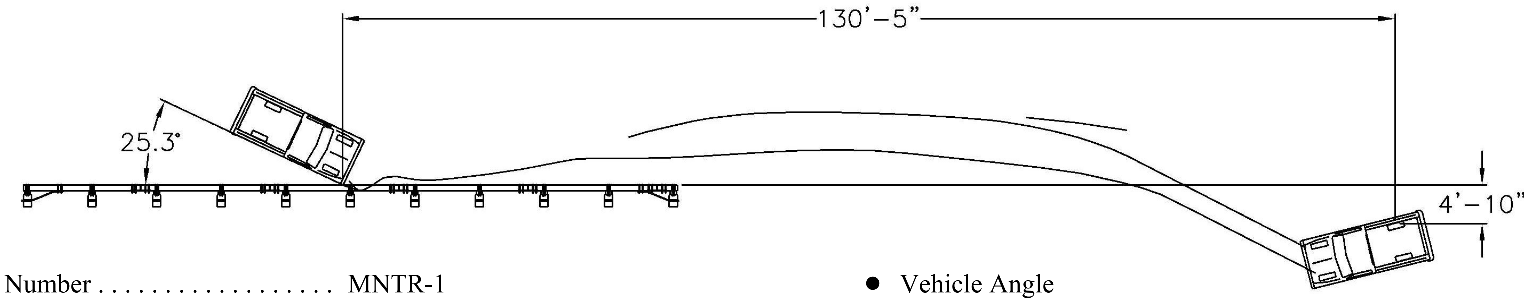


0.054 sec

0.118 sec

0.222 sec

0.362 sec



- Test Number MNTR-1
- Date 7/16/04
- Appurtenance .... Minnesota's Timber Rub Rail for Noise Barriers
- Total Length .... 81 ft
- Glulam Wood Rail
  - Material .... Southern Pine, Combination No. 48
  - Dimensions .... 13½ in. x 8¾ in. by 81-ft long
  - Top Mounting Height .... 30 in.
- Post Nos. 1-11
  - Material .... Concrete
  - Dimensions .... 12 in. x 18 in. by 16-ft long
  - Embedment Depth .... 6 ft
  - Spacing .... 8 ft
- Wood Spacer Blocks Nos. 1-11
  - Material .... Southern Pine, Combination No. 48
  - Dimensions .... 9 in. x 6 in. by 13½ in.-long
- Vehicle Model .... 1999 GMC 2500 ¾-ton pickup
  - Curb .... 4,367 lbs
  - Test Inertial .... 4,386 lbs
  - Gross Static .... 4,386 lbs
- Vehicle Speed
  - Impact .... 61.8 mph
  - Exit .... 35.7 mph
- Vehicle Angle
  - Impact .... 25.3 deg
  - Exit .... 4.1 deg
- Vehicle Snagging .... Minor
- Vehicle Pocketing .... None
- Vehicle Stability .... Satisfactory
- Occupant Ridedown Deceleration (10 msec avg.)
  - Longitudinal .... 8.45 g's < 20 g's
  - Lateral (not required) .... 9.76 g's
- Occupant Impact Velocity
  - Longitudinal .... 29.42 ft/s < 39.37 ft/s
  - Lateral (not required) .... 22.33 ft/s
- PHD .... 10.27 g's
- THIV .... 38.02 ft/s
- Vehicle Damage .... Moderate
  - TAD[4] 1-RFQ-6
  - SAE[5] 1-FZEW5
- Vehicle Stopping Distance .... 130 ft-5 in. downstream; 4 ft-10 in. laterally behind
- Barrier Damage .... Minimal
- Maximum Rail Deflections
  - Permanent Set .... 2.2 in.
  - Dynamic .... 3.6 in.
- Working Width .... 44.6 in.

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

APPENDIX C

Occupant Compartment Deformation Data, Test MNTR-1

VEHICLE PRE/POST CRUSH INFO
Set 1

TEST: MNTR-1
VEHICLE: 1999/GMC/white

POINT	X	Y	Z	X'	Y'	Z'	DEL X	DEL Y	DEL Z
1	51.25	6.75	0	51	6.75	5.5	-0.25	0	5.5
2	53.75	12	-4	52.5	8	6.5	-1.25	-4	10.5
3	54.25	16.5	-3	53.75	12.5	4.25	-0.5	-4	7.25
4	54.5	20.25	-2.75	54.25	16.25	2.5	-0.25	-4	5.25
5	54.75	24.5	-2.25	53.75	20.25	4	-1	-4.25	6.25
6	54.75	29.25	-1.25	52.5	24.75	4.5	-2.25	-4.5	5.75
7	46.25	12.5	-6	45.75	11	2	-0.5	-1.5	8
8	47	16.5	-5.75	46.5	14	-0.75	-0.5	-2.5	5
9	47	19.75	-5.5	46.5	17.25	-3.75	-0.5	-2.5	1.75
10	46.75	24.5	-4.5	47	21	-6	0.25	-3.5	-1.5
11	46.75	29	-4.5	47.25	24.5	1	0.5	-4.5	5.5
12	39.75	12.25	-6.25	39.5	11.25	-5.25	-0.25	-1	1
13	39.75	16.25	-6	39.5	15.25	-3.25	-0.25	-1	2.75
14	39.5	21.25	-5.5	39.5	19.75	-5.25	0	-1.5	0.25
15	39.75	25.25	-5.25	39.75	22.75	-7.5	0	-2.5	-2.25
16	39.5	28.75	-5	39.5	25	0.5	0	-3.75	5.5
17	32	12	-7	31.5	11	-4	-0.5	-1	3
18	31.75	16	-6.5	31.75	15	-4.5	0	-1	2
19	31.75	21	-5.75	31.5	20.25	-4.25	-0.25	-0.75	1.5
20	31.75	24.75	-5.25	31.75	23.75	-5	0	-1	0.25
21	31.75	29	-5.25	NA		-5.75			-0.5
22	26.75	28.5	-5.25	NA		1			6.25
23	26.75	19.25	-6	26.75	18.5	20	0	-0.75	26
24	17	28.25	-5.5	16.75	27.75	20.25	-0.25	-0.5	25.75
25	10.25	14	-4.25	10.25	14.5	27.5	0	0.5	31.75
26	42.5	3.25	23.5	43	3.25		0.5	0	
27	41.5	12.5	25	41.5	12.5		0	0	
28	40.5	24	26.25	40.25	24.25		-0.25	0.25	
29									
30									

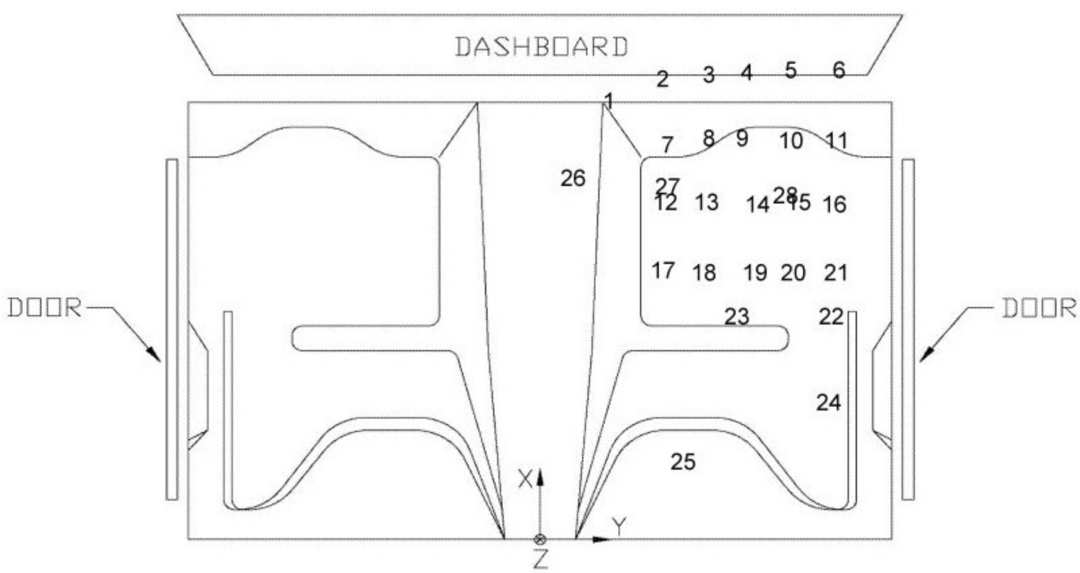


Figure C-1. Occupant Compartment Deformation Data - Set 1, Test MNTR-1

VEHICLE PRE/POST CRUSH INFO
Set 2

TEST: MNTR-1
VEHICLE: 1999/GMC/white

Note: 29,30, and 31 are additional points of significant crush.

POINT	X	Y	Z	X'	Y'	Z'	DEL X	DEL Y	DEL Z
1	45	17.5	0	44.25	17.75	1	-0.75	0.25	1
2	47.5	22.75	-4.5	46	19.75	-5	-1.5	-3	-0.5
3	48	27.25	-4	47	23.75	-4.75	-1	-3.5	-0.75
4	48.25	31	-4	47.75	27	-6.25	-0.5	-4	-2.25
5	48.5	35.25	-3.75	47	31.5	-6	-1.5	-3.75	-2.25
6	48.5	40	-3.5	46	33.75	-4.75	-2.5	-6.25	-1.25
7	40	23.25	-6.5	39	22.25	-4	-1	-1	2.5
8	40.75	27.25	-6.5	39.5	25	-4.5	-1.25	-2.25	2
9	40.75	30.5	-6.5	39.75	28.25	-5.75	-1	-2.25	0.75
10	40.5	35.25	-6.25	40.5	31.75	-8	0	-3.5	-1.75
11	40.5	39.75	-6.5	40.75	35.5	-10.25	0.25	-4.25	-3.75
12	33.5	23	-6.5	32.75	22.25	-5.5	-0.75	-0.75	1
13	33.5	27	-6.75	32.75	26.25	-4.25	-0.75	-0.75	2.5
14	33.25	32	-6.5	32.75	31	-4.5	-0.5	-1	2
15	33.5	36	-6.5	33	34.25	-6.5	-0.5	-1.75	0
16	33.25	39.5	-6.75	32.75	37	-10	-0.5	-2.5	-3.25
17	25.75	22.75	-7	25	22	-6.25	-0.75	-0.75	0.75
18	25.5	26.75	-6.75	25	26	-5.5	-0.5	-0.75	1.25
19	25.5	31.75	-6.5	25	31.25	-4.75	-0.5	-0.5	1.75
20	25.5	35.5	-6.5	25.25	34.75	-4.75	-0.25	-0.75	1.75
21	25.5	39.75	-6.75						
22	20.5	39.25	-6.75						
23	20.5	30	-6.5	20.25	29.5	-5.75	-0.25	-0.5	0.75
24	10.75	39	-6.75	10.5	38.5	-3.5	-0.25	-0.5	3.25
25	4	24.75	-3.5	3.75	24.75	24.5	-0.25	0	28
26			24.25			25			0.75
27			24.75			25.5			0.75
28			25						
29	48	13	7.5	47.25	10.5	3.75	-0.75	-2.5	-3.75
30	48	14.75	7.75	44.5	13.25	4	-3.5	-1.5	-3.75
31	49.5	31.25	4.75	46.25	23.75	7.25	-3.25	-7.5	2.5

6.25	10.75
51.25	6.75
53.75	12
54.25	16.5
54.5	20.25
54.75	24.5
54.75	29.25
46.25	12.5
47	16.5
47	19.75
46.75	24.5
46.75	29
39.75	12.25
39.75	16.25
39.5	21.25
39.75	25.25
39.5	28.75
32	12
31.75	16
31.75	21
31.75	24.75
31.75	29
26.75	28.5
26.75	19.25
17	28.25
10.25	14
42.5	3.25
41.5	12.5
40.5	24

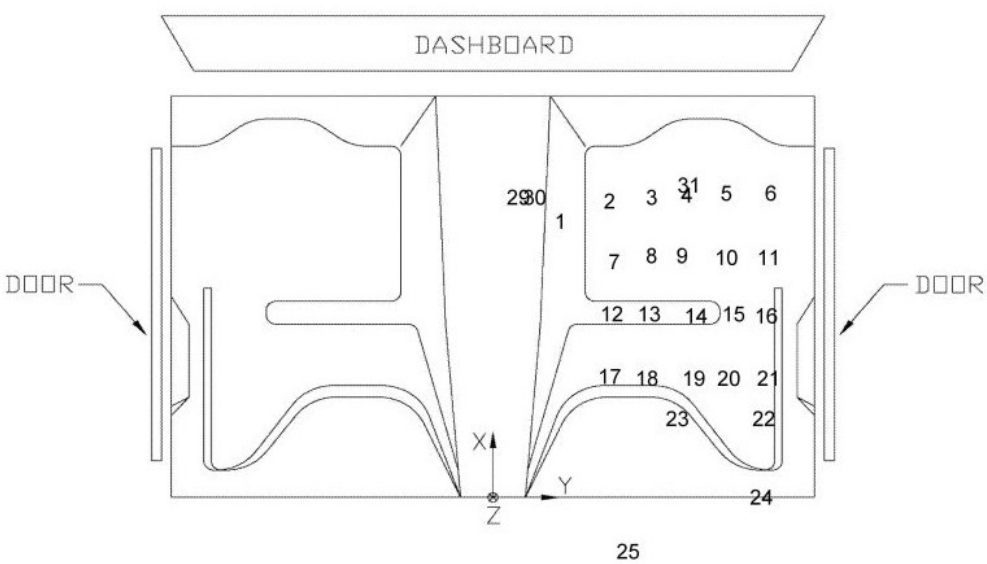


Figure C-2. Occupant Compartment Deformation Data - Set 2, Test MNTR-1

Occupant Compartment Deformation Index (OCDI)

Test No. MNTR-1
Vehicle Type: 2000p

OCDI = XXABCDEFGHI

XX = location of occupant compartment deformation

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

B = distance between the roof and the floor panel

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

D = distance between the lower dashboard and the floor panel

E = interior width

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

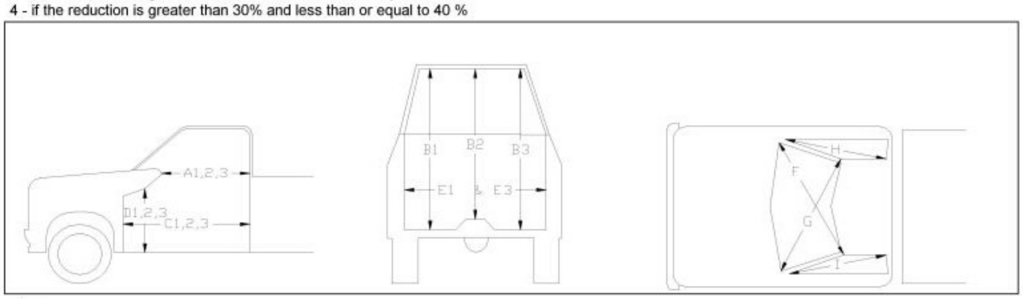
G = distance between the lower edge of left window and the upper edge of right window

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

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

Severity Indices

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



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

Location:

Measurement	Pre-Test (in.)	Post-Test (in.)	Change (in.)	% Difference	Severity Index
A1	39.00	40.00	1.00	2.56	0
A2	40.50	41.25	0.75	1.85	0
A3	39.50	39.50	0.00	0.00	0
B1	47.25	46.75	-0.50	-1.06	0
B2	43.50	42.50	-1.00	-2.30	0
B3	47.25	47.50	0.25	0.53	0
C1	58.25	58.25	0.00	0.00	0
C2	54.25	53.00	-1.25	-2.30	0
C3	57.25	54.50	-2.75	-4.80	1
D1	21.50	22.25	0.75	3.49	1
D2	16.25	17.50	1.25	7.69	1
D3	21.75	22.50	0.75	3.45	1
E1	62.50	56.50	-6.00	-9.60	1
E3	64.00	62.50	-1.50	-2.34	0
F	58.25	57.75	-0.50	-0.86	0
G	59.25	59.75	0.50	0.84	0
H	42.25	40.75	-1.50	-3.55	1
I	40.75	40.50	-0.25	-0.61	0

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

	RF A B C D E F G H I
Final OCDI:	0 0 1 1 1 0 0 1 0

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

APPENDIX D

Accelerometer and Rate Transducer Data Analysis, Test MNTR-1

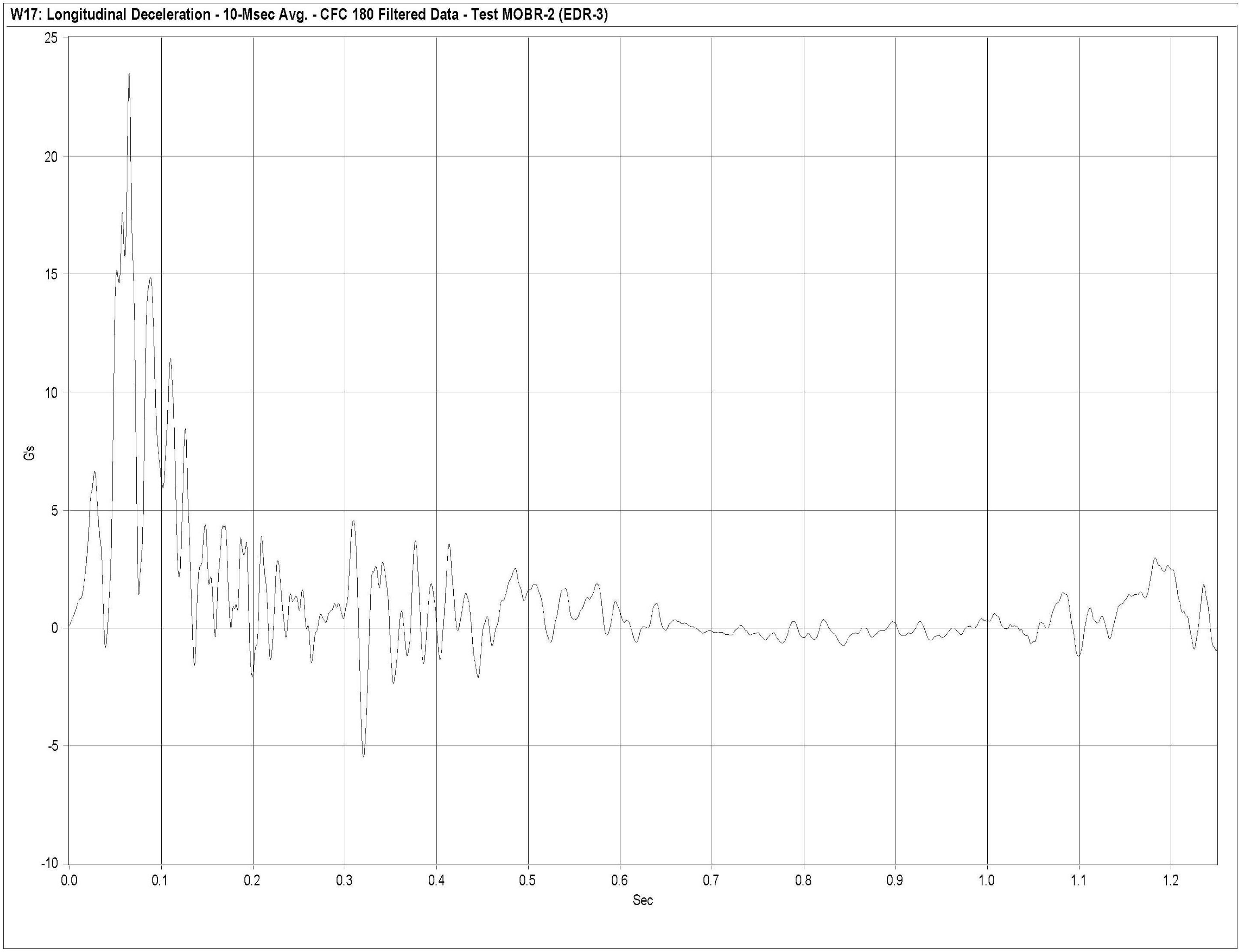


Figure D-1. Graph of Longitudinal Deceleration, Test MNTR-1

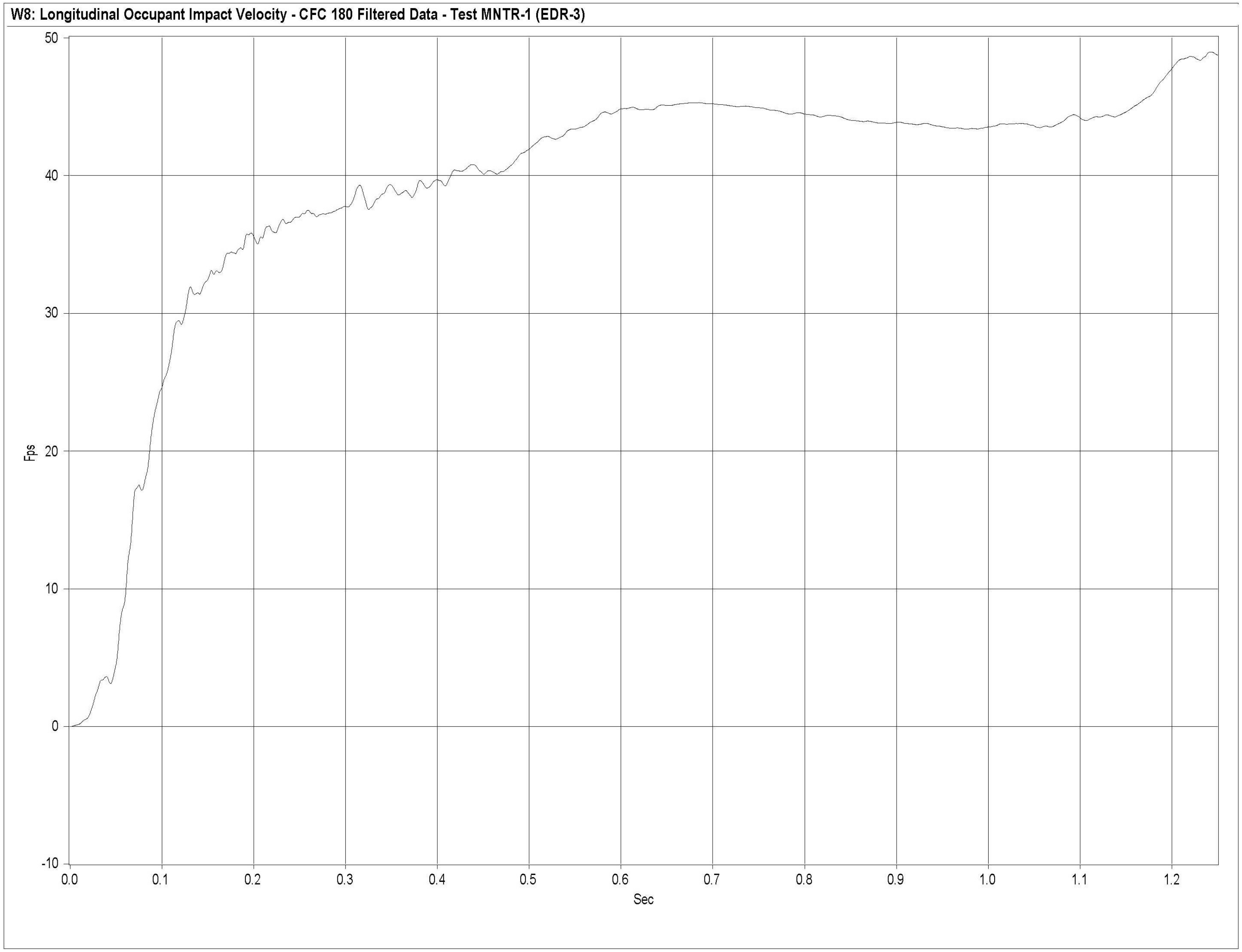


Figure D-2. Graph of Longitudinal Occupant Impact Velocity, Test MNTR-1

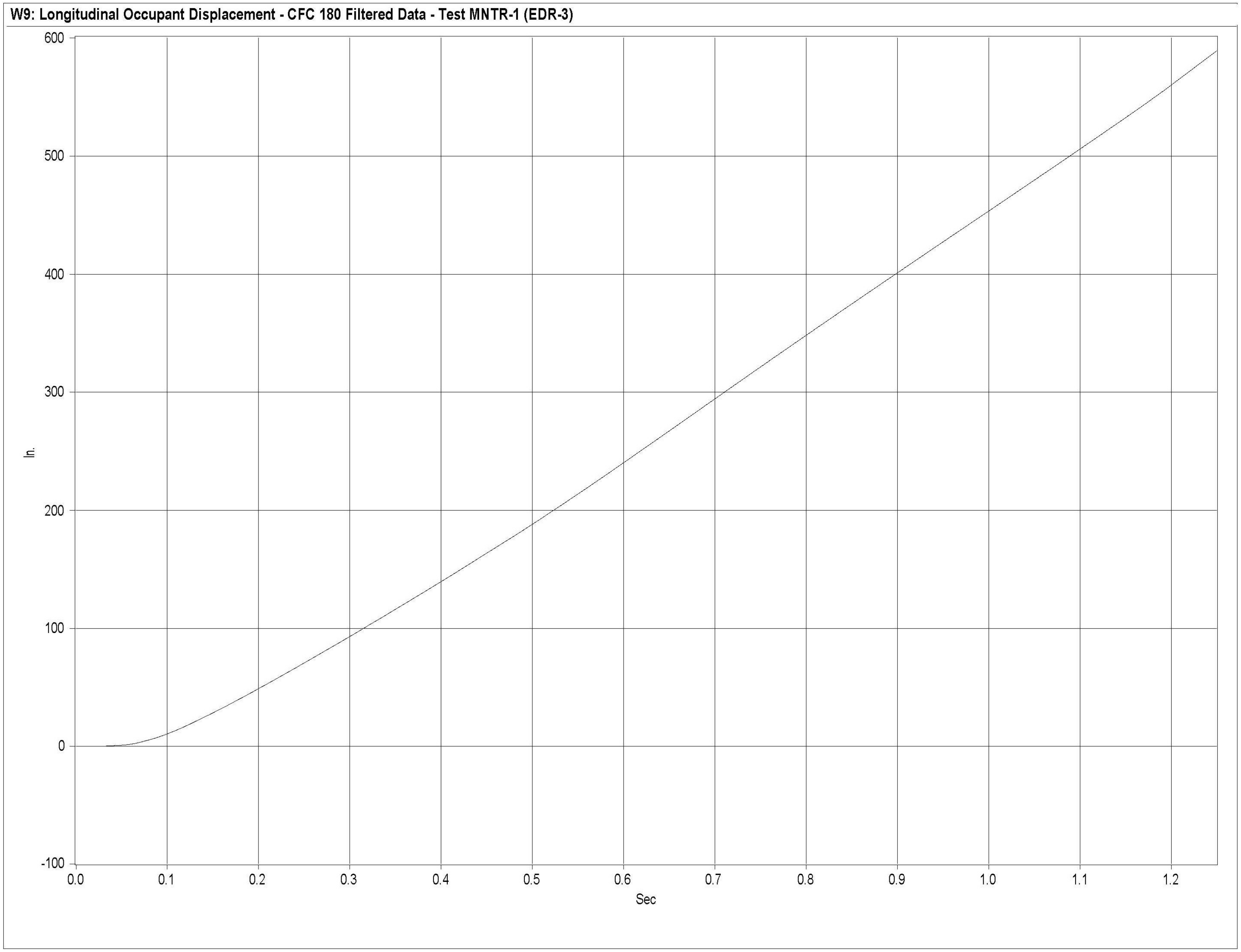


Figure D-3. Graph of Longitudinal Occupant Displacement, Test MNTR-1

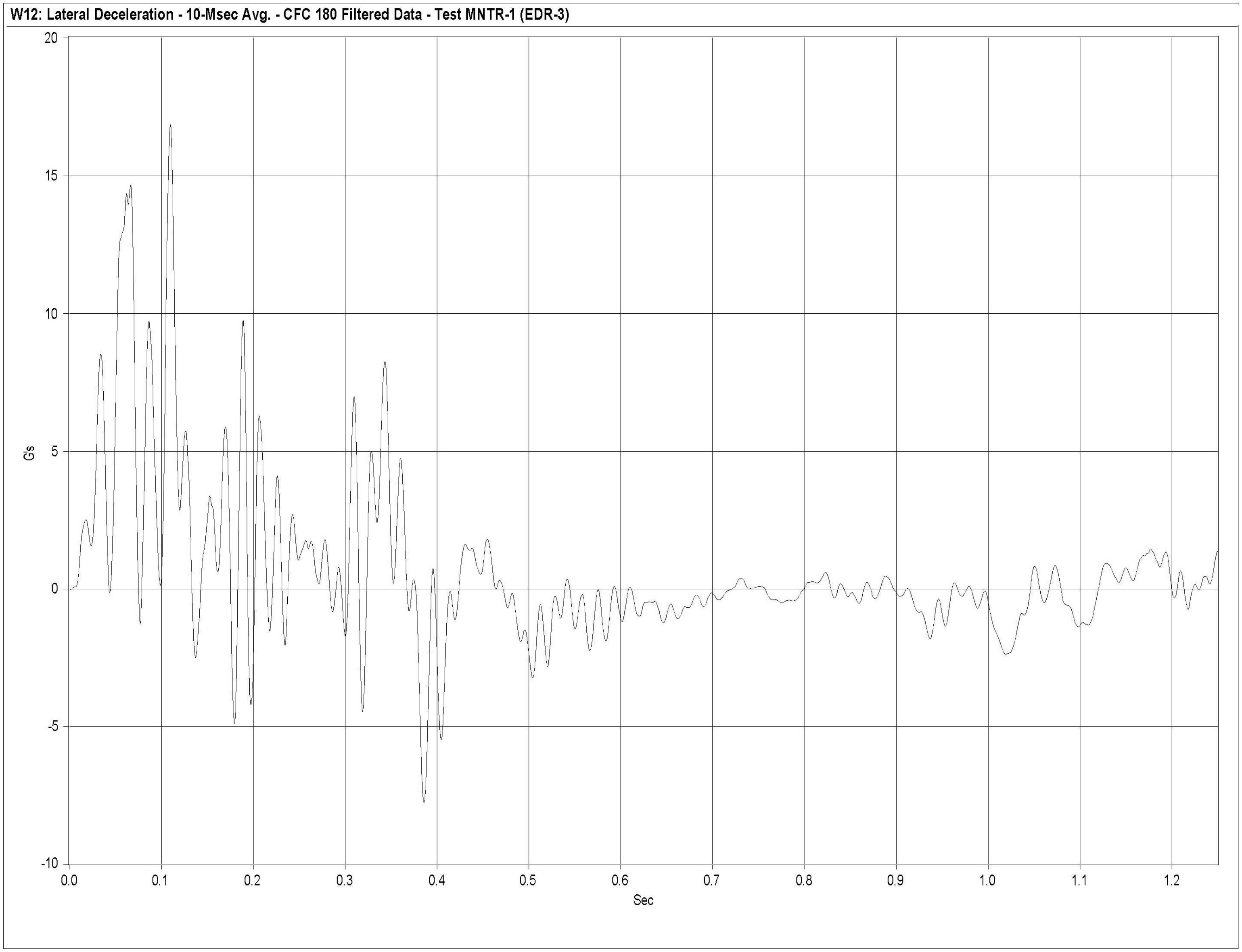


Figure D-4. Graph of Lateral Deceleration, Test MNTR-1

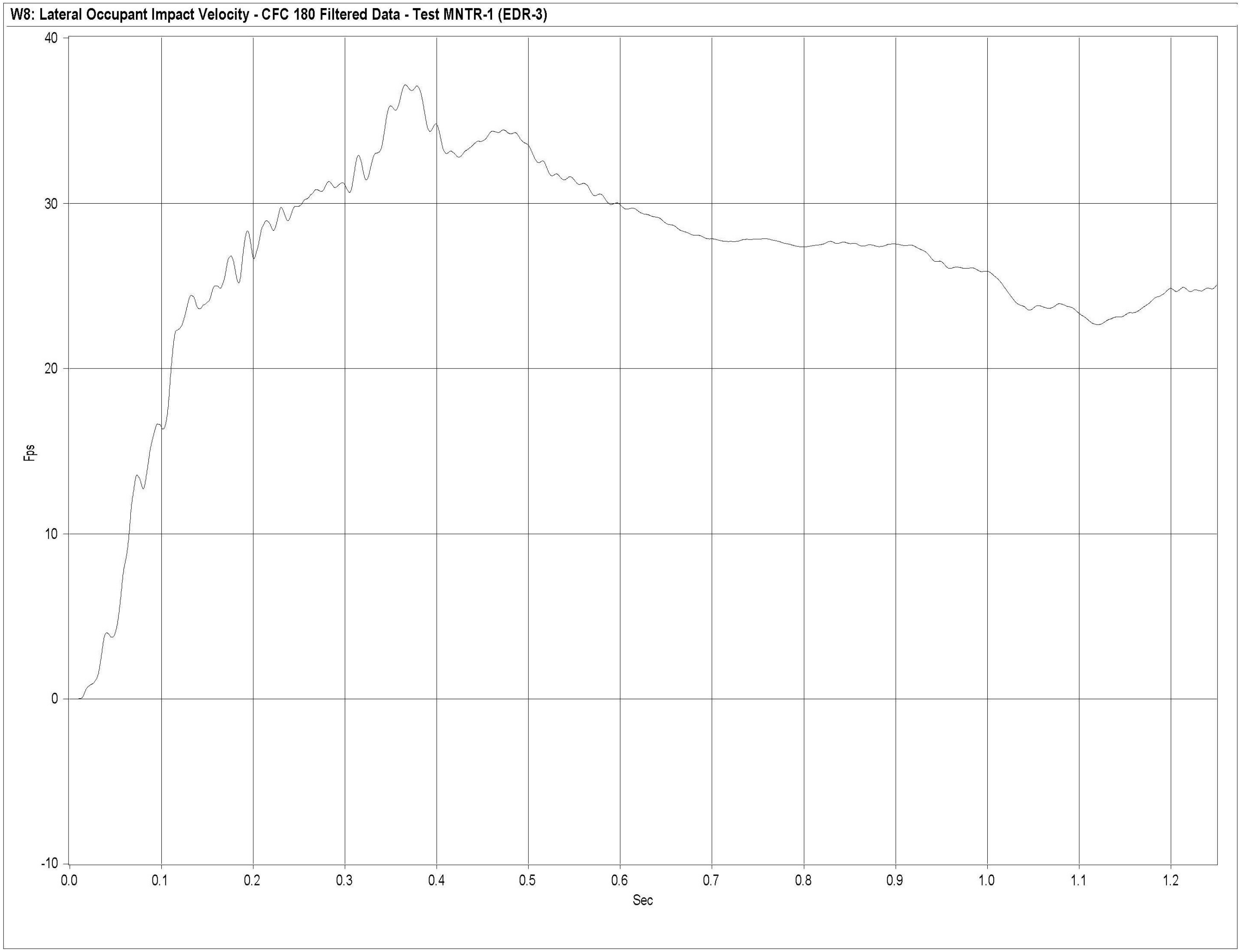


Figure D-5. Graph of Lateral Occupant Impact Velocity, Test MNTR-1

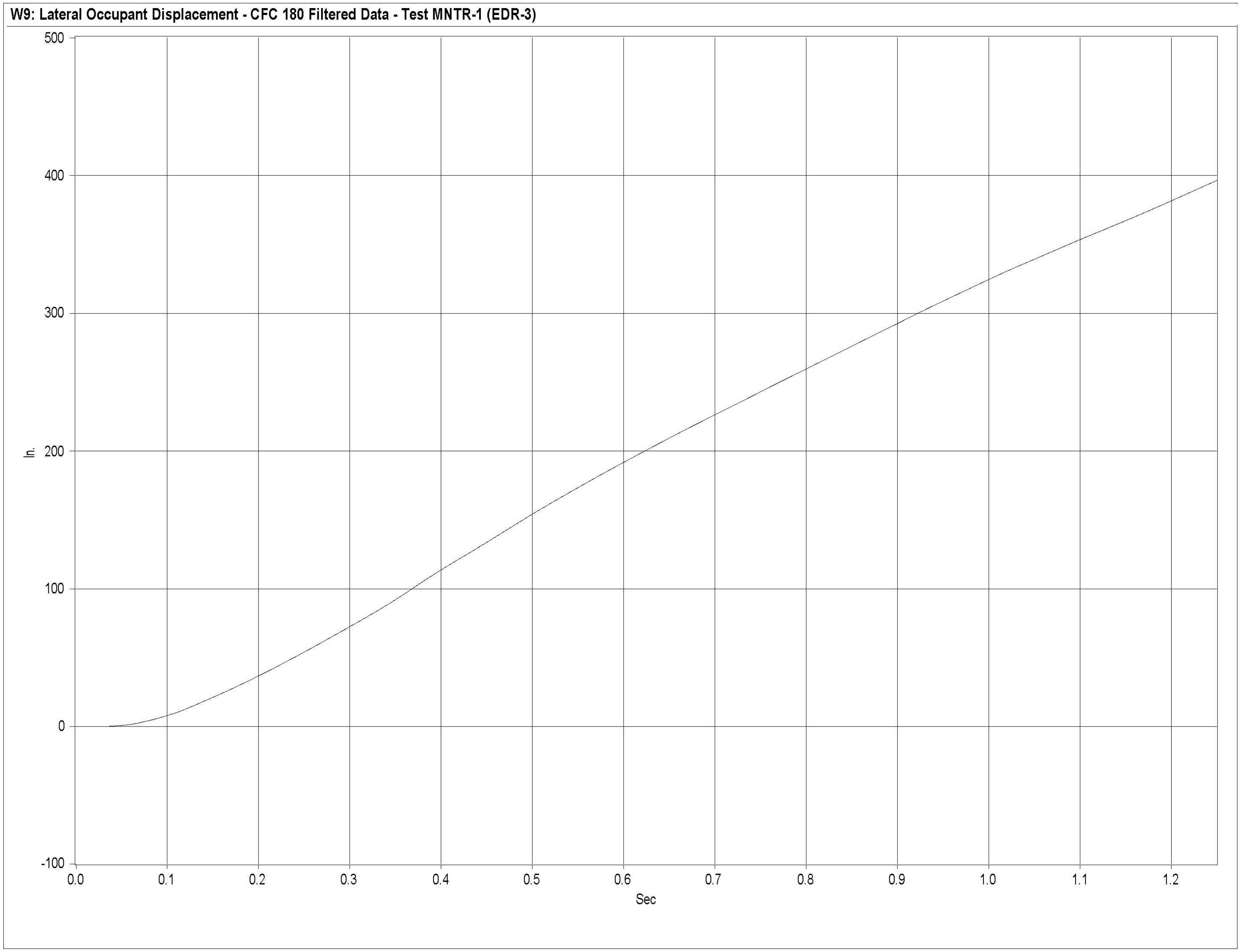


Figure D-6. Graph of Lateral Occupant Displacement, Test MNTR-1

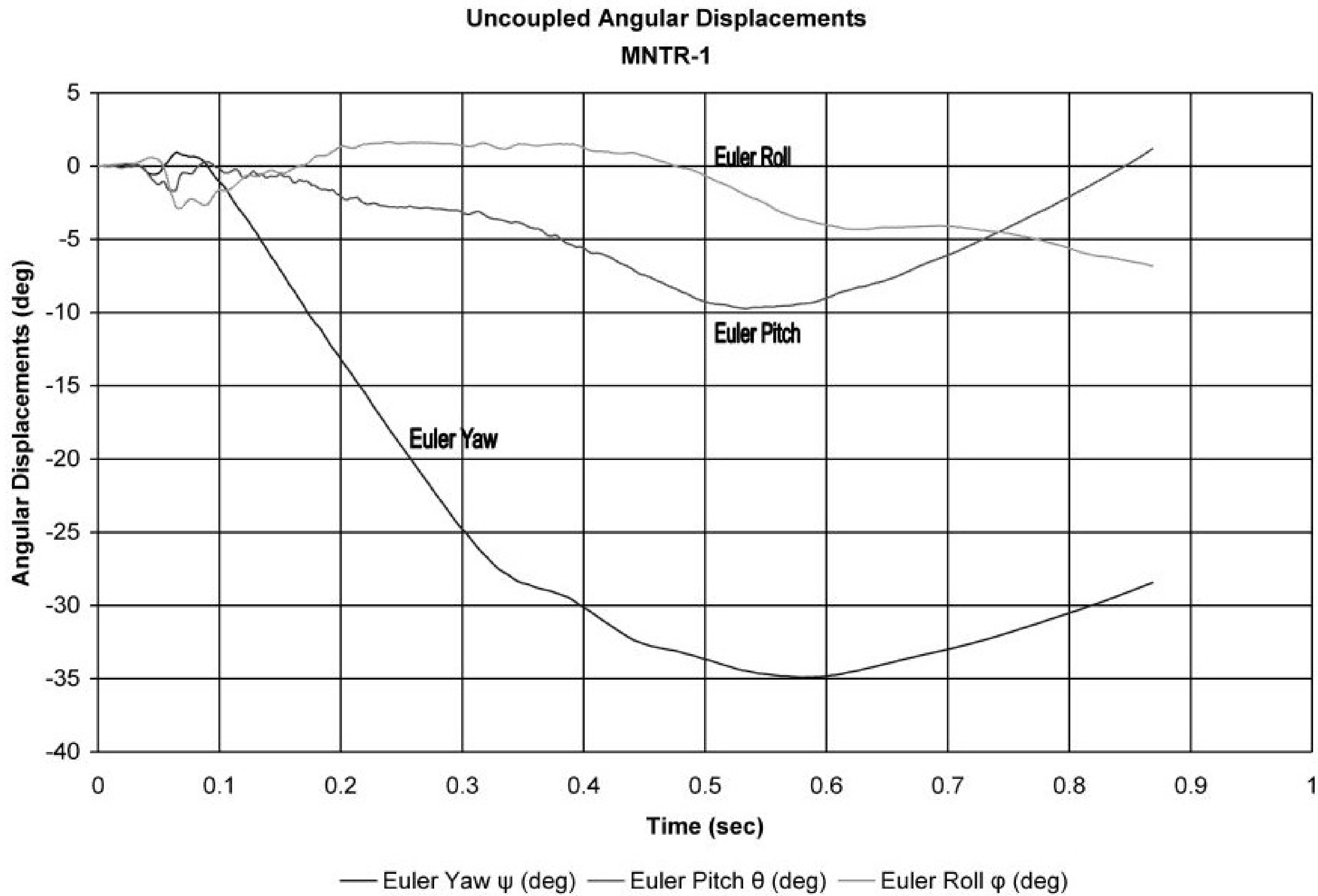


Figure D-7. Graph of Roll, Pitch, and Yaw Angular Displacements, Test MNTR-1

APPENDIX E

Timber Rail Certificate of Conformance

Figure E-1. Timber Rail Certificate of Conformance

ENGINEERED WOOD SYSTEMS

APA EWS

Certificate of Conformance

Certificate 090660

THE UNDERSIGNED MANUFACTURER HEREBY CERTIFIES that the structural wood products identified below and marked with a collective mark of **Engineered Wood Systems (EWS)** were manufactured in accordance with the specifications indicated below.

- [X] ANSI Standard A190.1-1992, for Structural Glued Laminated Timber
- [ ] ______________________
- [ ] ______________________

Job Name University of Nebraska

Job Location Lincoln, NE

Customer's Order No. 4500105456 Date 12/16/03 Mfgr's Order No. 99-3489

Signature ______________ Title QUALITY CONTROL

Company ALAMCO WOOD PRODUCTS, INC. Address 1410 WEST 9TH STREET, ALBERT LEA, MN 56007 Date 12/16/03

IT IS HEREBY CERTIFIED that the structural glued laminated timber production of the above-named manufacturer which carries a collective mark of Engineered Wood Systems (EWS) is subject to regular audit by Engineered Wood Systems, such audit consisting of the inspection with reasonable frequency of the manufacturing process, with adequate sampling to verify the quality of glulam construction and the adequacy of glue bond.

JAN 22 2004

by ______________

Thomas G. Williamson
Executive Vice President

ENGINEERED WOOD SYSTEMS – A RELATED CORPORATION OF APA

Figure E-1. Timber Rail Certificate of Conformance