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DEVELOPMENT OF AN APPROACH GUARDRAIL TRANSITION ATTACHED TO A THRIE BEAM AND CHANNEL BRIDGE RAILING

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16. Abstract (Limit: 200 words)

An approach guardrail transition was developed for use with Missouri's thrie beam and channel bridge railing system. Two 2000-kg pickup truck crash tests were performed unsuccessfully on two previous designs according to the requirements specified in NCHRP Report 350: *Recommended Procedures for the Safety Performance Evaluation of Highway Features*. In both instances, the pickup truck rolled over upon redirection. For these two prior designs, a rubrail was used below the thrie beam guardrail in the transition region to prevent wheel snagging on the first bridge post; since, the bridge railing system did not incorporate post blockouts. The inclusion of the rubrail in the design was believed to have greatly influenced the angular motions of the vehicles during both impacts.

Upon reviewing the crash test results, it was deemed necessary to modify the bridge railing system to incorporate spacers in order to position the thrie beam away from the face of the bridge posts. This change would allow the rubrail to be completely removed as the potential for wheel snagging would be essentially eliminated. After Missouri approved the use of spacer blocks, it became apparent that an existing NCHRP 350 TL-4 transition design could be modified slightly and easily adapted for use with Missouri's bridge railing system. The TL-4 transition design was initially developed for the Forest Products Laboratory of the U.S. Forest Service. A modified transition detail was prepared for use with Missouri's bridge railing system, and a request was sent to the Federal Highway Administration (FHWA) seeking approval of this new design without additional crash testing. Subsequently, the transition system was approved for use by FHWA as a TL-3 transition system contingent upon the inclusion of spacer blocks in the bridge railing system.

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1 INTRODUCTION

1.1 Background

For many years, the Missouri Department of Transportation (MoDOT) constructed a thrie beam and steel channel bridge railing system on bridges located on their highways. Although this bridge railing system had performed acceptably in the field, no full-scale vehicle crash tests had been conducted on the system to evaluate its safety performance. During the early1980's, full-scale vehicle crash testing became recognized as a more appropriate and reliable method of evaluating the acceptability of a longitudinal barrier system.

In 1988, the Texas Transportation Institute (TTI), in cooperation with the MoDOT and the Federal Highway Administration (FHWA), conducted a safety performance evaluation of both this bridge railing system and an approach guardrail transition (1). Three full-scale vehicle crash tests - two on the bridge railing and one on the transition - were performed according to the criteria provided in the National Cooperative Highway Research Program (NCHRP) Report No. 230, *Recommended Procedures for the Safety Performance Evaluation of Highway Appurtenances* (2). Following an analysis of the test results, the researchers reported that the bridge railing system generally met the requirements set forth in NCHRP Report No. 230, although some of the criteria were met only marginally. In addition, the approach guardrail transition attached to the bridge railing system performed unsatisfactorily and did not meet the requirements set forth in NCHRP Report No. 230.

Following the unacceptable performance of the transition system, MoDOT officials replaced the approach guardrail transition system attached to the thrie beam and channel bridge rail with a new configuration (3). The new approach guardrail transition system was similar to a transition system, attached to a New Jersey concrete safety shape end section, which was successfully crash tested by the Southwest Research Institute (SwRI) in 1989 (4). Although the system crash tested by SwRI met the NCHRP Report No. 230 impact safety standards, SwRI researchers and the FHWA recommended that MoDOT construct the transition system with one additional post located upstream from the concrete end section to improve system performance.

In 1993, the Midwest Roadside Safety Facility (MwRSF) crash tested a transition design attached to a New Jersey concrete safety shape end section for MoDOT according to NCHRP Report No. 230 safety standards (5). This transition system was similar to that tested previously by SwRI; however, it included the additional post recommended by FHWA and incorporated one 3.42-mm thick single thrie beam rail instead of two 2.66-mm thick nested thrie beam. The transition system tested by MwRSF was determined to be unacceptable according to the NCHRP Report No. 230 criteria. Wheel snagging on the concrete end section occurred, resulting in excessive occupant compartment deformations.

1.2 Problem Statement

Following a review of the unacceptable test results on Missouri's transition to a concrete safety shape end section (5), MwRSF researchers reasoned that similar test results would have been obtained for a sedan impact with the transition configuration provided in Drawing No. 606.23D (3). Based on this fact, the need existed to develop a new approach guardrail transition that could be adapted to the thrie beam and channel bridge railing. In addition, the new design must be developed according to current impact safety standards which are based on crash tests with pickup trucks rather than passenger-size sedans.

1.3 Research Objective

The objective of the research project was to develop a new approach guardrail transition attached to Missouri's thrie beam and channel bridge railing. The transition system must be designed such that it meets the Test Level 3 (TL-3) safety performance criteria set forth in NCHRP Report No. 350, *Recommended Procedures for the Safety Performance Evaluation of Highway Features* (6).

1.4 Scope

The research objective was accomplished with a series of tasks. First, a literature search was performed to review the approach guardrail transition designs previously evaluated according to the NCHRP Report No. 350 safety standards. Second, an analysis and design phase was undertaken to determine the best method for attaching the flexible guardrail system to the more rigid bridge railing system. After final design and subsequent fabrication, two full-scale vehicle crash tests were performed according to the TL-3 impact conditions of NCHRP Report No. 350. The crash tests were performed with ¾-ton pickup trucks, weighing approximately 2,000 kg, with a target impact speed and angle of 100 km/hr 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 newly developed approach guardrail transition.

2 LITERATURE REVIEW

Since the inception of the NCHRP Report 350 guidelines, a limited number of research studies have been performed to develop, test, and evaluate thrie beam approach guardrail transitions attached to rigid bridge railing systems according to the TL-3 criteria.

In 1994, researchers at the MwRSF, in cooperation with the Midwest States Regional Pooled Fund Program, successfully developed and tested an approach guardrail transition for use with the single-slope concrete median barrier (7-8). The transition was constructed with 3.42-mm thick thrie beam rails and was supported by nine W152x13.5 steel posts. Post spacings consisted of one at 292 mm, five at 476 mm, and three at 952 mm. Specially designed steel structural tube blockouts were used to connect the thrie beam rail to the steel posts.

In 1997, MwRSF researchers successfully developed and tested two approach guardrail transition designs for use with concrete safety shape parapets and, once again, in cooperation with the Midwest States Regional Pooled Fund Program (9-10). Both transition designs were constructed with two nested thrie beam rails, measuring 2.66-mm thick. The first transition design was supported by nine W152x13.5 steel posts, while the second transition design was supported by nine 152-mm x 203-mm wood posts. For both systems, post spacings consisted of one at 292 mm, five at 476 mm, and three at 952 mm. A triangular-shape concrete curb was constructed below the thrie beam rail on each approach guardrail transition system.

Also in 1997, MwRSF developed and tested another approach guardrail transition for use with a vertical concrete parapet and a redesigned tapered end section according to TL-3 of NCHRP Report No. 350 (11). The transition design was constructed with two nested thrie beam rails, measuring 2.66-mm thick, and was supported by two W152x37.2 steel posts and four W152x22.3

steel posts. Post spacings consisted of one at 1,879 mm, four at 952.5 mm, and one at 1,905 mm. During the impact, the pickup truck was contained and redirected in a stable manner. However, the wheel assembly collapsed and extended under the deformed thrie beam in a unique manner, contacting the upstream end of the tapered concrete section. This wheel contact led to significant occupant compartment deformations as well as the test being judged a failure.

An approach guardrail transition for use with the New Jersey safety shape barrier was tested according to TL-3 of NCHRP Report No. 350 by SwRI in 1994 (12). During the impact, the pickup truck was contained but after redirection the vehicle rolled onto its side. Thus, the test failed NCHRP Report No. 350 requirements. The transition was constructed with two 2.66-mm thick nested thrie beam rails and was supported by eight 152 mm x 203 mm timber posts. Post spacings consisted of one at 292 mm, three at 476 mm, and four at 952 mm.

In 1994, researchers at TTI successfully designed and tested an approach guardrail transition for use with a concrete safety shape barrier according to the TL-3 of NCHRP Report No. 350 (13). The transition was constructed with a 3.43-mm thick thrie beam rail, two nested 3.43-mm thick W-beam to thrie beam transition sections, and was supported by six 178-mm diameter timber posts. Post spacings consisted of four at 476 mm, one at 952 mm, and one at 1,905 mm. The cylindrical wood posts made this transition unacceptable for the MoDOT.

3 TEST REQUIREMENTS AND EVALUATION CRITERIA

3.1 Test Requirements

Longitudinal barriers, such as approach guardrail transitions, must satisfy the requirements provided in NCHRP Report No. 350 to be accepted for use on new construction projects or as a replacement for existing transition designs not meeting current safety standards. According to Test Level 3 (TL-3) of NCHRP Report No. 350, approach guardrail transitions must be subjected to two full-scale vehicle crash tests: (1) a 2,000-kg pickup truck impacting at a speed of 100.0 km/hr and at an angle of 25 degrees; and (2) an 820-kg small car impacting at a speed of 100.0 km/hr and at an angle of 20 degrees. However, thrie beam barriers struck by small cars have been shown to meet safety performance standards and to be essentially rigid (14-16), with no significant potential for occupant risk problems arising from wheel snagging on the posts. Therefore, the 820-kg small car crash test was deemed unnecessary for this project.

3.2 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. It is also an indicator for 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 1. The full-scale vehicle crash tests were conducted and reported in accordance with the procedures provided in NCHRP Report No. 350.

Table 1. NCHRP Report 350 Evaluation Criteria for 2000P Pickup Truck Crash Test.

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.
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 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 devise.

4 DESIGN CONSIDERATIONS

Missouri's bridge railing system was configured using a 3.42-mm thick single thrie beam rail which attached to front face of W152x29.8 steel posts spaced 1,905 mm on center. It is noted that no blockouts were used between the posts and thrie beam rail. A C203x17.1 steel channel was also mounted to the top of the steel bridge posts and placed slightly below the top height of the thrie beam rail. The base of each post was welded to a steel plate which was rigidly attached to the concrete deck surface with six anchor bolts.

As discussed previously in Section 1.1, the thrie bream and channel bridge railing system was successfully crash tested according to the guidelines provided in NCHRP Report No. 230 (1). The bridge railing system was evaluated using two crash tests - an 901-kg small car impacting at a speed of 95.9 km/hr and an angle of 15.0 degrees and a 2,041-kg sedan impacting at an speed of 98.0 km/hr and an angle of 24.0 degrees. Although no NCHRP Report No. 350 crash tests had been performed on the bridge railing system, FHWA later provided an equivalent TL-3 rating for this bridge railing system (17).

Following a review of the TTI test results, MwRSF researchers believed that the potential existed for wheel snagging to occur on the bridge posts when impacted by a pickup truck at the TL-3 test conditions of NCHRP Report No. 350. However, this wheel snagging potential could be greatly reduced with the addition of spacers to block the thrie beam rail away from the front face of the bridge posts. Consequently, this approach was met with reluctance by MoDOT officials for two basic reasons. First, the concern for providing adequate roadway width is always an issue. Spacers incorporated into the railing system on each side of the roadway would decrease the available roadway width by approximately 304 mm. It should be noted that this lost roadway width likely could be recovered by modifying the post-to-deck attachment detail. Second, the thrie beam and channel bridge railing system was satisfactorily crash tested according to the NCHRP Report No. 230 criteria and subsequently provided a equivalent TL-3 rating by FHWA. Therefore, the approach guardrail transition would be developed for use with a thrie beam and channel bridge railing system where the thrie beam attached directly to the bridge posts without the use of spacers.

Since rail spacers would not be used in the bridge railing system, the potential for wheel snagging on the first bridge post still remained. This wheel snag potential exists for the scenario of a pickup truck impacting the transition region at the critical impact location (CIP). Therefore, the design of Missouri's approach guardrail transition must incorporate a means by which wheel snagging on the first bridge post will be eliminated. Historically, the common method for preventing wheel snagging in an approach guardrail transition system involved the placement of a rubrail below the main guardrail member and attached to the front face of the transition posts. Typically, the rubrail overlapped and was rigidly attached to the base of the rigid bridge railing system where snagging was likely to occur. This method has worked well in the past, as documented by the many successful crash tests on transition designs using passenger-size sedans.

A review was conducted on approach guardrail transitions developed for the TL-3 impact conditions to determine if any features of those designs could be implemented into the new transition configuration. Following this review, MwRSF researchers selected a transition system designed in 1997 for the Midwest States Regional Pooled Fund Program to form the basis of the transition design (9-10). Although this previously tested transition was used, modifications to this system would be necessary to account for the differences in bridge railing geometries as well as to eliminate the potential for wheel snagging.

5 APPROACH GUARDRAIL TRANSITION - DESIGN NO. 1

The total length of the installation was 26.67 m. Design details of the approach guardrail transition and bridge railing systems are provided in Figures 1 through 6. Photographs of the approach guardrail transition and bridge railing systems are shown in Figures 7 and 8. The test installation consisted of five major structural components: (1) two nested 3,810-mm long thrie beam rail sections (2.66 mm); (2) a C152x12.2 steel channel rubrail; (3) an 1,905-mm long W-beam to thrie beam transition section (2.66 mm); (4) a 15,240-mm long W-beam rail section (2.66 mm) attached to a simulated anchorage device; and (5) a 3,810-mm long thrie beam and channel bridge railing system with an attached simulated anchorage device.

The approach guardrail transition system was constructed with seventeen guardrail posts, as shown in Figures 1 through 4. Post nos. 1 through 7 consisted of galvanized, ASTM A36 steel W152x13.5 sections measuring 1,980-mm long. Post nos. 8 through 15 were also W152x13.5 steel sections but measured 1,830-mm long. Post nos. 16 and 17 were timber posts measuring 140-mm wide x 190-mm deep x 1,080-mm long and were placed in steel foundation tubes. The timber posts and foundation tubes were part of an anchorage system used to develop the required tensile capacity of the guardrail at the upstream end of the system. Lap-splice connections between the rail sections were configured to reduce vehicle snagging at the splice during the crash tests.

For post nos. 1 through 7, a wood spacer blockout, developed previously at MwRSF (9), was chosen for use with the thrie beam guardrail, as shown in Figures 1 through 3, and 8. The wood block spacer was selected since it eliminates problems associated with the torsional collapse commonly observed to occur with wide-flanged blockouts. At post no. 8, wood spacer blockouts measuring152-mm wide x 203-mm deep x 455-mm long were used, as shown in Figure 3. As shown in Figure 4, routed wood spacer blockouts measuring 152-mm wide x 203-mm deep x 360-mm long were used at post nos. 9 through 15.

The soil embedment depths for post nos. 1 through 7, 8, and 9 through 15 were 1,245 mm, 1,052 mm, and 1,100 mm, respectively, as shown in Figures 3 and 4. The steel posts were placed in a compacted coarse, crushed limestone material that met Grading B of AASHTO M147-65 (1990) as found in NCHRP Report No. 350.

A C152x12.2 steel channel rubrail was placed below the thrie beam rail and shielded the traffic-side face of transition post nos. 1 through 4, as shown in Figures 1 through 2, 4, and 7 through 8. The rubrail was rigidly attached to transition post nos. 2 and 4 and extended onto the bridge railing where it bolted to the last two bridge posts located at the end of the bridge railing system.

The thrie beam and channel bridge railing system was rigidly attached to the concrete tarmac located at the MwRSF's outdoor test site, as shown in Figures 5 and 7 through 8. All construction details for the bridge railing system are provided in Figures 5 through 6. As shown in Figure 7, a steel anchorage device was attached to the downstream end of the bridge railing to simulate a full-length bridge and to develop the required tensile capacity of the bridge railing system.

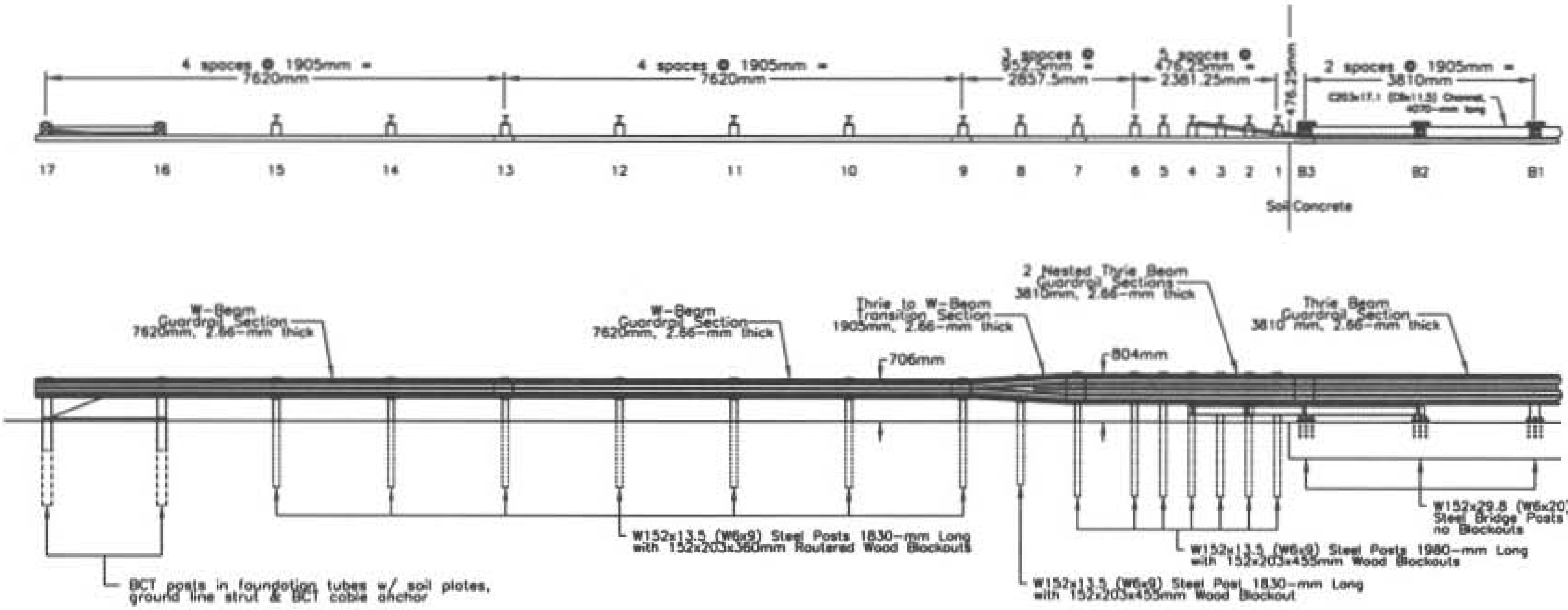


Figure 1. Installation Layout, Design No. 1

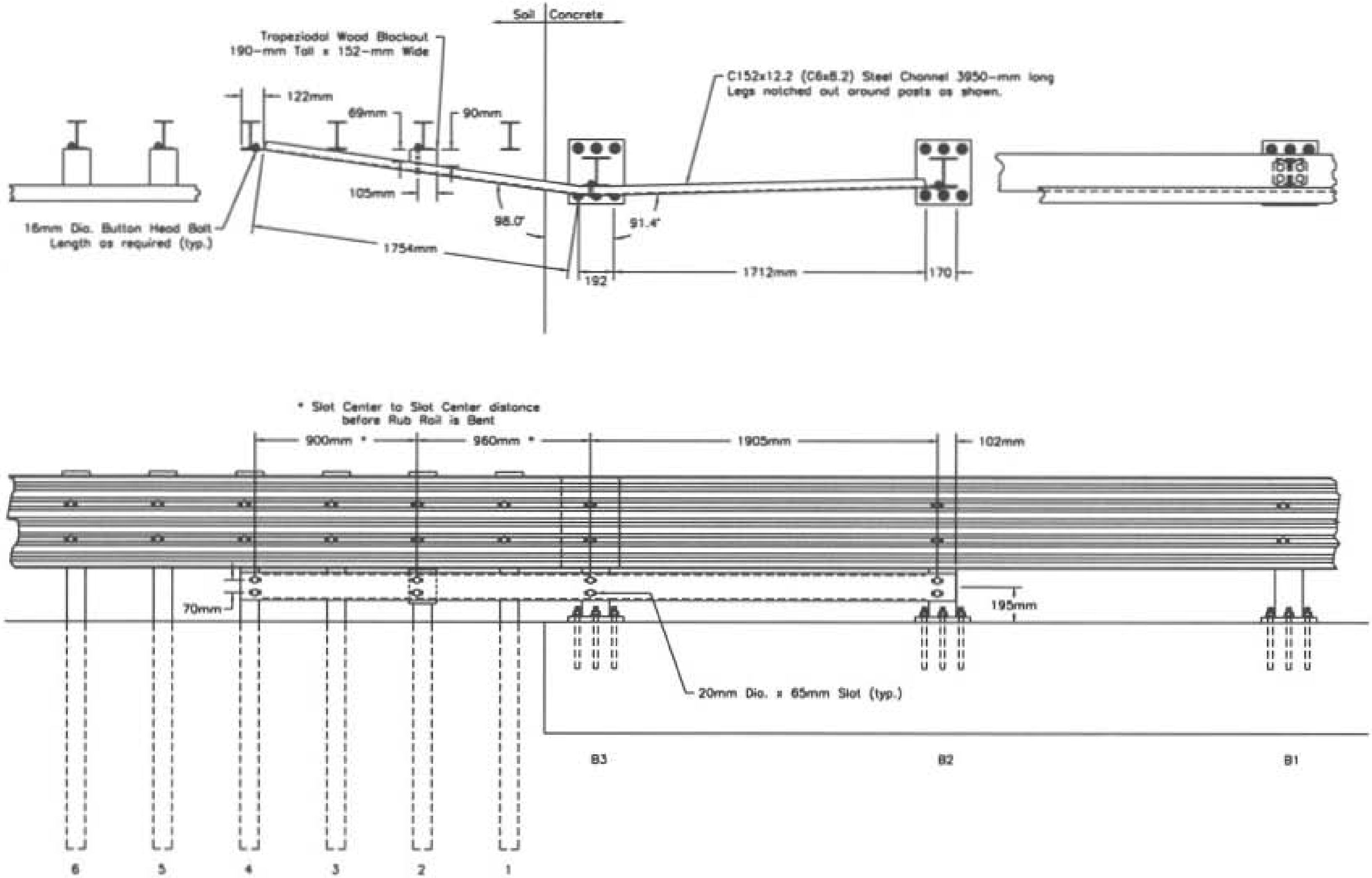


Figure 2. Installation Layout and Design Details, Design No. 1

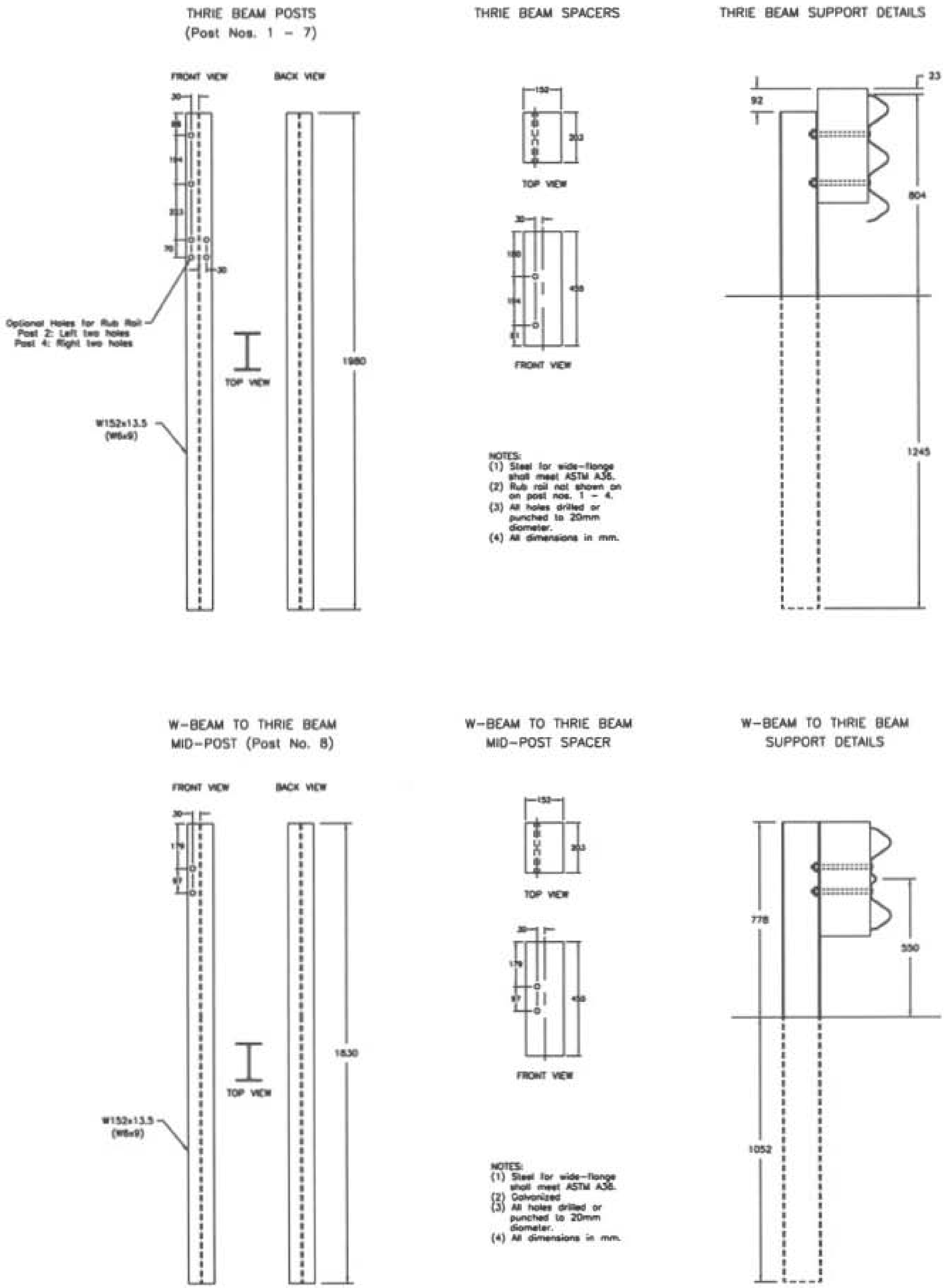


Figure 3. Design Details, Design No. 1

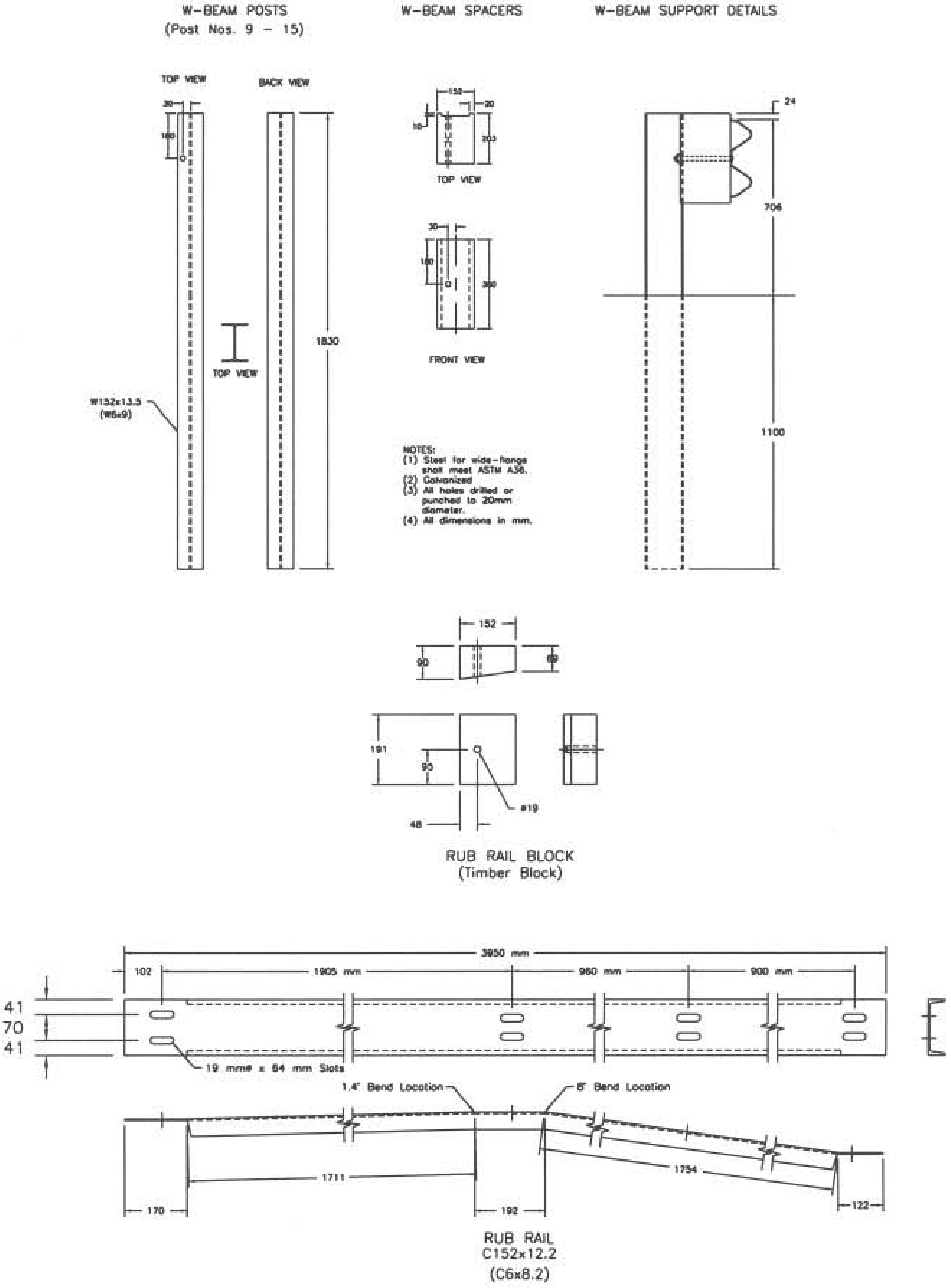


Figure 4. Design Details, Design No. 1 (Continued)

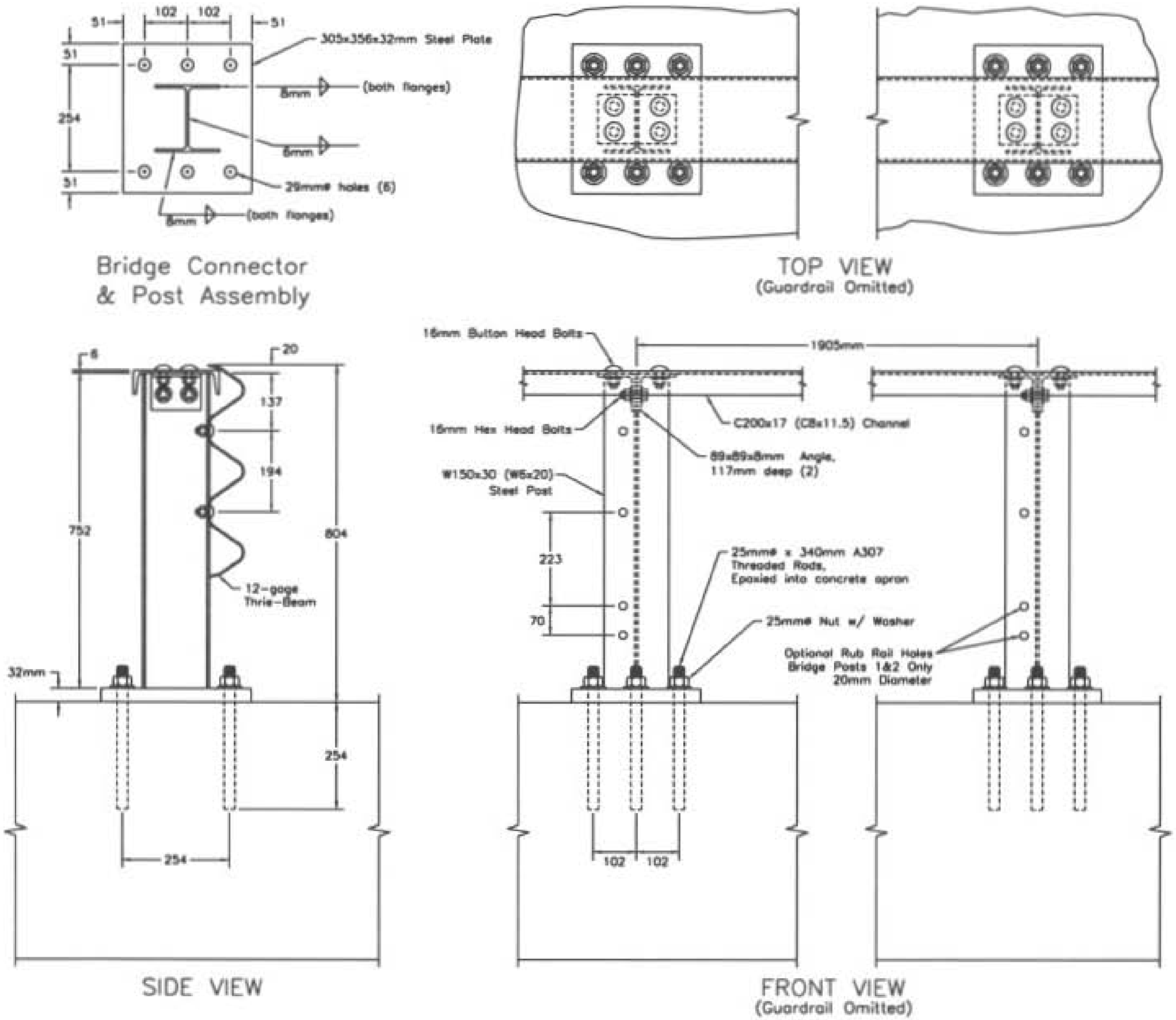
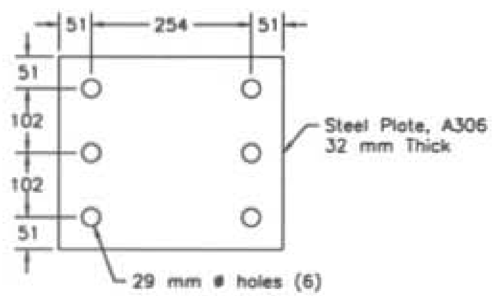
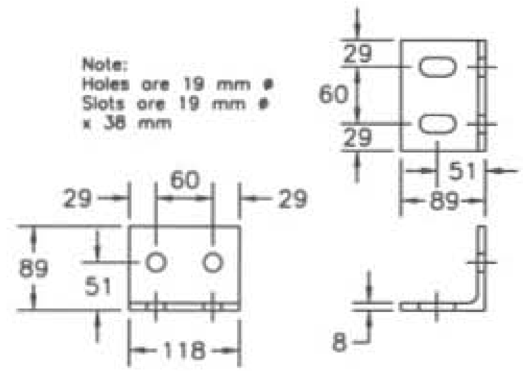


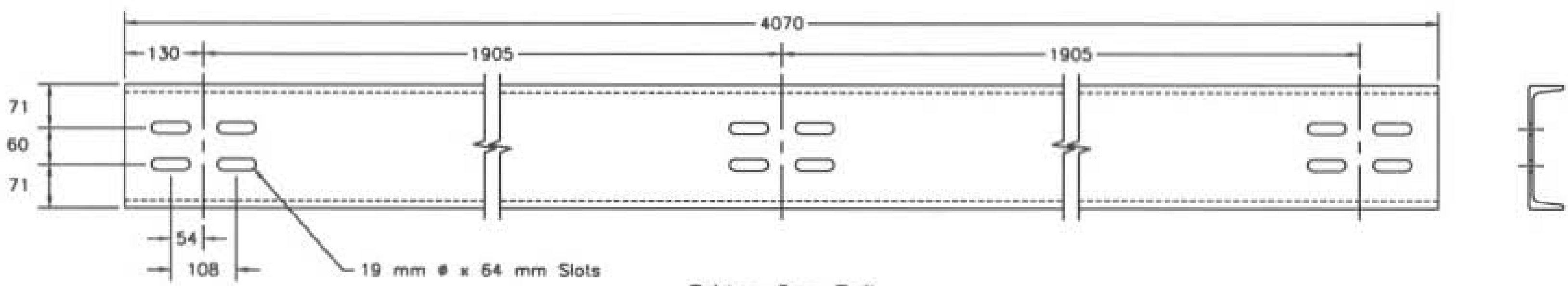
Figure 5. Thrie Beam and Channel Bridge Rail Design Details, Design No. 1



Bridge Plate
306 mm x 356 mm x 32 mm



Angle Clips
89 mm x 89 m x 8 mm



Bridge Cap Rail
C200x17
(C8x11.5)

Figure 6. Thrie Beam and Channel Bridge Rail Design Details, Design No. 1 (Continued)

Figure 7. Approach Guardrail Transition, Design No. 1

Figure 8. Approach Guardrail Transition, Design No. 1 (Continued)

6 TEST CONDITIONS

6.1 Test Facility

The testing facility is located at the Lincoln Air-Park on the NW end of the Lincoln Municipal Airport and is approximately 8.0 km NW of the University of Nebraska-Lincoln. The site is protected by an 2.44-m high chain-link security fence.

6.2 Vehicle Tow and Guidance System

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

A vehicle guidance system developed by Hinch (18) was used to steer the test vehicle. A guide-flag, attached to the front-left wheel and the guide cable, was sheared off before impact. The 9.5-mm diameter guide cable was tensioned to approximately 13.3 kN, and supported by hinged stanchions in the lateral and vertical directions and spaced every 30.48 m initially and at 15.24 m toward the end of the guidance system. 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.

6.3 Test Vehicles

For test MST-1, a 1992 GMC 2500 ¾-ton pickup truck was used as the test vehicle. The test inertial and gross static weights were 1,991 kg. The test vehicle is shown in Figure 9, and vehicle dimensions are shown in Figure 10.

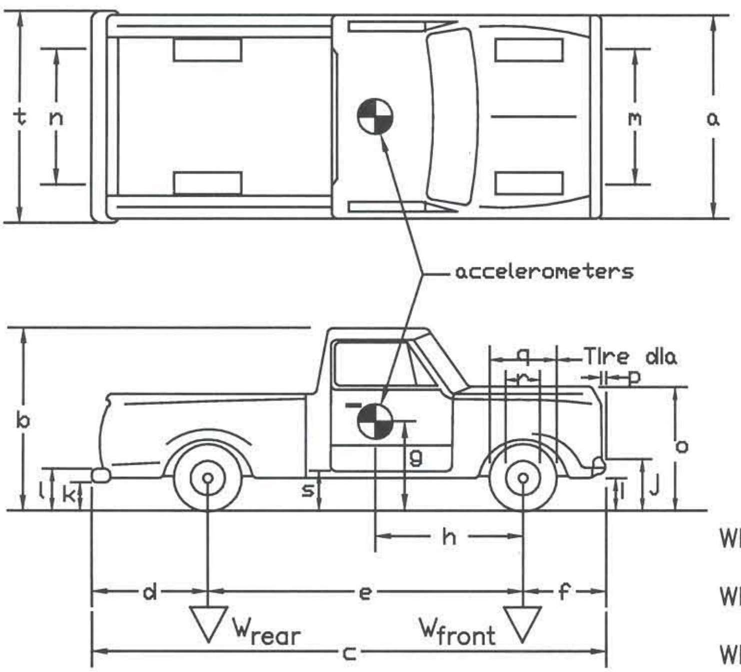
Figure 9. Test Vehicle, Test MST-1

Date: 6/24/98 Test Number: MST-1 Model: 2500

Make: GMC Vehicle I.D.#: 1GDGC24K1NE541321

Tire Size: LT245/75R16 Year: 1992 Odometer: 155,839

*(All Measurements Refer to Impacting Side)



Vehicle Geometry – mm

a	1867	b	1854
c	5550	d	1314
e	3327	f	953
g	738	h	1401
I	445	J	673
k	603	l	800
m	1603	n	1626
o	1067	p	95
q	752	r	441
s	483	t	1867

Wheel Center Height Front 368

Wheel Center Height Rear 381

Wheel Well Clearance (FR) 902

Wheel Well Clearance (RR) 956

Engine Type V-8 Gas

Engine Size 5.7 L

Transmission Type:

Automatic or Manual

FWD or RWD or 4WD

Weights – kg	Curb	Test Inertial	Gross Static
W_{front}	1182	1153	1153
W_{rear}	911	838	838
W_{total}	2093	1991	1991

Note any damage prior to test: no back window, patches on box corners

Figure 10. Vehicle Dimensions, Test MST-1

For test MST-2, a 1993 Chevrolet C-2500 ¾-ton pickup truck was used as the test vehicle. The test inertial and gross static weights were 2,042 kg. The test vehicle is shown in Figure 11, and vehicle dimensions are shown in Figure 12.

The Suspension Method (19) was used to determine the vertical component of the center of gravity for the test vehicles. This method is based on the principle that the center of gravity 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 center of gravity were established. The intersection of these planes pinpointed the location of the center of gravity. 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 10 through 12.

Square, black and white-checkered targets were placed on the vehicle to aid in the analysis of the high-speed film, as shown in Figures 9 through 14. One target was placed on the center of gravity on the driver's side door, 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 vehicles would track properly along the guide cable. Two 5B flash bulbs were mounted on both the hood and roof of the vehicles to pinpoint the time of impact with the approach guardrail transition on the high-speed film. 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.

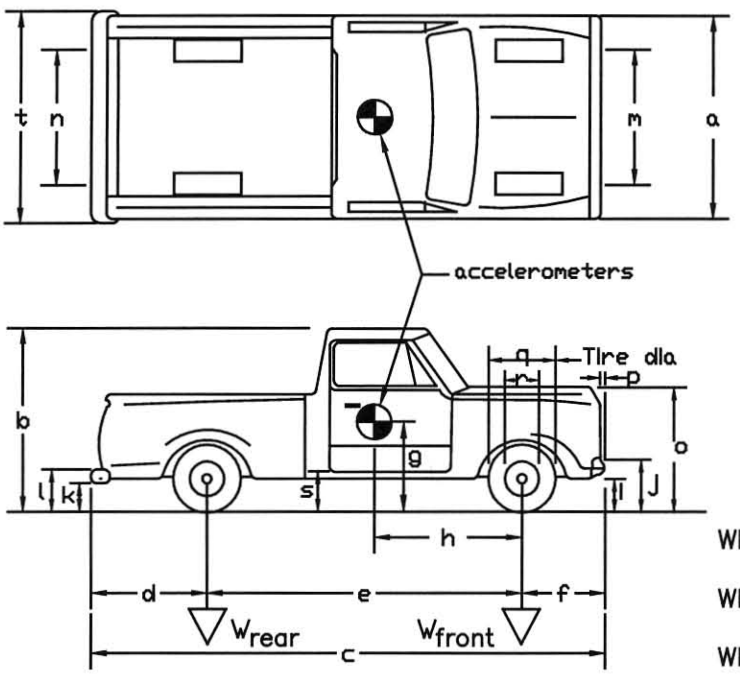
Figure 11. Test Vehicle, Test MST-2

Date: 12/4/98 Test Number: MST-2 Model: 2500

Make: Chevrolet Vehicle I.D.#: 1GCGC34K6PE251749

Tire Size: LT245/75R16 Year: 1993 Odometer: 190,761

*(All Measurements Refer to Impacting Side)



Vehicle Geometry – mm

a	1899	b	1861
c	5563	d	1283
e	3327	f	927
g	738	h	1446
I	489	J	711
k	610	l	806
m	1588	n	1626
o	1067	p	25
q	762	r	445
s	508	t	1854

Wheel Center Height Front 365

Wheel Center Height Rear 371

Wheel Well Clearance (FL) 924

Wheel Well Clearance (RL) 968

Engine Type V-8 Gas

Engine Size 5.7 L

Transmission Type:

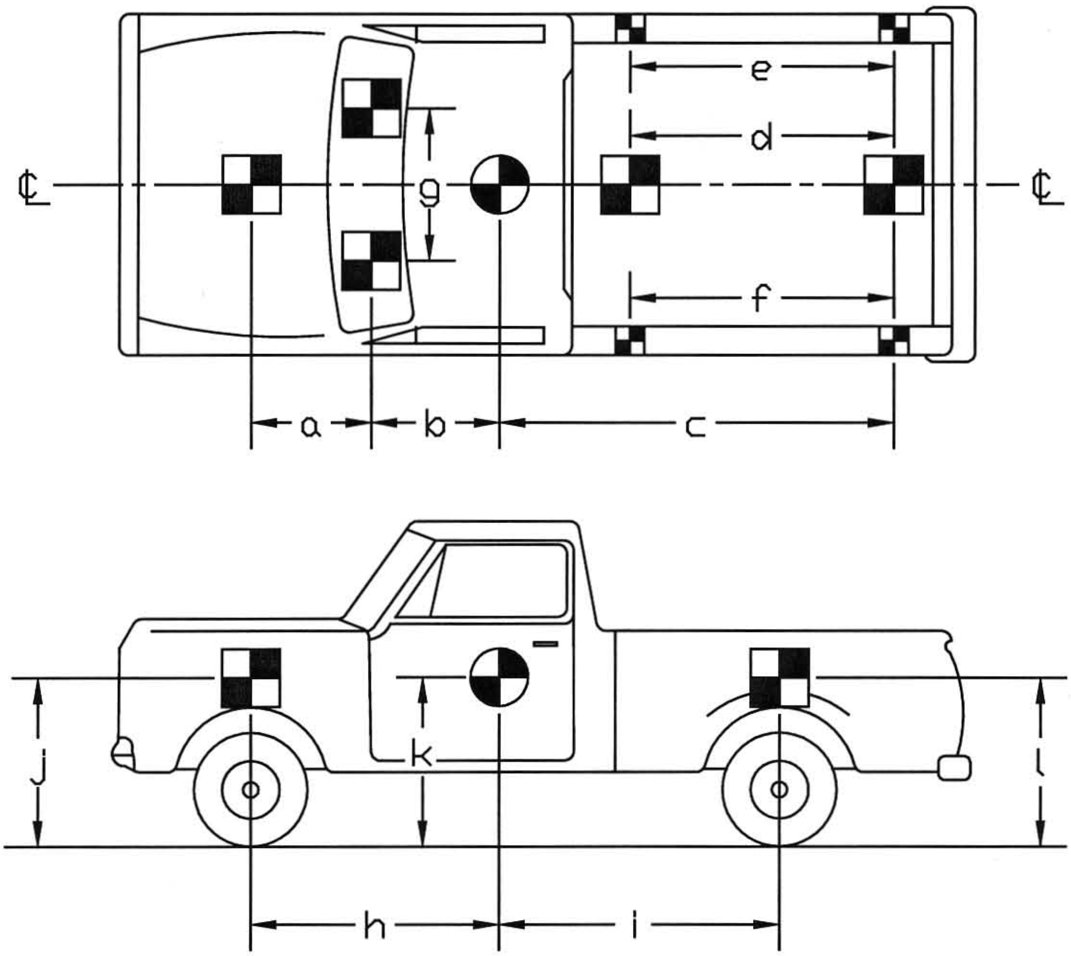
Automatic or Manual

FWD or RWD or 4WD

Weights – kg	Curb	Test Inertial	Gross Static
W_{front}	1222	1155	1155
W_{rear}	983	888	888
W_{total}	2205	2043	2043

Note any damage prior to test: dent by passenger door hinge

Figure 12. Vehicle Dimensions, Test MST-2

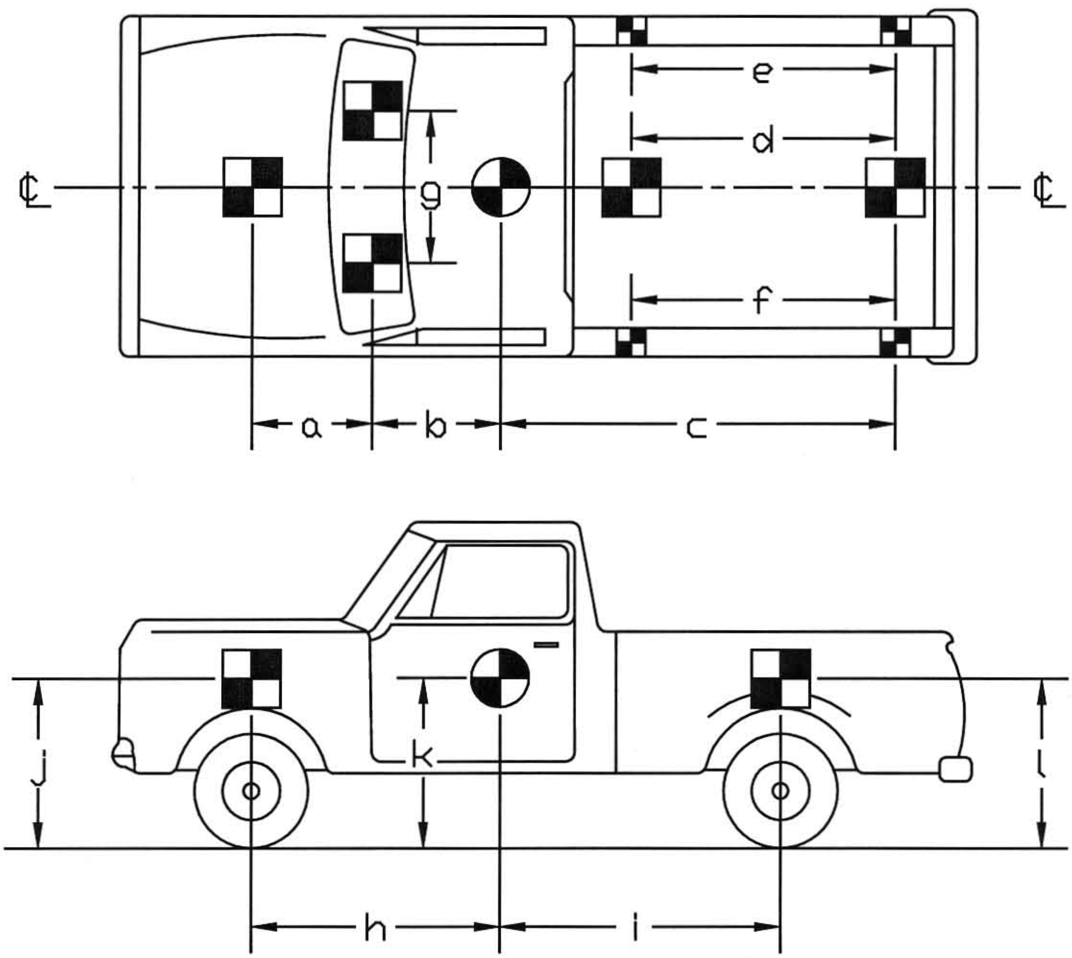


TEST #: MST-1

TARGET GEOMETRY (mm)

a	1158	b	616	c	2515	d	1607
e	2070	f	2080	g	860	h	1401
i	1956	j	1003	k	738	l	1064

Figure 13. Vehicle Target Locations, Test MST-1



TEST #: MST-2

TARGET GEOMETRY (mm)

a	991	b	718	c	2356	d	1578
e	2153	f	2153	g	1019	h	1446
i	1905	j	1016	k	738	l	1067

Figure 14. Vehicle Target Locations, Test MST-2

6.4 Data Acquisition Systems

6.4.1 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" were used to digitize, analyze, and plot the accelerometer data.

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

6.4.2 Rate Transducer

A Humphrey 3-axis rate transducer with a range of 250 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 vehicles 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 plotting. Computer software, "DynaMax 1

(DM-1)" and "DADiSP" were used to digitize, analyze, and plot the rate transducer data.

6.4.3 High-Speed Photography

For test MST-1, six high-speed 16-mm Red Lake Locam cameras, with operating speeds of approximately 500 frames/sec, were used to film the crash test. A Locam, with a wide-angle 12.5-mm lens, was placed above the test installation to provide a field of view perpendicular to the ground. A Locam with a zoom lens, a SVHS video camera, and a 35-mm still camera were placed downstream from the impact point and had a field of view parallel to the barrier. A Locam, with a zoom lens, and a SVHS video camera were placed on the traffic side of the barrier and had a field of view perpendicular to the barrier. A Locam, with a 12.5-mm lens, was placed upstream and behind the barrier. A Locam and a SVHS video camera were placed downstream and behind the barrier. Another Locam was placed downstream and behind the barrier but closer to the system. A schematic of all ten camera locations for test MST-1 is shown in Figure 15.

For test MST-2, five high-speed 16-mm Red Lake Locam cameras, with operating speeds of approximately 500 frames/sec, were used to film the crash test. A Locam ,with a wide-angle 12.5-mm lens, was placed above the test installation to provide a field of view perpendicular to the ground. A Locam, with a zoom lens, a SVHS video camera, and a 35-mm still camera were placed downstream from the impact point and had a field of view parallel to the barrier. A Locam, with a zoom lens, and a SVHS video camera were placed on the traffic side of the barrier and had a field of view perpendicular to the barrier. A Locam, with a 12.5-mm lens, was placed downstream and behind the barrier. Another Locam was placed downstream and behind the barrier but closer to the system. A schematic of all eight camera locations for test MST-2 is shown in Figure 16. The film was analyzed using the Vanguard Motion Analyzer. Actual camera speed and camera divergence factors were considered in the analysis of the high-speed film.

6.4.4 Pressure Tape Switches

For both crash tests, five pressure-activated tape switches, spaced at 2-m 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 left front tire of the test vehicle passed over it. Test vehicle speeds were determined from electronic timing mark data recorded on "Test Point" software. Strobe lights and high-speed film analysis are used only as a backup in the event that vehicle speeds cannot be determined from the electronic data.

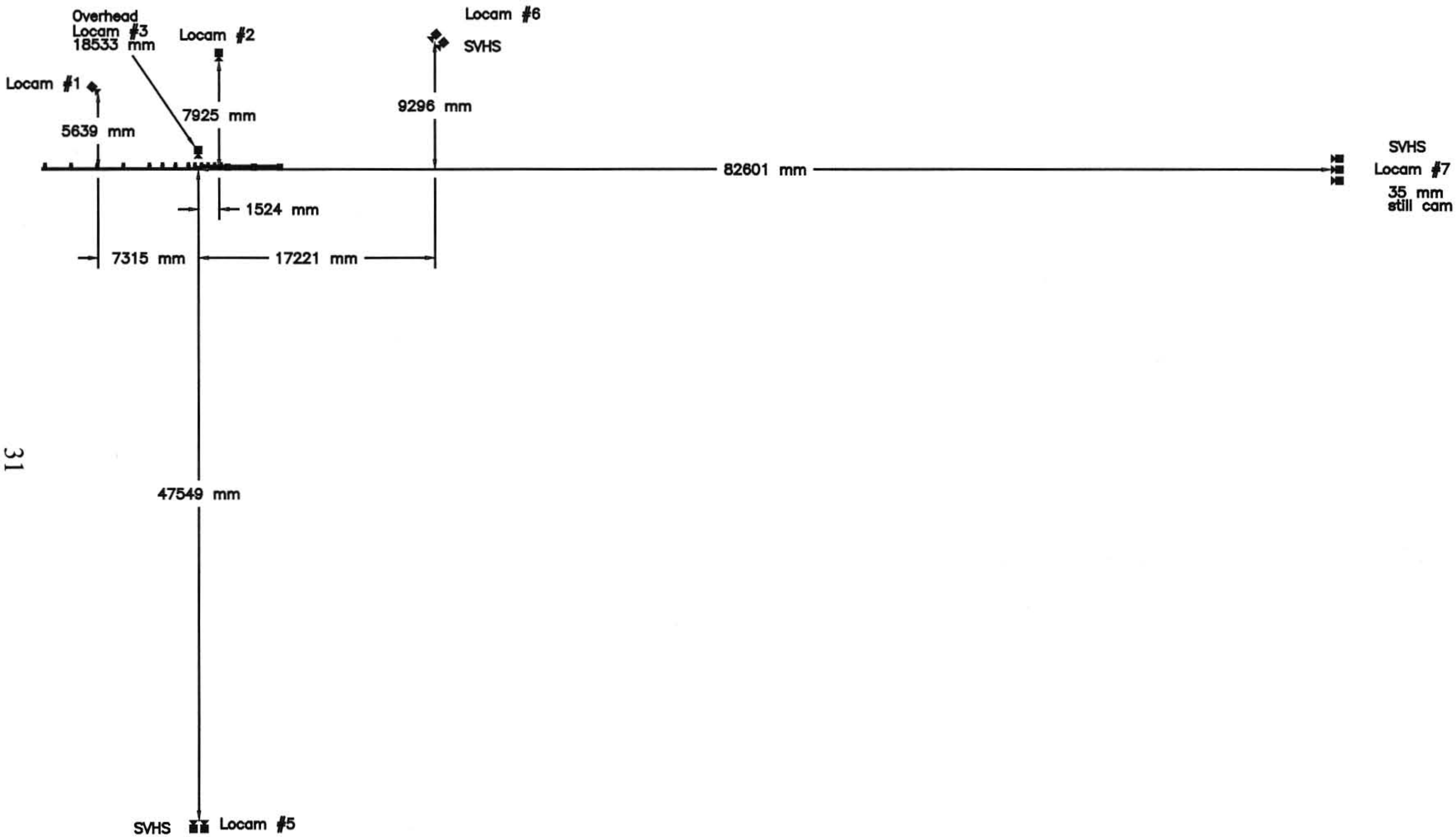


Figure 15. Location of High-Speed Cameras, Test MST-1

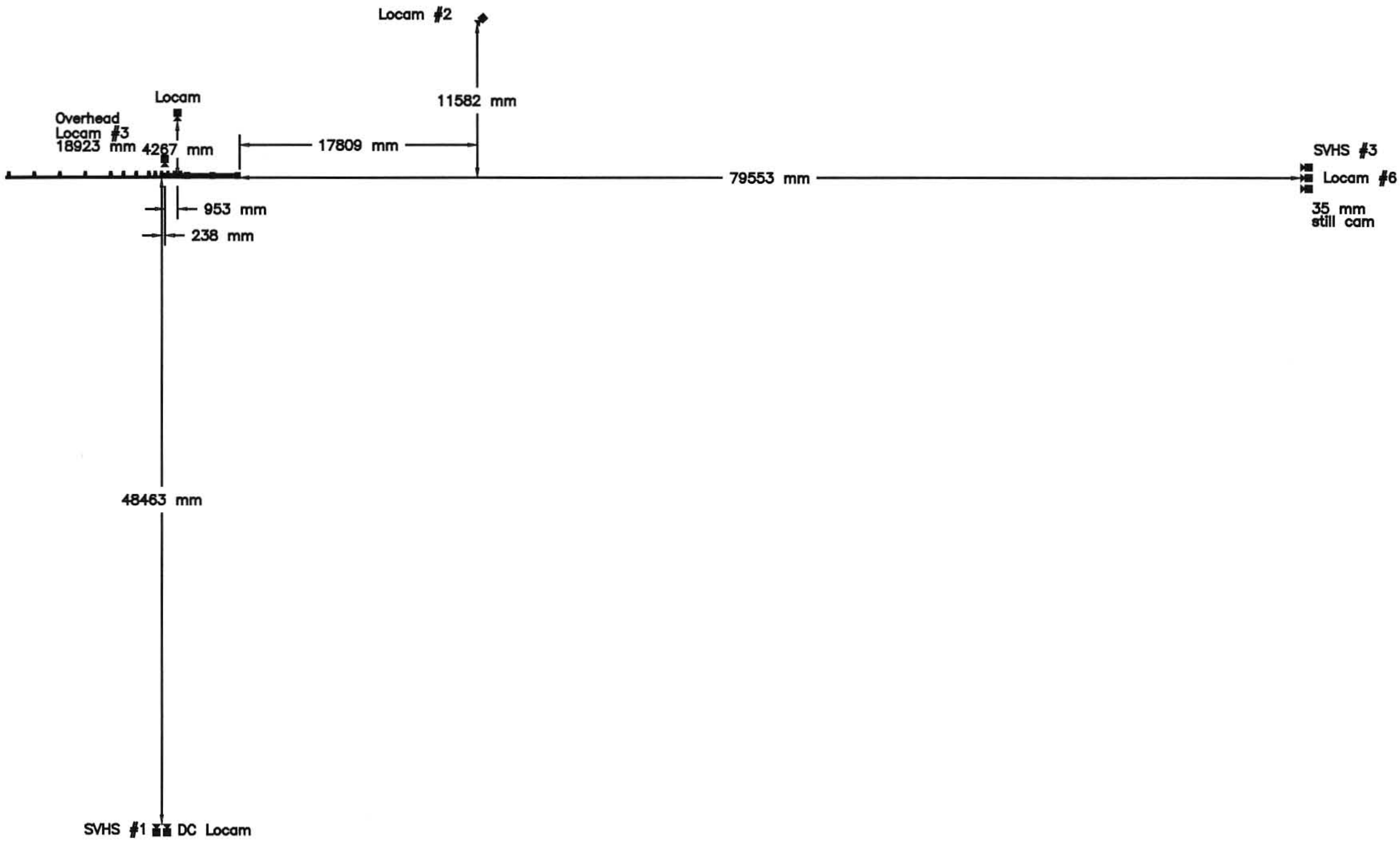


Figure 16. Location of High-Speed Cameras, Test MST-2

7 COMPUTER SIMULATION - DESIGN NO. 1

7.1 Background

Computer simulation modeling with BARRIER VII (20) was performed to analyze and predict the dynamic performance of an approach guardrail transition design attached to Missouri's thrie beam and channel rail bridge railing prior to full-scale vehicle crash testing. The simulations were conducted modeling a 2000-kg pickup truck impacting at a speed of 100.0 km/hr and at an angle of 25 degrees. Typical computer simulation input data files are shown in Appendix A.

Computer simulation was also used to determine the critical impact point (CIP) for the approach guardrail transition. The CIP was based upon the impact condition which produced the greatest potential for wheel-assembly snagging on the upstream side of the first bridge post and occurring in combination with the maximum lateral dynamic rail deflection. The researchers believe that wheel snag distances in excess of 51 mm, for the outer tire or steel rim, results in an increased potential for snagging and contact on the front flange of the first bridge post. As previously discussed, the bridge posts were not blocked away from the back of the thrie beam rail. Therefore, a steel channel rubrail was added to the system in order to reduce the potential for wheel snagging on the first bridge post.

7.2 Design Option

BARRIER VII computer simulation modeling was performed on only one design option. However, the analysis was repeated using two different post capacities to determine a potential range in performance. The transition design was constructed with two nested thrie beam rails, measuring 2.66-mm thick, and supported by nine W152x13.5 steel posts. Post spacings consisted of six at 476 mm and three at 952 mm. Post nos. 1 through 7 were 1,980-mm long with a 1,245-mm embedment depth. It is noted that the C152x12.2 steel channel rubrail was not included in the model; since, a member of this particular size and orientation does not significantly effect the dynamic performance of the approach guardrail transition system.

7.3 BARRIER VII Results

Eleven computer simulation runs were performed on one design option but with two different post capacities and at different impact locations. The computer simulation results, as shown in Table 2, indicated that the potential for wheel snagging on the first bridge post would not occur if 152-mm deep spacer blocks were incorporated into the bridge railing system. As shown in Table 2, the maximum tire or rim overlap distance was found to be 88 mm which is considerably less than the 152-mm distance a blocked-out post would be positioned away from the back of the guardrail. However, since the MoDOT chose not to use spacer blocks in the bridge railing, a rubrail was required in the transition system to eliminate the potential for wheel snagging. The CIP was also determined to occur with an impact between post nos. 4 and 5 or 2,143 mm upstream from the centerline of the first bridge post. For the CIP, the predicted maximum lateral dynamic thrie beam rail deflection ranged between 136 and 151 mm, as measured to the center height of the rail.

Table 2. Computer Simulation Test Matrix and Results - Design No. 1

Run No.	Impact Node	Transition Post Yield Moment (kN-mm)	Impact Distance[1] (mm)	Maximum Tensile Force @ Thrie Beam (kN)	Maximum Dynamic Rail Deflection (Center Height) (mm)	Maximum Permanent Set Rail Deflection (Center Height) (mm)	Lateral Wheel-Assembly Snag Potential[2]	
							Tire Contact Distance (mm)	Rim Contact Distance (mm)
A0	25	47454	2858	292.60	150	68	28	NA
A1	26	47454	2619	321.83	151	66	50	19
A2	27	47454	2381	336.11	145	70	69	31
A3	28	47454	2153	348.92	136	72	78	39
A4	29	47454	1905	297.54	124	64	79	44
A5	30	47454	1667	224.23	107	57	75	49
A6	31	47454	1429	146.08	88	52	64	42
B2	27	38010	2381	397.36	164	91	80	39
B3	28	38010	2153	402.70	151	92	87	47
B4	29	38010	1905	337.66	135	82	88	51
B5	30	38010	1667	251.90	115	69	82	53

[1] - Longitudinal distance measured from the impact location to the centerline of the first bridge post.
[2] - Lateral distance of wheel-assembly measured behind original location of thrie beam rail. This lateral distance is measured when the longitudinal position of the outer tire or steel rim reaches the front flange of the first bridge post.

8 CRASH TEST NO. 1

8.1 Test MST-1

The 1,991-kg pickup truck impacted the approach guardrail transition at a speed of 101.4 km/hr and an angle of 27.5 degrees. A summary of the test results and the sequential photographs are shown in Figure 17. Additional sequential photographs are shown in Figures 18 through 19. Documentary photographs of the crash test are shown in Figures 20 and 21.

8.2 Test Description

Initial impact occurred between post nos. 4 and 5 or 238-mm downstream from the center of post no. 5, as shown in Figure 22. At 0.014 sec after impact, the left-front corner of the vehicle was at post no. 4, and the guardrail was crushing the front bumper and left-front corner of the vehicle inward toward the engine compartment. At 0.028 sec, the vehicle's left-front corner was at post no. 3 and later began to override the rail between post nos. 3 and 4. At this same time, the right side of the engine hood popped open. At 0.038 sec, post no. 3 rotated backward, and the left-front corner of the vehicle contacted the wood blockout at post no. 3. At 0.042 sec, the left-front corner of the vehicle was at post no. 2, and the vehicle was overriding the rail between post nos. 2 and 4. At 0.048 sec, the left-front corner of the vehicle contacted the top of the wood blockout at post no. 2 as post no. 2 rotated backward. At 0.052 sec, the front of the vehicle was at post no. 1, and the vehicle had not been redirected away from its original yaw orientation. At 0.068 sec, the front of the vehicle was at bridge post no. B3, and the vehicle was overriding the guardrail between post nos. B3 and 4. At this same time, the top of the left-side door separated from the top of the cab. At 0.077 sec, post no. 1 rotated backward as the blockout at post no. 1 fractured. At 0.104 sec, the front of the vehicle was at the midspan between bridge post nos. B2 and B3, and the vehicle began to roll counter-clockwise

(CCW). At this same time, the left-side door was deforming around the rail, and the left-side window shattered. At 0.120 sec, the right-front tire became airborne. At 0.130 sec, the vehicle was redirecting with the left-rear side of the cab in contact with the system. At 0.154 sec, the front of the vehicle was at bridge post no. B2. At 0.198 sec, the left-front corner of the vehicle was at the midspan between bridge post nos. B1 and B2. At 0.242 sec, the vehicle rolled CCW, allowing the right-rear tire to become airborne. At 0.272 sec, the vehicle continued to be redirected when it yawed CW with the left-rear corner of the vehicle contacting the system. At 0.278 sec after impact, the vehicle pitched forward. At 0.320 sec, the left-front tire bent under the vehicle. At 0.354 sec after impact, the vehicle became parallel to the barrier with a velocity of 67.7 km/hr as the vehicle rolled CCW. At 0.485 sec after impact, the vehicle, which continued to roll CCW, exited the guardrail at an angle of 1.9 degrees and a speed of 66.5 km/hr. At 0.582 sec, the left-front corner of the vehicle impacted the ground. At 0.802 sec, the vehicle slid along the ground with the left-front corner in contact with the ground. At 1.352 sec after impact, the left-side door contacted the ground as the vehicle rolled CCW onto its side. The vehicle's post-impact trajectory is shown in Figures 17 and 23. The vehicle came to rest 39.62 m downstream from impact and 7.47 m away from the traffic-side face of the rail, as shown in Figures 17 and 23.

8.3 Barrier Damage

Damage to the barrier was moderate, as shown in Figures 24 through 25. Barrier damage consisted mostly of deformed thrie beam, contact marks on the thrie beam, top channel, rubrail, and bridge post base plate, and damaged spacer blocks. The thrie beam damage consisted of moderate deformation and flattening of the impacted section between post nos. 5 and B3. Contact marks were found on the thrie beam between post nos. 5 and B2. Contact marks were also found on the rubrail from the centerline of post no. 3 to 330 mm downstream of bridge post no. B3. Superficial contact marks were found on the top face of the upper channel and the base plate of bridge post no. B3. The wooden spacer blocks of post nos. 1 through 3 were contacted by the thrie beam rail and were damaged. No significant damaged occurred to the posts, the W-beam, nor the W-beam to thrie beam transition rails.

The permanent set of the guardrail and posts is shown in Figure 25. The maximum lateral permanent set thrie beam rail, post, and channel rail deflections were approximately 58 mm at the center line of post no. 2, 57 mm at post no. 2, and 16 mm at bridge post no. B3, respectively, as measured in the field. The maximum lateral dynamic thrie beam rail, post, and channel rail deflections were 152 mm at the centerline of post no. 3, 141 mm at post no. 4, and 54 mm at bridge post no. B3, respectively, as determined from the high-speed film analysis.

8.4 Vehicle Damage

Exterior and interior vehicle damage was extensive and occurred at several body locations, as shown in Figures 26 through 28. The left-front quarter, including the fender, bumper, wheel assembly, and suspension components were crushed inward toward the engine compartment. The left-front upper control arm was disengaged, and the tire rod was ripped off. The perimeter of the left-rear steel rim had minor damage, and the tire was flat. The left-rear leaf spring shackle was disengaged. Scrape marks were found along the left side. Major damage occurred to the left door, including a rip in the lower rear of the door, outward buckling of the top of the door, and a shattered window. The hood popped open, and the right door was ajar. Minor cracking occurred to the windshield and the dash was also buckled. The floorboard of the occupant compartment also sustained significant plastic deformations due to the severe impact with the barrier as well as from vehicle rollover. The right-door and rear windows remained undamaged.

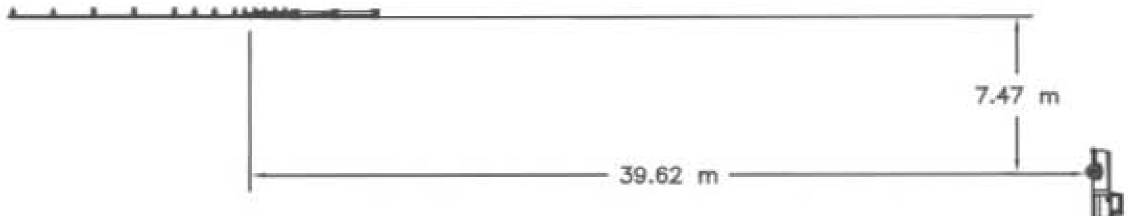
8.5 Occupant Risk Values

The normalized longitudinal and lateral occupant impact velocities were determined to be 6.16 m/sec and 6.78 m/sec, respectively. The maximum 0.010-sec average occupant ridedown decelerations in the longitudinal and lateral directions were 14.28 g's and 20.98 g's (not required), respectively. It is noted that the occupant impact velocities (OIV) and occupant ridedown decelerations (ORD) were within the suggested limits provided in NCHRP Report No. 350. The results of the occupant risk, determined from accelerometer data, are summarized in Figure 17. Results are shown graphically in Appendix B. The results from the rate transducer are shown graphically in Appendix C.

8.6 Discussion

The analysis of the test results for test MST-1 showed that the barrier satisfactorily contained the vehicle but inadequately redirected the vehicle since the vehicle did not remain upright after collision with the approach guardrail transition. Detached elements, fragments, or other debris from the test article did not penetrate or show potential for penetrating the occupant compartment, or present undue hazard to other traffic. Major deformations to the occupant compartment were evident and were considered excessive enough to cause serious injuries to the occupants. After collision, the vehicle's trajectory intruded into adjacent traffic lanes. Therefore, test MST-1 conducted on the approach guardrail transition was determined to be unacceptable according to the NCHRP Report No. 350 criteria.

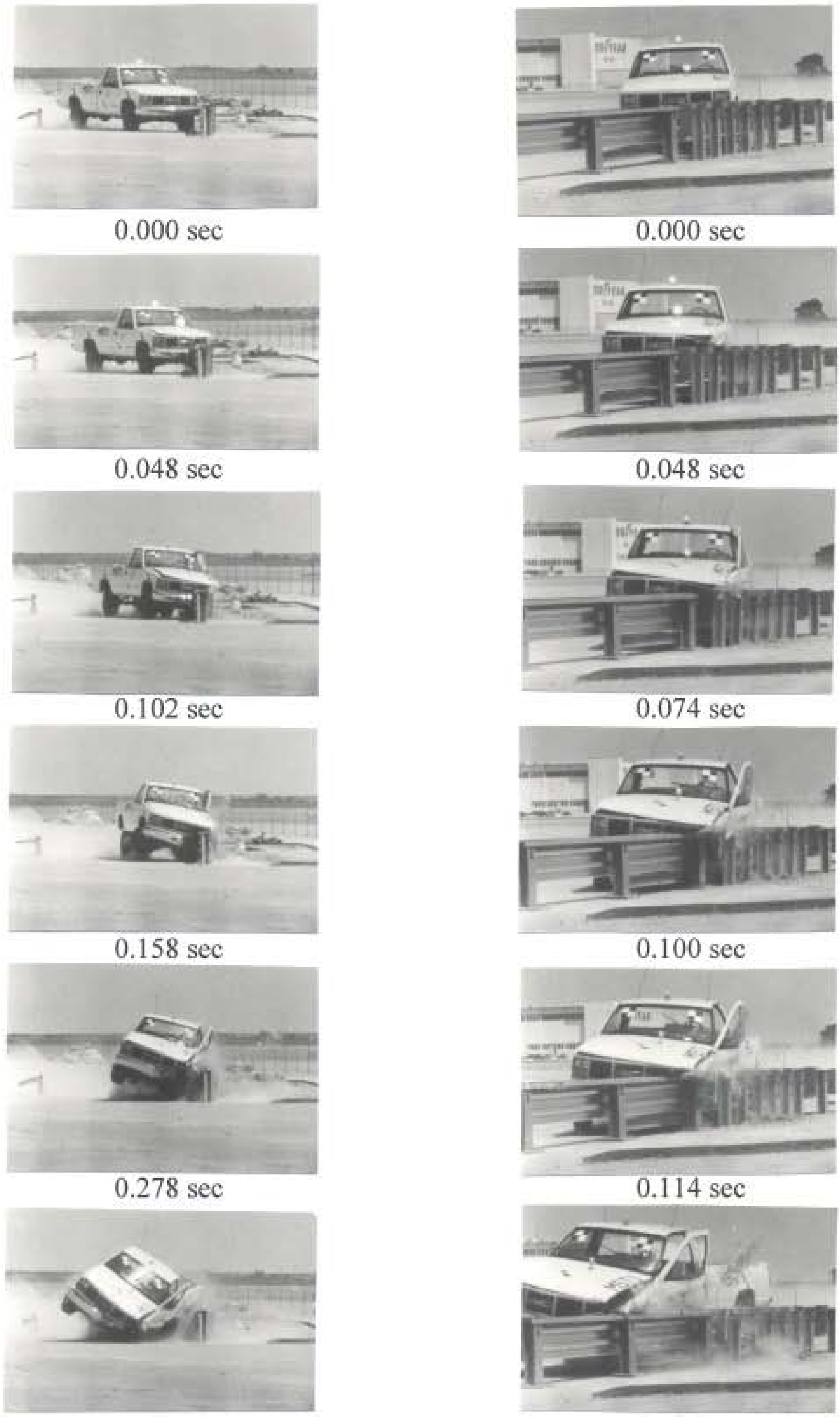
0.000 sec　0.042 sec　0.104 sec　0.154 sec　0.272 sec



• Test Number	MST-1
• Date	6/24/98
• Appurtenance	Approach Guardrail Transition to a Thrie Beam and Channel Bridge Railing
• Total Length	26.67 m
• Steel Thrie Beam (Nested)	
Thickness	2.66 mm
Top Mounting Height	804 mm
• Steel Posts	
Post Nos. 1 - 7	W152x13.5 by 1,980-mm long
Post Nos. 8 - 15	W152x13.5 by 1,830-mm long
• Steel Spacer Blocks	
Post Nos. 1 - 8	W152x203 by 455-mm long
Post Nos. 9 - 15	W152x203 by 360-mm long
• Soil Type	Grading B - AASHTO M 147-65 (1990)
• Vehicle Model	1992 GMC 2WD
Curb	2,093 kg
Test Inertial	1,991 kg
Gross Static	1,991 kg
• Vehicle Speed	
Impact	101.4 km/hr
Exit	66.5 km/hr

• Vehicle Angle	
Impact	27.5 degrees
Exit	1.9 degrees
• Vehicle Snagging	Minor contact on top of spacer blocks
• Vehicle Pocketing	None
• Vehicle Stability	Vehicle rollover
• Occupant Ridedown Deceleration (10 msec avg.)	
Longitudinal	14.10 < 20 G's
Lateral (not required)	21.62
• Occupant Impact Velocity	
Longitudinal	7.26 < 12 m/s
Lateral (not required)	7.76
• Vehicle Damage	Extensive
TAD[21]	NA
SAE[22]	NA
• Vehicle Stopping Distance	39.62 m downstream 7.47 m traffic-side face
• Barrier Damage	Moderate
• Maximum Deflections	
Permanent Set – Thrie Beam	58 mm
Channel Rail	16 mm
Dynamic – Thrie Beam	152 mm
Channel Rail	54 mm

Figure 17. Summary of Test Results and Sequential Photographs, Test MST-1



0.000 sec | 0.000 sec

0.048 sec | 0.048 sec

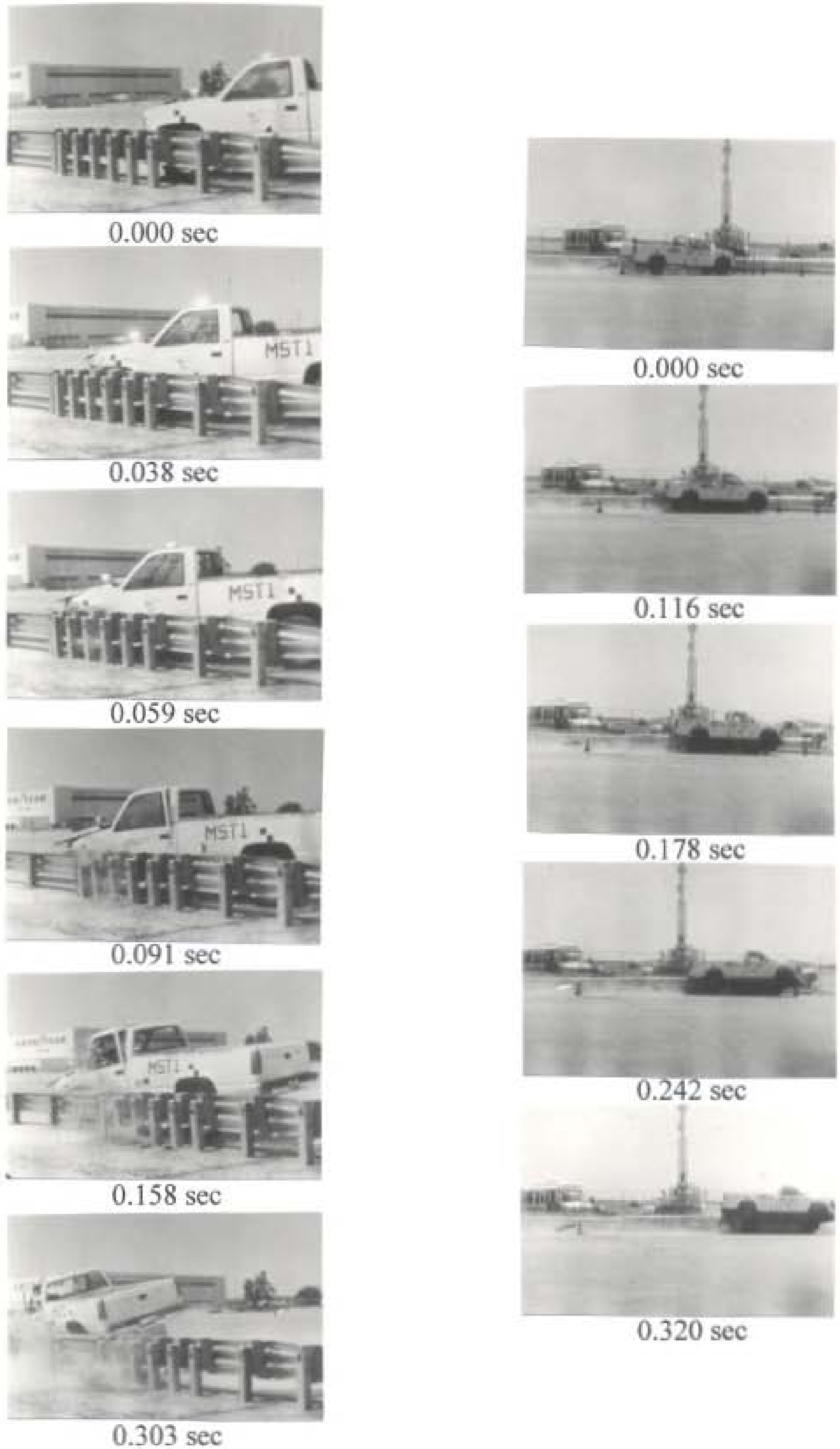
0.102 sec | 0.074 sec

0.158 sec | 0.100 sec

0.278 sec | 0.114 sec

0.486 sec | 0.184 sec

Figure 18. Additional Sequential Photographs, Test MST-1



0.000 sec

0.038 sec

0.059 sec

0.091 sec

0.158 sec

0.303 sec

0.000 sec

0.116 sec

0.178 sec

0.242 sec

0.320 sec

Figure 19. Additional Sequential Photographs, Test MST-1

Figure 20. Documentary Photographs, Test MST-1

Figure 21. Documentary Photographs, Test MST-1

Figure 22. Impact Location, Test MST-1

Figure 23. Final Vehicle Position, Test MST-1

Figure 24. Approach Guardrail Transition Damage, Test MST-1

Figure 25. Permanent Set Deflections, Test MST-1

Figure 26. Vehicle Damage, Test MST-1

Figure 27. Vehicle Damage, Test MST-1

Figure 28. Occupant Compartment Deformations, Test MST-1

9 DISCUSSION AND MODIFICATIONS (DESIGN NO. 2)

Following the unsuccessful crash test of Design No. 1, it was necessary to determine the cause of the poor barrier performance and subsequent vehicle rollover so that design modifications could be made to the system. A careful examination of the damaged barrier system and an analysis of the test results revealed that the vehicle contacted the transition system and exited the system with barrier deflections that were within those predicted by computer simulation. As the vehicle was redirected, excessive roll and yaw motions were experienced in conjunction with the left-front wheel assembly collapsing into a horizontal position. As previously discussed, the approach guardrail transition incorporates a rubrail to prevent wheel snagging on the first bridge post; since, the bridge railing does not incorporate a blockout to position the thrie beam away from the face of the bridge posts. Therefore, it is believed that the contact between the wheel assembly and the rubrail may have influenced the angular motions of the vehicle enough to cause the vehicle to roll onto its side upon redirection.

After this investigation, the researchers believed that the safety performance of the approach guardrail transition could be significantly improved with a reduction in lateral rail deflections and minimize the effect of the wheel and rubrail interaction. Several alternatives were investigated to improve the safety performance of the approach guardrail transition. These alternatives include the following: (1) increasing the stiffness of the transition region in order to reduce the effect of the contact between the rubrail and wheel assembly; (2) eliminating the rubrail completely; and (3) configuring the bridge railing with blockouts and removing the rubrail. Based on a review by MoDOT - Bridge Division, it was recommended that we proceed with the first alternative.

The modifications made to the approach guardrail transition system were as follows. The length of post nos. 1 through 7 were increased by 305 mm, resulting in a total length of 2,135 mm. The embedment depths for post nos. 1 through 4 and 5 through 7 were increased by 99 mm and 63 mm, respectively, resulting in total embedment depths of 1,344 mm and 1,308 mm, respectively. The length of the wood blockout for post nos. 1 through 4 was reduced by 99 mm, resulting in a total length of 356 mm. The vertical positioning of the wooden blockout as well as the post embedment depth for post nos. 1 through 7 were also modified. A channel cap rail was added to the transition region between post nos. 1 and 4. Design details of the modified approach guardrail transition and bridge railing systems are provided in Figures 29 through 35. Photographs of the modified approach guardrail transition and bridge railing systems are shown in Figures 36 and 37.

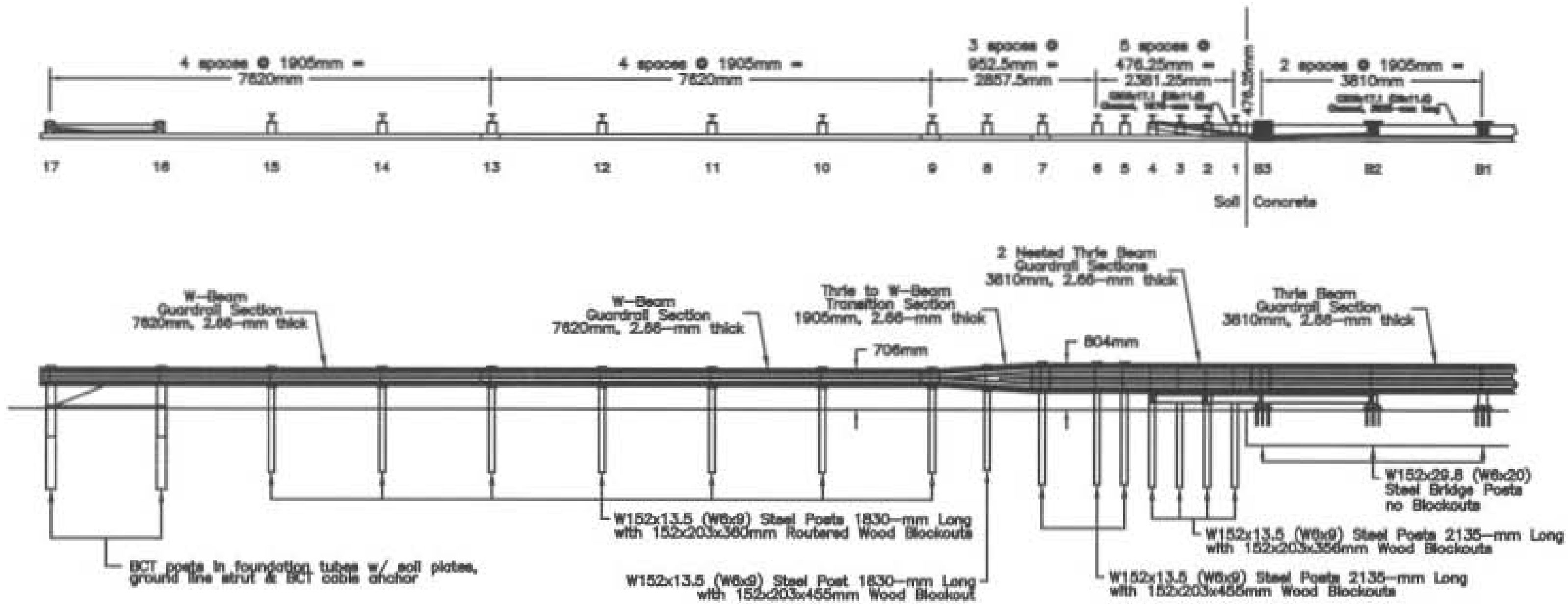


Figure 29. Installation Layout, Design No. 2

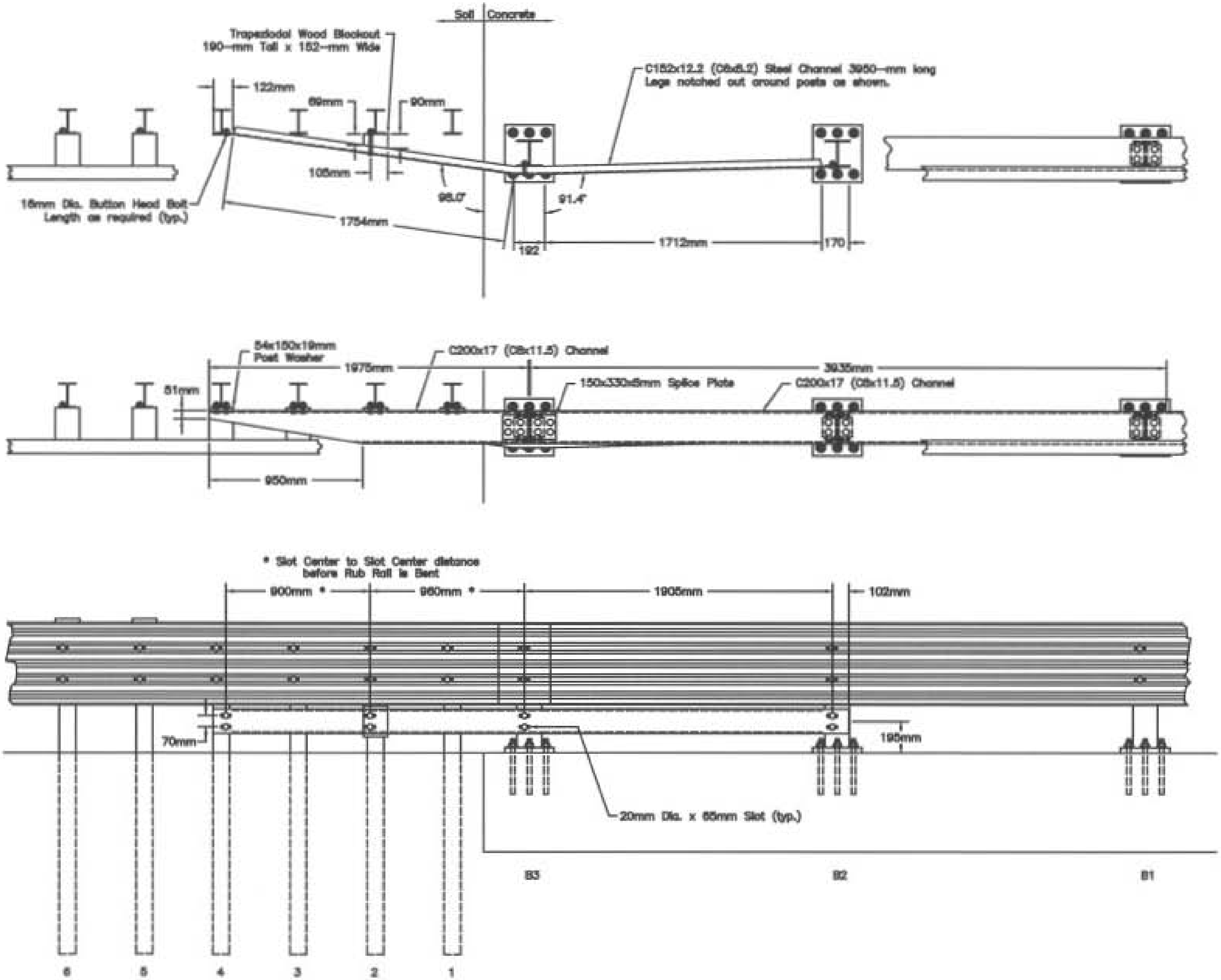


Figure 30. Installation Layout and Design Details, Design No. 2

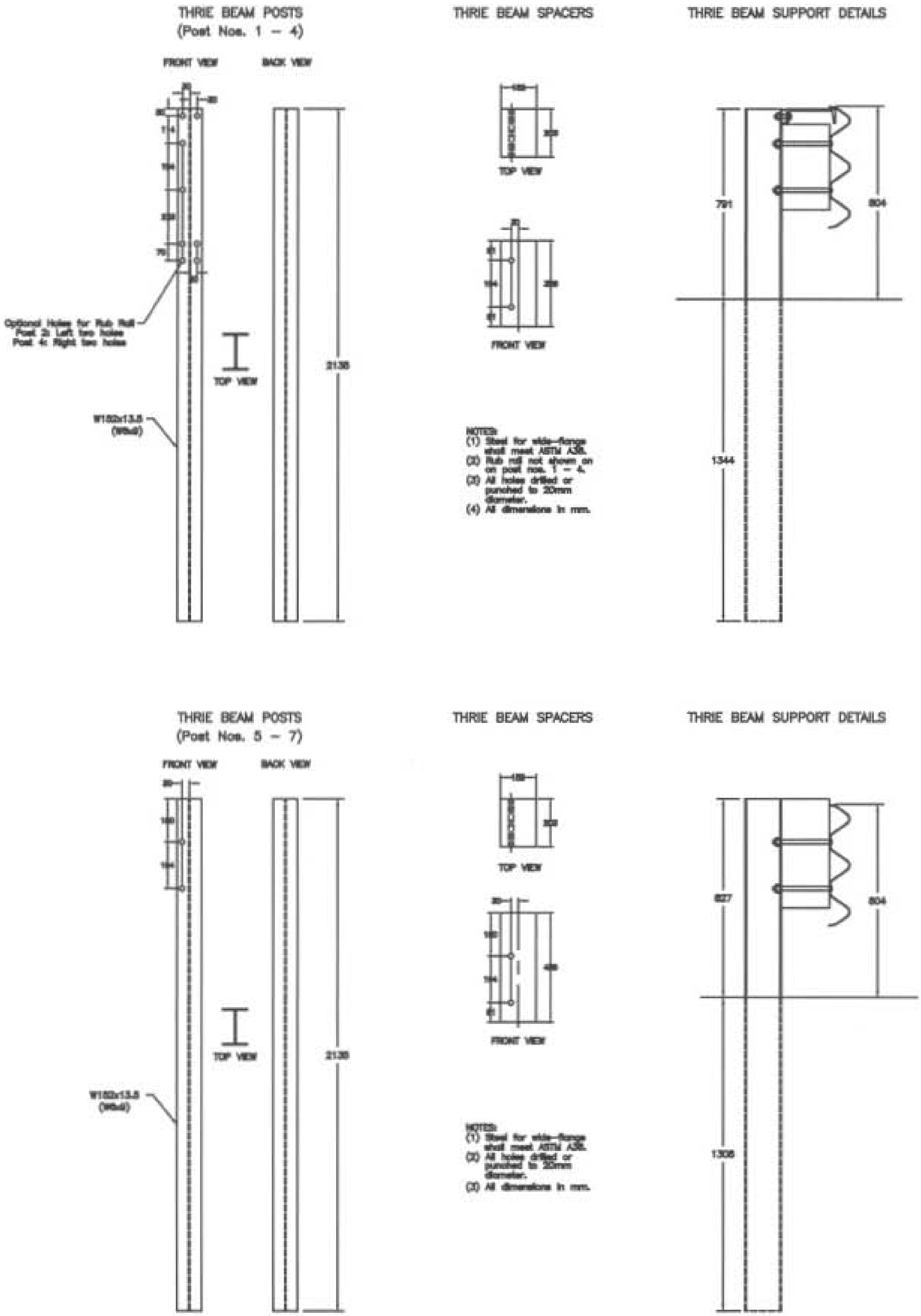


Figure 31. Design Details, Design No. 2

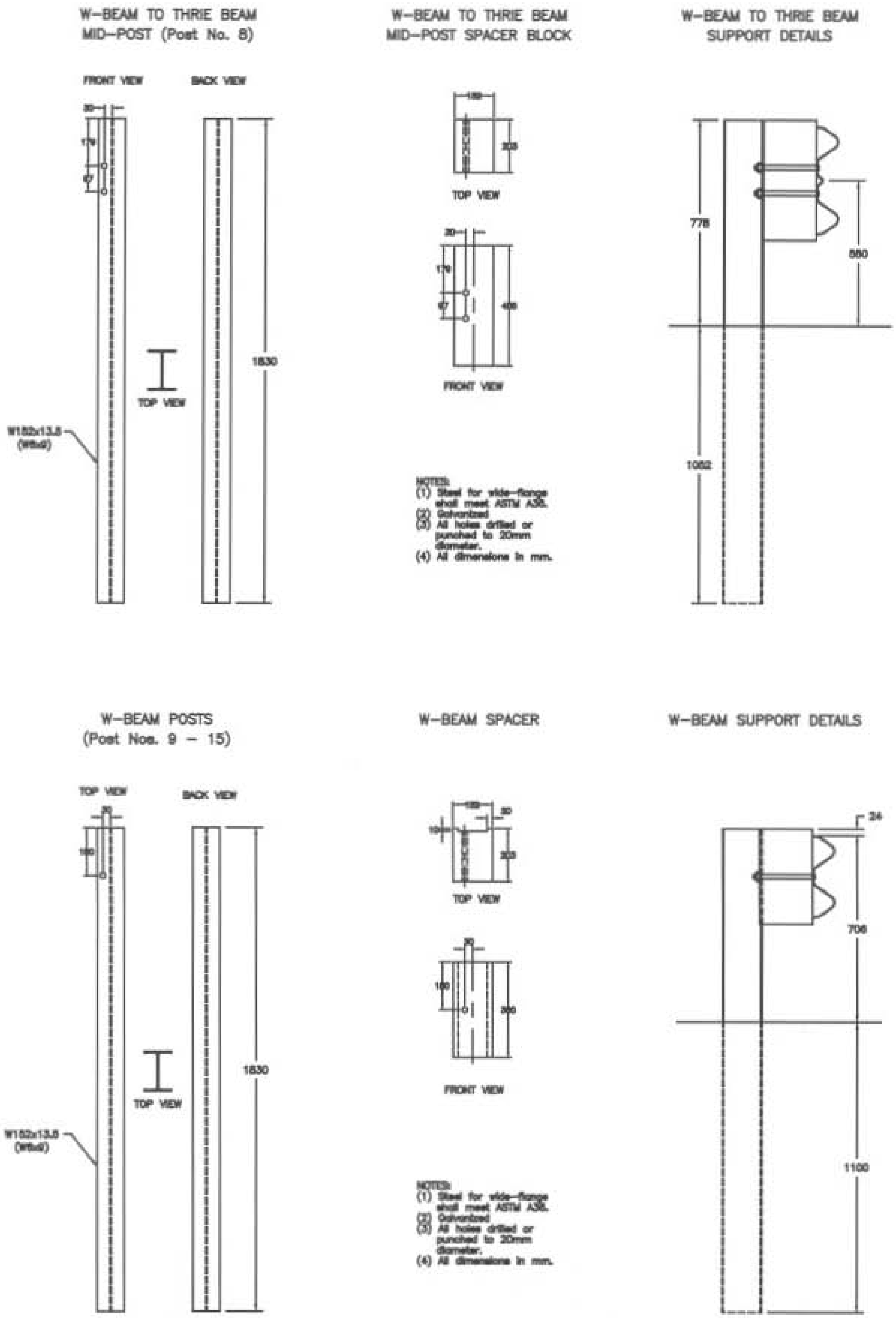
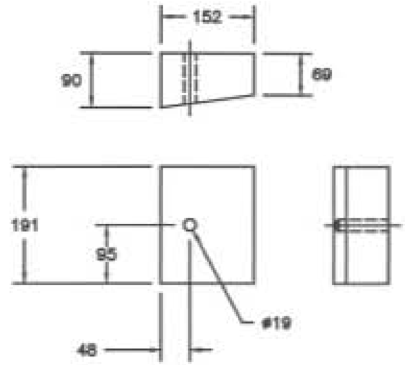
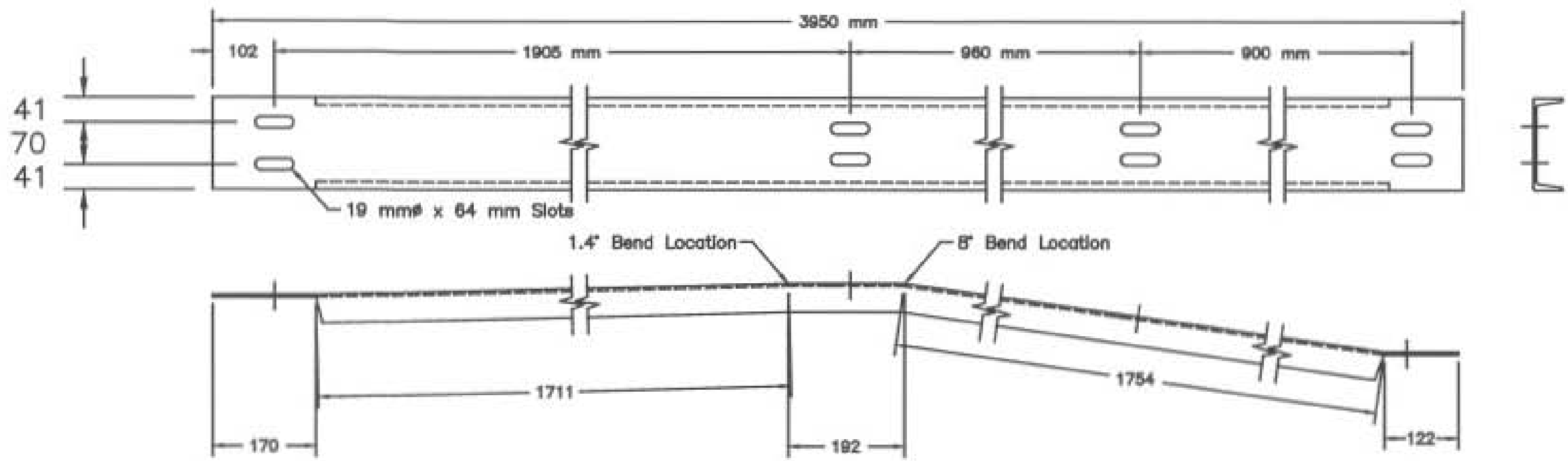


Figure 32. Design Details, Design No. 2 (Continued)



RUB RAIL BLOCK
(Timber Block)



RUB RAIL
C152x12.2
(C6x8.2)

Figure 33. Design Details, Design No. 2 (Continued)

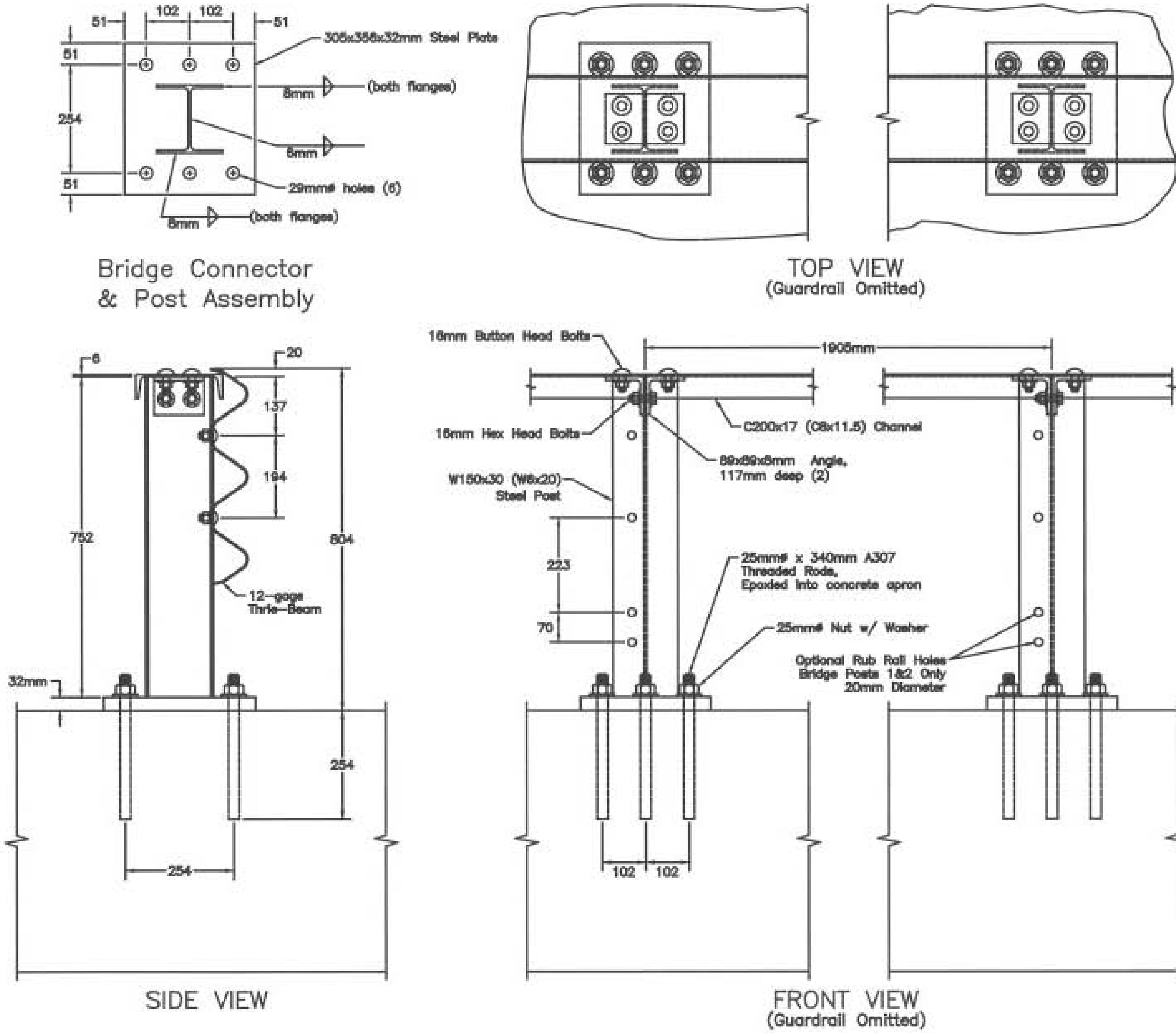


Figure 34. Thrie Beam and Channel Bridge Rail Design Details, Design No. 2

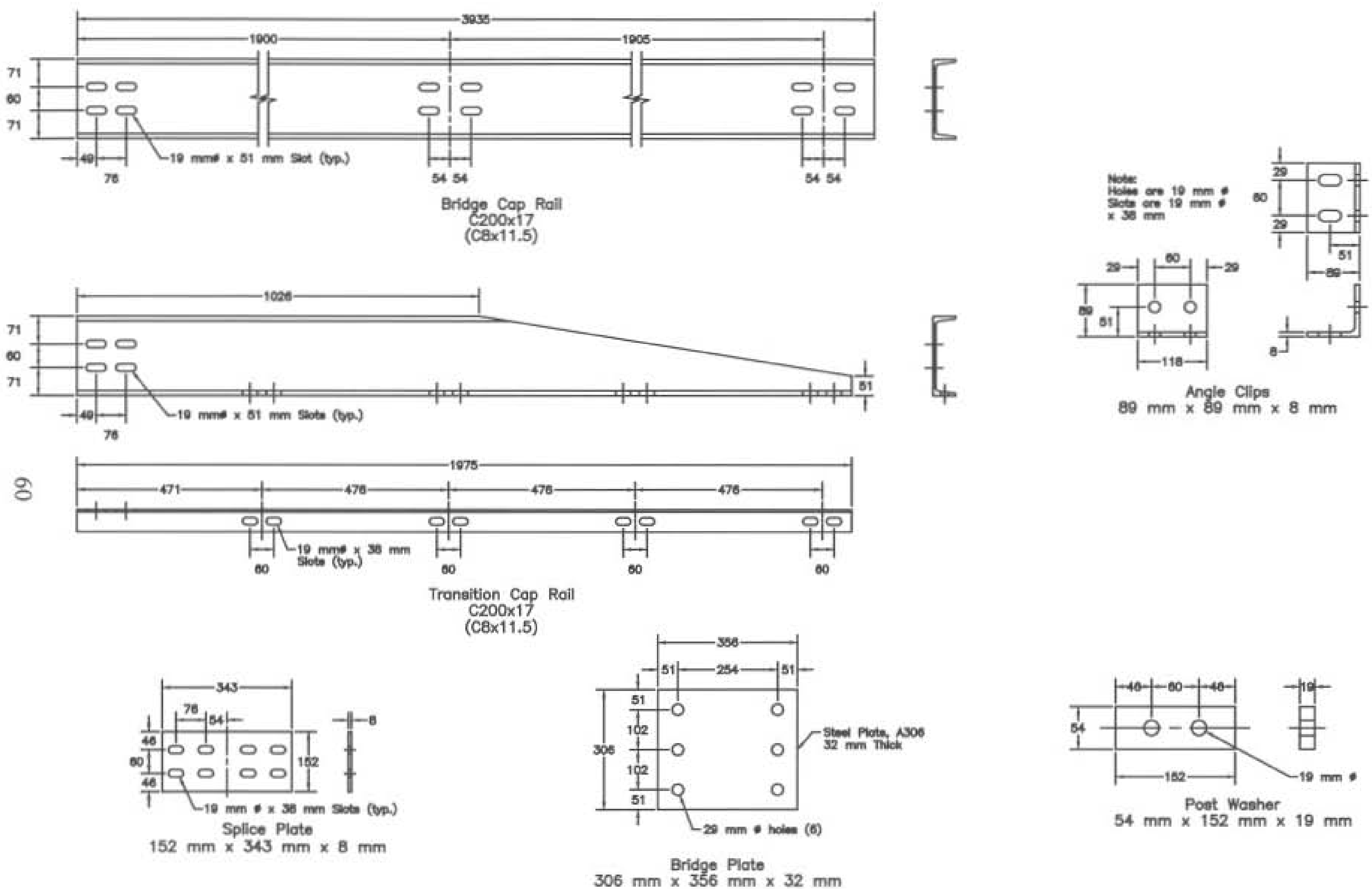


Figure 35. Thrie Beam and Channel Bridge Rail Design Details, Design No. 2 (Continued)

Figure 36. Approach Guardrail Transition, Design No. 2

Figure 37. Approach Guardrail Transition, Design No. 2 (Continued)

10 COMPUTER SIMULATION - DESIGN NO. 2

10.1 Design Option

BARRIER VII computer simulation modeling was performed on only one modified approach guardrail transition design option with the same post capacities. The transition design was constructed with two nested thrie beam rails, measuring 2.66-mm thick, and supported by nine W152x13.5 steel posts. Post spacings consisted of six at 476 mm and three at 952 mm. Post nos. 1 through 4 were 2,134-mm long with a 1,343-mm embedment depth. Post nos. 5 through 7 were 2,134-mm long with a 1,307-mm embedment depth. It is noted that the C152x12.2 steel channel rubrail was not included in the model; since, a member of this particular size and orientation does not significantly effect the dynamic performance of the approach guardrail transition system.

10.2 BARRIER VII Results

Five computer simulation runs were performed on one design option with the same post capacities but at different impact locations. Once again, a typical computer simulation input data file is shown in Appendix D. The computer simulation results, as shown in Table 3, indicated that the potential for wheel snagging on the first bridge post would not occur if spacer blocks were incorporated into the bridge railing system; since, the maximum tire or rim overlap distance was found to be 68 mm. However, since the MoDOT chose not to use spacer blocks in the bridge railing, a rubrail was required in the transition system to eliminate the potential for wheel snagging. The CIP was also determined to occur with an impact between post nos. 3 and 4 or 1,667 mm upstream from the centerline of the first bridge post. For the CIP, wheel snag distances for the outer tire and inner steel rim were calculated to be approximately 68 mm and 71 mm, respectively. For the CIP, the predicted maximum lateral dynamic thrie beam rail deflection was 78 mm, as measured to the center height of the rail.

Table 3. Computer Simulation Test Matrix and Results - Design No. 2.

Run No.	Impact Node	Transition Post Yield Moment (kN-mm)	Impact Distance[1] (mm)	Maximum Dynamic Rail Deflection (Center Height) (mm)	Maximum Dynamic Top Channel Deflection (Center Height) (mm)	Maximum Permanent Set Rail Deflection (Center Height) (mm)	Lateral Wheel-Assembly Snag Potential[2]	
							Tire Contact Distance (mm)	Rim Contact Distance (mm)
D2	27	47453	2381	103	149	65	30	12
D3	28	47453	2143	95	133	66	49	27
D4	29	47453	1905	84	123	65	66	51
D5	31	47453	1667	78	111	71	68	71
D6	33	47453	1429	73	106	92	52	67

[1] - Longitudinal distance measured from the impact location to the centerline of the first bridge post.
[2] - Lateral distance of wheel-assembly measured behind original location of thrie beam rail. This lateral distance is measured when the longitudinal position of the outer tire or steel rim reaches the front flange of the first bridge post.

11 CRASH TEST NO. 2

11.1 Test MST-2

The 2,042-kg pickup truck impacted the approach guardrail transition at a speed of 99.5 km/hr and an angle of 27.9 degrees. A summary of the test results and the sequential photographs are shown in Figure 38. Additional sequential photographs are shown in Figures 39 and 40. Documentary photographs of the crash test are shown in Figures 41 and 42.

11.2 Test Description

Initial impact occurred between post nos. 3 and 4 or 238-mm downstream from the center of post no. 4, as shown in Figure 43. At 0.016 sec, the left-front corner of the vehicle was at post no. 2 and was deforming inward toward the engine compartment. At 0.028 sec, the vehicle's left-front corner was at post no. 1, and the top of the left-front corner was overriding the barrier. At 0.044 sec, the front of the vehicle was at bridge post no. B3. At this same time, the left-front corner of the vehicle was overriding the rail between post nos. B3 and 3. At 0.056 sec, the left-side parking light disengaged from the vehicle. At 0.061 sec, the left-side door popped open. At 0.075 sec, the front of the vehicle was at the midspan between post nos. B2 and B3. At 0.117 sec, the front of the truck was at bridge post no. B2. At this same time, the left-door was open and the cab rolled counter-clockwise (CCW) toward the barrier. At 0.123 sec, the right-front tire became airborne and the left-side door deformed around the guardrail. At 0.153 sec, the vehicle began to redirect while the left-front quarter panel and door deformed around the guardrail and contacted the top of the cap rail. At 0.163 sec, the right-rear tire became airborne. At 0.228 sec after impact, the vehicle became parallel to the guardrail with a velocity of 74.1 km/hr. At this same time, the hood popped open. At 0.250 sec, the vehicle continued to roll CCW, and the left-front tire became airborne. At 0.442

sec, the vehicle exited the system at an angle of 6.8 degrees and a speed of 74.0 km/hr. At 0.669 sec, the vehicle's left door contacted the ground as the vehicle continued to roll CCW. At 1.181 sec, the truck slid along the ground on its left side. The vehicle's post-impact trajectory is shown in Figure 38. The vehicle came to rest 47.09 m downstream from impact and 5.94 m away from the traffic-side face of the rail, as shown in Figure 38.

11.3 Barrier Damage

Damage to the barrier was moderate, as shown in Figures 44 through 46. Barrier damage consisted mostly of deformed thrie beam and contact marks on the thrie beam and rubrail. The thrie beam damage consisted of moderate deformation and flattening of the impacted section of rail between post nos. 3 through B3. Contact marks were found on the thrie beam between post nos. 3 and B2. Contact marks were also found on the rubrail from the center line of post no. 1 to the midpoint of the span between bridge post nos. B2 and B3. No significant damage occurred to the posts, wood blockouts, the W-beam, nor the W-beam to thrie beam transition section.

The permanent set of the guardrail and posts is shown in Figures 45 through 46. The maximum lateral permanent set thrie beam rail, post, and channel rail deflections were approximately 21 mm at the center line of post no. 2, 22 mm at post no. 1, and 25 mm at bridge post no. B3, respectively, as measured in the field. The maximum lateral dynamic thrie beam rail, post, and channel rail deflections were 67 mm at the centerline of post no. 2, 55 mm at post no. 1, and 38 mm at bridge post no. B3, respectively, as determined from the high-speed film analysis.

11.4 Vehicle Damage

Exterior and interior vehicle damage was extensive and occurred at several body locations, as shown in Figures 47 through 49. Most of the vehicle damage occurred near the left-front corner of the vehicle, consisting primarily of damage to the fender, hood, bumper, and door. This damage also included disengagement of the front wheel from the upper A-frame connection, disengagement of the tie rod end, and deformation of the lower A-frame. The rear of the cab was crushed on the left side. The engine hood of the vehicle buckled, and the windshield was cracked. The left-rear tire was deflated. The floorboard of the occupant compartment also sustained significant plastic deformations due to the severe impact with the barrier as well as from vehicle rollover. The right door, left door, and rear windows remained undamaged.

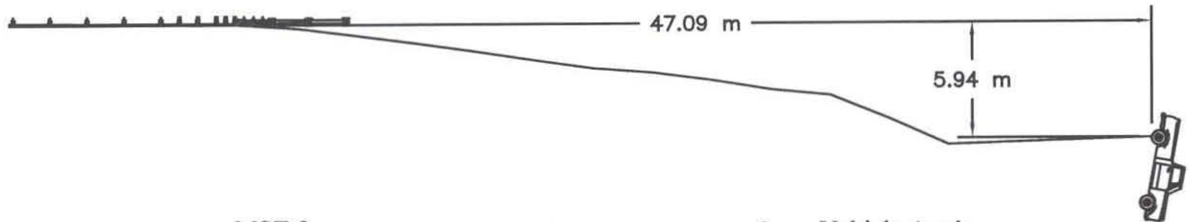
11.5 Occupant Risk Values

The normalized longitudinal and lateral occupant impact velocities were determined to be 5.83 m/sec and 7.02 m/sec, respectively. The maximum 0.010-sec average occupant ridedown decelerations in the longitudinal and lateral directions were 11.71 g's and 11.48 g's, respectively. It is noted that the occupant impact velocities (OIV) and occupant ridedown decelerations (ORD) were within the suggested limits provided in NCHRP Report No. 350. The results of the occupant risk, determined from accelerometer data, are summarized in Figure 38. Results are shown graphically in Appendix E. The results from the rate transducer are shown graphically in Appendix F.

11.6 Discussion

The analysis of the test results for test MST-2 showed that the barrier satisfactorily contained the vehicle but inadequately redirected the vehicle since the vehicle did not remain upright after collision with the approach guardrail transition. Detached elements, fragments, or other debris from the test article did not penetrate or show potential for penetrating the occupant compartment, or present undue hazard to other traffic. Major deformations to the occupant compartment were evident and were considered excessive enough to cause serious injuries to the occupants. After collision, the vehicle's trajectory intruded into adjacent traffic lanes. Therefore, test MST-2 conducted on the approach guardrail transition was determined to be unacceptable according to the NCHRP Report No. 350 criteria.

0.000 sec　0.028 sec　0.061 sec　0.117 sec　0.228 sec



- Test Number MST-2
- Date 12/4/98
- Appurtenance . . . . Approach Guardrail Transition to a Thrie Beam and Channel Bridge Railing
- Total Length . . . . 26.67 m
- Steel Thrie Beam (Nested)
  - Thickness . . . . 2.66 mm
  - Top Mounting Height . . . . 804 mm
- Steel Posts
  - Post Nos. 1 - 7 . . . . W152x13.5 by 2,135-mm long
  - Post Nos. 8 - 15 . . . . W152x13.5 by 1,830-mm long
- Steel Spacer Blocks
  - Post Nos. 1 - 4 . . . . W152x203 by 356-mm long
  - Post Nos. 5 - 8 . . . . W152x203 by 455-mm long
  - Post Nos. 9 - 15 . . . . W152x203 by 360-mm long
- Soil Type . . . . Grading B - AASHTO M 147-65 (1990)
- Vehicle Model . . . . 1993 Chevrolet C-2500 2WD
  - Curb . . . . 2,205 kg
  - Test Inertial . . . . 2,043 kg
  - Gross Static . . . . 2,043 kg
- Vehicle Speed
  - Impact . . . . 99.5 km/hr
  - Exit . . . . 74.0 km/hr
- Vehicle Angle
  - Impact . . . . 27.9 degrees
  - Exit . . . . 6.8 degrees
- Vehicle Snagging . . . . Minor contact on top of bridge and transition channel caps
- Vehicle Pocketing . . . . None
- Vehicle Stability . . . . Vehicle rollover
- Occupant Ridedown Deceleration (10 msec avg.)
  - Longitudinal . . . . 5.25 < 20 G's
  - Lateral (not required) 11.53
- Occupant Impact Velocity
  - Longitudinal . . . . 6.63 < 12 m/s
  - Lateral (not required) 7.82
- Vehicle Damage . . . . Extensive
  - TAD[21] . . . . NA
  - SAE[22] . . . . NA
- Vehicle Stopping Distance . . . . 47.09 m downstream, 5.94 m traffic-side face
- Barrier Damage . . . . Moderate
- Maximum Deflections
  - Permanent Set – Thrie Beam . . . . 21 mm
  - Permanent Set – Channel Rail . . . . 25 mm
  - Dynamic – Thrie Beam . . . . 67 mm
  - Dynamic – Channel Rail . . . . 38 mm

Figure 38. Summary of Test Results and Sequential Photographs, Test MST-2

0.000 sec

0.062 sec

0.083 sec

0.163 sec

0.298 sec

1.181 sec

0.000 sec

0.028 sec

0.036 sec

0.056 sec

0.086 sec

0.157 sec

Figure 39. Additional Sequential Photographs, Test MST-2

0.000 sec

0.014 sec

0.032 sec

0.056 sec

0.068 sec

0.108 sec

0.000 sec

0.116 sec

0.148 sec

0.212 sec

0.250 sec

Figure 40. Additional Sequential Photographs, Test MST-2

Figure 41. Documentary Photographs, Test MST-2

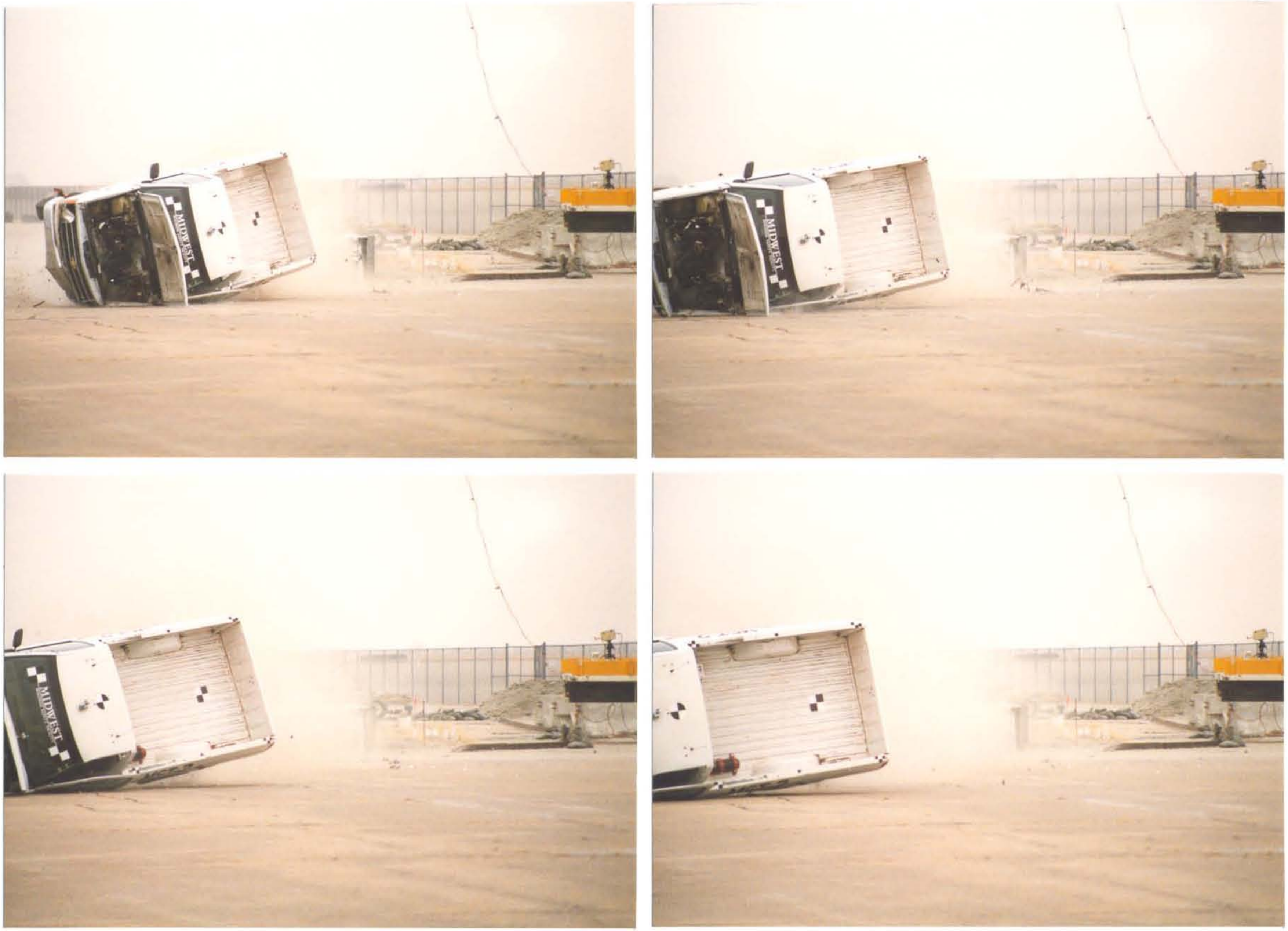


Figure 42. Documentary Photographs, Test MST-2

Figure 43. Impact Location, Test MST-2

Figure 44. Approach Guardrail Transition Damage, Test MST-2

Figure 45. Approach Guardrail Transition Damage and Permanent Set Deflections, Test MST-2

Figure 46. Permanent Set Deflections, Test MST-2

Figure 47. Vehicle Damage, Test MST-2

Figure 48. Vehicle Damage, Test MST-2

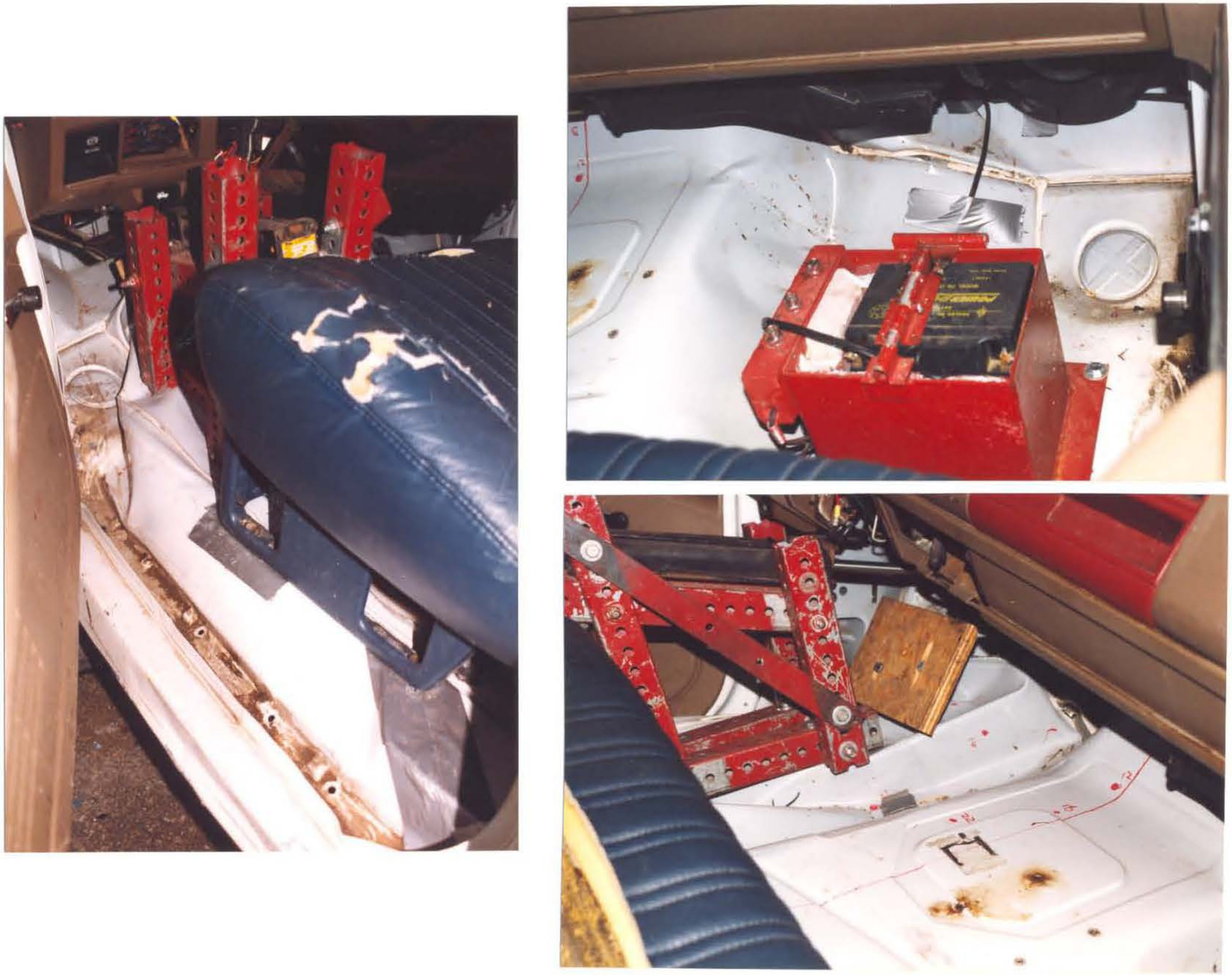


Figure 49. Occupant Compartment Deformations, Test MST-2

12 SUMMARY AND CONCLUSIONS

An approach guardrail transition attached to a thrie beam and channel bridge railing was developed and full-scale vehicle crash tested. Two full-scale vehicle crash tests were performed according to the TL-3 criteria found in NCHRP Report No. 350. The first crash test, test no. MST-1, failed due to the vehicle rolling onto its side during redirection and major occupant compartment deformations. This vehicle's instability occurred as a result of excessive angular motions occurring during vehicle redirection as a result of the contact between the left-front wheel assembly and the rubrail.

Based on knowledge gained from test no. MST-1, the approach guardrail transition system was redesigned to reduce the magnitude of the lateral rail deflections and minimize the effect of the wheel assembly/rubrail interaction. The primary changes included: lengthening the posts in the transition, increasing the embedment depths of the posts in the transition, shortening the wood blockouts in the transition, and extending the channel cap rail to the transition region. A second test, test no. MST-2, was performed on the modified approach guardrail transition system. During vehicle redirection, the pickup truck once again rolled onto its side, and the test was determined to be unacceptable according to the safety performance criteria presented in NCHRP Report No. 350. The vehicle's instability was attributed to the excessive angular motions of the vehicle which were experienced as the vehicle was redirected. The excessive vehicle motions were once again attributed to the inclusion of the rubrail. A summary of the safety performance evaluation is provided in Table 4.

Table 4. Summary of Safety Performance Evaluation Results - Long-Span Guardrail System

Evaluation Factors	Evaluation Criteria	Test MST-1	Test MST-2
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.	U	U
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	S
	F. The vehicle should remain upright during and after collision although moderate roll, pitching and yawing are acceptable.	U	U
Vehicle Trajectory	K. After collision it is preferable that the vehicle's trajectory not intrude into adjacent traffic lanes.	U	U
	L. The occupant impact velocity in the longitudinal direction should not exceed 12 m/sec and the occupant ridedown acceleration in the longitudinal direction should not exceed 20 G's.	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 devise.	S	S

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

13 PROPOSED APPROACH GUARDRAIL TRANSITION SYSTEM

Based on knowledge gained from test nos. MST-1 and MST-2, it was necessary to redesign the approach guardrail transition system so as to minimize the effect of the wheel assembly/rubrail interaction. Following the failure of the previous two transition designs that included rubrails, discussions between MwRSF and MoDOT personnel resulted in Missouri reconsidering the placement of blockouts on the bridge railing system. With this action, the concern for wheel snag on the first bridge post was essentially eliminated, allowing the removal of the rubrail. Therefore, MwRSF researchers could once again consider the adaptation of existing NCHRP Report No. 350 approved transition designs to the thrie beam and channel bridge railing system.

Upon completion of a literature review of recently developed NCHRP Report No. 350 transition designs, MwRSF researchers determined that a Test Level 4 (TL-4) thrie beam transition system, developed in cooperation with the Forest Products Laboratory (FPL), could be modified slightly and easily adapted for use with Missouri's thrie beam and channel bridge railing system. The TL-4 transition system was originally developed for use with a thrie beam and tube bridge railing system which was attached to a transverse, glue-laminated timber deck. Details of the TL-4 system are included in Appendix G.

Modification of the FPL TL-4 thrie beam transition for use with Missouri's thrie beam and channel bridge railing was fairly simple. The proposed transition system would be nearly identical to the TL-4 system except for two features. First, the steel tube member, measuring 203-mm deep x 76-mm wide x 5-mm thick, was replaced with the C203x17.1 steel channel section. This change was made since the Missouri bridge railing posts were spaced on 1,905-mm centers rather than the 2,438-mm centers used in the FPL bridge railing system. For the FPL TL-4 bridge railing design, the structural tube was selected over the channel to provide additional strength to resist lateral bucking which was unnecessary for a 1,905-mm post spacing. With regards to bending about the strong axis, both sections provide relatively equal capacities with the channel providing a 10 percent increase in section modulus over the tube. Second, the proposed transition design provides one additional reduced post spacing of thrie beam as compared to the FPL TL-4 transition design. Design details for the proposed approach guardrail transition for use with Missouri's thrie beam and channel bridge railing systems are provided in Figures 50 through 56.

The approach guardrail transition design was detailed with eight guardrail posts, as shown in Figures 50 through 54. Post nos. 1 through 5 consist of galvanized, ASTM A36 steel W152x22.3 sections measuring 2,134-mm long. Post nos. 6 through 8 use W152x13.4 steel sections measuring 1,980-mm long. Lap-splice connections between the rail sections were configured to reduce vehicle snagging at the splices.

For post no. 1, a wood spacer blockout measuring 203-mm wide x 203-mm deep x 380-mm long was used, as shown in Figure 52. As shown in Figures 52 and 53, a wood spacer blockout measuring 203-mm wide x 203-mm deep, but 483-mm long was used for post nos. 2 through 5. At post no. 6, wood spacer blockout measuring 152-mm wide x 203-mm deep x 554-mm long was used, as shown in Figure 53. A 152-mm wide x 203-mm deep x 483-mm long wood spacer blockout was used at post no. 7, as shown in Figure 54. At post no. 8, wood spacer blockout measuring152-mm wide x 203-mm deep x 368-mm long was used, as shown in Figure 54. For bridge post nos. B1 through B3, ASTM A36 steel W152x22.3 sections measuring 346-mm long were used, as shown in Figures 50 and 55. The soil embedment depths for post nos. 1, 2 through 5, 6, 7, and 8 were 1,403 mm, 1,375 mm, 1,153 mm, 1,189 mm, and 1,250 mm, respectively, as shown in Figures 52 through

54. All construction details for the bridge railing system are provided in Figures 55 through 56.

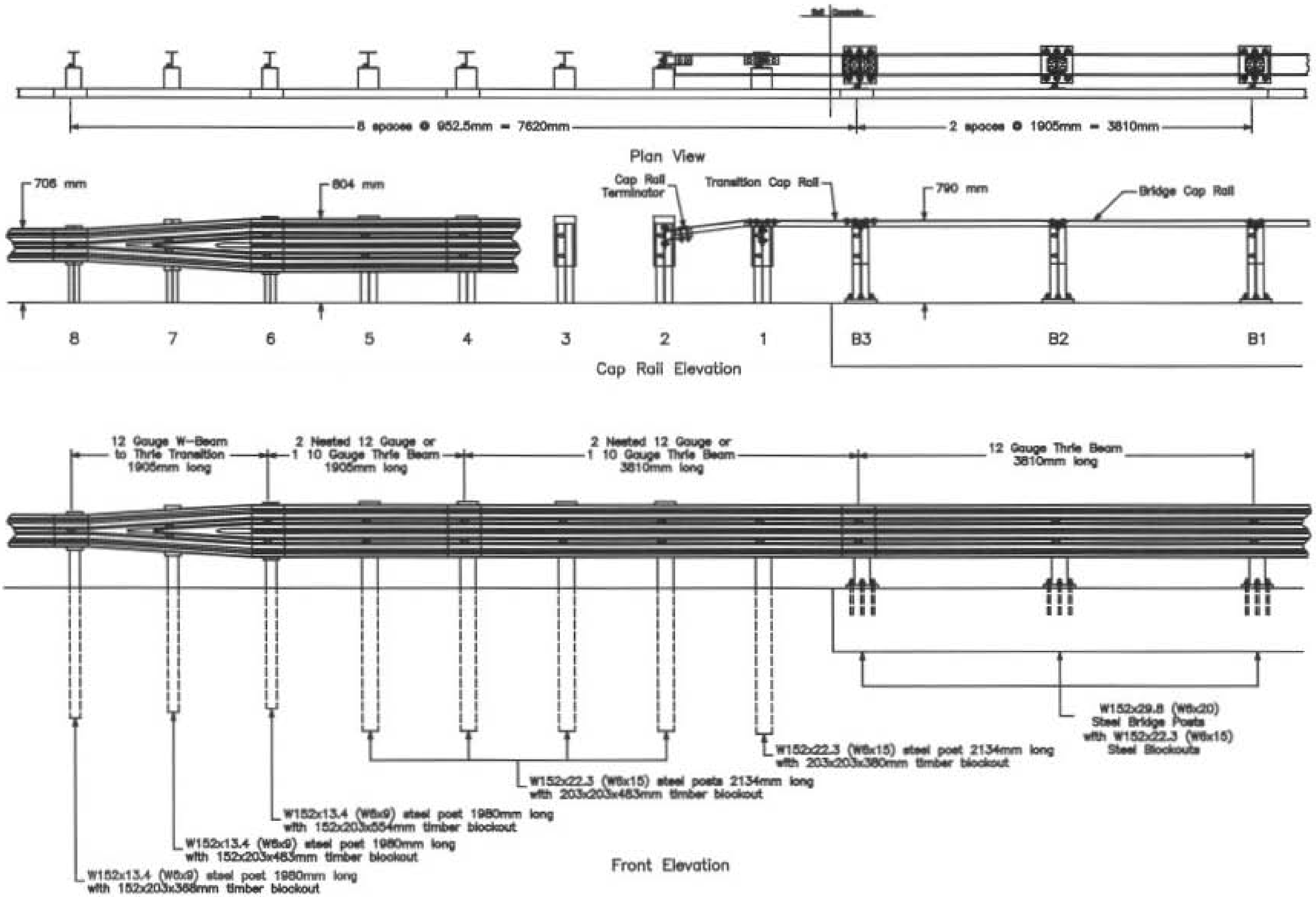


Figure 50. Proposed Design Installation Layout

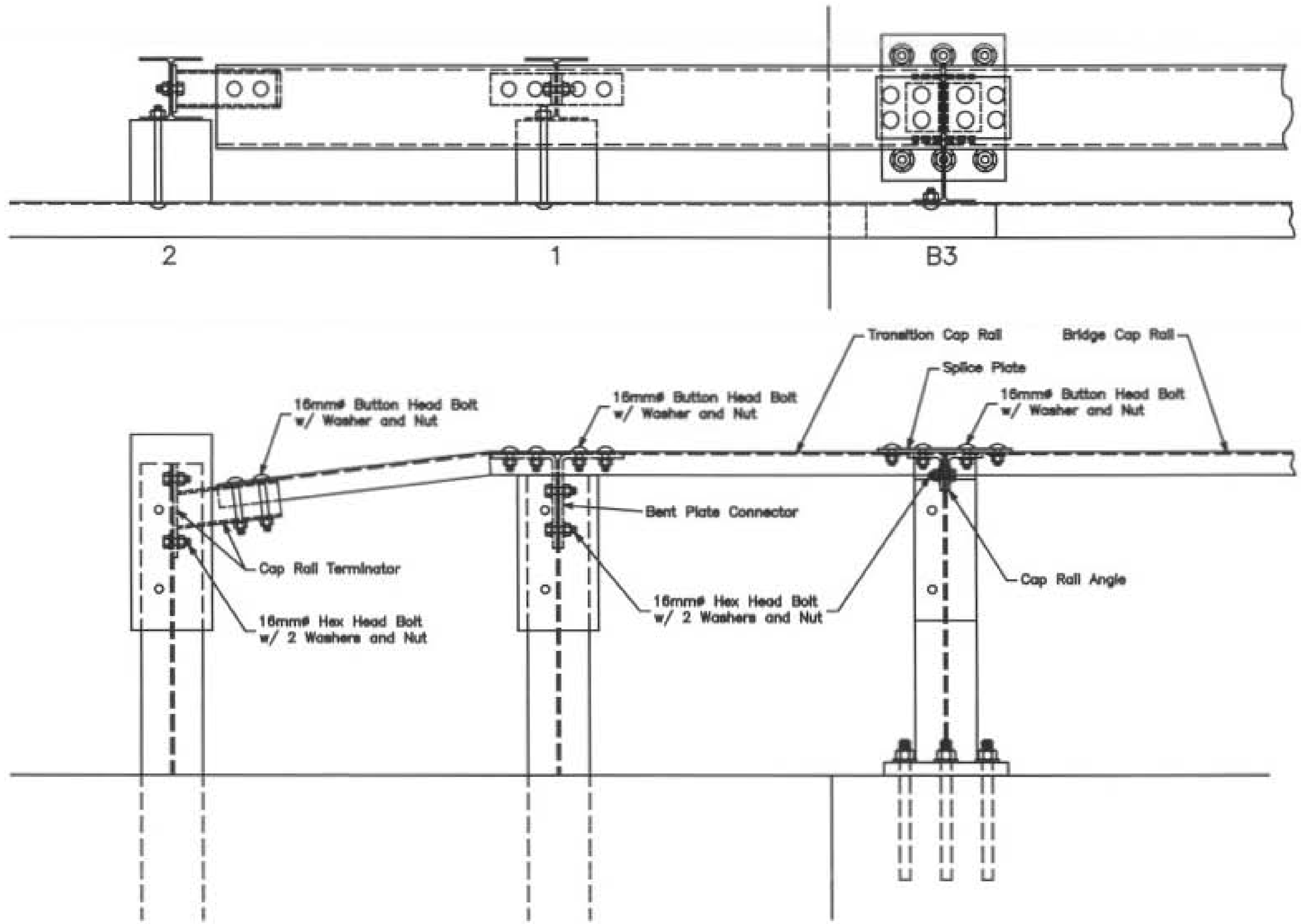


Figure 51. Proposed Design Installation Layout and Design Details

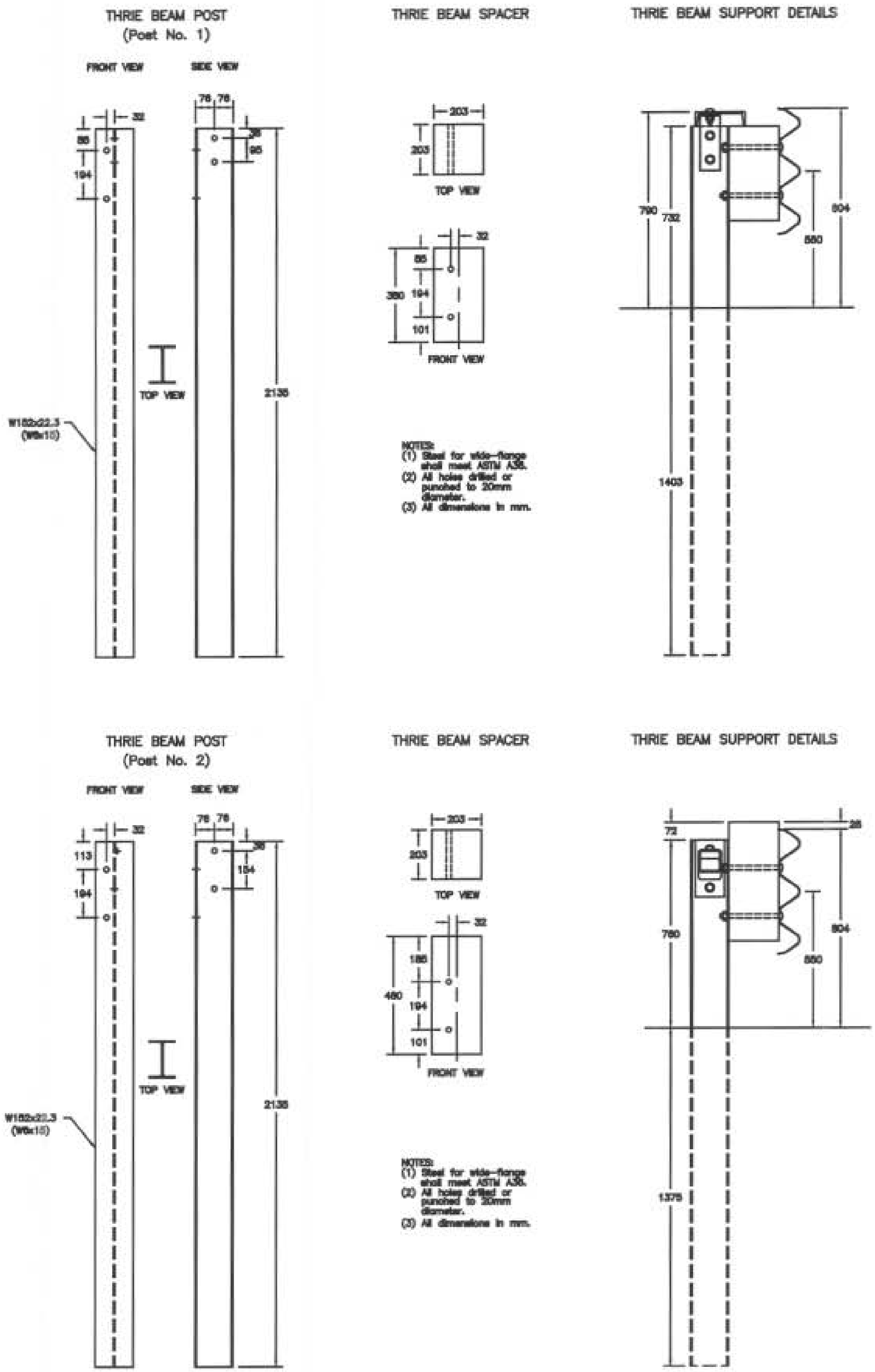


Figure 52. Proposed Design Details

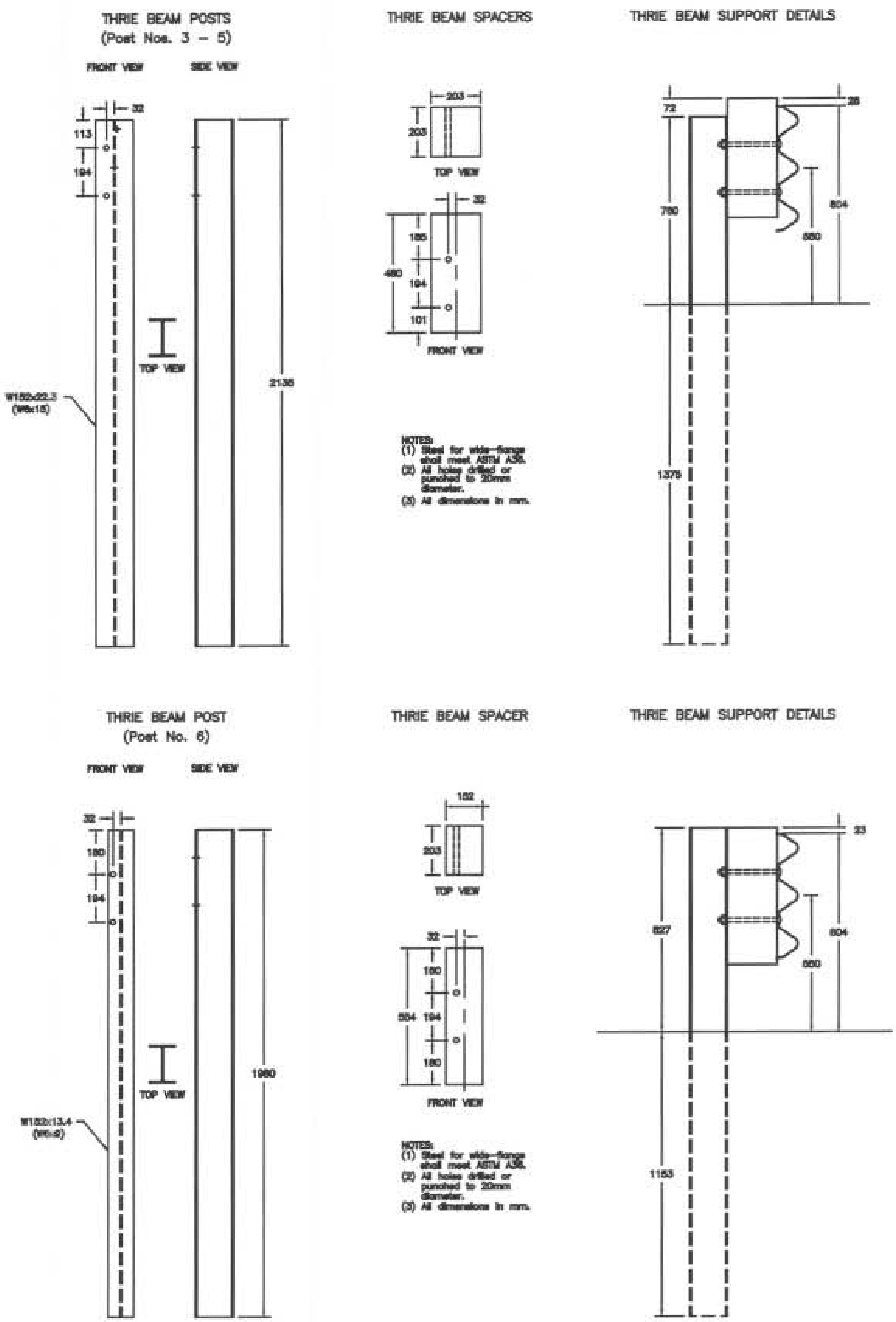


Figure 53. Proposed Design Details (Continued)

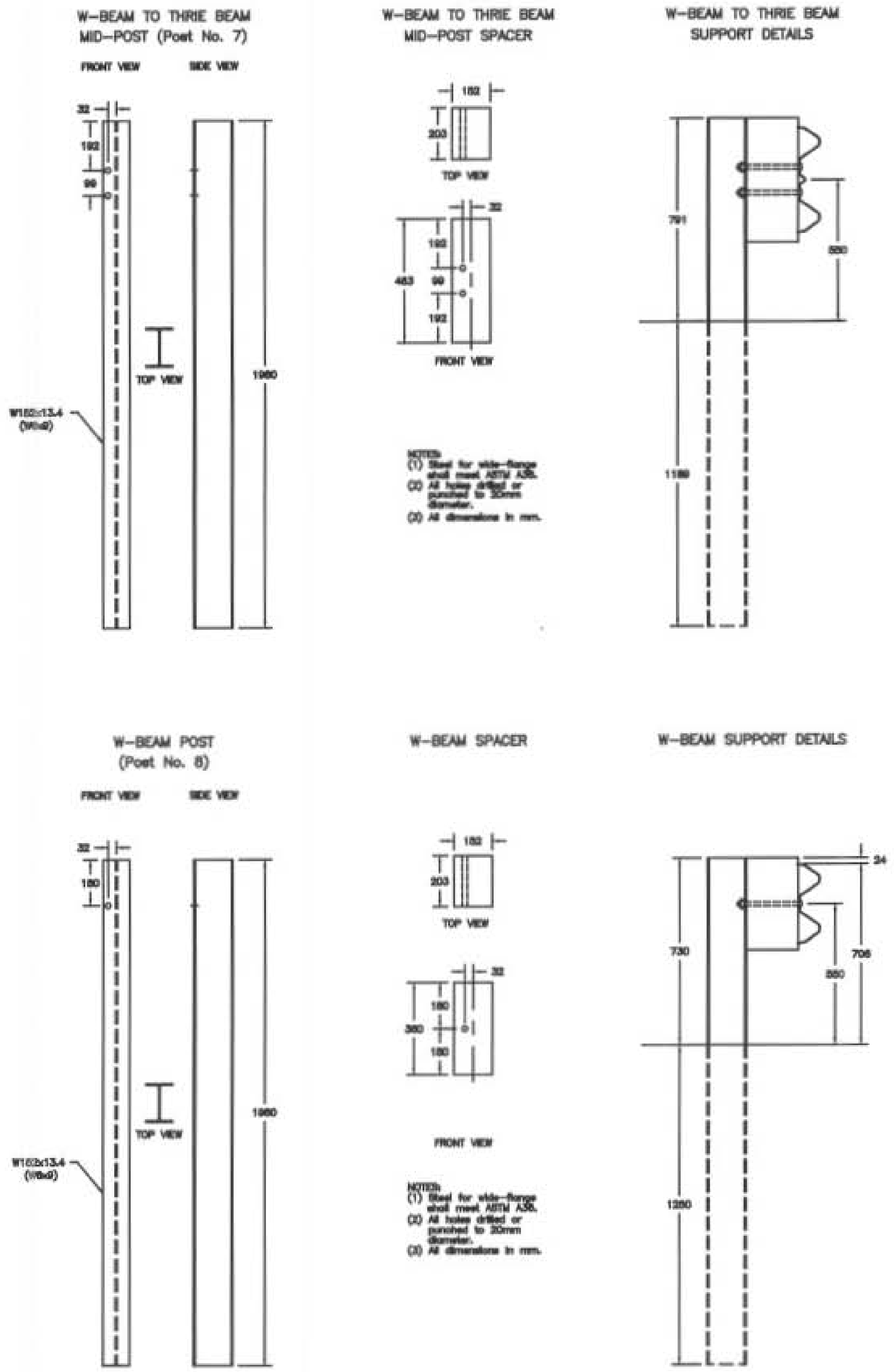


Figure 54. Proposed Design Details (Continued)

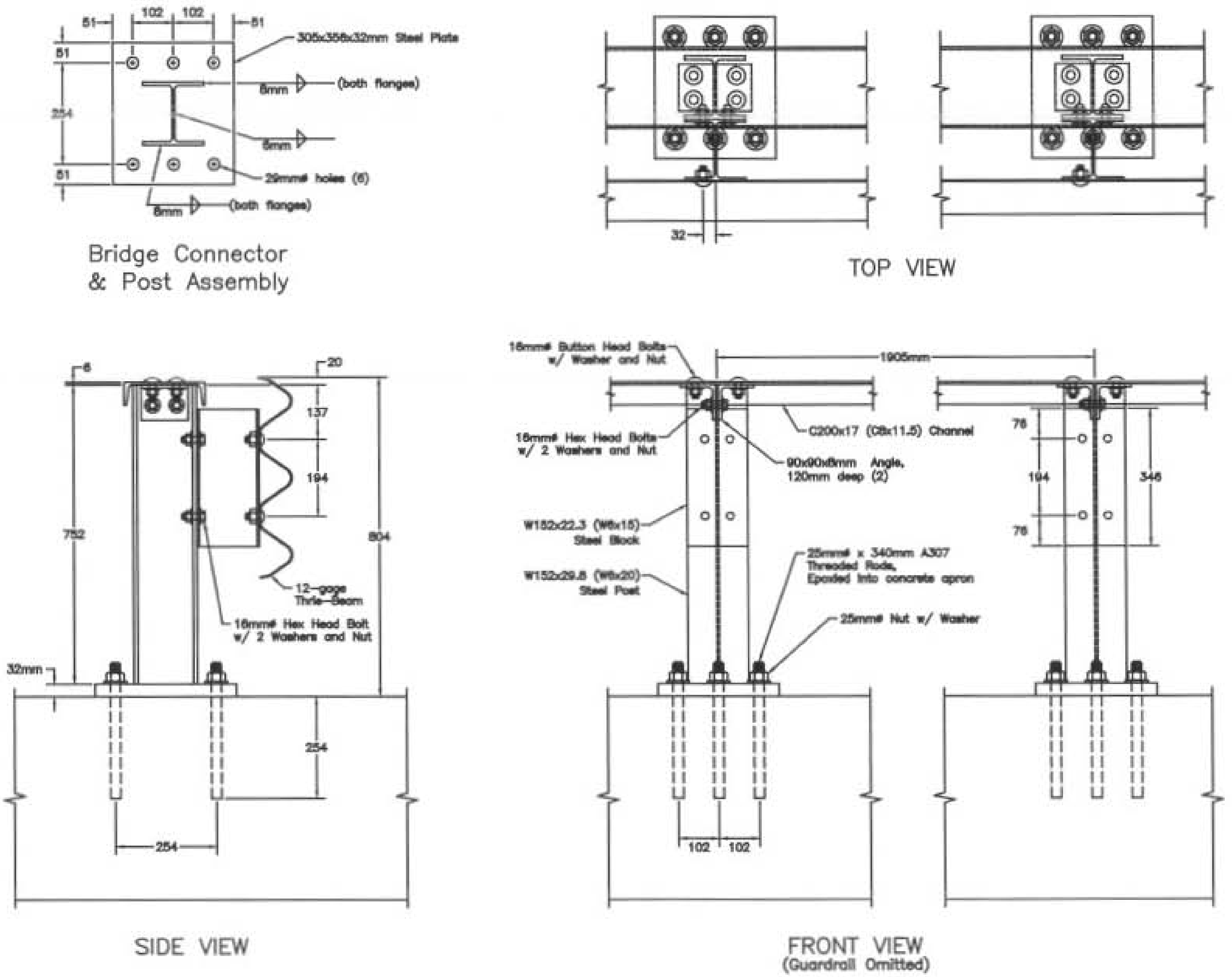


Figure 55. Proposed Design Thrie Beam and Channel Bridge Rail Design Details

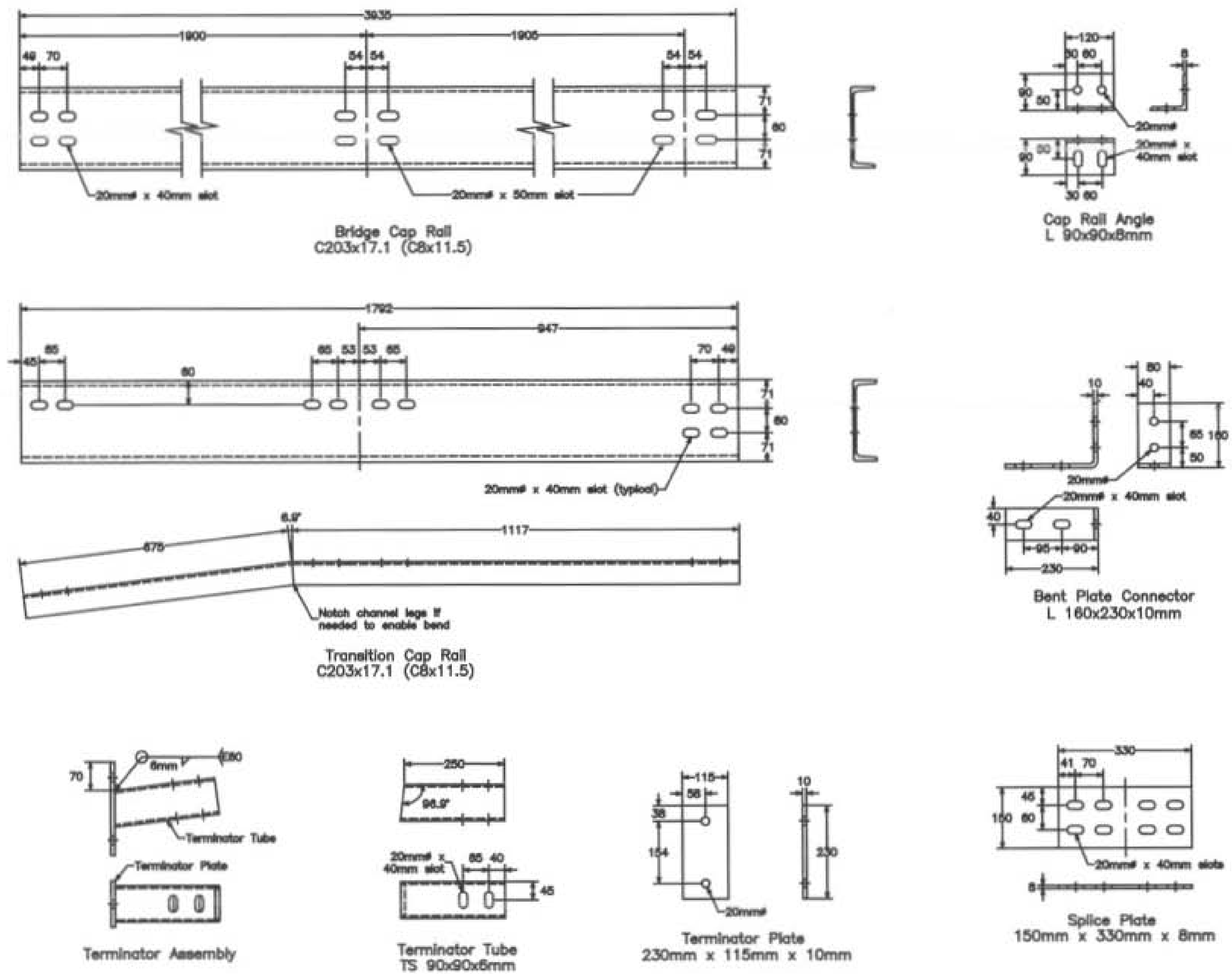


Figure 56. Proposed Design Thrie Beam and Channel Bridge Rail Design Details (Continued)

14 RECOMMENDATIONS

An approach guardrail transition for use with Missouri's thrie beam and channel bridge railing system has been designed. This design is based on the successful full-scale vehicle crash testing on a NCHRP Report No. 350 TL-4 thrie beam transition design previously developed for FPL. Based on similarities between the crash-tested FPL TL-4 thrie beam transition and the proposed transition system for Missouri, we believe that the proposed transition would meet the TL-3 criteria of NCHRP Report No. 350. On April 19, 1999, a letter requesting approval of this transition design without additional crash testing was forwarded to Mr. Richard Powers of FHWA, Washington, D.C. A copy of that letter, which included the documentation and supporting information for the request, is provided in Appendix G. In response to our request, on June 4, 1999, Mr. Dwight Horne, Director, Office of Highway Safety Infrastructure - FHWA, granted approval of the transition design without additional testing. However, it should be noted that the approval is contingent on the use of a W152x22.3 steel blockout at each bridge post location. A copy of the letter is provided in Appendix H.

15 REFERENCES

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16 APPENDICES

APPENDIX A

Typical BARRIER VII Input File

Note that the example BARRIER VII input data files included in Appendix A correspond with the critical impact point for test MST-1.

```
MISSOURI'S TRANSITION TO THRIE BEAM AND CHANNEL BRIDGE RAIL - A3.DAT (2 12-GA. NESTED THRIE/NODE 28)
  50   23   21    2   68   18    2    0
   0.0001    0.0001        0.50  300    0       1.0    1
   1    5    5    5    5    5    1
   1        0.0          0.0
   3      75.00          0.0
   5     150.00          0.0
   7     225.00          0.0
   9     300.00          0.0
  11     375.00          0.0
  13     450.00          0.0
  15     525.00          0.0
  17     600.00          0.0
  19     637.50          0.0
  21     675.00          0.0
  25     712.50          0.0
  27     731.25          0.0
  29     750.00          0.0
  31     768.75          0.0
  33     787.50          0.0
  35     806.25          0.0
  37     825.00          0.0
  38     825.00          0.0
  45     900.00          0.0
  46     900.00          0.0
  49     975.00          0.0
  50     975.00          0.0
   1    3    1    1           0.0
   3    5    1    1           0.0
   5    7    1    1           0.0
   7    9    1    1           0.0
   9   11    1    1           0.0
  11   13    1    1           0.0
  13   15    1    1           0.0
  15   17    1    1           0.0
  17   19    1    1           0.0
  19   21    1    1           0.0
  21   25    1    1           0.0
  25   27    1    1           0.0
  27   29    1    1           0.0
  29   31    1    1           0.0
  31   33    1    1           0.0
  33   35    1    1           0.0
  35   37    1    1           0.0
  37   45    1    2           0.0
  45   49    1    2           0.0
  38   46    1    2           0.0
  46   50    1    2           0.0
   1   43       0.35
  49   47   45   43   41   39   37   36   35   34
  33   32   31   30   29   28   27   26   25   24
  23   22   21   20   19   18   17   16   15   14
  13   12   11   10    9    8    7    6    5    4
   3    2    1
   2    7       0.35
  50   48   46   44   42   40   38
 100   10
   1       2.30        1.99       37.50    30000.0       6.92       99.5      68.5 0.10 12-GAUGE W-BEAM
   2      2.475       3.125       18.75    30000.0      7.405     106.25     73.75 0.10 12-GAUGE W-BEAM TO THRIE BEAM
   3       2.84        2.40       18.75    30000.0      8.375      120.0      84.0 0.10 12-GAUGE W-BEAM TO THRIE BEAM
   4      3.205        2.68       18.75    30000.0       9.35      134.0      94.0 0.10 12-GAUGE W-BEAM TO THRIE BEAM
   5      3.575        2.96       18.75    30000.0     10.325      148.0    104.25 0.10 12-GAUGE W-BEAM TO THRIE BEAM
   6       7.52        6.20       9.375    30000.0      21.62      310.0     219.0 0.10 12-GAUGE NESTED THRIE BEAM
   7       3.76        3.10       18.75    30000.0      10.81      155.0     109.5 0.10 12-GAUGE THRIE BEAM
   8       3.76        3.10       37.50    30000.0      10.81      155.0     109.5 0.10 12-GAUGE THRIE BEAM
   9       29.6        3.89       18.75    30000.0      13.25     140.04    343.80 0.10 C8x11.5 CHANNEL RAIL
  10       29.6        3.89       37.50    30000.0      13.25     140.04    343.80 0.10 C8x11.5 CHANNEL RAIL
 300    6
   1       21.0         0.0      1000.0     1000.0      250.0    10000.0   10000.0 0.10 SIMULATED ANCHORAGE DEVICE
   200.0      200.0         2.0         2.0
   2       21.0         0.0        2.00       4.72       54.0       96.6    255.57 0.10 W6x9 STEEL POST (44 9/16" E.D.) [BOGIE TEST IBT-3/4 USED 43" E.D.]
     6.0       15.0        16.0        16.0
   3       21.0         0.0        2.00       4.72       54.0       96.6    255.57 0.10 W6x9 STEEL POST (42 9/16" E.D.)
     6.0       15.0        16.0        16.0
   4       21.0         0.0        2.00       4.72       63.0       96.6     420.0 0.10 W6x9 STEEL POST (49" E.D.) [BOGIE TEST IBT-1]
     6.0       20.0        10.0        10.0
   5       21.0      30.625       129.0      200.0      612.5      362.9     804.6 0.10 W6x20 STEEL BRIDGE POST
    20.0       45.0         2.0         2.0
   6       21.0      30.625      2000.0     2000.0     1000.0    10000.0   10000.0 0.10 STRONG POST ANCHOR
   400.0      400.0         2.0         2.0
   1    1    2   16    1  101         0.0         0.0         0.0
  17   17   18         1  102         0.0         0.0         0.0
  18   18   19         1  103         0.0         0.0         0.0
  19   19   20         1  104         0.0         0.0         0.0
  20   20   21         1  105         0.0         0.0         0.0
  21   21   22   24    1  106         0.0         0.0         0.0
  25   25   26   36    1  106         0.0         0.0         0.0
  37   37   39   40    2  107         0.0         0.0         0.0
  41   45   47   42    2  108         0.0         0.0         0.0
  43   38   40   46    2  109         0.0         0.0         0.0
  47   46   48   48    2  110         0.0         0.0         0.0
  49    1        50    2  301         0.0         0.0         0.0         0.0         0.0
  51    5        57    2  302         0.0         0.0         0.0         0.0         0.0
  58   19                303         0.0         0.0         0.0         0.0         0.0
  59   21                304         0.0         0.0         0.0         0.0         0.0
  60   25        65    2  304         0.0         0.0         0.0         0.0         0.0
  66   37   38   67    2  305         0.0         0.0         0.0         0.0         0.0
  68   49   50            306         0.0         0.0         0.0         0.0         0.0
  4400.0    40000.0    20    6    6    0    1
   1      0.055        0.12        6.00        17.0
   2      0.057        0.15        7.00        18.0
   3      0.062        0.18       10.00        12.0
   4      0.110        0.35       12.00         6.0
   5       0.35        0.45        6.00         5.0
   6       1.45        1.50       15.00         1.0
   1     100.75      15.875    1       12.0    1    0    0    0
   2     100.75      27.875    1       12.0    1    0    0    0
   3     100.75      39.875    2       12.0    1    0    0    0
   4      88.75      39.875    2       12.0    1    0    0    0
   5      76.75      39.875    2       12.0    1    0    0    0
   6      64.75      39.875    2       12.0    1    0    0    0
   7      52.75      39.875    2       12.0    1    0    0    0
   8      40.75      39.875    2       12.0    1    0    0    0
   9      28.75      39.875    2       12.0    1    0    0    0
  10      16.75      39.875    2       12.0    1    0    0    0
  11     -13.25      39.875    3       12.0    1    0    0    0
  12     -33.25      39.875    3       12.0    1    0    0    0
  13     -53.25      39.875    3       12.0    1    0    0    0
  14     -73.25      39.875    3       12.0    1    0    0    0
  15     -93.25      39.875    3       12.0    1    0    0    0
  16    -113.25      39.875    4       12.0    1    0    0    0
```

```
17   -113.25    -39.875   4       12.0    0    0    0    0
18    100.75    -39.875   1       12.0    0    0    0    0
19     69.25     37.75    5        1.0    1    0    0    0
20    -62.75     37.75    6        1.0    1    0    0    0
 1     69.25     32.75        0.0      608.
 2     69.25    -32.75        0.0      608.
 3    -62.75     32.75        0.0      492.
 4    -62.75    -32.75        0.0      492.
 1      0.0       0.0
 3    740.625     0.0        25.0      62.14       0.0       0.0       1.0
```

```
MISSOURI'S TRANSITION TO THRIE BEAM AND CHANNEL BRIDGE RAIL - B3.DAT (2 12-GA. NESTED THRIE/NODE 28)
   50   23   21    2   68   18    2    0
  0.0001    0.0001       0.50  300    0        1.0     1
    1    5    5    5    5    5    1
    1        0.0          0.0
    3      75.00          0.0
    5     150.00          0.0
    7     225.00          0.0
    9     300.00          0.0
   11     375.00          0.0
   13     450.00          0.0
   15     525.00          0.0
   17     600.00          0.0
   19     637.50          0.0
   21     675.00          0.0
   25     712.50          0.0
   27     731.25          0.0
   29     750.00          0.0
   31     768.75          0.0
   33     787.50          0.0
   35     806.25          0.0
   37     825.00          0.0
   38     825.00          0.0
   45     900.00          0.0
   46     900.00          0.0
   49     975.00          0.0
   50     975.00          0.0
    1    3    1    1         0.0
    3    5    1    1         0.0
    5    7    1    1         0.0
    7    9    1    1         0.0
    9   11    1    1         0.0
   11   13    1    1         0.0
   13   15    1    1         0.0
   15   17    1    1         0.0
   17   19    1    1         0.0
   19   21    1    1         0.0
   21   25    1    1         0.0
   25   27    1    1         0.0
   27   29    1    1         0.0
   29   31    1    1         0.0
   31   33    1    1         0.0
   33   35    1    1         0.0
   35   37    1    1         0.0
   37   45    1    2         0.0
   45   49    1    2         0.0
   38   46    1    2         0.0
   46   50    1    2         0.0
    1   43       0.35
   49   47   45   43   41   39   37   36   35   34
   33   32   31   30   29   28   27   26   25   24
   23   22   21   20   19   18   17   16   15   14
   13   12   11   10    9    8    7    6    5    4
    3    2    1
    2    7       0.35
   50   48   46   44   42   40   38
  100   10
    1       2.30       1.99      37.50   30000.0      6.92     99.5      68.5 0.10 12-GAUGE W-BEAM
    2      2.475      2.125      18.75   30000.0     7.405   106.25     73.75 0.10 12-GAUGE W-BEAM TO THRIE BEAM
    3       2.84       2.40      18.75   30000.0     8.375    120.0      84.0 0.10 12-GAUGE W-BEAM TO THRIE BEAM
    4      3.205       2.68      18.75   30000.0      9.35    134.0      94.0 0.10 12-GAUGE W-BEAM TO THRIE BEAM
    5      3.575       2.96      18.75   30000.0    10.325    148.0    104.25 0.10 12-GAUGE W-BEAM TO THRIE BEAM
    6       7.52       6.20      9.375   30000.0     21.62    310.0     219.0 0.10 12-GAUGE NESTED THRIE BEAM
    7       3.76       3.10      18.75   30000.0     10.81    155.0     109.5 0.10 12-GAUGE THRIE BEAM
    8       3.76       3.10      37.50   30000.0     10.81    155.0     109.5 0.10 12-GAUGE THRIE BEAM
    9       29.6       3.89      18.75   30000.0     13.25   140.04    343.80 0.10 C8x11.5 CHANNEL RAIL
   10       29.6       3.89      37.50   30000.0     13.25   140.04    343.80 0.10 C8x11.5 CHANNEL RAIL
  300    6
    1       21.0        0.0     1000.0    1000.0     250.0  10000.0   10000.0 0.10 SIMULATED ANCHORAGE DEVICE
   200.0      200.0        2.0       2.0
    2       21.0        0.0       2.00      4.72      54.0     96.6    255.57 0.10 W6x9 STEEL POST (44 9/16" E.D.) [BOGIE TEST IBT-3/4 USED 43" E.D.]
     6.0       15.0       16.0      16.0
    3       21.0        0.0       2.00      4.72      54.0     96.6    255.57 0.10 W6x9 STEEL POST (42 9/16" E.D.)
     6.0       15.0       16.0      16.0
    4       21.0        0.0       2.00      4.72      63.0     96.6    316.42 0.10 W6x9 STEEL POST (49" E.D.) (Fy)(Sx)(1.5)
     6.0       20.0       10.0      10.0
    5       21.0     30.625      129.0     200.0     612.5    362.9     804.6 0.10 W6x20 STEEL BRIDGE POST
    20.0       45.0        2.0       2.0
    6       21.0     30.625     2000.0    2000.0    1000.0  10000.0   10000.0 0.10 STRONG POST ANCHOR
   400.0      400.0        2.0       2.0
    1    1    2   16    1  101       0.0       0.0       0.0
   17   17   18         1  102       0.0       0.0       0.0
   18   18   19         1  103       0.0       0.0       0.0
   19   19   20         1  104       0.0       0.0       0.0
   20   20   21         1  105       0.0       0.0       0.0
   21   21   22   24    1  106       0.0       0.0       0.0
   25   25   26   36    1  106       0.0       0.0       0.0
   37   37   39   40    2  107       0.0       0.0       0.0
   41   45   47   42    2  108       0.0       0.0       0.0
   43   38   40   46    2  109       0.0       0.0       0.0
   47   46   48   48    2  110       0.0       0.0       0.0
   49    1        50    2  301       0.0       0.0       0.0       0.0       0.0
   51    5        67    2  302       0.0       0.0       0.0       0.0       0.0
   58   19                 303       0.0       0.0       0.0       0.0       0.0
   59   21                 304       0.0       0.0       0.0       0.0       0.0
   60   25        65    2  304       0.0       0.0       0.0       0.0       0.0
   66   37   38   67    2  305       0.0       0.0       0.0       0.0       0.0
   68   49   50            306       0.0       0.0       0.0       0.0       0.0
  4400.0    40000.0   20    6    4    0    1
    1      0.055       0.12       6.00      17.0
    2      0.057       0.15       7.00      18.0
    3      0.062       0.18      10.00      12.0
    4      0.110       0.35      12.00       6.0
    5       0.35       0.45       6.00       5.0
    6       1.45       1.50      15.00       1.0
    1     100.75     15.875    1      12.0    1    0    0    0
    2     100.75     27.875    1      12.0    1    0    0    0
    3     100.75     39.875    2      12.0    1    0    0    0
    4      88.75     39.875    2      12.0    1    0    0    0
    5      76.75     39.875    2      12.0    1    0    0    0
    6      64.75     39.875    2      12.0    1    0    0    0
    7      52.75     39.875    2      12.0    1    0    0    0
    8      40.75     39.875    2      12.0    1    0    0    0
    9      28.75     39.875    2      12.0    1    0    0    0
   10      16.75     39.875    2      12.0    1    0    0    0
   11     -13.25     39.875    3      12.0    1    0    0    0
   12     -33.25     39.875    3      12.0    1    0    0    0
   13     -53.25     39.875    3      12.0    1    0    0    0
   14     -73.25     39.875    3      12.0    1    0    0    0
   15     -93.25     39.875    3      12.0    1    0    0    0
   16    -113.25     39.875    4      12.0    1    0    0    0
```

```
17   -113.25    -39.875   4       12.0    0     0     0     0
18    100.75    -39.875   1       12.0    0     0     0     0
19     69.25     37.75    5        1.0    1     0     0     0
20    -62.75     37.75    6        1.0    1     0     0     0
 1     69.25     32.75       0.0       608.
 2     69.25    -32.75       0.0       608.
 3    -62.75     32.75       0.0       492.
 4    -62.75    -32.75       0.0       492.
 1      0.0       0.0
 3   740.625      0.0       25.0      62.14        0.0         0.0         1.0
```

APPENDIX B

Accelerometer Data Analysis, Test MST-1

Figure B-1. Graph of Longitudinal Deceleration, Test MST-1

Figure B-2. Graph of Longitudinal Occupant Impact Velocity, Test MST-1

Figure B-3. Graph of Longitudinal Occupant Displacement, Test MST-1

Figure B-4. Graph of Lateral Deceleration, Test MST-1

Figure B-5. Graph of Lateral Occupant Impact Velocity, Test MST-1

Figure B-6. Graph of Lateral Occupant Displacement, Test MST-1

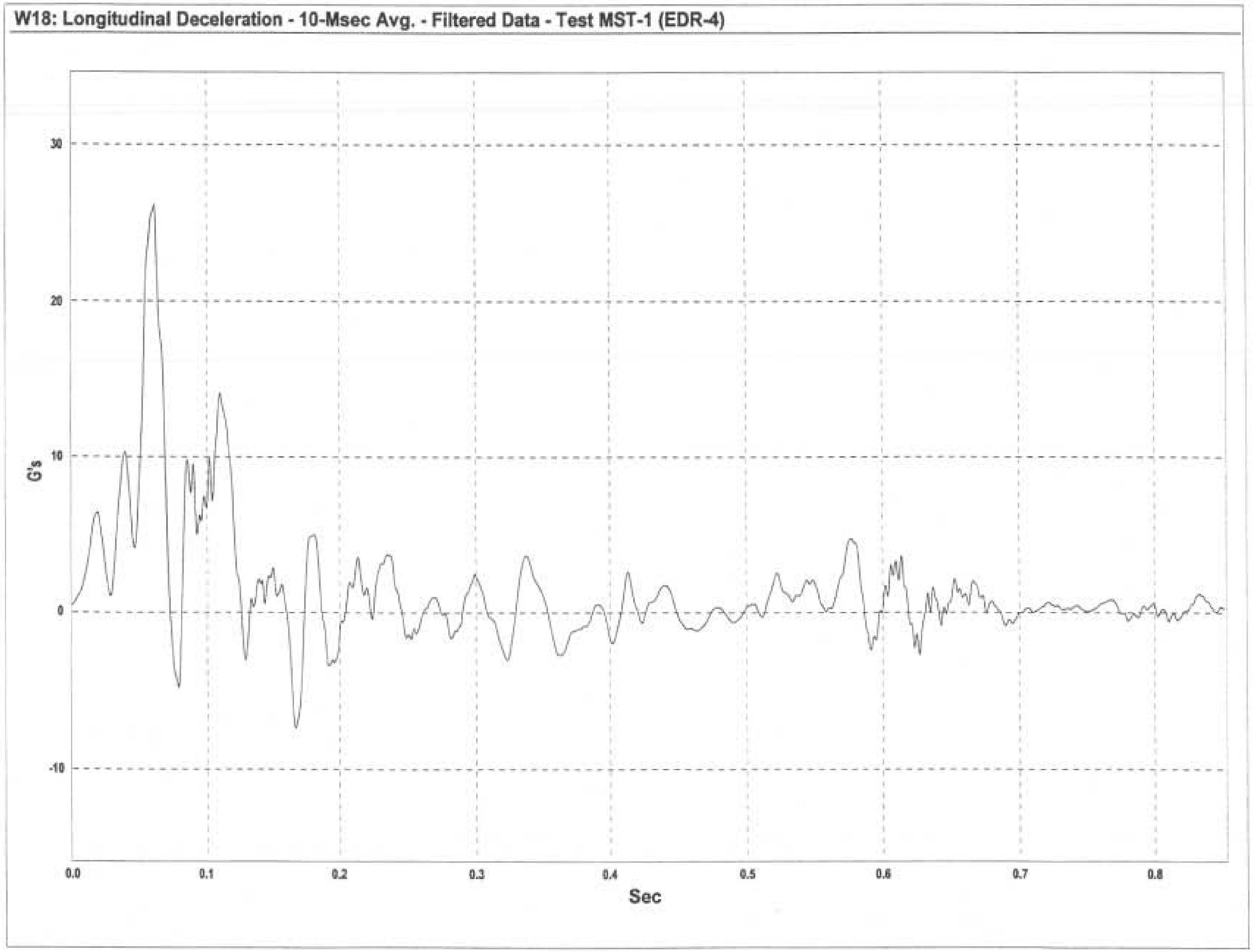


Figure B-1. Graph of Longitudinal Deceleration, Test MST-1

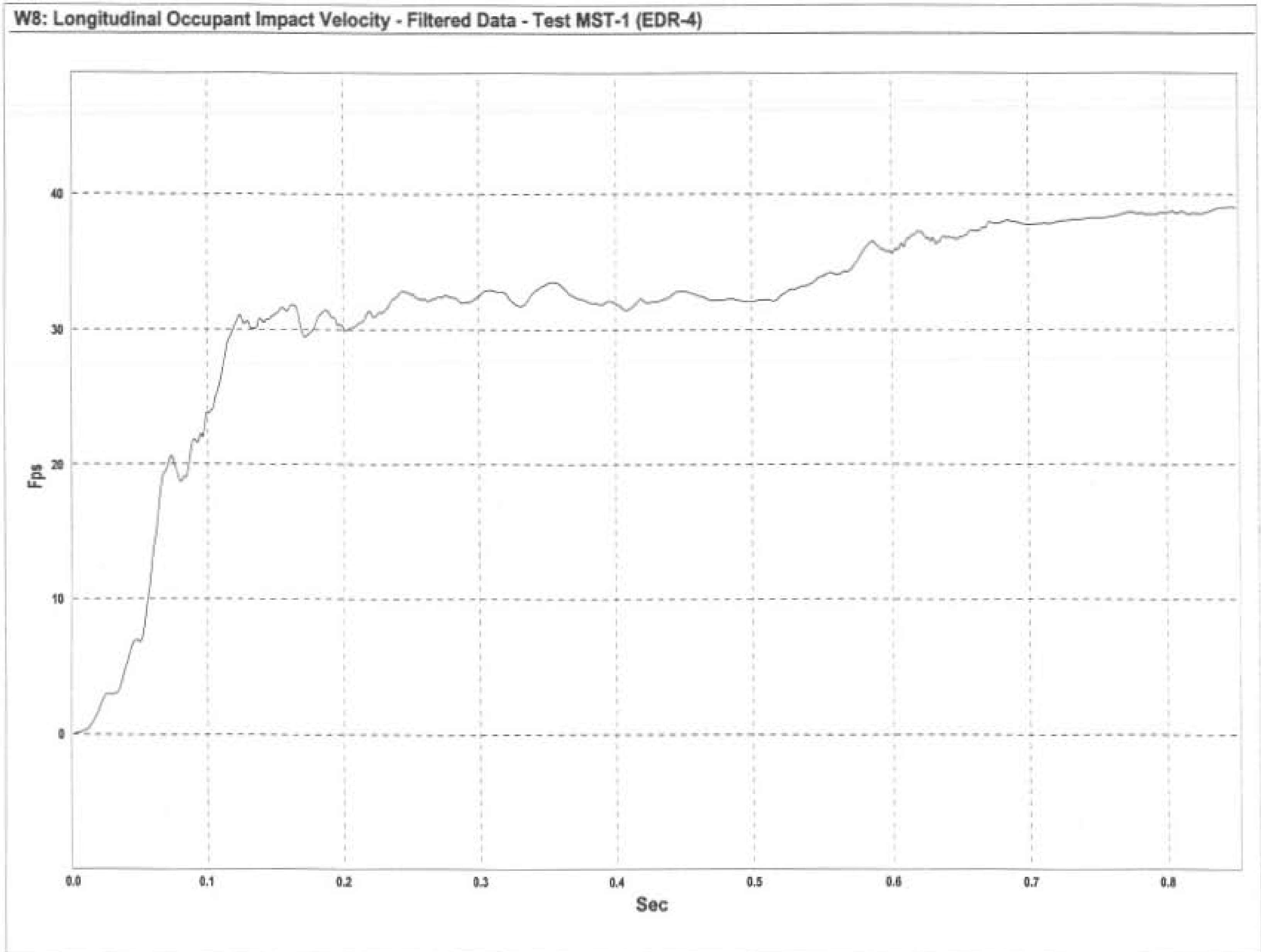


Figure B-2. Graph of Longitudinal Occupant Impact Velocity, Test MST-1

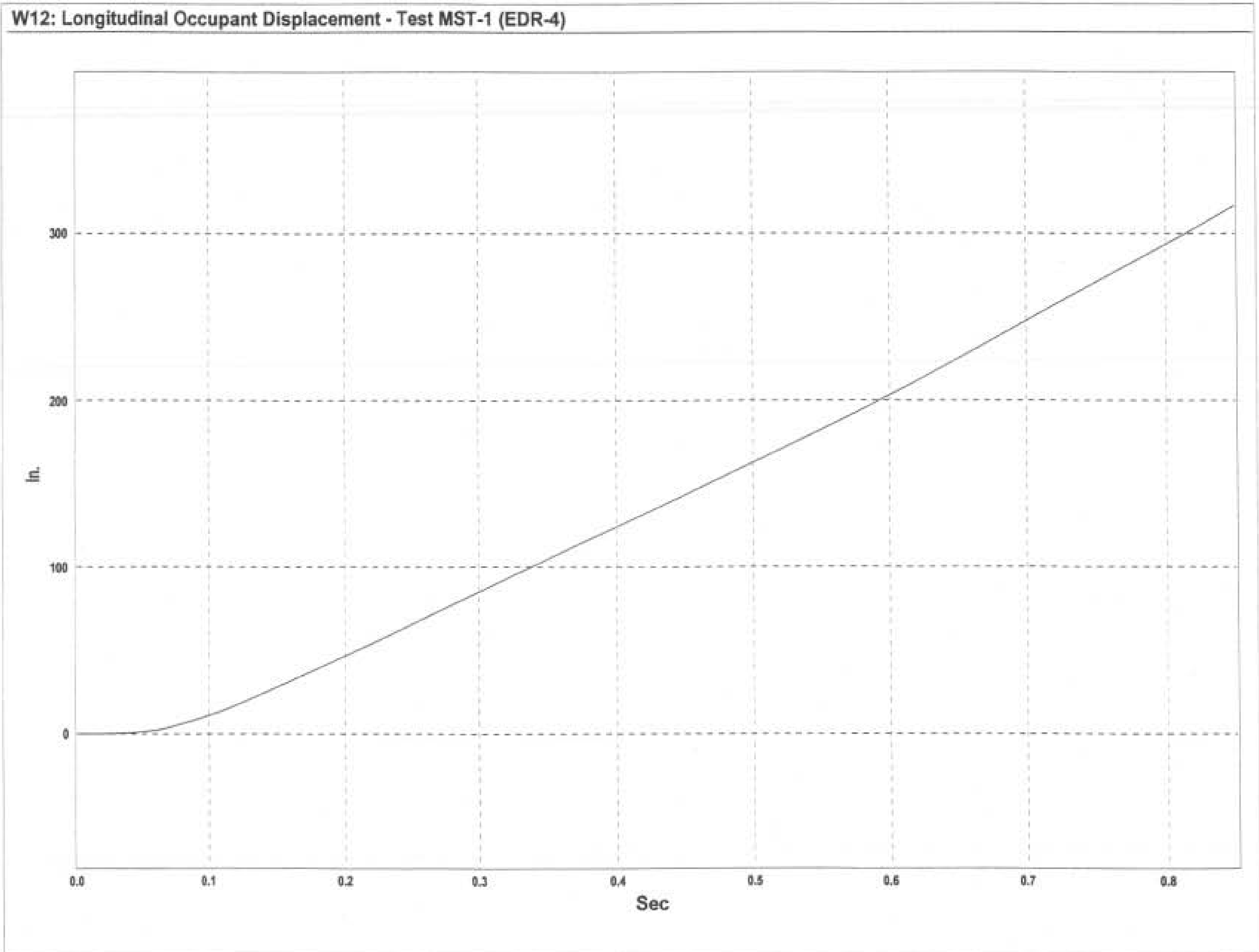


Figure B-3. Graph of Longitudinal Occupant Displacement, Test MST-1

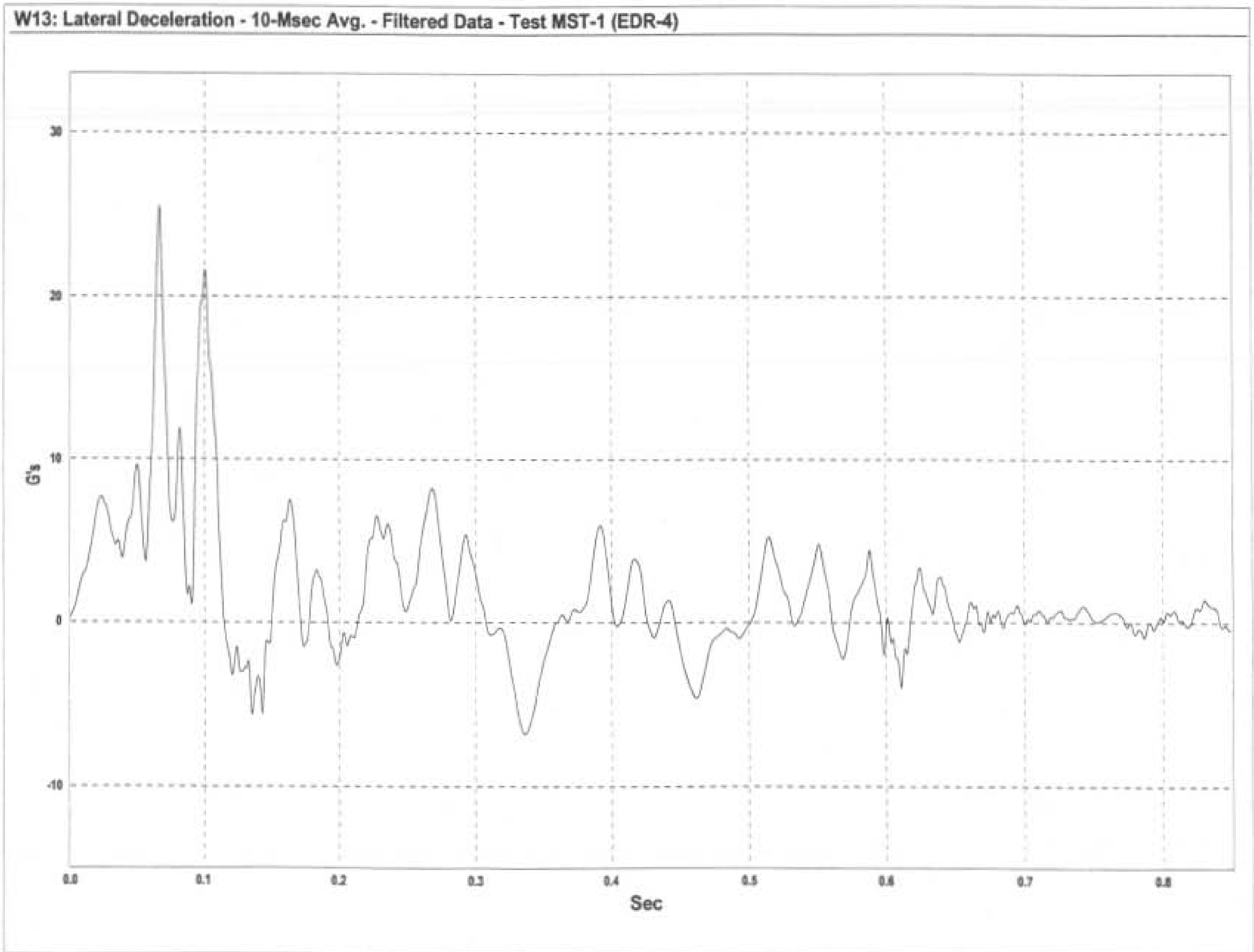


Figure B-4. Graph of Lateral Deceleration, Test MST-1

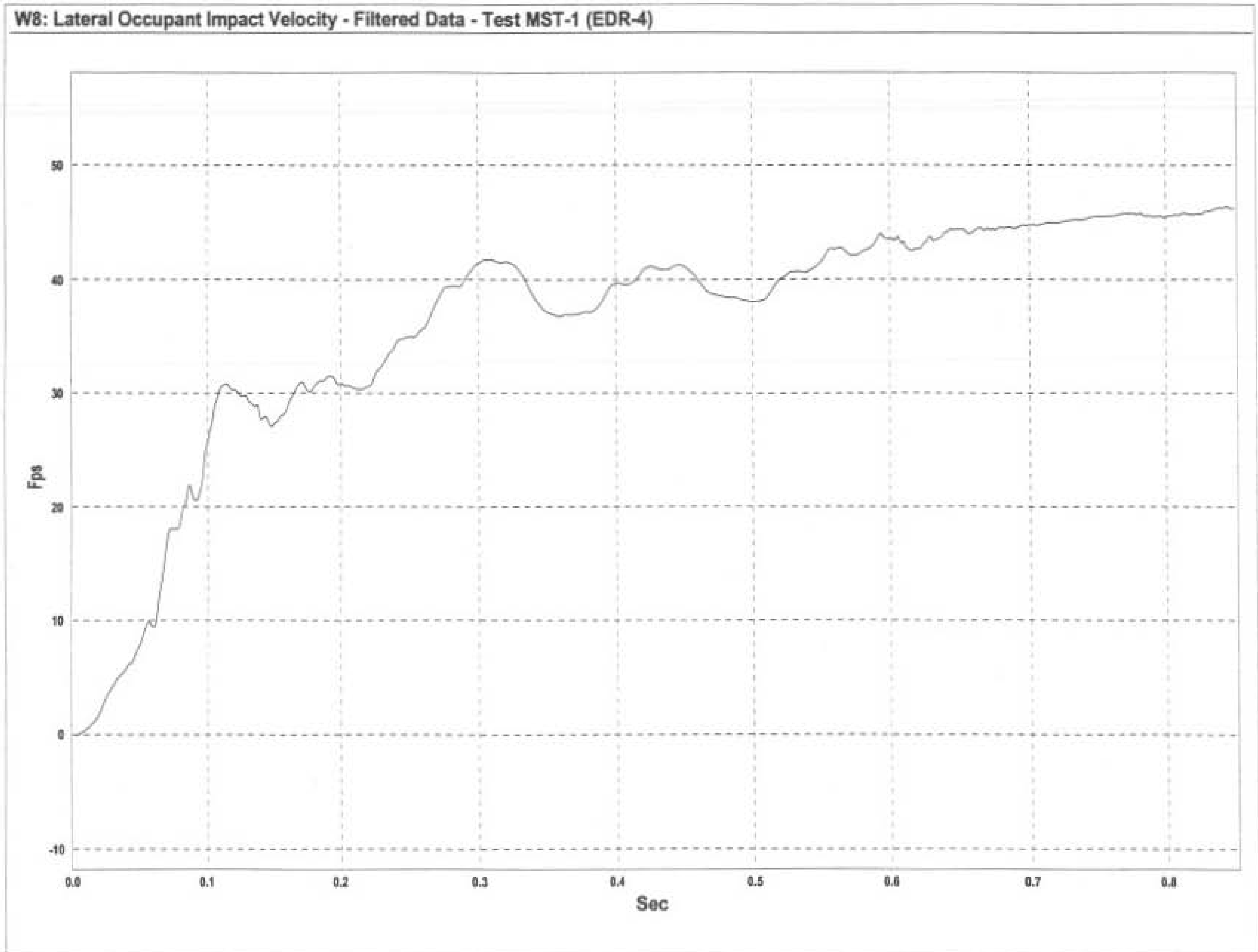


Figure B-5. Graph of Lateral Occupant Impact Velocity, Test MST-1

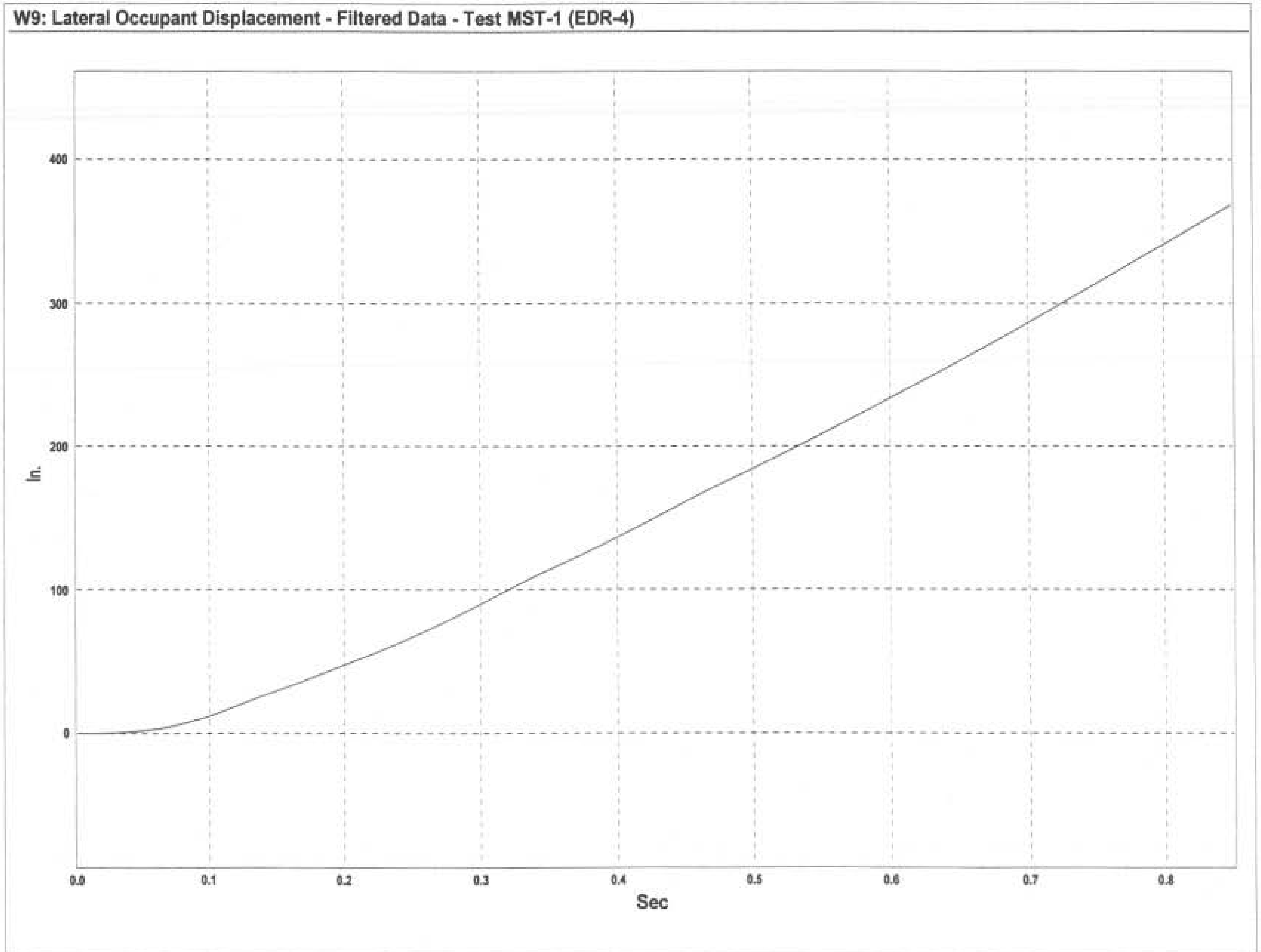


Figure B-6. Graph of Lateral Occupant Displacement, Test MST-1

APPENDIX C

Rate Transducer Data Analysis, Test MST-1

Figure C-1. Graph of Roll, Pitch, and Yaw Angular Displacements, Test MST-1

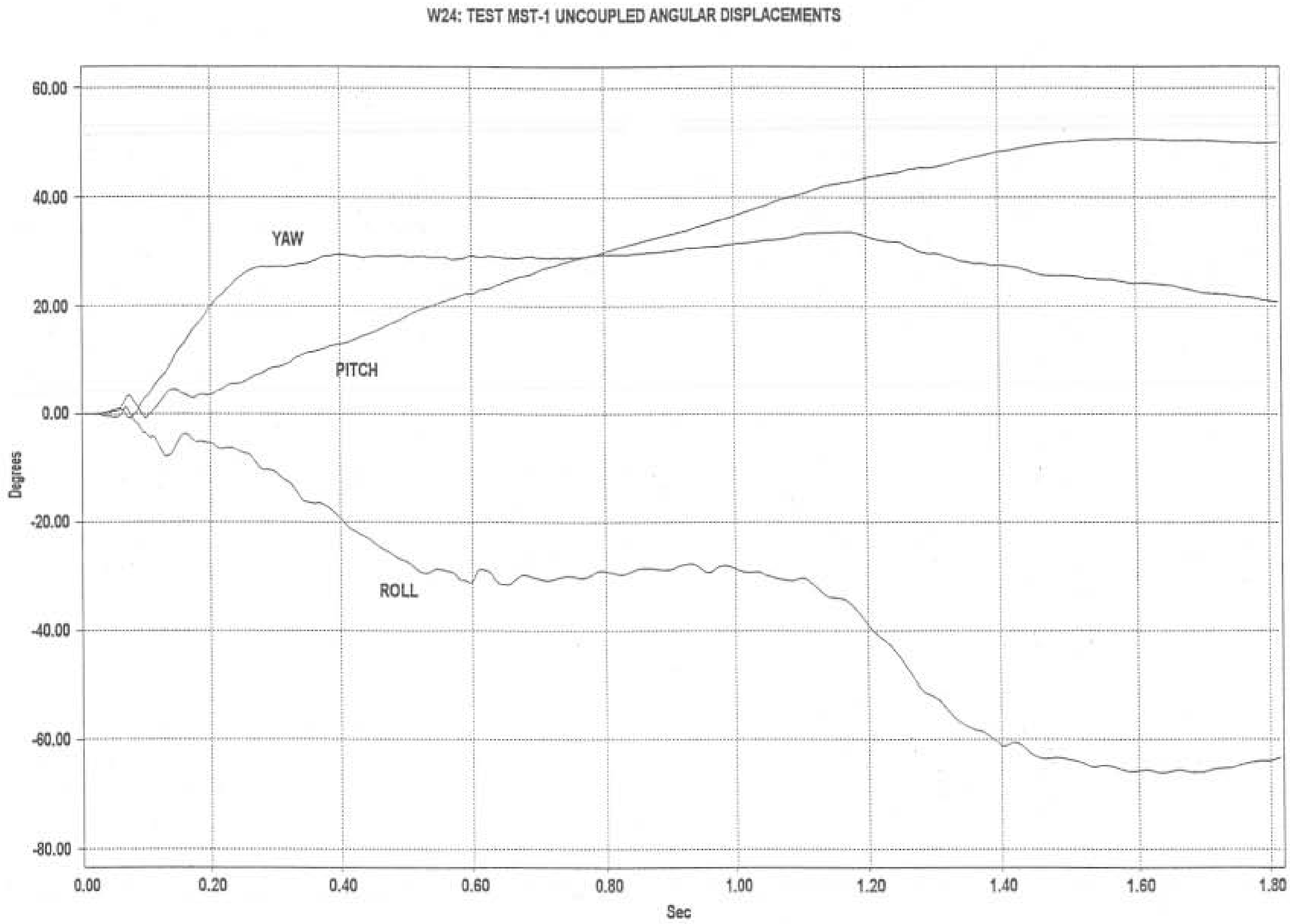


Figure C-1. Graph of Roll, Pitch, and Yaw Angular Displacements, Test MST-1

APPENDIX D

Typical BARRIER VII Input File

Note that the example BARRIER VII input data file included in Appendix D correspond with the critical impact point for test MST-2.

```
MISSOURI'S TRANSITION TO THRIE BEAM AND CHANNEL BRIDGE RAIL - D5.DAT (2 12-GA. NESTED THRIE/NODE 31) - Design 2
  58   27   25    3   76   25    2    0
   0.0001      0.0001      0.50  800     0        1.0    1
   1    5    5    5    5    5    1
   1        0.0          0.0
   3       75.00         0.0
   5      150.00         0.0
   7      225.00         0.0
   9      300.00         0.0
  11      375.00         0.0
  13      450.00         0.0
  15      525.00         0.0
  17      600.00         0.0
  19      637.50         0.0
  21      675.00         0.0
  25      712.50         0.0
  27      731.25         0.0
  29      750.00         0.0
  30      750.00         0.0
  33      768.75         0.0
  34      768.75         0.0
  37      787.50         0.0
  38      787.50         0.0
  41      806.25         0.0
  42      806.25         0.0
  45      825.00         0.0
  46      825.00         0.0
  53      900.00         0.0
  54      900.00         0.0
  57      975.00         0.0
  58      975.00         0.0
   1    3    1    1        0.0
   3    5    1    1        0.0
   5    7    1    1        0.0
   7    9    1    1        0.0
   9   11    1    1        0.0
  11   13    1    1        0.0
  13   15    1    1        0.0
  15   17    1    1        0.0
  17   19    1    1        0.0
  19   21    1    1        0.0
  21   25    1    1        0.0
  25   27    1    1        0.0
  27   29    1    1        0.0
  29   33    1    2        0.0
  33   37    1    2        0.0
  37   41    1    2        0.0
  41   45    1    2        0.0
  45   53    1    2        0.0
  53   57    1    2        0.0
  30   34    1    2        0.0
  34   38    1    2        0.0
  38   42    1    2        0.0
  42   46    1    2        0.0
  46   54    1    2        0.0
  54   58    1    2        0.0
   1   43       0.35
  57   55   53   51   49   47   45   43   41   39
  37   35   33   31   29   28   27   26   25   24
  23   22   21   20   19   18   17   16   15   14
  13   12   11   10    9    8    7    6    5    4
   3    2    1
   2    7       0.35
  50   48   46   44   42   40   38
 100   15
   1       2.30        1.99       37.50     30000.0        6.92       99.5      68.5 0.10 12-GAUGE W-BEAM
   2      2.475       2.125       18.75     30000.0       7.405     106.25     73.75 0.10 12-GAUGE W-BEAM TO THRIE BEAM
   3       2.84        2.40       18.75     30000.0       8.375      120.0      84.0 0.10 12-GAUGE W-BEAM TO THRIE BEAM
   4      3.205        2.68       18.75     30000.0        9.35      134.0      94.0 0.10 12-GAUGE W-BEAM TO THRIE BEAM
   5      3.575        2.96       18.75     30000.0      10.325      148.0    104.25 0.10 12-GAUGE W-BEAM TO THRIE BEAM
   6       7.52        6.20       9.375     30000.0       21.62      310.0     219.0 0.10 12-GAUGE NESTED THRIE BEAM
   7       3.76        3.10       18.75     30000.0       10.81      155.0     109.5 0.10 12-GAUGE THRIE BEAM
   8       3.76        3.10       37.50     30000.0       10.81      155.0     109.5 0.10 12-GAUGE THRIE BEAM
   9       0.72        1.06       9.375     30000.0        3.44      21.26     14.18 0.10 CUT C8x11.5 CHANNEL RAIL
  10       1.75        1.32       9.375     30000.0        4.55      21.26     26.64 0.10 CUT C8x11.5 CHANNEL RAIL
  11       4.86        1.69       9.375     30000.0        5.80      21.26     52.92 0.10 CUT C8x11.5 CHANNEL RAIL
  12      11.48        2.19       9.375     30000.0        7.50      21.26     98.64 0.10 CUT C8x11.5 CHANNEL RAIL
  13       32.6        3.38       9.375     30000.0       11.50      21.26    343.80 0.10 C8x11.5 CHANNEL RAIL
  14       32.6        3.38       18.75     30000.0       11.50     121.68    343.80 0.10 C8x11.5 CHANNEL RAIL
  15       32.6        3.38       37.50     30000.0       11.50     121.68    343.80 0.10 C8x11.5 CHANNEL RAIL
 300    7
   1       21.0         0.0      1000.0      1000.0       250.0    10000.0   10000.0 0.10 SIMULATED ANCHORAGE DEVICE
   200.0     200.0         2.0         2.0
   2       21.0         0.0        2.00        4.72        54.0       96.6    255.57 0.10 W6x9 POST (44 9/16" E.D.) [BOGIE TEST INT-3/4 USED 43" E.D.]
     6.0      15.0        16.0        16.0
   3       21.0         0.0        2.00        4.72        54.0       96.6    255.57 0.10 W6x9 POST (42 9/16" E.D.)
     6.0      15.0        16.0        16.0
   4       21.0         0.0        2.00        4.72        63.0       96.6     420.0 0.10 W6x9x7' POST (51.5" E.D.)
    10.0      30.0        10.0        10.0
   5       21.0      30.625        2.00        4.72        63.0       96.6     420.0 0.10 W6x9x7' POST (52.9" E.D.)
    10.0      30.0        10.0        10.0
   6       21.0      30.625       129.0       200.0       612.5      362.9     804.6 0.10 W6x20 BRIDGE POST
    20.0      45.0         3.0         3.0
   7       21.0      30.625      2000.0      2000.0      1000.0    10000.0   10000.0 0.10 STRONG POST ANCHOR
   400.0     400.0         2.0         2.0
   1    1    2   16    1  101         0.0         0.0         0.0
  17   17   18         1  102         0.0         0.0         0.0
  18   18   19         1  103         0.0         0.0         0.0
  19   19   20         1  104         0.0         0.0         0.0
  20   20   21         1  105         0.0         0.0         0.0
  21   21   22   24    1  106         0.0         0.0         0.0
  25   25   26   28    1  106         0.0         0.0         0.0
  29   29   31   36    2  106         0.0         0.0         0.0
  37   45   47   40    2  107         0.0         0.0         0.0
  41   53   55   42    2  108         0.0         0.0         0.0
  43   30   32            109         0.0         0.0         0.0
  44   32   34            110         0.0         0.0         0.0
  45   34   36            111         0.0         0.0         0.0
  46   36   38            112         0.0         0.0         0.0
  47   38   40   50    2  113         0.0         0.0         0.0
  51   46   48   54    2  114         0.0         0.0         0.0
  55   54   56   56    2  115         0.0         0.0         0.0
  57    1        58    2  301         0.0         0.0         0.0         0.0         0.0
  59    5        65    2  302         0.0         0.0         0.0         0.0         0.0
  66   19                 303         0.0         0.0         0.0         0.0         0.0
  67   21                 304         0.0         0.0         0.0         0.0         0.0
  68   25        69    2  304         0.0         0.0         0.0         0.0         0.0
  70   29   30   73    4  305         0.0         0.0         0.0         0.0         0.0
  74   45   46   75    8  306         0.0         0.0         0.0         0.0         0.0
  76   57   58            307         0.0         0.0         0.0         0.0         0.0
  4400.0   40000.0   20    6    4    0    1
```

```
   1     0.055      0.12      6.00      17.0
   2     0.057      0.15      7.00      18.0
   3     0.062      0.18     10.00      12.0
   4     0.110      0.35     12.00       6.0
   5      0.35      0.45      6.00       5.0
   6      1.45      1.50     15.00       1.0
   1    100.75    15.875   1       12.0    1     0     0     0
   2    100.75    27.875   1       12.0    1     0     0     0
   3    100.75    39.875   2       12.0    1     0     0     0
   4     88.75    39.875   2       12.0    1     0     0     0
   5     76.75    39.875   2       12.0    1     0     0     0
   6     64.75    39.875   2       12.0    1     0     0     0
   7     52.75    39.875   2       12.0    1     0     0     0
   8     40.75    39.875   2       12.0    1     0     0     0
   9     28.75    39.875   2       12.0    1     0     0     0
  10     16.75    39.875   2       12.0    1     0     0     0
  11    -13.25    39.875   3       12.0    1     0     0     0
  12    -33.25    39.875   3       12.0    1     0     0     0
  13    -53.25    39.875   3       12.0    1     0     0     0
  14    -73.25    39.875   3       12.0    1     0     0     0
  15    -93.25    39.875   3       12.0    1     0     0     0
  16   -113.25    39.875   4       12.0    1     0     0     0
  17   -113.25   -39.875   4       12.0    0     0     0     0
  18    100.75   -39.875   1       12.0    0     0     0     0
  19     69.25     37.75   5        1.0    1     0     0     0
  20    -62.75     37.75   6        1.0    1     0     0     0
   1     69.25     32.75      0.0      608.
   2     69.25    -32.75      0.0      608.
   3    -62.75     32.75      0.0      492.
   4    -62.75    -32.75      0.0      492.
   1       0.0       0.0
   3   759.375       0.0     25.0     62.14       0.0       0.0       1.0
```

APPENDIX E

Accelerometer Data Analysis, Test MST-2

Figure E-1. Graph of Longitudinal Decelerations, Test MST-2

Figure E-2. Graph of Longitudinal Occupant Impact Velocity, Test MST-2

Figure E-3. Graph of Longitudinal Occupant Displacement, Test MST-2

Figure E-4. Graph of Lateral Deceleration, Test MST-2

Figure E-5. Graph of Lateral Occupant Impact Velocity, Test MST-2

Figure E-6. Graph of Lateral Occupant Displacement, Test MST-2

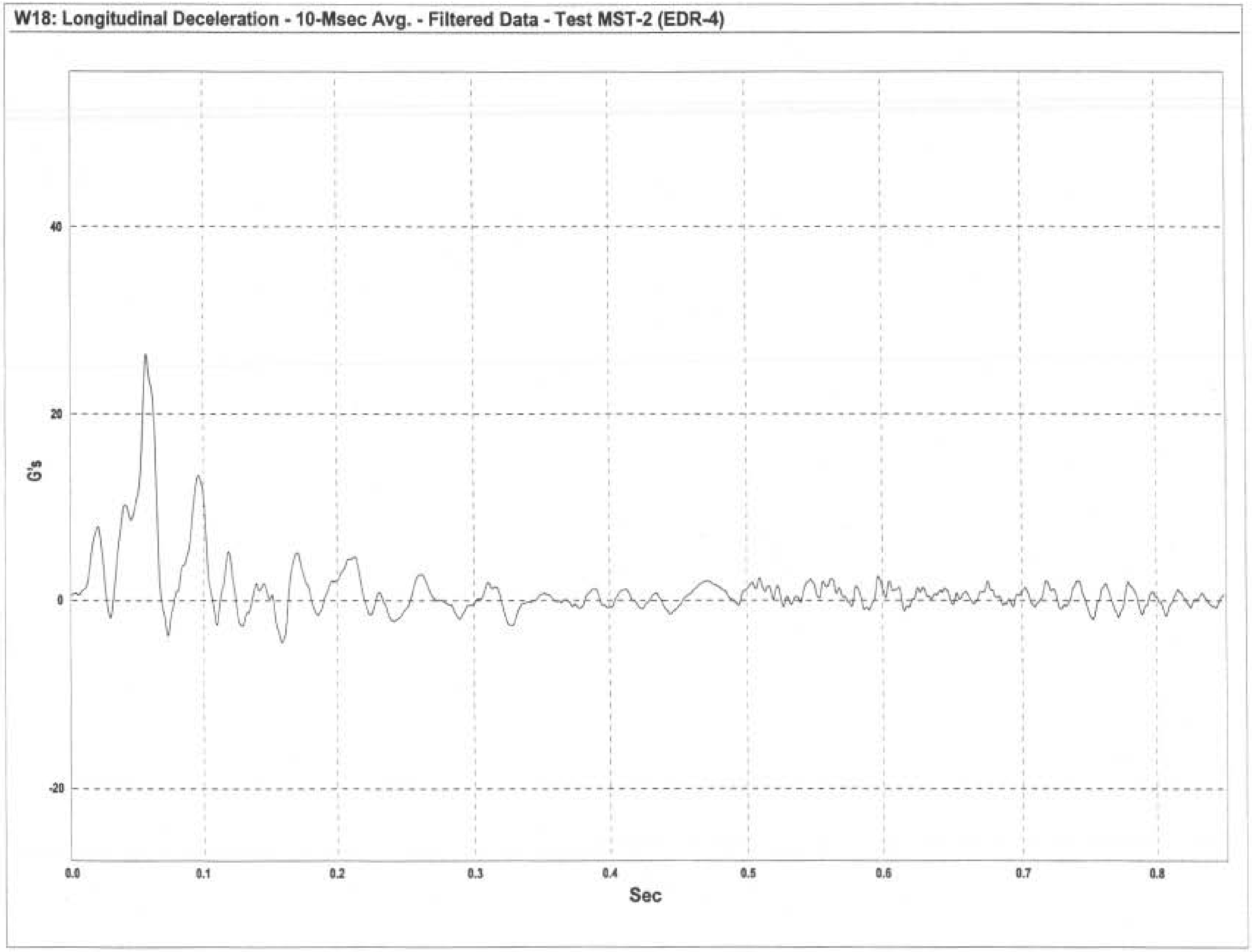


Figure E-1. Graph of Longitudinal Deceleration, Test MST-2

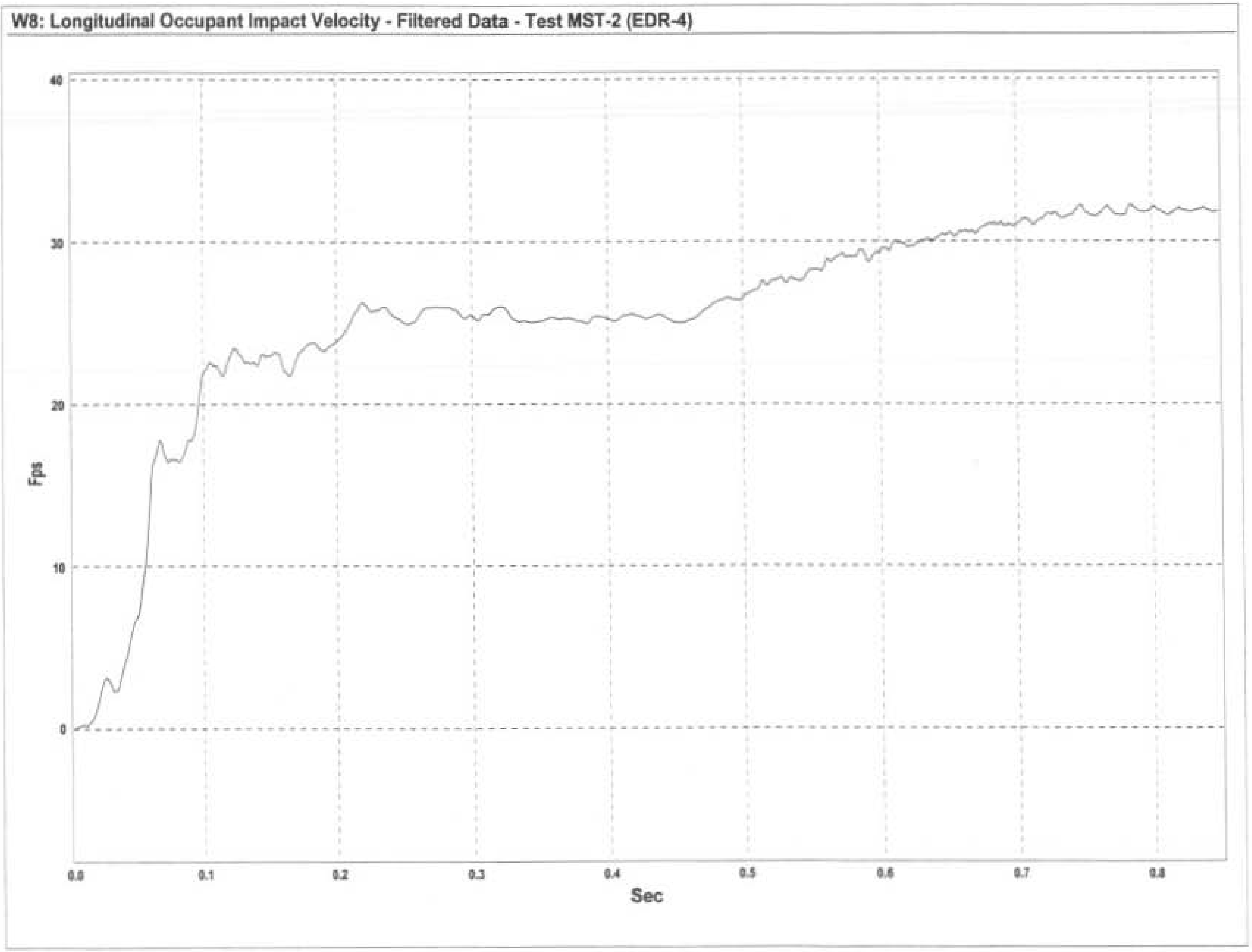


Figure E-2. Graph of Longitudinal Occupant Impact Velocity, Test MST-2

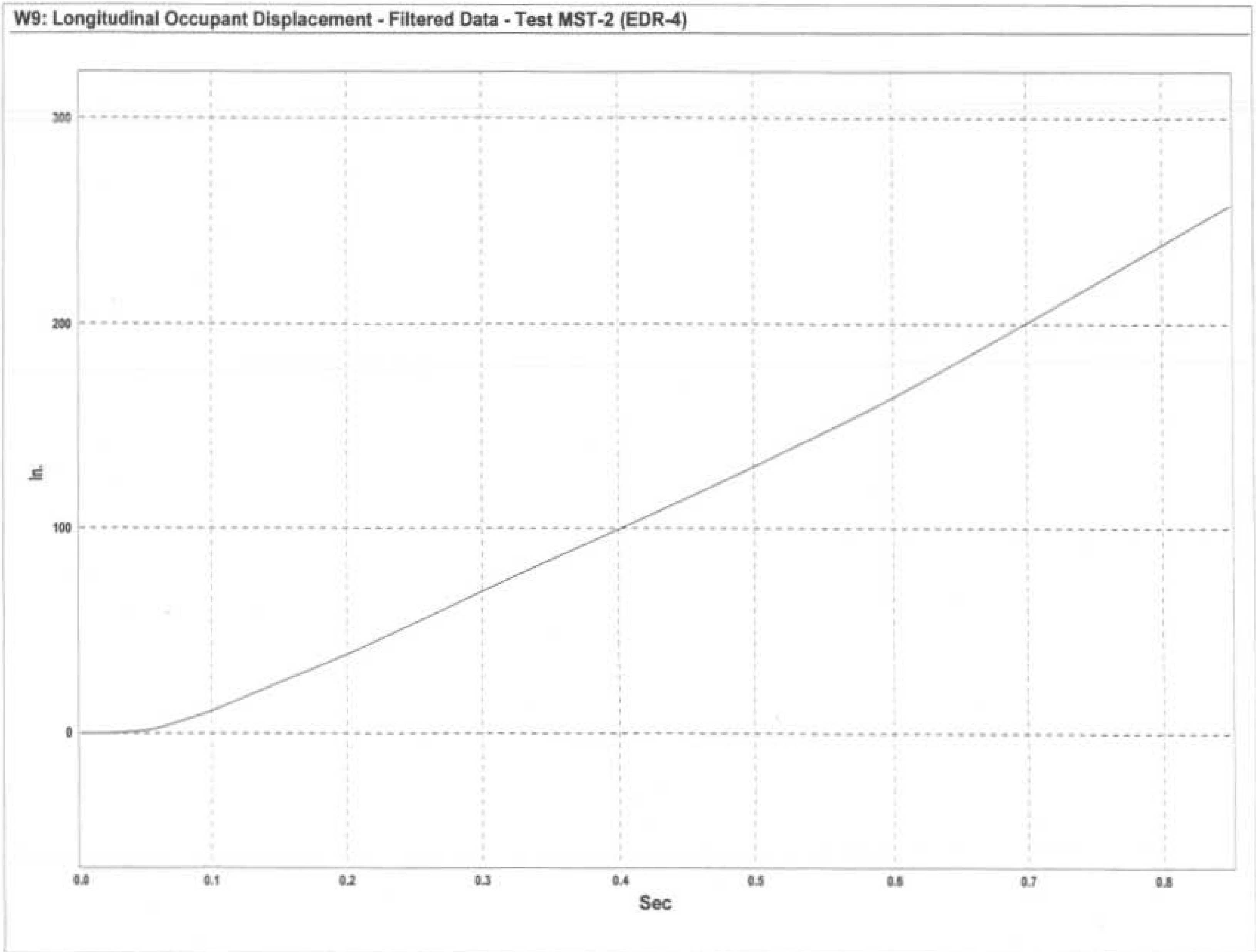


Figure E-3. Graph of Longitudinal Occupant Displacement, Test MST-2

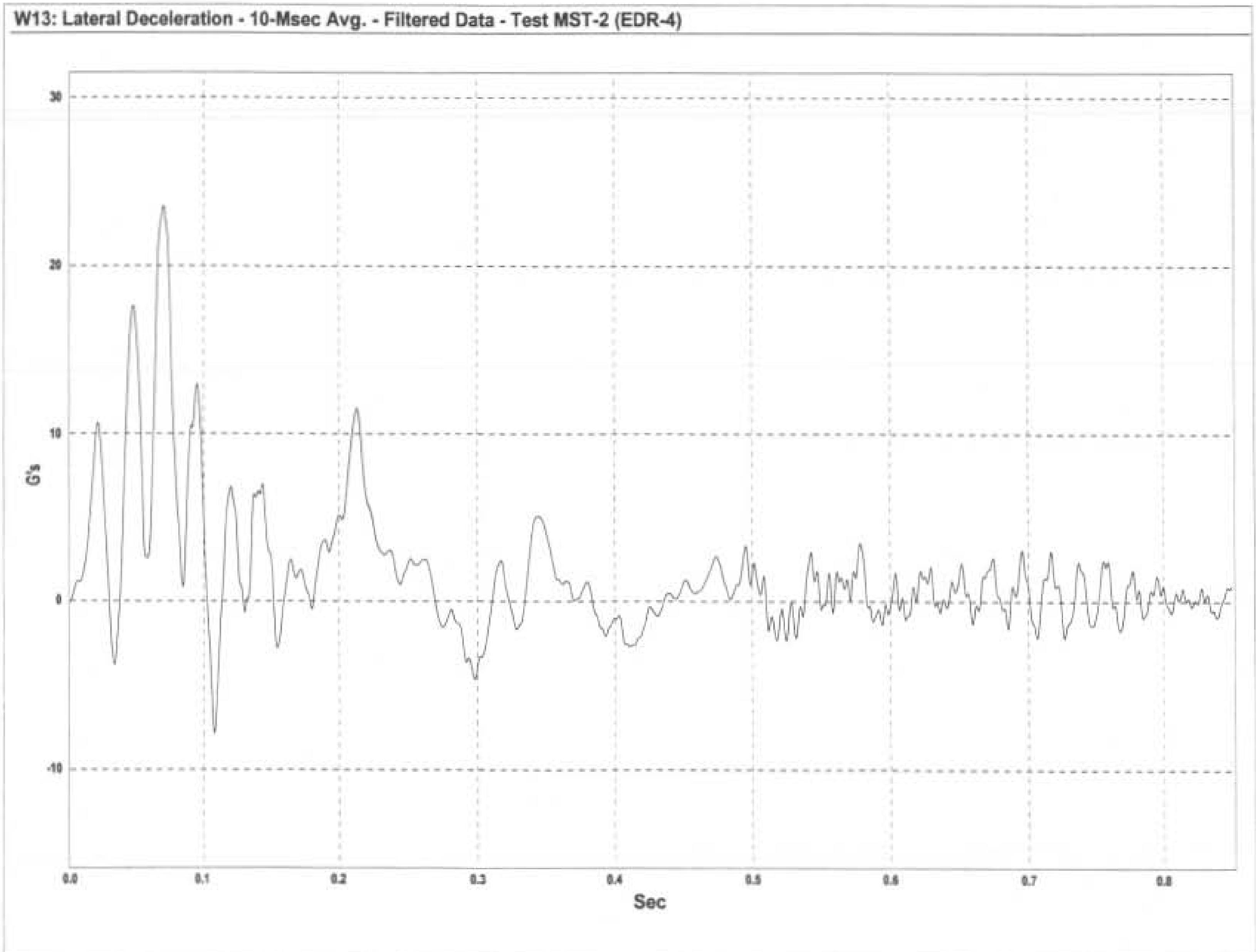


Figure E-4. Graph of Lateral Deceleration, Test MST-2

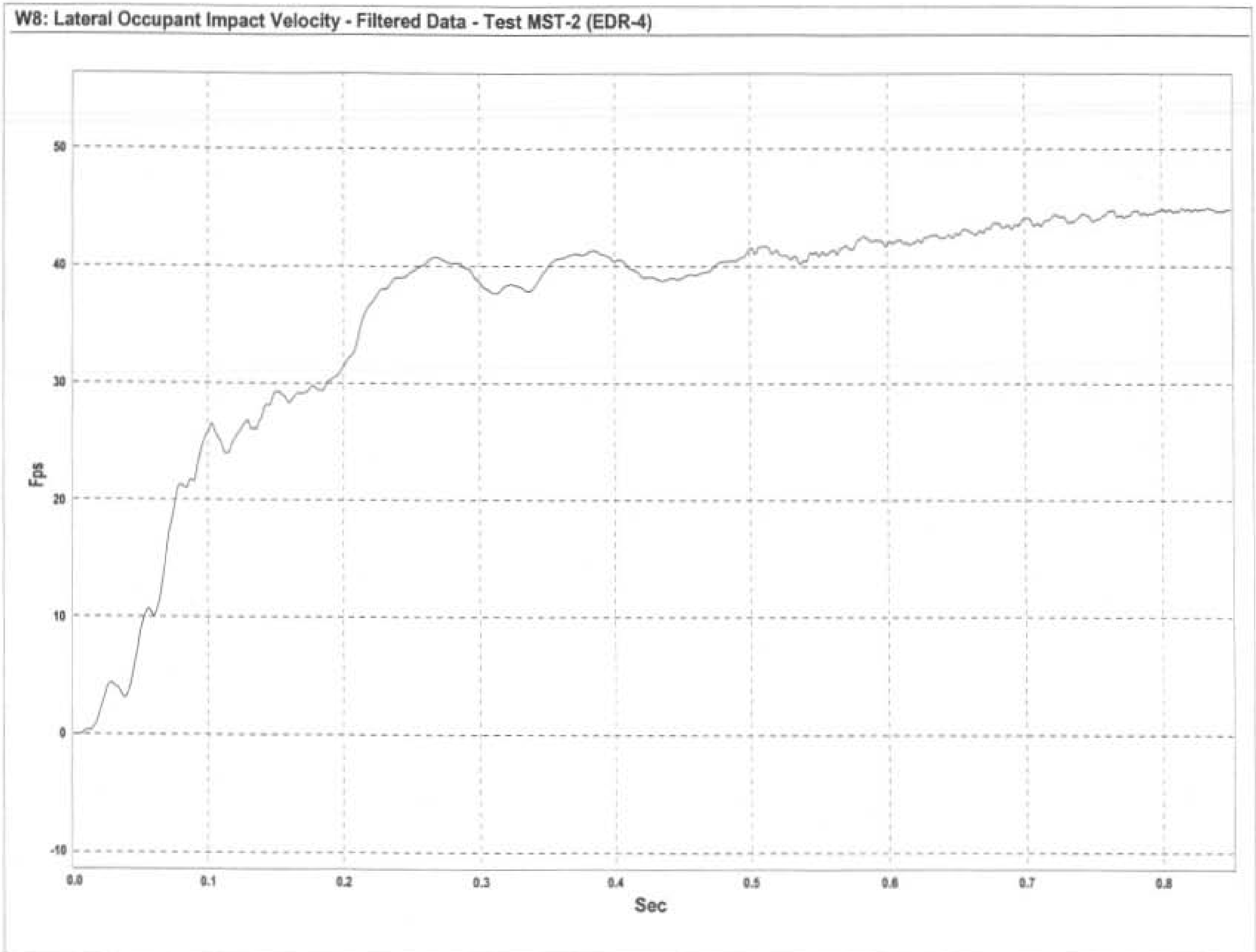


Figure E-5. Graph of Lateral Occupant Impact Velocity, Test MST-2

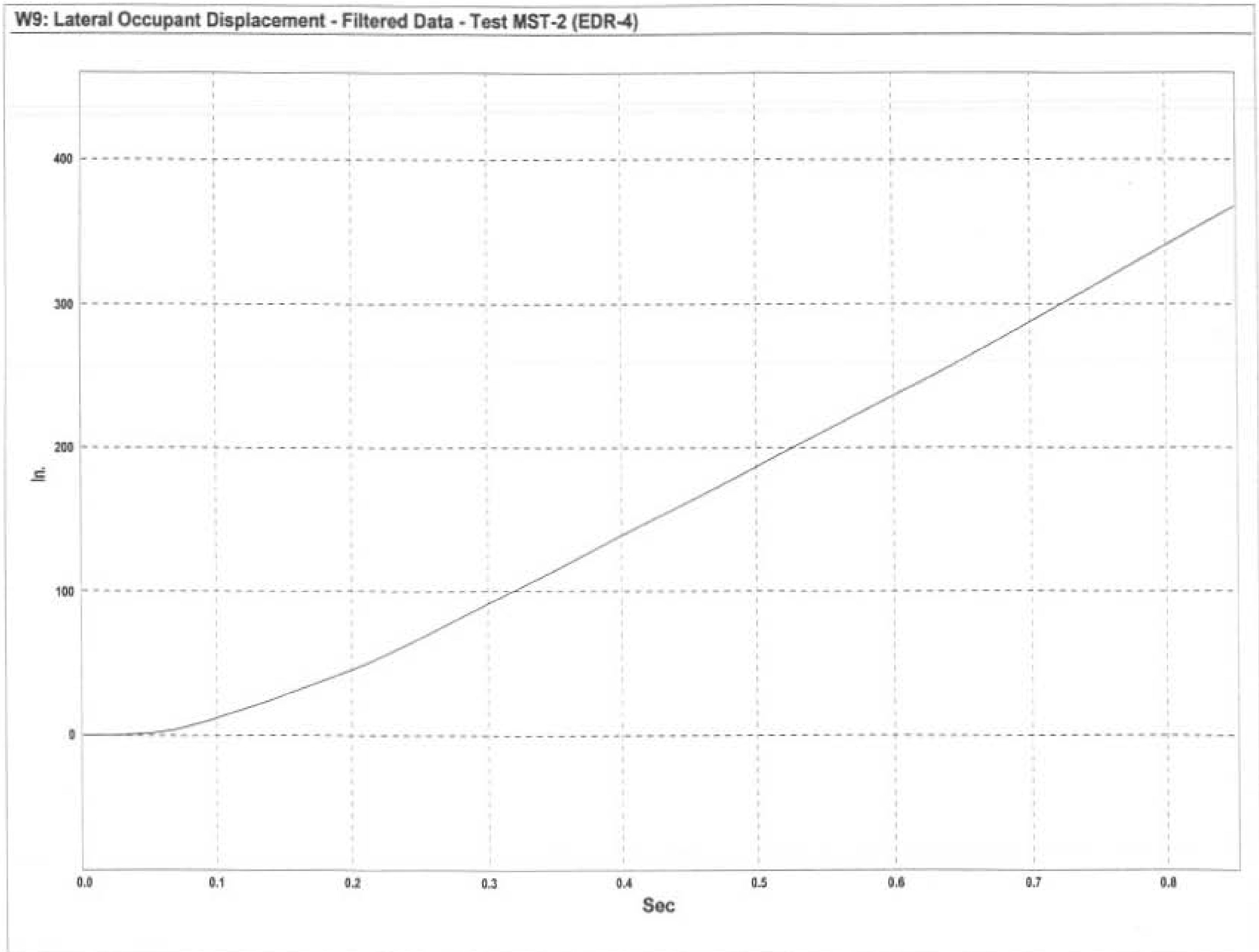


Figure E-6. Graph of Lateral Occupant Displacement, Test MST-2

APPENDIX F

Rate Transducer Data Analysis, Test MST-2

Figure F-1. Graph of Roll, Pitch, and Yaw Angular Displacements, Test MST-2

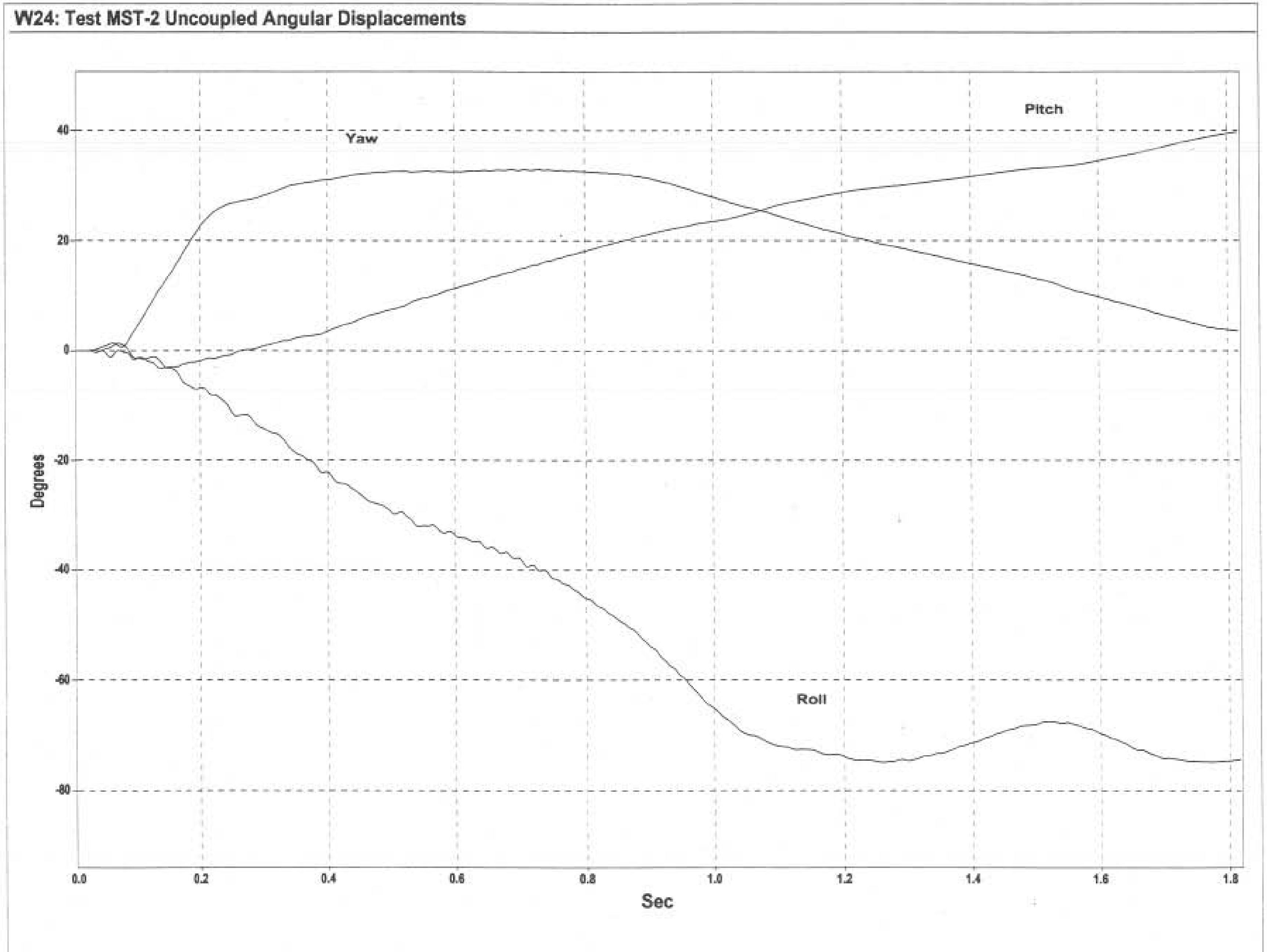


Figure F-1. Graph of Roll, Pitch, and Yaw Angular Displacements, Test MST-2

APPENDIX G

Letter to FHWA

University of
Nebraska
Lincoln

Midwest Roadside Safety Facility
Civil Engineering Department
1901 'Y' Street, Bldg. C
P.O. Box 880601
Lincoln, NE 68588-0601

April 19, 1999

Mr. Richard Powers
Federal Highway Administration - HNG-1
400 7th Street, S.W.
Washington, D.C. 20590

Dear Mr. Powers:

During the last year, the Midwest Roadside Safety Facility (MwRSF) conducted a research study to develop and crash test an approach guardrail transition for use with Missouri's thrie beam and channel bridge railing system. A schematic of the bridge railing system is shown in Attachment A. This bridge railing system was originally crash tested by TTI in 1988 according to the NCHRP Report No. 230 safety performance guidelines. On May 30, 1997, the Federal Highway Administration (FHWA) published a Memorandum, entitled "Crash Testing of Bridge Railings" - Part II, which provided an equivalent rating of TL-3 for the bridge railing according to the NCHRP Report No. 350 guidelines.

The research study was initiated with a review of recently developed NCHRP 350 transition designs, such as the thrie beam transition attached to a safety shape concrete parapet. Following this review, MwRSF researchers believed that the thrie beam transition design, tested with ITNJ-2 and ITNJ-4 by MwRSF, could be adapted for use with Missouri's thrie beam and channel bridge railing system with only slight modification. However, with the new transition design, there remained a concern for wheel snagging on the first bridge post since blockouts were not included on the bridge railing system. Since the Missouri Department of Transportation (MoDOT) was unwilling to incorporate blockouts in the bridge railing, MwRSF engineers were required to consider a means for eliminating the wheel snag potential on the first bridge post. The wheel snag potential was eventually resolved by incorporating a channel rubrail below the thrie beam and on the face of the posts.

The first crash test, test MST-1, was performed unsuccessfully on the thrie beam transition design that included a rubrail. A schematic of this transition system is shown in Attachment B. The pickup truck was redirected with significant vehicular motions, resulting in rollover. Failure of the transition system was mainly attributed to the inclusion of the rubrail. Following the failed crash test, the transition system was modified in order to reduce lateral rail deflections and minimize the effect of the wheel/rubrail interaction. A schematic of the redesigned transition system is shown in Attachment C. Subsequently, the second crash test, test MST-2, was also performed unsuccessfully on the thrie beam and rubrail transition design. Once again, the pickup truck was redirected with significant vehicular motions and resulted in vehicle rollover. Failure of the transition system was again attributed to the inclusion of the rubrail. I have enclosed a VHS tape which shows the two MST crash tests on the thrie beam and channel rubrail transition designs.

Following the failure of the previous two transition designs, discussions between MwRSF and MoDOT personnel resulted in Missouri reconsidering the placement of blockouts on the bridge railing system. With this action, the concern for wheel snag on the first bridge post was essentially eliminated. Therefore, MwRSF researchers could once again consider the adaptation of existing NCHRP 350 transition designs to the thrie beam and channel bridge railing system.

Once again, MwRSF researchers reviewed the recently developed NCHRP 350 transition designs. Upon completion of this literature review, MwRSF researchers determined that a TL-4 thrie beam transition system, developed in cooperation with the Forest Products Laboratory (FPL), could be modified slightly and easily adapted for use with Missouri's thrie beam and channel bridge railing system. The TL-4 transition system was originally developed for use with a thrie beam and tube bridge railing system which was attached to a transverse, glue-laminated timber deck. A schematic of the TL-4 transition system is shown in Attachment D. Two crash tests were successfully performed on the transition system - an 8000S single unit truck and a 2000P pickup truck. I have enclosed a VHS tape which shows the two STTR crash tests on the TL-4 thrie beam transition design.

Modification of the FPL TL-4 thrie beam transition for use with Missouri's thrie beam and channel bridge railing was fairly simple. The proposed transition system would be nearly identical to the TL-4 system except for two features. First, the steel tube member, measuring 8x3x3/16, was replaced with the C8x11.5 steel channel section. This change was made since the Missouri bridge railing posts were spaced on 6-ft 3-in. centers rather than the 8-ft centers used in the FPL bridge railing system. For the FPL TL-4 bridge railing design, the structural tube was selected over the channel to provide additional strength to resist lateral buckling which was unnecessary for a 6-ft 3-in. post spacing. With regards to bending about the strong axis, both sections provide relatively equal capacities with the channel providing a 10 percent increase in section modulus over the tube. Second, the proposed transition design provides one additional reduced post spacing of thrie beam as compared to the FPL TL-4 transition design. Details for the proposed transition design for use with Missouri's bridge railing system are included in Attachment E.

Based on similarities between the crash-tested FPL TL-4 thrie beam transition and the proposed transition system for Missouri, we believe that the proposed transition would meet the TL-3 criteria of NCHRP 350. Therefore, we request that FHWA strongly consider the proposed transition design as an acceptable TL-3 safety feature and not require additional crash testing. If you agree with our assessment, please respond within two weeks. If you have any questions or comments regarding the enclosed information, please feel free to contact me at (402) 472-6864.

Sincerely,

Ronald K. Faller

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

x.c.: Dean L. Sicking, Ph.D., P.E., MwRSF Director and Associate Professor

Attachments:

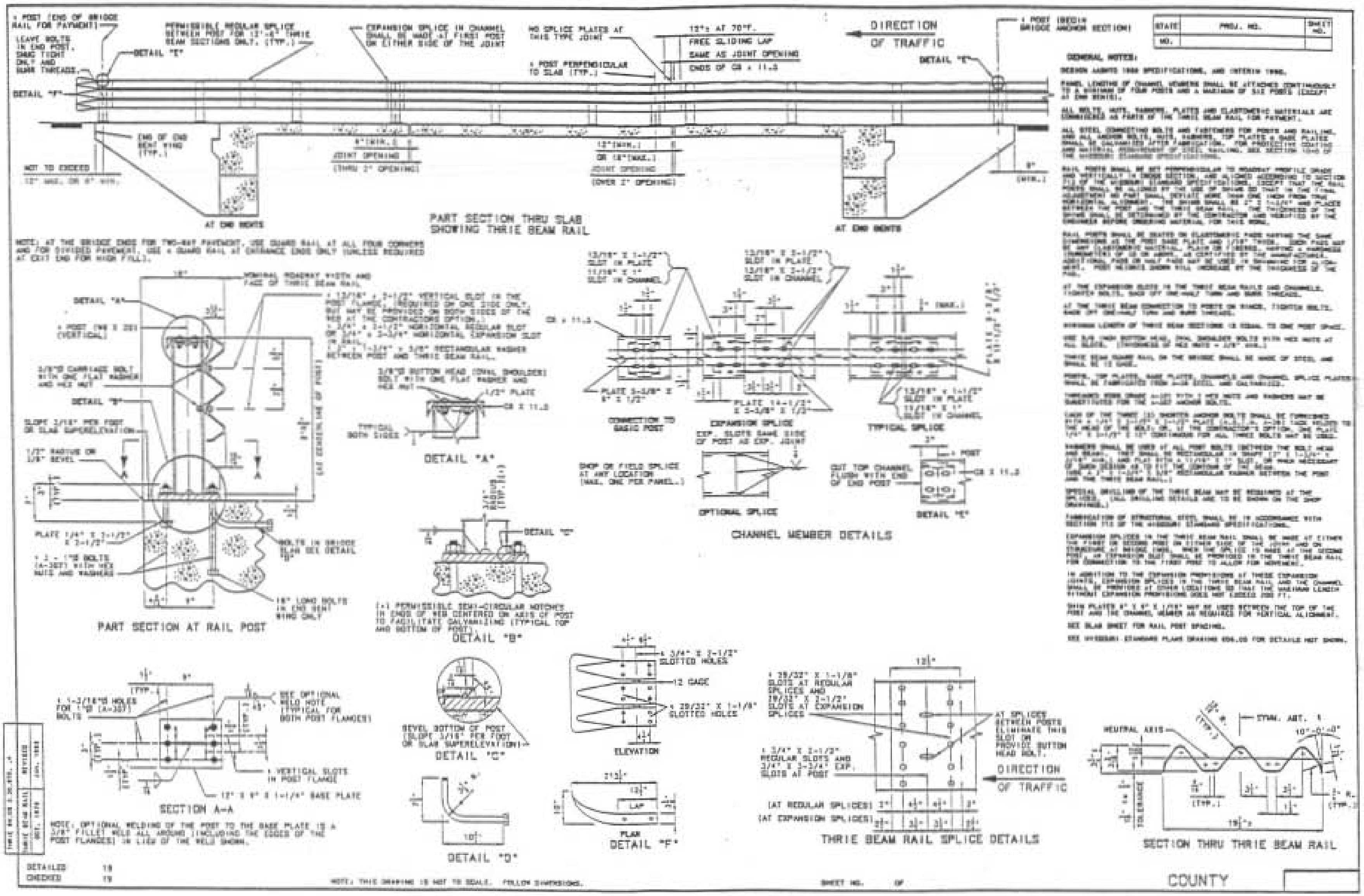
Attachment A - Schematic of Missouri's Thrie Beam and Channel Bridge Railing System
Attachment B - Schematic of an Approach Guardrail Transition - Test MST-1
Attachment C - Schematic of an Approach Guardrail Transition - Test MST-2
Attachment D - Schematic of FPL's TL-4 Approach Guardrail Transition Design - Test STTR-3 and STTR-4
Attachment E - Schematic of a Proposed Transition Design for Missouri DOT

Enclosures:

VHS tape of MST-1 and MST-2 crash tests
VHS tape of STTR-3 and STTR-4 crash tests

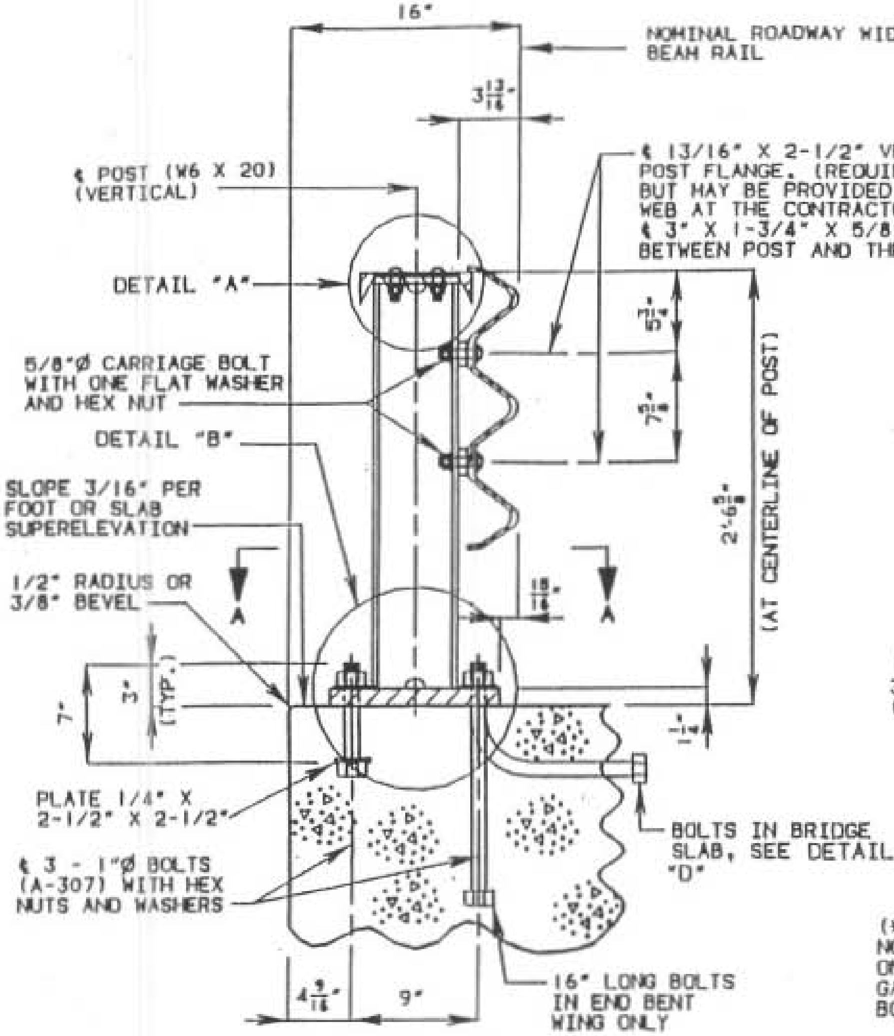
Attachment A

Schematic of Missouri's Thrie Beam and Channel Bridge Railing System

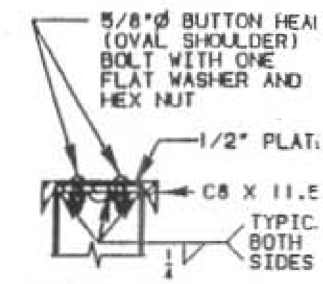

DIRECTION OF TRAFFIC
PART SECTION THRU SLAB SHOWING THRIE BEAM RAIL
AT END BENTS
GENERAL NOTES:
PART SECTION AT RAIL POST
DETAIL "A"
DETAIL "B"
CHANNEL MEMBER DETAILS
SECTION A-A
DETAIL "C"
DETAIL "D"
ELEVATION
DETAIL "F"
THRIE BEAM RAIL SPLICE DETAILS
SECTION THRU THRIE BEAM RAIL
NOTE: THIS DRAWING IS NOT TO SCALE. FOLLOW DIMENSIONS.
COUNTY

DETAILS: (CONT.)

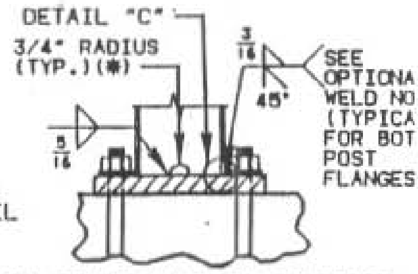
PART SECTION AT RAIL POST



PART SECTION AT RAIL POST

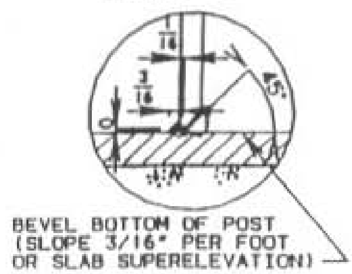


DETAIL "A"

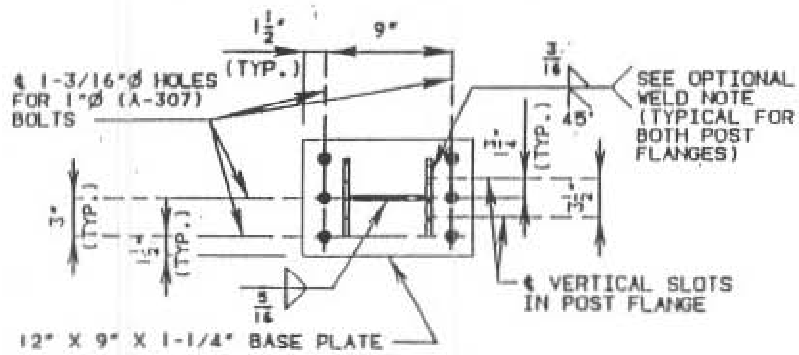


(*) PERMISSIBLE SEMI-CIRCULAR NOTCHES IN ENDS OF WEB CENTERED ON AXIS OF POST TO FACILITATE GALVANIZING (TYPICAL TOP AND BOTTOM OF POST).

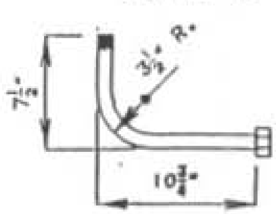
DETAIL "B"



DETAIL "C"



SECTION A-A



DETAIL "D"

NOTE: OPTIONAL WELDING OF THE POST TO THE BASE PLATE IS A 3/8" FILLET WELD ALL AROUND (INCLUDING THE EDGES OF THE POST FLANGES) IN LIEU OF THE WELD SHOWN.

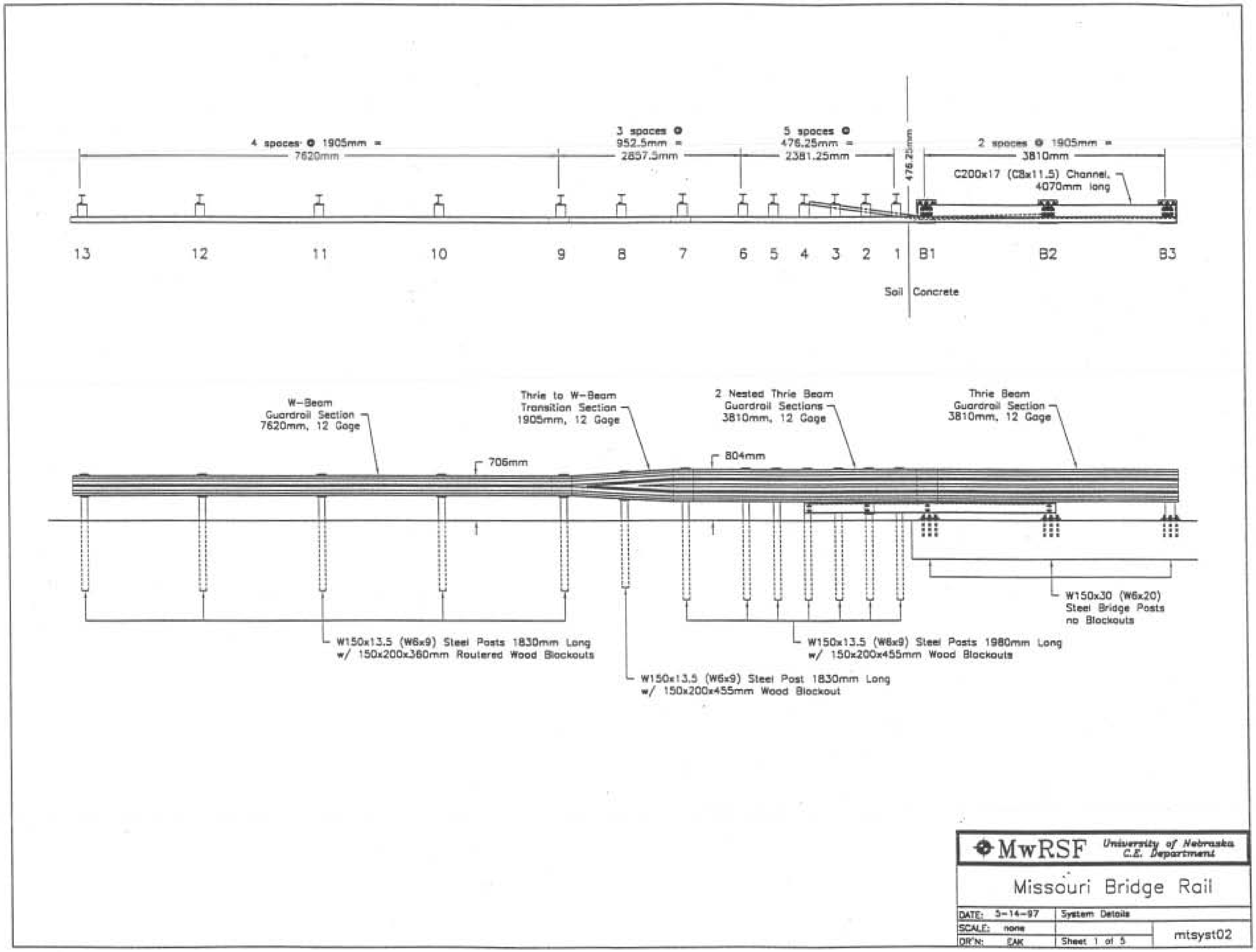
NOTE: DESIGN WEIGHT OF THE THRIE BEAM BRIDGE RAIL = 35#/LIN. FT.

REVISED: NOV. 1991

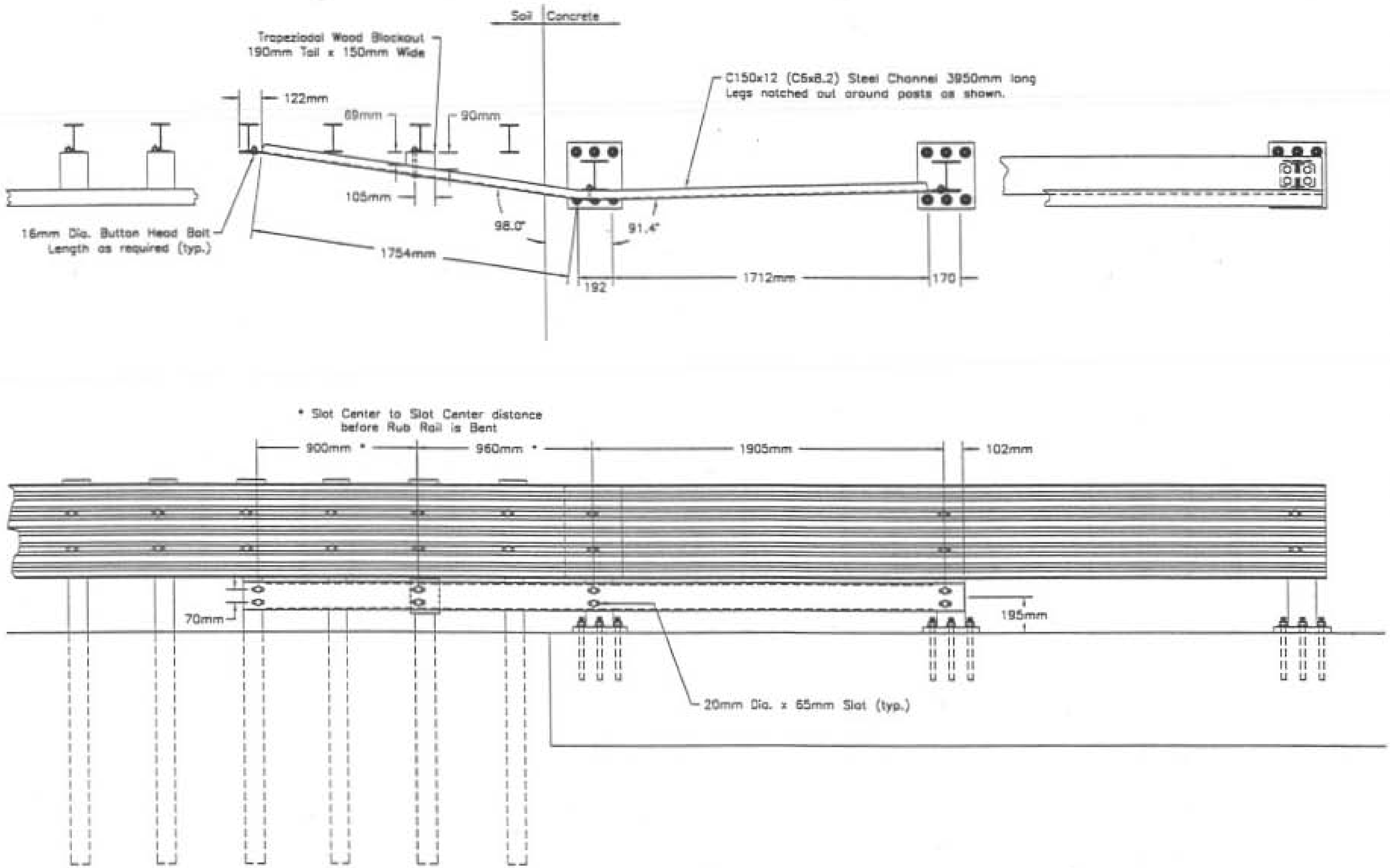
SEC. 3.30 6.1.3

Attachment B

Schematic of an Approach Guardrail Transition - Test MST-1



4 spaces @ 1905mm = 7620mm
3 spaces @ 952.5mm = 2857.5mm
5 spaces @ 476.25mm = 2381.25mm
476.25mm
2 spaces @ 1905mm = 3810mm
C200x17 (C8x11.5) Channel, 4070mm long
13 12 11 10 9 8 7 6 5 4 3 2 1 B1 B2 B3
Soil
Concrete
W-Beam Guardrail Section 7620mm, 12 Gage
Thrie to W-Beam Transition Section 1905mm, 12 Gage
2 Nested Thrie Beam Guardrail Sections 3810mm, 12 Gage
Thrie Beam Guardrail Section 3810mm, 12 Gage
706mm
804mm
W150x30 (W6x20) Steel Bridge Posts no Blockouts
W150x13.5 (W6x9) Steel Posts 1830mm Long w/ 150x200x360mm Routered Wood Blockouts
W150x13.5 (W6x9) Steel Posts 1980mm Long w/ 150x200x455mm Wood Blockouts
W150x13.5 (W6x9) Steel Post 1830mm Long w/ 150x200x455mm Wood Blockout
MwRSF
University of Nebraska C.E. Department
Missouri Bridge Rail
DATE: 5-14-97
System Details
SCALE: none
DR'N: EAK
Sheet 1 of 5
mtsyst02

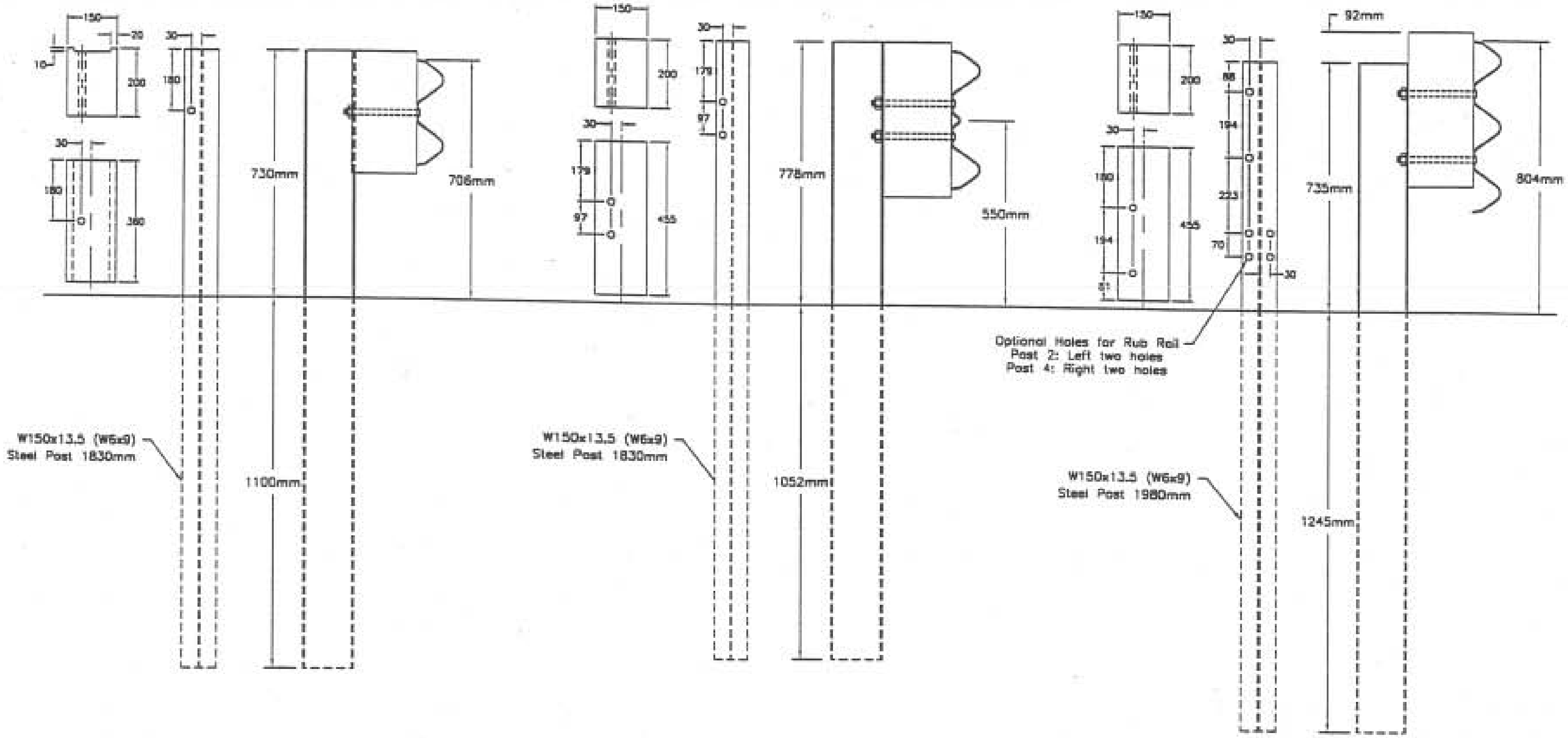


MwRSF University of Nebraska C.E. Department

Missouri Bridge Rail

DATE: 5-14-98	Rub Rail Details	
SCALE: none		rrtop
DR'N: CAK	Sheet 3 of 5	

W-Beam Posts 9-13 | Thrie to W Beam Transition Post 8 | Thrie Beam Posts 1-7

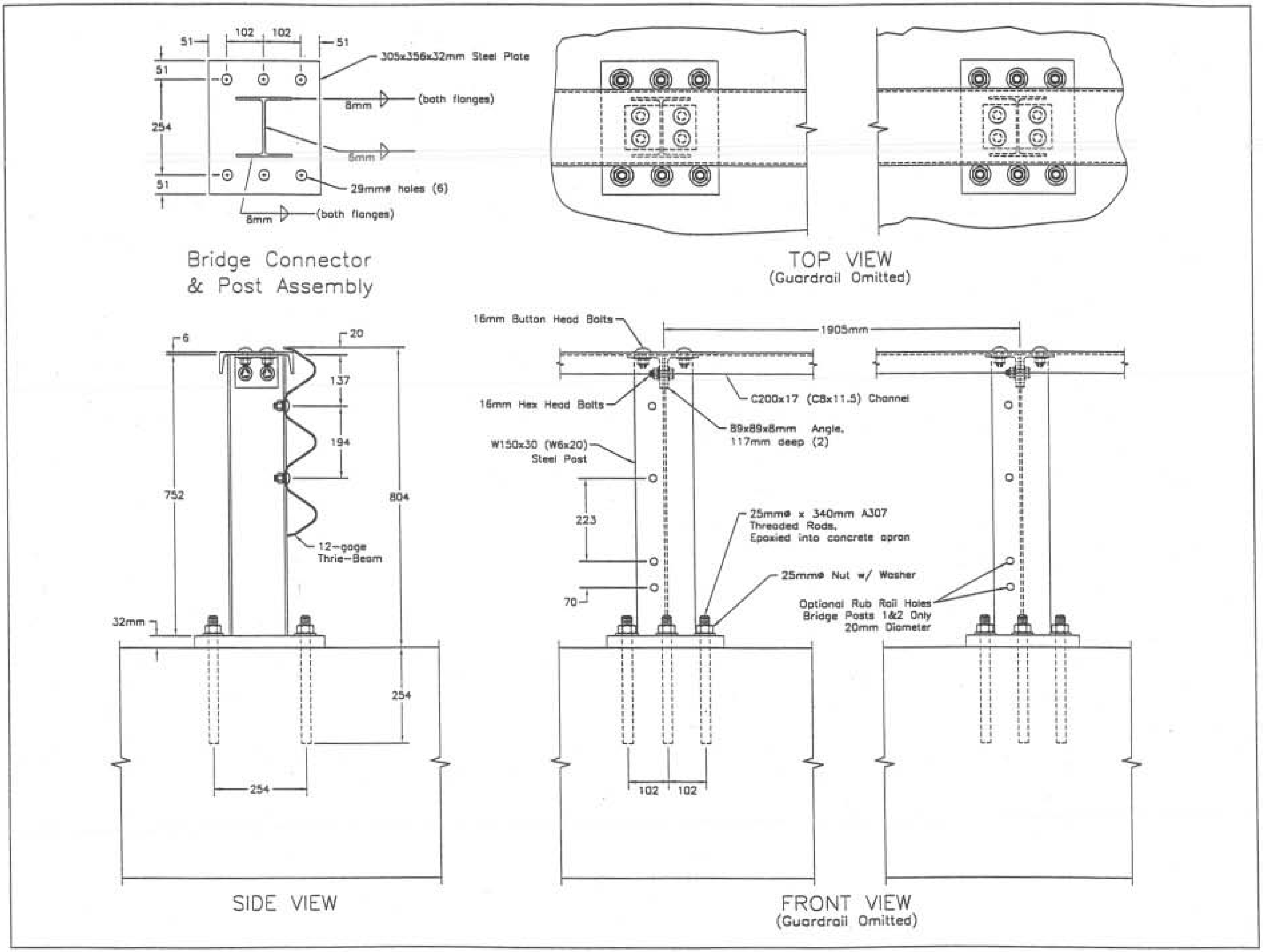


Note: All holes 20mm Dia.

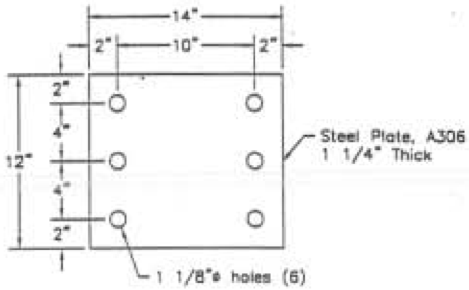
MwRSF University of Nebraska C.E. Department

Missouri Bridge Rail

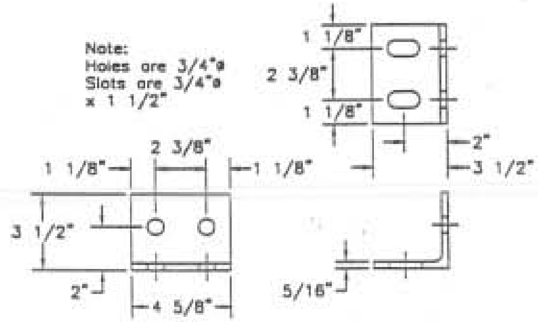
DATE: 5-14-97	Transition Post Details	
SCALE: none		mttposts
DR'N: EAK	Sheet 4 of 5	



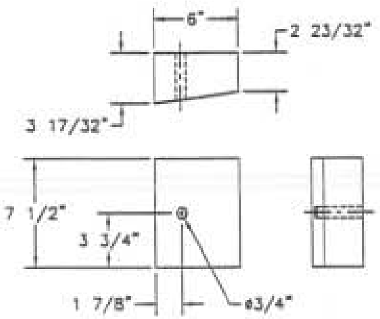
305x356x32mm Steel Plate
8mm (both flanges)
8mm
29mm⌀ holes (6)
8mm (both flanges)
51
102
102
51
51
254
51
Bridge Connector
& Post Assembly
TOP VIEW
(Guardrail Omitted)
6
20
137
194
752
804
12-gage
Thrie-Beam
32mm
254
254
SIDE VIEW
16mm Button Head Bolts
1905mm
C200x17 (C8x11.5) Channel
16mm Hex Head Bolts
89x89x8mm Angle,
117mm deep (2)
W150x30 (W6x20)
Steel Post
223
70
25mm⌀ x 340mm A307
Threaded Rods,
Epoxied into concrete apron
25mm⌀ Nut w/ Washer
Optional Rub Rail Holes
Bridge Posts 1&2 Only
20mm Diameter
102
102
FRONT VIEW
(Guardrail Omitted)



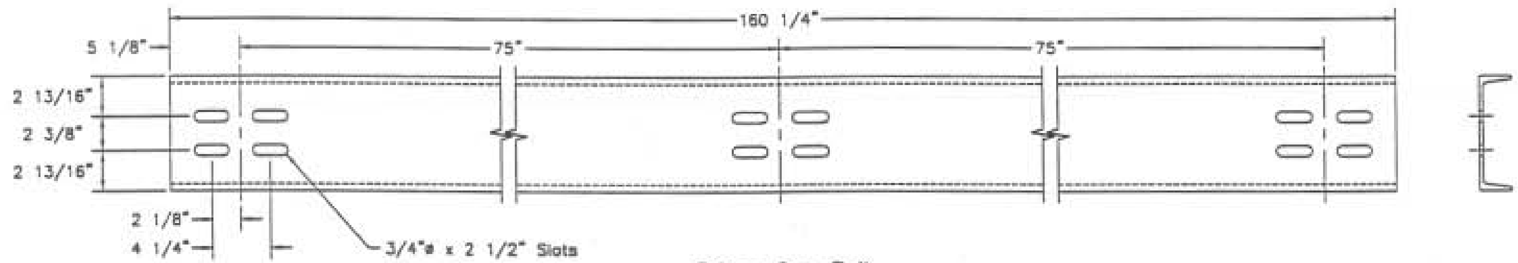
Bridge Plate
12"x 14"x 1 1/4"



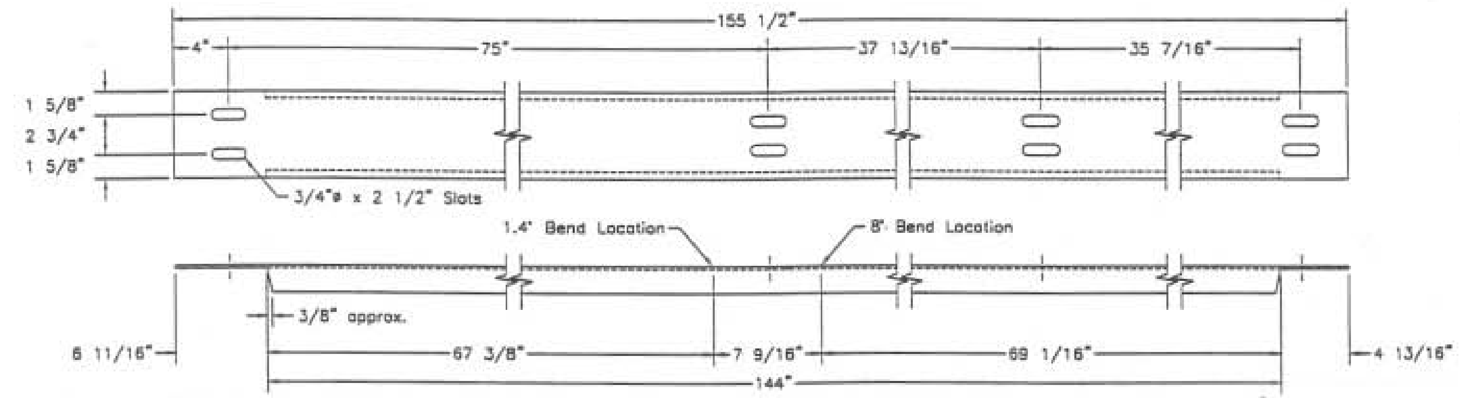
Angle Clips
3 1/2"x 3 1/2"x 5/16"



Rub Rail Block
Timber Block



Bridge Cap Rail
C8x11.5



Rub Rail
C6x8.2

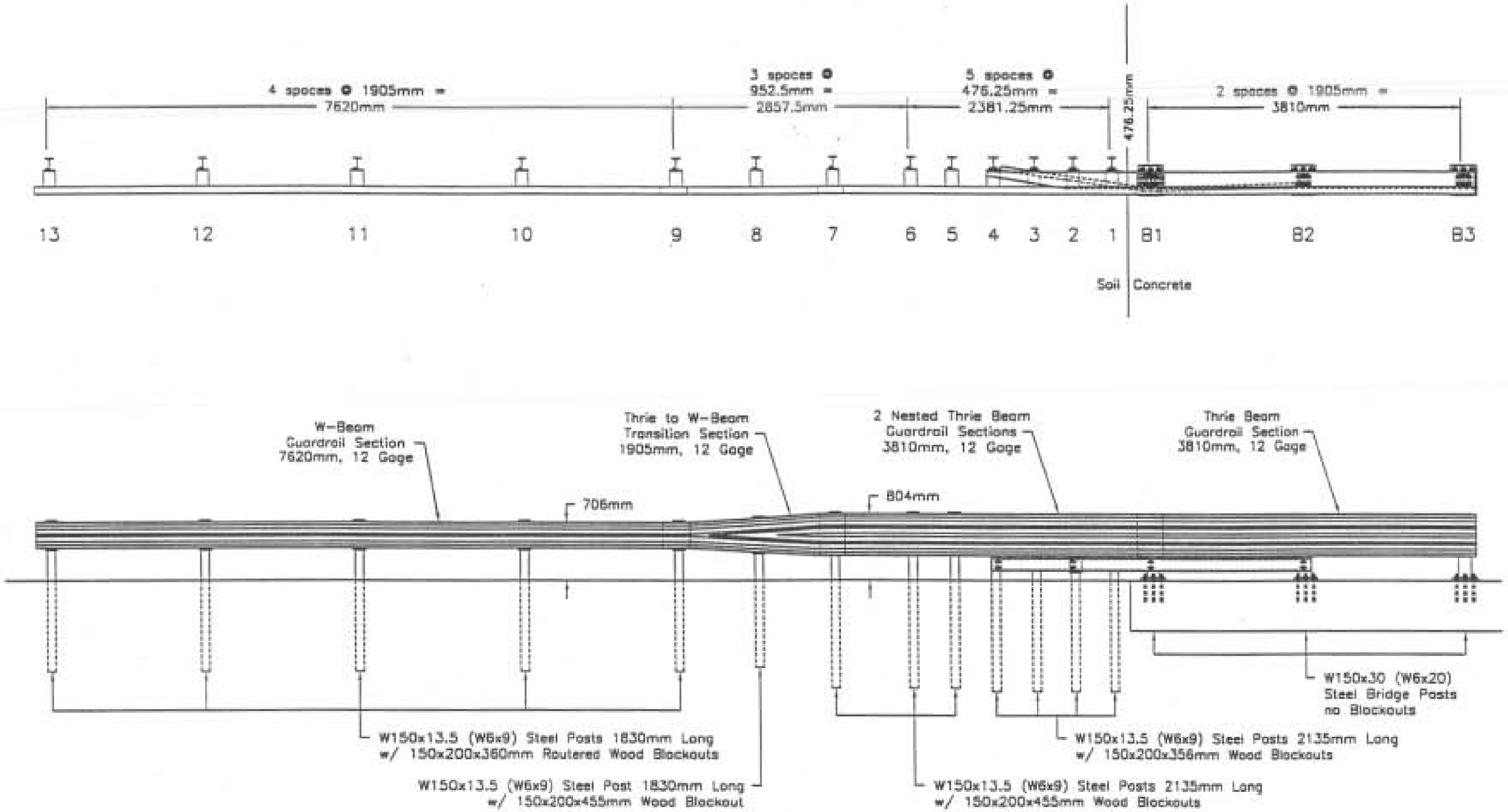
MwRSF University of Nebraska C.E. Department

Missouri Bridge Rail

DATE: 5-21-98	Details of Selected Parts	
SCALE: none		topparts
DR'N: EAK	Sheet 5 of 5	

Attachment C

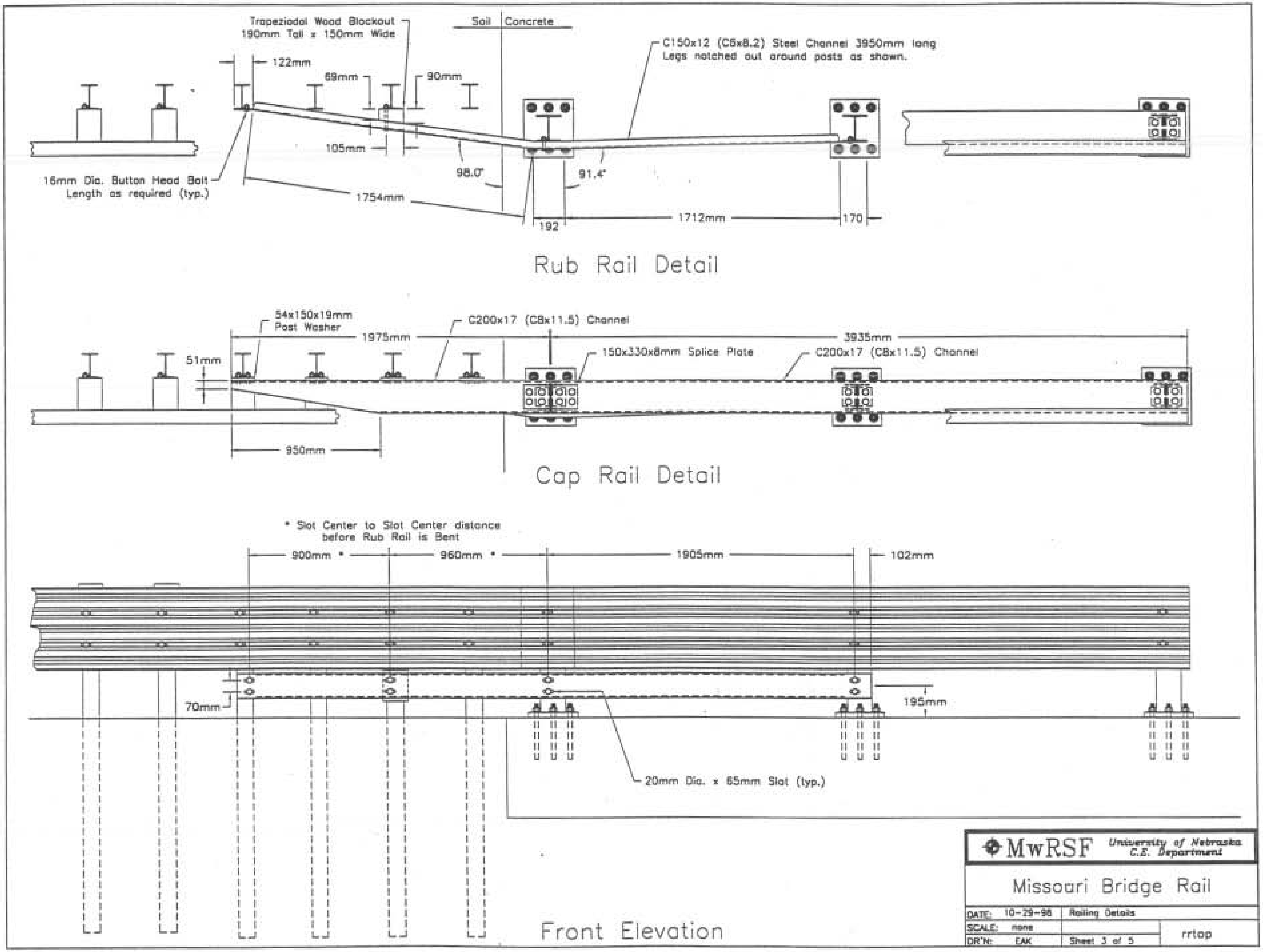
Schematic of an Approach Guardrail Transition - Test MST-2



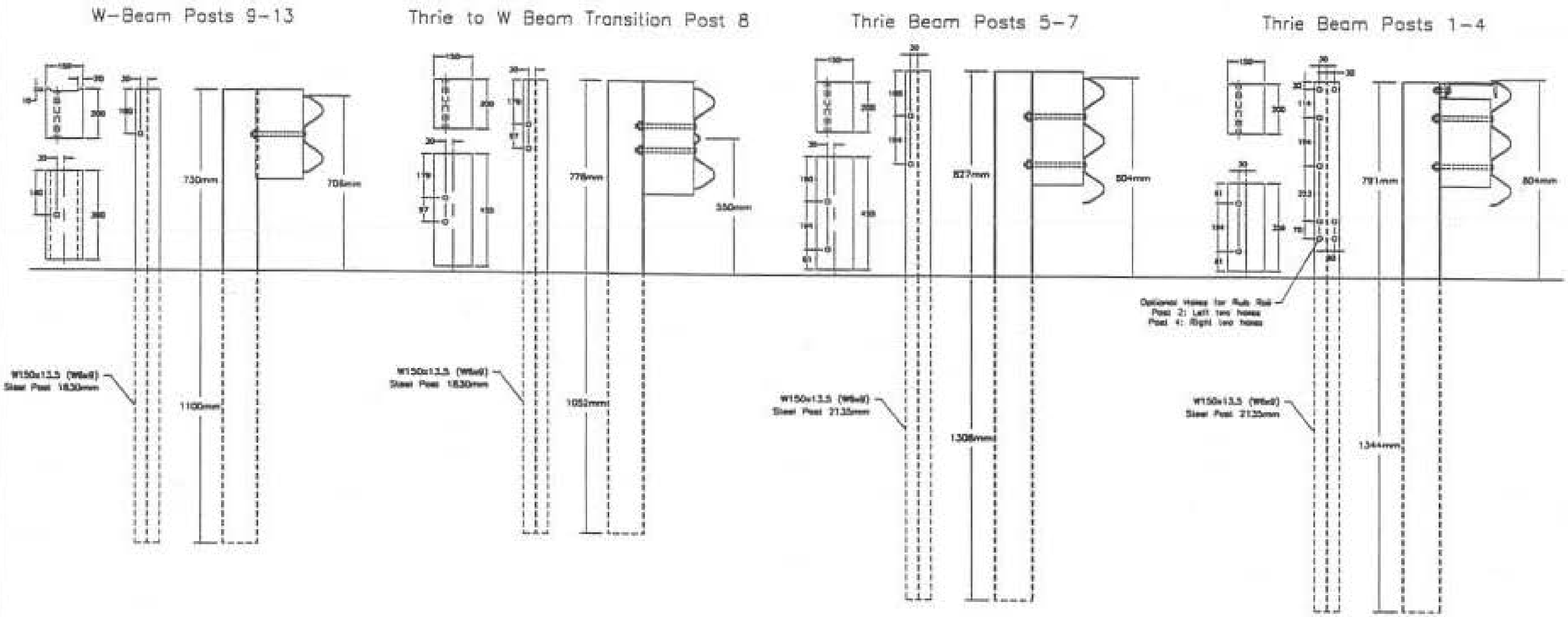
MwRSF University of Nebraska C.E. Department

Missouri Bridge Rail

DATE: 10-29-98	System Details	mtsyst02
SCALE: none		
DR'N: EAK	Sheet 1 of 5	



Trapeziodal Wood Blockout
190mm Tall x 150mm Wide
Soil
Concrete
C150x12 (C6x8.2) Steel Channel 3950mm long
Legs notched out around posts as shown.
122mm
69mm
90mm
105mm
16mm Dia. Button Head Bolt
Length as required (typ.)
98.0°
91.4°
1754mm
192
1712mm
170
Rub Rail Detail
54x150x19mm
Post Washer
C200x17 (C8x11.5) Channel
1975mm
3935mm
51mm
150x330x8mm Splice Plate
C200x17 (C8x11.5) Channel
950mm
Cap Rail Detail
* Slot Center to Slot Center distance
before Rub Rail is Bent
900mm *
960mm *
1905mm
102mm
70mm
195mm
20mm Dia. x 65mm Slot (typ.)
Front Elevation
MwRSF
University of Nebraska
C.E. Department
Missoari Bridge Rail
DATE: 10-29-98
Railing Details
SCALE: none
DR'N: EAK
Sheet 3 of 5
rrtop

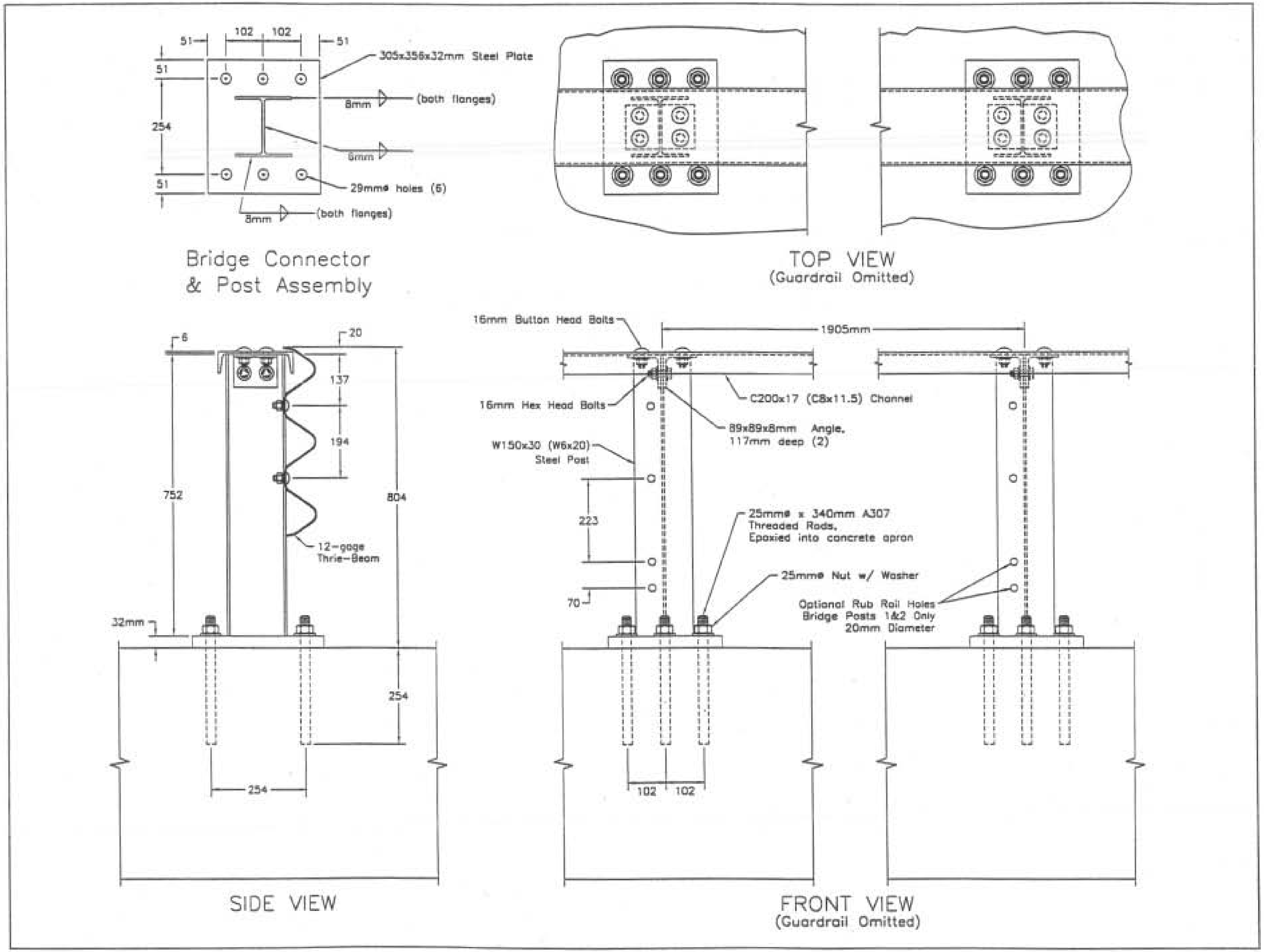


Note: All holes 20mm Dia.

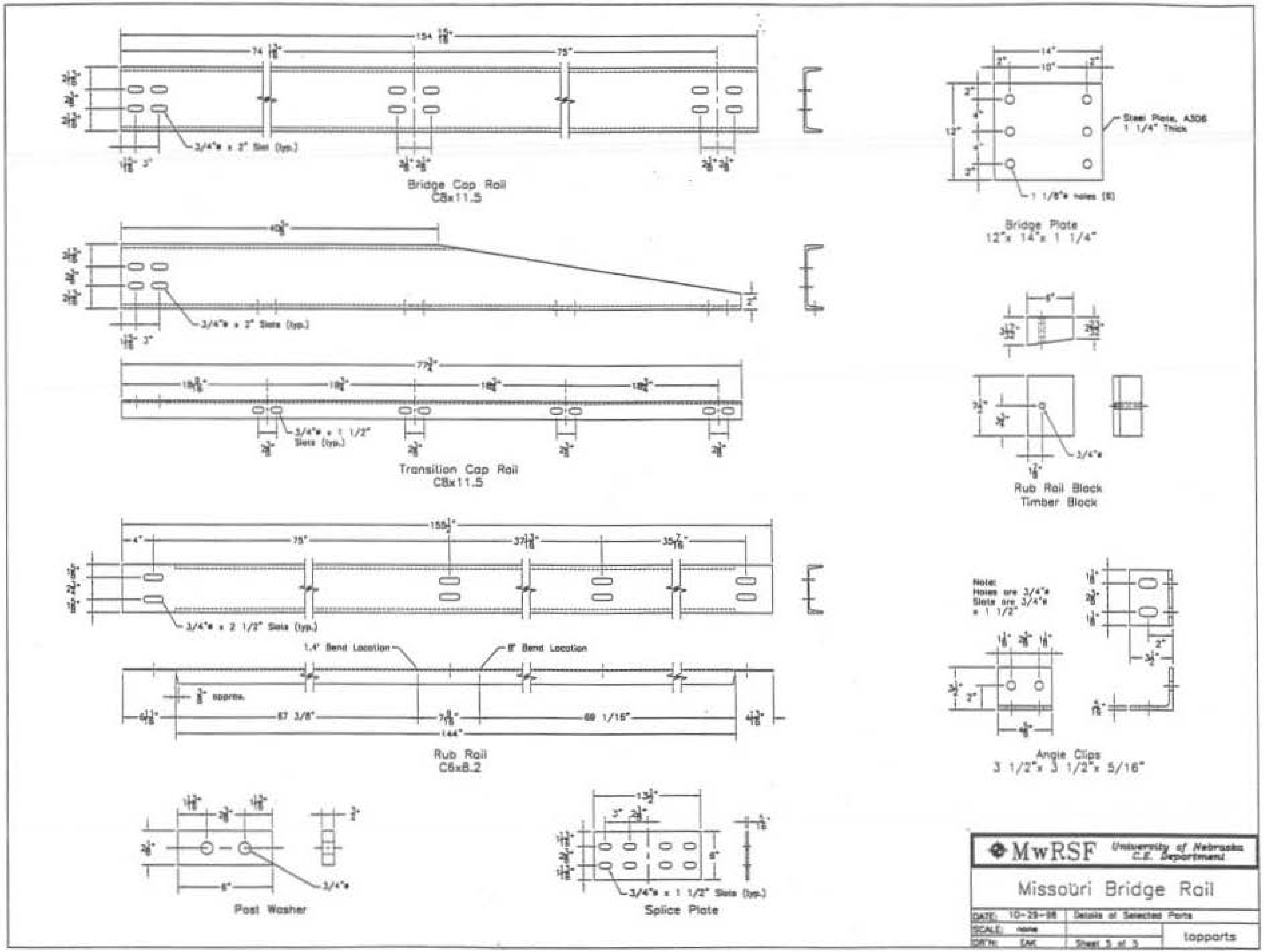
MwRSF University of Nebraska C.E. Department

Missouri Bridge Rail

DATE: 5-14-97	Transition Post Details	
SCALE: none		mttposts
DR'N: EAK	Sheet 4 of 5	



305x356x32mm Steel Plate
8mm (both flanges)
8mm
29mm⌀ holes (6)
8mm (both flanges)
51
102
102
51
51
254
51
Bridge Connector
& Post Assembly
TOP VIEW
(Guardrail Omitted)
6
20
137
194
752
804
12-gage
Thrie-Beam
32mm
254
254
SIDE VIEW
16mm Button Head Bolts
1905mm
16mm Hex Head Bolts
C200x17 (C8x11.5) Channel
89x89x8mm Angle,
117mm deep (2)
W150x30 (W6x20)
Steel Post
223
25mm⌀ x 340mm A307
Threaded Rods,
Epoxied into concrete apron
25mm⌀ Nut w/ Washer
70
Optional Rub Rail Holes
Bridge Posts 1&2 Only
20mm Diameter
102
102
FRONT VIEW
(Guardrail Omitted)

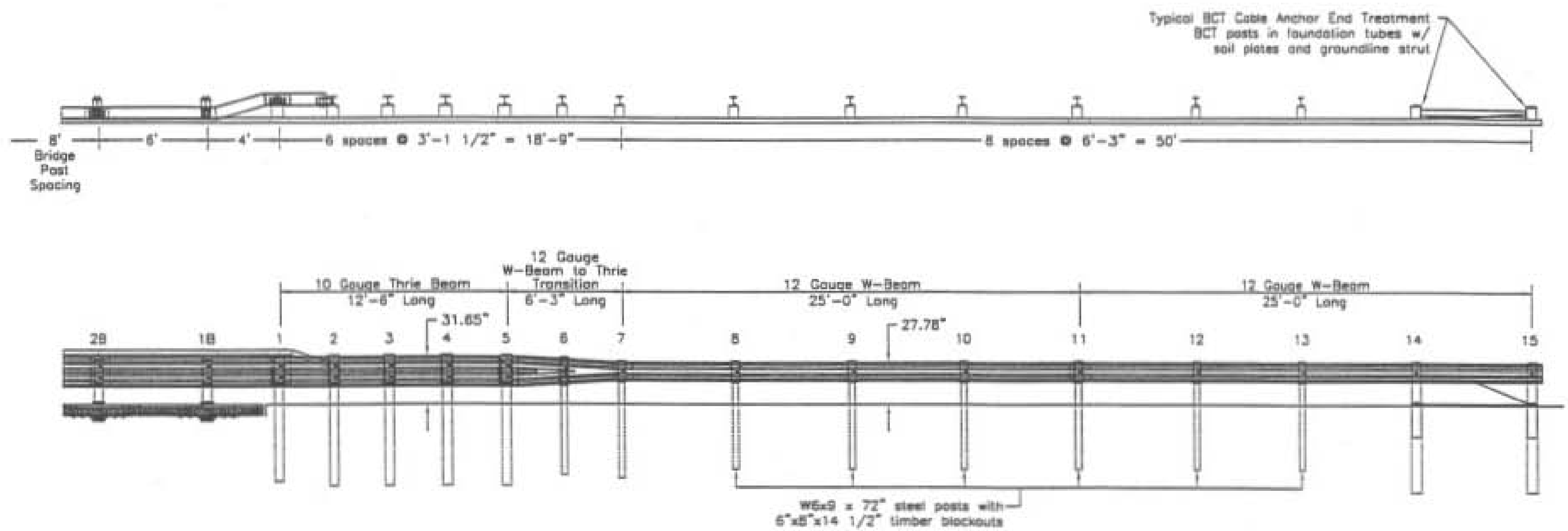


Bridge Cap Rail
C8x11.5
3/4"ø x 2" Slot (typ.)
Bridge Plate
12"x 14"x 1 1/4"
Steel Plate, A36
1 1/4" Thick
1 1/8"ø holes (6)
Transition Cap Rail
C8x11.5
3/4"ø x 2" Slots (typ.)
3/4"ø x 1 1/2" Slots (typ.)
Rub Rail Block
Timber Block
3/4"ø
Rub Rail
C6x8.2
3/4"ø x 2 1/2" Slots (typ.)
1.4' Bend Location
8' Bend Location
Note:
Holes are 3/4"ø
Slots are 3/4"ø x 1 1/2"
Angle Clips
3 1/2"x 3 1/2"x 5/16"
Post Washer
3/4"ø
Splice Plate
3/4"ø x 1 1/2" Slots (typ.)
MwRSF
University of Nebraska
C.E. Department
Missouri Bridge Rail
DATE: 10-25-96
SCALE: none
DRAWN: EAK
Details of Selected Parts
Sheet 5 of 5
topparts

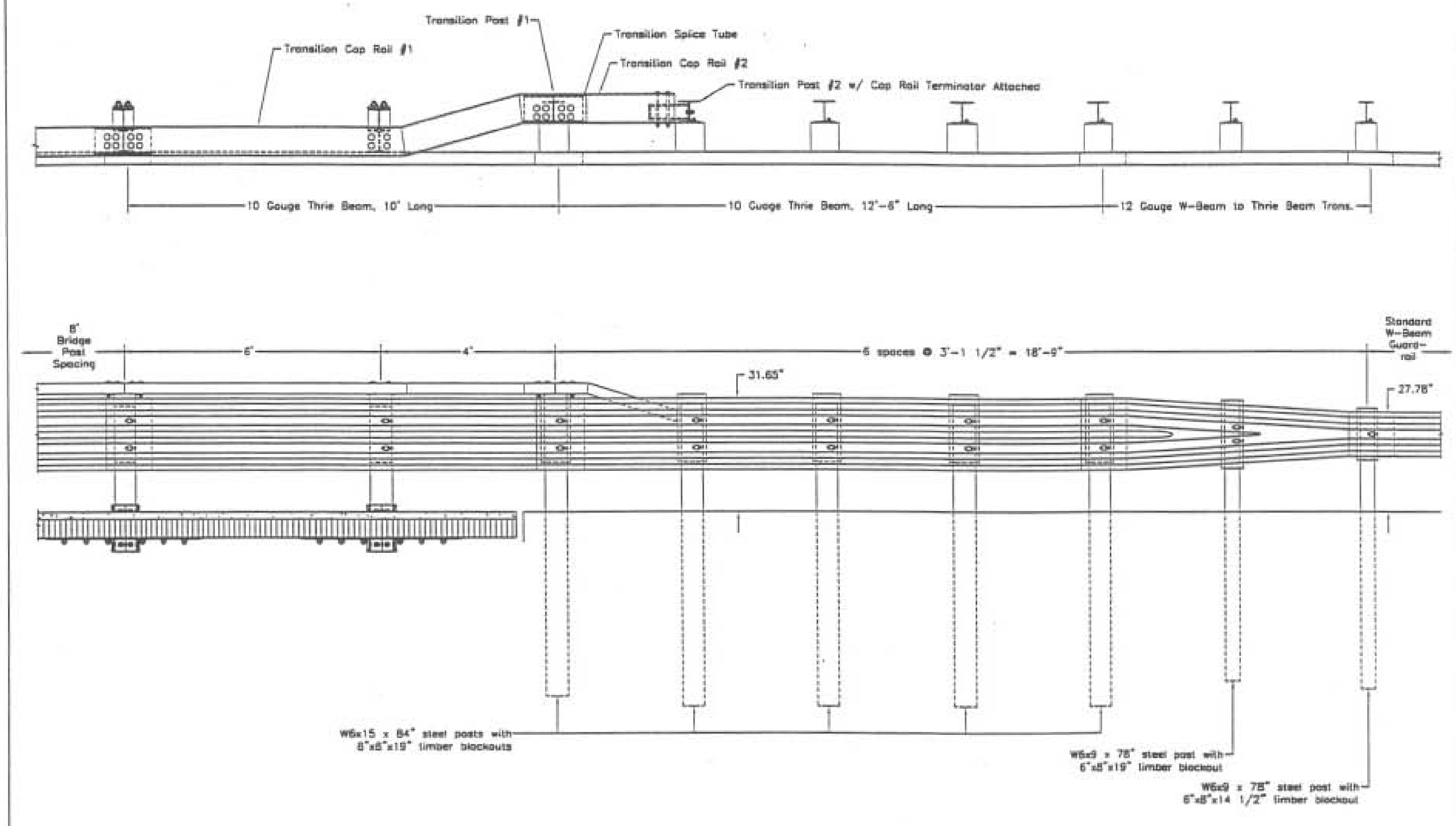
Attachment D

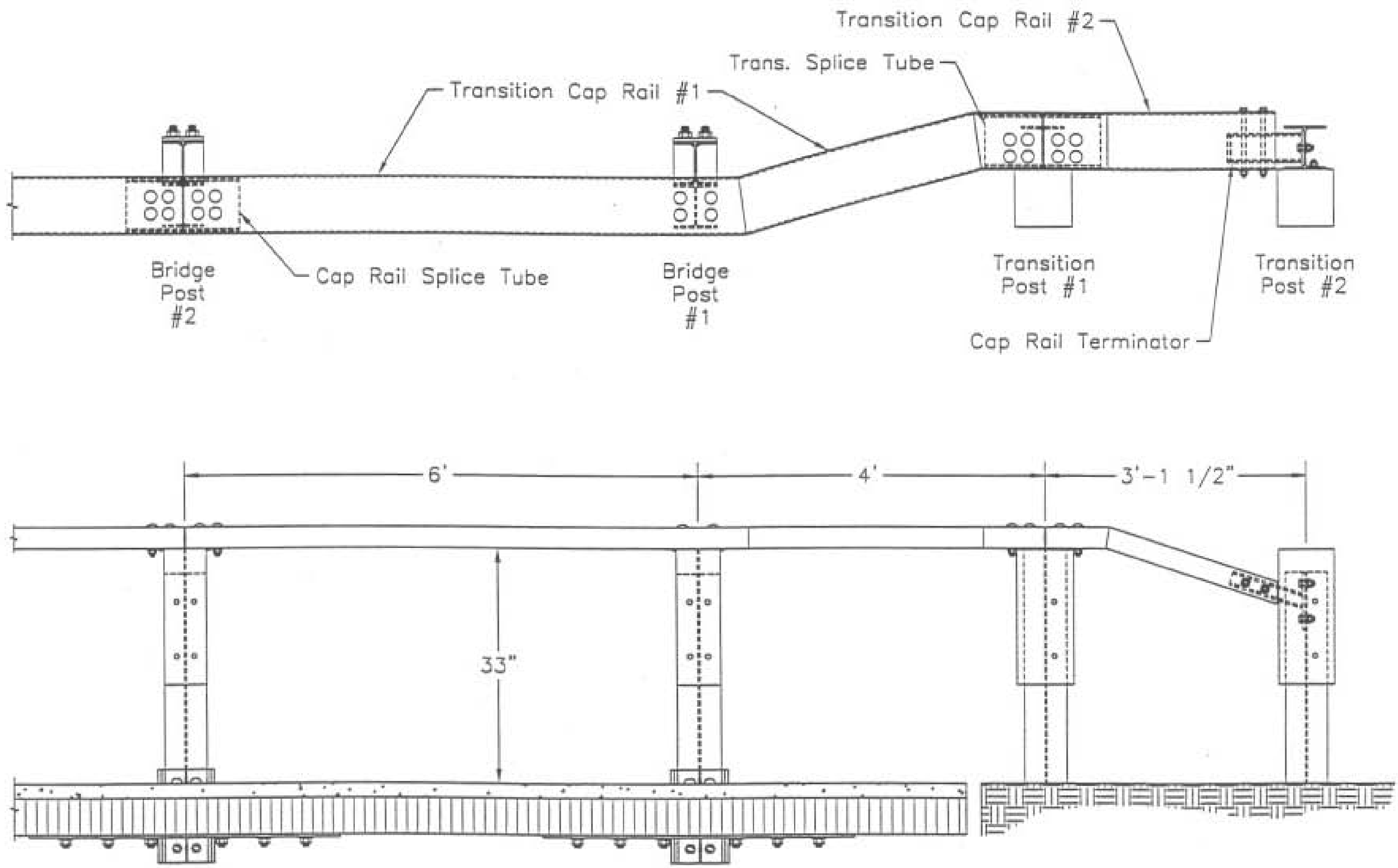
Schematic of FPL's TL-4 Approach Guardrail Transition Design - Test STTR-3 and STTR-4

54. All construction details for the bridge railing system are provided in Figures 55 through 56.

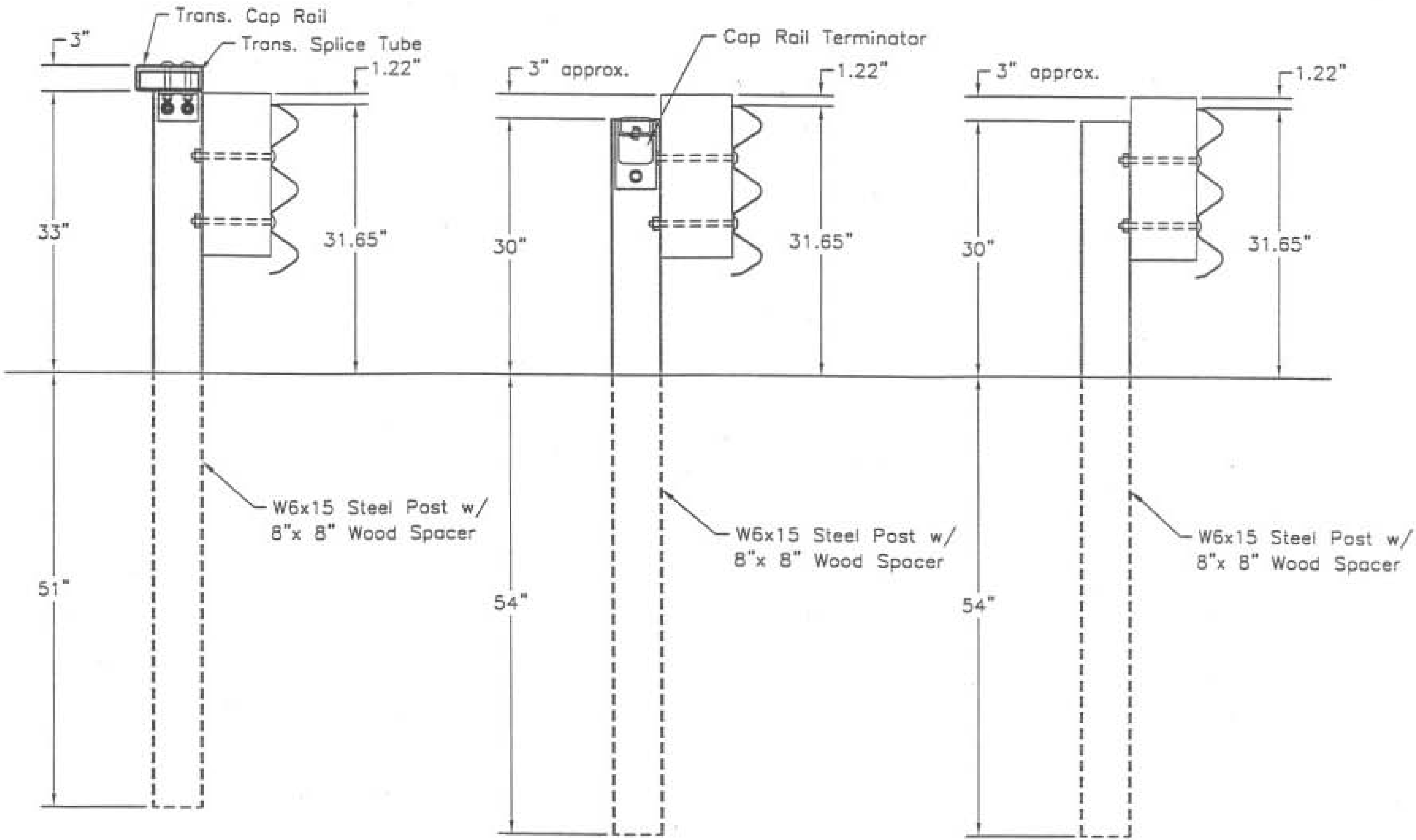


Typical BCT Cable Anchor End Treatment
BCT posts in foundation tubes w/
soil plates and groundline strut
8'
Bridge
Post
Spacing
6'
4'
6 spaces @ 3'-1 1/2" = 18'-9"
8 spaces @ 6'-3" = 50'
12 Gauge
W-Beam to Thrie
Transition
6'-3" Long
10 Gauge Thrie Beam
12'-6" Long
12 Gauge W-Beam
25'-0" Long
12 Gauge W-Beam
25'-0" Long
31.65"
27.78"
2B
1B
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
W6x9 x 72" steel posts with
6"x8"x14 1/2" timber blockouts


Transition Post #1
Transition Splice Tube
Transition Cap Rail #1
Transition Cap Rail #2
Transition Post #2 w/ Cap Rail Terminator Attached
10 Gauge Thrie Beam, 10' Long
10 Gauge Thrie Beam, 12'-6" Long
12 Gauge W-Beam to Thrie Beam Trans.
8' Bridge Post Spacing
6'
4'
6 spaces @ 3'-1 1/2" = 18'-9"
Standard W-Beam Guard-rail
31.65"
27.78"
W6x15 x 84" steel posts with 6"x8"x19" timber blockouts
W6x9 x 78" steel post with 6"x8"x19" timber blockout
W6x9 x 78" steel post with 6"x8"x14 1/2" timber blockout



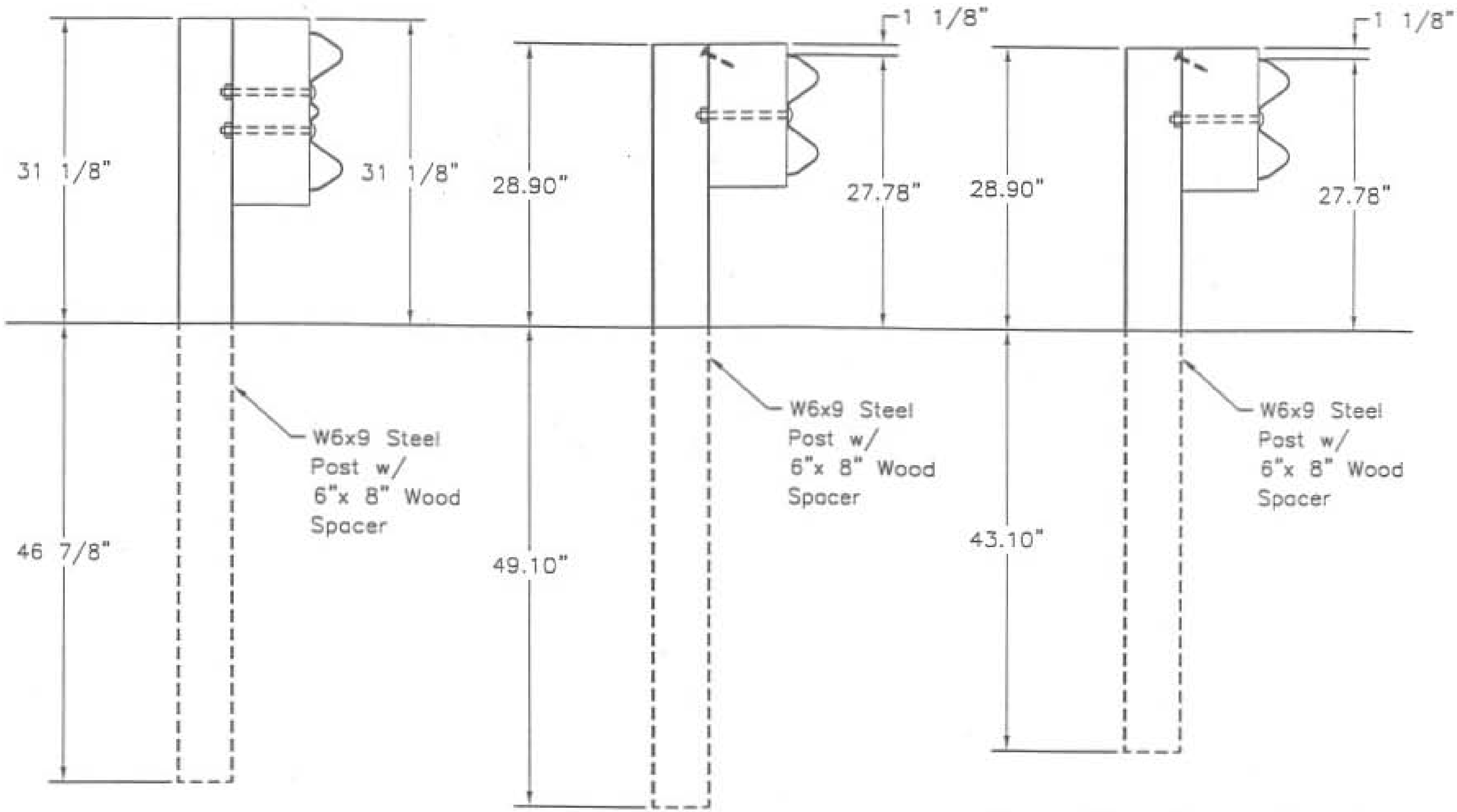
NOTE: Thrie Beam rail omitted for detail clarity.



Transition Post #1

Transition Post #2

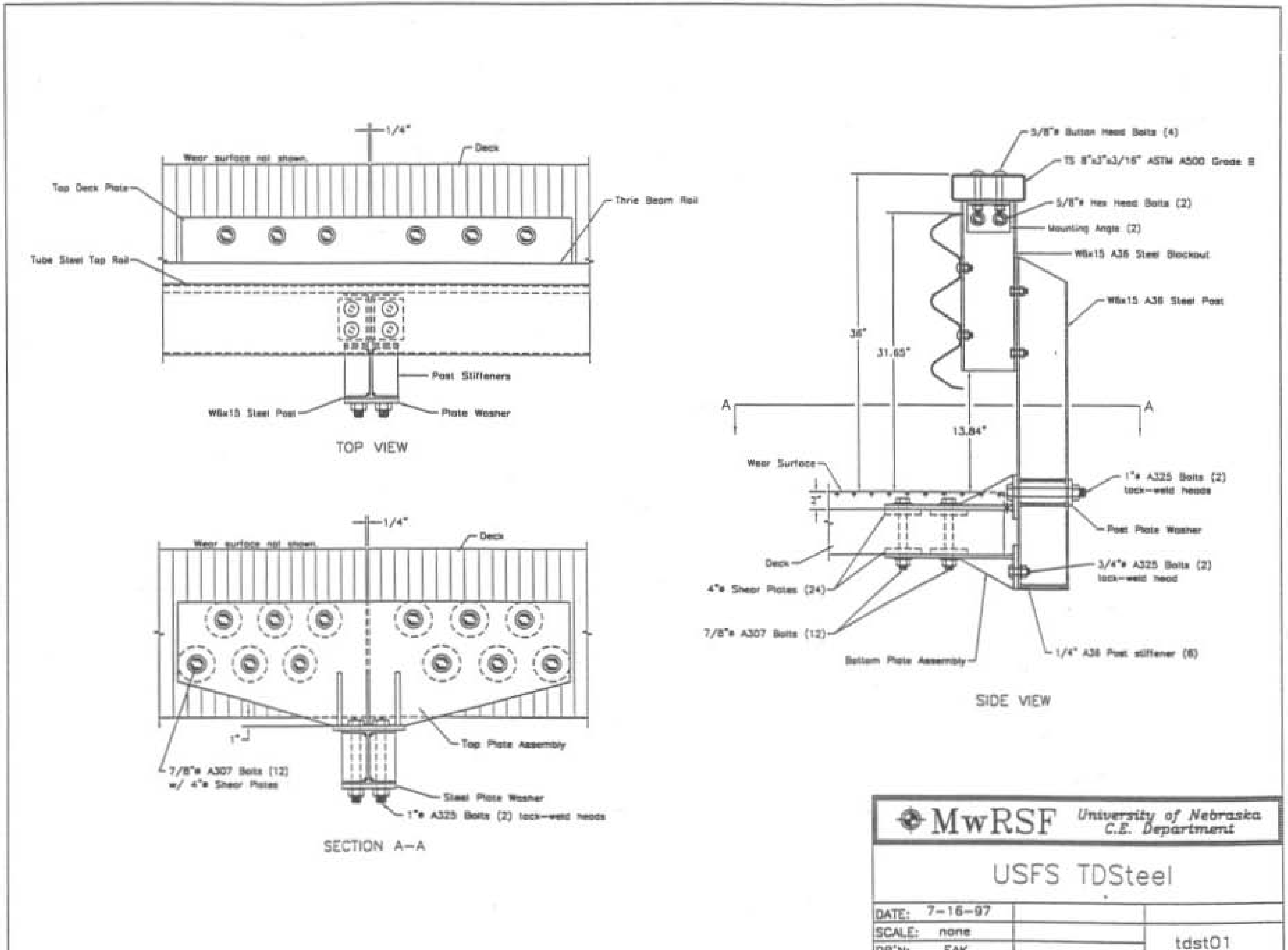
Transition Posts 3–5

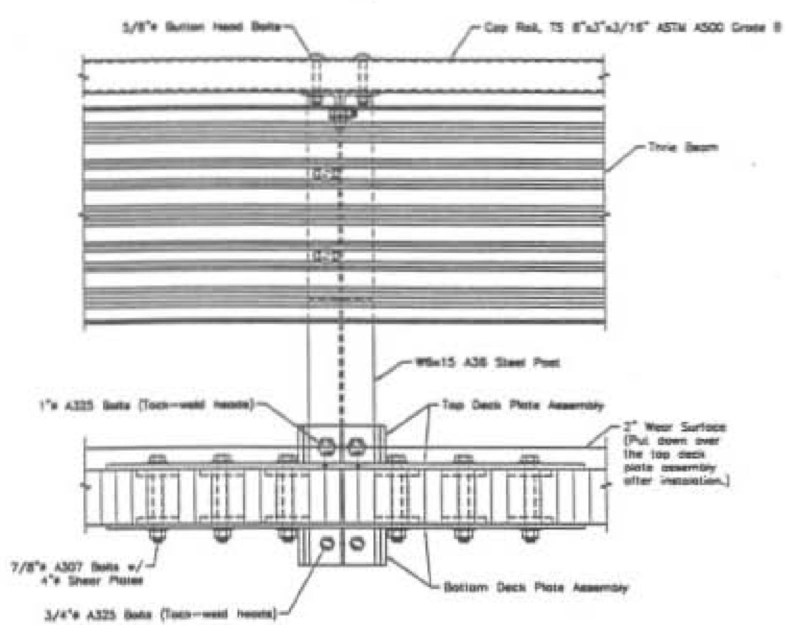


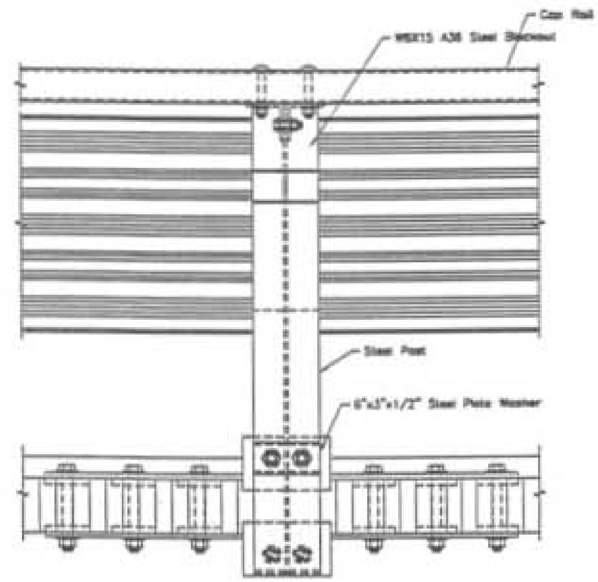
Transition Post 6
Thrie-W Transition

Transition Post 7

Transition Posts 8-13


1/4"
Deck
Wear surface not shown.
Top Deck Plate
Thrie Beam Rail
Tube Steel Top Rail
Post Stiffeners
W6x15 Steel Post
Plate Washer
TOP VIEW
1/4"
Deck
Wear surface not shown.
1"
7/8"ø A307 Bolts (12)
w/ 4"ø Shear Plates
Top Plate Assembly
Steel Plate Washer
1"ø A325 Bolts (2) lock-weld heads
SECTION A-A
5/8"ø Button Head Bolts (4)
TS 8"x3"x3/16" ASTM A500 Grade B
5/8"ø Hex Head Bolts (2)
Mounting Angle (2)
W6x15 A36 Steel Blockout
W6x15 A36 Steel Post
36"
31.65"
13.84"
A
A
Wear Surface
2"
1"ø A325 Bolts (2)
lock-weld heads
Post Plate Washer
Deck
3/4"ø A325 Bolts (2)
lock-weld head
4"ø Shear Plates (24)
7/8"ø A307 Bolts (12)
Bottom Plate Assembly
1/4" A36 Post stiffener (6)
SIDE VIEW
MwRSF
University of Nebraska
C.E. Department
USFS TDSteel
DATE: 7-16-97
SCALE: none
DR'N: EAK
tdst01



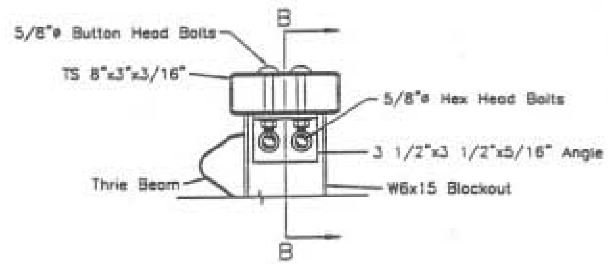


MwRSF University of Nebraska C.E. Department

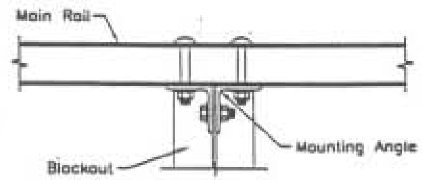
USFS TDSteel

DATE: 8-14-97		
SCALE: none		tdst02
DR'N: EAK		

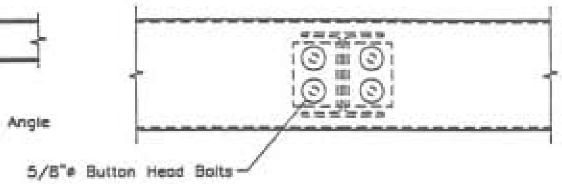
Cap Rail Connection Details



END VIEW

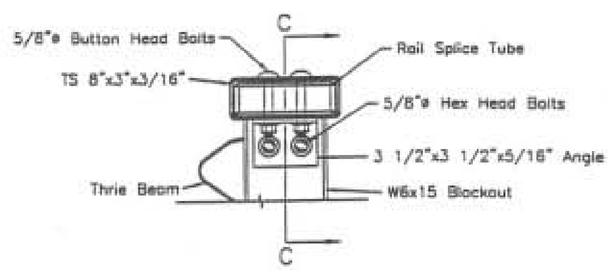


SECTION B–B

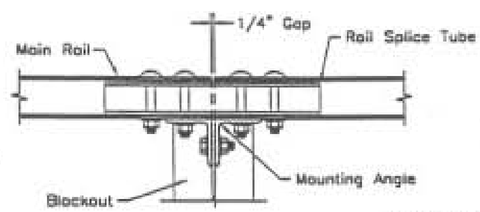


TOP VIEW

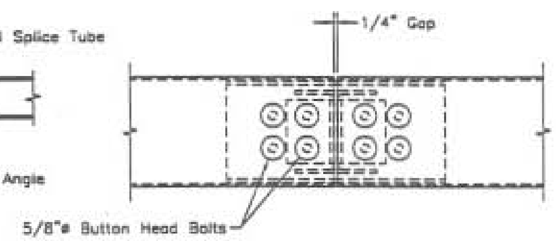
Cap Rail Splice Connection Details



END VIEW



SECTION C–C



TOP VIEW

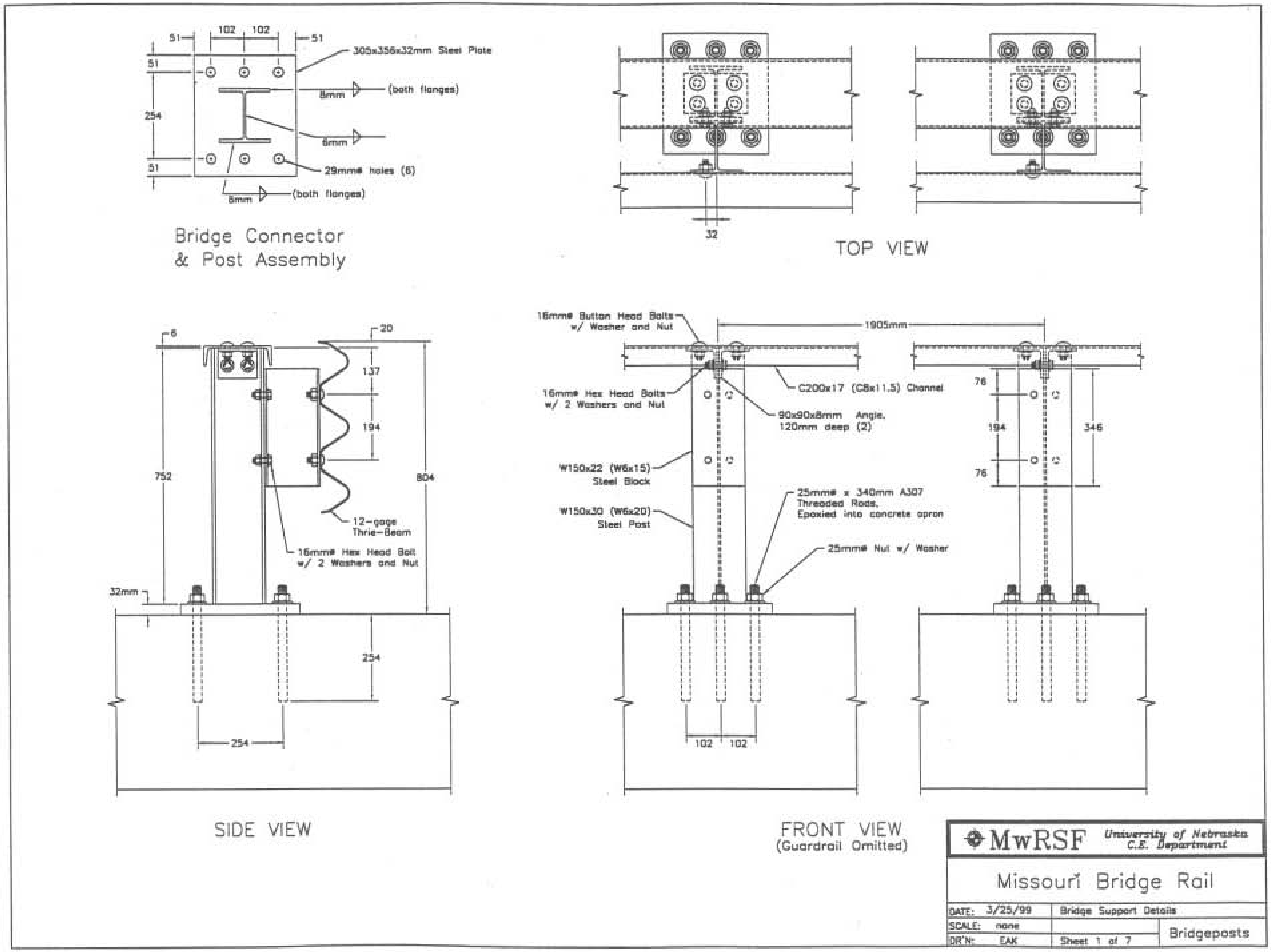
MwRSF | University of Nebraska C.E. Department

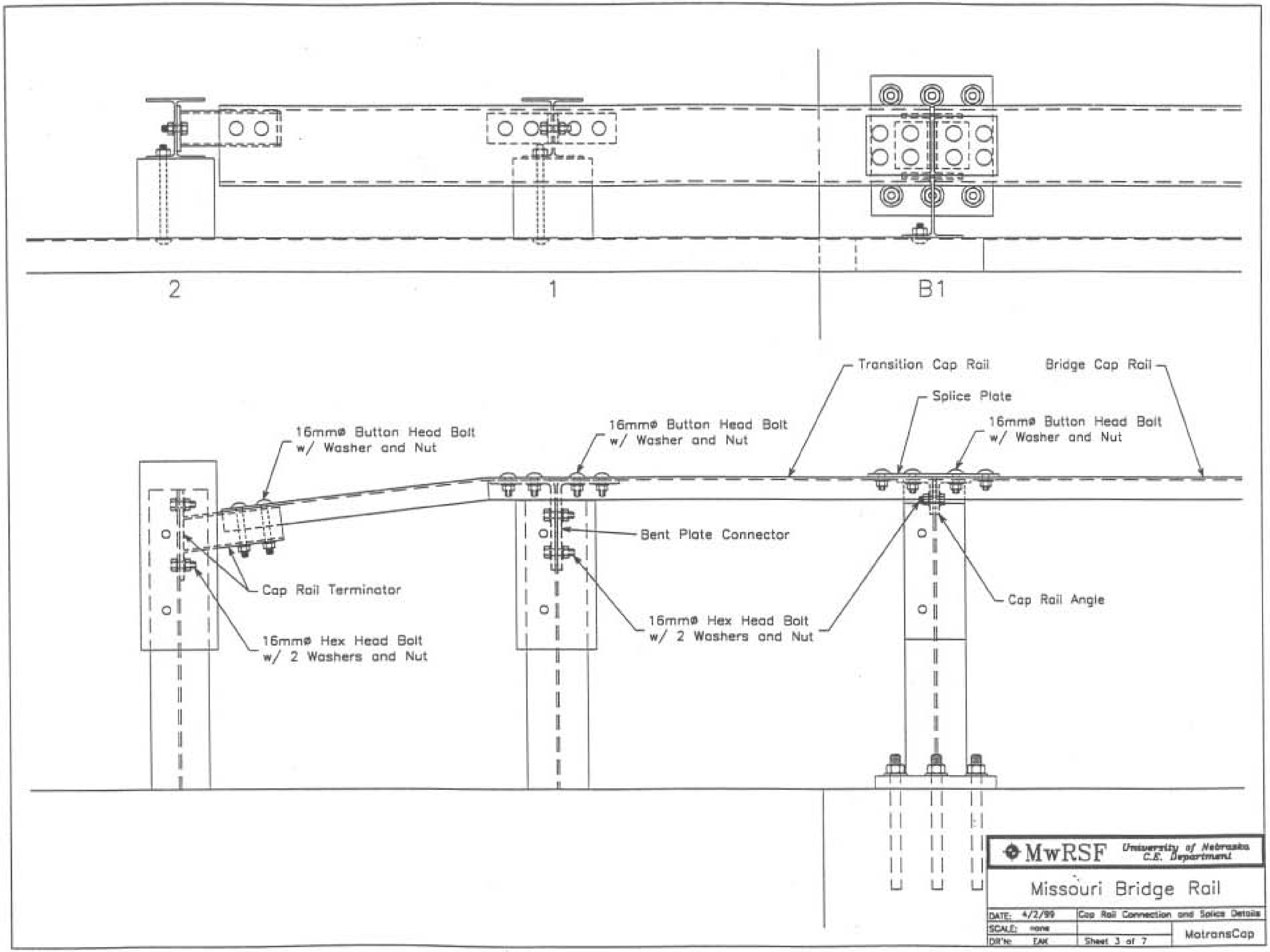
USFS TDSteel

DATE: 8–14–97		
SCALE: none		tdst03
DR'N: EAK		

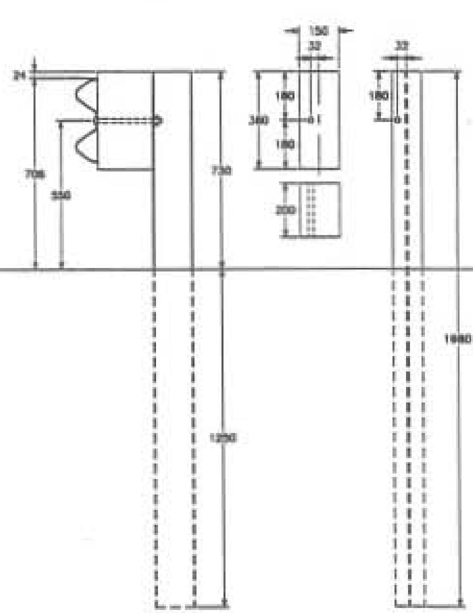
Attachment E

Schematic of a Proposed Transition Design for Missouri DOT

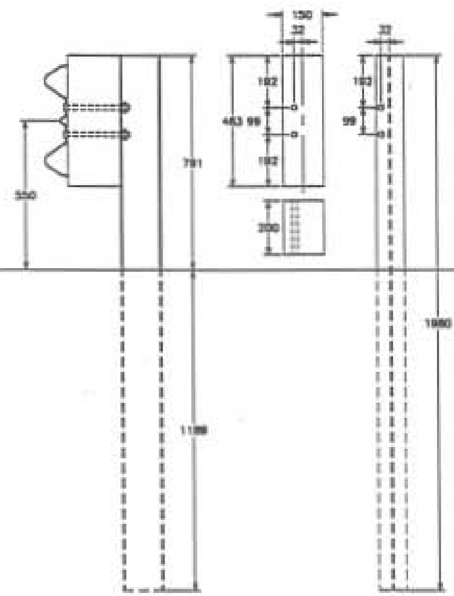

305x356x32mm Steel Plate
8mm (both flanges)
6mm
29mm⌀ holes (6)
8mm (both flanges)
Bridge Connector & Post Assembly
TOP VIEW
16mm⌀ Button Head Bolts w/ Washer and Nut
1905mm
C200x17 (C8x11.5) Channel
16mm⌀ Hex Head Bolts w/ 2 Washers and Nut
90x90x8mm Angle, 120mm deep (2)
W150x22 (W6x15) Steel Block
W150x30 (W6x20) Steel Post
25mm⌀ x 340mm A307 Threaded Rods, Epoxied into concrete apron
25mm⌀ Nut w/ Washer
12-gage Thrie-Beam
16mm⌀ Hex Head Bolt w/ 2 Washers and Nut
32mm
SIDE VIEW
FRONT VIEW
(Guardrail Omitted)
MwRSF
University of Nebraska C.E. Department
Missouri Bridge Rail
DATE: 3/25/99
SCALE: none
DR'N: EAK
Bridge Support Details
Sheet 1 of 7
Bridgeposts



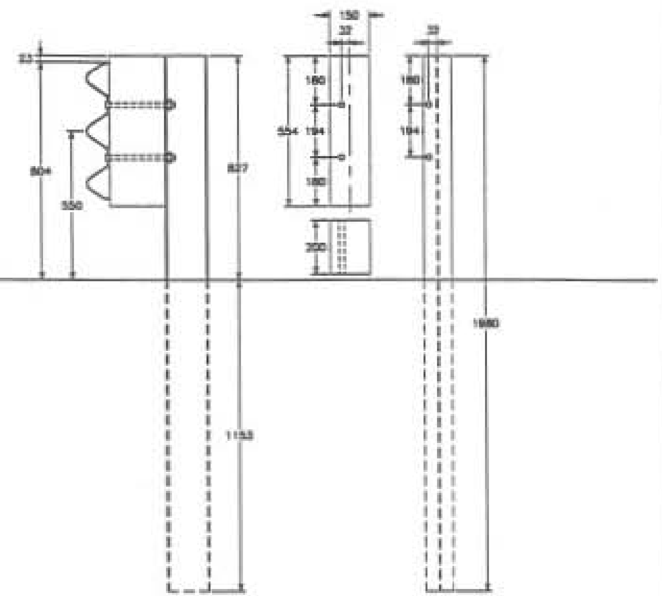
2
1
B1
Transition Cap Rail
Bridge Cap Rail
Splice Plate
16mmø Button Head Bolt w/ Washer and Nut
16mmø Button Head Bolt w/ Washer and Nut
16mmø Button Head Bolt w/ Washer and Nut
Bent Plate Connector
Cap Rail Terminator
Cap Rail Angle
16mmø Hex Head Bolt w/ 2 Washers and Nut
16mmø Hex Head Bolt w/ 2 Washers and Nut
MwRSF
University of Nebraska C.E. Department
Missouri Bridge Rail
DATE: 4/2/99
Cap Rail Connection and Splice Details
SCALE: none
DR'N: EAK
Sheet 3 of 7
MotransCap



Post 8
W150x13.5 (W6x9)



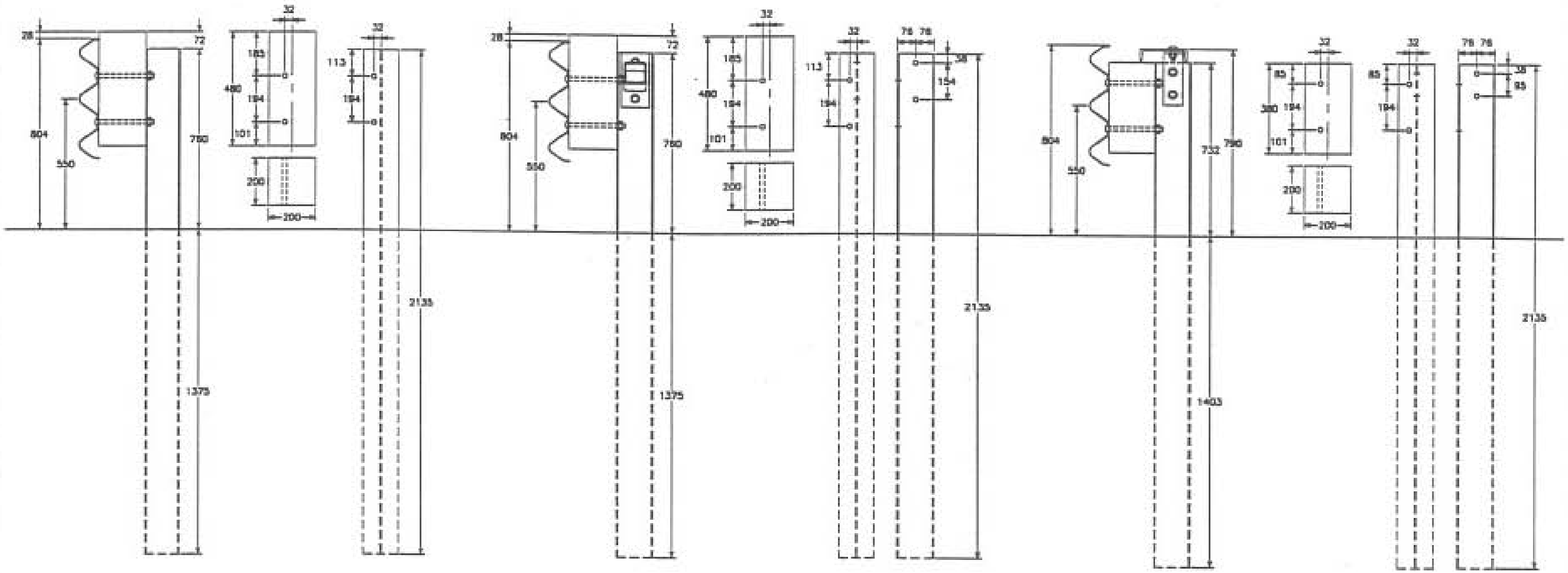
Post 7
W150x13.5 (W6x9)



Post 6
W150x13.5 (W6x9)

* ALL HOLES 20mm Diameter

MwRSF	University of Nebraska C.E. Department	
Missouri Bridge Rail		
DATE: 4/1/99	Transition Posts Details	
SCALE: none		MoPosts
DR'N: EAK	Sheet 4 of 7	



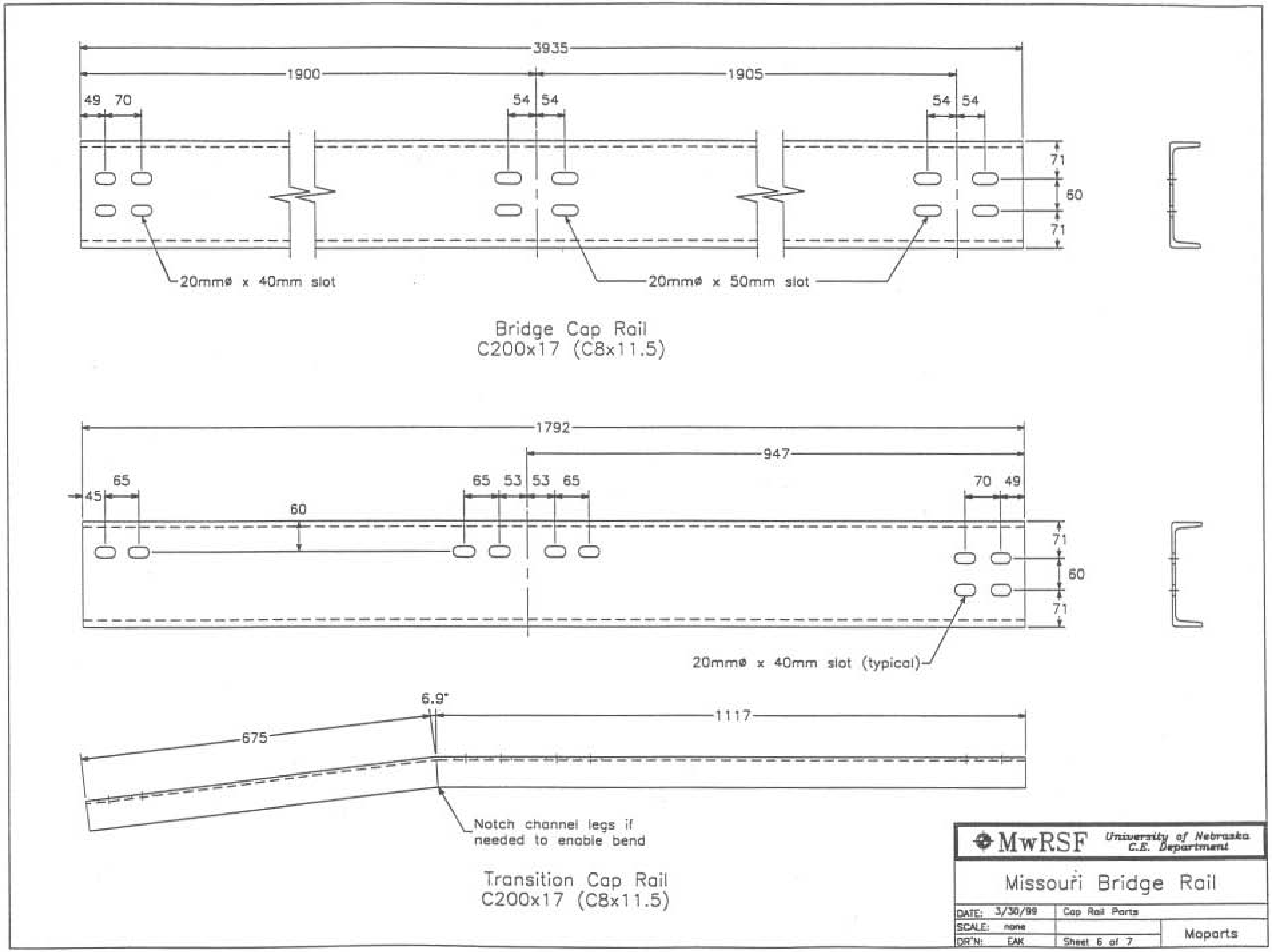
Posts 5–3
W150x22 (W6x15)

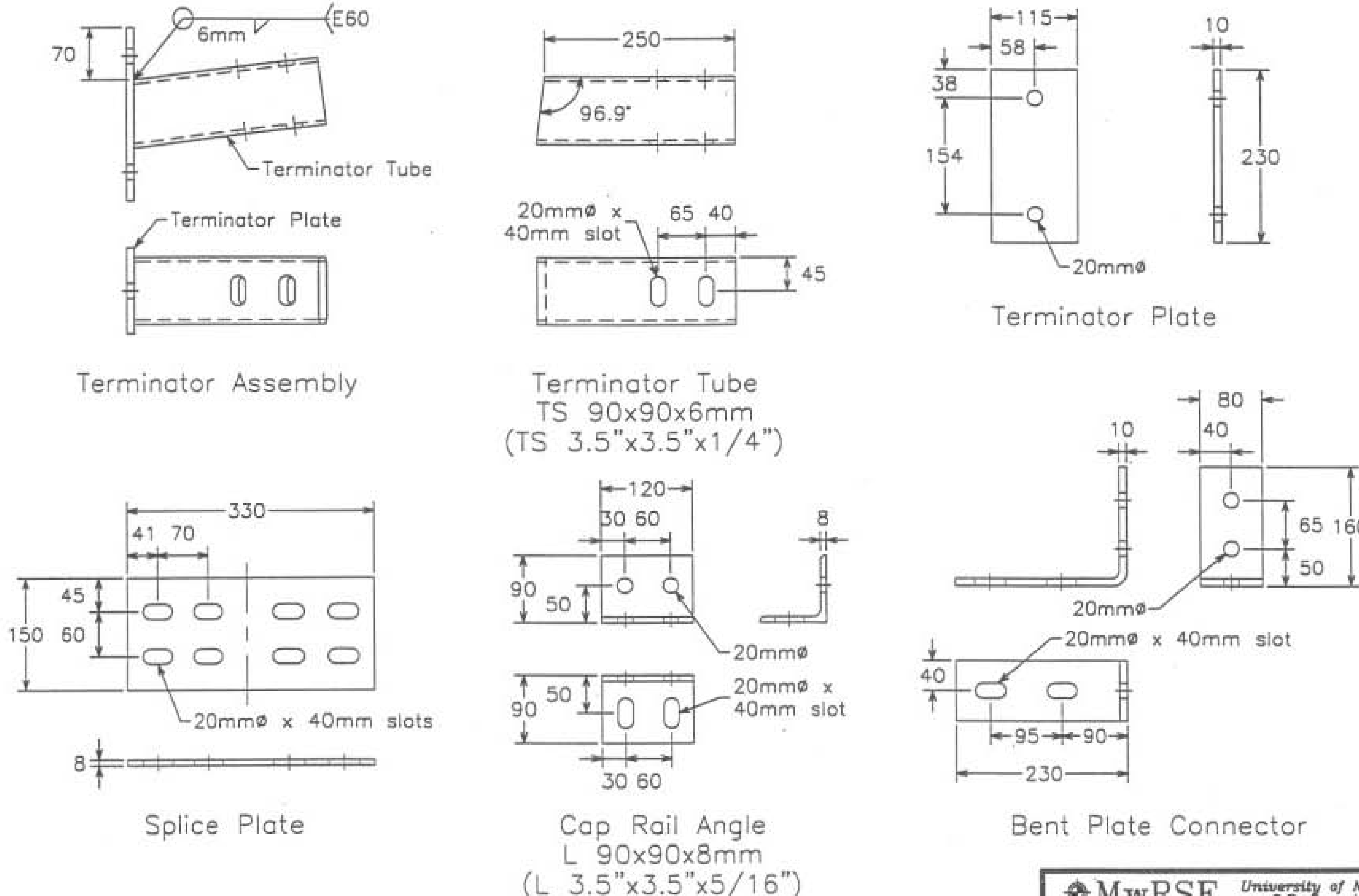
Post 2
W150x22 (W6x15)

Post 1
W150x22 (W6x15)

* ALL HOLES 20mm Diameter

MwRSF	University of Nebraska C.E. Department
Missouri Bridge Rail	
DATE: 4/1/99	Transition Posts Details
SCALE: none	MoPosts
DR'N: EAK	Sheet 5 of 7


3935
1900
1905
49
70
54
54
54
54
71
60
71
20mmø x 40mm slot
20mmø x 50mm slot
Bridge Cap Rail
C200x17 (C8x11.5)
1792
947
45
65
65
53
53
65
70
49
60
71
60
71
20mmø x 40mm slot (typical)
6.9°
675
1117
Notch channel legs if
needed to enable bend
Transition Cap Rail
C200x17 (C8x11.5)
MwRSF
University of Nebraska
C.E. Department
Missouri Bridge Rail
DATE: 3/30/99
Cap Rail Parts
SCALE: none
DR'N: EAK
Sheet 6 of 7
Moparts



MwRSF University of Nebraska C.E. Department

Missouri Bridge Rail

DATE: 3/30/99	Cap Rail Attachment Parts	
SCALE: none		Moparts
DR'N: EAK	Sheet 7 of 7	

APPENDIX H

Letter from FHWA

U.S. Department
of Transportation
**Federal Highway
Administration**

June 4, 1999

400 Seventh St., S.W.
Washington, D.C. 20590

Refer to: HMHS

Ronald K. Faller, Ph.D., P.E.
Midwest Roadside Safety Facility
1901 'Y' Street, Building C
P.O. Box 880601
Lincoln, NE 68588-0601

Dear Dr. Faller:

In your April 19 letter to Mr. Richard Powers of my staff, you requested Federal Highway Administration acceptance of a guardrail-to-bridge rail transition design for use with the Missouri Department of Transportation's Thrie-Beam and Channel Bridge Railing System. Your design is a modification of a transition design that you have successfully tested at the National Cooperative Highway Research Program (NCHRP) Report 350 test level 4 (TL-4). A videotape of the transition tests was included with your original letter and an advance copy of a paper detailing the tests was received on June 3 in response to Mr. Powers' request for additional information on the 2000-kg pickup truck and the 8000-kg single unit truck tests you conducted to verify a TL-4 rating for the original design.

The design for which you asked acceptance differs from the design you tested to TL-4 in two respects: it uses an additional 1905-mm section of 10 gauge (or nested 12 gauge) w-beam making it 7620-mm long and it is stiffened with a C200x17 (C8x11.5) steel channel instead of the 8x3x3/16 structural tube used in the tested design. You stated that the steel channel has a section modulus approximately 10 percent higher than the structural tube. Details of the modified transition are enclosed. We noted that the maximum dynamic deflection of the transition, when struck by the pickup truck, was reported to be 143-mm and thus concluded that its performance would be equally satisfactory with the changes noted above.

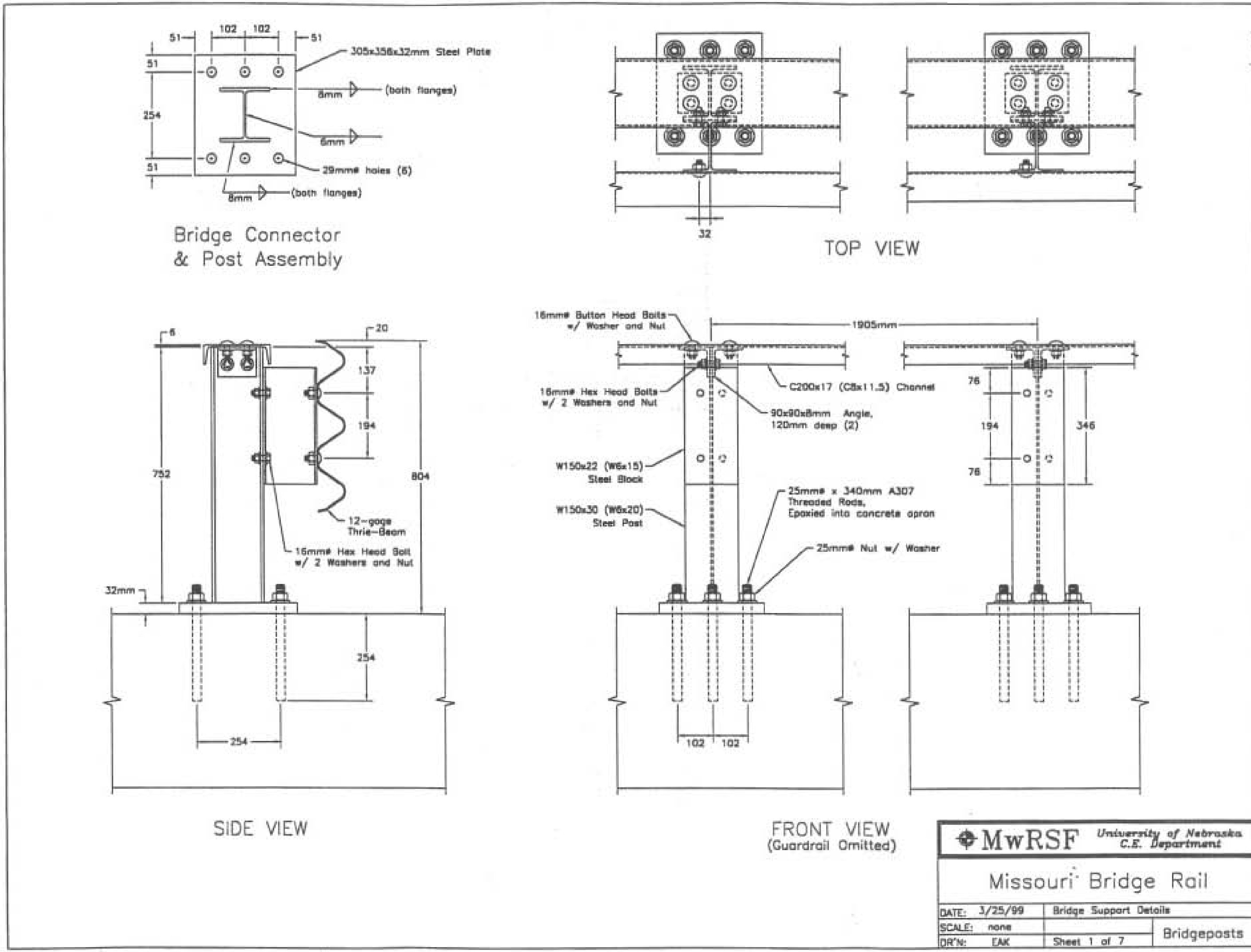
Based on our review of the information you sent, we will accept the modified transition design at NCHRP Report 350 test level 3 (TL-3) without an additional test for use with the Missouri Thrie-Beam and Channel Bridge Railing when that railing is modified to include the use of a W150x22 (W6x15) steel block at each bridge rail post location.

Sincerely yours,

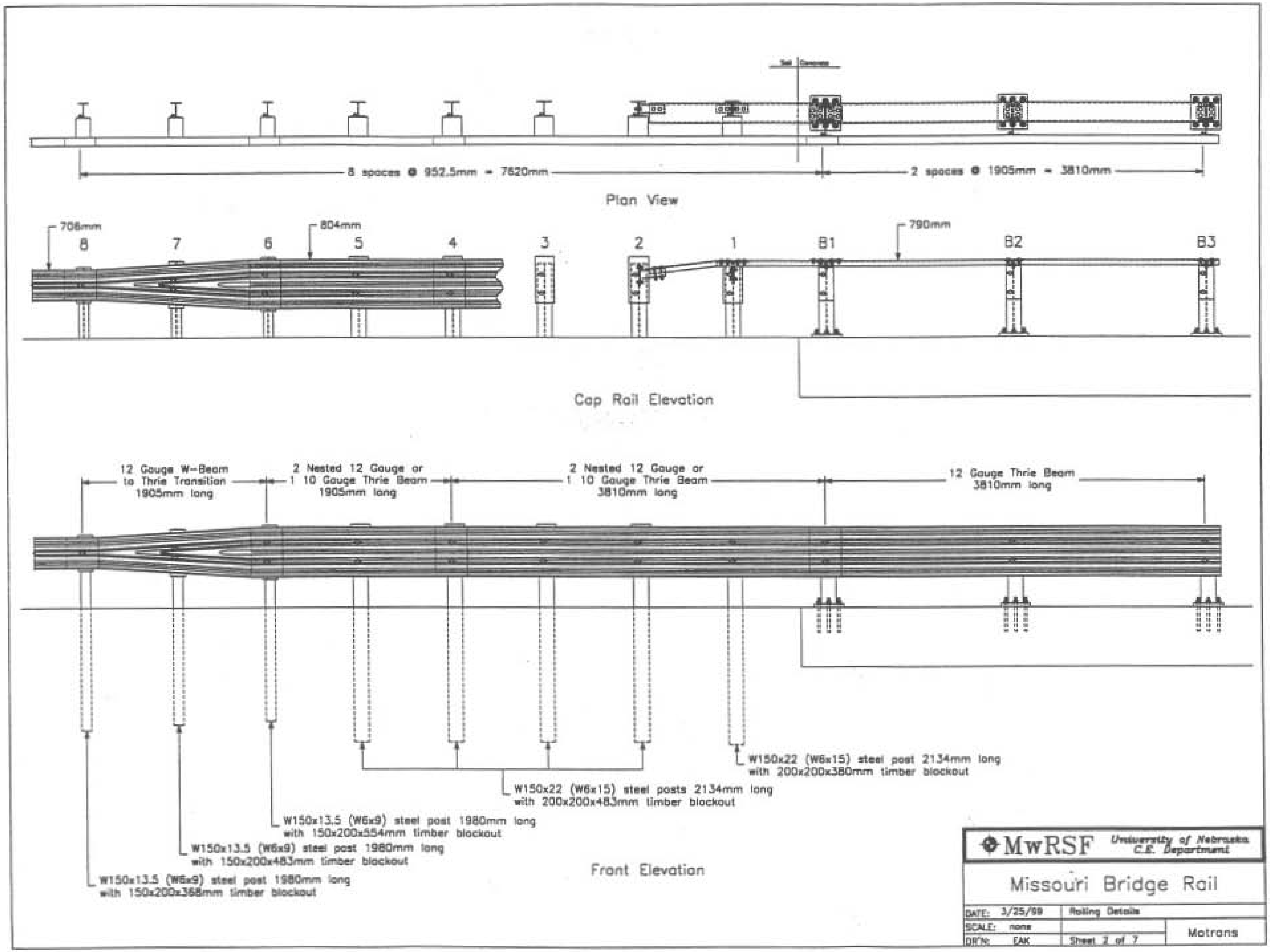
Dwight A. Horne

Dwight A. Horne
Director, Office of Highway Safety Infrastructure

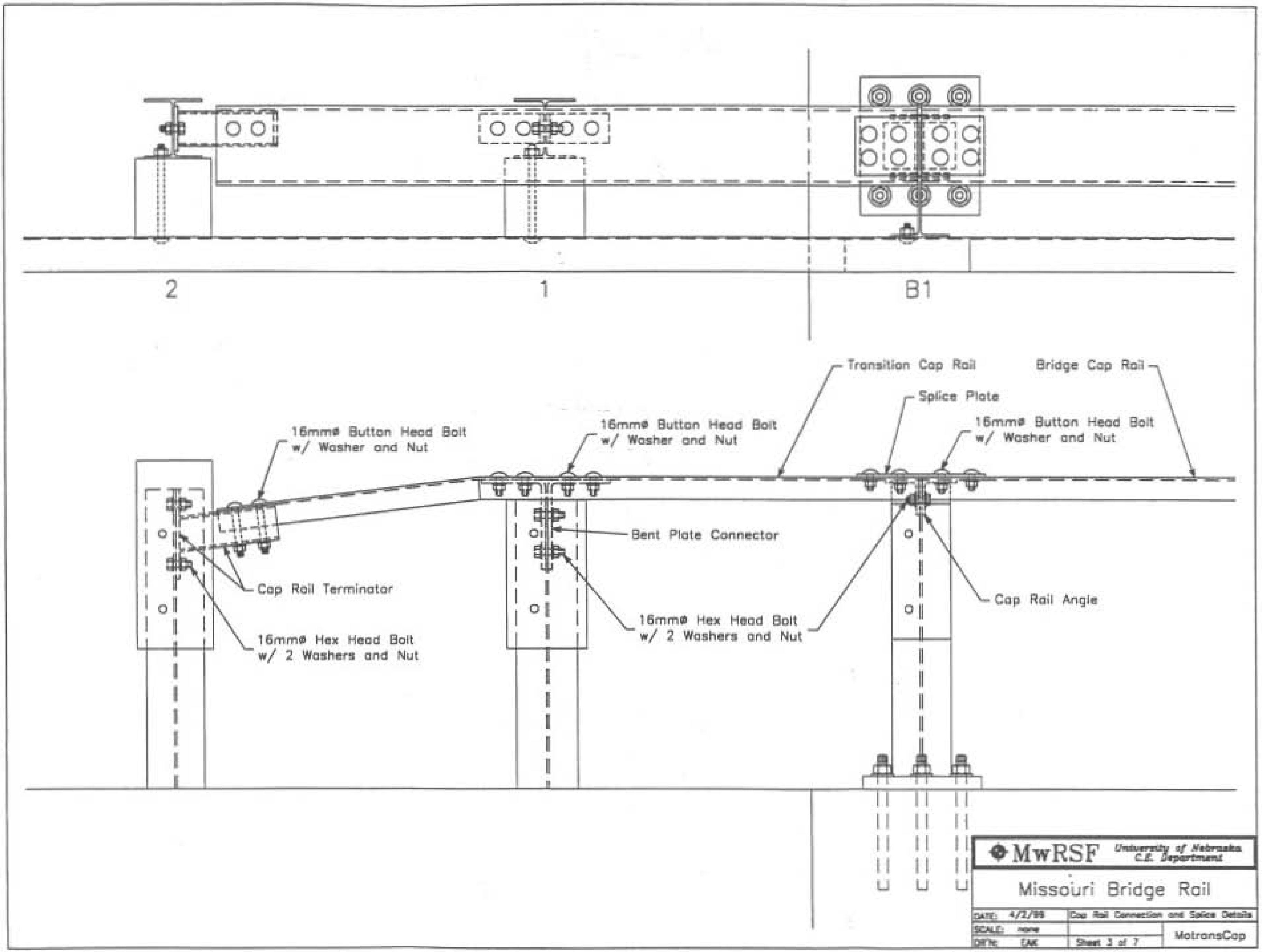
Enclosure

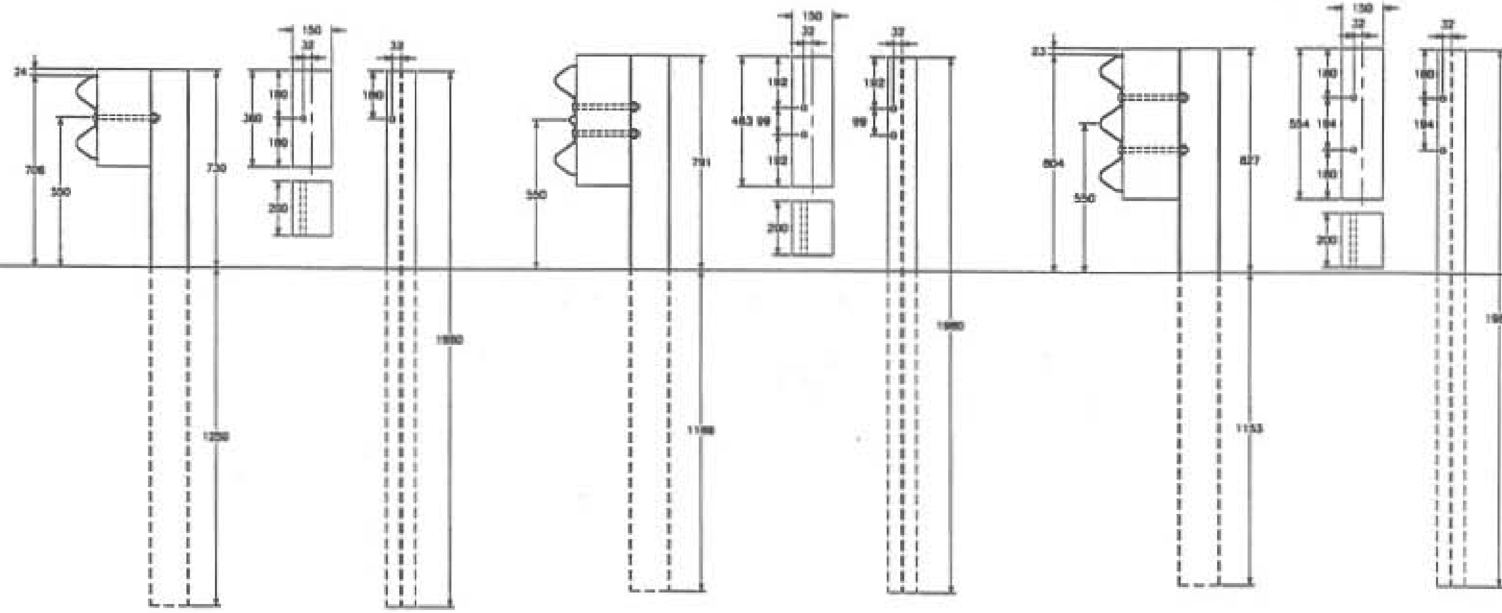


305x356x32mm Steel Plate
8mm (both flanges)
6mm
29mm# holes (6)
8mm (both flanges)
51
102
102
51
51
254
51
32
Bridge Connector
& Post Assembly
TOP VIEW
6
20
137
194
752
804
12-gage Thrie-Beam
16mm# Hex Head Bolt w/ 2 Washers and Nut
32mm
254
254
SIDE VIEW
16mm# Button Head Bolts w/ Washer and Nut
1905mm
16mm# Hex Head Bolts w/ 2 Washers and Nut
C200x17 (C8x11.5) Channel
90x90x8mm Angle, 120mm deep (2)
W150x22 (W6x15) Steel Block
W150x30 (W6x20) Steel Post
25mm# x 340mm A307 Threaded Rods, Epoxied into concrete apron
25mm# Nut w/ Washer
76
194
76
346
102
102
FRONT VIEW
(Guardrail Omitted)
MwRSF
University of Nebraska C.E. Department
Missouri Bridge Rail
DATE: 3/25/99
Bridge Support Details
SCALE: none
DR'N: EAK
Sheet 1 of 7
Bridgeposts



8 spaces @ 952.5mm = 7620mm
2 spaces @ 1905mm = 3810mm
Plan View
706mm
804mm
790mm
8
7
6
5
4
3
2
1
B1
B2
B3
Cap Rail Elevation
12 Gauge W-Beam to Thrie Transition 1905mm long
2 Nested 12 Gauge or 1 10 Gauge Thrie Beam 1905mm long
2 Nested 12 Gauge or 1 10 Gauge Thrie Beam 3810mm long
12 Gauge Thrie Beam 3810mm long
W150x22 (W6x15) steel post 2134mm long with 200x200x380mm timber blockout
W150x22 (W6x15) steel posts 2134mm long with 200x200x483mm timber blockout
W150x13.5 (W6x9) steel post 1980mm long with 150x200x554mm timber blockout
W150x13.5 (W6x9) steel post 1980mm long with 150x200x483mm timber blockout
W150x13.5 (W6x9) steel post 1980mm long with 150x200x368mm timber blockout
Front Elevation
MwRSF
University of Nebraska C.E. Department
Missouri Bridge Rail
DATE: 3/25/99
Railing Details
SCALE: none
DR'N: EAK
Sheet 2 of 7
Motrans


2
1
B1
Transition Cap Rail
Bridge Cap Rail
Splice Plate
16mmø Button Head Bolt w/ Washer and Nut
16mmø Button Head Bolt w/ Washer and Nut
16mmø Button Head Bolt w/ Washer and Nut
Bent Plate Connector
Cap Rail Terminator
Cap Rail Angle
16mmø Hex Head Bolt w/ 2 Washers and Nut
16mmø Hex Head Bolt w/ 2 Washers and Nut
MwRSF
University of Nebraska C.E. Department
Missouri Bridge Rail
DATE: 4/2/99
Cap Rail Connection and Splice Details
SCALE: none
DRW: EAK
Sheet 3 of 7
MotransCap



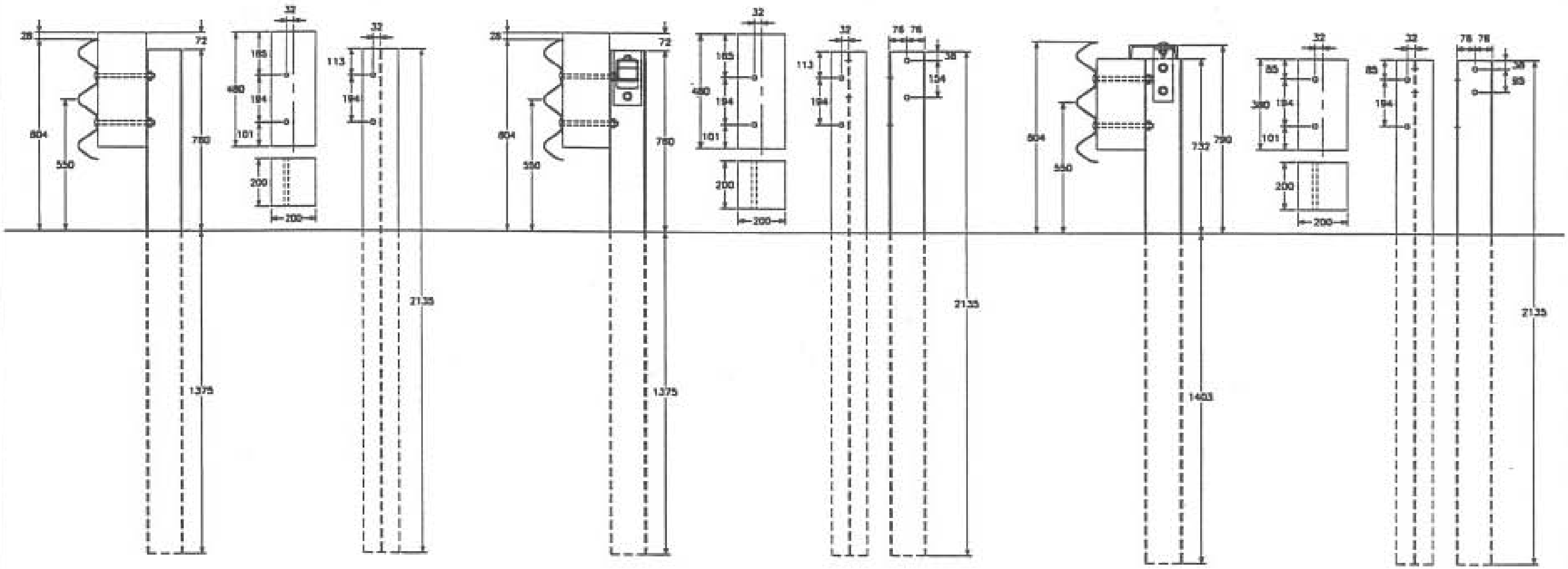
Post 8
W150x13.5 (W6x9)

Post 7
W150x13.5 (W6x9)

Post 6
W150x13.5 (W6x9)

* ALL HOLES 20mm Diameter

MwRSF University of Nebraska C.E. Department		
Missouri Bridge Rail		
DATE: 4/1/99	Transition Posts Details	
SCALE: none		MoPosts
DR'N: EAK	Sheet 4 of 7	



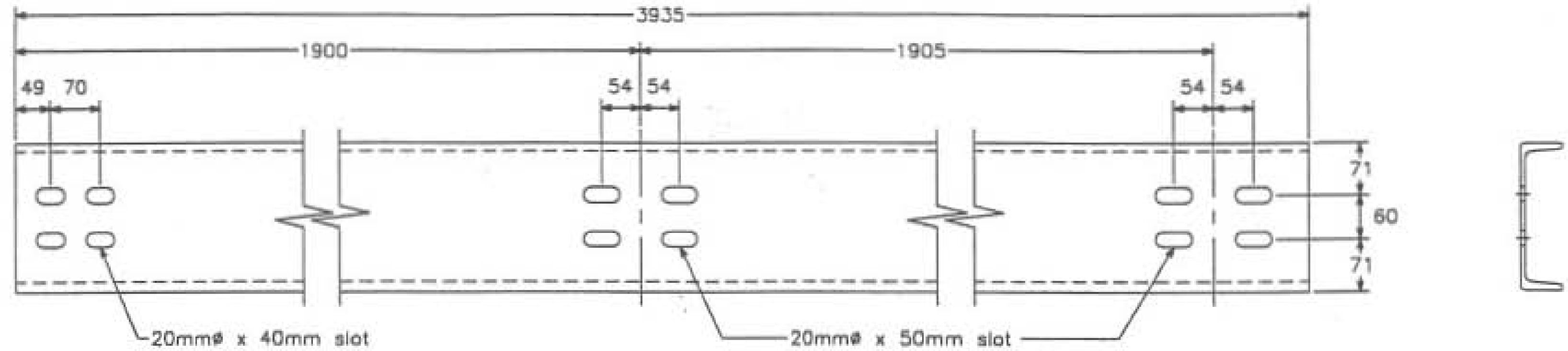
Posts 5–3
W150x22 (W6x15)

Post 2
W150x22 (W6x15)

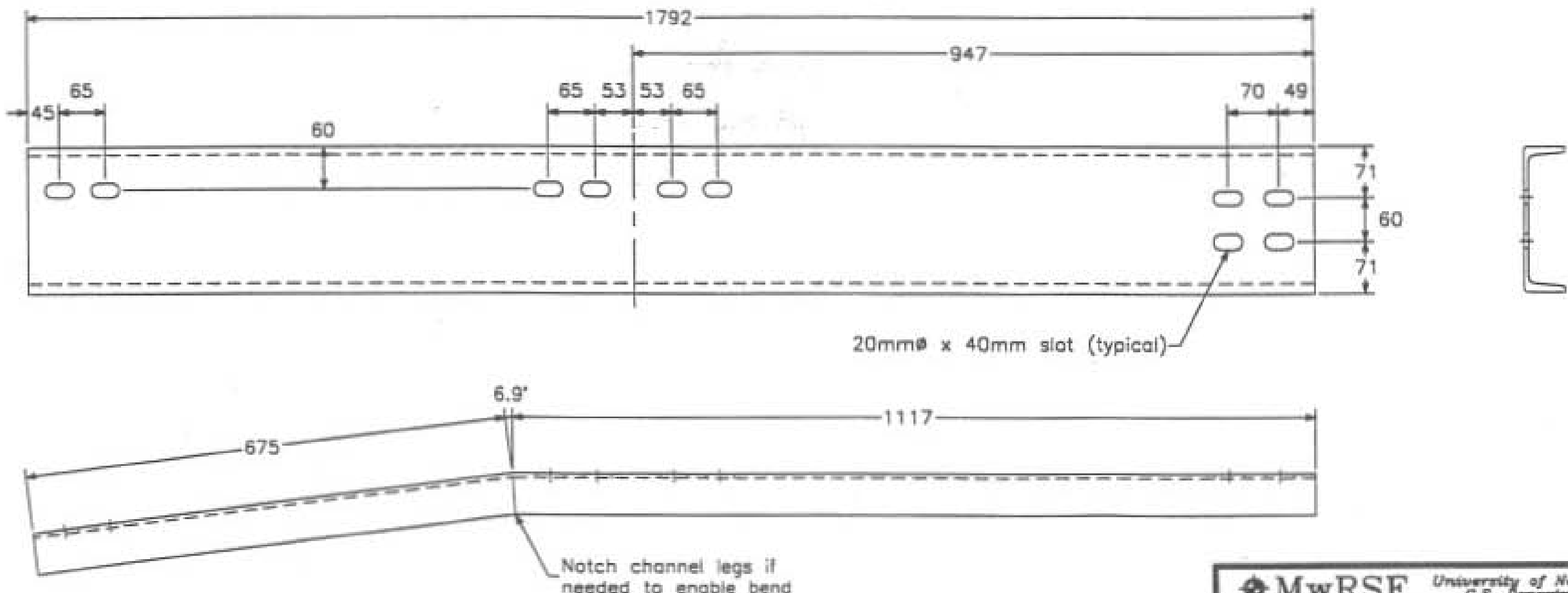
Post 1
W150x22 (W6x15)

* ALL HOLES 20mm Diameter

MwRSF	University of Nebraska C.E. Department	
Missouri Bridge Rail		
DATE: 4/1/99	Transition Posts Details	
SCALE: none		MoPosts
DR'N: EAK	Sheet 5 of 7	

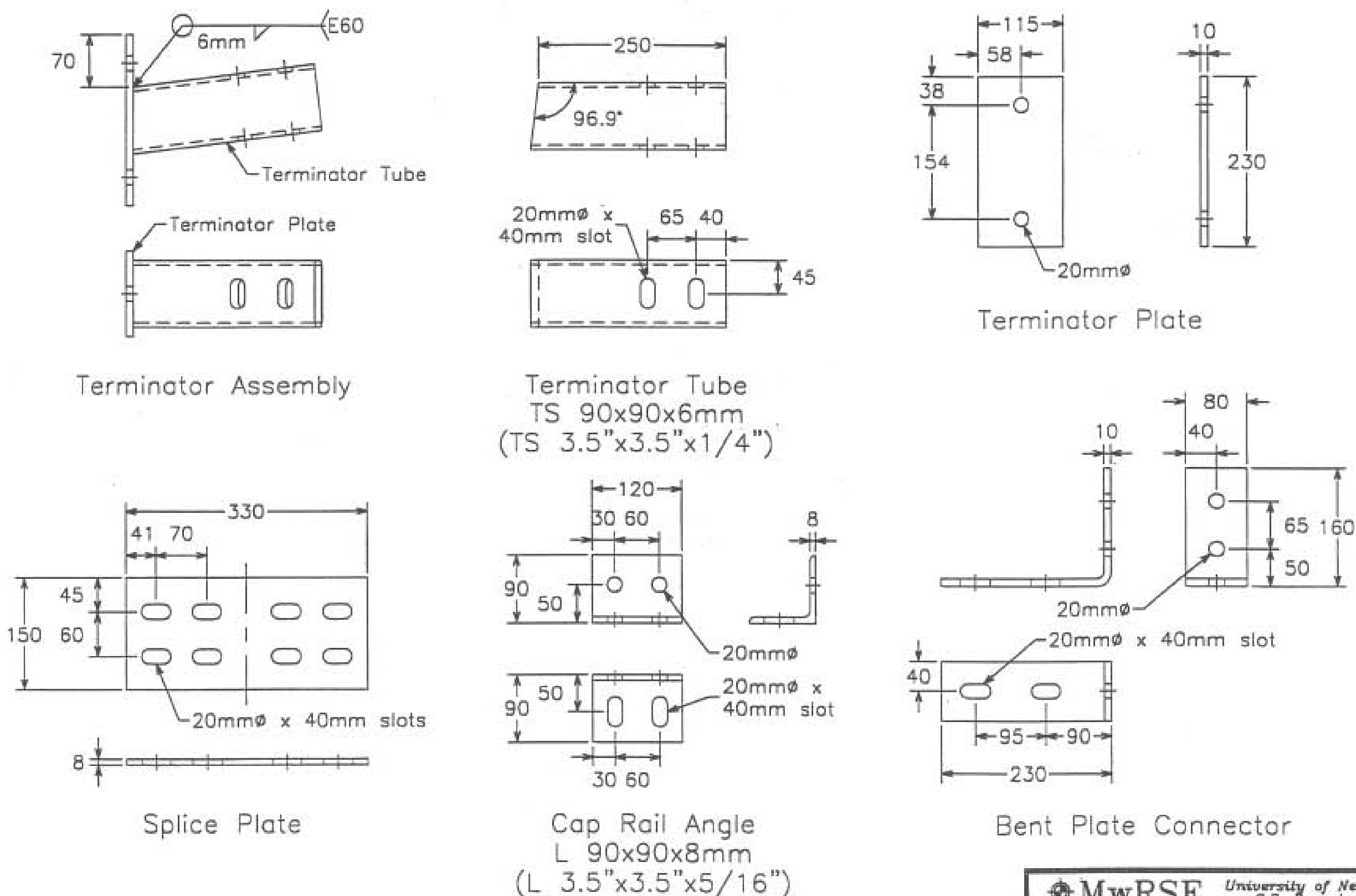


Bridge Cap Rail
C200x17 (C8x11.5)



Transition Cap Rail
C200x17 (C8x11.5)

MwRSF	University of Nebraska C.E. Department	
Missouri Bridge Rail		
DATE: 3/30/99	Cap Rail Parts	Moparts
SCALE: none		
DR'N: EAK	Sheet 6 of 7	



MwRSF University of Nebraska C.E. Department

Missouri Bridge Rail

DATE: 3/30/99	Cap Rail Attachment Parts	
SCALE: none		Moparts
DR'N: EAK	Sheet 7 of 7	