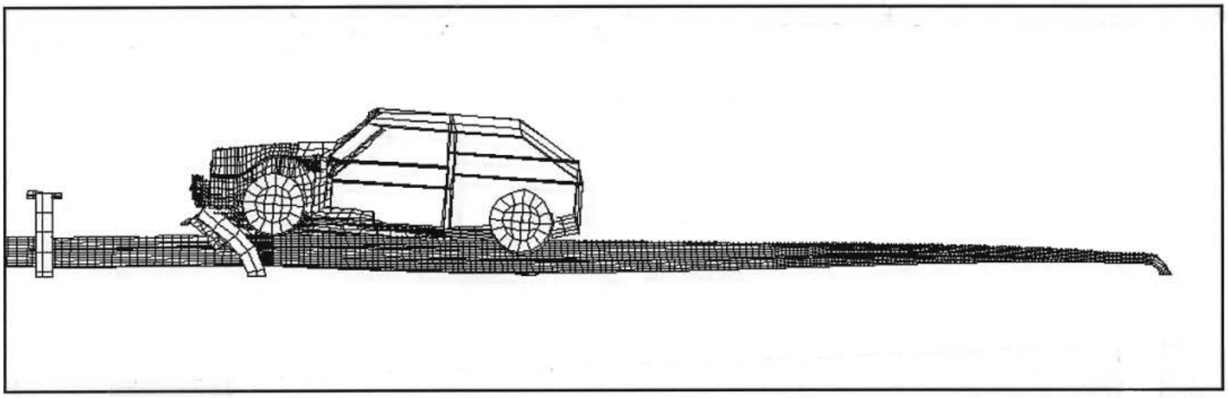
Concept Design and Analysis of Nebraska Turned-Down Approach Terminal Sections



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ABSTRACT

Turned-down terminal sections were analyzed using LS-DYNA3D, a finite element modelling package with capabilities for simulating vehicular impacts into roadside hazards. A baseline simulation was conducted on the existing turned-down approach terminal section, as well as on various retrofit options. The simulation package was used to select the two most promising options.

Six low speed bogie tests, and one high speed bogie test were conducted on the modified Nebraska Turned-Down Approach Terminal Sections. All tests were conducted with a 1979 Honda Civic with a gross static weight of 885-kg (1945-lb). Impact conditions were at 0 degrees with a 36-cm (15-in.) offset toward the roadway. The low-speed tests were conducted at 16 kph (10 mph), and the high-speed test was conducted at 96 kph (59.5 mph).

The high-speed test was conducted and reported in accordance with the requirements specified in the Recommended Procedures for the Safety Performance Evaluation of Highway Appurtenances, National Cooperative Highway Research Program (NCHRP) Report No. 230. The safety performance of the modified Nebraska Turned-Down Approach Terminal Section was determined to be unacceptable according to the NCHRP 230 criteria. However, the desired behavior of the turned-down section was achieved. It is believed, that revising the post installation procedures could create a terminal section that would perform satisfactorily.

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1 INTRODUCTION

1.1 Problem Statement

For many years, guardrails have been an important component of our highway safety system. Guardrails installed with improper end termination can pose a significant hazard. Early guardrails incorporated no special procedures to mitigate the severity of end impacts, and it was not uncommon for vehicles to be impaled with the blunt end of the guardrail.

Recognizing the problem with blunt end guardrails, early guardrail designs were tapered to the ground or "turned-down", to eliminate the spearing effect. These turned-down designs eliminated the spearing effect, but caused small vehicles to vault and rollover. Later terminals were designed to drop down upon impact and allow the vehicle to penetrate behind the barrier. Unfortunately, additional downsizing of the vehicle fleet caused these systems to function poorly when impacted by smaller cars. Prior crash testing demonstrated that Nebraska's turned-down terminal can launch a mini-size vehicle. This launching effect caused the automobile to be airborne for considerable distances, thereby increasing the possibility of vehicle rollovers.

Thousands of turned-down approach terminal sections exist in Nebraska and other states even though the Federal Highway Administration (FHWA) has recently prohibited the construction of turned-down approach terminal sections as an acceptable end treatment on high-speed and high-volume highways. Therefore, there is a need to develop an acceptable retrofit for existing turned-down terminals to meet current crash testing safety standards.

1.2 Objective

The objective of this research project was to develop a retrofit concept that would meet the safety requirements provided by National Cooperative Highway Research Program Report (NCHRP) No. 230 (1).

1.3 Scope

Several concepts, as shown in Appendix A, were proposed to weaken the system, allowing it drop more easily. The most feasible concepts were analyzed and evaluated using computer simulation modelling. A finite element model, developed with LS-DYNA3D, was used to study the effects of the most feasible concepts on the behavior of the system. The results of the finite element analyses were used to determine which of the new concepts warranted further testing.

Six low speed un-instrumented vehicle bogie tests (Tests NETD-LS{1-6}) were conducted with an 885-kg (1945-lbs) mini-compact sedan at the target conditions of 16 kph (10 mph) and 0 degrees with an offset of *W/4* toward the roadway, where *W* is the track width. The low speed tests were used to verify several concepts which yielded promising results from computer simulation. A high-speed bogie test was performed on the best concept based on the results of the low-speed tests. One full-scale vehicle crash test (Test NETD-3) was conducted with an 885-kg (1945-lbs) mini-compact sedan at the target conditions of 100 kph (62 mph) and 0 degrees with an offset of *W/4* toward the roadway (NCHRP 230 Test Designation No. 45). The test matrix required by NCHRP 230 involves conducting three full-scale vehicle crash tests (Test Designation Nos. 41, 44, 45). NCHRP 230 also comments that some of the tests may be omitted if it can be demonstrated through engineering analysis that these tests are less severe than other tests in the matrix. From a literature review, on the testing of existing turned-down terminal sections, it was found that Test No. 45 was the most stringent test for meeting crash test safety standards.

2 BACKGROUND

The first efforts to reduce the severity of impacts with turned-down end treatments were sponsored by the Texas Department of Highways and Public Transportation and Federal Highway Administration. The objective of the research was to improve the turned-down guardrail end treatment and come up with a simple retrofit to the turned-down design(2).

Figure 1 shows the Texas guardrail system employing 17.8-cm (7-in.) diameter wood posts. The end treatment is 15.24-m (50-ft) in length, the first 7.62-m (25-ft) being twisted down from the guardrail height to the ground without posts. The next 7.62-m (25-ft) of the terminal was fastened to five wooden posts using a 0.3-cm x 1.9-cm x 20.3-cm (1/8-in. x 3/4-in. x 9-in.) mild steel strap. A W-section backup plate was bolted to the post, then the guardrail was attached to the plate using the steel strap, as shown in Figure 2. This system, allowed the rail to drop down when hit head on, but remained in place when impacted from the side.

In 1981, Texas Transportation Institute (TTI) researched modifications to their previous design for the Oklahoma Department of Transportation (3). The state of Oklahoma used 15.2-cm x 20.3-cm (6-in. x 8-in.) wood posts in their guardrail system. The study modified the original TTI design to work with the 15.2-cm x 20.3-cm (6-in. x 8-in.) wood posts. The Oklahoma design, shown in Figure 3, extended the nested release mechanism over the first eight posts. The design also specified a wood blockout on all posts after Post No. 2. The TTI report also concluded that the guardrail should not reach the specified height of 29 inches until the 3rd post.

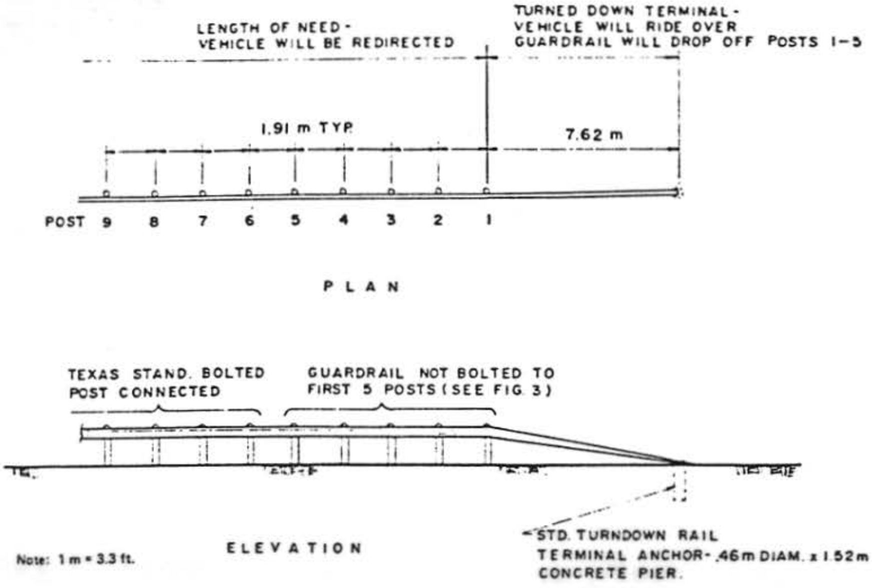


FIGURE 1. Texas "Nested" Guardrail With Turned-Down Terminal.

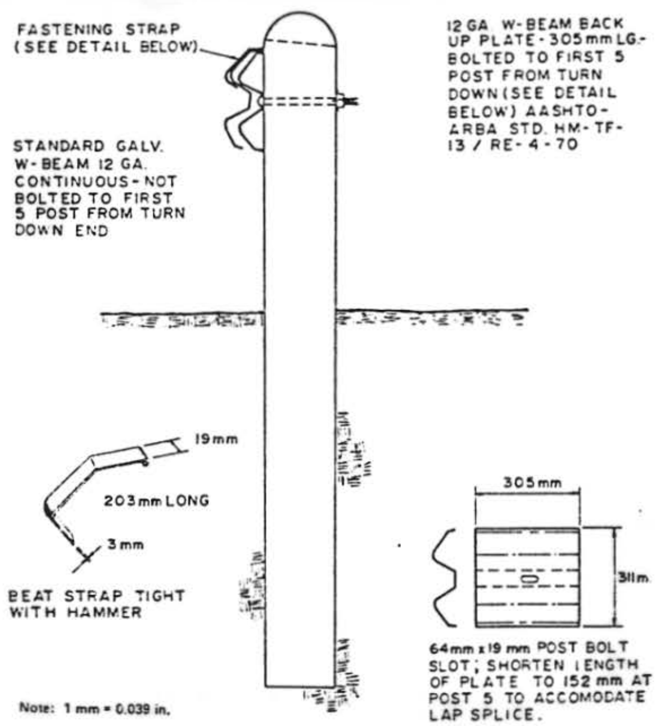


FIGURE 2. Modified Guardrail-to-Post Connection.
NOTE: From Ref. 2, pg 70.

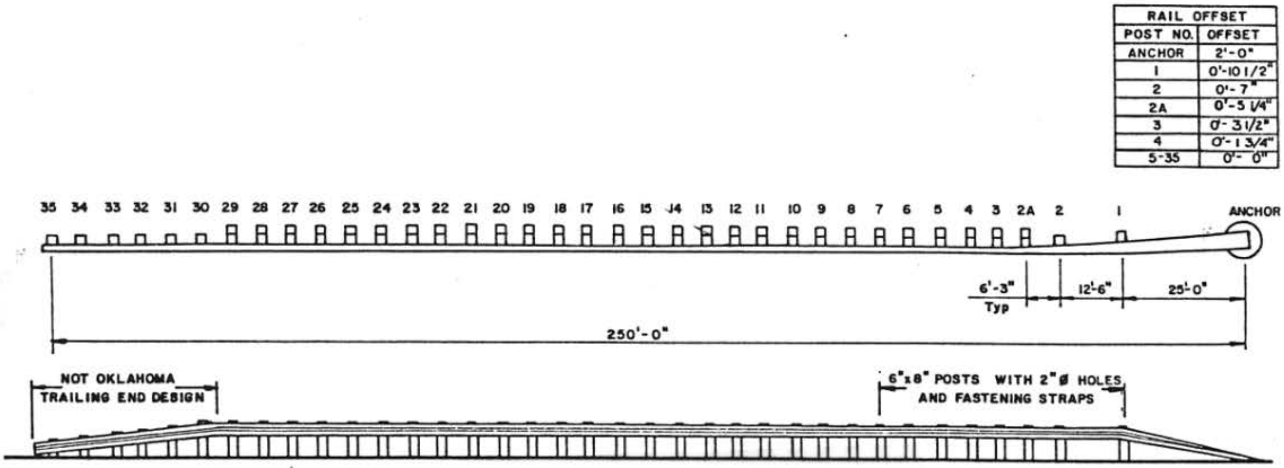


FIGURE 3. Final Modified Oklahoma Guardrail End Treatment.
NOTE: From Ref. 3, pg 6.

In 1980, TTI conducted a similar study on the Maryland guardrail system (4). Maryland used W6 x 8.5 steel posts in their standard design. The modified design used a 15.2-cm x 20.3-cm (6-in. x 8-in.) wood post at the first post and standard steel posts at the remaining post locations. The nested release mechanism in this design was applied to the first six posts.

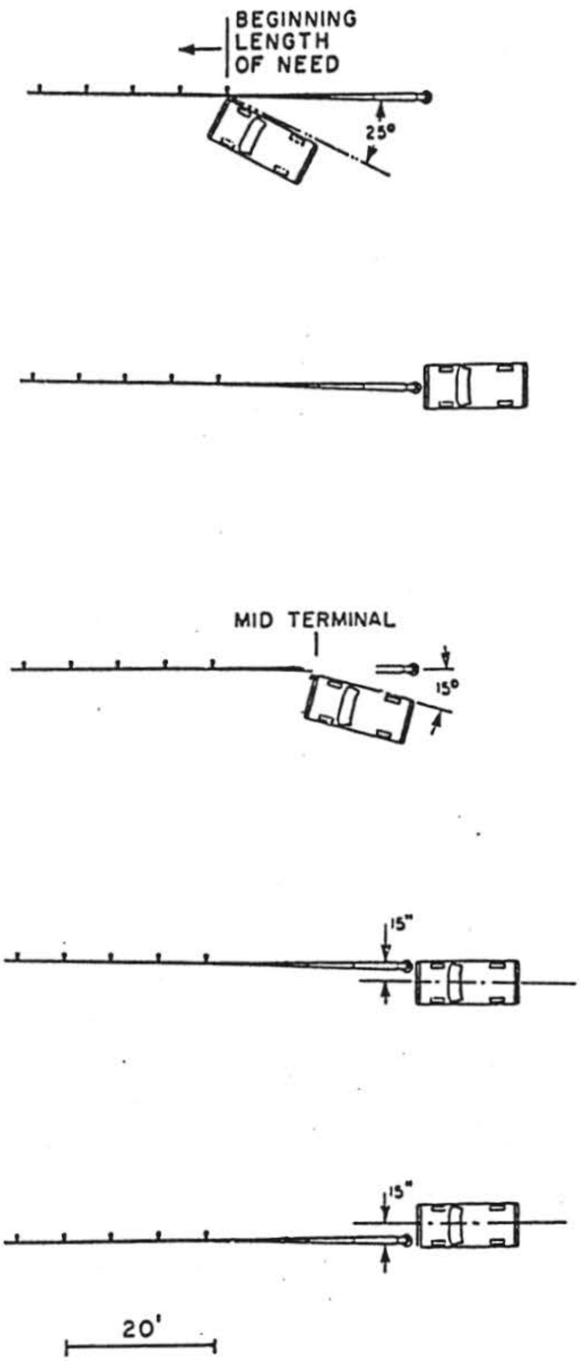
These three designs were tested in accordance with the guidelines set forth in Transportation Research Circular 191 (TRC 191) (4). TRC 191 (1978) outlined procedures for crash testing of highway appurtenances. TRC 191 specified the testing of 2040-kg (4500-lb) and 1020-kg (2250-lb) vehicles. However, in 1981, the National Cooperative Highway Research Program (NCHRP) produced Report 230 (1) that added more stringent regulations that must be satisfied by all highway appurtenances. NCHRP 230 replaced TRC 191 and added a requirement that barriers be subjected to tests involving an 820-kg (1800-lb) vehicle instead of the 1020-kg (2250-lb) vehicles.

Figure 4 provides a graphical representation of the various test conditions from TRC 191 and NCHRP 230. The last two graphics in the figure describe the additional regulations specified by NCHRP 230. NCHRP 230 Test 45 specifies the use of an 820-kg (1800-lb) test vehicle.

These added requirements provided problems for the existing designs. In 1982, TTI performed further crash tests to modify the Maryland turned-down guardrail terminal to obtain satisfactory behavior when impacted by 820-kg (1800-lb) minicar (5). The modified design, shown in Figure 5, specifies the use of two 15.2-cm x 20.3-cm (6-in. x 8-in.) wooden posts with a 5.1-cm (2-in.) diameter hole at ground level. The design also specifies that a flat plate be used in lieu of W-beam railing for the first 7.62-m (25-ft) of the terminal section. The nested release mechanism was applied to the first five posts.

The design failed when tested according to NCHRP 230 Test 45. The parameters of this test specified the use of an 820-kg (1800-lb) test vehicle (Honda Civic), impacting with a speed of 96.5 kph (60 mph) and at an angle of 0 deg with a 38.1-cm (15-in.) eccentric offset at the end of the terminal. Although the guardrail dropped, the first post did not break off, and it launched the vehicle and caused it to rollover.

In 1984, ENSCO, INC. performed several crash tests in accordance with NCHRP 230 (6). The purpose was to test the existing Texas "nested" design as well as to



DESCRIPTION	TRC 191 TYPE	NCHRP 230 TYPE
25° - BEGINNING LON	2	40
0° - NO OFFSET	1 & 3	41
15° - MID TERMINAL	4	42 & 44
0° - 15" OFFSET ROADSIDE	NOT REQUIRED	43 & 45
0° - 15" OFFSET FIELDSIDE	NOT REQUIRED	43 & 45

FIGURE 4. Various Test Conditions from TRC 191 and NCHRP 230.
NOTE: From Ref. 6, pg 22.

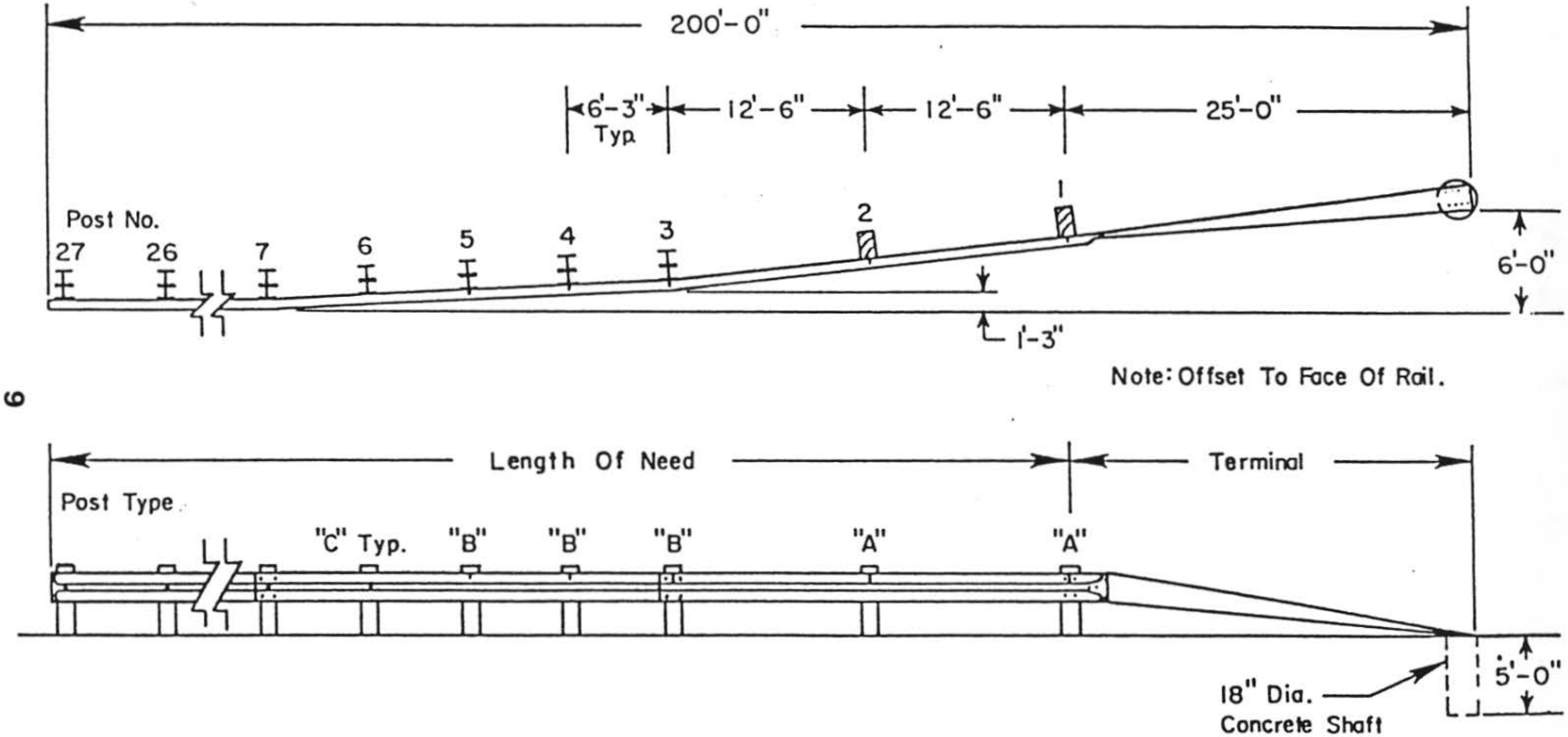


FIGURE 5. Final Terminal Design Maryland Guardrail System

NOTE: From Ref. 5, pg 58

develop a new design that would satisfy the requirements of NCHRP 230. Testing on the Texas "nested" system yielded unsatisfactory results.

Other developmental tests performed by ENSCO yielded interesting results and led to some important conclusions. In their tests, the W-beam terminal section was replaced with a C-rail. The C-rail and W-beam are shown in Figure 6. The C-rail has a lower section modulus than the W-beam, so it provided a less rigid barrier when impacted head-on. The reduction in section modulus allowed the rail to deflect more easily, and reduce the severity of the impact. This improved the performance of the guardrail end terminal for 820-kg (1800-lb) vehicles, since the W-beam sections would capture the small tires of the minicompacts and prevent the vehicle from overriding the rail.

The final ENSCO design, or CRT (Controlled Releasing Terminal), is shown in Figure 7. This design employed a C-rail for the turned-down terminal section as opposed to the W-beam that was used for the remaining section of the guardrail installation. The first ten posts in this design were 15.2-cm x 20.3-cm (6-in. x 8-in.) modified wood posts, with a 8.9-cm (3.5-in.) diameter hole bored 40.6-cm (16-in.) below ground level. The remaining posts in the system, after Post No. 10, were standard W6x8.5 steel posts. Figure 8 shows the modified steel blockout and bendaway attachment that is used to hold the rail to the first twelve posts. The standard wood blockouts and backup plates used in the nested design are replaced by a modified steel blockout. The bendaway attachment screws onto the 1.6-cm (5/8-in.) bolt that extends through the post and secures the steel blockout to the post

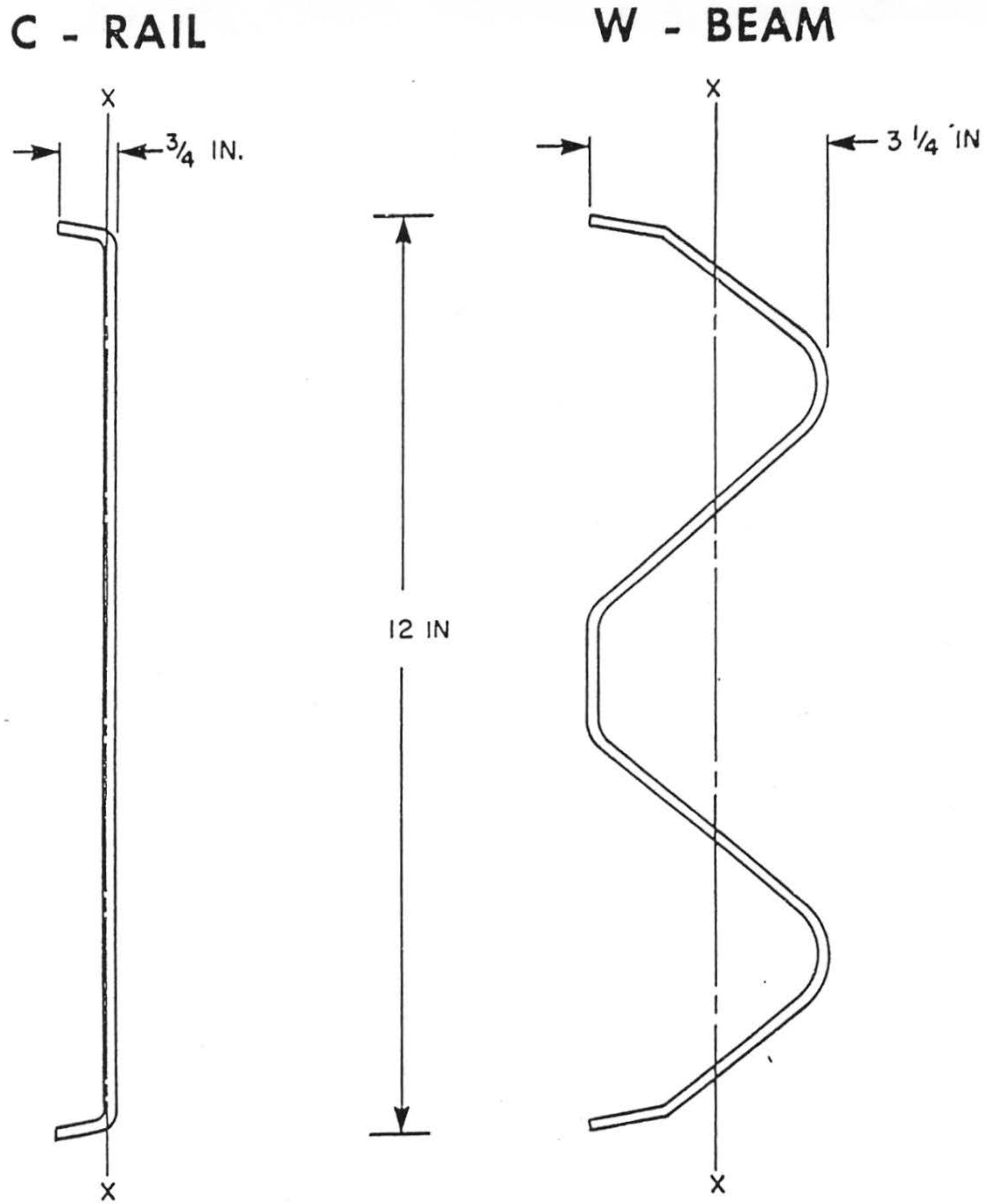


FIGURE 6. Cross Section of C-Rail and W-beam.
NOTE: From Ref. 6, pg 107.

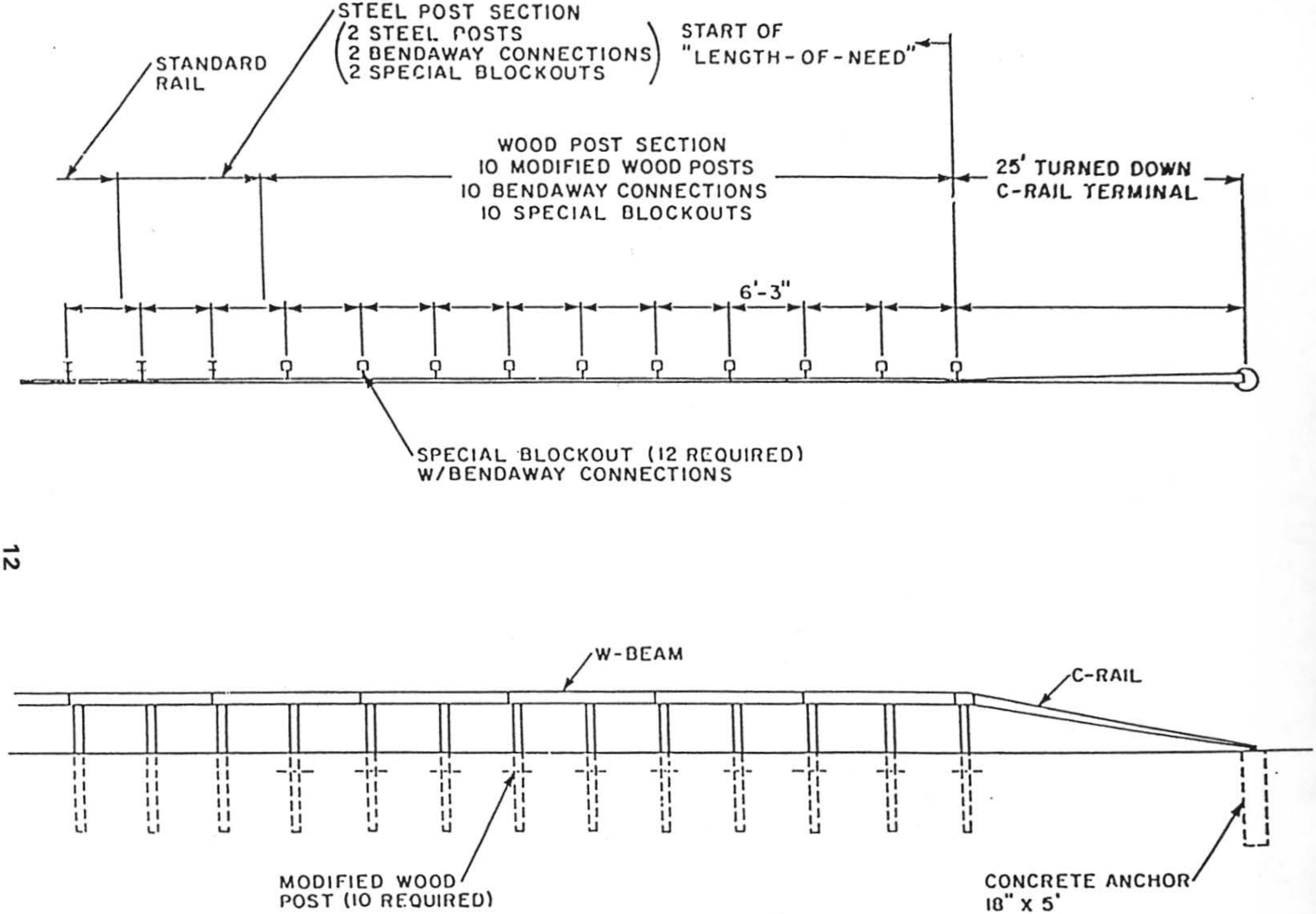


FIGURE 7. Final CRT Design

NOTE: From Ref. 6, pg 21

as well as securing the W-beam to the blockout. Two special retaining rings are used to hold the W-beam on the bendaway attachment.

The CRT design proposed by ENSCO nearly met NCHRP 230 requirements. It successfully passed Test No. 45, involving an 820-kg (1800-lb) test vehicle impacting at 96.5 kph (60 mph) - 0 deg - 38.1-cm (15-in.) offset to the fieldside. However, when impacted at 96.5 kph (60 mph) - 0 deg - 38.1-cm (15-in.) offset to the roadside the system failed. The test results indicated that the offset to the roadside is the most stringent of the tests.

The state of Nebraska employs a system which is a modified version of the Texas "nested" system. The Nebraska system uses 15.2-cm x 20.3-cm (6-in. x 8-in.) wood posts with wood blockouts and backup plates. In 1989, the Nebraska Department of Roads found a problem with the current design. NDOR reported that vibrations from passing traffic and fluctuations in temperature caused the clips of the nested design to expand. These problems caused the guardrail to drop to the ground without being impacted.

The Civil Engineering Department at the University of Nebraska was asked to study the problem by conducting static testing on the terminal section (7). From the results of the static tests, the researchers recommended the placement of No. 10 bolts in the W-beam at Post Nos. 1 and 3, the bolt attachment is shown in Figure 9. There is no connection between the W-beam and the backup plate on Post Nos. 2, 4, and 5, and the steel straps designed by TTI were eliminated completely. In 1992, the Midwest Roadside Safety Facility in Lincoln, Nebraska performed a full-scale crash test

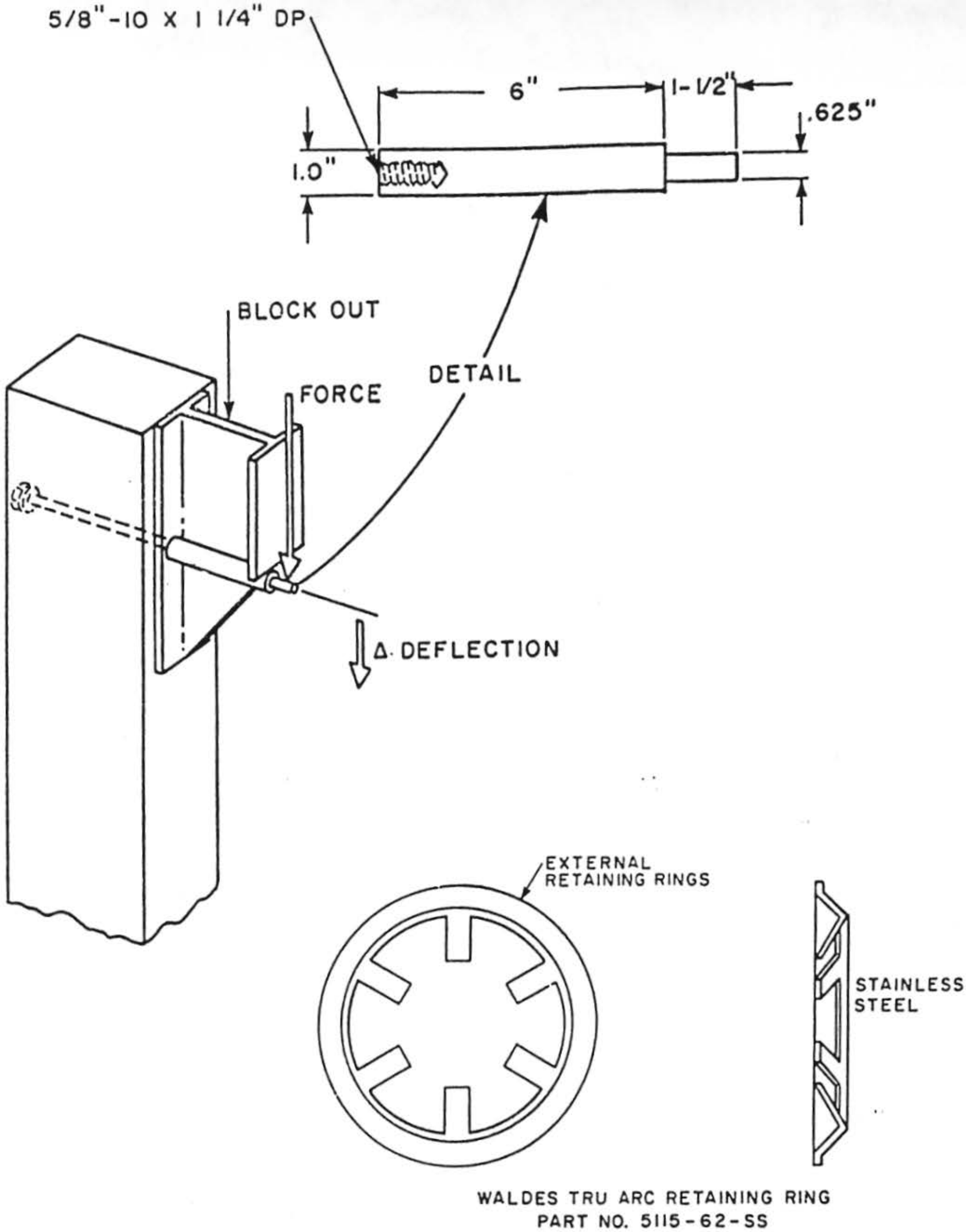


FIGURE 8. Modified Steel Blockout, Bendaway Attachment, and Retaining Ring.
NOTE: From Ref. 6, pg 52, 55.

on this design shown in Figure 10 (8). The test of NCHRP 230 No 45 was a failure as the 830-kg (1830-lb) Dodge Colt was launched in the air and rolled over.

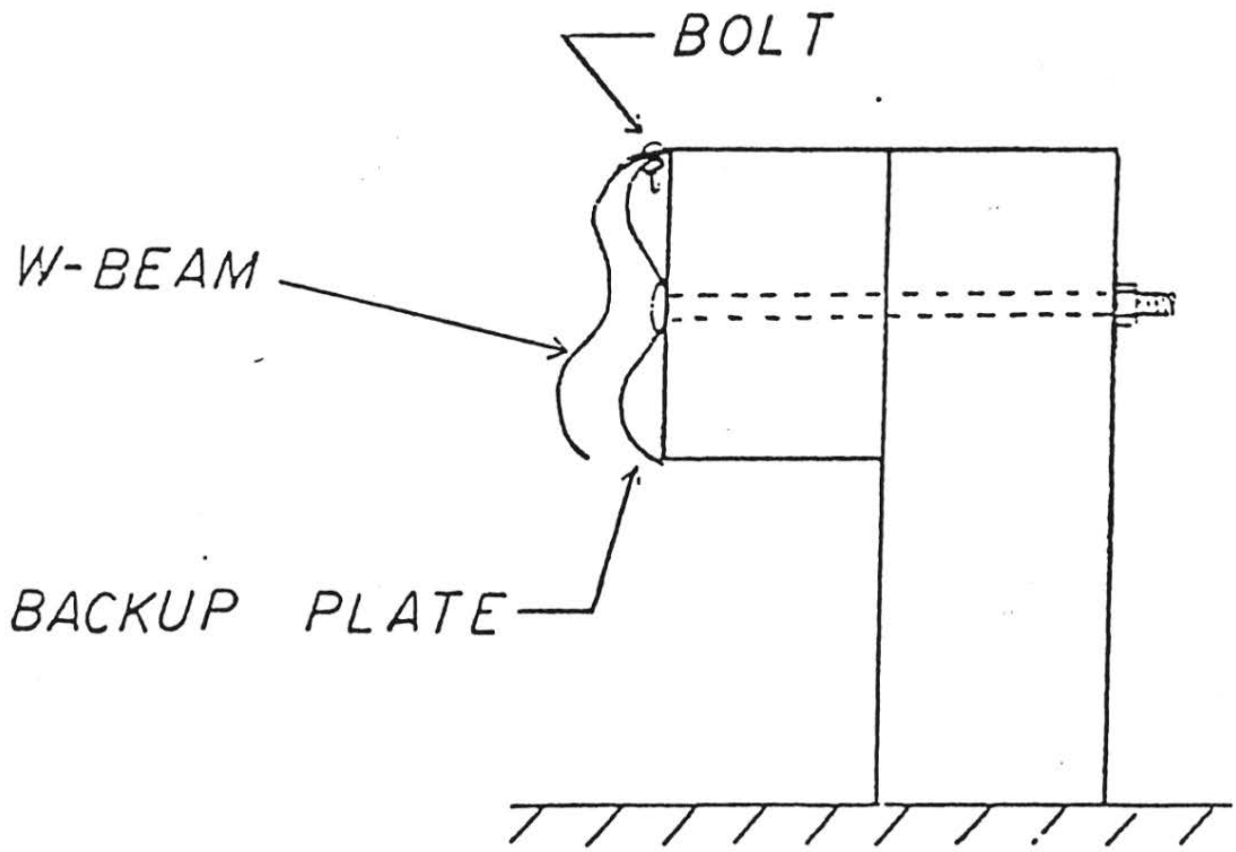


FIGURE 9. Modified Breakaway Design, Location of No. 10 Bolt Connection.
NOTE: From Ref. 7, pg 5.

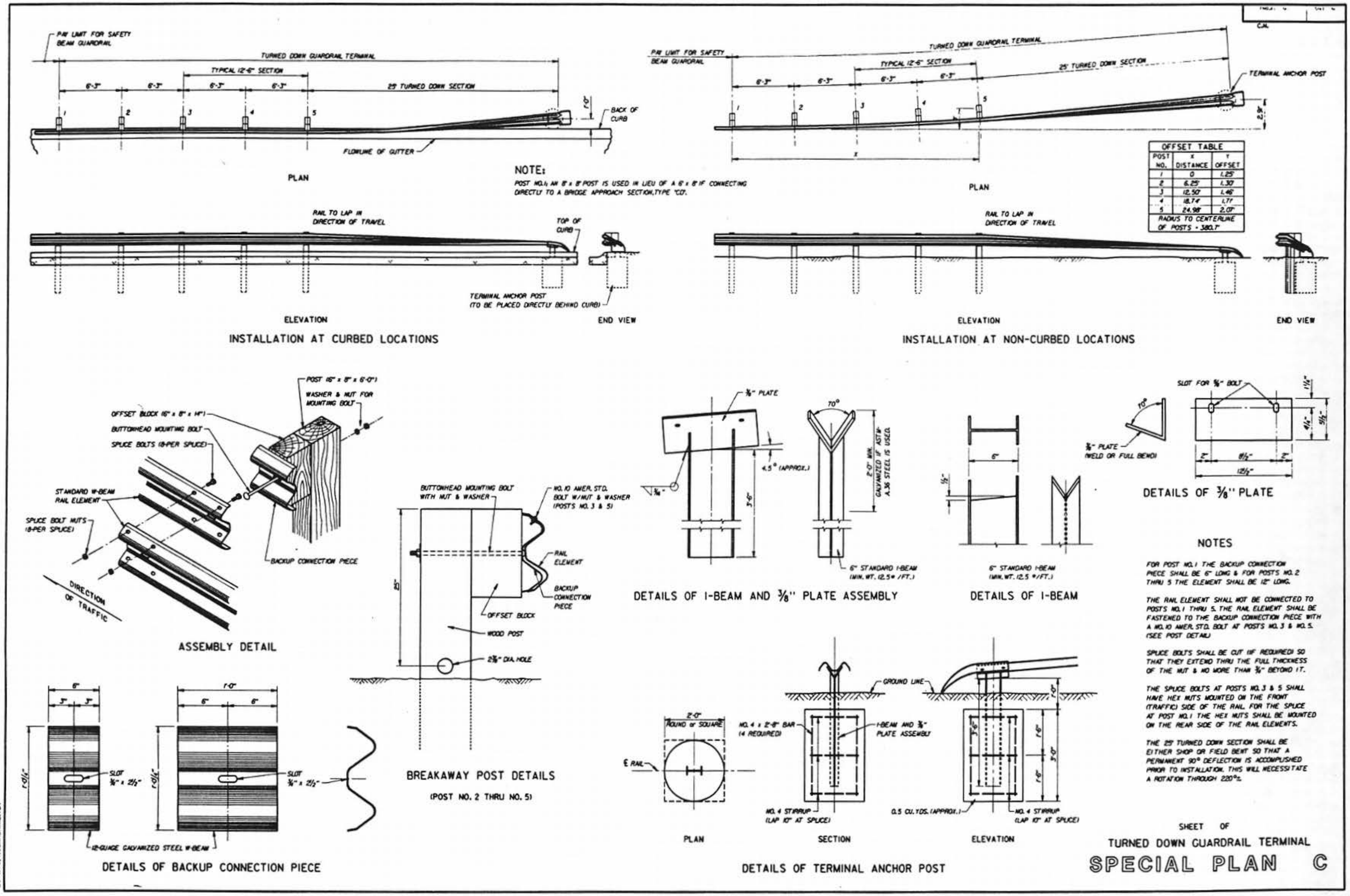


FIGURE 10. Nebraska Turned-Down Approach Terminal Section Design Details.
NOTE: From Ref. 8, pg 11

3 CONCEPT ANALYSIS AND DESIGN

3.1 Finite Element Analysis

The focus of this section is to describe the finite element analysis (FEA) used for simulation of the vehicle-guardrail impact and its redesign.

3.1.1 Baseline Simulation

A critical step in the analysis is to develop a baseline model of the existing system to be modified. Figure 11 shows the model of a small vehicle impacting a turned-down guardrail head-on at 26.8 mm/ms, or 96.5 kph (60 mph). The Nebraska turned-down guardrail terminal is composed of a steel W-beam attached to thirteen wooden posts. Figure 12 depicts the terminal section of the guardrail (from the terminal anchor to Post No. 1). This section is referred to as the turned-down approach terminal section and is 7.62-m (25-ft) long. Details of the guardrail can be found in Figure 10.

3.1.1.1 The Model

The initial mini-size vehicle model was obtained from Anthony Lee at Lawrence Livermore National Laboratories (LLNL). Because a vehicle exhibits little damage when riding up a guardrail, the majority of the vehicle was merged into a single rigid body. The exceptions were a few parts underneath the carriage (lower radiator tie-bar, oil pan, cradle, rear midrail and rear channel), the suspension system (modeled using beam elements) and the tires. Total mass of the vehicle model was approximately 840-kg (1850-lbs). Gravity was applied to the model.

The guardrail was modeled from the upstream end of the turned-down section up until Post No. 6. This was done because after Post No. 6 the W-beam rail is rigidly attached to the posts and are not part of the release mechanism. Thus, the remainder of the guardrail has little or no influence on the baseline simulation. Figure 13 shows a typical post model. W-beam back-up plates are attached to the post as shown in Figure 13. The W-beam rail is then attached to the back-up plates with small bolts at Post Nos. 1, 3, 5 and 6. The turned-down guardrail is designed to drop when these bolts shear. The bolts were modeled as small welds with a shear strength comparable to the bolts incorporated into the physical system. The W-beam is simply held up by the backup plates at Post Nos. 2 and 4 with no hard connections. Mesh of the W-beam rail is refined at the posts due to the contact interface with the backup plates.

3.1.1.2 Simulation

Because of its' advanced sliding interfaces and shell element formulation algorithms, LS-DYNA3D (9) was used to perform the simulation. Figure 14 shows the completed simulation at 350 milliseconds. The vehicle has now hit Post No. 1 and is beginning to rollover. The timing and trajectory of the simulation was in close correlation with the physical test previously done (8). The model could now be used for redesign. This simulation required 10 CPU hours on a Cray C90 supercomputer. Initial model developed was performed on a Sun Sparc 10 Model 51. Complete simulation of the vehicle-rail impact takes approximately one week on the Sparc 10.

3.1.2 Retrofit Design I

Until recently, the only means of redesigning most highway safety hardware was through physical testing, which has been found to be too costly to correct the

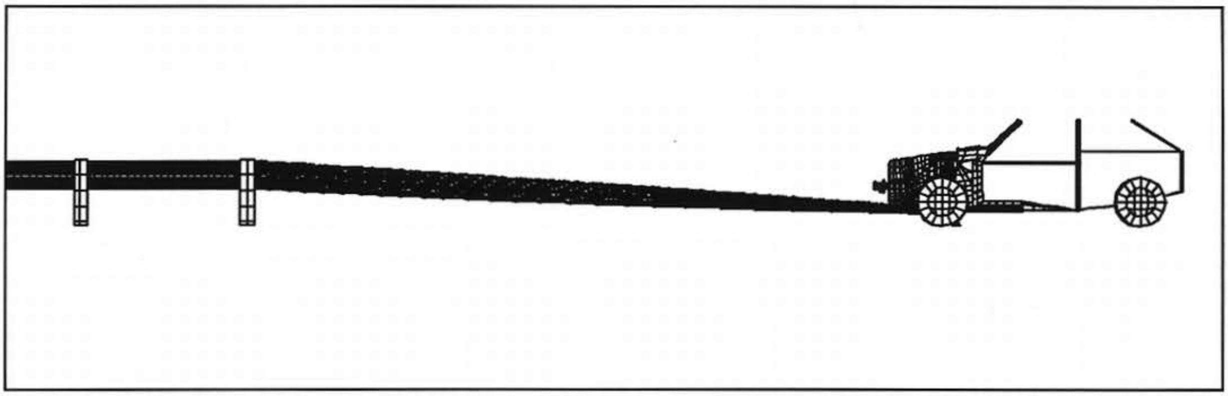


FIGURE 11. Small Vehicle into Turned-Down Guardrail.

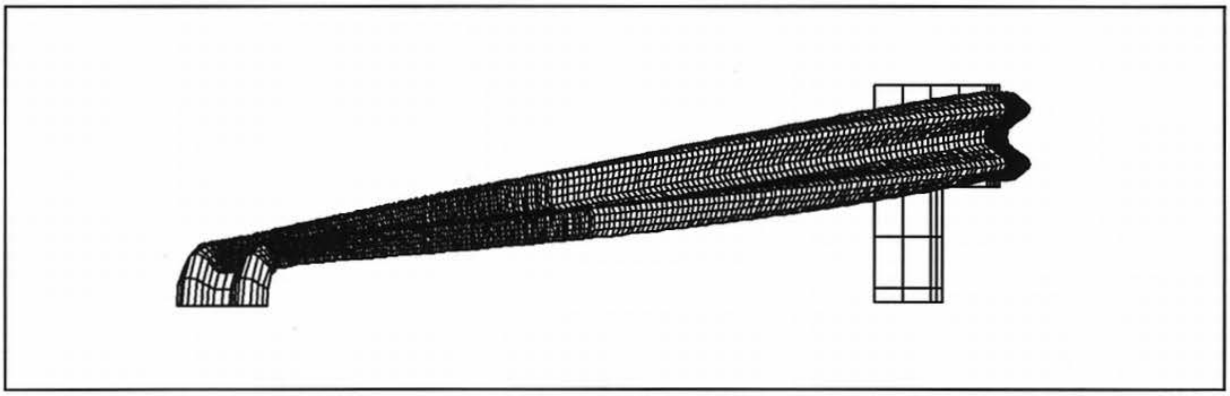


FIGURE 12. Turned-Down Approach Terminal Section

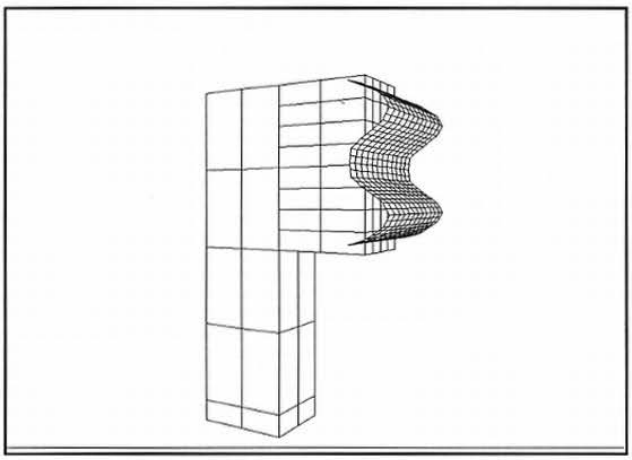


FIGURE 13. Typical Post Model

small vehicle head-on impact problem. The FEA simulation of the accident scenario now allows multiple design concepts to be tested at a fraction of the cost. Additionally, a detailed analysis is possible through the immense amount of data available from FEA. Many parameters were studied, including the connection methods between the W-beam and the posts, the anchor post design that holds the end of the turned-down portion of the W-beam at ground level, and the beam shape over the turned-down section.

One particular area of detailed scrutiny was the rail connection at post 1. Figure 15 shows the baseline model simulation of the rail just before the vehicle reaches Post No. 1. In this figure, it can be seen that the rail is still strongly being held up by the back-up plate with little deformation. It is known that larger vehicles would, by this time in the accident, have forced the rail to drop to the ground.

By examining cross sections in the rail before and after Post No. 1 it is possible to determine the forces and moments that are holding the rail up (10). The cross section analysis showed that during impact, the rail is forced both downward and towards the post. The force towards the post is caused by the twisted guardrail geometry and the angle of the rail as it approaches Post No. 1. Due to the back-up plate being the same shape as the rail, the force towards the post resists the downward force, thus preventing the release of the rail. For larger vehicles the downward force is large enough to overcome the inward force.

History of the back-up plate shows that its importance was mainly for rail systems with steel posts, to prevent cutting of the rail. These back-up plates were adapted to wooden posts on turned-down terminals as a mechanism for holding the rail up during redirectional impacts. After several concepts, the back-up plate was reduced to a steel angle bracket, as shown in Figure 16. This bracket is strong enough to hold the dead weight of the rail, yet will bend down when large forces are exerted downward, allowing the rail to drop as desired. Connection of the rail to the new brackets was changed to include shear-away bolts at Post Nos. 1, 3 and 6. There are no direct rail connections at Post Nos. 2, 4, 5, 7-9, while standard hard connections are applied at Posts Nos. 10 and 11. Effectively, the release mechanism is extended from Post No. 5 back to Post No. 10. This allows a longer moment arm to be applied to the dropping of the rail during the accident. Figures 17 and 18 indicate the possibility of success with this new design concept.

3.1.3 Retrofit Design II

Unfortunately, the new back-up plate concept does not change the direction of the rail-to-post forces. With the new design the direction of the twist in the rail still produces a major inward force in the rail toward the post, which may require very high impact forces to overcome, causing the rail to drop. Meaning, slower speed tests may not drop the rail.

To redirect the forces away from the posts an additional modification was made to retrofit design I. This concept involves twisting the turned-down section clockwise instead of the standard counter-clockwise direction, as shown in Figure 19. The reverse twist provides a redirection of the rail forces away from the post. Allowing it to drop even in low speed impacts. Additionally, using the modified back-up plates

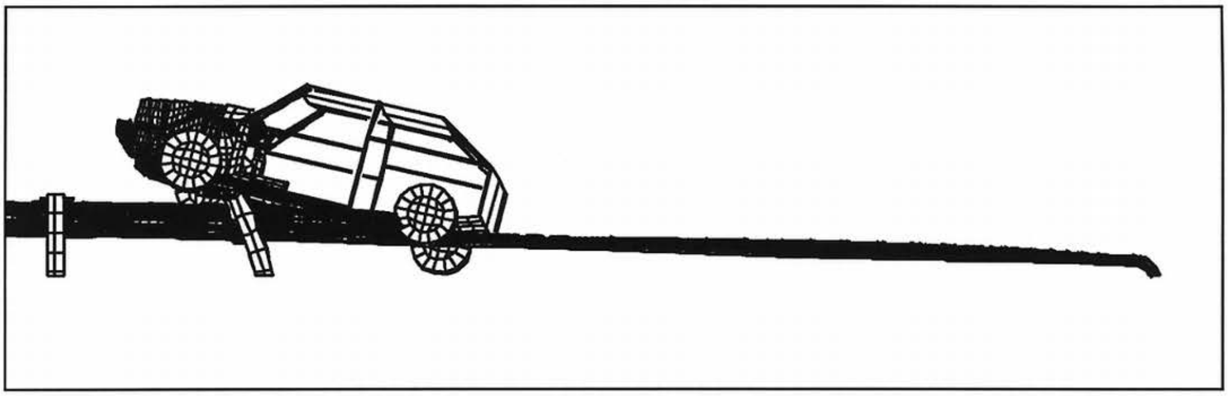


FIGURE 14. Small Vehicle into Turned-Down Guardrail
Guardrail supports do not breakaway, rollover is imminent.

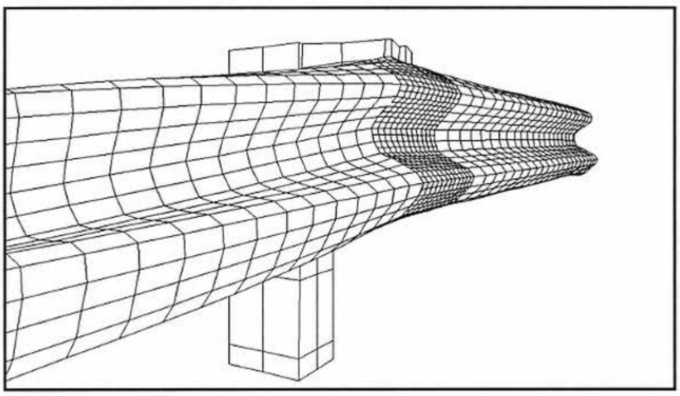


FIGURE 15. Post No. 1 and Guardrail Just Prior to Vehicle Impacting the Post

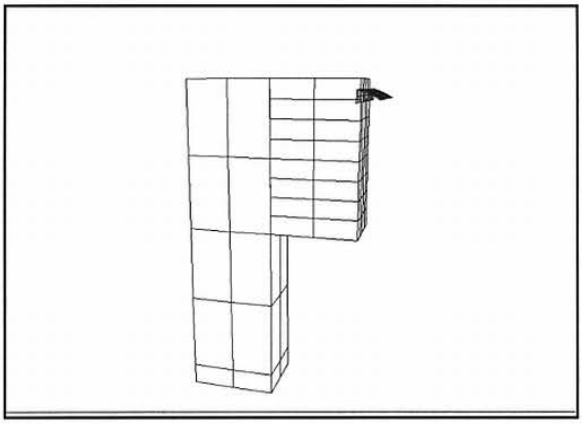


FIGURE 16. Redesigned Back-up Plate: Steel Angle Bracket

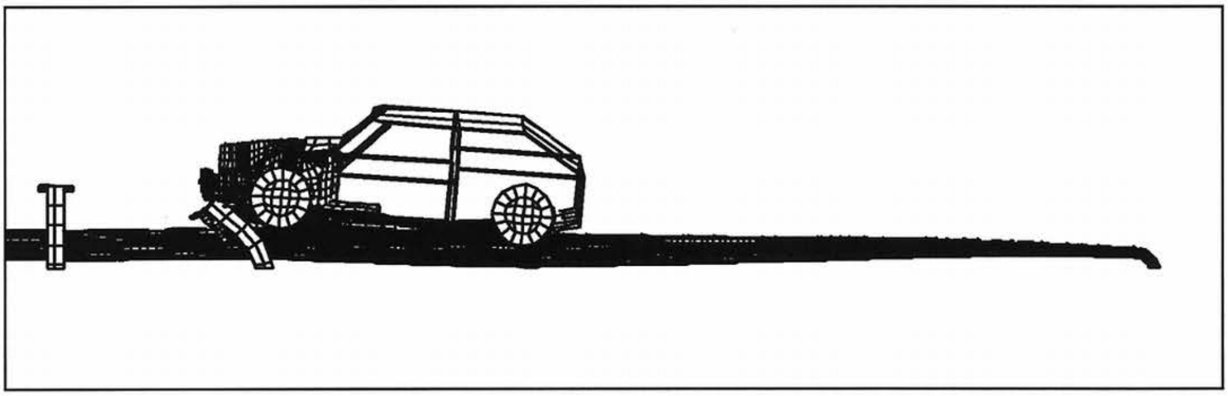


FIGURE 17. Small Vehicle into Turned-Down Guardrail - Retrofit Design Concept
Guardrail supports breakaway, rollover is prevented.

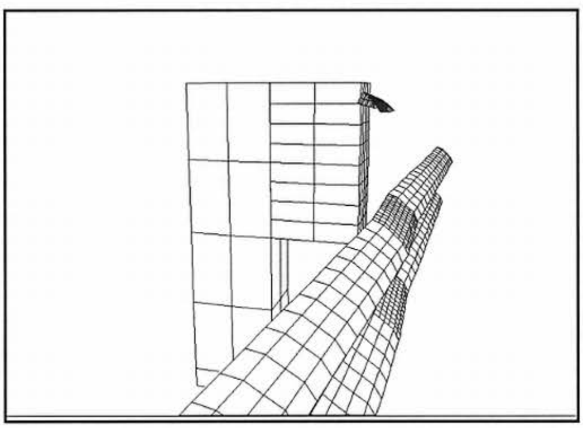


FIGURE 18. Post No. 1 and Guardrail Just Prior to Vehicle Impacting the Post - Retrofit Concept

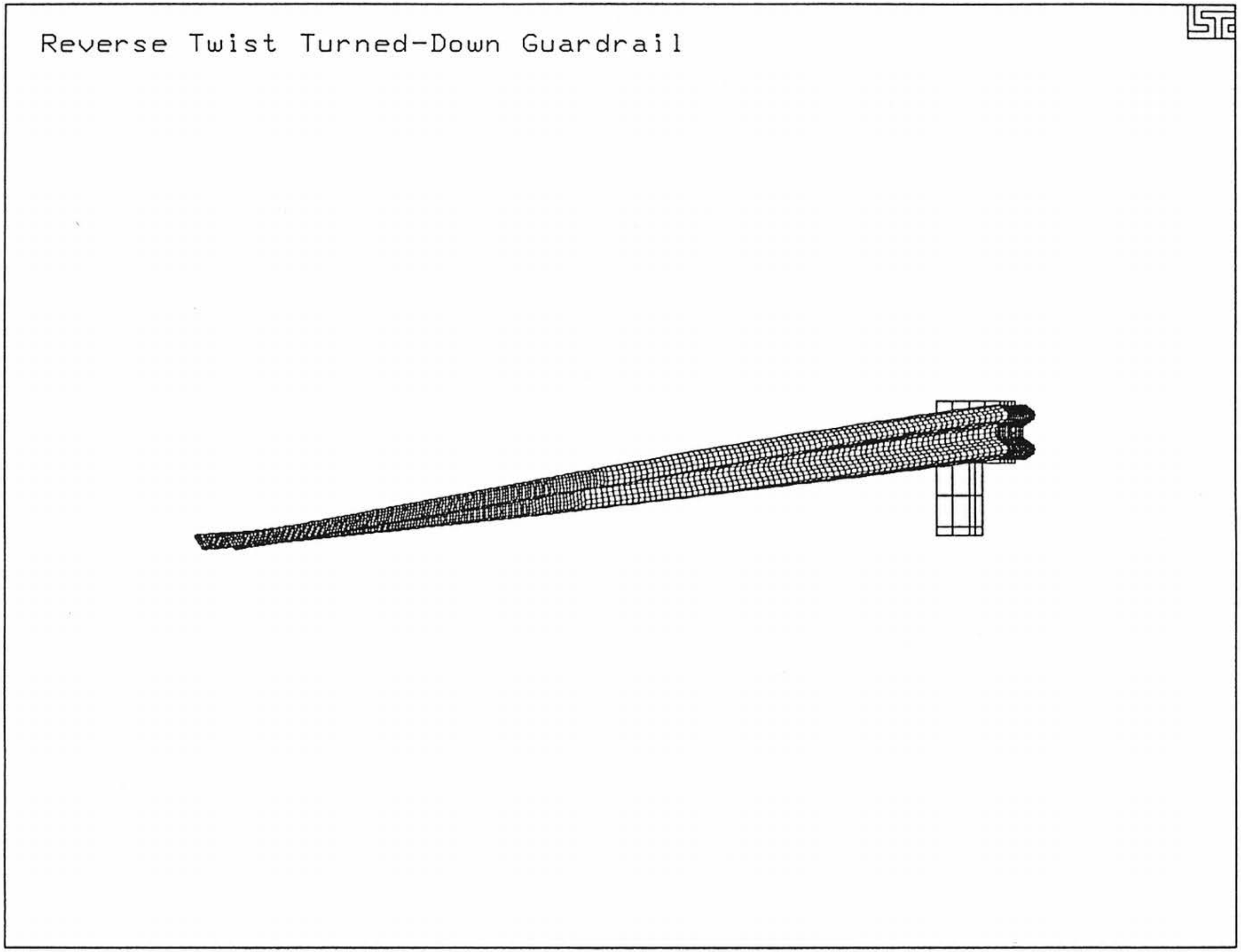


FIGURE 19. Finite Element Model of Reverse Twist Turned-Down Guardrail.

reduces the downward forces needed to drop the rail. Combining theses concepts constitutes the proposed design II.

Simulation results of retrofit design II were similar to design I. The rail behavior was as desired. Notable exceptions include the positive aspect of achieving redirection of the rail forces away from the post. These forces are actually achieved through the reverse moment acting on the rail due to the reverse twist. Additionally, however, it should be noted that the reverse twisted rail indicates that the vehicle has an increased tendency to pitch forward. This behavior is caused by gouging into the upward facing sides of the W-beam.

3.2 Part Design

The configuration of the system in the finite element model needed to be designed with real life materials so that it would accurately represent the model. The components would also be designed so that they would support the weight of the guardrail.

The redesigned backup plate in *Retrofit Design I*, model (Figure 16) had the shape of the top 5-cm (2-in.) of the W-beam with a length of 30.48-cm (12-in.). It was proposed that the backup plate be constructed of 2.657-mm (12-gauge) A36 steel. In the present Nebraska-Turned Down Guardrail, there is 2.54-cm (1-in.) between the top of the wood blockout and the top of the rail. It was proposed that the backup plate be fastened to the blockout in this 2.54-cm (1-in.) gap with an 0.635-cm (0.25-in.) diameter lag screw. This steel angle bracket used as a backup plate will be called the Reid Backup Plate. Design details are shown in Figure 20.

Analysis was performed (Appendix B) on these components to insure that the A36 Steel Plate, with a yield strength of 250 MPa (36 ksi), could support the weight of the guardrail. Design calculations were also performed to confirm that there was sufficient strength in the connection between the 0.635-cm diameter x 10.2-cm long (0.25-in. diameter x 4-in. long) lag screw and the timber block-out.

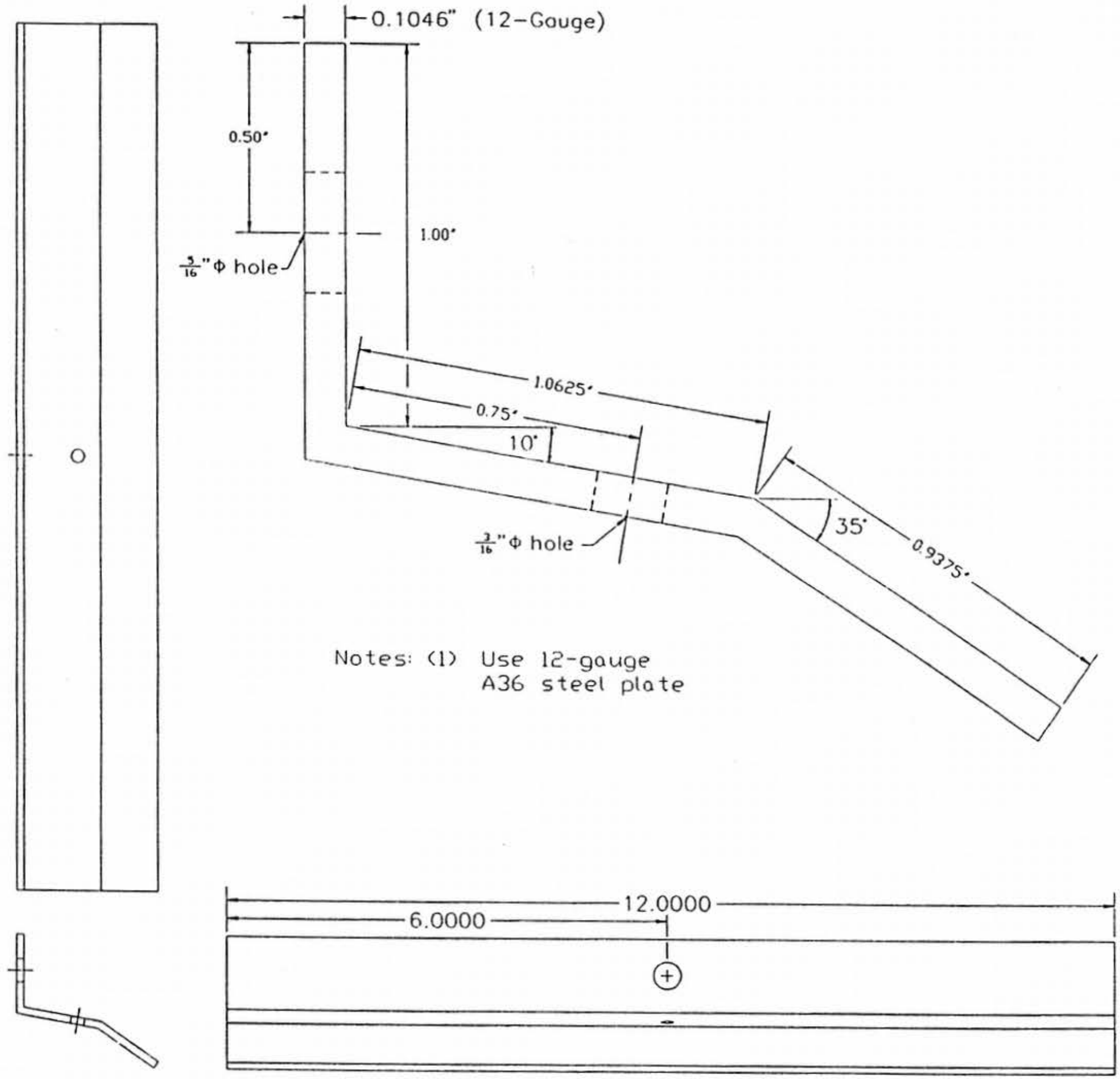


FIGURE 20. Reid Backup Plate

4 TEST CONDITIONS

4.1 Test Facility

4.1.1 Test Site

The testing facility is located at the Lincoln Air-Park on the NW end of the Lincoln Municipal Airport. The test facility is approximately 8.1 km (5 mi) NW of the University of Nebraska-Lincoln. The site is surrounded and protected by an 2.5-m (8-ft) high chain-link security fence.

4.1.2 Vehicle Tow System

A reverse cable tow with a 1:2 mechanical advantage was used to propel the test vehicle during the high-speed bogie test. The distance traveled and the speed of the tow vehicle are one-half of that of the test vehicle. The test vehicle is released from the tow cable before impact with the guardrail. The tow vehicle used in the test is equipped with a fifth-wheel speedometer apparatus. The fifth wheel, built by the Nucleus Corporation, was used in conjunction with a digital speedometer to increase the accuracy of the test vehicle impact speed during the high speed bogie test.

4.1.3 Vehicle Guidance System

A vehicle guidance system developed by Hinch (11) was used to steer the test vehicle during the high speed bogie test. A guide flag attached to the front left wheel and the guide cable was sheared off before impact. The 0.95-cm (0.375-in.) diameter guide cable was tensioned to 13.4 kN (3,000 lbs), and supported laterally and vertically every 30.5 m (100 ft) by hinged stanchions. The hinged stanchions stood upright while holding up the guide cable, but as the vehicle was towed down the line, the guide-flag struck and knocked each stanchion to the ground. The vehicle guidance system was 215 m (700 ft) long for the test.

4.2 Nebraska Turned Down Guardrail Terminal Design Details

The initial installation of the Nebraska turned-down guardrail was constructed so that it physically represented the finite element model discussed in Section 3.1.2, *Retrofit Design*.

The installation of the Nebraska turned-down guardrail consisted of four major structural components: (1) turned-down approach terminal section; (2) timber posts; (3) W-beam guardrail; and (4) back-up plates. The turned-down approach terminal section was 7.62 m (25 ft) long. The terminal section, as well as the rest of the system, was constructed with 12-gauge W-beam guardrail. The W-beam was twisted 90 degrees counter-clockwise and anchored below grade. Figure 21 shows a detailed plan and elevation view of the system, with explanation of the post numbering system.

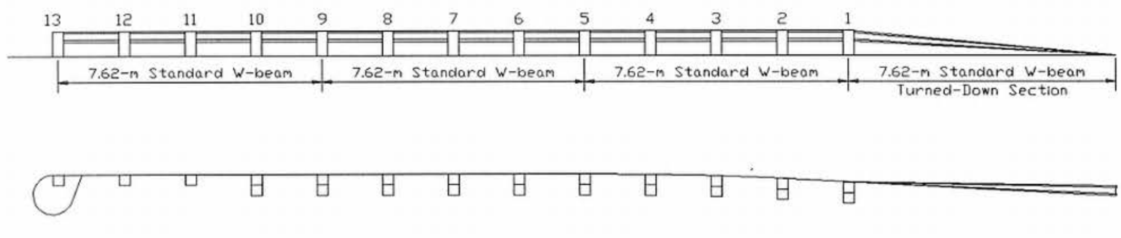


FIGURE 21. Plan and Elevation View of Installation.

The upstream end of the terminal section was anchored into the soil with a galvanized A36 steel anchor post assembly which was cast into a reinforced concrete footing. The W-beam was anchored in such a way so the top of the terminal end was below the grade of the soil.

The total installation was constructed with thirteen timber posts. The post holes were augered, and the posts were placed in the holes and tamped with a pneumatic tamper. The dimensions of the posts measured 15.2 cm x 20.3 cm x 182.9 cm (6 in. x 8 in. x 6 ft). Post Nos. 1-9 were breakaway posts. These posts were modified by drilling a 8.9-cm (3.5-in.) diameter hole at a location 71.12 cm (28 in.) below the top of the post in the 20.32-cm (8-in.) side. Post Nos. 10 and 11 were standard 15.2-cm x 20.3-cm x 182.9-cm (6-in. x 8-in. x 6-ft) wooden posts. Post Nos. 12 and 13 were BCT posts. The BCT posts measured 14.0 cm x 19.1 cm x 109.2 cm (5.5 in. x 7.5 in. x 3 ft 7 in.) with a 6.0-cm (2.325-in) diameter hole drilled 63.5 cm (25 in.) from the top. In addition, a timber spacer block measuring 15.2 cm x 20.3 cm x 35.6 cm (6 in. x 8 in. x 14 in.) was attached to Post Nos. 1 through 11. Figure 22 shows the post, blockout, and backup plate configuration.

Posts Nos. 1 through 13 were spaced at 190.5 cm (6 ft 3 in.) on centers. The soil type was a native "silty clay" topsoil. The soil was not in conformance with either the strong soil (S-1) or the weak soil (S-2) defined in NCHRP 230. The decision to deviate from the recommended testing procedures in NCHRP 230 was made to evaluate the appurtenance under typical soil conditions encountered in Nebraska.

The standard W-section backup plates were removed from the design of the guardrail. The Reid Backup Plate, as shown in Figure 9, was fastened to the wood blockouts on Post Nos. 1-9, with a 0.635-cm (0.25-in) diameter x 10.2-cm (4-in.) long lag screw. The guardrail was bolted directly to all posts downstream from and including Post No. 10. The W-beam guardrail was not connected to Post Nos. 1

FIGURE 22. Post, Blockout, and Backup Plate Configuration.

FIGURE 23. Guardrail-to-Backup Plate Connection.

through 9. The guardrail was bolted to the Reid Backup Plates with a No. 10 bolt at Post Nos. 1, 3, and 6 (Figure 23).

At Post Nos. 1, 5, and 9, two sections of W-beam are joined in a splice with a series of eight bolts 1.6-cm (5/8-in.) diameter. A problem found in construction, was that the 30.5-cm (12-in.) long Reid Backup Plate would not fit in the space between the bolts in the splice. A field retrofit was required to solve this problem. Notches were cut in the Reid Backup Plate at Post Nos. 1, 5, and 9 to account for the splice bolts.

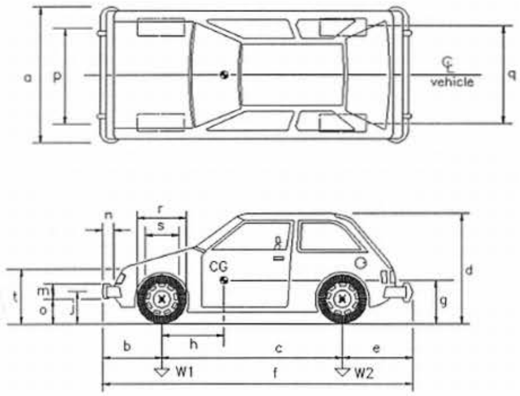
4.3 Test Vehicle

The test vehicle used for Test NETD-3 as well as for the low speed tests (NETD-LS{1-6}) was a 1979 Honda Civic. The test vehicle had a gross static weight of 885 kg (1945 lbs). The vehicle dimensions are shown in Figure 24. The front wheels of the test vehicle were aligned for camber, caster, and toe-in values of zero so that the vehicle would track properly along the guide cable.

The passenger front seat and rear seat were removed from the vehicle to reduce the gross static weight to 885 kg (1945 lbs). In addition, the gas tank was removed from the test vehicle, both to reduce weight and to reduce the risk of fuel ignition. A dummy with a weight of 74.8 kg (165 lbs) was belted to the driver's seat for all of the tests.

A remote controlled brake system was fixed to the vehicle. This was done so that the vehicle could be preserved if something went wrong with the test and it had to be aborted.

Make:	Honda	Test No.:	NETD-3
Model:	Civic	Tire Size:	155 R12 76S
Year:	1979	VIN:	SG-D5004141
Date:	09/30/1994		



Vehicle Geometry
centimeters (in.)

a — 151.1 (59.5)	b — 77.5 (30.5)
c — 219.7 (86.5)	d — 132.7 (52.25)
e — 73.7 (29.0)	f — 370.8 (146.0)
g — 53.3 (21.0)	h — 67.9 (26.7)
j — 43.2 (17.0)	m — 12.7 (5.0)
n — 15.2 (6.0)	o — 35.6 (14.0)
p — 129.5 (51.0)	q — 127.0 (50.0)
r — 53.3 (21.0)	s — 33.0 (13.0)
t — 77.5 (30.5)	

Engine Size: 4 cyl.

Transmission: Automatic

Weight: kg (lbs)	Curb	Test Inertial	Gross Static
W1	640 (1410)	560 (1230)	585 (1287)
W2	335 (740)	250 (550)	300 (658)
Wtotal	975 (2150)	810 (1780)	885 (1945)

Damage prior to test: Large Dent in Left Front Quarter.

FIGURE 24. Test Vehicle Dimensions.

4.4 Data Acquisition System

4.4.1 Accelerometers

A 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 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 filter. Computer software, "DynaMax 1 (DM-1)" and "DADiSP" were used to digitize, filter, analyze, and plot the accelerometer data. The data was filtered using a 180 Hz low pass filter and processed with a 10 ms moving average.

4.4.2 High Speed Photography

Three high-speed 16-mm cameras, with operating speeds of approximately 500 frames/sec, were used to film the crash test. A Photec IV, with an 80-mm lens, was placed approximately 45 m (150 ft) downstream of the impact point. A Locam 51, with a 25-mm, lens was placed approximately 45 m (150 ft) perpendicular to the system on the roadside. A DC powered Locam, with a 12.5-mm lens, was placed 40 m (130 ft) from the system on the fieldside. The film was analyzed using the Vanguard Motion Analyzer.

5 PERFORMANCE EVALUATION CRITERIA

The performance evaluation criteria used to evaluate the crash test was taken from NCHRP Report No. 230 (1). The test conditions for the required test matrix are shown in Table 1. The evaluation criteria are shown in Table 2. The safety performance of the Nebraska Turned-Down Approach Terminal Section was evaluated according to three major factors: (1) structural adequacy; (2) occupant risk; and (3) vehicle trajectory after collision. These three evaluation criteria are defined and explained in NCHRP 230. In addition, the turned-down approach terminal section with attached W-beam should readily activate in a predictable manner by dropping toward the ground during a head-on impact.

The vehicle damage was assessed by the traffic accident scale (TAD) (12) and the vehicle damage index (VDI) (13)

TABLE 1. Test Matrix for Terminals (1)

NCHRP 230 Designation No.	Test Vehicle kg (lb)	Impact Conditions		Impact Location	Evaluation Criteria
		Speed kph (mph)	Angle (deg)		
41	2000 (4500)	100 (60)	0	Center nose of device	C,D,E,F,H,J
44	820 (1800)	100 (60)	15	Midway between nose and L.O.N.	C,D,E,F,H,I,J
45	820 (1800)	100 (60)	0	Offset 36 cm (15 in) from center nose of device	C,D,E,F,H,J

L.O.N. - Length of Need

TABLE 2. NCHRP Report 230 Safety Evaluation Guidelines.

Evaluation Factors	Evaluation Criteria
Structural Adequacy	C. Acceptable test article performance may be by redirection, controlled penetration, or controlled stopping of the vehicle.
	D. Detached elements, fragments or other debris from the test article should not penetrate or show potential for penetrating the passenger compartment or present an undue hazard to other traffic.
Occupant Risk	E. The vehicle should remain upright during and after collision although moderate roll, pitching and yawing are acceptable. Integrity of the passenger compartment must be maintained with essentially no deformation or intrusion.
	F. Impact velocity of hypothetical front seat passenger against vehicle interior, calculated from vehicle accelerations and 61 cm (24 in.) forward and 30 cm (12 in.) lateral displacements shall be less than: Occupant Impact Velocity Longitudinal: 9 m/s (30 fps) — Lateral: 6 m/s (20 fps) and vehicle highest 10 ms average accelerations subsequent to instant of hypothetical passenger impact should be less than: Occupant Ridedown Accelerations - g's Longitudinal 15 — Lateral 15
Vehicle Trajectory	H. After Collision, vehicle trajectory and final stopping position shall intrude a minimum distance, if at all, into adjacent traffic lanes.
	I. In test where the vehicle is judged to be redirected into or stopped while in adjacent traffic lanes, vehicle speed change during test article collision should be less than 24 kph (15 mph) and the exit angle from the test article should be less than 60 percent of the test impact angle, both measured at the time of vehicle loss of contact with test device.
	J. Vehicle trajectory behind the test article is acceptable.

6 TEST RESULTS

6.1 Low Speed Tests NETD-LS{1-6}

Low-speed bogie tests were performed to evaluate design modifications in a controlled atmosphere. Due to the likelihood of the turned-down section rolling the car over at high speeds, the low speed tests enabled several tests to be run in a short amount of time. In the low-speed tests, the effect of different design concepts could be evaluated without destroying the test vehicle. The test matrix is shown in Table 3.

6.1.1 Test NETD-LS1 (16 kph, 0 deg, offset 36 cm toward roadway)

Test NETD-LS1 was conducted with a 1979 Honda Civic under the impact conditions of 16 kph (10 mph) and 0 deg (head-on) with respect to a line parallel to the roadway and offset 36 cm (14 in.) toward the roadway. The impact location is shown in Figure 25.

The turned-down terminal section was constructed so that it physically represented *Retrofit Design I*, described in Section 3.1.2. The turned-down section for this test was rotated 90 deg counter-clockwise (CCW) and anchored below grade. A No. 10 shear bolt was used to fasten the W-beam rail to the Reid Backup Plate at Post Nos. 1, 3, and 6.

Upon impact with the rail, the vehicle rode up the rail, struck the first post and rolled about 75 degrees before landing on all four wheels. The vehicle came to rest beside the rail. The No. 10 bolt on Post No. 1 sheared, but the shear bolts on Post Nos. 3 and 6 did not shear, causing the rail to remain attached to the post. The Reid Backup Plate on Post No. 1 was destroyed, so it was replaced for the next test.

TABLE 3. TEST MATRIX

TEST NO.	Modified Backup Plate Location	Shear Bolt Size and Location	Impact Conditions	Beam Orientation and Anchorage	Test Results
NETD-LS1	Post Nos. 1-9	No. 10 Bolt at Post Nos. 1, 3, 6	16 kph, 0 deg, offset 36-cm toward the roadway	Beam rotated 90 deg CCW and anchored below grade	Rail did not disengage from the backup plates.
NETD-LS2	Post Nos. 1-9	No. 8 Bolt at Post Nos. 1, 6	16 kph, 0 deg, offset 36-cm toward the roadway	Beam rotated 90 deg CCW and anchored below grade	Rail disengaged from the plates as the vehicle came to rest on top of the rail.
NETD-LS3	Post Nos. 1-9	No. 8 Bolt at Post Nos. 1, 6	16 kph, 0 deg, center-line of the vehicle	Beam rotated 90 deg CW and anchored below grade	Rail disengaged as the front of the vehicle traversed the midpoint of the turned-down section.
NETD-LS4	Post Nos. 1-9	No. 8 Bolt at Post Nos. 1, 6	16 kph, 0 deg, offset 36-cm toward the roadway	Beam rotated 90 deg CCW and anchored above grade	Rail disengaged just before the vehicle struck Post No. 1.
NETD-LS5	Post Nos. 1-9	No. 8 Bolt at Post Nos. 1, 6	16 kph, 0 deg, center-line of the vehicle	Beam rotated 90 deg CCW and anchored above grade	Rail was not disengaged and the vehicle came to a rest on top of the beam.
NETD-LS6	Post Nos. 1-9	No. 8 Bolt at Post Nos. 1, 6	16 kph, 0 deg, offset 36-cm toward the roadway	Beam rotated 90 deg CW and anchored below grade	Rail disengaged as the front of the vehicle traversed the midpoint of the turned-down section.
NETD-3	Post Nos. 1-9	No. 8 Bolt at Post Nos. 1, 6	96 kph, 0 deg, offset 36-cm toward the roadway	Beam rotated 90 deg CW and anchored below grade	Rail disengaged as the front of the vehicle traversed the midpoint of the turned-down section.

FIGURE 25. Impact Location

6.1.2 <u>Test NETD-LS2 (16 kph, 0 deg, offset 36 cm toward the roadway)</u>

Test NETD-LS2 was conducted with a 1979 Honda Civic under the impact conditions of 16 kph (10 mph) and 0 deg (head-on) with respect to a line parallel to the roadway and offset 36 cm (14 in.) toward the roadway.

The turned-down section for this test was rotated 90 deg counter-clockwise (CCW) and anchored below grade. The shear bolt connection was changed for this test. The No. 10 bolt at Post Nos. 1, 3, and 6 were replaced with a No. 8 shear bolt at Post Nos. 1 and 6.

Upon impact with the rail, the test vehicle rode up the rail and rolled a few degrees off of the rail. The vehicle dropped on the rail, causing the rail to drop. The No. 8 shear bolts did not fail until the vehicle came to a stop. At this point, the No. 8 bolts on Post Nos. 1 and 6 failed, allowing the rail to drop.

6.1.3 <u>Test NETD-LS3 (16 kph, 0 deg, center-line)</u>

Test NETD-LS3 was conducted with a 1979 Honda Civic under the impact conditions of 16 kph (10 mph) and 0 deg (head-on) with respect to a line parallel to the roadway along the centerline of the vehicle.

The turned-down terminal section was constructed so that it physically represented *Retrofit Design II*, described in Section 3.1.3. The orientation of the turned-down section for this test was rotated in the opposite direction of the previous tests so that it contained a 90 deg clockwise (CW) twist, as shown in Figure 26. The end of the beam was then anchored below grade. A No. 8 shear bolt fastened the W-beam rail to the Reid Backup Plate at Post Nos. 1 and 6.

The rail disengaged upon impact with the vehicle. The car continued to travel along the dropped rail and sheared off Post No. 1 before the brakes could be applied to stop the vehicle. The No. 8 bolt on Post No. 1 failed, and the lag screw that held the Reid Backup Plate to the blockout at Post No. 6 sheared.

The Backup Plate at Post No. 1 was replaced as well as Post No. 1 and the block out at Post No. 6. After the first three low-speed tests, there was very little damage to the test vehicle, with the exception of small scratches and dents to the undercarriage of the car.

6.1.4 Test NETD-LS4 (16 kph, 0 deg, offset 36 cm toward roadway)

Test NETD-LS4 was conducted with a 1979 Honda Civic under the impact conditions of 16 kph (10 mph) and 0 deg (head-on) with respect to a line parallel to the roadway and offset 36 cm (14 in.) toward the roadway.

The turned-down section for this test was rotated in the original direction of 90 deg counter-clockwise (CCW). The configuration of the anchor was changed for this test so the end of the W-beam was anchored 23 cm (9 in.) above grade. A Michigan end shoe was added to the end of the beam. A No. 8 shear bolt was used to fasten the W-beam rail to the Reid Backup Plate at Post Nos. 1 and 6. The system configuration is shown in Figure 27.

The test vehicle straddled the rail and rode up it. The rail fell down just before the vehicle impacted Post No. 1. The No. 8 bolts on Post Nos. 1 and 6 sheared, allowing the rail to drop. The vehicle did not appear to have any rolling action.

6.1.5 Test NETD-LS5 (16 kph, 0 deg, center-line)

Test NETD-LS5 was conducted with a 1979 Honda Civic under the impact conditions of 16 kph (10 mph) and 0 deg (head-on) with respect to a line parallel to the roadway along the centerline of the vehicle.

FIGURE 26. Turned-Down Terminal Section with 90 deg CW Twist.

FIGURE 27. Turned-Down Terminal Anchored Above Grade with Michigan End Shoe

The turned-down section for this test was rotated 90 deg counter-clockwise (CCW) and anchored 23 cm (9 in.) above grade. A Michigan end shoe was added to the end of the beam. A No. 8 shear bolt fastened the W-beam rail to the Reid Backup Plate at Post Nos. 1 and 6.

The test vehicle rode up the rail and came to rest on the top of the beam. The rail remained intact and never disengaged from the system.

6.1.6 Test NETD-LS6 (16 kph, 0 deg, offset 36 cm toward roadway)

Test NETD-LS6 was conducted with a 1979 Honda Civic under the impact conditions of 16 kph (10 mph) and 0 deg (head-on) with respect to a line parallel to the roadway and offset 36 cm (14 in.) toward the roadway.

The system configuration was identical to that used in test NETD-LS3. The turned-down section W-beam for this test was rotated in the opposite direction of the original design, so that it contained a 90 deg CW twist. The position of the anchor was changed back to its original format, where the end of the beam was anchored below grade. A No. 8 shear bolt fastened the W-beam rail to the Reid Backup Plate at Post Nos. 1 and 6.

The rail disengaged upon impact with the front of the vehicle. The car continued to travel along the rail and impacted the block out at Post No. 1 before the brakes could be applied to stop the vehicle. The No. 8 bolt on Post Nos. 1 and 6 failed.

6.2 Test NETD-3 (96 kph, 0 deg, offset 36 cm toward roadway)

Test NETD-3 was conducted with a 1979 Honda Civic under the impact conditions of 96 kph (59.5 mph) and 0 deg (head-on) with respect to a line parallel to the roadway and offset 36 cm (14 in.) toward the roadway, as shown in (Figure 28).

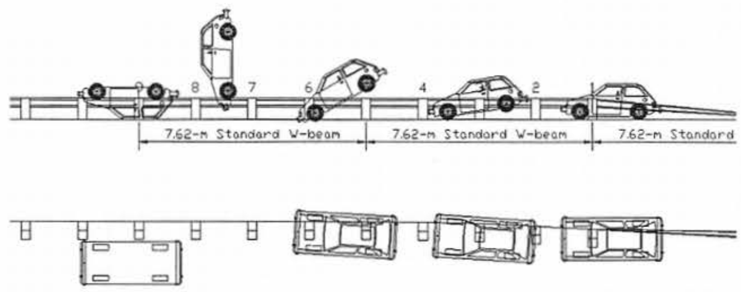
FIGURE 28. System Configuration and Impact Location for NETD-3.

The system was set-up so that it has the same configuration as test NETD-LS6. The turned-down section for this test was rotated in such a manner so that it contained a 90 deg clockwise (CW) twist. The end of the beam was anchored below grade. A No. 8 shear bolt fastened the W-beam rail to the Reid Backup Plate at Post Nos. 1 and 6. A summary of the test results and sequential diagram is shown in Figure 29.

The test vehicle impacted the rail 1.5 m (5 ft) downstream from the anchor. The shear bolt at Post No. 1 failed approximately 0.088 seconds after the initial impact with the turned-down approach terminal section. The rail only partially dropped at this point since the shear bolt at Post No. 6 was still intact. The vehicle continued travelling forward and impacted Post No. 1 approximately 0.208 seconds after impact. At approximately the same time, the shear bolt at Post No. 6 failed, causing the rail to completely drop to the ground. The vehicle fractured Post No. 2 approximately 0.282 seconds after impact.

When the test vehicle impacted Post No. 3, the post was pulled out of the ground instead of fracturing. After Post No. 3 pulled out of the ground, it slid along the surface of the ground. The test vehicle began to pitch forward prior to impacting Post No. 4. The vehicle continued to pitch over its front end as it sheared off Post Nos. 4, 5, and 6.

The car rotated 180 deg about its front axle and came to rest on its roof downstream of Post No. 7. Post No. 7 was split and bent over by the vehicle as it landed upside down.



Test Number	NETD-3
Date	09/30/1994
Appurtenance	Nebraska Turned-Down Approach Terminal Section
Total Length	30.5 m (100 ft)
Steel W-beam Guardrail	
Mounting Height	68.58 cm (27 in)
Length-of-Need	22.86 m (75 ft)
Material Size	12 Gauge
Terminal Section	7.62 m (25 ft)
Material Size	12 Gauge
Timber Posts	
Post Nos. 1-11	15.2 cm x 20.3 cm x 182.9 cm (6 in x 8 in x 6 ft)
Post Nos. 12-13	14 cm x 19.1 cm x 109.2 cm (5.5 in x 7.5 in x 3.6 ft)
Timber Spacer Blocks	
Post Nos. 1-11	15.2 cm x 20.3 cm x 35.6 cm (6 in x 8 in x 14 in)
Soil Type	Silty-Clay (SL)(Dry)
Vehicle	
Model	1979 Honda Civic
Weight	
Curb	975 kg (2150 lbs)
Test Inertial	810 kg (1780 lbs)
Gross Static	885 kg (1945 lbs)

Vehicle Speed	
Impact	96 kph (59.5 mph)
Vehicle Angle	
Impact	0 deg
Vehicle Snagging	Snag on Post No. 3
Vehicle Stability	Vehicle Rollover
Occupant Ridedown Deceleration	
Longitudinal	13.47 G's <15
Lateral	N/A
Occupant Impact Velocity	
Longitudinal	6.79 m/s < 9.0
Vehicle Damage	
TAD	12-FD-5, 12-LBQ-6
VDI	12-FDLW2, 12-LBGO4
Vehicle Stopping Distance	
Longitudinal	21 m (69 ft)
Lateral	0.7 m (2.3 ft)
Guardrail Damage	Minor
Post Damage	Post Nos. 1-7 were destroyed.
Backup Plate Damage	Plates on Post Nos. 1-9 were destroyed.
Shear Bolt Damage	Bolts on Post Nos. 1 and 6 sheared.

FIGURE 29. Test Results and Test Sequence, Test NETD-3.

Exterior vehicle damage is shown in Figure 30. The majority of the damage occurred in two body panel locations. The front bumper and front of undercarriage, as well as the hood received significant damage from impacting the posts. The right rear, top corner of the vehicle sustained a large degree of damage from landing on Post No. 9 after rollover. The hatch did not come open during the test as is shown in Figure 30.

Damage to the guardrail is shown in Figure 31. The guardrail is laying on the ground and the posts are sheared off as described above. Figures 32 and 33 show the post damage for Post No. 3. Figure 32 shows the top portion of Post No. 1. The post has been gouged and scuffed by the test vehicle. Post No. 1 came to rest just past the hole for Post No. 3. In the upper right corner of the photograph in Figure 32, the hole for Post No. 3 can be seen. The hole for Post No. 3 is elongated where the post was pulled out of the ground. Figure 33 shows Post No. 3 laying at the location of Post No. 4. The top half of Post No. 4 is shown laying under Post No. 3. Figure 34 shows a different view of the post damage.

The longitudinal occupant impact velocity was determined to be 6.79 m/s. The highest 0.010-sec average occupant ridedown deceleration in the longitudinal direction was 13.47 G's. The results of the occupant risk, determined from accelerometer data, are summarized in Figure 29. The results are shown graphically in Appendix C.

FIGURE 30. Test Vehicle Damage.

FIGURE 31. Guardrail Damage

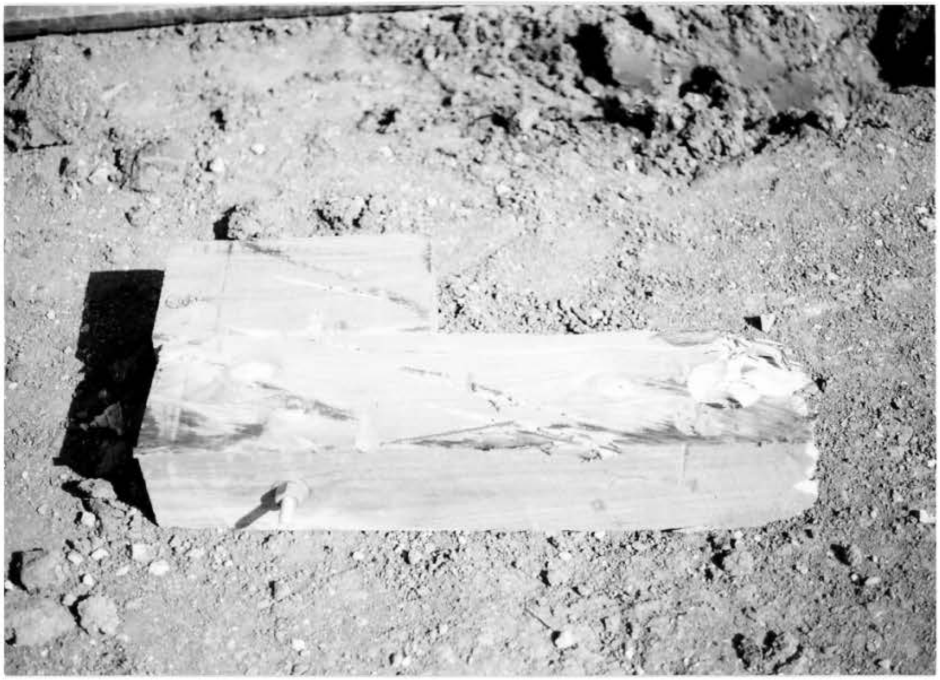


FIGURE 32. Top Portion of Post No. 1.

FIGURE 33. Post No. 3 After Impact.

FIGURE 34. Post Damage.

7 CONCLUSIONS

The Nebraska Turned-Down Approach Terminal Section performed unacceptably based on the requirements set forth by NCHRP 230, Test 45. However, the appurtenance shows potential for satisfying the criteria with additional modifications. The guardrail behaved desirably in several aspects. For example, the W-beam guardrail fell to the ground when impacted at 0 deg (head-on). Post Nos. 1 and 2 sheared off as designed, after the guardrail dropped to the ground.

The following list documents the requirements set forth by NCHRP 230 for Test Designation 45, and how the system performed in test NETD-3. Explanation of the test criteria are shown in Table 2.

[Criteria C] The test article allowed controlled penetration of the test vehicle, but did not provide controlled stopping of the vehicle. - **FAIL**

[Criteria D] No detached elements or fragments from the appurtenance penetrated the occupant compartment. - **PASS**

[Criteria E] Vehicle failed to remain upright during and after the test. - **FAIL**

[Criteria F] Occupant impact velocities did not exceed 9 m/s (30 fps). - **PASS**
The occupant ridedown accelerations did not exceed 15 G's - **PASS**

[Criteria H] The vehicle did not intrude into adjacent traffic lanes and it acceptably came to rest behind the test article. - **PASS**

The safety performance of the Nebraska Turned-Down Approach Terminal Section was determined to be unacceptable according to two of the criteria presented in Tables 1 and 2. However, no conclusions can be made about the success or failure of the retrofit based upon the results of test NETD-3. The fact that the rail dropped without imparting high lifting forces to the impacting vehicle, proves that the design has potential for meeting crash testing safety standards.

8 DISCUSSION

After tests NETD-LS1 and NETD-LS2 were conducted with Reid Backup Plates on Post Nos. 1-9, it appeared that *Retrofit Design I* was inadequate at low speeds. When the guardrail was twisted 90 deg in a clockwise direction (reverse-twist) as in *Retrofit Design II*, the performance of the system was improved greatly.

When the W-beam was twisted in a counter-clockwise manner, it contained a residual stress that produced a torque that directed the W-beam toward the posts. This force prevented the rail from falling down when impacted by an automobile. Reversing the twist in the turned-down section changed the direction of this torque so the W-beam tended to pull away from the posts. This is shown graphically in Figure 35. The degree by which this reverse-twist improved the turned-down system

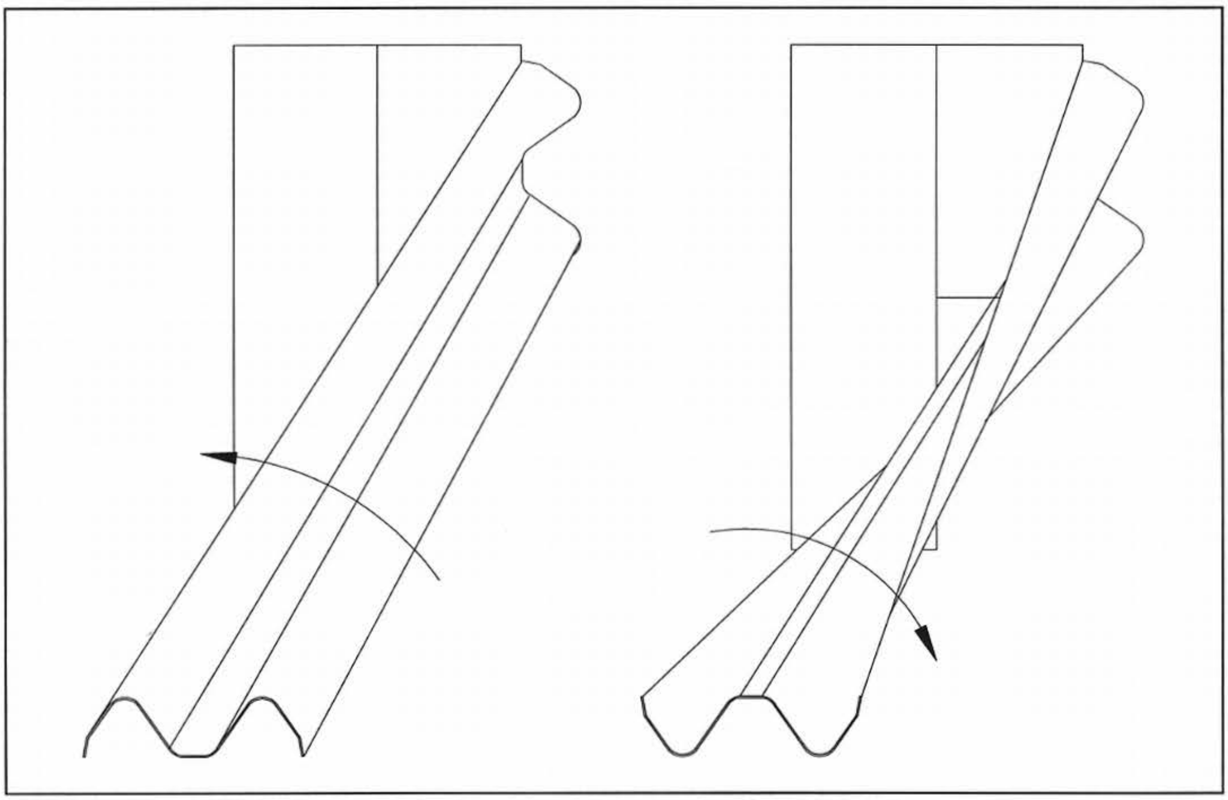


FIGURE 35. Residual Torque in Guardrail Twist

was extensive, as seen in tests NETD-LS3, NETD-LS6, and NETD-3. This design change was probably more important than the changes made by substituting the Reid backup plate for the standard W-beam backup plate.

This final design, with Reid backup plate, reverse twist, and anchor below grade, is based on the premise that once the rail falls down, the energy of the moving vehicle is to be absorbed by shearing the posts. Under these conditions, hopefully, the driver can get the car under control. To allow the posts to shear more easily, a 8.89-cm (3.5-in.) diameter hole was bored in the posts parallel to the direction of traffic, 71.12 cm (28 in.) below the top of the post. In crash test NETD-3, Post Nos. 1 and 2 sheared-off nicely, and the test vehicle continued in a forward path with no signs of rollover. However, Post No. 3 failed to shear; instead, it was pulled completely out of the ground.

Figures 32, 33, and 34 show the area around Post No. 3 after the test. Gouges on Post No. 3 indicate that it may have snagged on the bumper or underside of the test vehicle. Another reason for the post being pulled out may be that it was inadequately tamped, even though all posts were tamped with a pneumatic tamper using conventional procedures.

Figure 32 shows that the top half of Post No. 1 is scuffed, probably from being dragged by the undercarriage of the vehicle. Some time after Post No. 3 was pulled from the ground, the vehicle began to pitch forward. The forces involved with pulling Post No. 3 out of the ground were, most likely, the primary contributors to the pitching motion. However, the location of Post No. 1 after the test indicates that the right-rear tire ran over the post as the vehicle started to pitch forward. Once the car began to pitch forward, the vehicle impact with the remaining posts magnified the pitching motion until the vehicle's rear end became airborne.

An estimate of material and labor costs for retrofitting the existing Nebraska Turned-Down Terminal is detailed below. The proposed retrofit design is similar to the configuration used in vehicle crash test NETD-3. Table 4 details the material costs of retrofitting the system, while Table 5 details the estimated labor hours. A detailed analysis of the costs to retrofit a turned-down approach terminal section revealed approximately $200 in material costs and 10 man-hours of labor. Wage rates for employees of the Nebraska Department of Roads were not available. A detailed description of the retrofit process is discussed in Appendix D.

Table 4. MATERIAL COSTS

Estimates for purchasing materials were made assuming that material would be purchased in bulk quantities, so as to retrofit 25 systems.

Description of Part	Quantity Per System	Unit Price	Total Price
Galvanized Backup Plate (Reid Backup Plate) 12 gauge A36 Steel Plate 15.2-cm (6-in.) long	9 plates	$1.40	$12.60
Plated Hex Lag Screw: 0.8-cm (5/16-in.) dia. x 10-cm (4-in.) long	9 screws	$0.082	$0.75
Round Head Slotted Steel Machine Screw 8-32 x 1.9-cm (0.75-in.) (No. 8)	2 screws	$0.012	$0.03
Machine Screw Nut 8-32 (No. 8)	2 nuts	$0.013	$0.03
8.9-cm (3.5-in.) Hole Saw	1 saws	$11.38	$11.38
Arbor for Hole Saw	1 arbor	$13.15	$13.15
Bearing Plate Galvanized A36 Steel Plate 10-cm x 10-cm x 0.6-cm (4-in. x 4-in. x 0.25-in.) 2.5-cm (1-in.) dia. hole bored in center	9 plates	$1.30	$11.70
Galvanized Wire Rope 1.1-cm (7/16-in.) dia. 6x19 - RRLGIPSIWRC Import Wire Rope Nominal Strength - 8 tons (16 kips)	75 feet	$1.04 per ft.	$78.00
Drop Forged Cable Clamps 1.1-cm (7/16-in.) dia.	20 clamps	$3.18	$63.60
Miscellaneous Material costs Needed for Modification of Anchor Post			$10.00
Total Material Costs			**$201.24**

Sources:
Apollo Steel, Lincoln, NE 466-8587
Omaha Slings Inc., Omaha, NE 1-800-258-3838
Tool House Inc., Lincoln, NE 476-6673

TABLE 5. LABOR COSTS

The following labor estimates assume a two man crew. The total man-hours accounts for both workers.

Task	Total Manhours
Remove bolts from eleven posts and lay the rail down.	1 hour
Bore 8.9-cm (3.5-in.) holes in wooden posts at ground level.	4 hours
Cut down anchor; weld or bolt new anchor plate to remaining I-beam.	1.5 hours
Clamp wire rope to anchor; String wire rope through holes in first nine posts; Clamp bearing plate behind each post.	1 hour
Bolt blockouts back on to posts; Pre-drill holes for lag screw; Fasten modified backup plate to blockout;	1.5 hours
Put W-beam rail back up; Bolt W-beam to backup plates; Twist W-beam; Bolt to anchor.	1 hour
Total Labor Hours	**10 hours**

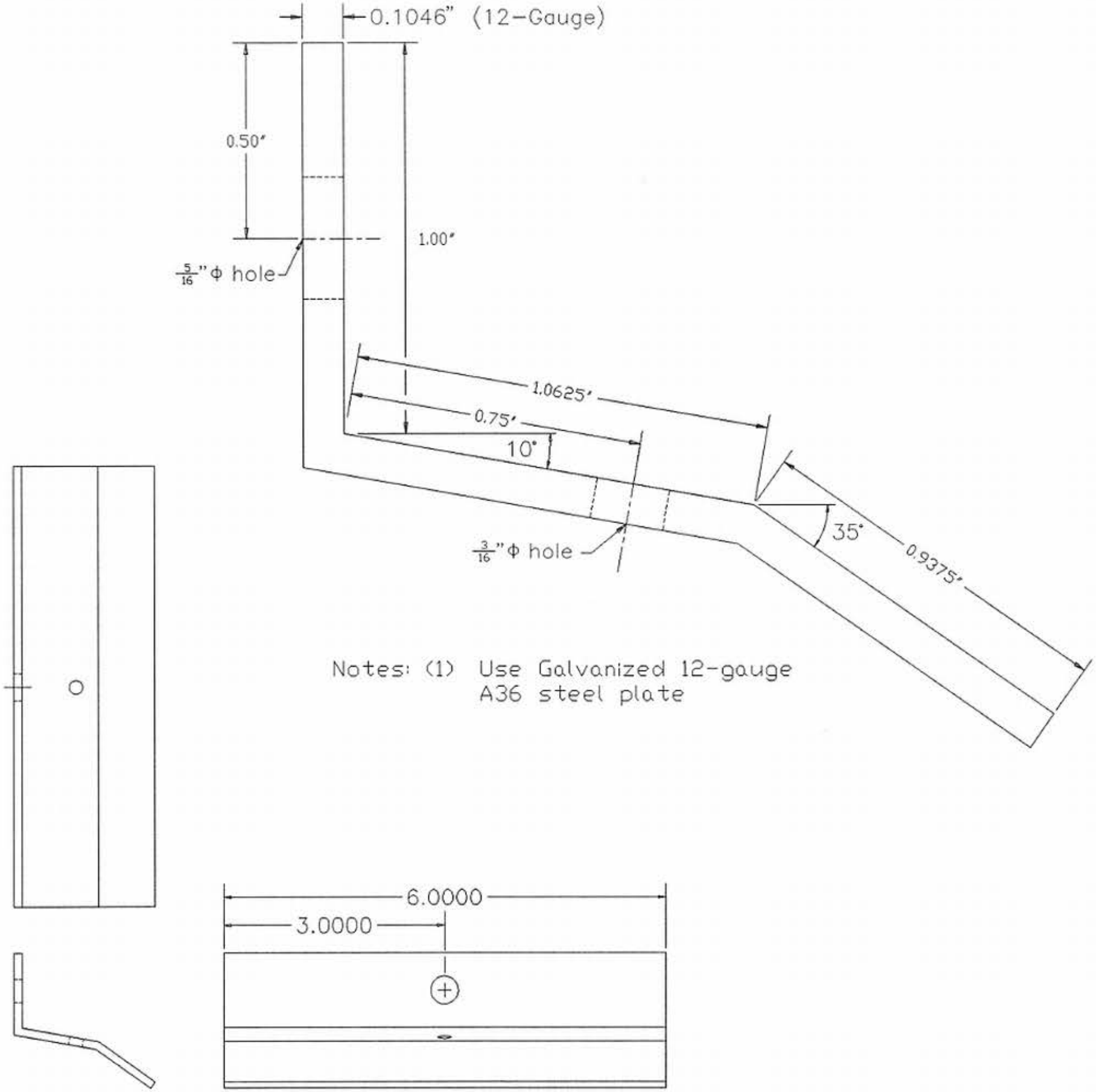


FIGURE 36. Modified Reid Backup Plate

9 RECOMMENDATIONS

Following test NETD-3, it is apparent that the Nebraska Turned-Down Approach Terminal Section has potential for being modified to satisfy the requirements set forth in NCHRP 230. Reversing the twist in the terminal section provided the greatest improvement of the system. The reverse-twist provided such an improvement to the system, that the Reid Backup Plate may not be required. It is recommended that further testing be conducted to determine if this modification could be eliminated. During the construction of the modified turned-down terminal, the backup plates and lag screw connection appeared to be very weak. Making this component more rigid would be beneficial to long term use of this design, when considering such factors as vibrations, fatigue, and temperature fluctuations. It is recommended that a 0.8-cm (5/16-in.) diameter lag screw replace the 0.635-cm (0.25-in.) diameter lag screw.

It is also recommended that the length of the Reid Backup Plate be reduced to 15.24 cm (6 in.), then the backup plate would fit between the bolts in the W-beam splices at Post Nos. 1, 5, and 9. Figure 36 shows a recommended modification for the Reid Backup Plate. This will eliminate the need to cut notches in the backup plate at these posts.

It is also recommended that test NETD-3 be repeated to further examine the problems that occurred at Post No. 3. It is unclear whether Post No. 3 failed to fracture due to inadequate tamping problems, or from other problems in the design. If another high-speed vehicle crash test shows the same problems with post fracture, then it is recommended that a mechanism be added to assist in fracturing of the posts.

A mechanism was developed by TTI in 1988 (14) which allowed the posts to fracture more readily, this mechanism is shown in Figure 37. This mechanism would consist of clamping a 1.1-cm (7/16-in.) diameter cable to the terminal post anchor of the terminal and running the cable through the holes in each of the posts. A 10-cm x 10-cm x 1.3-cm (4-in. x 4-in. x 0.5-in.) steel bearing plate was clamped to the downstream side of the first nine posts. This mechanism should

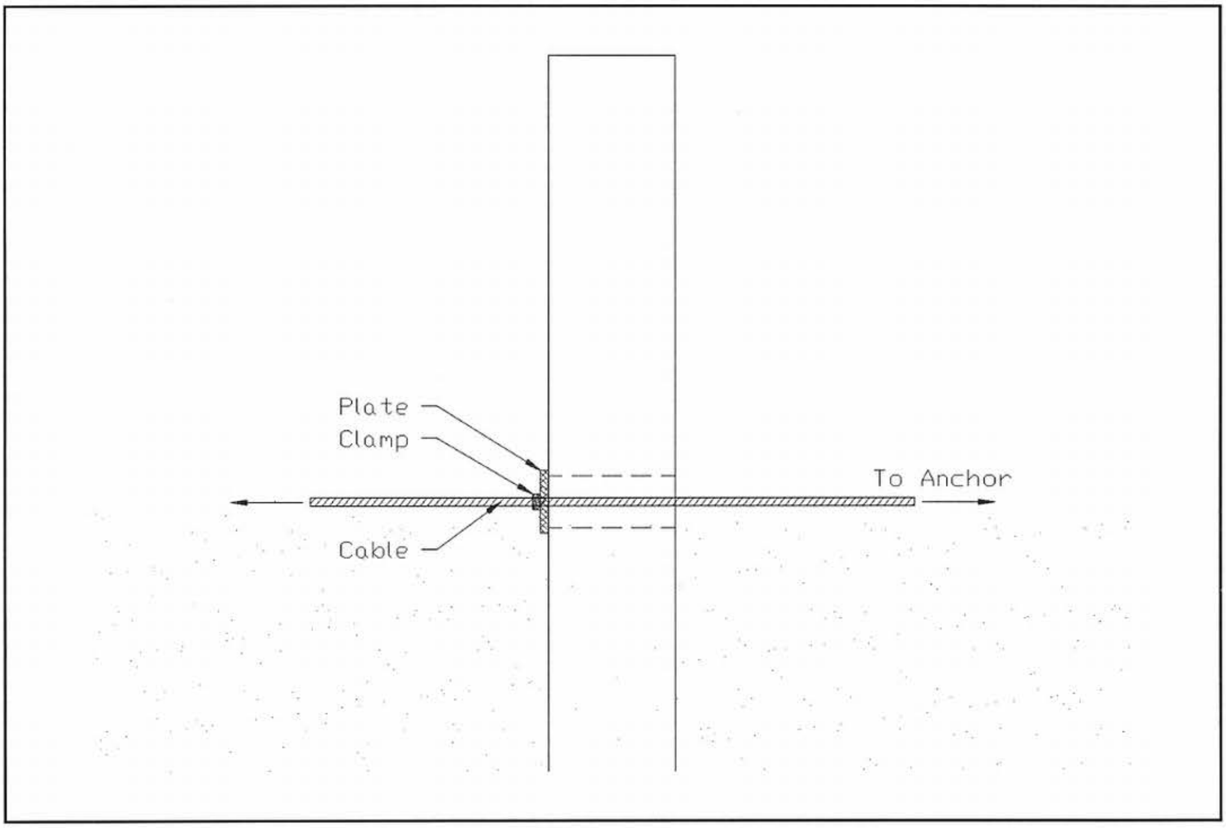


FIGURE 37. Post Fracture Mechanism

eliminate any problems resulting from inadequately tamped soil.

It is also recommended that additional full-scale vehicle crash testing be performed on this retrofit to determine if the design would meet other tests specified by NCHRP 230.

10 REFERENCES

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11 APPENDICIES

APPENDIX A.

DESIGN CONCEPTS

The following is a list of the design concepts proposed to weaken the system. To allow the rail to drop more easily. This list was conceived in a brainstorming session before any physical testing or finite element analysis were performed. A brief discussion is included with each of the ideas presented.

1. Bury the steel anchor post and Michigan end shoe -

   In test NETD-1 (8), significant damage occurred to the end shoe during impact. This indicates that, the end shoe may have contributed to rolling the automobile, by causing the initial uplift forces on the undercarriage of the vehicle.

2. Extend the release mechanism over more posts -

   In the existing Nebraska Turned-Down design, the release mechanism extends over the first five posts. Providing a greater number of release mechanisms should create a less rigid connection of the W-beam guardrail and the post backup plate, thus allowing it to drop more easily.

3. Reduce the flexural strength in the turned-down section -

   Replace the W-beam in the first 7.62-m (25-ft) of the terminal with a less rigid beam having a reduced section modulus, such as a C-rail, flat steel plate, or drilled W-beam. Another change that will reduce the section modulus, is changing the material the beam is constructed of. For example, use FRP - Fiber-Reinforced Plastic.

4. Twist the W-beam in the opposite direction -

   Twisting the guardrail in the opposite direction will create a residual torque that will tend to pull the W-beam away from the post.

5. Change the combination, location, and size of the shear bolts -

   Modify the existing design which consists of a No. 10 shear bolt at Post Nos. 1 and 3.

6. Reduce the depth of the W-beam backup plate -

   By reducing the depth of the backup plate, the guardrail will have less contact area with the backup plate. The reduction in surface area will reduce the friction force and should allow the rail to release more easily.

7. Place a spacer between the W-beam and backup plate to reduce nesting effects -

   Similar to #6, this concept will reduce contact between the W-beam and the backup plate, and therefore reduce the likelihood of snagging between the W-beam and backup plate.

8. Implement a pull-down mechanism -

   Implement a cable system that would pull down the rail, when a vehicle impacts an actuating lever mounted at the end of the terminal.

9. Reduce the terminal ramp length -

   A reduced terminal length offers a reduction of the moment arm between the downward impact force and the guardrail connection to Post No. 1.

APPENDIX B.

DESIGN CALCULATIONS

The steel angle bracket used in the finite element analysis, shown in Figure 16, had to be designed in such a manner that the piece would withstand the static loads applied during the construction of the system, namely support the dead weight of the guardrail. The following calculations were made to assist in the design of the piece.

The Reid Backup Plate was designed so that it would support the dead weight of the guardrail. Since the posts are spaced 1.905 m (6.25 ft) apart, the largest magnitude in dead weight occurs at Post No. 1, since there is 7.62 m (25 ft) between the first post and the anchor. It was assumed that the backup plate at this post will support the weight of 4.74 m (15.5 ft) of rail. If standard W-beam has a weight of 204.4 N/m (14 lbs/ft) then this first backup plate should support a weight of 970 N (220 lbs). If the weight is assumed to act at the midpoint of the 5.08 cm (2 in.) lip of the backup plate then the following calculations indicate that the backup plate can be constructed of 12-gauge A36 steel plate. The primary stress in the member is due to bending. The bending moment is generated by a force of 970 N acting at a distance 2.54 cm from the base of the lip.

h = Thickness of the Material = 0.2657 cm (0.1046 in.)

b = Width of Backup Plate = 15.24 cm (6 in) (Modified Backup Plate, Fig. 37)

M = Moment Due to the Dead Weight of the W-beam = 24.638-N·m (36.7 ft-lb)

c = Distance to the Neutral Axis = 0.13285-cm (0.0523 in.)

I = Second Moment of Area

σ = Tensile Stress in Member due to Bending

$$\sigma = \frac{Mc}{I};\ c = \frac{h}{2}$$

$$I = \frac{bh^3}{12} = \frac{(15.24)(.2657)^3}{12} = 23.822x10^{-3}cm^4$$

$$\sigma = \frac{(24.638\ N\cdot m)(0.13285\ cm)}{23.822\ x10^{-3}cm^4} = 137.0\ MPa$$

A36 Steel Plate has a yield strength of 250 MPa (36 ksi), so the plate design has a safety factor of 1.8. The shear stress in the 0.635 cm (0.25 in.) lag screw is 97.15 MPa, which is well below its yield strength in shear. The yield strength in shear is equal to 0.577 times its yield strength in tension.

The next important design calculation is to verify that the connection between the lag screw and the timber spacer block will support the load generated by the dead weight of the guardrail, 970-N (220-lbs). For Group II woods, such as Douglas Fir and Southern Pine, a 0.64-cm (0.25-in) diameter x 10.2-cm (4-in.) long lag screw will support a load of 1,068 N (240 lbs) (15). This capacity is greater than the 970 N (220 lbs) that the piece needs to support.

The final concern is the bearing stress on the wood from the lag screw. The bearing stress can be calculated in the following manner:

F = Dead Weight of the W-beam = 970 N (220 lbs)

L = Length of Lag Screw = 10.2 cm (4 in.)

d = Diameter of Lag Screw = .64 cm (0.25 in.)

$$\sigma = \frac{F}{Ld} = \frac{970\ N}{(10.2\ cm)(.64\ cm)} = 1.49\ MPa$$

The lag screw imparts a bearing stress of 1.49 MPa on the timber, Douglas Fir can support a compression load of 6.373 MPa (15) parallel to the grain. This calculation was made for the worst case, using a 0.64 cm (0.25 in.) diameter lag screw.

APPENDIX C.

ACCELEROMETER DATA ANALYSIS

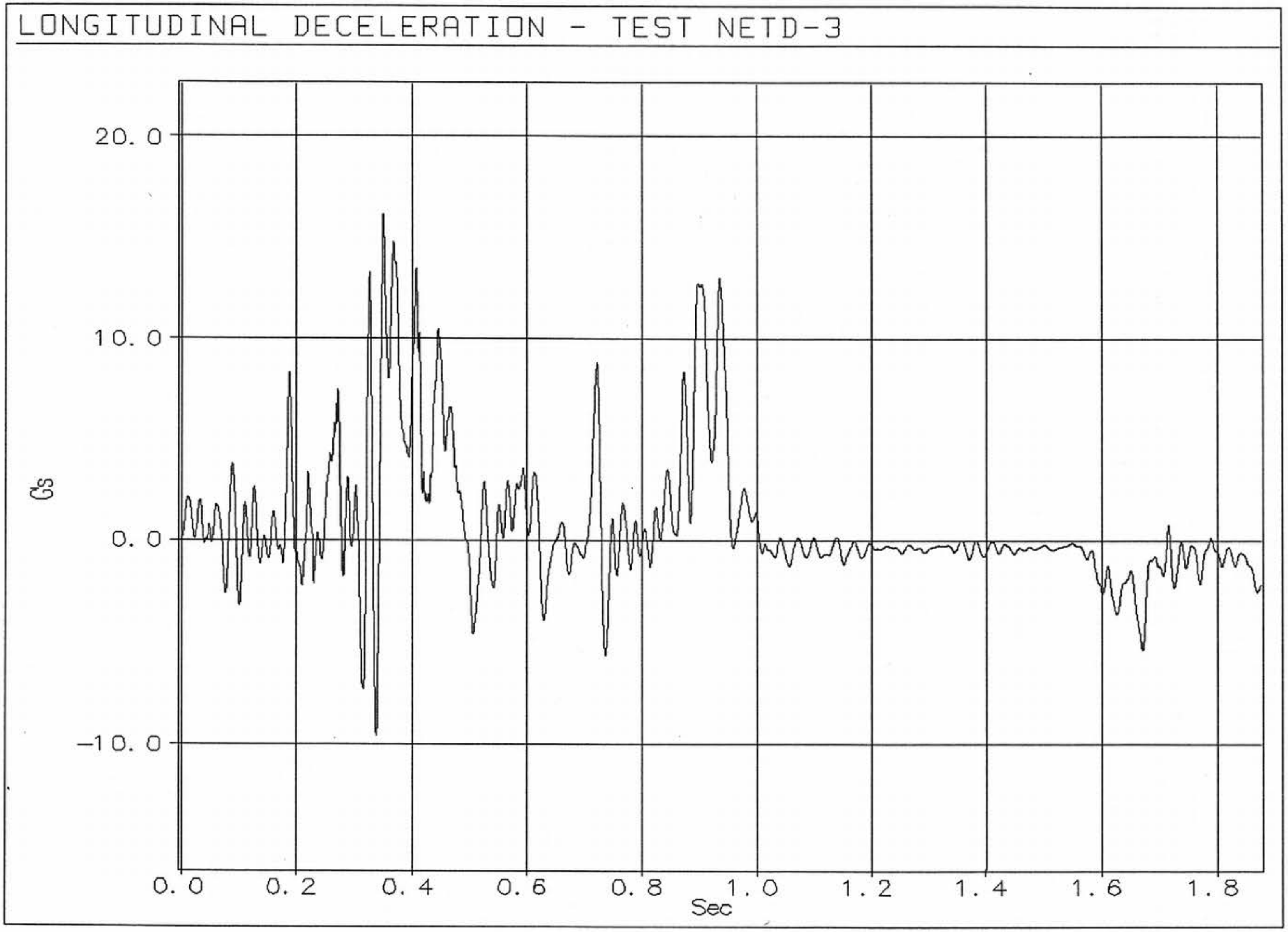

FIGURE C-1. Longitudinal Deceleration - Test NETD-3

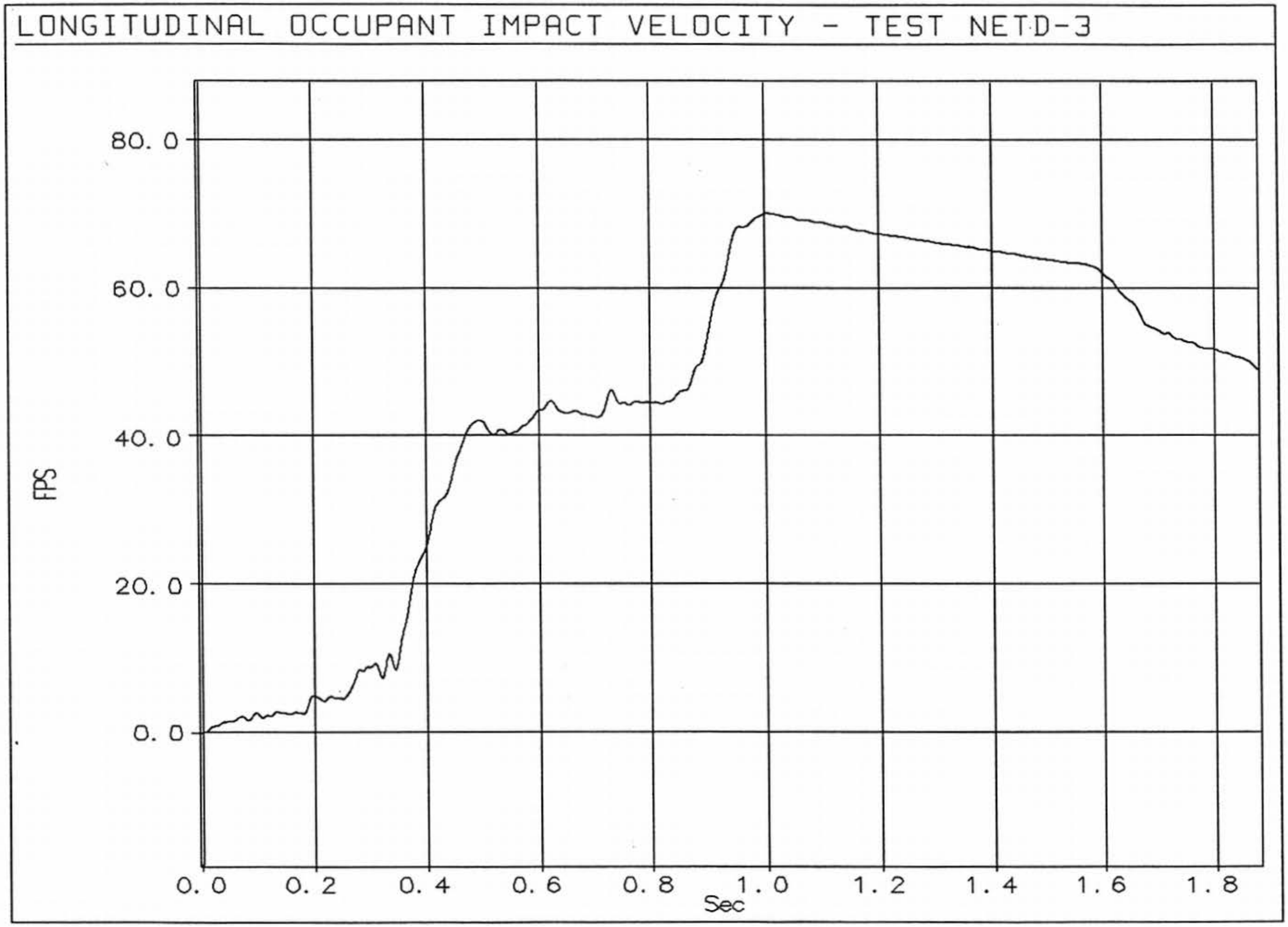

FIGURE C-2. Longitudinal Occupant Impact Velocity - Test NETD-3

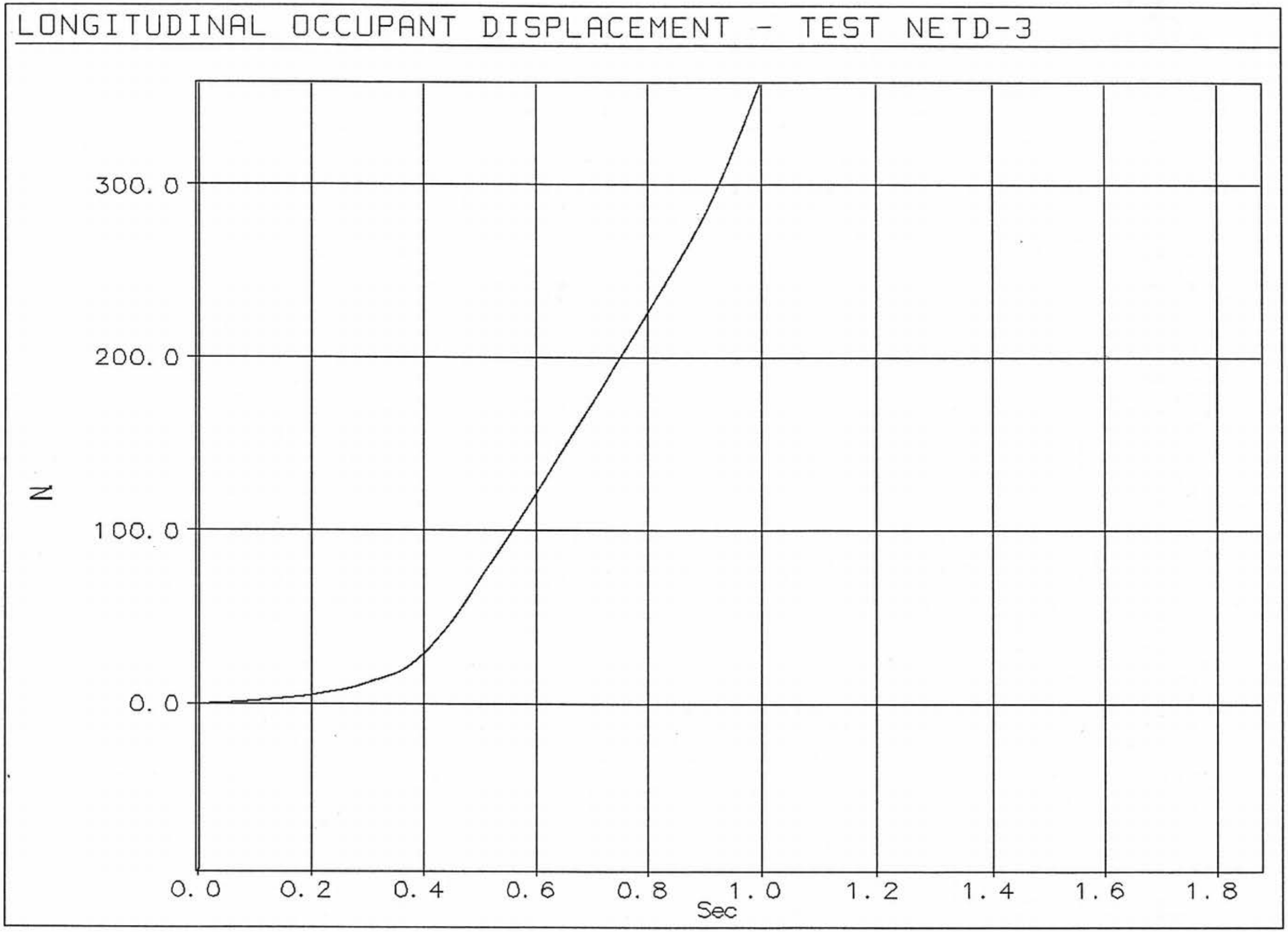

FIGURE C-3. Longitudinal Occupant Displacement - Test NETD-3

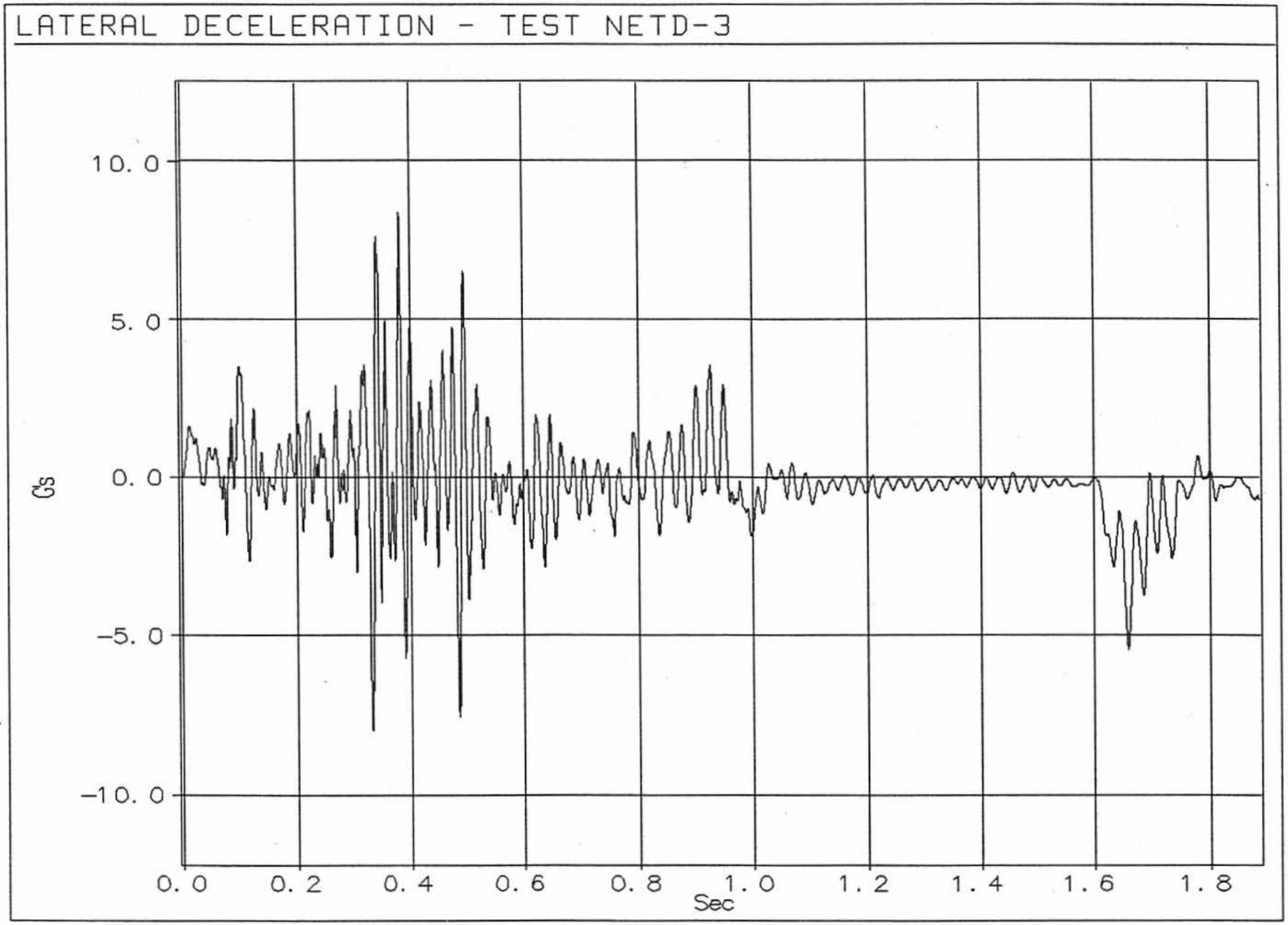

FIGURE C-4. Lateral Deceleration - Test NETD-3

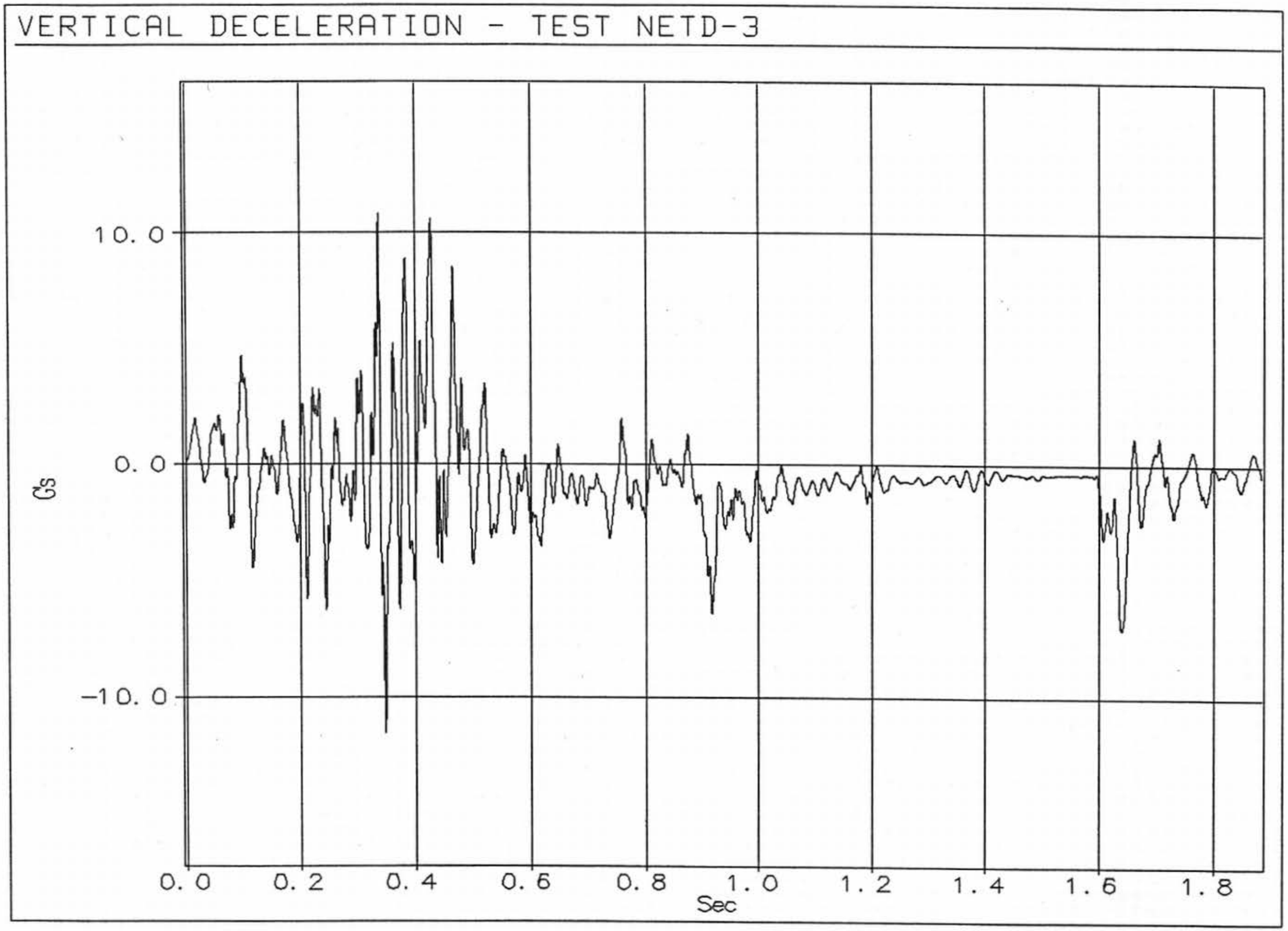

FIGURE C-5. Vertical Deceleration - Test NETD-3

APPENDIX D.

DETAILS OF THE RETROFIT PROCESS

The description below details the process involved in retrofitting the existing Nebraska Turned-Down Terminal. This description should provide insight to how and where the costs of this retrofit are consumed. When computing this estimate, it was assumed that the system currently existing on Nebraska roadways is constructed according to the plan in Figure 10.

First, the system was removed from the existing anchor and unbolted from the first eleven posts. The backup plates that are part of the existing installation were discarded, and replaced by a modified Reid backup plate, shown in Figure 36. Once the system was unbolted and the rail was laid on the ground, the posts were modified to meet the specifications. The first four posts in the existing system had a 6.0-cm (2-3/8-in.) diameter hole drilled in them at ground level. The new design required 8.9-cm (3.5-in.) diameter holes in the first nine posts, these were bored using a hole saw.

The anchor laid in concrete at the end of the system needs to be modified. With the current system, the top of the end of the rail rests at a height of 22.9-cm (9-in.) above the ground. The new design specifies that the top of the rail must be flush with the ground at the end. To accomplish this, the existing I-beam in the anchor was shortened. After shortening the I-beam, a plate (standard backup plate) was welded or bolted to the remaining I-beam so the end of the W-beam could be fastened to the anchor. A specific design of this modification has not been drafted, but an approximation of material and labor costs have been accounted for in the estimation. When the system was constructed for vehicle crash test NETD-3, the anchor was newly fabricated so there was no retrofitting done on this component.

A mechanism, shown in Figure 37 was added to the system to allow the posts to shear off more easily. 1.1-cm (7/16-in.) wire rope was clamped to the anchor and strung through the 8.9-cm (3.5-in.) holes at the base of the first nine posts. At each post a 10-cm x 10-cm (4-in. x 4-in.) bearing plate was clamped with two clamps to the downstream side of the post.

Once the modifications were completed to the posts in the system, the modified Reid backup plates were fastened to the wood blockouts of Post Nos. 1-9 using a 0.8-cm x 10-cm (5/16-in. x 4-in.) lag screw. The lag screws were screwed into a pre-bored hole in the blockout. At Post Nos. 1 and 6, a 0.5-cm (3/16-in.) hole was drilled in the W-beam rail so the No. 8 shear bolts could connect the guardrail to the backup plate at these two posts. Once the No. 8 bolts are installed at Post Nos. 1 and 6, the guardrail was bolted to the anchor with a 90 deg clockwise twist. The twist employed in this design was in the opposite direction of the standard Turned-Down Terminal.