CRASH TESTING AND EVALUATION OF THE MODIFIED G4(1S) W-BEAM GUARDRAIL ON 2:1 SLOPE

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16. Abstract

The objective of this study is to assess the performance of the modified G4(1S) guardrail system when placed on a slope equal to 2H:1V. This guardrail system is to be evaluated under the conditions and criteria of *NCHRP Report 350* TL-3. The guardrail system needs to be placed on the slope with such an offset that the face of the W-beam rail is aligned with the slope break.

The first step was to evaluate the performance of guardrail posts with various embedment lengths when impacted by a bogie vehicle. The next step was to build and calibrate finite element models of selected posts and then use them in full-scale simulations of candidate guardrail systems.

Based on the results of the cases simulated, the candidate design chose for testing was a W-beam (12 gauge) guardrail system with 8-ft posts placed on a 2H:1V slope. The posts are placed 1-ft off the slope break and spaced at 3 ft-1.5 inches (half the standard spacing for a strong-post W-Beam guardrail).

In the full-scale crash test, the 2000P vehicle was contained and redirected. However, after exiting the installation, the vehicle rolled onto its left side. Due to this rollover, the guardrail on 2H:1V slope did not meet the criteria for *NCHRP Report 350* test 3-11.

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SI* (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
		AREA		
in^2	square inches	645.2	square millimeters	mm^2
ft^2	square feet	0.093	square meters	m^2
yd^2	square yard	0.836	square meters	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	square kilometers	km^2
		VOLUME		
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.028	cubic meters	m^3
yd^3	cubic yards	0.765	cubic meters	m^3
		NOTE: volumes greater than 1000 L shall be shown in m^3		
		MASS		
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams (or "metric ton")	Mg (or "t")
		TEMPERATURE (exact degrees)		
^{o}F	Fahrenheit	5 (F-32)/9 or (F-32)/1.8	Celsius	^{o}C
		ILLUMINATION		
fc	foot-candles	10.76	lux	lx
fl	foot-Lamberts	3.426	candela/m^2	cd/m^2
		FORCE and PRESSURE or STRESS		
lbf	poundforce	4.45	newtons	N
lbf/in^2	poundforce per square inch	6.89	kilopascals	kPa

APPROXIMATE CONVERSIONS FROM SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
		AREA		
mm^2	square millimeters	0.0016	square inches	in^2
m^2	square meters	10.764	square feet	ft^2
m^2	square meters	1.195	square yards	yd^2
ha	hectares	2.47	acres	ac
km^2	square kilometers	0.386	square miles	mi^2
		VOLUME		
mL	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m^3	cubic meters	35.314	cubic feet	ft^3
m^3	cubic meters	1.307	cubic yards	yd^3
		MASS		
g	grams	0.035	ounces	oz
kg	kilograms	2.202	pounds	lb
Mg (or "t")	megagrams (or "metric ton")	1.103	short tons (2000 lb)	T
		TEMPERATURE (exact degrees)		
^{o}C	Celsius	1.8C+32	Fahrenheit	^{o}F
		ILLUMINATION		
lx	lux	0.0929	foot-candles	fc
cd/m^2	candela/m^2	0.2919	foot-Lamberts	fl
		FORCE and PRESSURE or STRESS		
N	newtons	0.225	poundforce	lbf
kPa	kilopascals	0.145	poundforce per square inch	lbf/in^2

*SI is the symbol for the International System of Units. Appropriate rounding should be made to comply with Section 4 of ASTM E380.
(Revised March 2003)

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1. INTRODUCTION

1.1 PROBLEM

The American Association of State Highway and Transportation Officials (AASHTO) Roadside Design Guide recommends that guardrail be installed with the back edge of the guardrail posts 2 ft from a slope break.[1] In many mountainous areas or in locations with tight environmental controls, this width is difficult to provide. As a result, designers often have to make a trade-off between reduced shoulder width and a less than optimal guardrail placement. The Washington Department of Transportation (WSDOT) Design Manual provides for the placement of the guardrail post closer to or on slopes as steep as 1H:1V, as shown in figure 1.1. A research effort undertaken by Polivka, et al (October 2000) of the Midwest Roadside Safety Facility (MwRSF) recommended a design with 7 ft long posts spaced 3 ft-1-1/2 inches on center with the back edge of the post placed at the break to a 2H:1V slope.[2] However, in many cases, steeper slopes are encountered and more width is desired.

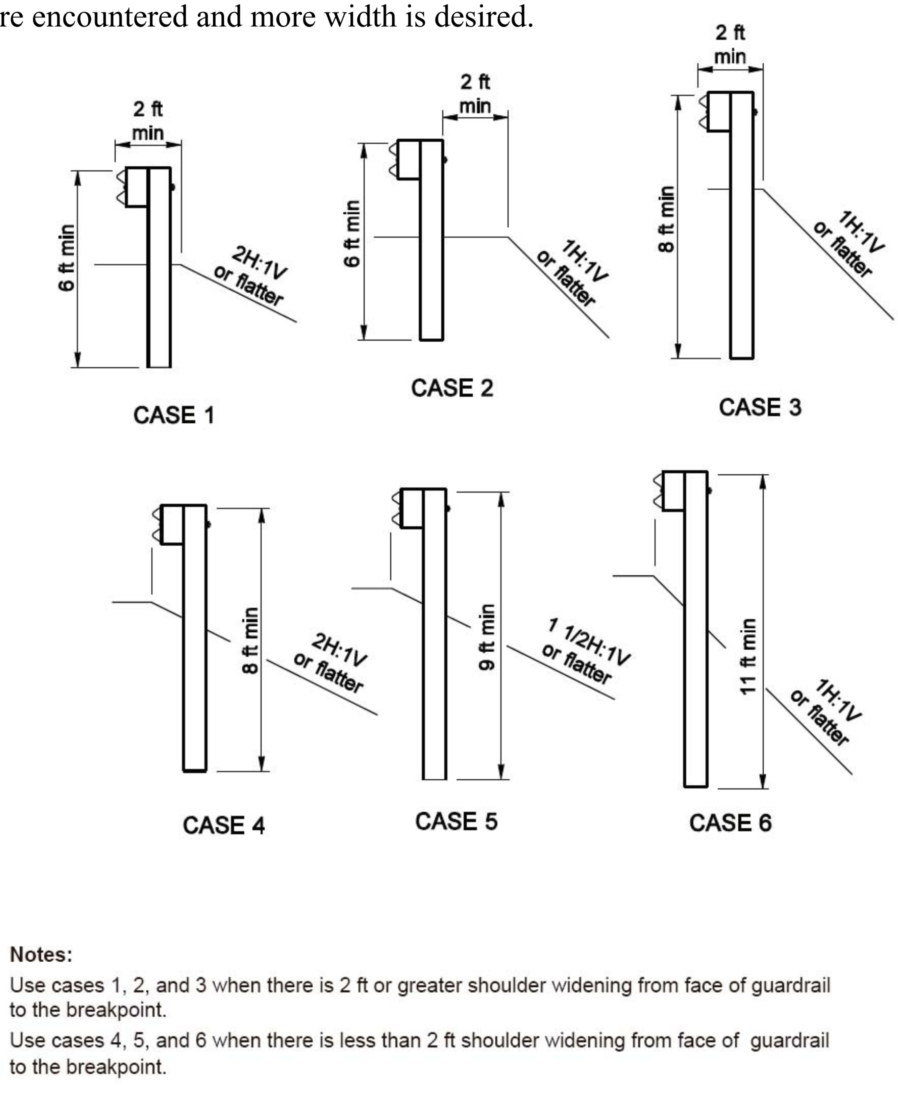


Figure 1.1. Allowable post on slope installation cases from WSDOT Design Manual, page 710-25.[6]

1.2 BACKGROUND

Earliest known research regarding guardrail placement on slopes was conducted by ENSCO, Inc. (1988) which included a battery of pendulum tests on a single post and three full scale crash tests.[3] Two tests of a large sedan impacting a G4(1S) guardrail system installed on a break point of a 2H:1V slope were considered to be successful per National Cooperative Highway Research Program (NCHRP) *Report 230* evaluation criteria.[4] One of the tests had a 6 ft post length while the other had a 7 ft post length. The 7 ft post length installation had a better performance (less rail deflection and vehicle impact speed change) than the 6 ft post length installation.

Polivka, et al (October 2000) performed another battery of bogie tests and a crash test of a steel post guardrail system with a 2000P test vehicle per *NCHRP Report 350* Test level 3.[2,5] The region that encompassed the impact point had 7 ft long W6x8.5 steel posts placed 3 ft 1.5 inches on center. These posts were placed at the break of a 2H:1V slope with 4 ft 7 inch embedment depth. The crash test was considered successful per *NCHRP Report 350* evaluation criteria.

1.3 OBJECTIVES/SCOPE OF RESEARCH

The objectives of this project were to investigate the sensitivity of standard guardrail to the placement in front of or on a slope and develop an alternate method for installing guardrail in front of or on slopes steeper than 2H: 1V. The plan of work to achieve this is summarized as follows.

1.3.1 Perform Engineering Analysis/Design/Drawings

The researchers reviewed the design details of guardrails on slope previously developed to evaluate the behavior of the guardrail when subjected to *NCHRP Report 350* tests. Lateral stiffness of the guardrail system is the primary design feature that determines the maximum deflection of the guardrail during a collision and changes in lateral stiffness of the guardrail system along its length are the key feature influencing pocketing of a vehicle. Design features found to be important in terms of capacity of the guardrail to contain and redirect a vehicle are slope ratio, post length, post placement, and soil strength. It is assumed the soil to be used is compliant with *NCHRP Report 350* standard soil definition. Moreover, since the desired placement of the post is to be on the slope rather than at the break of the slope, it is assumed the post offset from the slope break is approximately 1 ft 6 inches. This would make the face of the rail aligned with the slope break, given the 8 inch deep blockout is used. Thus, the focus of this research effort will be on investigating post length and post placement design parameters on the performance of the guardrail placed on slope.

1.3.2 Perform Bogie Tests

Researchers performed bogie tests to identify the performance of a given post length placed on a slope. First, a benchmark bogie test of a 6 ft long post placed 2 ft in front of a slope break was performed. This provided a reference point for subsequent bogie tests and simulations. Then, other bogie tests were performed using various post lengths placed on the slope. Each post was placed on the candidate slope configurations (the 2H:1V and the 1½H:1V) for these tests. By comparing the “on the slope” tests with the “in front of the break” test, the sensitivity of the placement of the post can be investigated. Thus, these tests help identify the post length-slope configuration that will most likely perform successfully when used in a guardrail installation on slope.

1.3.3 Perform Computer Simulation

The LS-DYNA computer program was used to evaluate the performance of the proposed guardrail design when tested per *NCHRP Report 350* test designation 3-11. First, a model was built to replicate the test performed at the MwRSF so as to establish scope and limitations of the model for such systems. Then simulation of a bogie test of the chosen post-slope configuration was performed to validate the model for the desired configuration. The model parameters from the bogie simulations were incorporated into the full-scale system model. This model was used to simulate the potential selected system designs, evaluate expected deflections of the barrier, and predict vehicle performance.

1.3.4 Perform Full-Scale Vehicle Crash Test

The researchers performed *NCHRP Report 350* test 3-11 (2000P vehicle, 62 mi/h, 25 degree) on the selected design. It is believed this is the critical test for this design and test 3-10 (820C vehicle, 62 mi/h, 20 degree) is not required.

2. COMPUTER SIMULATION

2.1 RESEARCH METHODOLOGY

The first step was to evaluate the performance of several posts of various embedment lengths when impacted by a bogie vehicle. The next step was to build and calibrate a finite element mode of a few candidate posts length from the bogie test pool and then use that in full scale simulation of such posts in system installation.

2.2 INITIAL SET OF BOGIE TESTS

Five bogie tests of W6x8.5 steel posts were performed. The first test was a reference test of a standard 6-ft post installed on level ground with slope break 2 ft behind the back of the post. The second test was conducted on a 7 ft steel post placed on a 2H:1V slope 1 ft down from the slope break. The third and fourth tests were performed on 8-ft long posts placed 1 ft down from the slope break on 2H:1V and 1.5H:1V slopes, respectively. The last test was conducted on a 9 ft steel post placed on a 1.5H:1V slope 1 ft down from the slope break. The nominal target speed for the 849 kg (1871 lb) bogie vehicle with a crushable honeycomb nose assembly was 21 mph. Typical post placement is shown in figure 2.1.

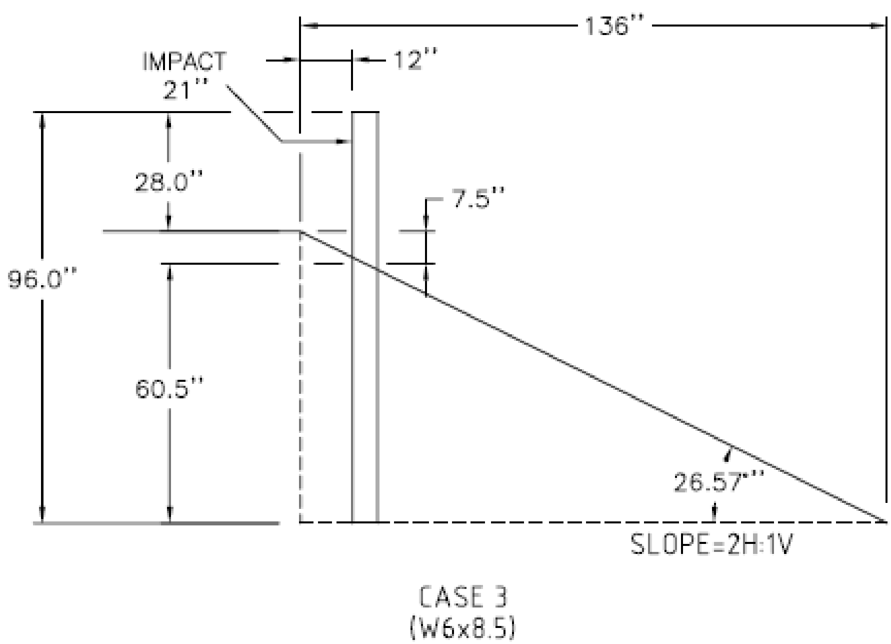


Figure 2.1. Typical post placement.

In all tests except test 2, the posts yielded at a point below grade and were displaced through the surrounding soil. In test 2, the 7-ft long post did not plastically bend, but merely deflected through the surrounding soil. A summary of the bogie test results is shown in table 2.1.

Table 2.1. Summary of bogie tests.

Test No.	**1**	**2**	**3**	**4**	**5**	**Units**
Initial Velocity	20.8	22.2	20.4	21.1	21	mph
Height of Post	72	84	96	96	108	inch
Embedment depth	44	48.5	60.5	58	70	inch
Distance to Bend from Soil Surface	8	N/A	15.5	15	16.5	inch
Max force 10-ms Average	16.82	11.15	11.40	11.96	11.01	kips
Max force 50-ms Average	14.02	8.45	9.59	8.73	8.92	
Max Kinetic Energy	28757.61	26944.96	24262.77	21839.22	19036.93	ft-lb
Max accel 10-ms Average	-8.45	-5.61	-5.73	-6.01	-5.53	
Max accel 50-ms Average	-7.05	-4.25	-4.82	-4.39	-4.48	g
Peak dynamic Deflection Due to Primary Impact in X Direction	480	818	635	722	695	mm
	18.9	32.2	25.0	28.4	27.4	inch

The five bogie tests of the W6x8.5 steel posts were analyzed to identify the best suited post length for the on slope placement. Moreover, simulations of these bogie tests were conducted to calibrate the post-soil model for use in full scale simulations of the guardrail on slope system.

An energy based approach was used to identify the best post length and slope configuration. The 7-ft and the 8-ft long posts with 2H:1V slope ratio (Tests 2 and 3, respectively) have the closest energy profile compared to the reference test (Test 1) as shown in figure 2.2.

However, when the posts were extracted from the soil after testing, the 7-ft post did not show any sign of yielding or permanent deformation (see figure 2.3). Therefore, the 7-ft post was not considered sufficient for on slope placement, and the 8-ft post with 2H:1V slope was selected for further investigation.

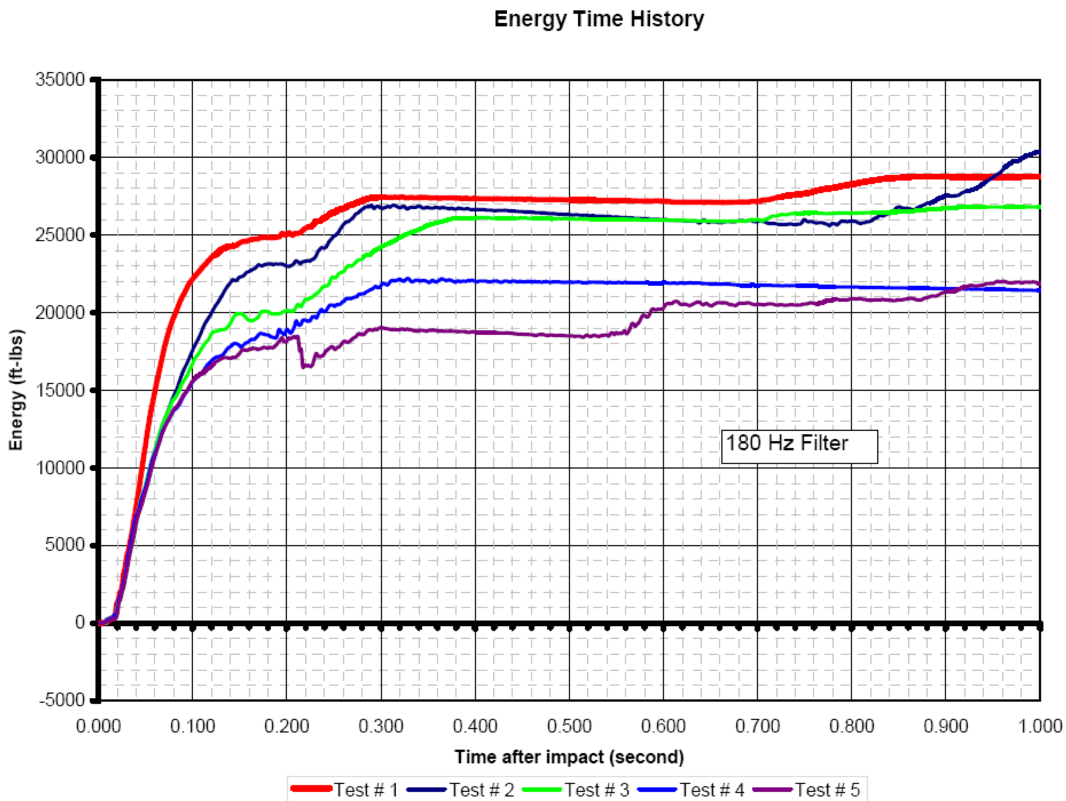


Figure 2.2. Energy plots for bogie tests.

Figure 2.3. Extracted posts after first set of the bogies tests.

2.3 SIMULATION OF BOGIE TESTS

Simulation of key bogie tests was performed to validate component models. The simulation effort consisted of modeling the soil, the post and the bogie impactor. Figure 2.4 shows a section of the modeled post. Different thicknesses were assigned to the part comprising the web and flanges as appropriate.

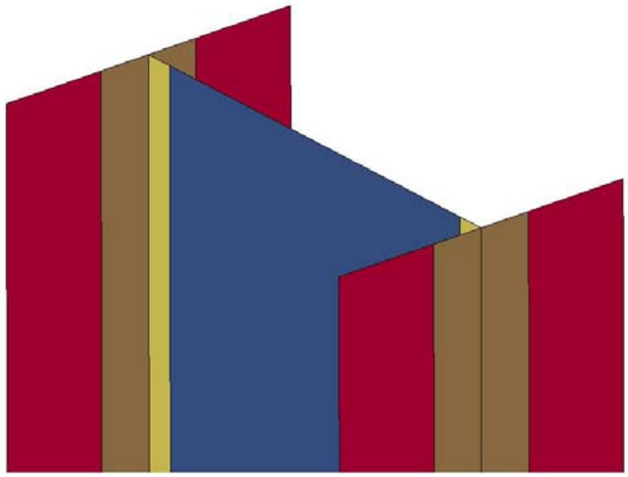


Figure 2.4. Cross section of the post model.

The soil was modeled using continuum solid elements and the post-soil interaction was defined via contact definitions in LS-DYNA. A typical soil model with embedded posts is shown in figure 2.5.

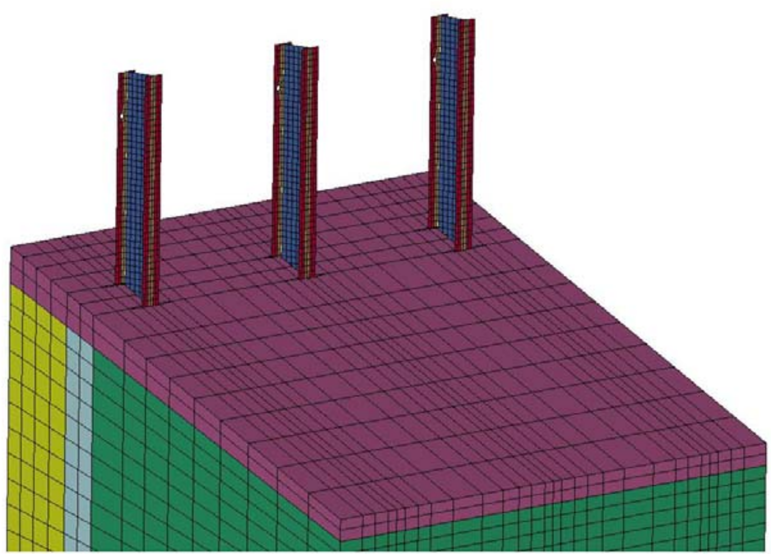


Figure 2.5. Soil model with posts embedded on the sloped face.

Tests that were simulated include test 1 (6-ft post on flat ground), test 2 (7-ft post on 2V:1H slope) and test 3 (8-ft post on 2V:1H slope). Comparisons between tests and simulations for test 3 are shown in figures 2.6 and 2.7.

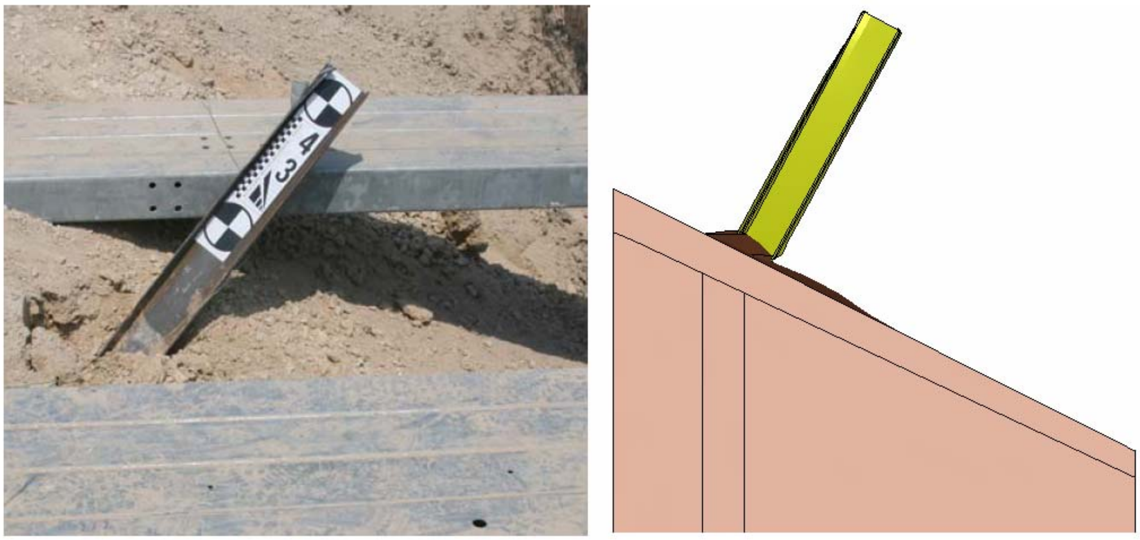


Figure 2.6. Test 3 and simulation of test 3.

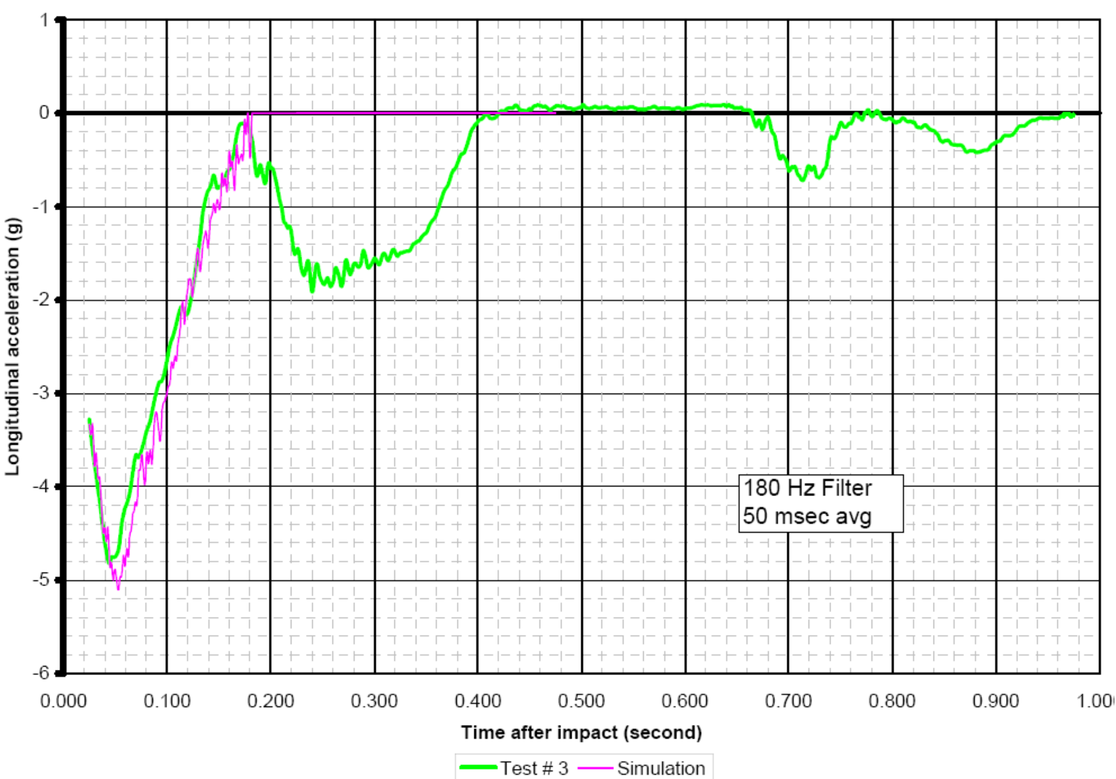


Figure 2.7. Acceleration for both bogie test 3 and its simulation.

The guardrail design selected for further evaluation through finite element modeling and simulation. Case 1 incorporates 8-ft long W6x9 steel posts spaced at 6 ft-3 inches and a 12-gauge W-beam rail element aligned with the break point of a 2H:1V slope. The full guardrail system is shown in figure 2.8. The model was then used to simulate the impact of the 2000 kg pick up truck test vehicle impacting the rail at 100 km/hr and 25 degrees (i.e., *NCHRP Report 350* test designation 3-11).

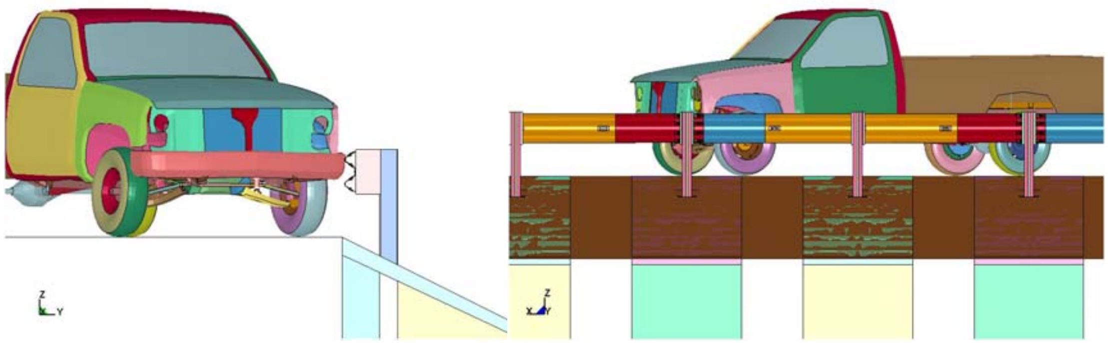


Figure 2.8. Guardrail on slope system with 6 ft-3 inch post spacing.

Early in the simulation, the front left corner of the truck began to over-ride the rail. As the simulation progressed, the front left tire also began to over-ride the rail. The simulation stopped just as the tire passed over the rail. Figure 2.9 shows images of the truck-rail interaction during this simulation. It is evident that the truck would continue to climb and over-ride the rail, and that the system would not be effective in redirecting the truck.

Two additional analyses were performed on guardrail systems on slope using 8-ft long posts. The additional designs simulated are:

Case 2: A 12-Gauge W-Beam with half (3 ft-1.5 inch) post spacing as shown in figure 2.11.

Case 3: A 10-Gauge W-beam with standard (6 ft-3 inch) post spacing as shown in figure 2.10.

All the systems shared the following parameters and conditions:

1) The posts were placed 1-foot on the 2H:1V slope as shown in figure 2.12.
2) All the posts are 8-ft long W6x9 steel posts with a standard block out.
3) Test conditions are per *NCHRP Report 350* test designation 3-11 (2000 kg pickup, impact speed is 100 km/hr and impact angle 25 degrees).

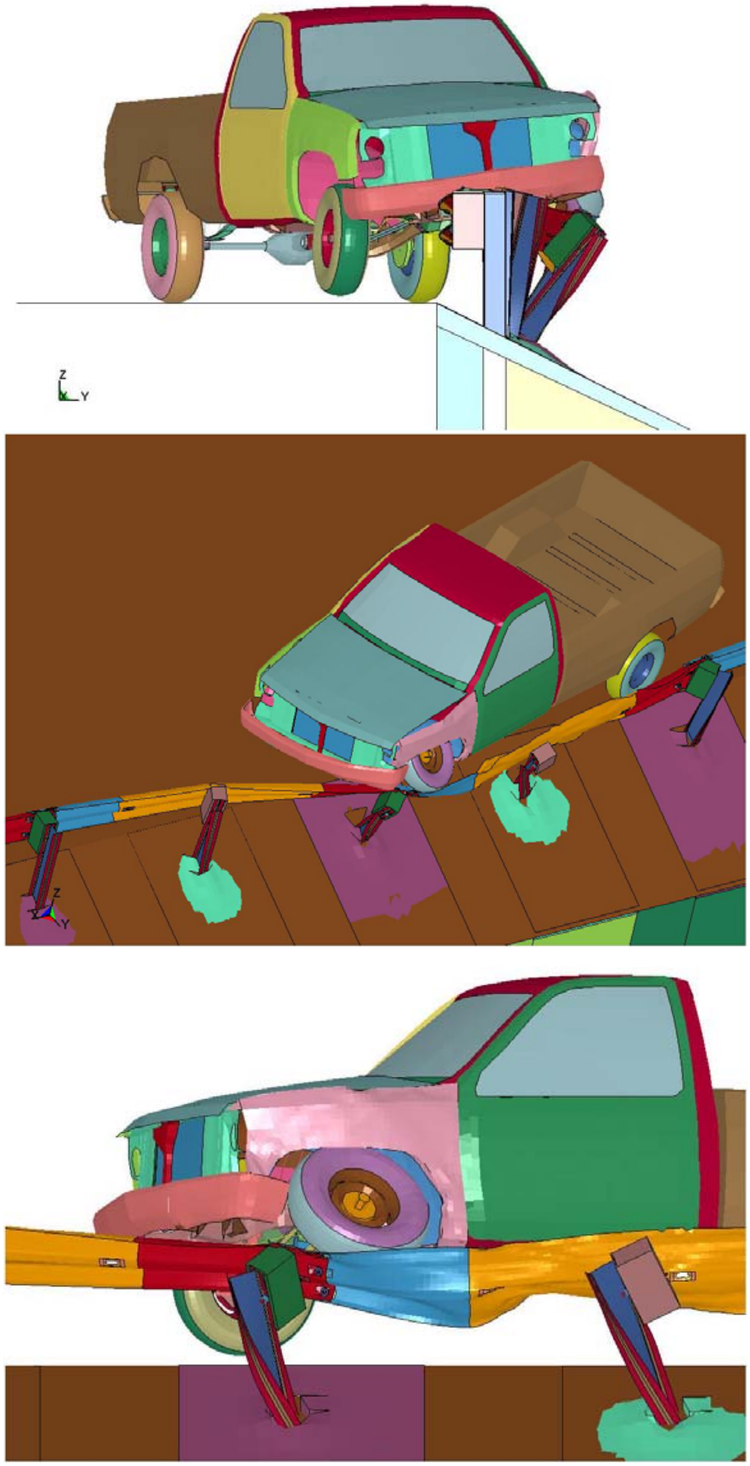


Figure 2.9. Vehicle-barrier interaction associated with test 3-11 impact of a guardrail on 2H:1V slope with 8-ft long posts spaced at 6 ft-3 inch.

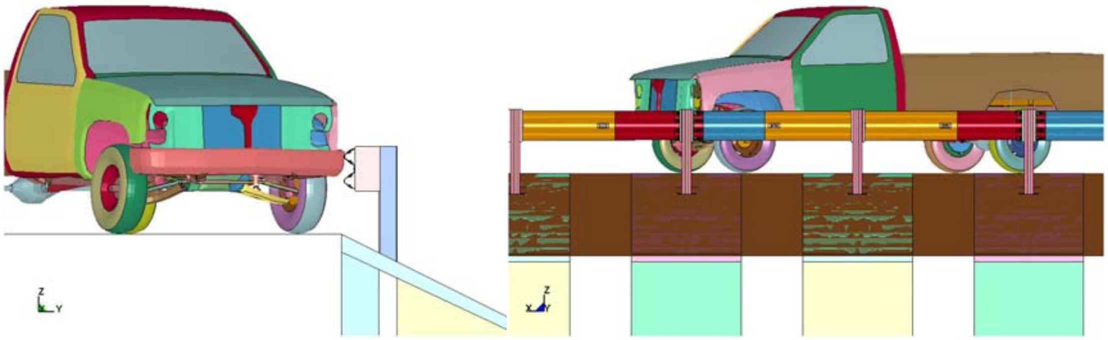


Figure 2.10. Guardrail on slope system with 6 ft-3 inch post spacing.

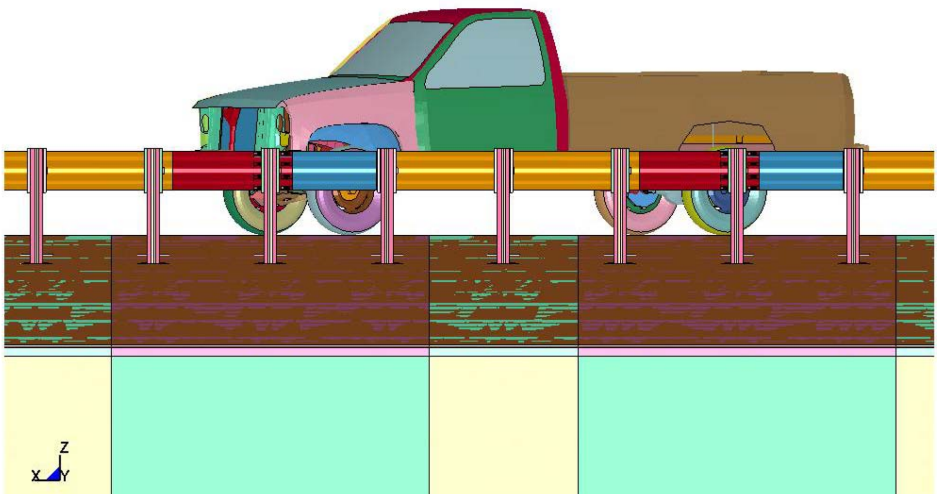


Figure 2.11. Guardrail on slope system with 3 ft-1.5 inch post spacing.

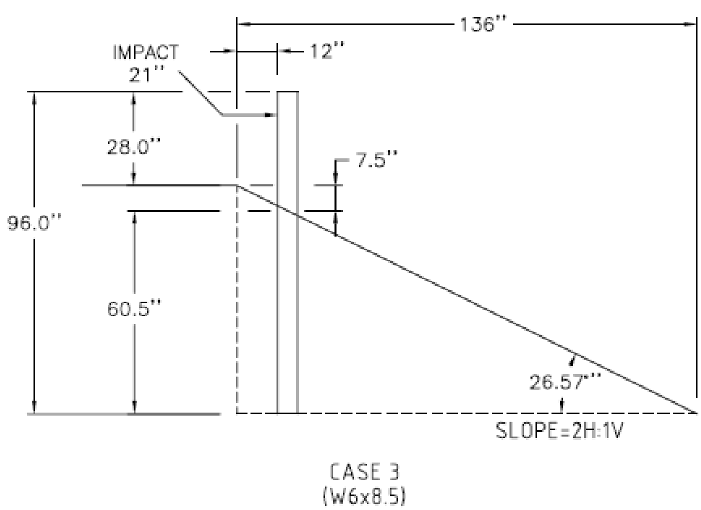


Figure 2.12. Cross section of post placement.

The simulation results for each design are summarized below:

Case 1: The simulation suggests that the truck would climb and over-ride the rail as shown in figure 2.13.

Case 2: The system would most likely re-direct the vehicle without overriding, however; there is increased snagging between the front left wheel and the posts. This caused increased pitching of the vehicle and subsequently an increased roll angle. This is shown in figure 2.14.

Case 3: The system would most likely re-direct the vehicle without overriding. Snagging, pitching, and rolling are not as pronounced as in Case 2. A snap shot of the simulation is shown in figure 2.15.

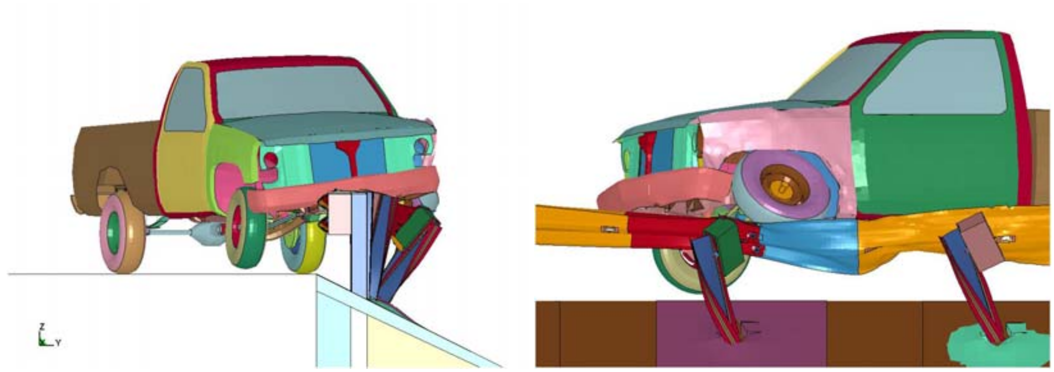


Figure 2.13. Vehicle-barrier interaction associated with test 3-11 impact of a guardrail on 2H:1V slope with 8-ft long posts spaced at 6 ft-3 inch.

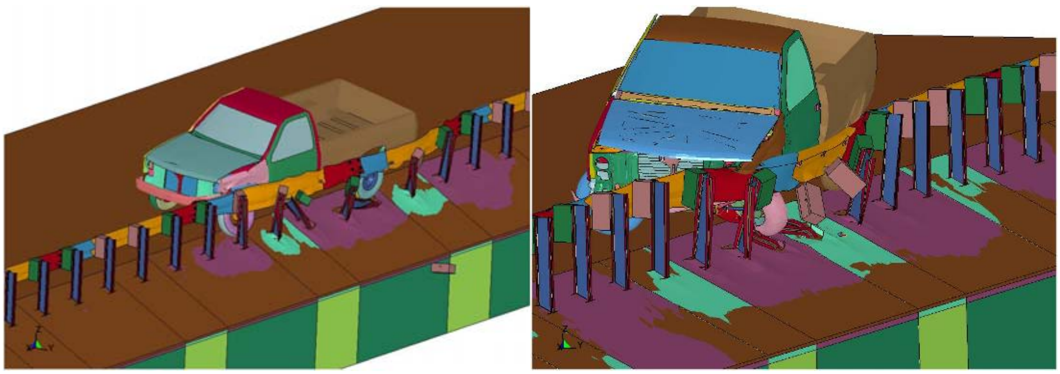


Figure 2.14. Simulation with 3 ft-1.5 inch post spacing.

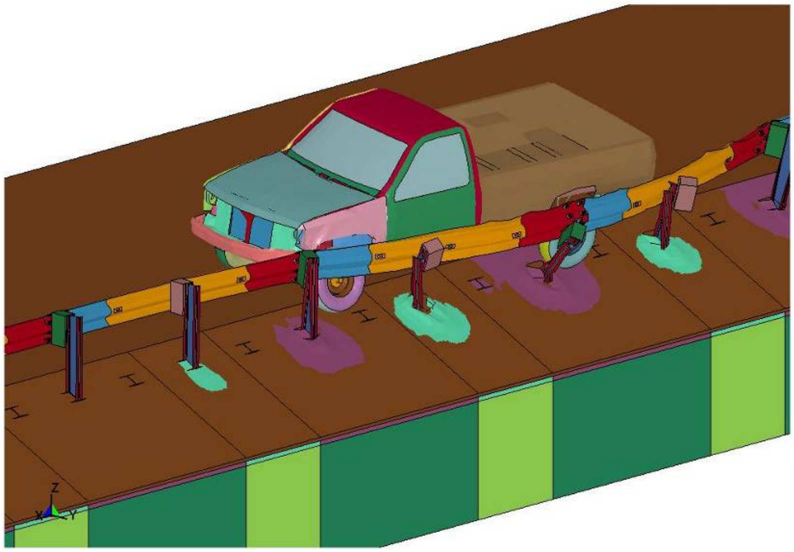


Figure 2.15. Guardrail on slope system with 6 ft-3 inch post spacing and 10-Gauge W-Beam.

2.4 SECOND SET OF BOGIE TESTS

Per the recommendation of the state technical representative, a new post design was identified for further analysis and testing. The design utilizes a 7-ft long W6x8.5 steel post placed 1 ft beyond the break point on a 2H:1V slope. A soil plate is welded to the post on the front flange in order to increase the overall post stiffness. One variation (Case 6) uses a 36 inch x12 inch by 1/4 inch thick plate, the second variation (Case 7) uses a 36 inch x18 inch by 3/8 inch thick plate and the third variation uses 36 inch x18 inch by 1/4 inch thick plate. Figures 2.16, 2.17 and 2.18 depict Case 6, Case 7 and Case 8, respectively.

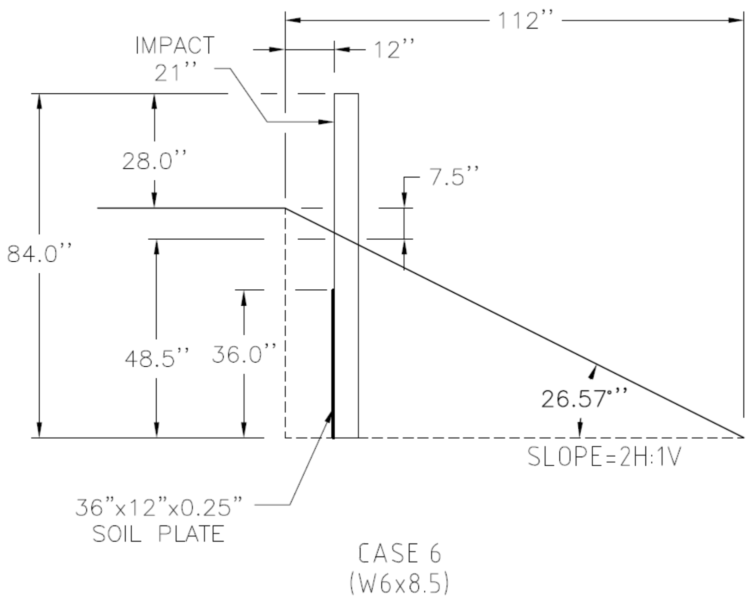


Figure 2.16. Placement of the new post design (Case 6).

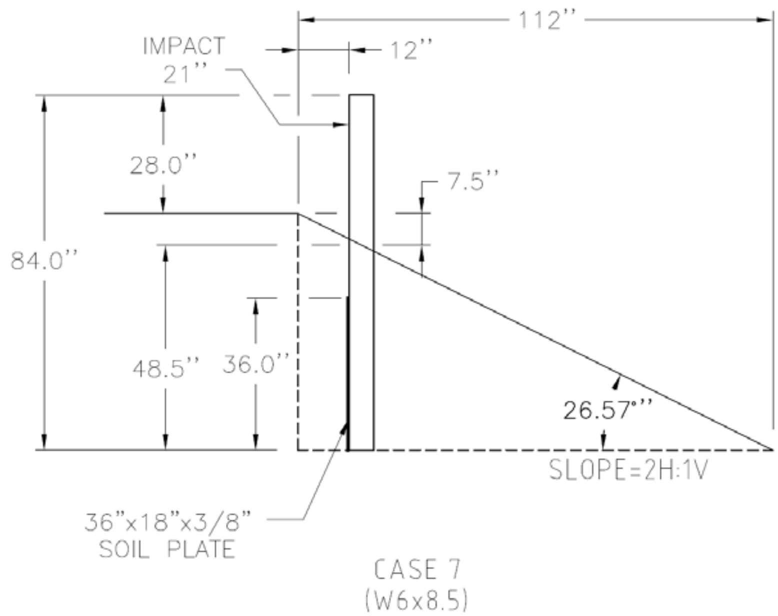


Figure 2.17. Placement of the new post design (Case 7).

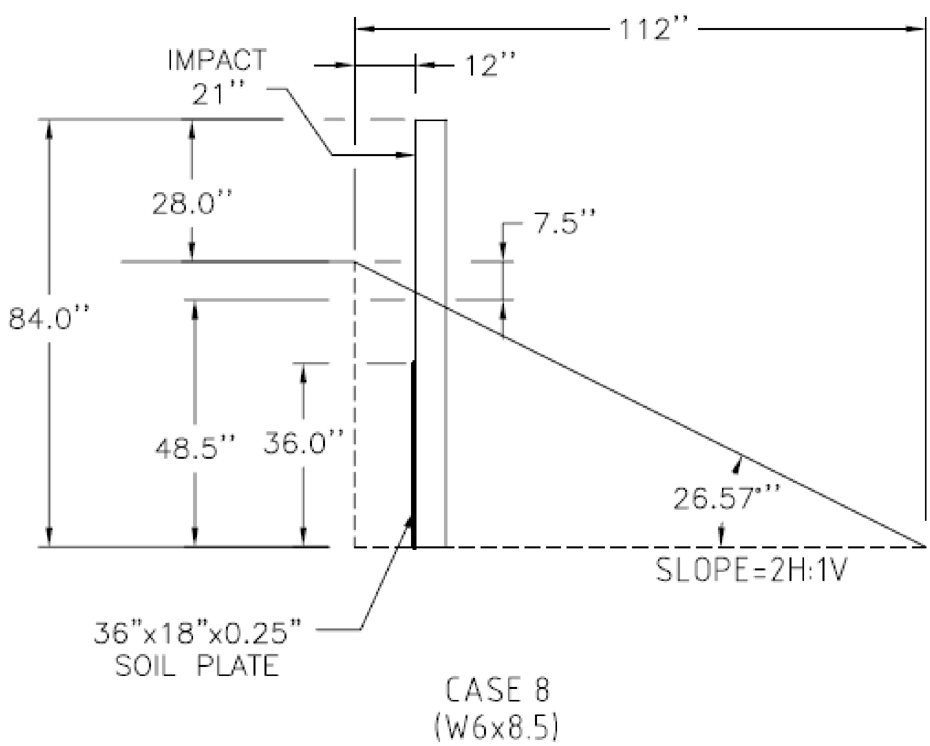


Figure 2.18. Placement of the new post design (Case 8).

These posts were fabricated and installed on the 2H:1V slope and then were impacted with the 849 kg (1871 lb) crushable nose bogie. Impact force histories of these tests along with that of the earlier test of the 7-ft post without a soil plate (Case 2) are shown in figure 2.19.

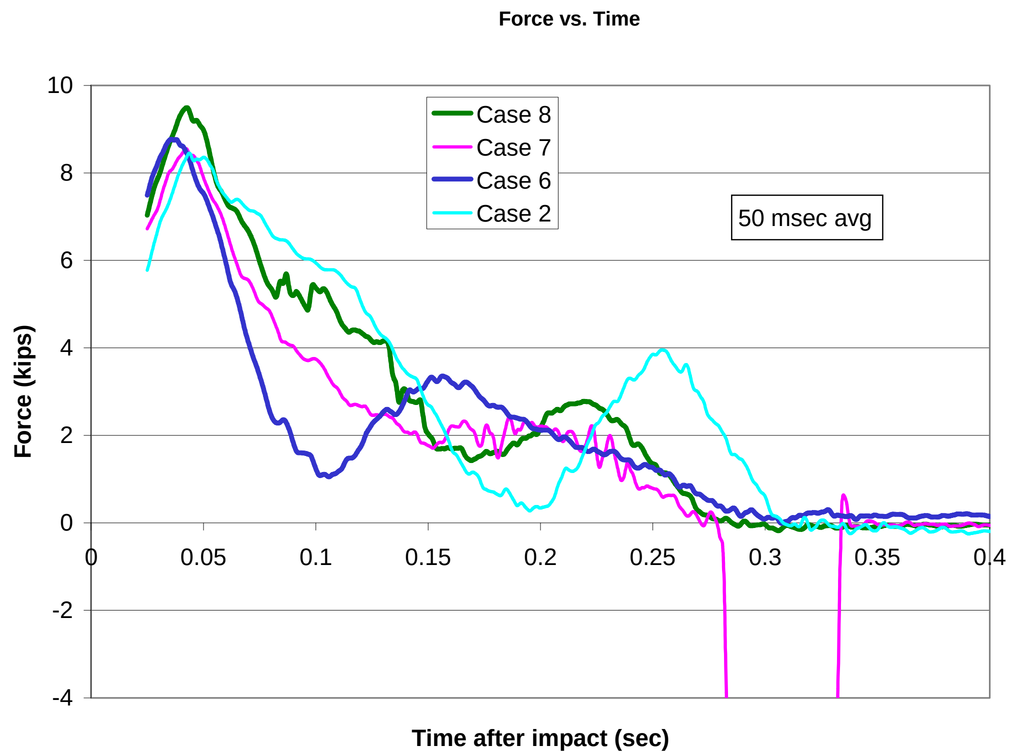


Figure 2.19. Force histories of the 7-ft long post without soil plate (case 2) and with soil plate (cases 6, 7 and 8).

The graph indicates that all tests are practically equal in terms of their maximum force capacity. This means that adding the soil plate to the post resulted in little increase of the maximum force sustained by the post upon impact.

However, upon inspecting the posts after the tests, all posts with soil plates yielded at the point above the soil plate top edge as shown figure 2.20. This is in contrast to the almost undeformed 7-ft post tested earlier as shown in figure 2.21.

This indicates that adding a soil plate would facilitate the creation of a plastic hinge in the post. Hence, adding the soil plate does help the interaction between the embedded depth of the post and the soil. Consequently, a model of the post with soil plate was constructed and the full scale model of the guardrail system was updated to include a 7-ft post with soil plate spaced at 6 ft-3 inches a part. The model of this configuration is shown in figure 2.22.

Figure 2.20. Deformed posts after test 6, 7 and 8.

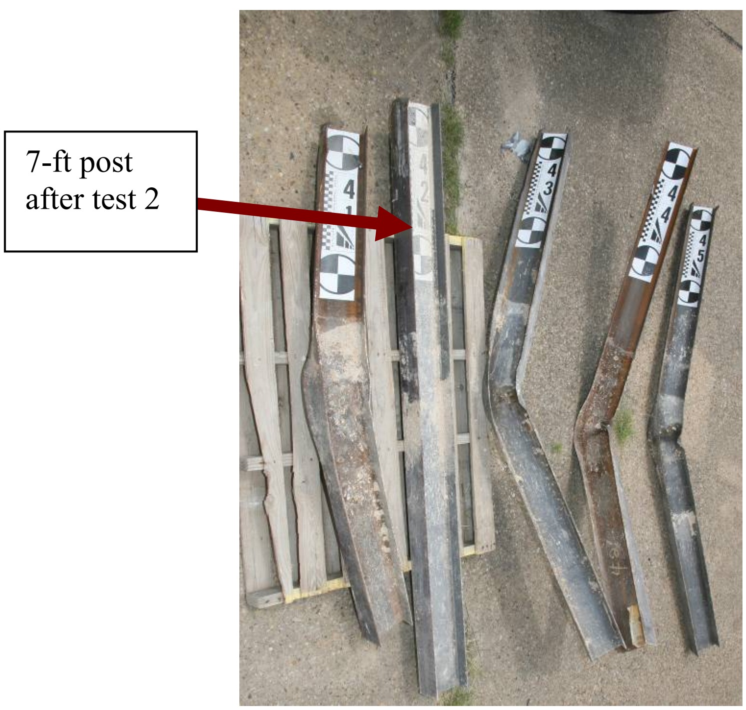


Figure 2.21. Pull posts from test 1,2,3,4 and 5.

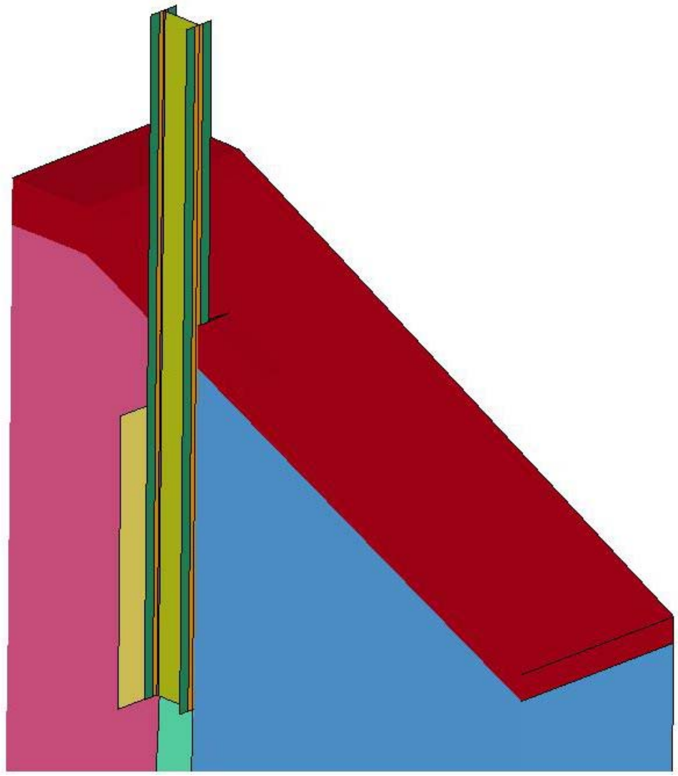


Figure 2.22. Model of steel post with soil plate.

The full scale simulation using the 7-ft post with steel plate showed comparable performance to the systems with 8-ft steel posts. The simulation results are listed in table 2.2 for the designs evaluated.

Based on the simulation results and feedback from the member states' technical representatives, the candidate design selected for full-scale crash testing was a W-beam (12 gauge) guardrail system with 8-ft posts placed on a 2H:1V slope. The posts are placed 1-ft off the slope break and are spaced at 3 ft-1.5 inches (half the standard spacing for a common strong-post W-Beam guardrail). Figure 2.23 shows a section of system to be selected for testing.

Table 2.2. Results of Simulation.

System	Posts	Likely Outcome
Standard spacing, 6-ft 3-in. (12 Gage W-beam.)	8-ft	Vehicle over riding the rail
Half standard spacing, 3-ft 1.5-in. (12 Gage W-beam.)	8-ft	Redirection and containment of the vehicle
Standard spacing, 6-ft 3-in, but with 10 Gage W-beam.	8-ft	Redirection and containment of the vehicle
Standard spacing, 6-ft 3-in, (12 Gage W-beam.)	7-ft with soil plate	Vehicle over riding the rail
Half standard spacing, 3-ft 1.5-in. (12 Gage W-beam.)	7-ft with soil plate	redirection and containment of the vehicle

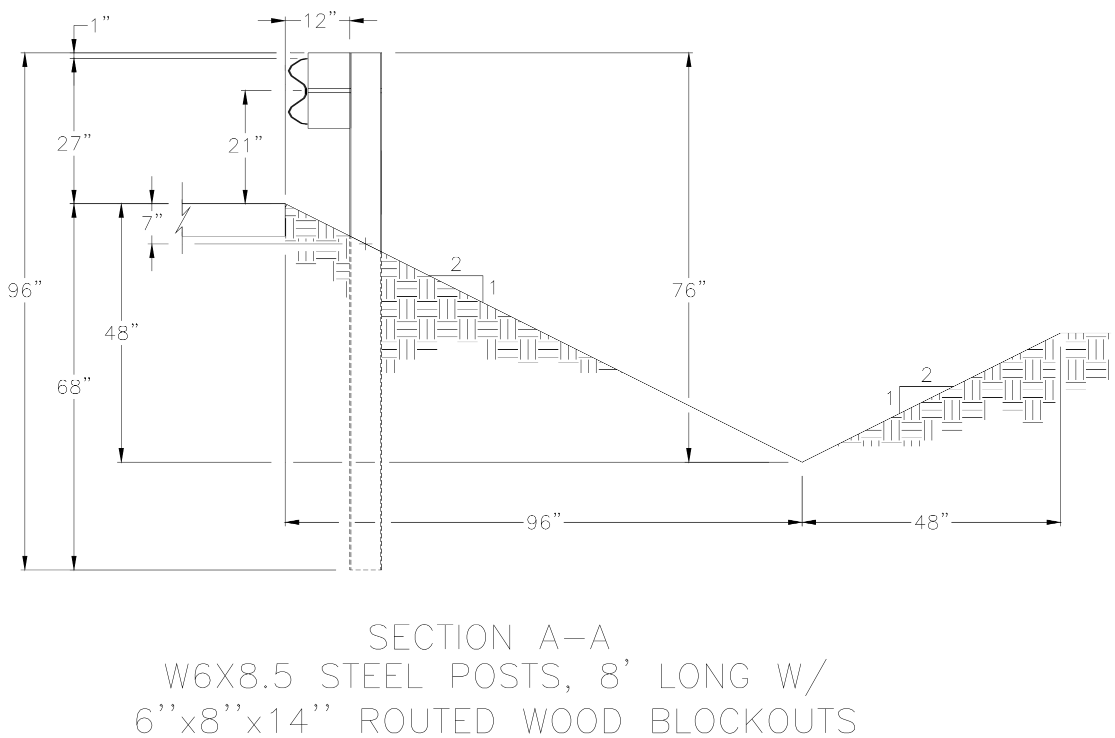


Figure 2.23. Section of the recommended system for full scale test.

3. FULL-SCALE CRASH TESTING

3.1 CRASH TEST PARAMETERS

3.1.1 Test Facility

The test facilities at the Texas Transportation Institute's Proving Ground consist of a 2000-acre complex of research and training facilities situated 10 mi northwest of the main campus of Texas A&M University. The site, formerly an Air Force Base, has large expanses of concrete runways and parking aprons well suited for experimental research and testing in the areas of vehicle performance and handling, vehicle-roadway interaction, durability and efficacy of highway pavements, and safety evaluation of roadside safety hardware. The site selected for the placement of the guardrail on slope is along the edge of a wide out-of-service apron. The apron consists of an unreinforced jointed concrete pavement in 12.5 ft by 15 ft blocks nominally 8-12 inches deep. The apron is over 50 years old and the joints have some displacement, but are otherwise flat and level.

3.1.2 Test Article – Design and Construction

The guardrail on slope system consists of 175 ft total length of 12 gauge W-beam mounted on W6x8.5 steel posts. The guardrail system comprised of a 100 ft length of need section and a 37.5 ft long ET Plus terminal on each end. A 2H:1V sloped ditch was excavated behind the rail to represent the sloped terrain. The ditch was centered along the installation length and was 68 ft-9 inches long and 8 ft wide.

Six-ft long posts were placed at 6 ft-3 inch spacing on the flat terrain portion of the guardrail. These are posts 7, 8, 9, 31, 32 and 33. Along the sloped section, the 8-ft long posts are placed at 3 ft-1.5 inch spacing. These are post 10 through post 30, as shown in the drawing in figure 3.1. Standard size 8 inch x 6 inch x 14 inch blocks were used in the length of need section.

Details of the installation are shown in figures 3.1 through 3.11, and the completed installation is shown in figure 3.12. The guardrail was constructed such that the face of the W-beam rail was aligned with the slope break of the ditch, as shown in figure 3.2.

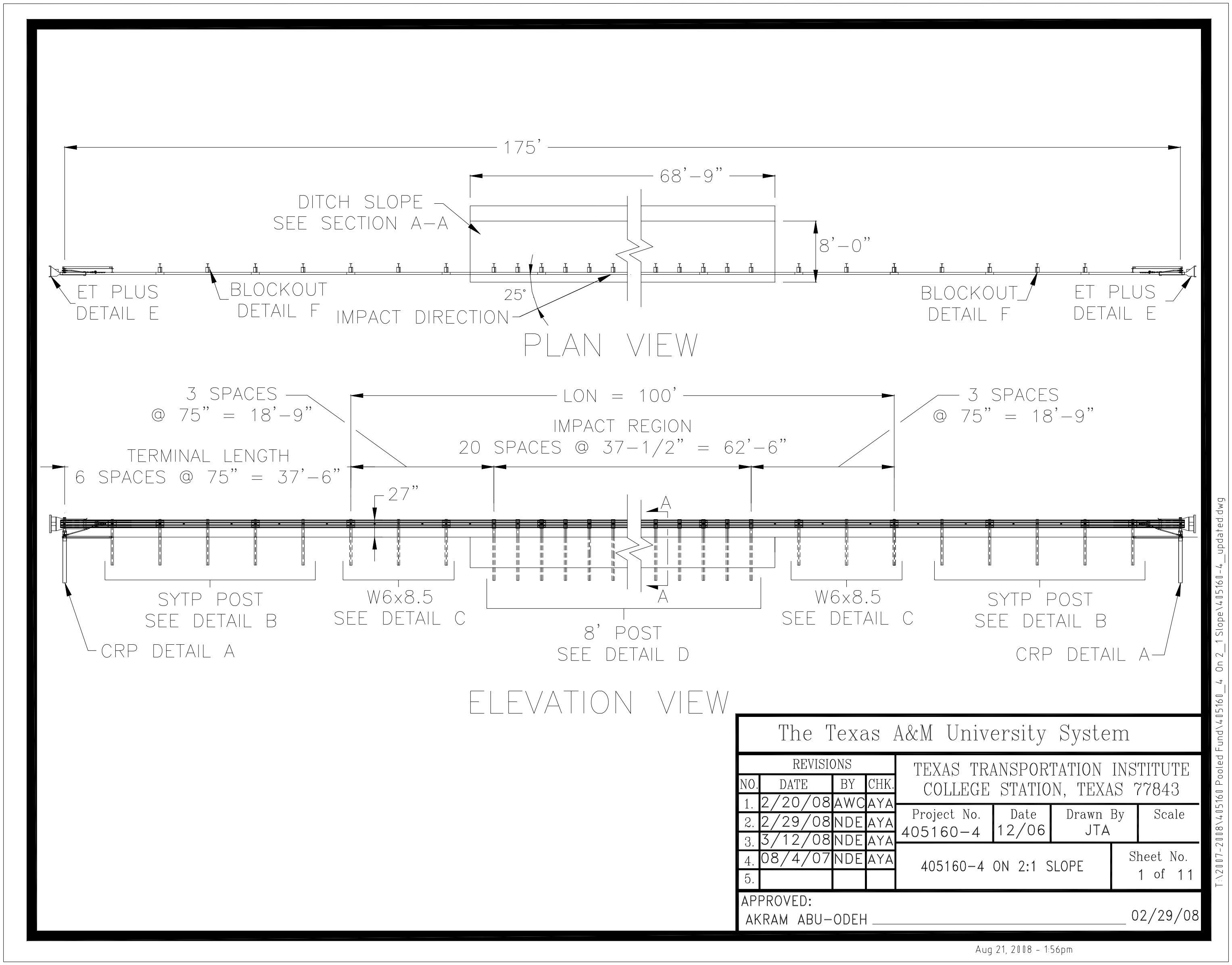


Figure 3.1. Details of guardrail on 2H:1V slope.

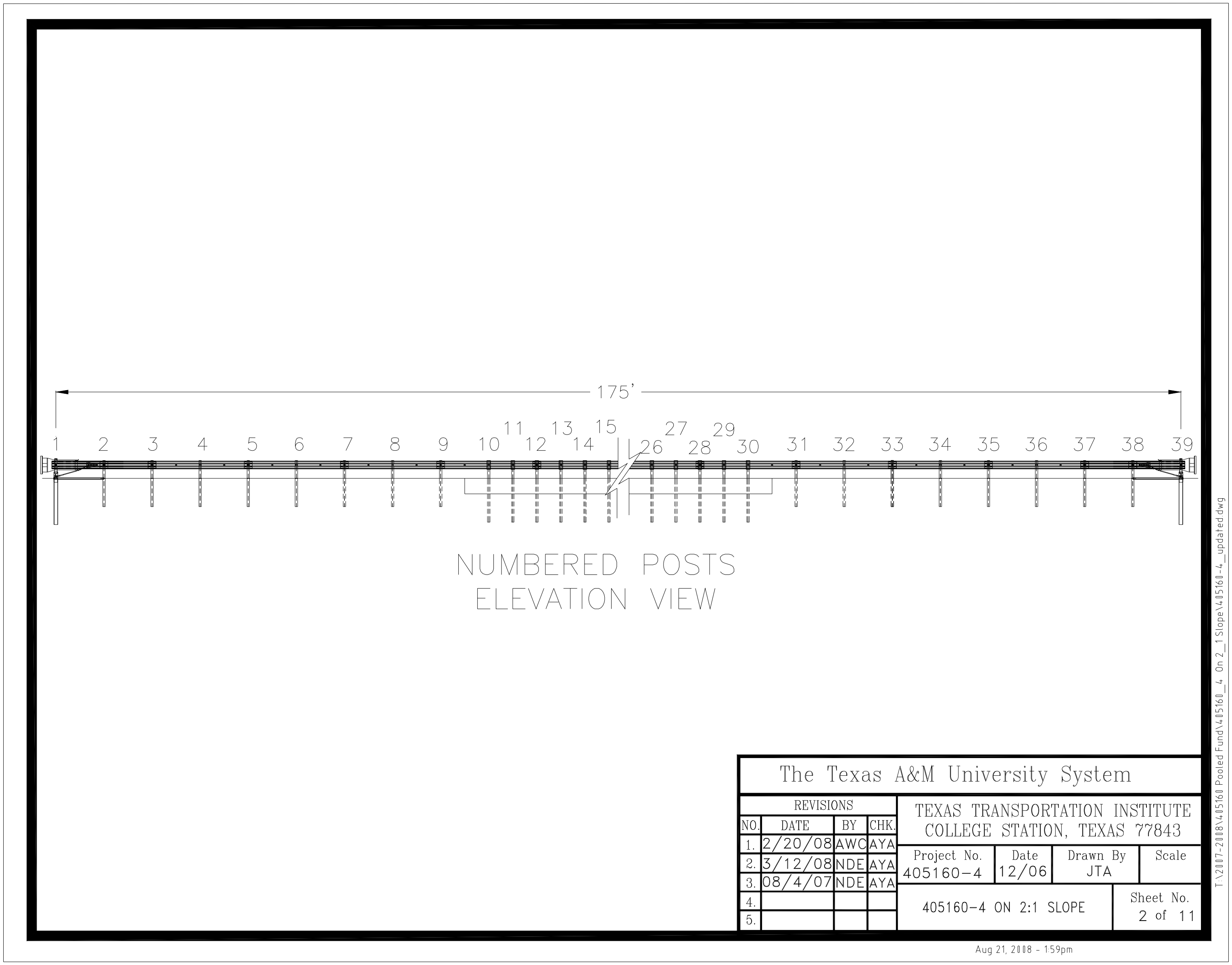


Figure 3.2. Post layout.

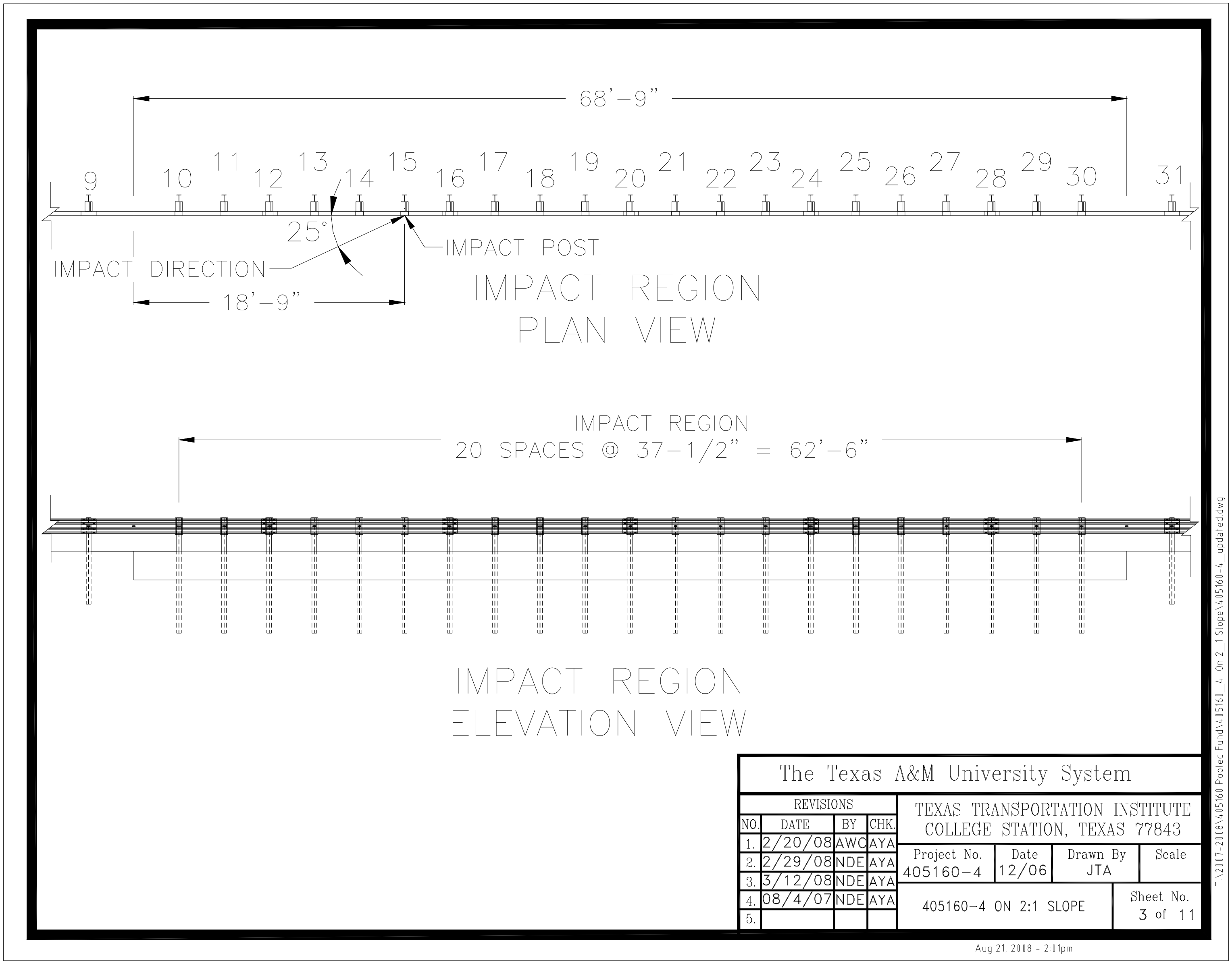


Figure 3.3. Detail of impact region.

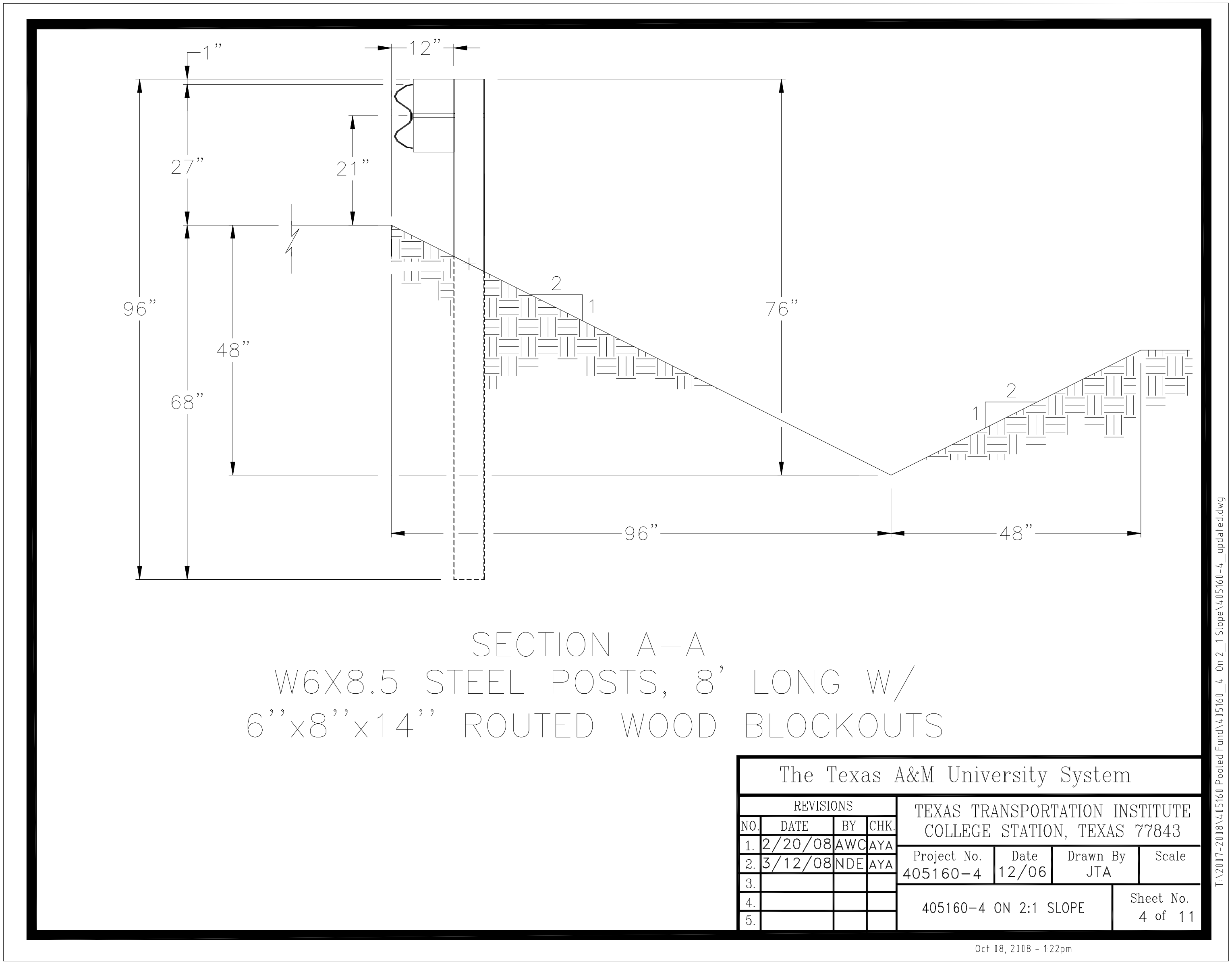


Figure 3.4. Cross section of guardrail on 2H:1V slope.

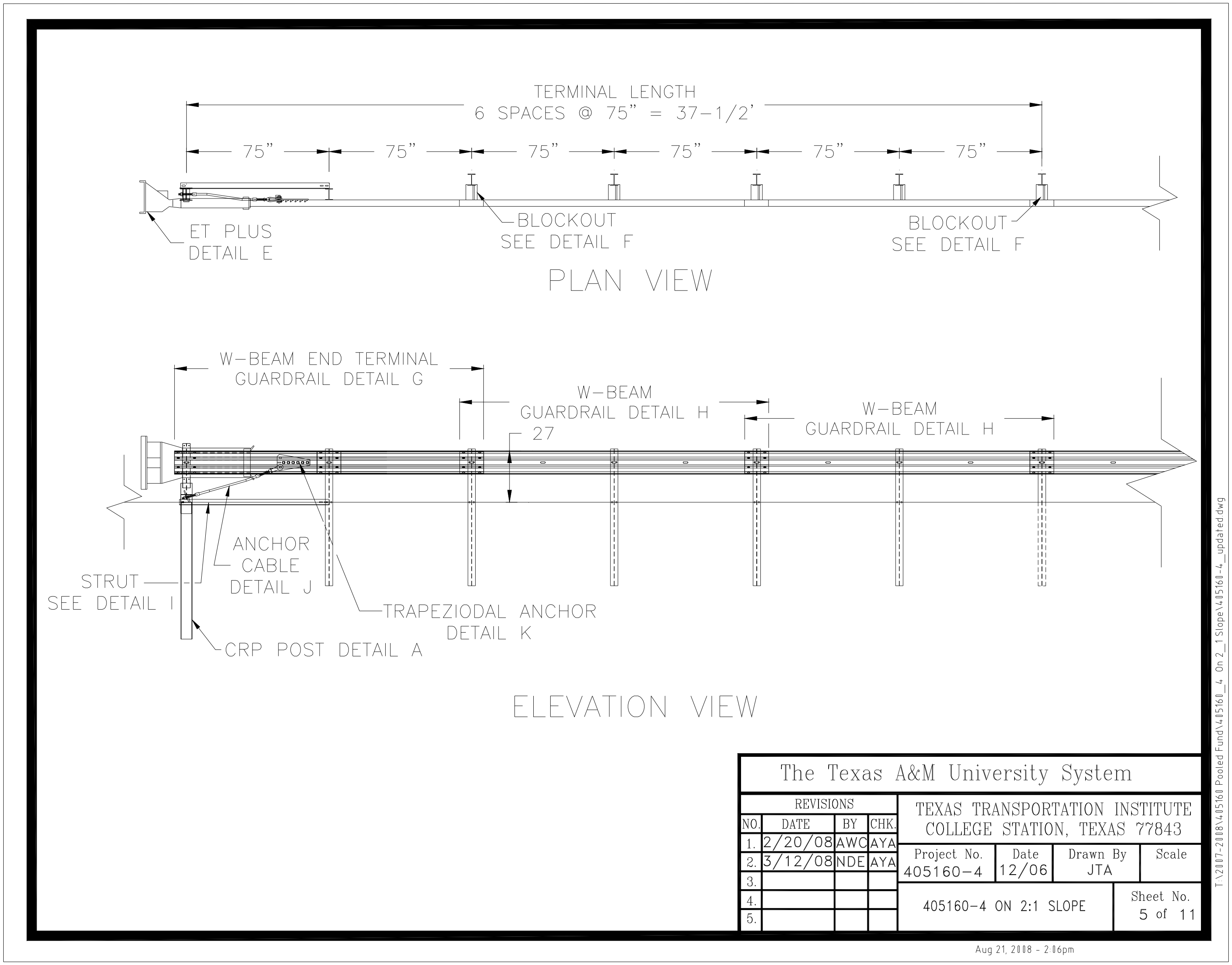


Figure 3.5. Terminal section detail.

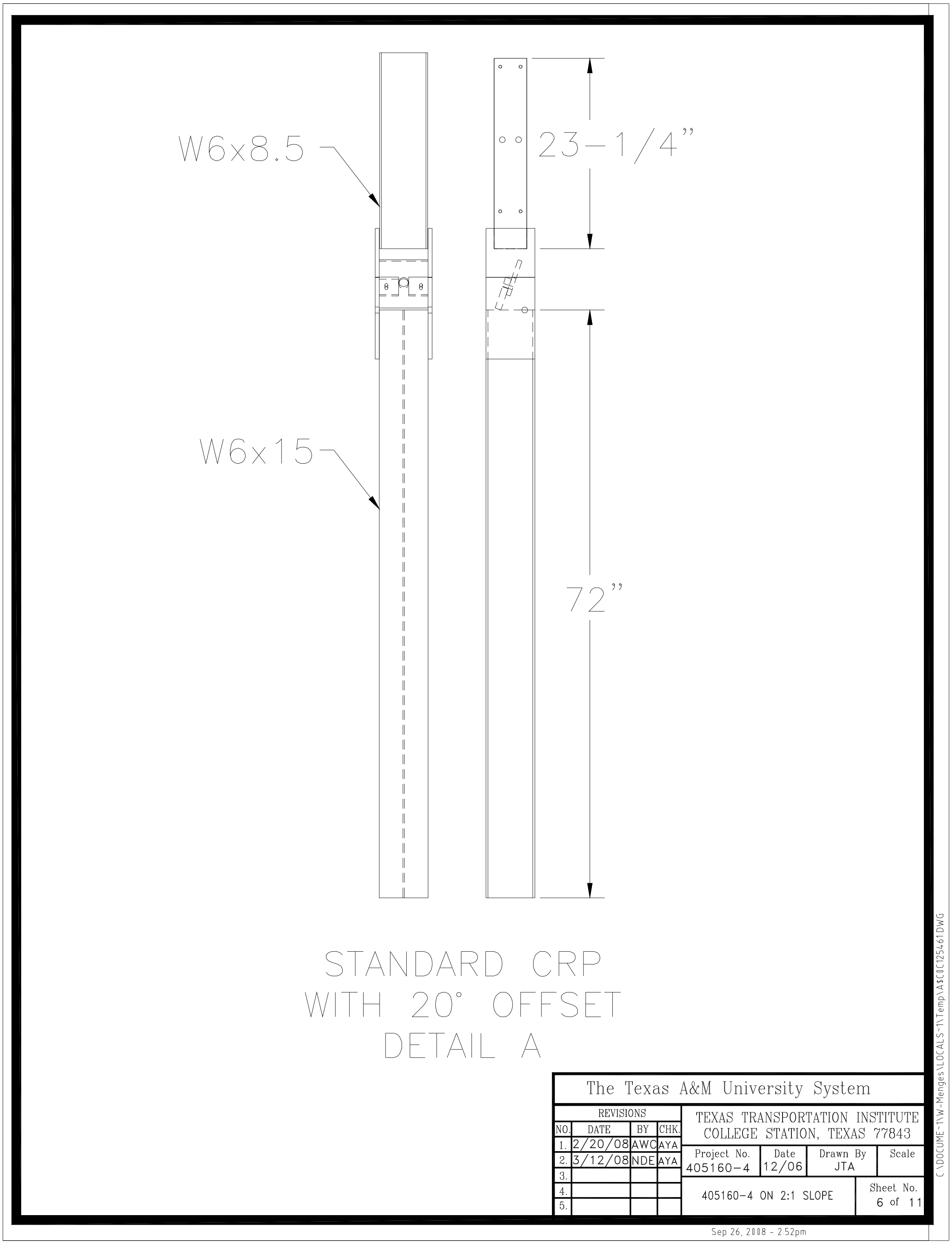


Figure 3.6. Standard CRP post detail.

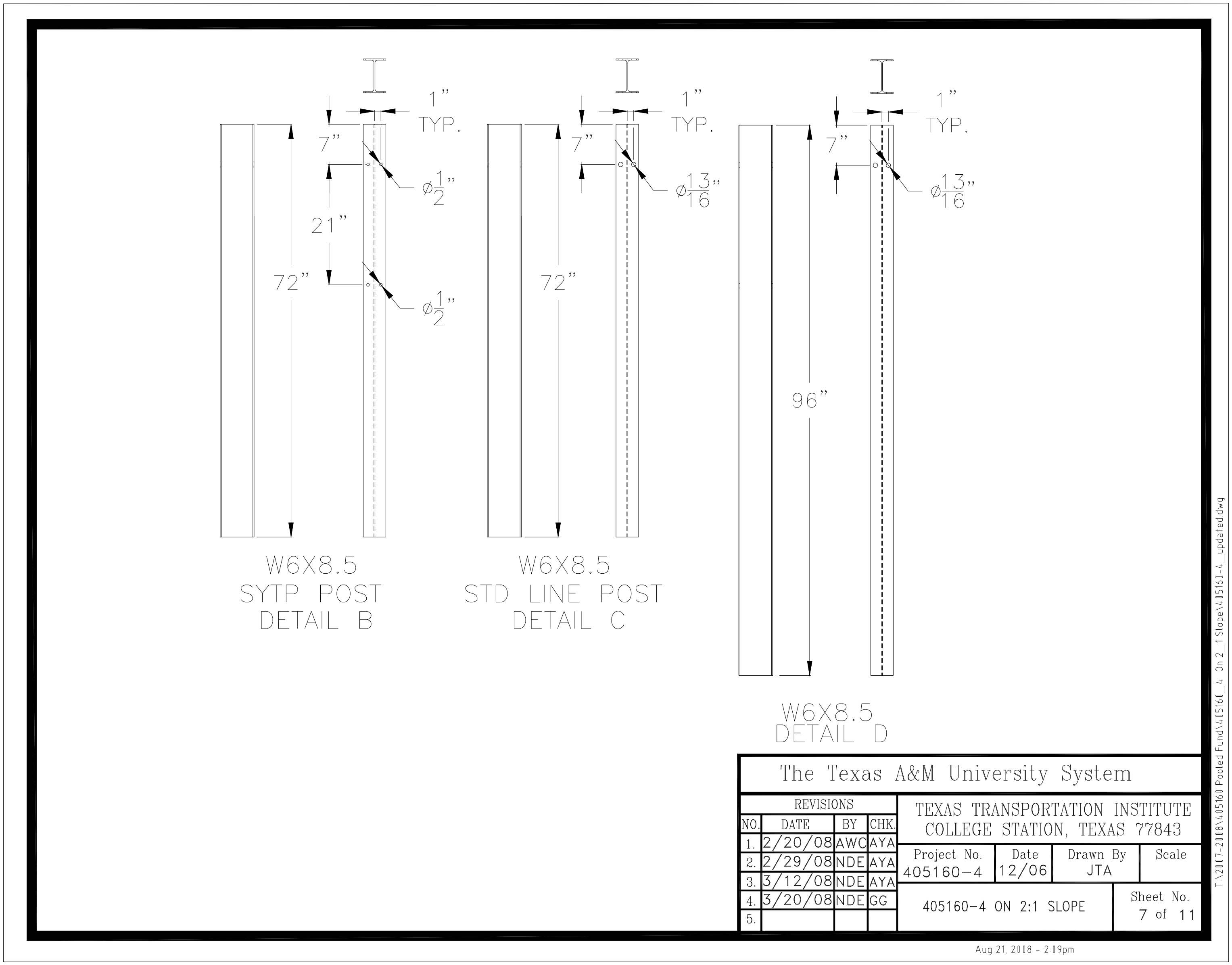


Figure 3.7. Post details.

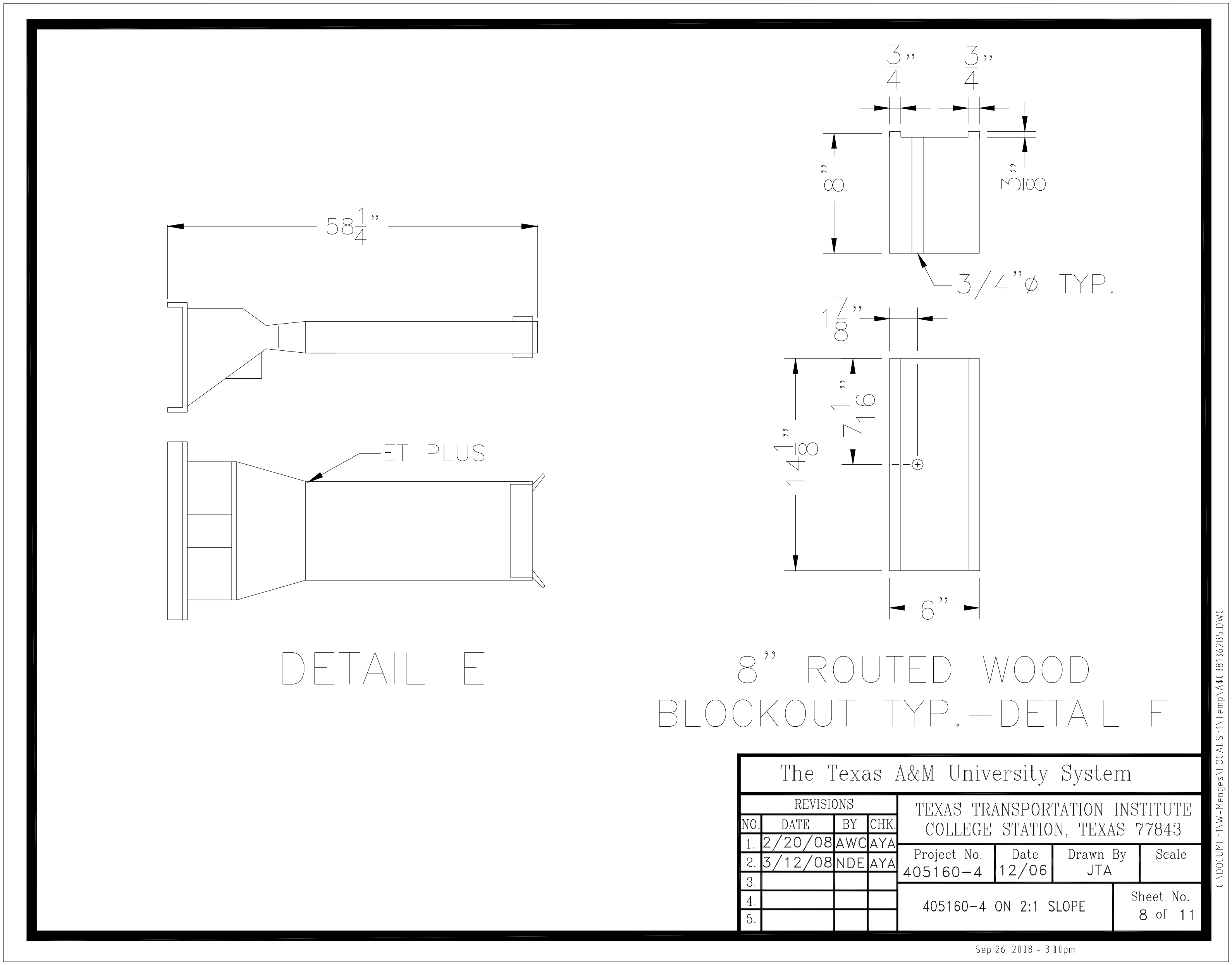


Figure 3.8. ET PLUS head and 8-inch block details.

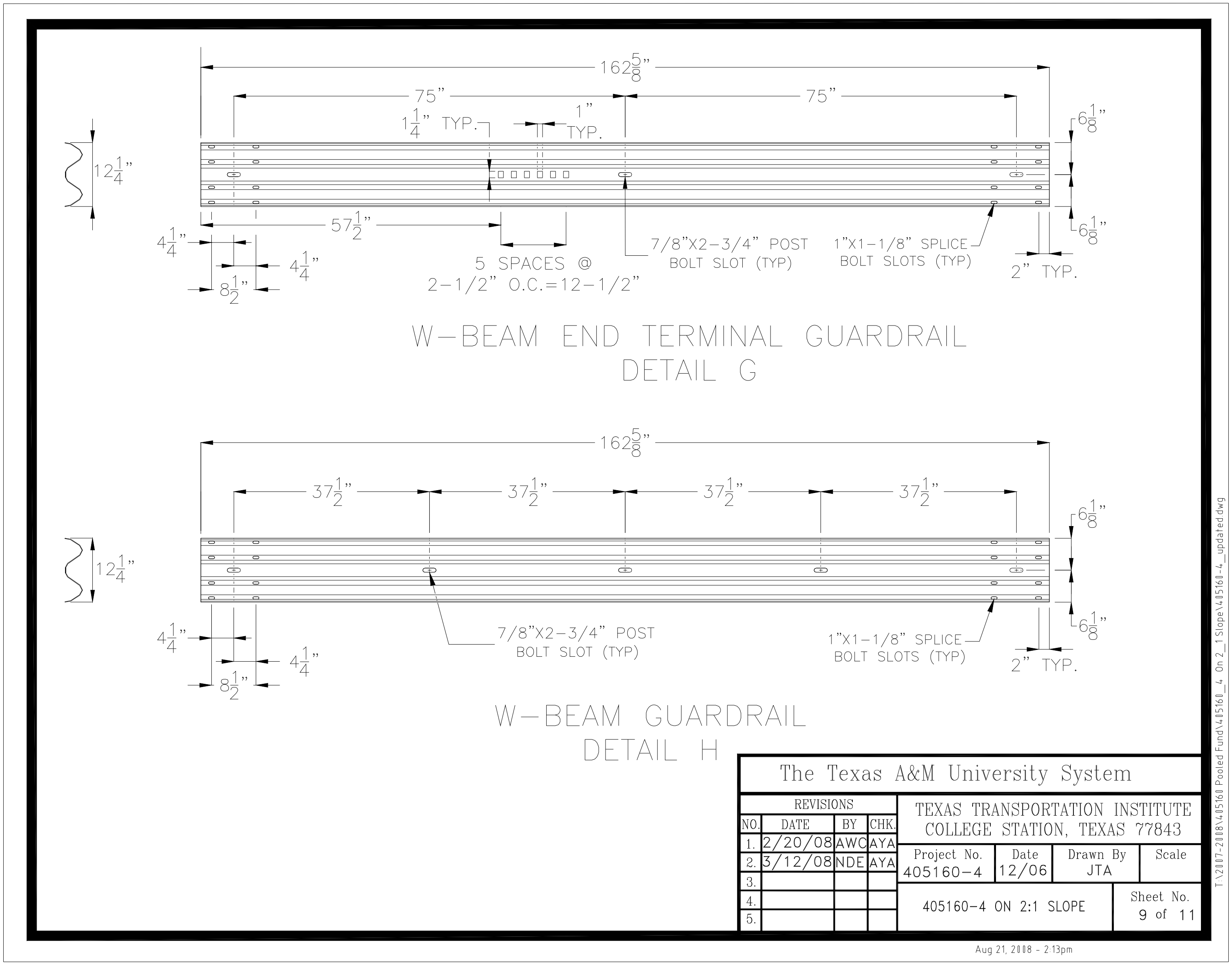


Figure 3.9. W-Beam rail element details.

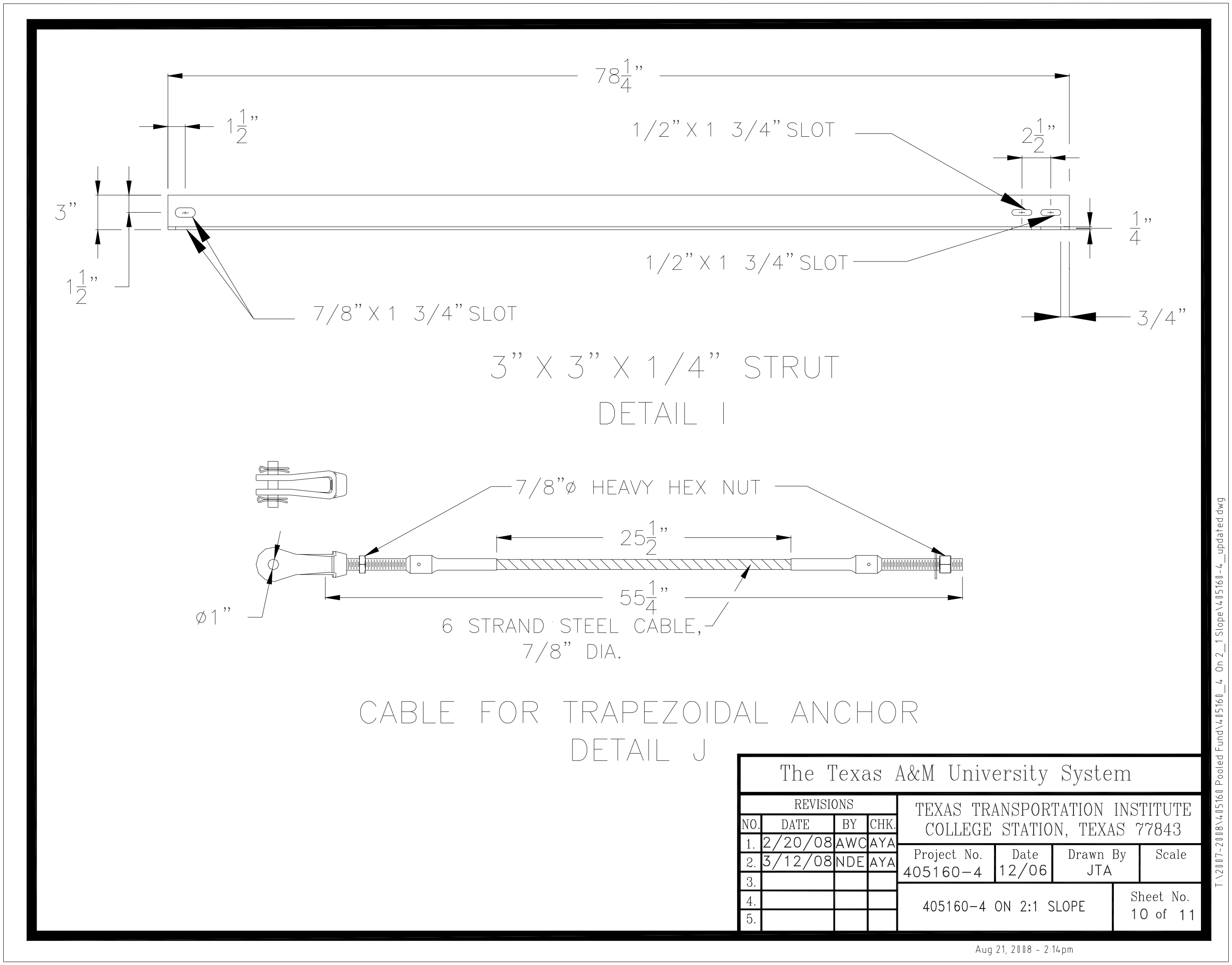


Figure 3.10. Strut and cable anchor details.

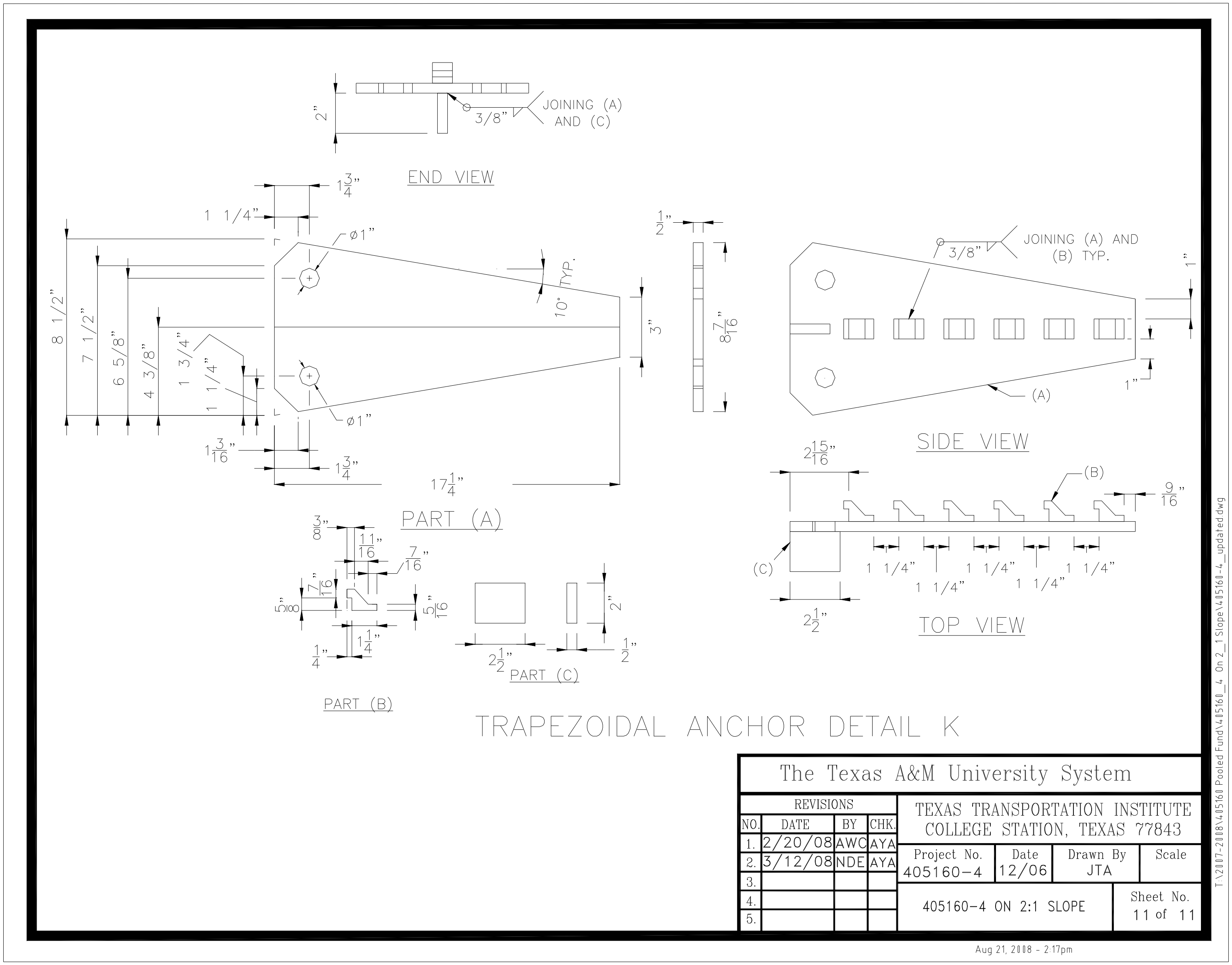


Figure 3.11. Anchor bracket details.

Figure 3.12. Guardrail on 2H:1V slope prior to testing.

3.1.3 Test Conditions

According to *NCHRP Report 350*, two tests are recommended to evaluate longitudinal barriers to test level three (TL-3) as described below.

> ***NCHRP Report 350* Test Designation 3-10:** 1808 lb vehicle impacting the critical impact point (CIP) of the length of need section at a speed of 62 mi/h and an angle of 20 degrees.
>
> ***NCHRP Report 350* Test Designation 3-11:** 4409 lb pickup truck impacting the CIP of the length of need section at a speed of 62 mi/h and an angle of 25 degrees.

The researchers performed *NCHRP Report 350* test 3-11 on the selected design. It is believed this is the critical test for this design and that test 3-10 is not required. Target CIP for *NCHRP Report 350* test 3-11 was post 15, or the sixth post from the beginning of the ditch, as shown in figure 3.13.

The crash test and data analysis procedures were in accordance with guidelines presented in *NCHRP Report 350*. Appendix A presents brief descriptions of these procedures.

3.1.4 Evaluation Criteria

The crash test was evaluated in accordance with the criteria presented in *NCHRP Report 350*. As stated in *NCHRP Report 350*, "Safety performance of a highway appurtenance cannot be measured directly but can be judged on the basis of three factors: structural adequacy, occupant risk, and vehicle trajectory after collision." Safety evaluation criteria from table 5.1 of *NCHRP Report 350* were used to evaluate the crash test reported herein.

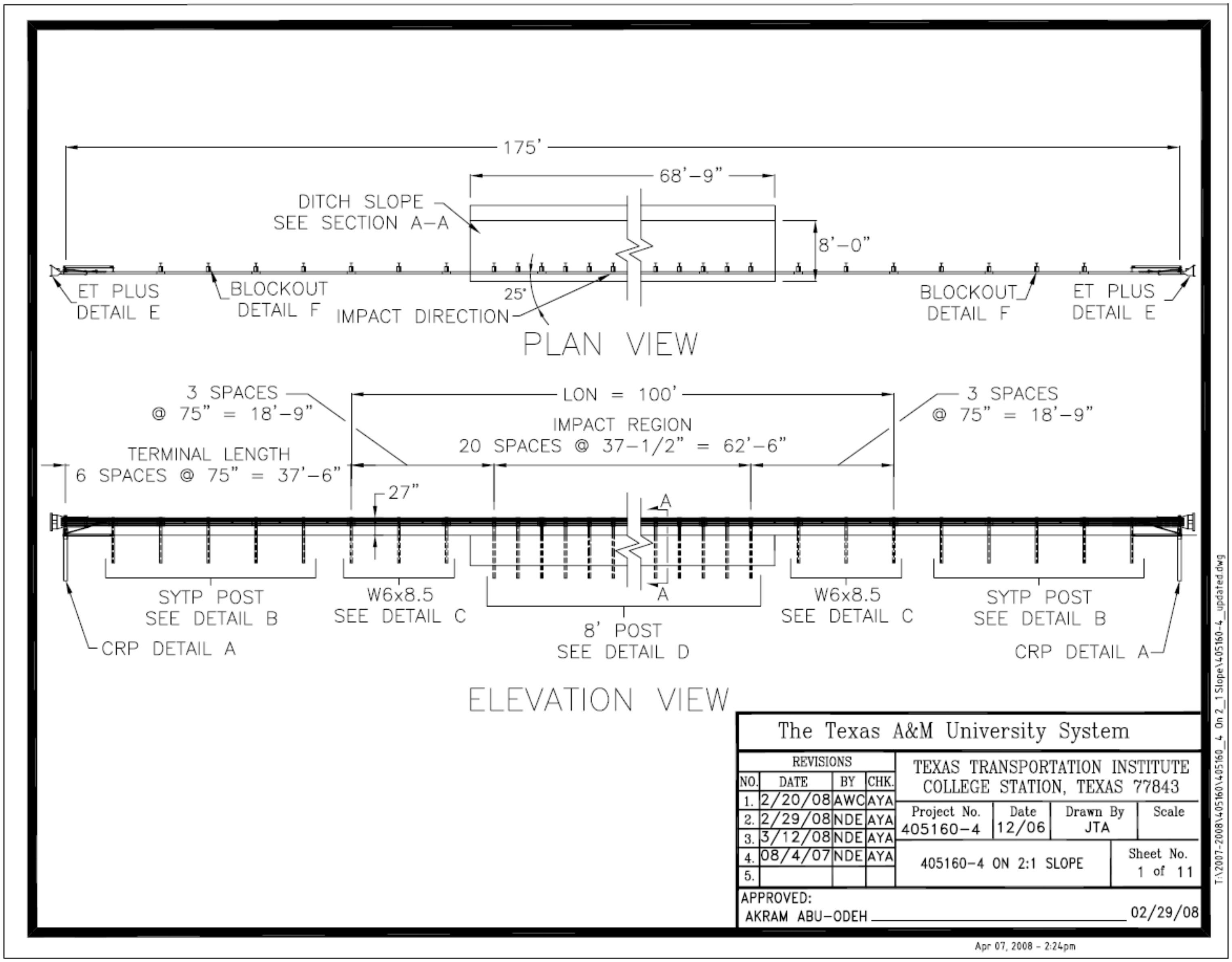


Figure 3.13. Target impact point for test on guardrail on 2H:1V slope.

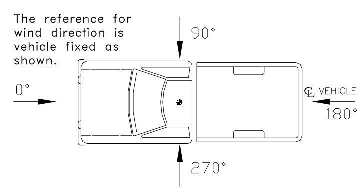
3.2 CRASH TEST 405160-4-1 (*NCHRP REPORT 350* TEST NO. 3-11)

3.2.1 Test Vehicle

A 2000 GMC C2500 pickup truck, shown in figures 3.14 and 3.15, was used for the crash test. Test inertia weight of the vehicle was 4610 lb, and its gross static weight was 4610 lb. The height to the lower edge of the vehicle front bumper was 16.25 inches, and the height to the upper edge of the front bumper was 25.0 inches. Additional dimensions and information on the vehicle are given in appendix B, figure B1. The vehicle was directed into the installation using the cable reverse tow and guidance system, and was released to be free-wheeling and unrestrained just prior to impact.

3.2.2 Soil and Weather Conditions

The crash test was performed the morning of April 16, 2008. No rainfall was recorded during the ten days prior to the test. Moisture content of the *NCHRP Report 350* soil in which the test article was installed was 6.5 percent. Weather conditions at the time of testing were: Wind speed: 16 mi/h; wind direction: 200 degrees with respect to the vehicle (vehicle was traveling in a northwesterly direction); temperature: 75 ºF; relative humidity: 54 percent.



3.2.3 Impact Description

The 2000 GMC C2500 pickup truck, traveling at a speed of 62.3 mi/h, impacted the guardrail on 2H:1V slope 5.9 inches downstream of post 15 at an impact angle of 25.1 degrees. At approximately 0.032 s after impact, the vehicle reached post 16, and by 0.059 s, the vehicle contacted post 17. The vehicle began to redirect at 0.066 s, and the vehicle contacted post 18 at 0.093 s. The W-beam rail element separated from post 17 and 18 at 0.102 s and 0.119 s, respectively. At 0.140 s, the vehicle contacted post 19, and at 0.176 s, post 20. The left rear of the vehicle contacted the W-beam rail element at 0.201 s, and the front of the vehicle contacted posts 21 and 22 at 0.213 s and 0.257 s, respectively. At 0.269 s, the vehicle began to travel parallel with the installation at a speed of 36.6 mi/h. The front of the vehicle contacted post 23 at 0.316 s, and the left front of the vehicle lost contact with the guardrail at 0.360 s. At 0.629 s, the left rear of the vehicle lost contact with the guardrail on 2H:1V slope, but was out of view and an exit speed and angle could not be obtained. As the vehicle exited the installation site, the vehicle rolled onto its left side. Sequential photographs of the test period are shown in appendix C, figures C1 and C2.

Figure 3.14. Vehicle/installation geometrics for test 405160-4-1.

Figure 3.15. Vehicle before test 405160-4-1.

3.2.4 Damage to Test Article

Damage to the guardrail on 2H:1V slope is shown in figures 3.16 and 3.17. Post 1 in the terminal was pulled downstream 0.2 inch, and no damage or movement was noted at posts 2-12. Post 13 was leaning toward the field side 88 degrees with a 0.4 inch gap in the soil on the traffic side at ground level. Post 14 was leaning toward the field side 86 degrees with a 1.1 inch gap in the soil on the traffic side at ground level. Post 15 was leaning toward the field side 85 degrees with a 2.75 inch gap in the soil on the traffic side and 0.4 inch gap on the field side at ground level. Post 16 was leaning toward the field side 78 degrees, 86 degrees downstream, rotated clockwise 25 degrees, with a 5.1 inch gap in the soil on the traffic side at ground level. The rail separated from post 17 and 18 and the posts leaned toward the field side 35 degrees, were rotated 45 degrees clockwise, with a 9.1 inch gap on the traffic side at ground level. The rail separated from post 19 and the post leaned toward the field side 50 degrees, was rotated 45 degrees clockwise, with an 11.8 inch gap on the traffic side at ground level.

The rail separated from post 20 and the post leaned toward the field side 70 degrees, was rotated 45 degrees clockwise, with a 9.1 inch gap on the traffic side at ground level. Also, the rail element was partially torn on the upstream side of the post at the splice bolts from the top to the midpoint. The rail separated from post 21 and the post leaned toward the field side 10 degrees, was rotated 45 degrees clockwise, and had a 8.9 inch gap on the traffic side and 3.1 on the downstream side at ground level. Post 22 was leaning toward traffic side 82 degrees with a 0.4 inch gap in the soil on the traffic side and 1.2 inch gap on the field side at ground level. Post 23 and 24 were leaning toward the field side 88 degrees with a 1.4 inch and 0.1 inch gap, respectively, in the soil on the traffic side at ground level. No damage or movement of the posts was noted at posts 25-37. The soil was disturbed around post 38, and post 39 was pulled downstream 0.2 inch. Working width was 4.01 ft. Maximum dynamic deflection during the test was 2.71 ft, and maximum permanent deflection was 1.90 ft.

3.2.5 Vehicle Damage

Damage to the vehicle is shown in figure 3.18. The left frame rail, left outer tie rod end, and transmission mount were deformed. Also damaged were the front bumper, grill, hood, left front fender, left door and door glass, left side of cab, left rear exterior bed, and left rear bumper. The left front wheel rim was deformed and the tire was deflated. A 15.7 inch long diagonal cut was in the door extending from just below the rear view mirror toward the lower rear corner. The upper portion of the left side of the vehicle was scuffed from rollover. Maximum exterior crush to the vehicle was 19.7 inches at the left front corner at bumper height. Maximum occupant compartment deformation was 0.8 inches in the lateral space across the floorpan from kickpanel to kickpanel. Photographs of the interior of the vehicle are shown in figure 3.19. Exterior vehicle crush and occupant compartment measurements are shown in appendix B, tables B1 and B2.

Figure 3.16. Vehicle trajectory path after test 405160-4-1.

Figure 3.17. Installation after test 405160-4-1.

After being uprighted

Figure 3.18. Vehicle after test 405160-4-1.

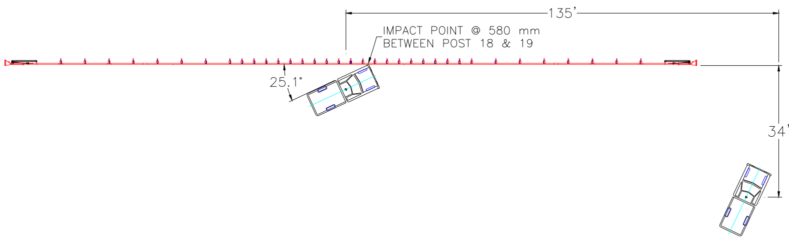
Before test

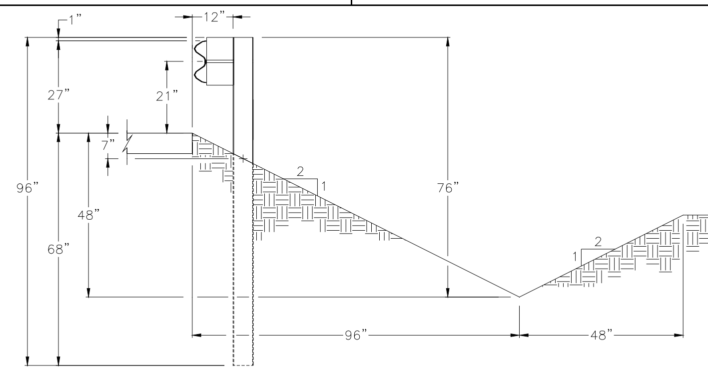
After test

Figure 3.19. Interior of vehicle for test 405160-4-1.

3.2.6 Occupant Risk Factors

Data from the triaxial accelerometer, located at the vehicle center of gravity, were digitized to compute occupant impact velocity and ridedown accelerations. Only the occupant impact velocity and ridedown accelerations in the longitudinal axis are required from these data for evaluation of criterion L of *NCHRP Report 350*. In the longitudinal direction, occupant impact velocity was 19.0 ft/s at 0.144 s, maximum 0.010-s ridedown acceleration was -10.2 g's from 0.152 to 0.162 s, and the maximum 0.050-s average was -6.4 g's between 0.112 and 0.162 s. In the lateral direction, the occupant impact velocity was 16.1 ft/s at 0.144 s, the highest 0.010-s occupant ridedown acceleration was 8.4 g's from 0.246 to 0.256 s, and the maximum 0.050-s average was 5.4 g's between 0.068 and 0.118 s. These data and other information pertinent to the test are presented in figure 3.20. Vehicle angular displacements and accelerations versus time traces are shown in appendix D, figures D1 through D7.





General Information	
Test Agency	Texas Transportation Institute
Test No.	405160-4-1
Date	2008-04-16
Test Article	
Type	Longitudinal Barrier
Name	Guardrail on 2H:1V Slope
Installation Length (ft)	175.0
Material or Key Elements	12 gauge W-Beam Mounted on W6x8.5 Steel Posts on 2H:1V Slope
Soil Type and Condition	Standard Soil, 6.5% Moisture Content
Test Vehicle	
Designation	2000P
Model	2000 GMC C2500 Pickup
Mass (lb)	
Curb	4731
Test Inertial	4610
Dummy	No dummy
Gross Static	4610

Impact Conditions	
Speed (mi/h)	62.3
Angle (deg)	25.1
Exit Conditions	
Speed (mi/h)	Out of
Angle (deg)	View
Occupant Risk Values	
Impact Velocity (ft/s)	
Longitudinal	19.0
Lateral	16.1
THIV (km/h)	24.9
Ridedown Accelerations (g's)	
Longitudinal	-10.2
Lateral	8.4
PHD (g's)	11.9
ASI	0.76
Max. 0.050-s Average (g's)	
Longitudinal	-6.4
Lateral	5.4
Vertical	2.9

Test Article Deflections (ft)	
Dynamic	2.71
Permanent	1.90
Working Width	4.01
Vehicle Damage	
Exterior	
VDS	11LFQ4
CDC	11LFEW4
Max. Exterior Vehicle Crush (inches)	19.7
Interior	
OCDI	LF0000000
Max. Occupant Compartment Deformation (inches)	0.8
Post-Impact Behavior	
(during 1.0 sec after impact)	
Max. Yaw Angle (deg)	137
Max. Pitch Angle (deg)	-22
Max. Roll Angle (deg)	-117

Figure 3.20. Summary of results for *NCHRP Report 350* test 3-11 on guardrail on 2H:1V slope.

4. SUMMARY AND CONCLUSIONS

4.1 ASSESSMENT OF CRASH TEST RESULTS

An assessment of the test based on applicable *NCHRP Report 350* safety evaluation criteria is presented below.

4.1.1 Structural Adequacy

A. Test article should contain and redirect the vehicle; the vehicle should not penetrate, underride, or override the installation although controlled lateral deflection of the test article is acceptable.

Results: The guardrail on 2H:1V slope contained and redirected the 2000P vehicle. The 2000P vehicle did not penetrated, underride, or override the installation. Maximum dynamic deflection of the W-beam rail element during the test was 2.71 ft. (PASS)

4.1.2 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. Deformation of, or intrusions into, the occupant compartment that could cause serious injuries should not be permitted.

Results: No detached elements, fragments, or other debris were present to penetrate, or show potential for penetrating the occupant compartment, or to present hazard to others in the area. Maximum occupant compartment deformation was 0.8 inches in the lateral space across the floorpan from kickpanel to kickpanel. (PASS)

F. The vehicle should remain upright during and after collision although moderate roll, pitching, and yawing are acceptable.

Results: The vehicle remained upright during the initial impact period with the guardrail on 2H:1V slope. However, after exiting the installation, the vehicle rolled onto its left side. (FAIL)

4.1.3 Vehicle Trajectory

K. After collision, it is preferable that the vehicle's trajectory not intrude into adjacent traffic lanes.

Result: The vehicle intruded into adjacent traffic lanes as it came to rest on its left side 135 ft downstream of impact and 34 ft forward of the traffic face of the rail. (FAIL)

L. *The occupant impact velocity in the longitudinal direction should not exceed 12 m/s* [39.4 ft/s] *and the occupant ridedown acceleration in the longitudinal direction should not exceed 20 g's.*

<u>Result</u>: Longitudinal occupant impact velocity was 19.0 ft/s and longitudinal ridedown acceleration was -10.2 g/s. (PASS)

M. *The exit angle from the test article preferably should be less than 60 percent of the test impact angle, measured at time of vehicle loss of contact with the test device.*

<u>Result</u>: Exit angle at loss of contact was not obtainable. (N/A)

The following supplemental evaluation factors and terminology, as presented in the FHWA memo entitled "Action: Identifying Acceptable Highway Safety Features," were used for visual assessment of test results: [7]

Passenger Compartment Intrusion

1. Windshield Intrusion

- *<u>a. No windshield contact</u>*
- *b. Windshield contact, no damage*
- *c. Windshield contact, no intrusion*
- *d. Device embedded in windshield, no significant intrusion*
- *e. Complete intrusion into passenger compartment*
- *f. Partial intrusion into passenger compartment*

2. Body Panel Intrusion *<u>yes</u>* *or* *no*

Loss of Vehicle Control

<u>1. Physical loss of control</u>
2. Loss of windshield visibility
3. Perceived threat to other vehicles
4. Debris on pavement

Physical Threat to Workers or Other Vehicles

1. Harmful debris that could injure workers or others in the area
2. Harmful debris that could injure occupants in other vehicles
<u>No debris was present.</u>

Vehicle and Device Condition

1. Vehicle Damage

- *a. None*
- *b. Minor scrapes, scratches or dents*
- *c. Significant cosmetic dents*
- *d. Major dents to grill and body panels*
- *<u>e. Major structural damage</u>*

2. Windshield Damage

- *<u>a. None</u>*
- *b. Minor chip or crack*
- *c. Broken, no interference with visibility*
- *d. Broken or shattered, visibility restricted but remained intact*
- *e. Shattered, remained intact but partially dislodged*
- *f. Large portion removed*
- *g. Completely removed*

3. *Device Damage*
   a. *None*
   b. *Superficial*
   c. *Substantial, but can be straightened*
   d. *Substantial, replacement parts needed for repair*
   e. *Cannot be repaired*

4.2 CONCLUSIONS

Based on the results of the simulation effort, a candidate guardrail design was selected for crash testing. The design was a W-beam (12 gauge) guardrail system with 8-ft posts placed on a 2H:1V slope. The posts were placed 1-ft off the slope break and were spaced at 3 ft-1.5 inches (half the standard spacing for a common strong-post W-Beam guardrail).

In the full-scale crash test, the 2000P vehicle was contained and redirected. However, after exiting the installation, the vehicle rolled onto its left side and came to rest on its left side 135 ft downstream of impact and 34 ft forward of the traffic face of the rail. Due to this rollover event, the guardrail on 2H:1V slope did not meet the criteria for *NCHRP Report 350* test 3-11, as shown in table 4.1.

Table 4.1. Performance evaluation summary for *NCHRP Report 350* test 3-11 on guardrail on 2H:1V slope.

Test Agency: Texas Transportation Institute | Test No.: 405160-4-1 | Test Date: 2008-04-16

NCHRP Report 350 **3-11 Evaluation Criteria**	**Test Results**	**Assessment**
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*	The guardrail on 2H:1V slope contained and redirected the 2000P vehicle. The 2000P vehicle did not penetrated, underride, or override the installation. Maximum dynamic deflection of the W-beam rail element during the test was 2.71 ft.	Pass
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.*	No detached elements, fragments, or other debris were present to penetrate, or show potential for penetrating the occupant compartment, or to present hazard to others in the area. Maximum occupant compartment deformation was 0.8 inches in the lateral space across the floorpan from kickpanel to kickpanel.	Pass
F. *The vehicle should remain upright during and after collision although moderate roll, pitching, and yawing are acceptable.*	The vehicle remained upright during the initial impact period with the guardrail on 2H:1V slope. However, after exiting the installation, the vehicle rolled onto its left side.	Fail
Vehicle Trajectory		
K. *After collision, it is preferable that the vehicle's trajectory not intrude into adjacent traffic lanes.*	The vehicle intruded into adjacent traffic lanes as it came to rest on its left side 135 ft downstream of impact and 34 ft forward of the traffic face of the rail.	Fail*
L. *The occupant impact velocity in the longitudinal direction should not exceed 12 m/s and the occupant ridedown acceleration in the longitudinal direction should not exceed 20 g's.*	Longitudinal occupant impact velocity was 19.0 ft/s and longitudinal ridedown acceleration was -10.2 g/s.	Pass
M. *The exit angle from the test article preferably should be less than 60 percent of test impact angle, measured at time of vehicle loss of contact with test device.*	Exit angle at loss of contact was not obtainable.	N/A*

*Criterion K and M are preferable, not required.

REFERENCES

1. American Association of State Highway and Transportation Officials (AAHSTO), *Roadside Design Guide*, Washington, D.C., 2002.

2. Polivka, K. A., *e .al*. “Development of a W-Beam Guardrail System for Use on a 2:1 Slope”, Midwest Roadside Safety Facility, October 16, 2000.

3. Stout, D., *et al* “Force-Deflection Characteristics of Guardrail Posts”, Report FHWA-RD-88-193, Performed by ENSCO, Inc., August 31, 1988.

4. J. D. Michie, *Recommended Procedures for the Safety Performance Evaluation of Highway Appurtenances*, National Cooperative Highway Research Program Report 230, Transportation Research Board, National Research Council, Washington, D.C., March 1981.

5. H.E. Ross, Jr., D.L. Sicking, R.A. Zimmer and J.D. Michie, *Recommended Procedures for the Safety Performance Evaluation of Highway Features*, National Cooperative Highway Research Program Report 350, Transportation Research Board, National Research Council, Washington, D.C., 1993.

6. Design Manual M 22-01, Chapter 710 “Traffic Barriers”, Washington State DOT, January 2005.

7. Federal Highway Administration Memorandum, from the Director, Office of Engineering, entitled: “ACTION: Identifying Acceptable Highway Safety Features,” dated July 25, 1997.

APPENDIX A. CRASH TEST PROCEDURES AND DATA ANALYSIS

The crash test and data analysis procedures were in accordance with guidelines presented in *NCHRP Report 350*. Brief descriptions of these procedures are presented as follows.

A1. ELECTRONIC INSTRUMENTATION AND DATA PROCESSING

The test vehicle was instrumented with three solid-state angular rate transducers to measure roll, pitch, and yaw rates; a triaxial accelerometer near the vehicle center of gravity (c.g.) to measure longitudinal, lateral, and vertical acceleration levels; and a backup biaxial accelerometer in the rear of the vehicle to measure longitudinal and lateral acceleration levels. These accelerometers were ENDEVCO® Model 2262CA, piezoresistive accelerometers with a ±100 g range.

The accelerometers are strain gage type with a linear millivolt output proportional to acceleration. Angular rate transducers are solid state, gas flow units designed for high-“g” service. Signal conditioners and amplifiers in the test vehicle increase the low-level signals to a ±2.5 volt maximum level. The signal conditioners also provide the capability of an R-cal (resistive calibration) or shunt calibration for the accelerometers and a precision voltage calibration for the rate transducers. The electronic signals from the accelerometers and rate transducers are transmitted to a base station by means of a 15-channel, constant-bandwidth, Inter-Range Instrumentation Group (IRIG), FM/FM telemetry link for recording and for display. Calibration signals from the test vehicle are recorded before the test and immediately afterwards. A crystal-controlled time reference signal is simultaneously recorded with the data. Wooden dowels actuate pressure-sensitive switches on the bumper of the impacting vehicle prior to impact by wooden dowels to indicate the elapsed time over a known distance to provide a measurement of impact velocity. The initial contact also produces an “event” mark on the data record to establish the instant of contact with the installation.

The multiplex of data channels, transmitted on one radio frequency, is received and demultiplexed onto TEAC® instrumentation data recorder. After the test, the data are played back from the TEAC® recorder and digitized. A proprietary software program (WinDigit) converts the analog data from each transducer into engineering units using the R-cal and pre-zero values at 10,000 samples per second, per channel. WinDigit also provides Society of Automotive Engineers (SAE) J211 class 180 phaseless digital filtering and vehicle impact velocity.

All accelerometers are calibrated annually according to the (SAE) J211 *4.6.1* by means of an ENDEVCO® 2901, precision primary vibration standard. This device and its support instruments are returned to the factory annually for a National Institute of Standards Technology (NIST) traceable calibration. The subsystems of each data channel are also evaluated annually, using instruments with current NIST traceability, and the results are factored into the accuracy of the total data channel, per SAE J211. Calibrations and evaluations are made any time data are suspect.

The Test Risk Assessment Program (TRAP) uses the data from WinDigit to compute occupant/compartment impact velocities, time of occupant/compartment impact after vehicle impact, and the highest 10-milliseconds (ms) average ridedown acceleration. WinDigit calculates change in vehicle velocity at the end of a given impulse period. In addition, maximum average accelerations over 50-ms intervals in each of the three directions are computed. For reporting purposes, the data from the vehicle-mounted accelerometers are filtered with a 60-Hz digital filter, and acceleration versus time curves for the longitudinal, lateral, and vertical directions are plotted using TRAP.

TRAP uses the data from the yaw, pitch, and roll rate transducers to compute angular displacement in degrees at 0.0001-s intervals and then plots yaw, pitch, and roll versus time. These displacements are in reference to the vehicle-fixed coordinate system with the initial position and orientation of the vehicle-fixed coordinate systems being initial impact.

A2. ANTHROPOMORPHIC DUMMY INSTRUMENTATION

Use of a dummy in the 2000P vehicle is optional according to *NCHRP Report 350*, and there was no dummy used in the tests with the 2000P vehicle.

A3. PHOTOGRAPHIC INSTRUMENTATION AND DATA PROCESSING

Photographic coverage of the test included three high-speed cameras: one overhead with a field of view perpendicular to the ground and directly over the impact point; one placed behind the installation at an angle; and a third placed to have a field of view parallel to and aligned with the installation at the downstream end. A flashbulb activated by pressure-sensitive tape switches was positioned on the impacting vehicle to indicate the instant of contact with the installation and was visible from each camera. The films from these high-speed cameras were analyzed on a computer-linked motion analyzer to observe phenomena occurring during the collision and to obtain time-event, displacement, and angular data. A mini-DV video camera and still cameras recorded and documented conditions of the test vehicle and installation before and after the test.

A4. TEST VEHICLE PROPULSION AND GUIDANCE

The test vehicle was towed into the test installation using a steel cable guidance and reverse tow system. A steel cable for guiding the test vehicle was tensioned along the path, anchored at each end, and threaded through an attachment to the front wheel of the test vehicle. An additional steel cable was connected to the test vehicle, passed around a pulley near the impact point, through a pulley on the tow vehicle, and then anchored to the ground such that the tow vehicle moved away from the test site. A two-to-one speed ratio between the test and tow vehicle existed with this system. Just prior to impact with the installation, the test vehicle was released to be free-wheeling and unrestrained. The vehicle remained free-wheeling, i.e., no steering or braking inputs, until the vehicle cleared the immediate area of the test site, at which time brakes on the vehicle were activated to bring it to a safe and controlled stop.

APPENDIX B. TEST VEHICLE PROPERTIES AND INFORMATION

Vehicle Inventory Number: 774

Date: 2008-04-16 Test No.: 405160-4-1 VIN No.: 1GTGC24R8YR162296

Year: 2000 Make: GMC Model: C2500

Tire Inflation Pressure: 60 psi Odometer: 216692 Tire Size: 245 75R16

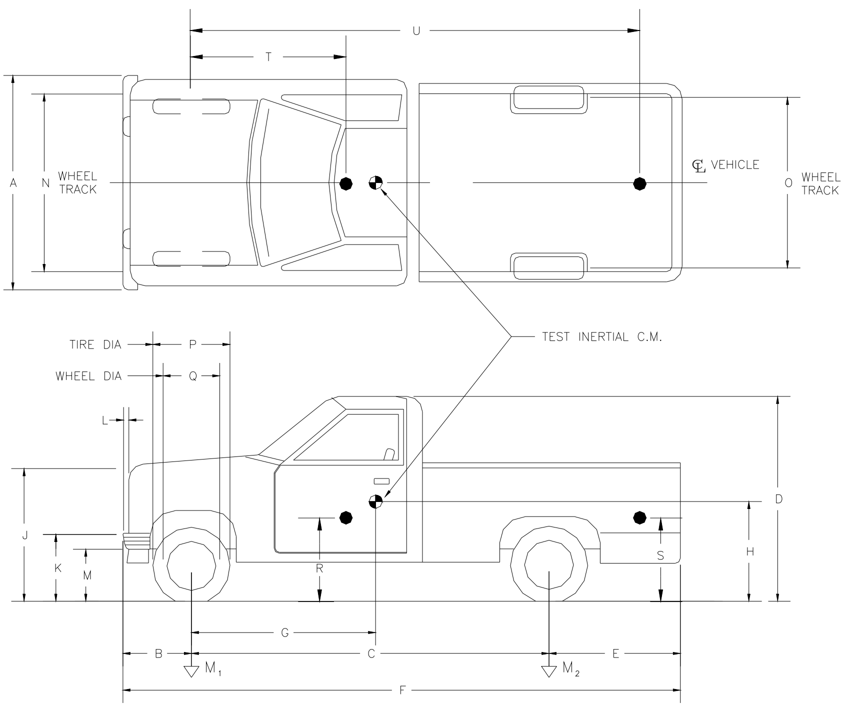
Describe any damage to the vehicle prior to test:

● Denotes accelerometer location.

NOTES:
8-lug

Engine Type: V8
Engine CID: 5.7 liter
Transmission Type:
x Auto
Manual
Optional Equipment:

Dummy Data:
Type: No dummy
Mass:
Seat Position:



Geometry (inches)

A	74.00	E	51.57	J	40.87	N	62.60	R	29.50
B	32.00	F	215.35	K	25.00	O	63.40	S	35.43
C	132.00	G	56.14	L	2.75	P	28.50	T	57.50
D	71.65	H		M	16.34	Q	17.32	U	132.28

Mass (lb)	Curb	Test Inertial	Gross Static
M_1	2712	2648	
M_2	2019	1962	
M_{Total}	4731	4610	

Mass Distribution (lb): LF: 1318 RF: 1329 LR: 955 RR: 1008

Figure B1. Vehicle properties for test 405160-4-1.

Table B1. Exterior crush measurements for test 405160-4-1.

Vehicle Inventory Number: 774

Date:	2008-04-16	Test No.:	405160-4-1	VIN No.:	1GTGC24R8YR162296
Year:	2000	Make:	GMC	Model:	C2500

VEHICLE CRUSH MEASUREMENT SHEET[1]

Complete When Applicable	
End Damage	Side Damage
Undeformed end width ________	Bowing: B1 _____ X1 _____
Corner shift: A1 ________	B2 _____ X2 _____
A2 ________	
End shift at frame (CDC)	Bowing constant
(check one)	$\frac{X1+X2}{2}$ = _______
< 4 inches ________	
≥ 4 inches ________	

Note: Measure C_1 to C_6 from Driver to Passenger side in Front or Rear impacts – Rear to Front in Side Impacts.

Specific Impact Number	Plane* of C-Measurements	Direct Damage		Field L**	C_1	C_2	C_3	C_4	C_5	C_6	±D
		Width** (CDC)	Max*** Crush								
1	Front plane at bumper ht	19.7	15.75	25.6	19.7	13.0	8.5	3.5	2.4	0	-12.8
2	Side plane at bumper ht	19.7	12.60	43.3	0	1.65	---	---	9.8	12.6	

[1]Table taken from National Accident Sampling System (NASS).

*Identify the plane at which the C-measurements are taken (e.g., at bumper, above bumper, at sill, above sill, at beltline, etc.) or label adjustments (e.g., free space).

Free space value is defined as the distance between the baseline and the original body contour taken at the individual C locations. This may include the following: bumper lead, bumper taper, side protrusion, side taper, etc. Record the value for each C-measurement and maximum crush.

**Measure and document on the vehicle diagram the beginning or end of the direct damage width and field L (e.g., side damage with respect to undamaged axle).

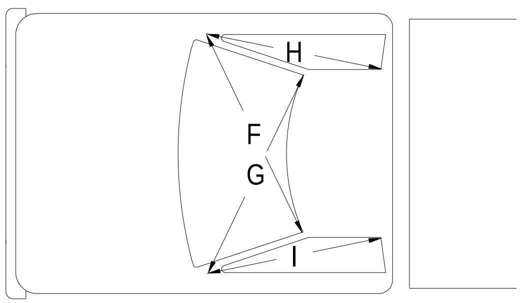
***Measure and document on the vehicle diagram the location of the maximum crush.

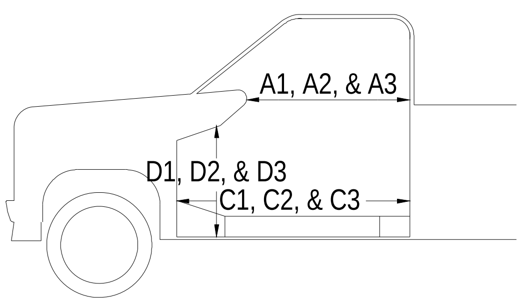
Note: Use as many lines/columns as necessary to describe each damage profile.

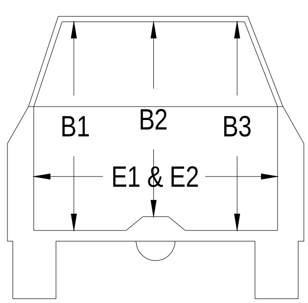
Table B2. Occupant compartment measurements for test 405160-4-1.

Vehicle Inventory Number: 774

Date:	2008-04-16	Test No.:	405160-4-1	VIN No.:	1GTGC24R8YR162296
Year:	2000	Make:	GMC	Model:	C2500







OCCUPANT COMPARTMENT
DEFORMATION MEASUREMENT

	Before (inches)	After (inches)
A1	34.25	34.25
A2	37.20	37.20
A3	36.61	36.61
B1	42.13	42.13
B2	37.32	37.32
B3	41.90	41.90
C1	53.94	53.94
C2	------	------
C3	53.94	53.94
D1	12.80	12.80
D2	6.14	6.14
D3	12.17	12.17
E1	62.48	61.65
E2	62.60	62.13
F	57.48	57.48
G	57.48	57.48
H	41.54	41.54
I	41.73	41.73
J*	59.92	59.57

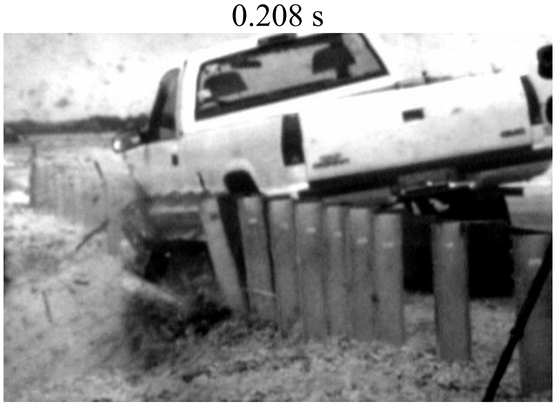
*Lateral area across the cab from
driver's side kickpanel to passenger's side kickpanel.

APPENDIX C. SEQUENTIAL PHOTOGRAPHS

0.000 s

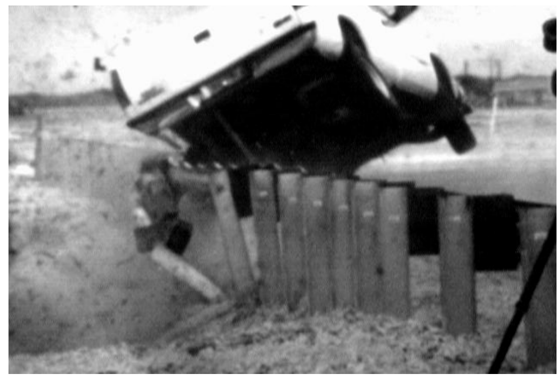
0.103 s

0.208 s

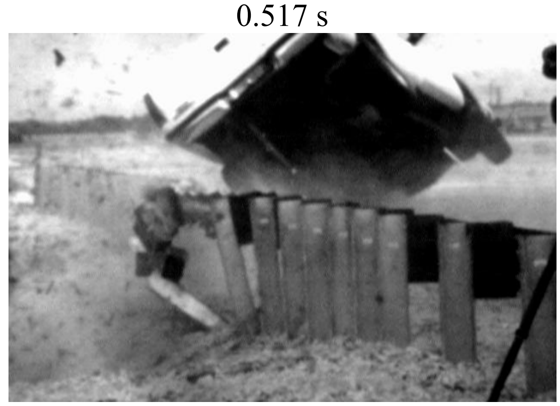


0.311 s

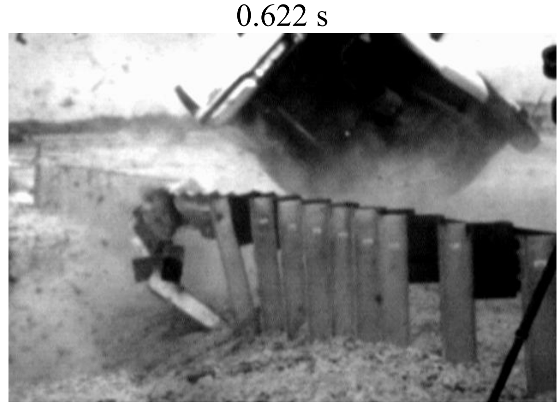
0.414 s



0.517 s



0.622 s



0.725 s

Figure C1. Sequential photographs for test 405160-4-1
(rear view).

0.000 s

0.103 s

0.208 s

0.311 s

Figure C2. Sequential photographs for test 405160-4-1
(overhead and frontal views).

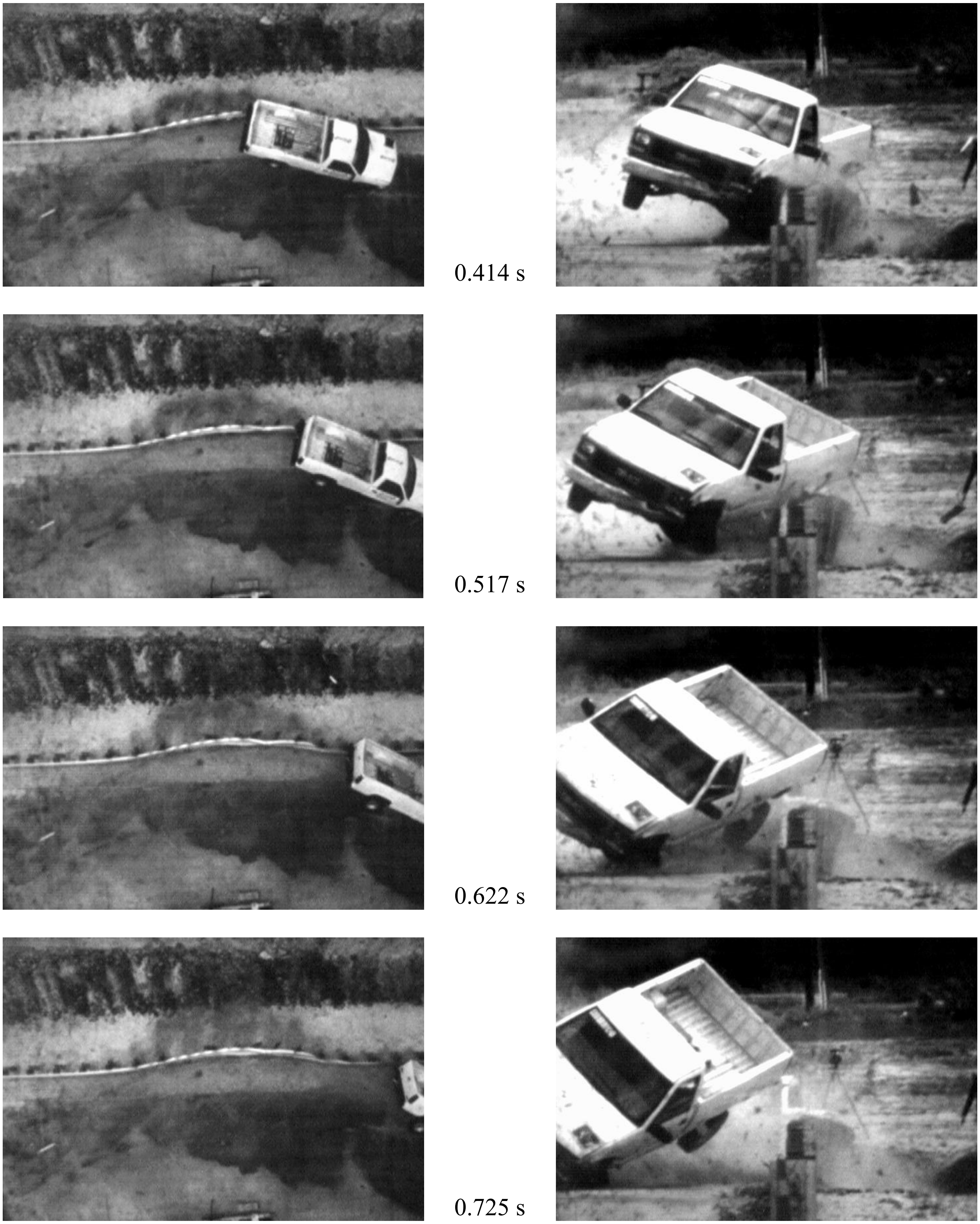


Figure C2. Sequential photographs for test 405160-4-1
(overhead and frontal views) (continued).

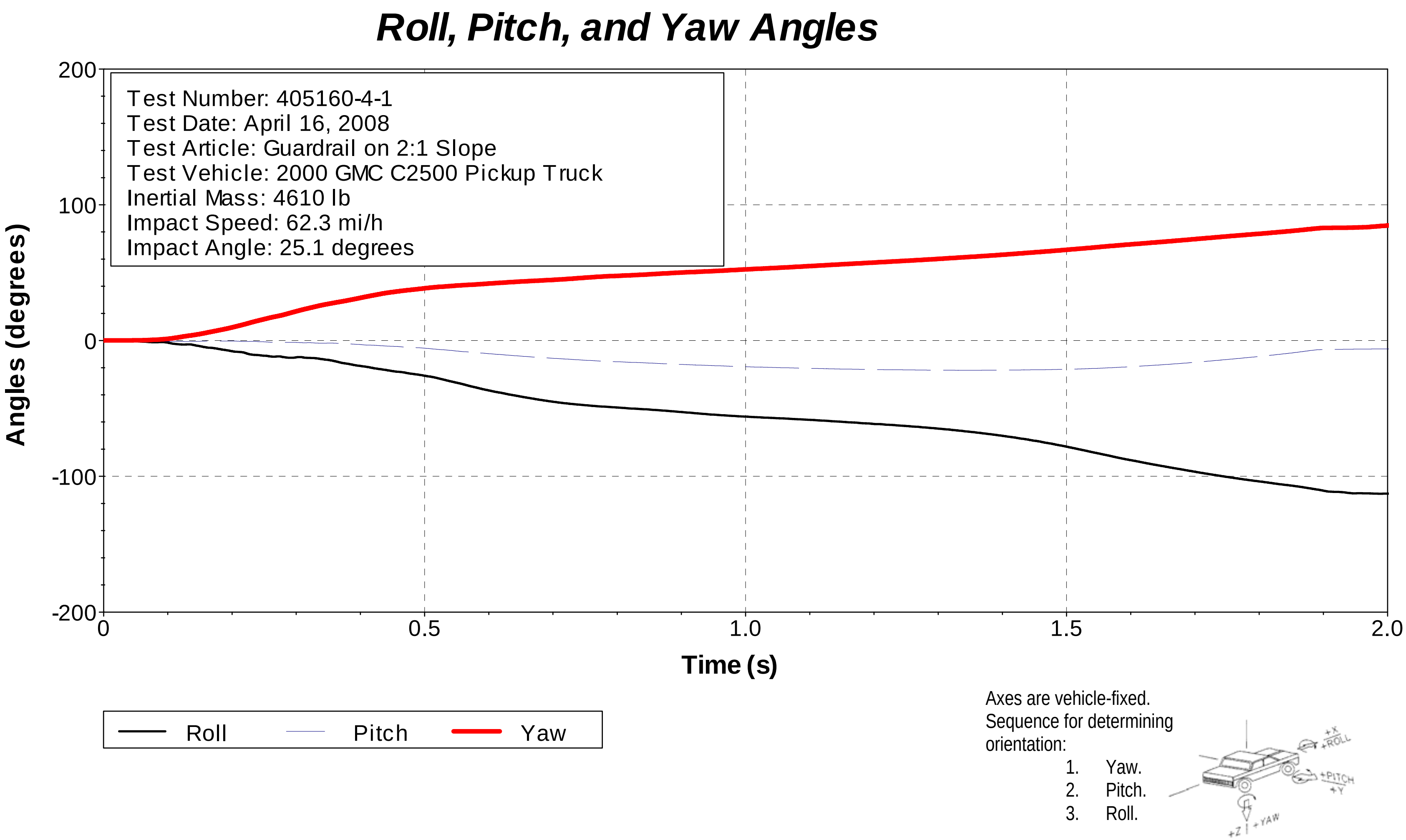


Figure D1. Vehicle angular displacements for test 405160-4-1.

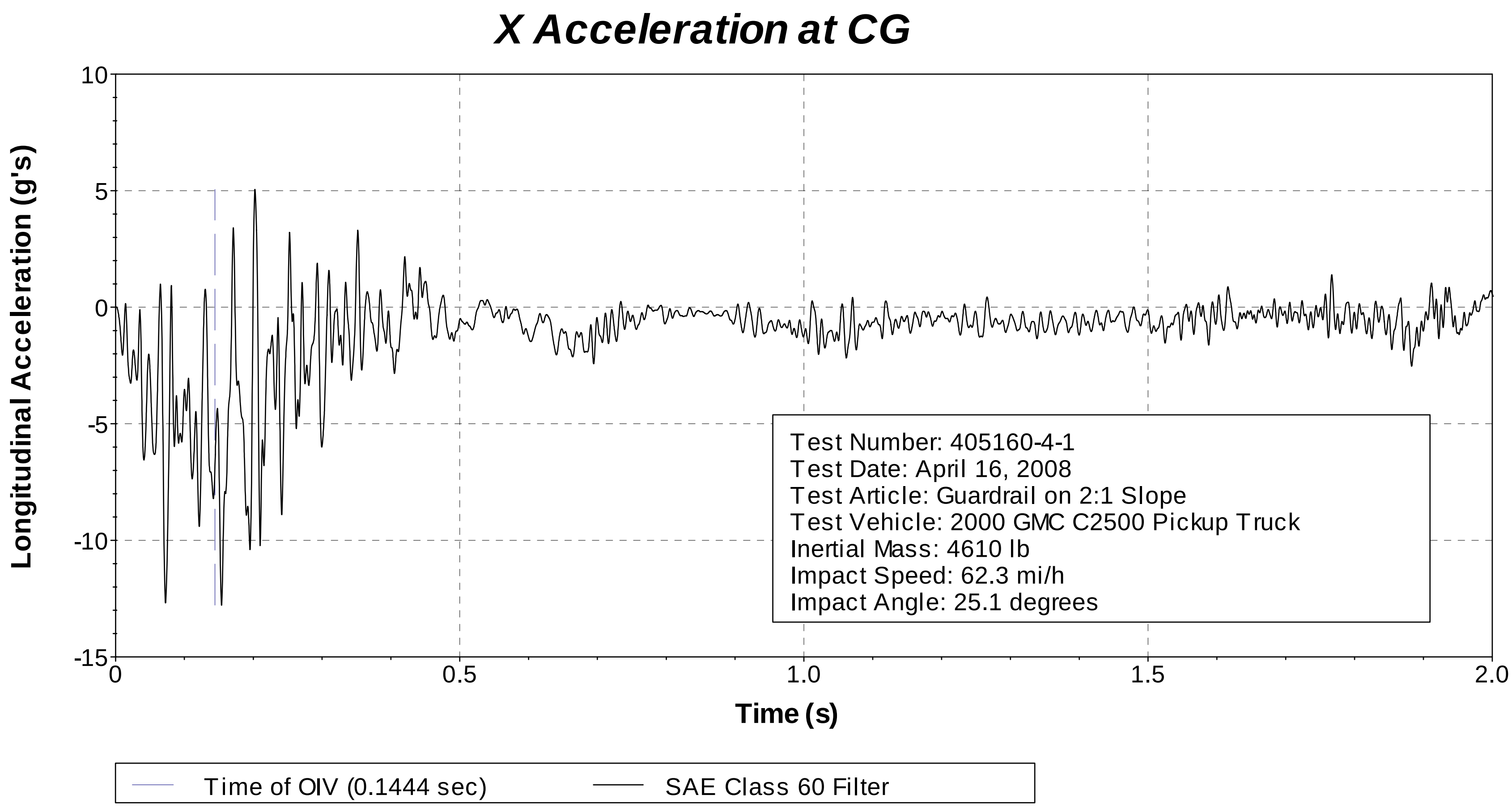


Figure D2. Vehicle longitudinal accelerometer trace for test 405160-4-1
(accelerometer located at center of gravity).

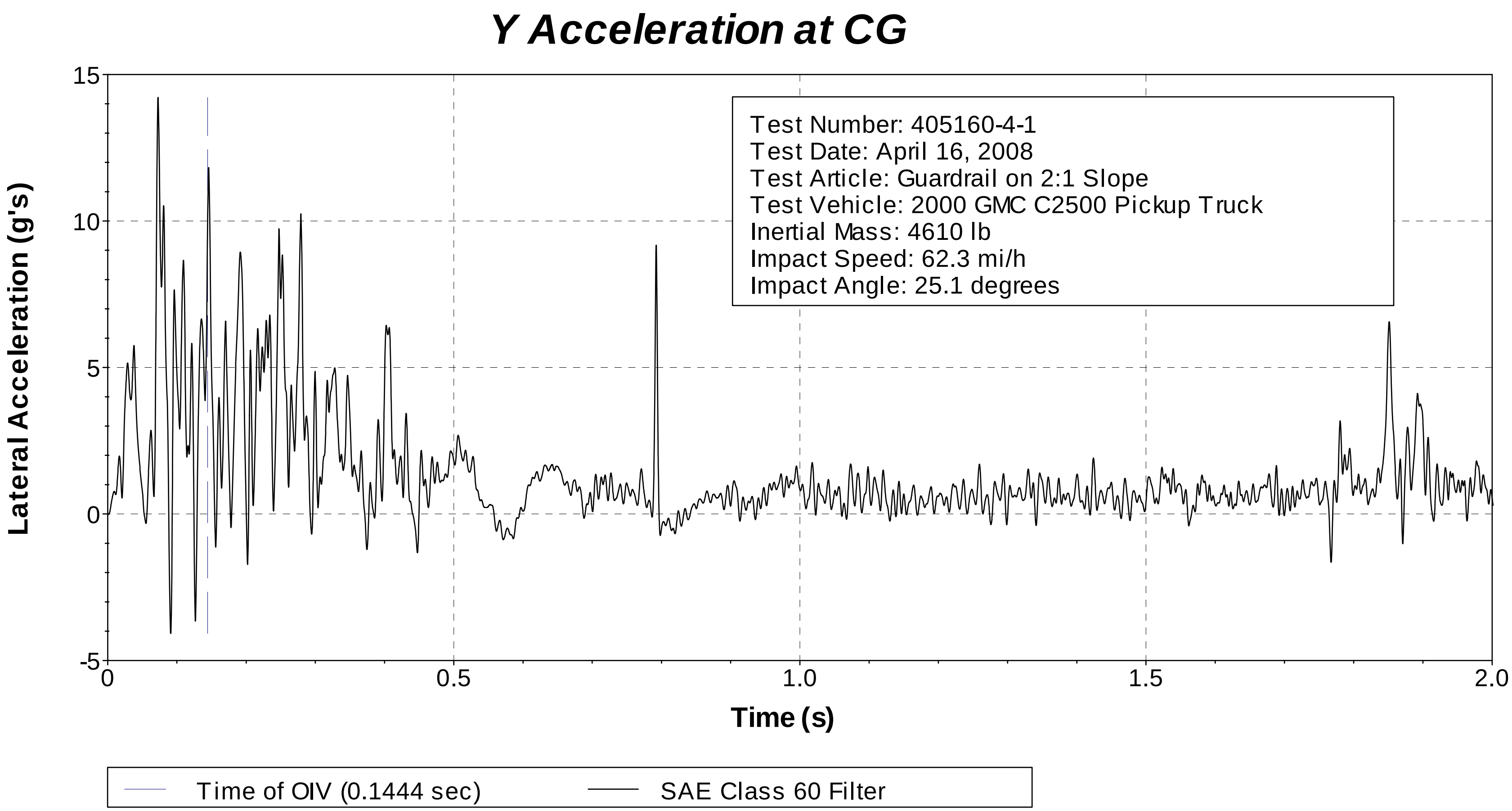


Figure D3. Vehicle lateral accelerometer trace for test 405160-4-1
(accelerometer located at center of gravity).

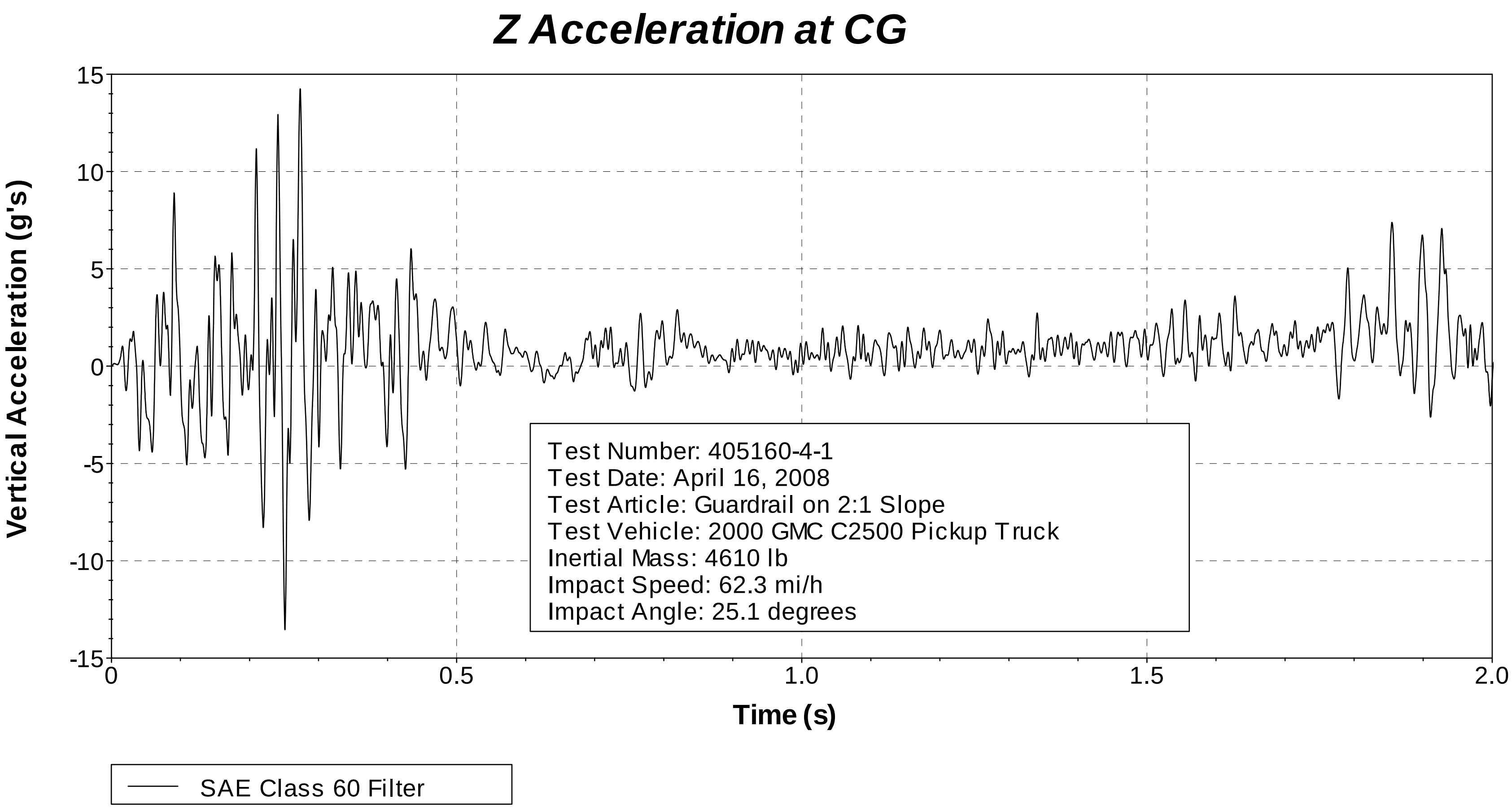


Figure D4. Vehicle vertical accelerometer trace for test 405160-4-1
(accelerometer located at center of gravity).

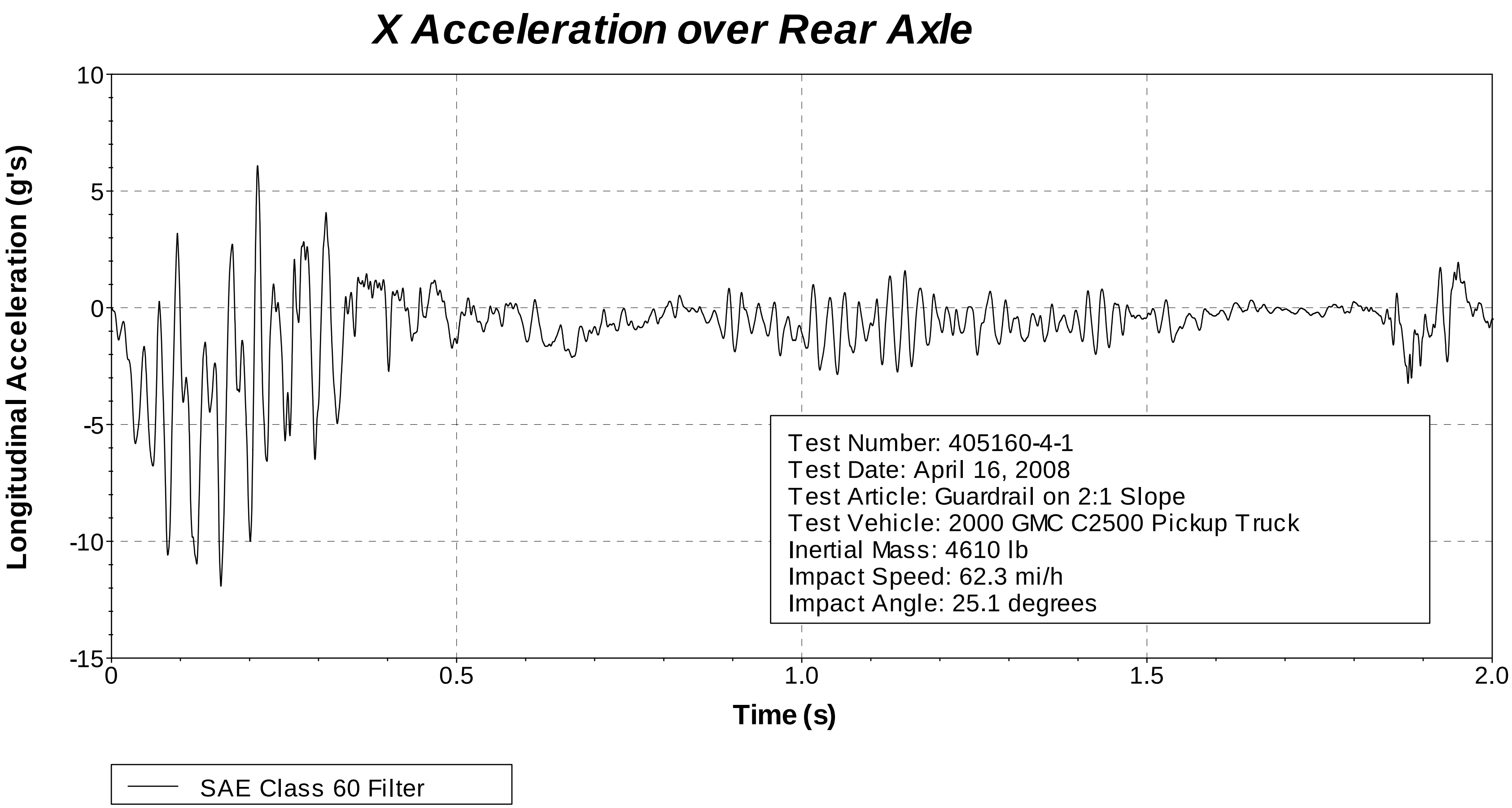


Figure D5. Vehicle longitudinal accelerometer trace for test 405160-4-1
(accelerometer located over rear axle).

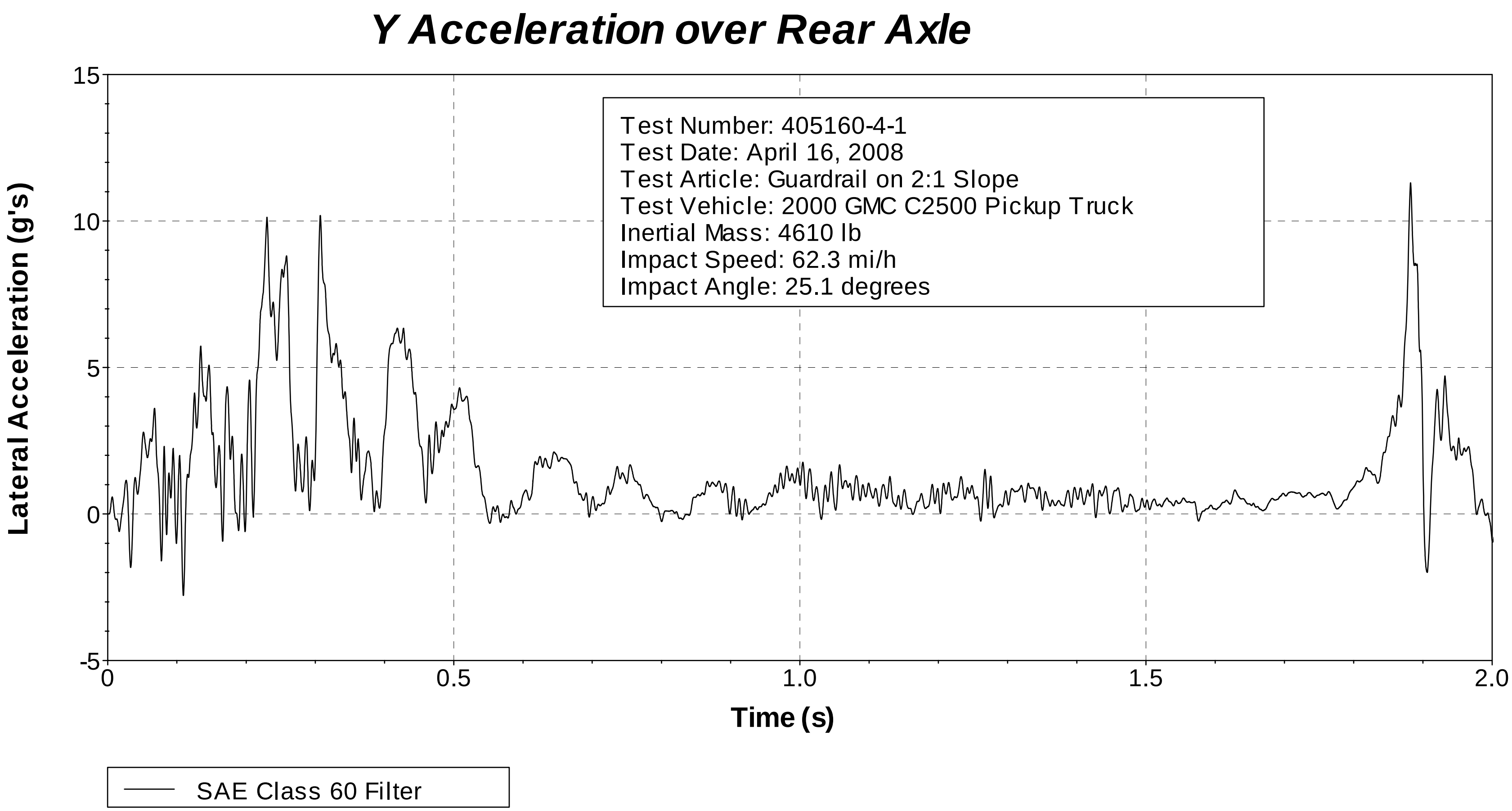


Figure D6. Vehicle lateral accelerometer trace for test 405160-4-1
(accelerometer located over rear axle).

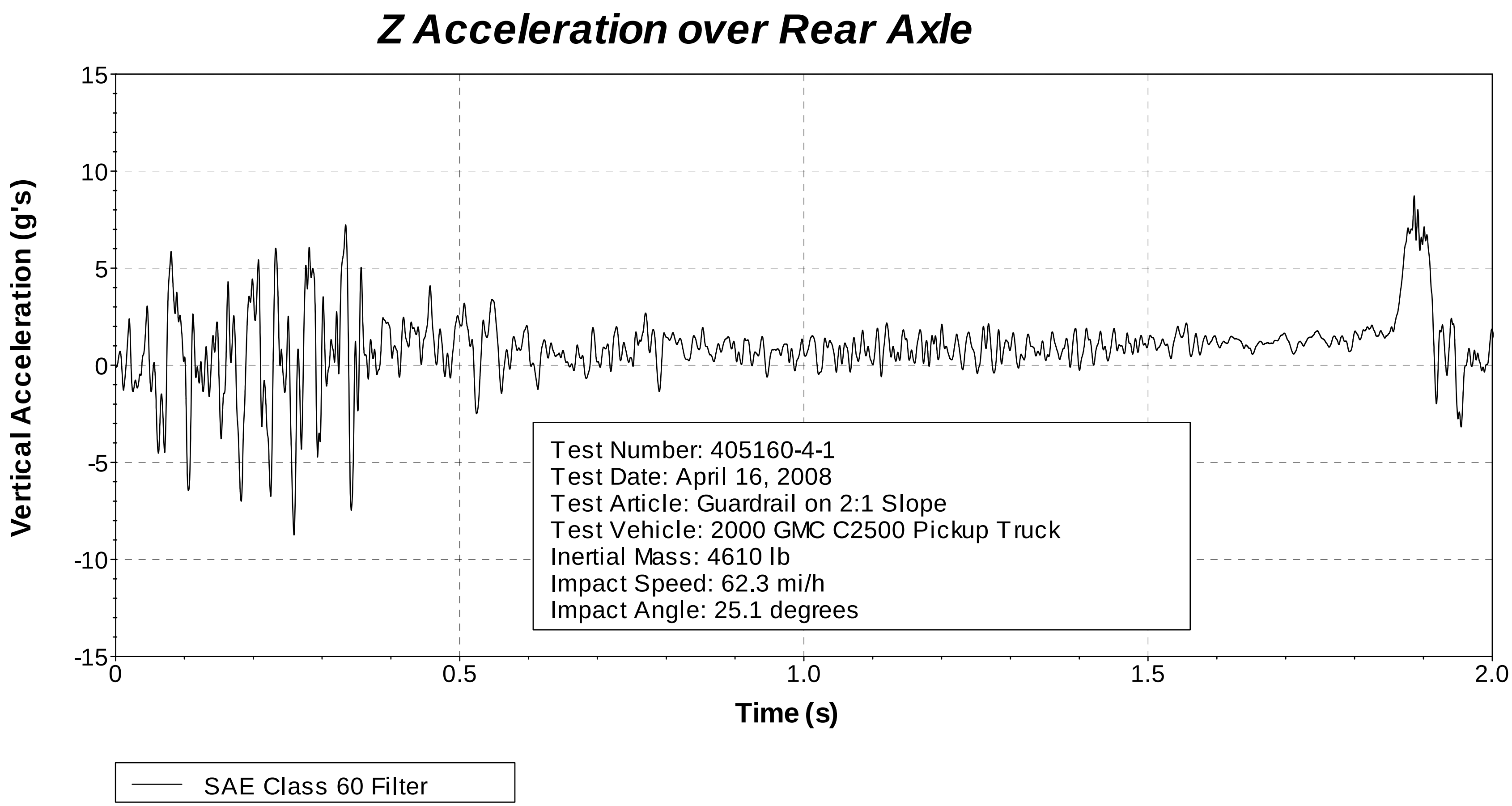


Figure D7. Vehicle vertical accelerometer trace for test 405160-4-1
(accelerometer located over rear axle).