TTI: 0-5210

Dynamic Testing of the T223 Bridge Rail

Bogie testing performed at:
TTI Proving Ground
3100 SH 47, Bldg 7091
Bryan, TX 77807

ACCREDITED
17025 Test Laboratory
Certificate # 2821.01

Technical Report 0-5210-8

Cooperative Research Program

TEXAS TRANSPORTATION INSTITUTE
THE TEXAS A&M UNIVERSITY SYSTEM
COLLEGE STATION, TEXAS

TEXAS DEPARTMENT OF TRANSPORTATION

in cooperation with the
Federal Highway Administration and the
Texas Department of Transportation
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16. Abstract

The TxDOT T203 bridge rail is often used on bridges where asphalt overlays reduce the effective height of the bridge rail. This reduction in height due to asphalt paving overlay is undesirable. For this project, several geometric features were changed to improve the strength and crash performance of the T203 rail. These features include increasing the rail height to 32 inches, increasing the size and strength of the rail, and increasing the thickness of the post. In addition, the width of the post was reduced to 4 ft and the openings between the posts were increased to 6 ft. Orientation, placement, and frequency of reinforcing steel in the rail, post, and deck were also evaluated to determine if impact damage to the deck can be reduced. These proposed changes to the T203 rail led to the development of the TxDOT Type T223 bridge rail design, which is reported herein.

The objective of this project was to evaluate the strength of the new TxDOT Type T223 Bridge Rail design with respect to different reinforcing steel details in the deck, rail, and posts. The strength of the new TxDOT Type T223 bridge rail was evaluated using dynamic bogie testing. These tests were performed at the ends/joint (two tests) and at mid-span locations (two tests). Reinforcing steel details varied at each test location to determine the preferred placement and orientation of reinforcing steel for the TxDOT Type T223 bridge rail and supporting deck to minimize deck damage during a design impact event.

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and the
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DISCLAIMER

This research was performed in cooperation with the Texas Department of Transportation (TxDOT) and the Federal Highway Administration (FHWA). The contents of this report reflect the views of the authors, who are responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official view or policies of the FHWA or TxDOT. This report does not constitute a standard, specification, or regulation, and its contents are not intended for construction, bidding, or permit purposes. In addition, the above listed agencies assume no liability for its contents or use thereof. The United States Government and the State of Texas do not endorse products or manufacturers. Trade or manufacturers' names appear herein solely because they are considered essential to the object of this report. The engineer in charge of the project was Roger P. Bligh, P.E. (Texas, #78550).

TTI PROVING GROUND DISCLAIMER

The results of the bogie testing reported herein apply only to the article being tested.

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CHAPTER 1. INTRODUCTION

BACKGROUND

The Texas Department of Transportation (TxDOT) Type T203 bridge rail is a commonly used bridge railing system on Texas bridges. The TxDOT Type T203 rail is a concrete post and beam bridge rail with a total height of 27 inches to the top of the rail. The posts are 7-1/2 inches wide, 5 ft in length and are spaced at 10 ft on centers. This bridge rail was successfully crash tested with respect to National Cooperative Highway Research Program (NCHRP) *Report 350* specifications for Test Level 3 (TL-3) requirements (1, 2). The TxDOT T203 Bridge Rail is often used on bridges where asphalt overlays reduce the effective height of the bridge rail. This reduction in height due to asphalt paving overlay is undesirable. For this project, several geometric features were changed to improve the strength and crash performance of the T203 rail. These features include increasing the rail height to 32 inches, increasing the size and strength of the rail, and increasing the thickness of the post. In addition, the width of the post was reduced to 4 ft and the clear opening between posts was increased to 6 ft. Orientation, placement, and frequency of reinforcing steel in the rail, post, and deck were also evaluated to assess if damage to the underlying bridge deck can be economically controlled. These proposed changes to the T203 rail led to the development of the TxDOT Type T223 Bridge Rail design, which is reported herein. Additional information is provided in this report.

OBJECTIVES/SCOPE OF RESEARCH

The objective of this research was to evaluate the strength of the new TxDOT Type T223 Bridge Rail design with respect to different reinforcing steel details in the deck, rail, and posts. The strength of the new TxDOT Type T223 bridge rail was evaluated using dynamic bogie testing. These tests were performed at the ends/joint (two tests) and at mid-span locations (two tests). Reinforcing steel details varied at each test location to determine the preferred placement and orientation of reinforcing steel for the TxDOT Type T223 bridge rail and supporting deck to minimize damage to the deck and rail in a design impact.

CHAPTER 2. CRASH TEST PROCEDURES

TEST FACILITY

The Texas Transportation Institute (TTI) Proving Ground is a 2000-acre complex of research and training facilities located 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 construction and testing of the bridge rail evaluated under this project is along an out-of-service apron. The apron consists of an unreinforced jointed-concrete pavement in 12.5 ft by 15 ft blocks nominally 8 to 12 inches deep. The apron is over 50 years old, and the joints have some displacement but are otherwise flat and level.

TEST ARTICLE

The Texas Department of Transportation (TxDOT) Type T223 bridge rail consists of a 19 inch x 15-1/2 inch concrete beam supported by 9-1/2 inch thick x 4 ft-0 inch wide concrete posts spaced on 10 ft-0 inch centers. The height of the bridge rail is 32 inches. Reinforcement in the beam consisted of nine #5 longitudinal reinforcing bars with four bars located on the front and back faces of the beam and one bar located in the top center of the beam. The longitudinal reinforcement in the beam was placed within #3 stirrup bars spaced at 6 inches on center along the entire length of the rail. For this project, TTI constructed approximately 74 ft of T223 bridge rail anchored on top of a 30-inch wide by 8-inch thick concrete deck cantilever constructed adjacent to a concrete apron at the TTI Proving Ground. The transverse reinforcement in the top layer of reinforcing in the deck cantilever consisted of #5 bars spaced at 6 inches on centers for all the posts excepts those on the ends of the installation. For the posts located on the ends of the installation, the transverse top reinforcement consisted of #5 reinforcing bars spaced at 3-1/2 inches on centers. The transverse reinforcement in the bottom layer of reinforcing consisted of #5 steel bars spaced at 18 inches on centers for the entire length of the installation. The longitudinal reinforcement in the top of the deck cantilever consisted of #4 bars spaced approximately 9 inches on centers. The longitudinal reinforcement in the bottom of the deck consisted of two #5 steel bars on the field side of the deck spaced at 3 inches on centers with the next adjacent # 5 steel bar spaced approximately 12 inches away towards the traffic face. All steel reinforcement used in the deck cantilever was bare steel (not epoxy coated) with minimum specified yield strength of 60 ksi.

The concrete posts were anchored to the deck using #5 “U” bars cast within the concrete deck. These bars extended approximately 10 inches from the top of the deck upwards into the concrete posts. The spacing of the “U” bars varied at the different test locations. For the posts located on the ends of the installation (test locations 1 and 2), the “U” bars were spaced at 3-1/2 inches on centers. For the remaining posts in the installation (including test locations 3 and 4), the “U” bars were spaced at 6 inches on centers and were placed with the transverse #5 top

reinforcement in the deck. Additional transverse reinforcement was provided in the deck. This additional reinforcement consisted of #5 "L" bars placed alongside the "U" bars in the top layer of deck reinforcing steel. Please refer to Figures 1 through 10 for additional information.

For the posts tested for this project, the orientation of the vertical reinforcement and the spacing varied. The concrete beam was anchored to the posts using #5 "V" bars. For the posts located on the ends (test locations 1 and 2), the "V" bars were spaced at 3-1/2 inches on centers. At test location 1, the "V" bars were oriented with the closed hook located on the top of the rail. At test location 2, the "V" bars were oriented with the closed hook located on the top of the deck. At test location 3, the "V" bars were spaced at 6 inches on centers and were oriented with the closed hook located near the top of the rail. At test location 4, the "V" Bars were spaced at 6 inches on centers and were oriented with the closed hook located on the top of the deck. At test locations 1 and 3, additional longitudinal reinforcement was added near the field side edge of the deck. This reinforcement, #5 "J" bars, was placed vertically near the edge of the deck and parallel to the top and bottom longitudinal reinforcement in the deck. A single #5 "J" bar was added at test location 1 and two #5 "J" bars were located at test location 3 (one on each side of the post).

All concrete for this project was provided by Transit Mix Concrete and Materials, Bryan, Texas. The compressive strength of the deck cantilever concrete on the first day the tests were performed (65 curing days) was 4014 psi. The compressive strength of the post concrete on the first day of testing (63 days age) was 3024 psi. The compressive strength of the beam concrete on the first day of testing (61 days age) was 6437 psi.

Please refer to Figures 1 through 10 for additional information. Figure 11 shows photographs of the test installation.

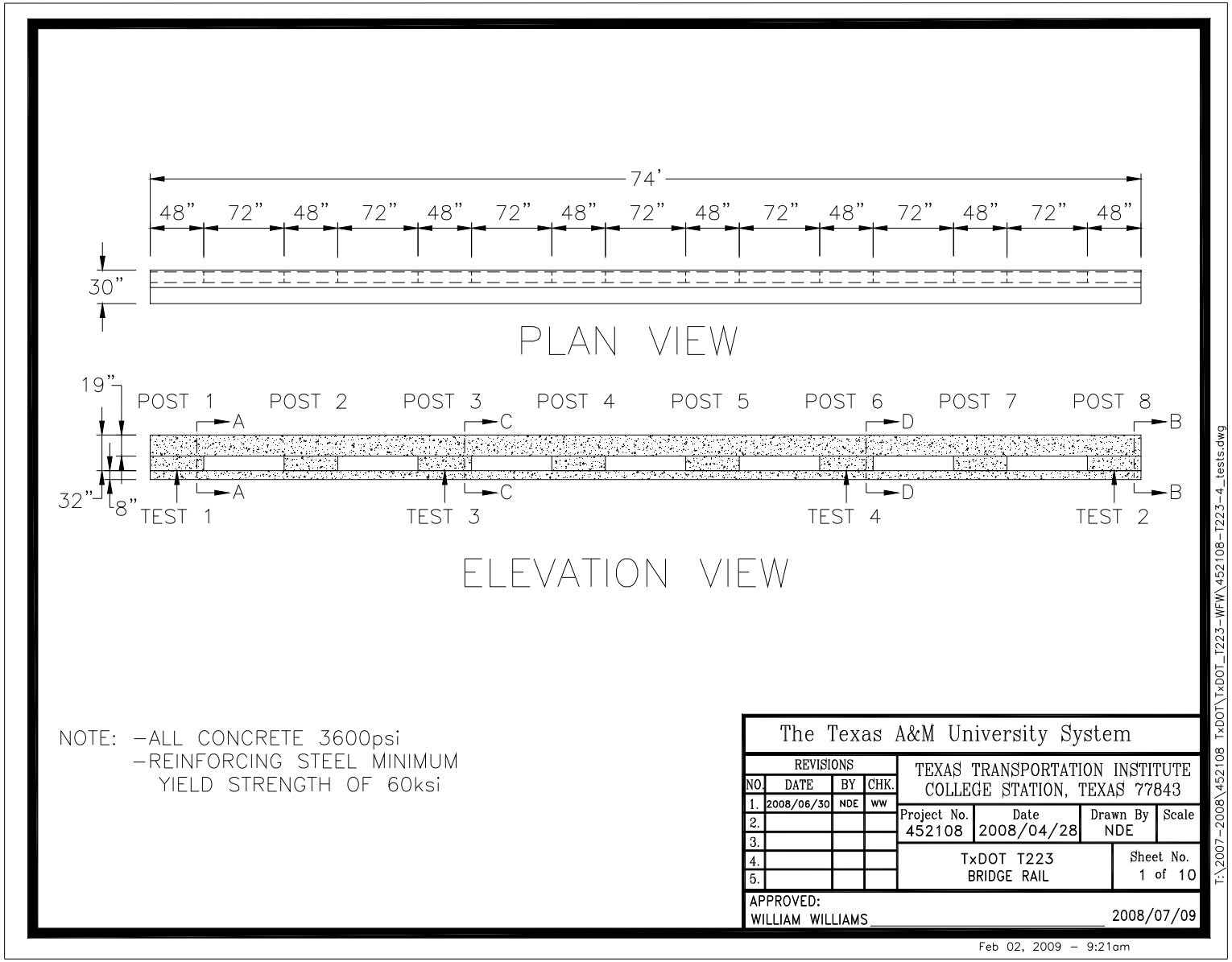


Figure 1. Layout of the T223 Bridge Rail Installation.

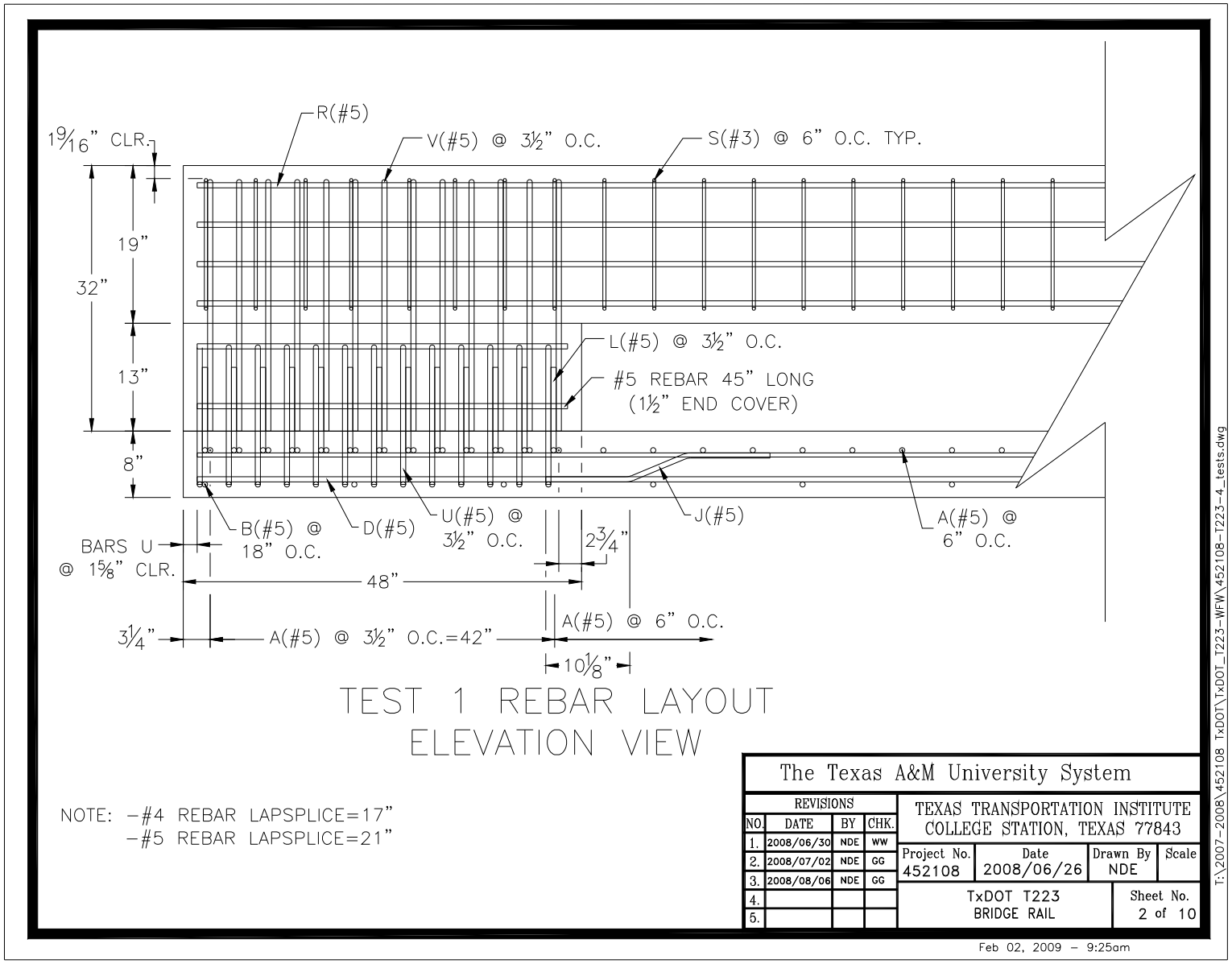


Figure 2. Rebar Layout at Post 1 for Test B1.

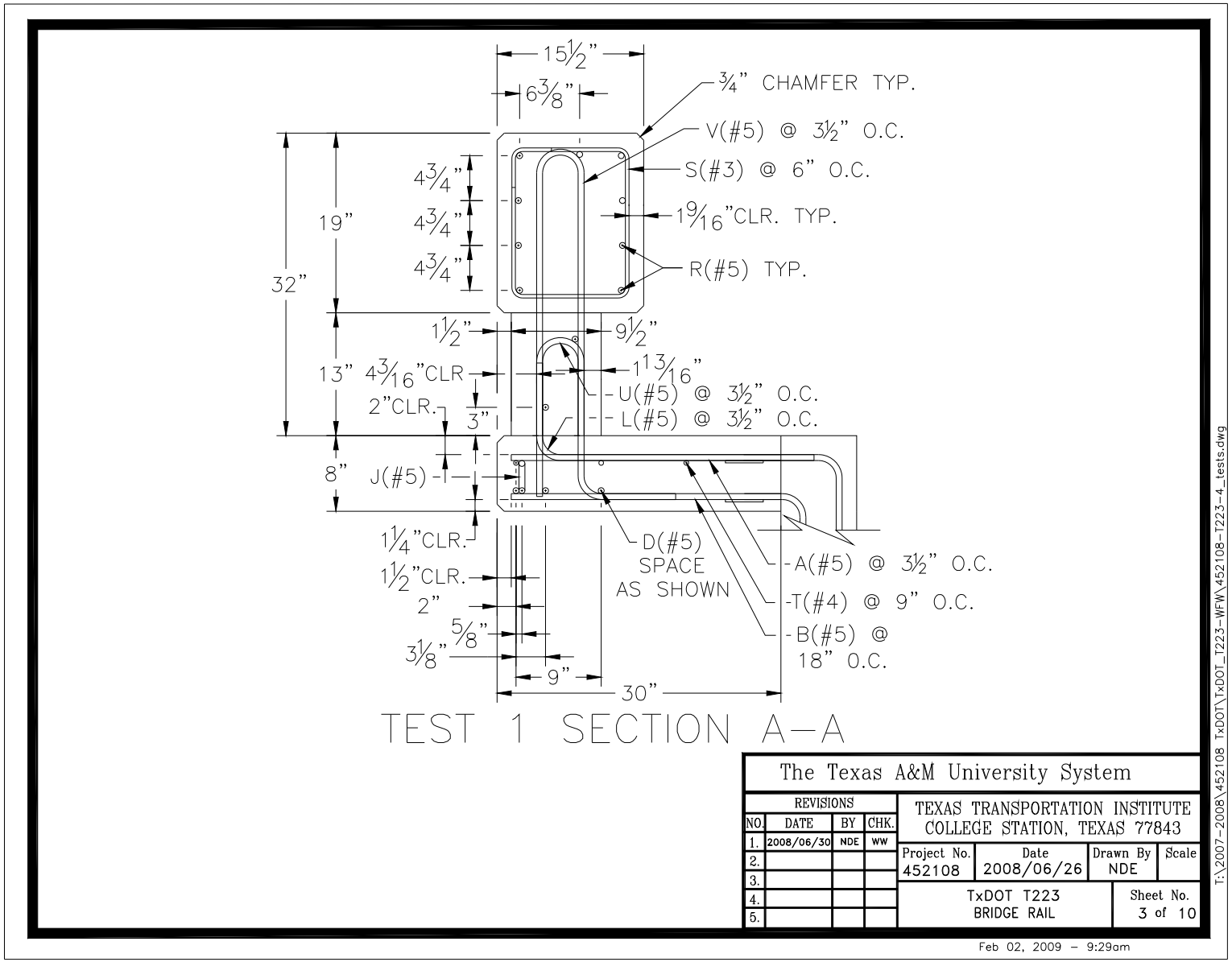


Figure 3. Cross Section at Post 1 for Test B1.

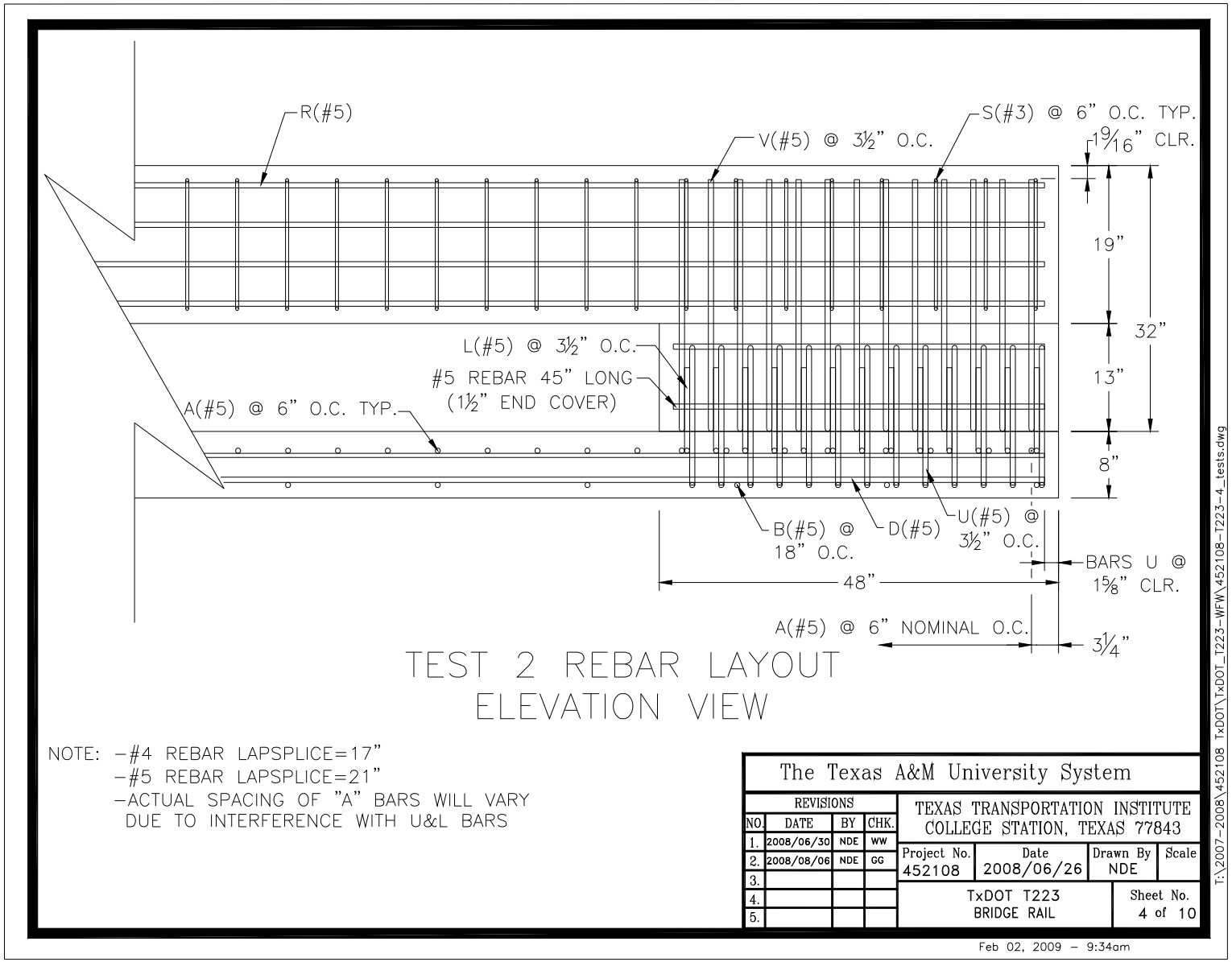


Figure 4. Rebar Layout at Post 8 for Test B2.

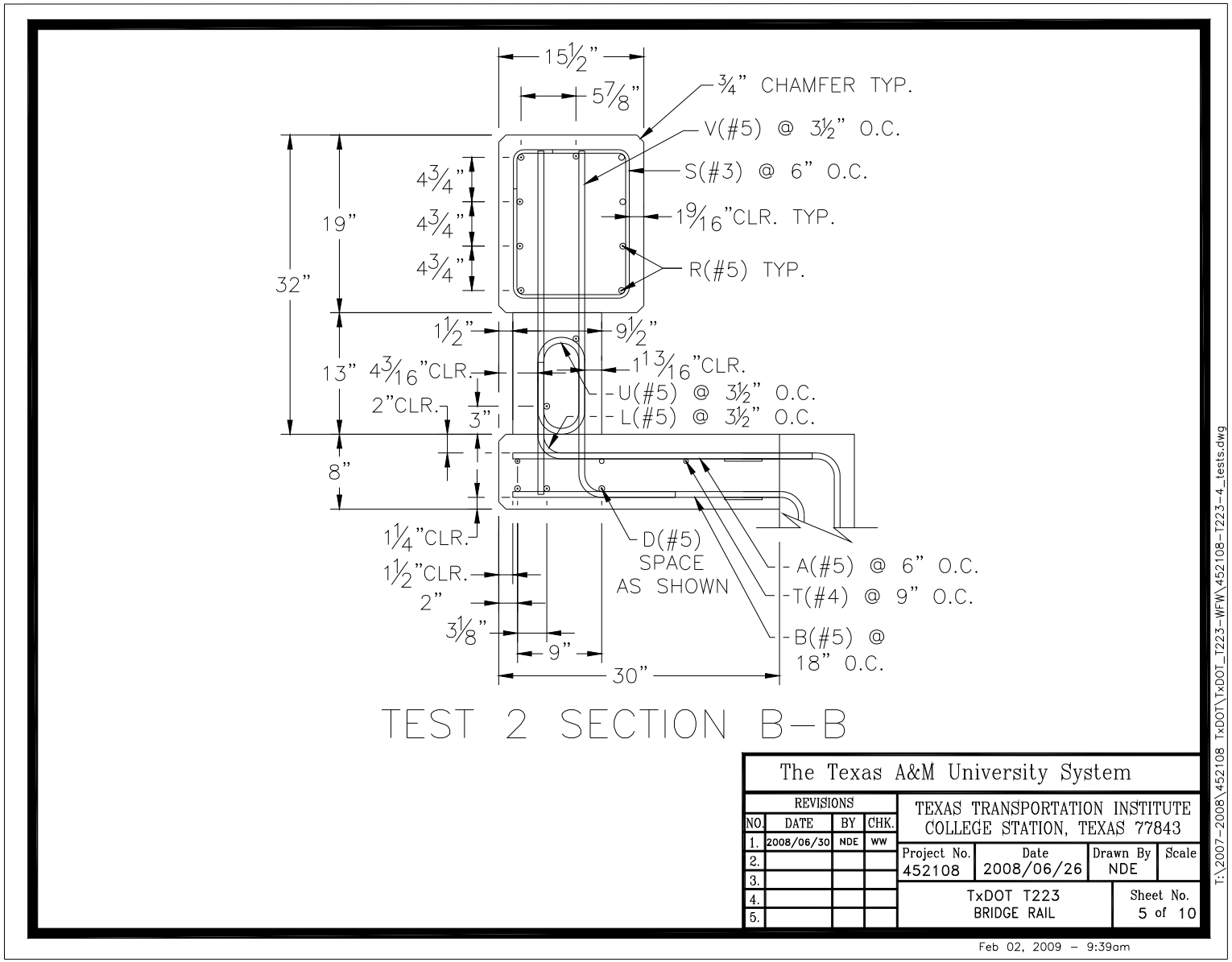


Figure 5. Cross Section of Post 8 for Test B2.

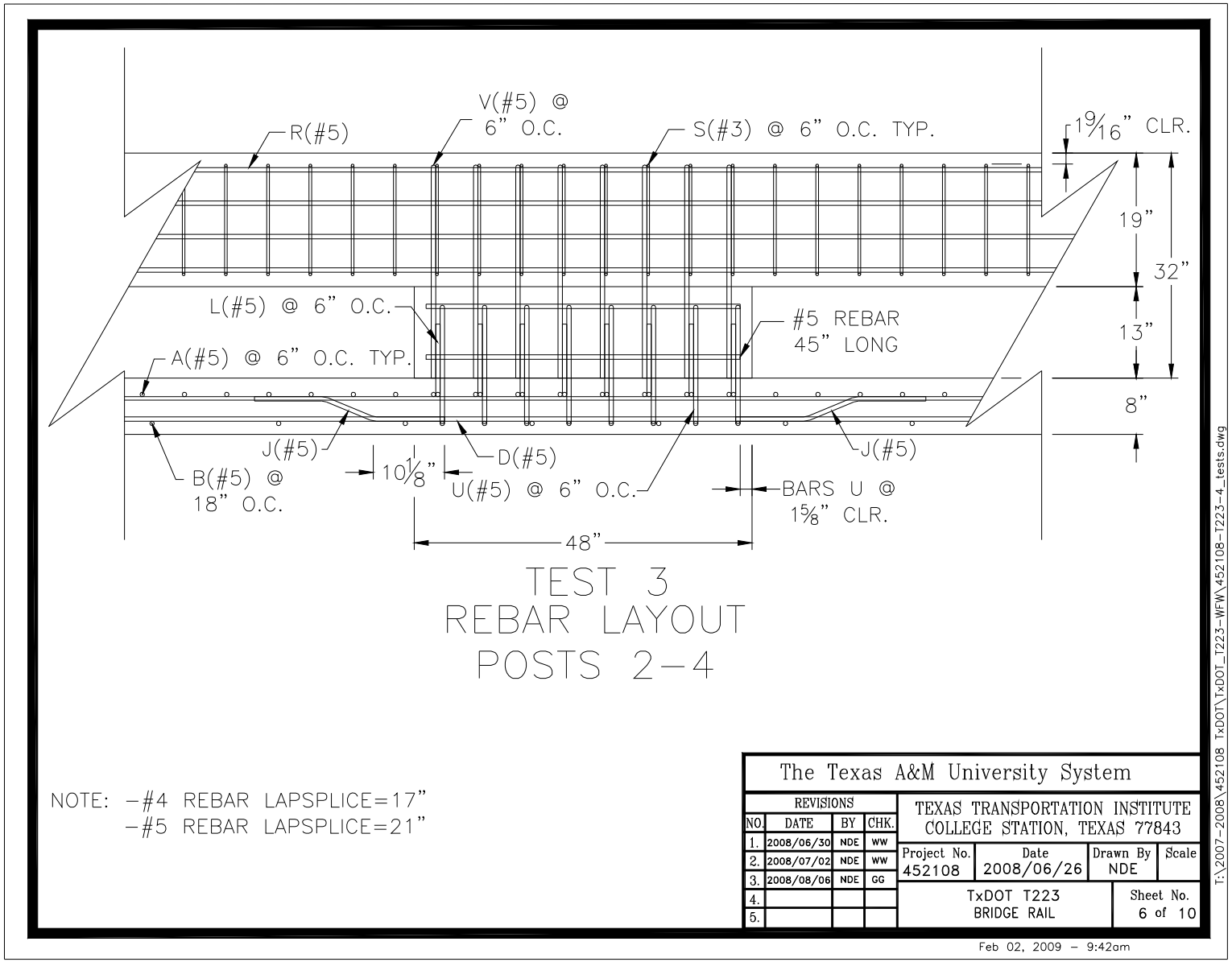


Figure 6. Rebar Layout at Posts 2-4 for Test B3.

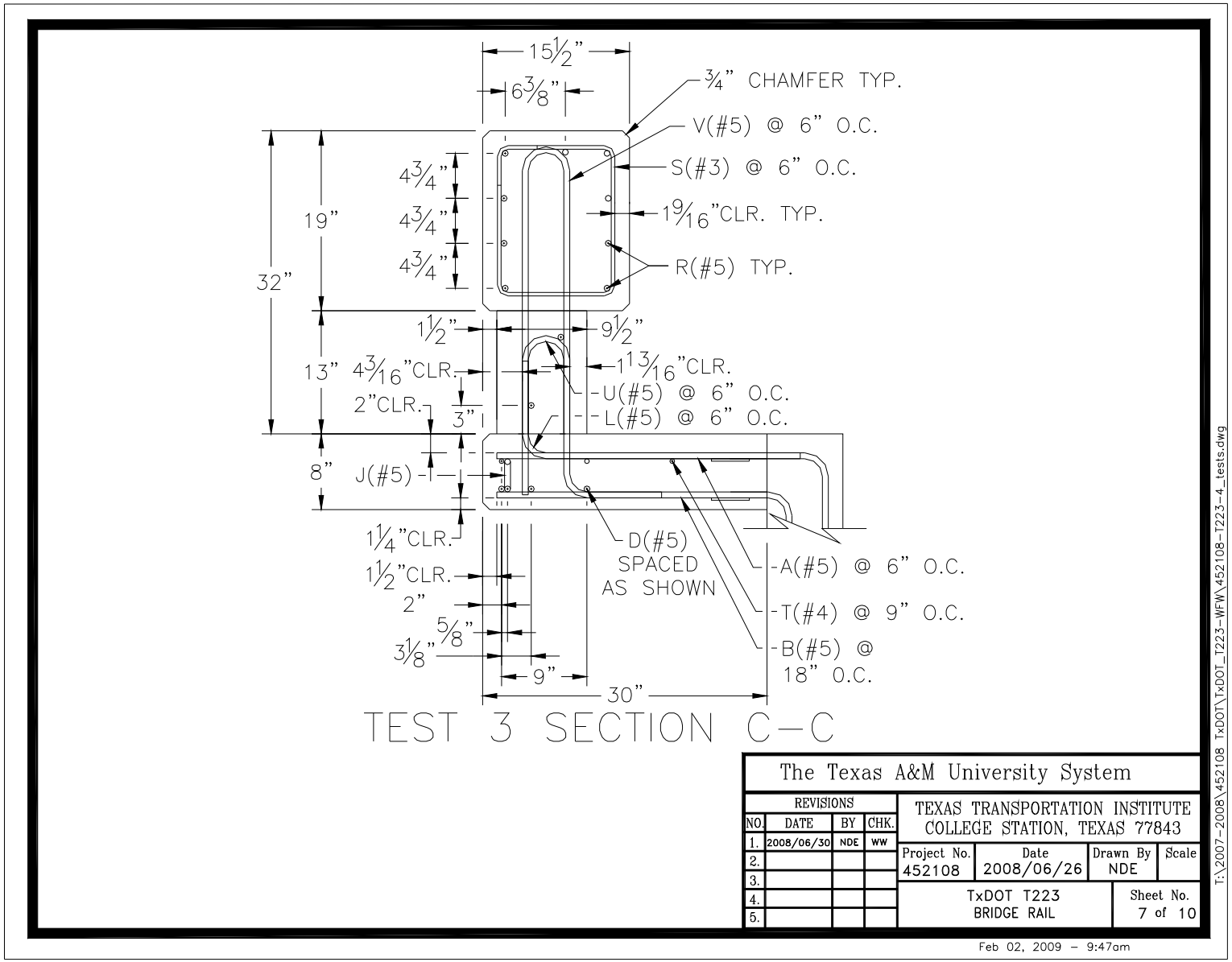


Figure 7. Cross Section at Posts 2-4 for Test B3.

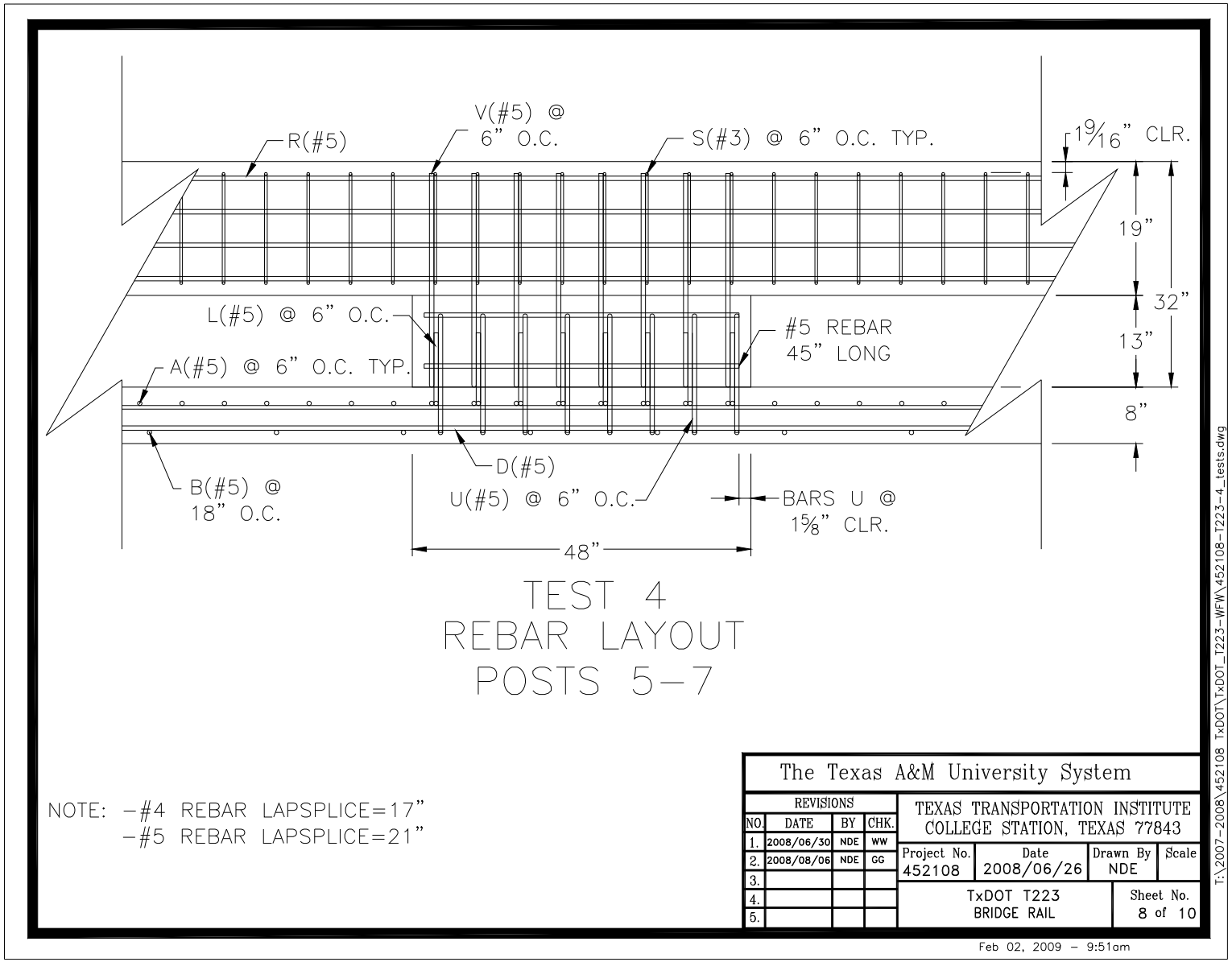


Figure 8. Rebar Layout at Posts 5-7 for Test B4.

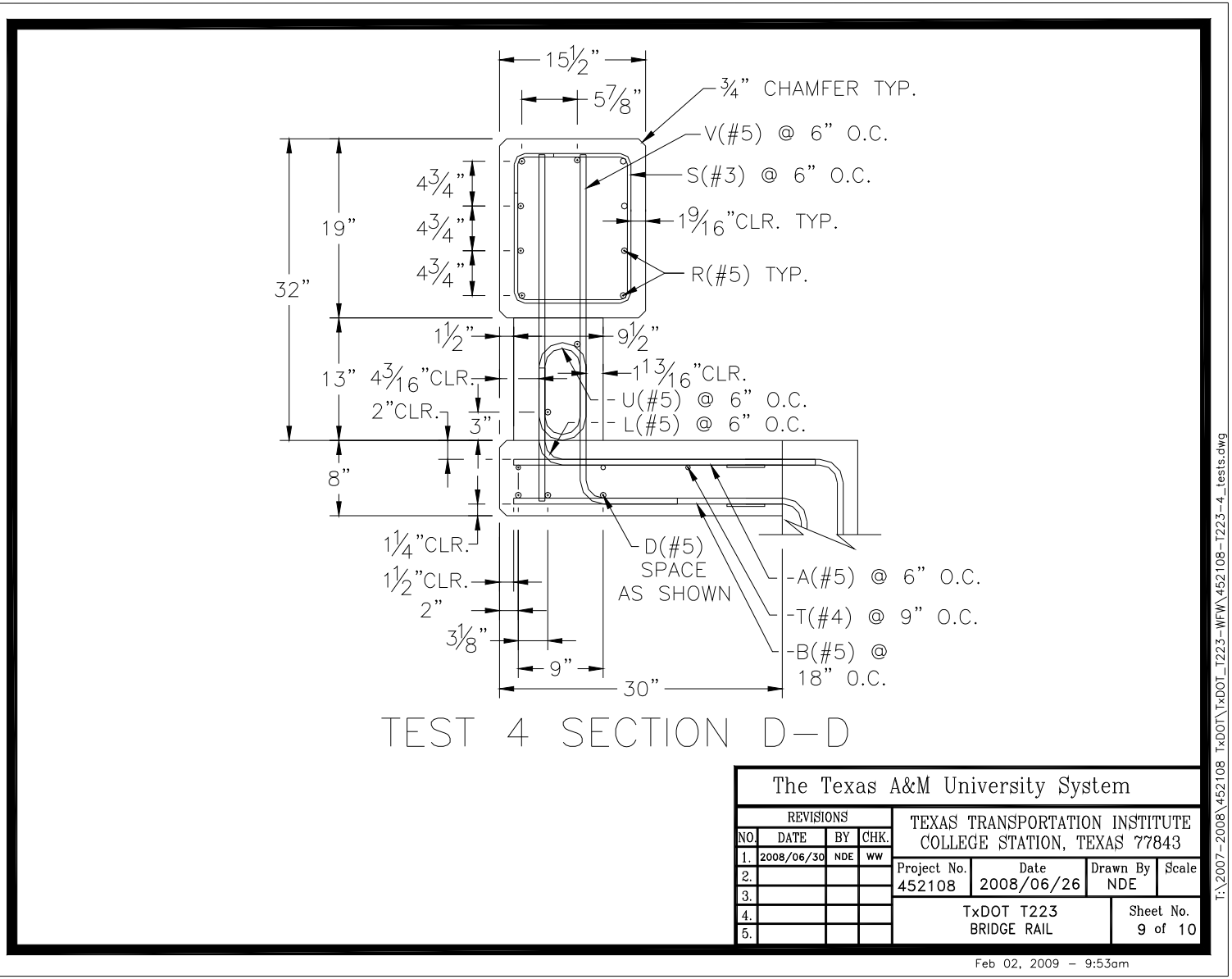


Figure 9. Cross Section at Posts 5-7 for Test B4.

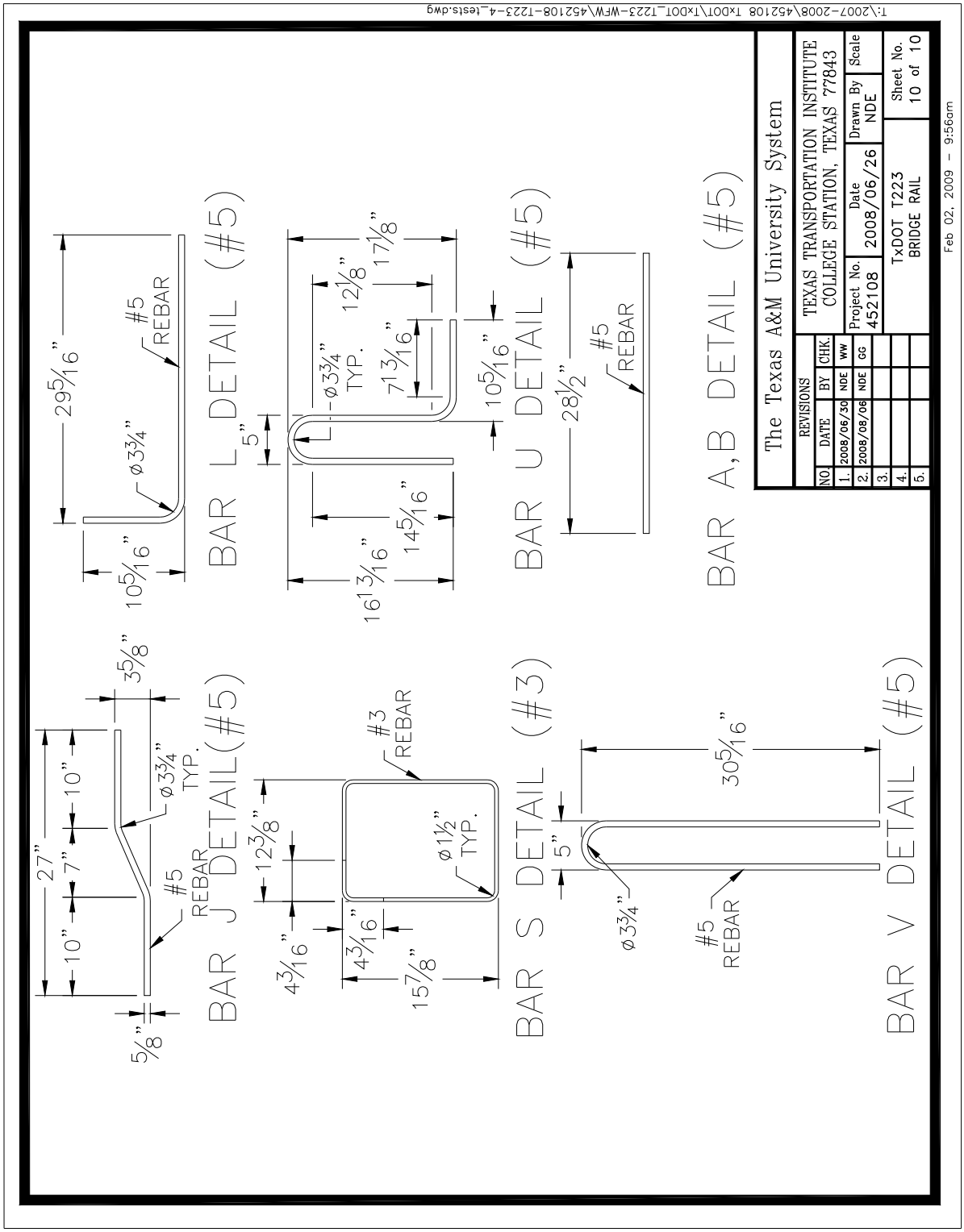


Figure 10. Rebar Bend Details.

Figure 11. T223 Bridge Rail Installation before Testing.

CRASH TEST CONDITIONS

Test Vehicle

A bogie vehicle, shown in Figure 12, was used for the crash test. Test inertia weight of the vehicle was 5004 lb. The height to the lower edge of the bogie's collapsible pipe nose was 18.5 inches, and it was 26.5 inches to the upper edge of the pipe nose. The bogie 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.

Soil and Weather Conditions

The tests were performed on December 11 and 12, 2008. Weather conditions at the time of testing were as follows: Wind speed: 2-14 mi/h; Wind direction with respect to the vehicle: 210 degrees on December 11 and 270 degrees on December 12 (vehicle was traveling in a westerly direction); Temperature: 38-62°F; Relative humidity: 27-67 percent.

Bogie Testing and Data Analysis Procedures

Brief descriptions of bogie test and data analysis procedures are presented in Appendix A.

CHAPTER 3. TEST RESULTS

TEST NO. 452109-B1

Test Description

The bogie vehicle, traveling at an impact speed of 15.4 mi/h, impacted post 1 of the T223 Bridge Rail at 90 degrees. Figure 12 depicts the orientation of the bogie with the bridge rail at impact. At approximately 0.060 s, the pipe sections began to deform. At 0.094 s, the bogie began to rebound. The bogie lost contact with the bridge rail at 0.115 s, traveling at an exit speed of -3.3 mi/h. Figure B1 in Appendix B shows sequential photographs of the test.

Damage to Test Installation

Figure 13 shows damage to post 1. Several cracks in the beam above the post were noted. Also, a crack radiated out from post 1 on the side adjacent to post 2. This crack began 2.5 inches toward the field side of the traffic face of the post and radiated toward the field side a distance of 15.5 inches. The crack then extended down the edge of the deck toward post 2 a distance of 23.5 inches. Maximum deflection of the bridge rail during the test was 0.99 inches. The deck and rail were still serviceable after the test.

Vehicle Damage

Maximum crush of the pipe nose was 9.0 inches. The bogie nose before and after the test is shown in Figure 14.

Electronic Data Analysis

Data from the accelerometer, located at the bogie center of gravity, were digitized and used to calculate a force-time history, which is shown in Figure 15. The maximum 50-ms average impact force was 61,985 lb, which exceeds the design impact force of 54,000 lb for a TL-3 impact.

Figure 12. Bogie/Installation Geometrics for Test 452109-B1.

Figure 13. Installation after Test 452109-B1.

Figure 14. Bogie before and after Test 452109-B1.

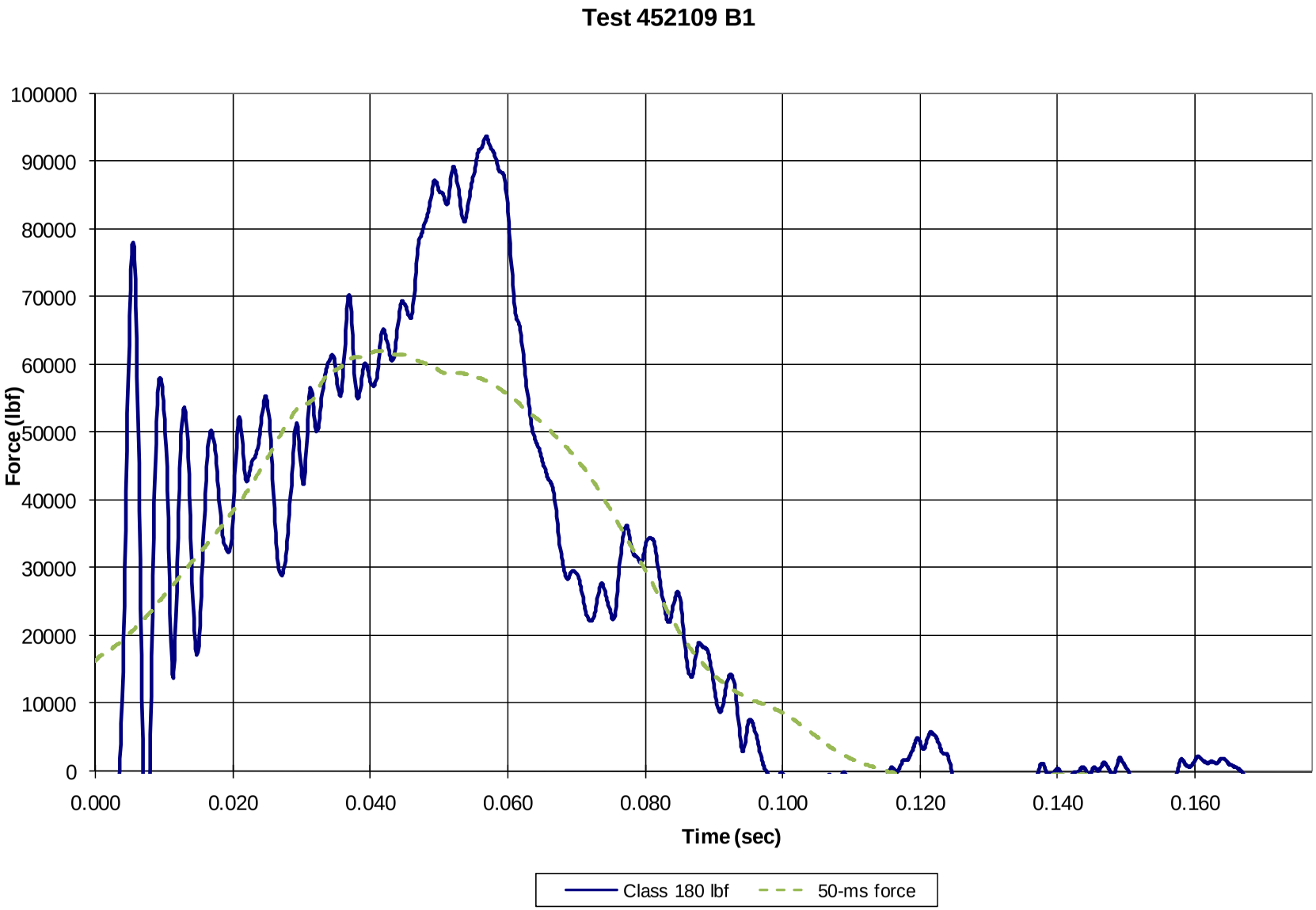


Figure 15. Force Trace for Test 452109-B1.

TEST NO. 452109-B2

Test Description

The bogie vehicle, traveling at an impact speed of 15.8 mi/h, impacted post 8 of the T223 Bridge Rail at 90 degrees. Figure 16 depicts the orientation of the bogie with the bridge rail at impact. At approximately 0.046 s, the pipe sections began to deform. At 0.120 s, the bogie began to rebound. The bogie lost contact with the bridge rail at 0.125 s, traveling at an exit speed of -3.2 mi/h. Figure B2 of Appendix B shows sequential photographs of the test.

Damage to Test Installation

Damage to post 1 is shown in Figure 17. Several cracks in the beam above the post were noted. Two cracks radiated out from post 8 on the side adjacent to post 7. One crack began 2.5 inches toward the field side of traffic face of the post and radiated toward the field side a distance of 11.5 inches. The crack then extended down the edge of the deck toward post 7 a distance of 23.0 inches. Another crack began at the field side corner, radiated toward the edge of the deck for 2 inches, and then joined the first crack about mid-height of the edge of the deck. The bridge rail had no measureable deflection during impact.

Vehicle Damage

Maximum crush of the pipe nose was 8.9 inches. Before and after photographs of the nose are shown in Figure 18.

Electronic Data Analysis

Data from the accelerometer, located at the bogie center of gravity, were digitized and used to calculate a force-time history, which is shown in Figure 19. The maximum 50-ms average impact force was 60,257 lb, which exceeds the design impact force of 54,000 lb for a TL-3 impact.

Figure 16. Bogie/Installation Geometrics for Test 452109-B2.

Figure 17. Installation after Test 452109-B2.

Figure 18. Bogie before and after Test 452109-B2.

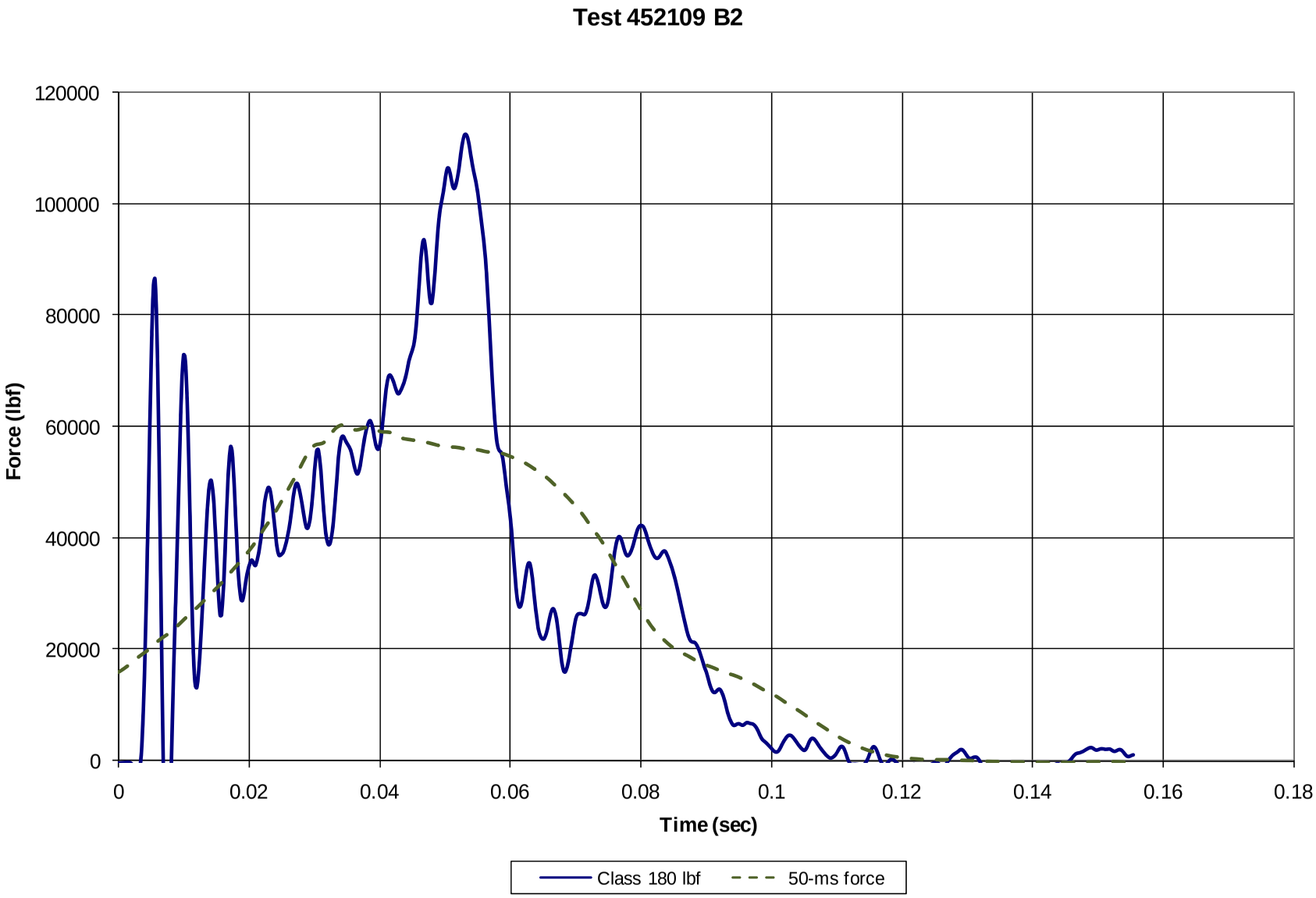


Figure 19. Force Trace for Test 452109-B2.

TEST NO. 452109-B3

Test Description

The bogie vehicle, traveling at an impact speed of 20.1 mi/h, impacted post 3 of the T223 Bridge Rail at 90 degrees. Figure 20 depicts the orientation of the bogie with the bridge rail at impact. At approximately 0.041 s, the pipe sections began to deform. At 0.080 s, the bogie began to rebound. The bogie lost contact with the bridge rail at 0.104 s, traveling at an exit speed of -2.7 mi/h. Figure B3 in Appendix B show sequential photographs of the test.

Damage to Test Installation

Figure 21 shows the damage to the bridge rail. Several cracks were evident in the beam and the rear of the post. Two cracks in the bridge deck on each side of post 3 radiated out toward the field side of the deck. These then radiated down and outward along the edge of the deck. The bridge rail had no measureable deflection during the impact.

Vehicle Damage

Maximum crush of the pipe nose was 10.5 inches. Figure 22 shows the bogie nose before and after the test.

Electronic Data Analysis

Data from the accelerometer, located at the bogie center of gravity, were digitized and used to calculate a force-time history, which is shown in Figure 23. The maximum 50-ms average impact force was 89,676 lb, which exceeds the design impact force of 54,000 lb for a TL-3 impact by 66 percent.

Figure 20. Bogie/Installation Geometrics for Test 452109-B3.

Figure 21. Installation after Test 452109-B3.

Figure 22. Bogie before and after Test 452109-B3.

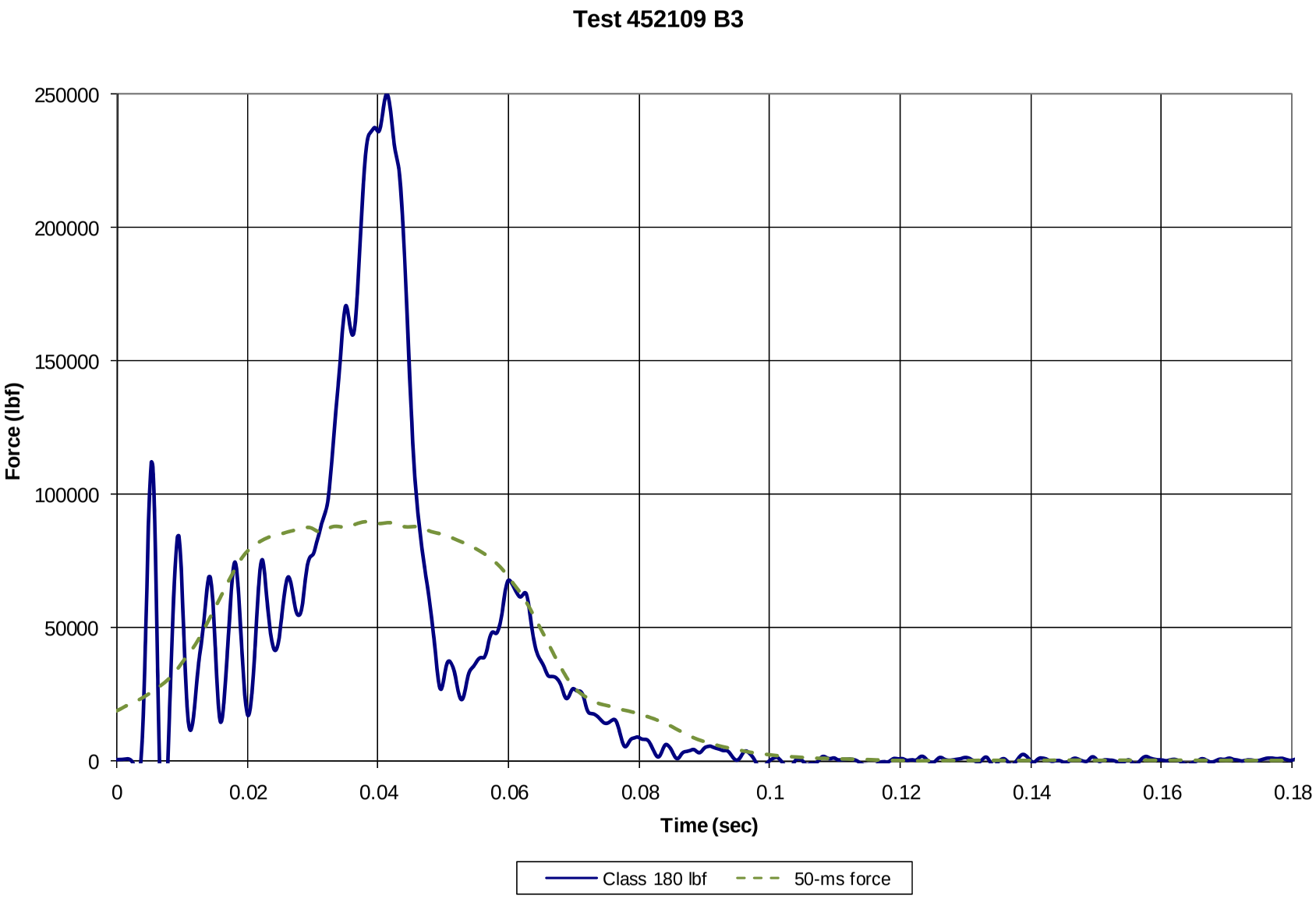


Figure 23. Force Trace for Test 452109-B3.

TEST NO. 452109-B4

Test Description

The bogie vehicle, traveling at an impact speed of 20.6 mi/h, impacted post 6 of the T223 Bridge Rail at 90 degrees. Figure 24 depicts the orientation of the bogie with the bridge rail at impact. At approximately 0.044 s, the pipe sections began to deform. At 0.068 s, the bogie began to rebound. The bogie lost contact with the bridge rail at 0.121 s, traveling at an exit speed of -2.9 mi/h. Figure B4 in Appendix B shows sequential photographs of the test.

Damage to Test Installation

Damage to post 6 is shown in Figure 25. The darker marks represent shrinkage cracks that were present before the test. The lighter marks represent the cracks sustained by impact with the bogie. Three cracks were noted in the traffic face of the beam and one in the traffic face of the post near the deck. Scattered cracks were observed on the top and field side of the beam. Two cracks in the deck radiated out from the left side of the post, one from the traffic face that radiated just to the edge of the deck, and the second from the field side corner of the post down the field side of the deck. One crack radiated from the right side of the post from the field side corner directly to the edge of the deck and down the field side of the deck. Maximum deflection of the bridge rail during the test was 0.99 inch.

Vehicle Damage

Maximum crush of the pipe nose was 10.8 inches. Photographs of the bogie nose before and after the test are shown in Figure 26.

Electronic Data Analysis

Data from the accelerometer, located at the bogie center of gravity, were digitized and used to calculate a force-time history, which is shown in Figure 27. The maximum 50-ms average impact force was 89,590 lb, which exceeds the design impact force of 54,000 lb for a TL-3 impact by 66 percent.

Figure 24. Bogie/Installation Geometrics for Test 452109-B4.

Figure 25. Installation after Test 452109-B4.

Figure 26. Bogie before and after Test 452109-B4.

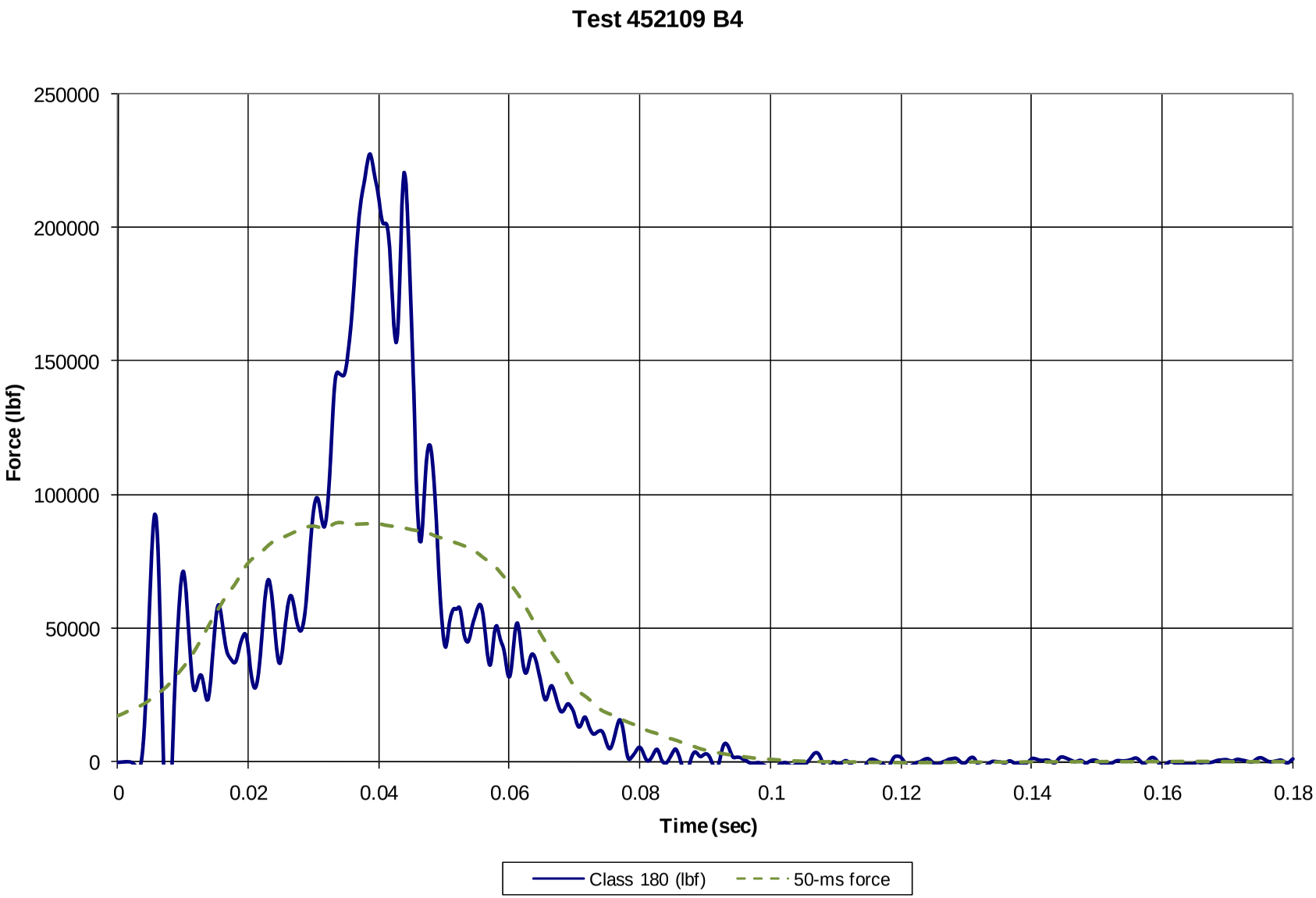


Figure 27. Force Trace for Test 452109-B4.

TEST NO. 452109-B5

Test Description

This test was a repeat of the first test on post 1. Figure 28 depicts the orientation of the bogie with the bridge rail at impact. The bogie vehicle, traveling at an impact speed of 15.8 mi/h, impacted post 1 of the T223 Bridge Rail at 90 degrees. At approximately 0.058 s, the pipe sections began to deform. At 0.070 s, the bogie began to rebound. The bogie lost contact with the bridge rail at 0.138 s, traveling at an exit speed of 3.5 mi/h. Figure B5 in Appendix B shows sequential photographs of the test period.

Damage to Test Installation

Figure 29 shows the damage to post 1. The darker marks represent cracks from impact in test B1, and the lighter marks represent the cracks sustained in test B5. The cracks marked in red increased in width on average of 1/16-inch from the previous test. The cracks in the beam from test B1 also extended further out with this impact. Maximum deflection of the bridge rail during the test was 2.14 inches.

Vehicle Damage

Maximum crush of the pipe nose was 8.7 inches. Before and after photographs of the nose are shown in Figure 30.

Electronic Data Analysis

Data from the accelerometer, located at the bogie center of gravity, were digitized and used to calculate a force-time history, which is shown in Figure 31. The maximum 50-ms average impact force was 55,442 lb, which exceeds the design impact force of 54,000 lb for a TL-3 impact. The end post had sufficient reserve capacity after test B1 to sustain a second design impact event with only moderate damage to the deck and rail.

Figure 28. Bogie/Installation Geometrics for Test 452109-B5.

Figure 29. Installation after Test 452109-B5.

Figure 30. Bogie before and after Test 452109-B5.

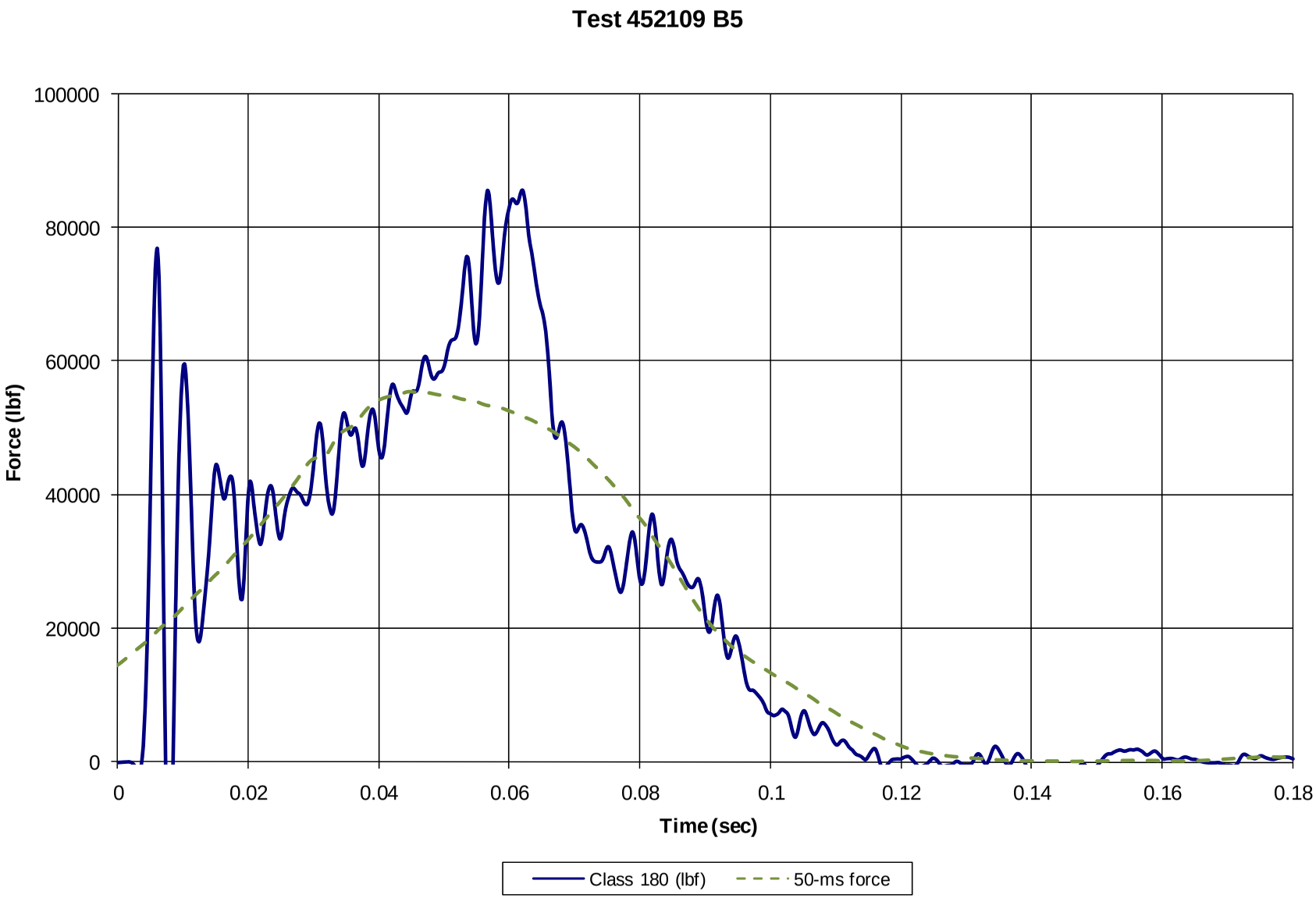


Figure 31. Force Trace for Test 452109-B5.

CHAPTER 4. SUMMARY AND CONCLUSIONS

SUMMARY OF TEST RESULTS

A summary of the reinforcing steel configurations in the T223 Bridge Rail and deck and the measured peak 50-ms impact force from the dynamic bogie tests is provided below.

Test B1 – Post No. 1 – End Post/Joint

For Test B1 – Post No. 1, the 13 #5 "U" bars anchoring the post to the concrete deck were spaced at 3-1/2 inches on centers. Thirteen #5 "L" bars were placed in the deck and provided additional reinforcement to the post. The top transverse #5 reinforcing steel was spaced at 3-1/2 inches on centers in the deck. Thirteen #5 upright "V" bars (bent at top of rail) were constructed in the post and provided reinforcement for the post and beam. In addition, one #5 "J" bar was placed in the deck near the field side edge and provided additional deck reinforcement. The peak 50-ms average impact force measured in the dynamic bogie test was 61.3 kips.

Test B2 – Post No. 8 – End Post/Joint

For Test B2 – Post No. 8, the 13 #5 "U" bars anchoring the post to the concrete deck were spaced at 3-1/2 inches on centers. Thirteen #5 "L" bars were placed in the deck and provided additional reinforcement to the post. The top transverse #5 reinforcing steel was spaced at 3-1/2 inches on centers in the deck. Thirteen #5 inverted "V" bars (bent at bottom of the post) were constructed in the post and provided reinforcement for the post and beam. The #5 "J" bar was omitted in this test. The peak 50-ms average impact force measured in the dynamic bogie test was 60.2 kips.

Test B3 – Post No. 3 – Mid-Span Post

For Test B3 – Post No. 3, the eight #5 "U" bars anchoring the post to the concrete deck were spaced at 6 inches on centers. Eight #5 "L" bars were placed in the deck and provided additional reinforcement to the post. The top transverse #5 reinforcing steel was spaced at 6 inches on centers in the deck. Eight #5 upright "V" bars (bent at the top of rail) were constructed in the post and provided reinforcement for the post and beam. In addition, one #5 "J" bar was placed on each side of the post in the deck near the field side edge and provided additional deck reinforcement. The peak 50-ms average impact force measured from the dynamic bogie test was 89.7 kips.

Test B4 – Post No. 6 – Mid-Span Post

For Test B4 – Post No. 6, the eight #5 "U" bars anchoring the post to the concrete deck were spaced at 6 inches on centers. Eight #5 "L" bars were placed in the deck and provided additional reinforcement to the post. The top transverse #5 reinforcing steel was spaced at 6 inches on centers in the deck. Eight #5 inverted "V" bars (bend at the bottom of the post) were constructed in the post and provided reinforcement for the post and beam. The peak 50-ms average impact force measured in the dynamic bogie test was 89.6 kips.

Test B5 – Post No. 1 – End Post/Joint (Residual Strength Test)

A second dynamic bogie test was performed at Post No. 1 to evaluate its reserve capacity after a severe impact. Some cracking was present in the bridge rail, post, and deck from the previous test performed at this location, and after the second impact, the cracks increased in width by 1/16-inch and also extended further out. The peak 50-ms average impact force from the second test at this location (Post No. 1) was 55.4 kips.

CONCLUSIONS

Based on the test results, recommendations regarding reinforcing steel and orientation for the T223 Bridge Rail are provided below.

T223 Bridge Rail End/Joint Post and Deck Reinforcing Steel Details

The measured peak 50-ms average impact forces for the two end posts tested for this study (Test B1 – Post No. 1 and Test B2 – Post No. 8) were not appreciably different, even though the reinforcing details were different for each. The use of the "J" bar in the deck did not appear to reduce the severity of the deck damage or increase the capacity of the T223 end/joint post. Therefore, it is recommended that this bar not be used in the T223 bridge rail design. The top transverse reinforcement in the deck at the end/joint post should be spaced 3-1/2 inches on centers. Based on the test results, the reinforcing steel details used for Test B1 – Post No. 1 are recommended for implementation in the T223 end post and deck locations.

T223 Bridge Rail Mid-Span Post and Deck Reinforcing Steel Details

The measured peak 50-ms average impact forces for the mid-span posts tested for this study (Test B3 - Post No. 3 and Test B4 – Post No. 6) were not appreciably different. The use of the "J" bars in the deck at Post No. 3 (Test B3) did not appear to reduce the severity of the deck damage at Post No. 3 or increase the capacity of the T223 bridge rail design for the mid-span testing condition. Therefore, it is recommended that this bar not be used in the T223 Bridge Rail design. Based on the test results, the reinforcing steel details used in Test B3 – Post No. 3 are recommended for implementation in the T223 mid-span post and deck locations.

CHAPTER 5. IMPLEMENTATION STATEMENT

The geometry of the new TxDOT Type T223 bridge rail as tested and presented herein is recommended for implementation on any new TxDOT Projects.

The following reinforcing steel details are recommended for the new TxDOT Type T223 bridge rail:

1.) The reinforcing steel details for the TxDOT Type T223 bridge rail end/joint post used at Post No. 1 (Test B1) as well as the details in the deck (with the exception of the use of the #5 "J" bar) are recommended for implementation. The "J" bar as constructed in the deck at Post No. 1 is not recommended for use.

2.) The reinforcing steel details for the TxDOT Type T223 bridge rail mid-span post used at Post No. 3 (Test B3) as well as the details in the deck (with the exception of the use of the #5 "J" bars) are recommended for implementation. The "J" bars as constructed in the deck at Post No. 3 are not recommended.

The new TxDOT Type 223 bridge rail has increased capacity and experiences less rail and deck damage during a design impact than the Type T203 bridge rail. In fact, the end post location sustained two design impact events with only moderate damage. Implementation of the new rail should result in reduced repair cost. Additionally, the 32-inch height of the Type T223 bridge rail enables it to accommodate a pavement overlay and still function as an *NCHRP Report 350* TL-3 railing.

REFERENCES

1. 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.

2. C. E. Buth, W. F. Williams, R. P. Bligh, W. L. Menges, and B. G. Butler, "Test 4, 5, & 6: NCHRP Report 350 Testing of the Texas Type T202 Bridge Rail," TxDOT Report 1804-5, Texas Transportation Institute, College Station, Texas, December 1998.

APPENDIX A. BOGIE TEST AND DATA ANALYSIS PROCEDURES

Brief descriptions of bogie test and data analysis procedures are presented below.

ELECTRONIC INSTRUMENTATION AND DATA PROCESSING

The bogie was instrumented with two accelerometers mounted at the rear of the bogie to measure longitudinal acceleration levels. The accelerometers were strain gage type with a linear millivolt output proportional to acceleration.

The electronic signals from the accelerometers were amplified and transmitted to a base station by means of constant bandwidth FM/FM telemetry link for recording on magnetic tape and for display on a real-time strip chart. Calibration signals were recorded before and after the test, and an accurate time reference signal was simultaneously recorded with the data. Pressure sensitive switches on the nose of the bogie were actuated by wooden dowel rods and initial contact to produce speed trap and "event" marks on the data record to establish the exact instant of contact with the installation, as well as impact velocity.

The multiplex of data channels, transmitted on one radio frequency, is received and demultiplexed onto a 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 bogie impact velocity.

The Test Risk Assessment Program (TRAP) uses the data from WinDigit to compute occupant/compartment impact velocities, time of occupant/compartment impact after bogie impact, and the highest 10-ms average ridedown acceleration. WinDigit calculates change in bogie velocity at the end of a given impulse period. In addition, maximum average accelerations over 50-ms are computed. For reporting purposes, the data from the bogie-mounted accelerometers were then filtered with a 180 Hz digital filter and plotted using a commercially available software package (Microsoft Excel®).

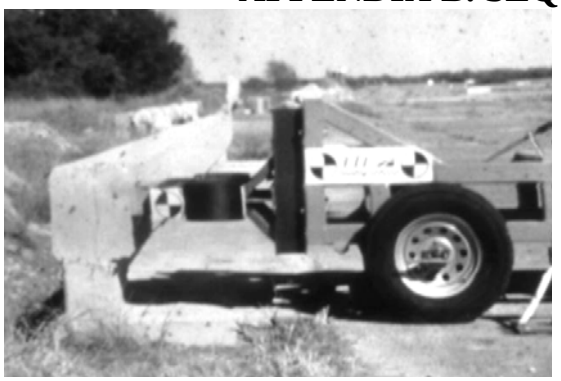
PHOTOGRAPHIC INSTRUMENTATION AND DATA PROCESSING

A high-speed digital camera, positioned perpendicular to the path of the bogie, was used to record the collision period. The film from this high-speed camera was analyzed on a computer to observe phenomena occurring during the collision and to obtain time-event, displacement, and angular data. A mini-DV camera and still cameras were used to document the crushable bogie nose and the test article before and after the test.

TEST VEHICLE PROPULSION AND GUIDANCE

The bogie 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 1-to-1 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 rebounded off the bridge rail.

APPENDIX B. SEQUENTIAL PHOTOGRAPHS



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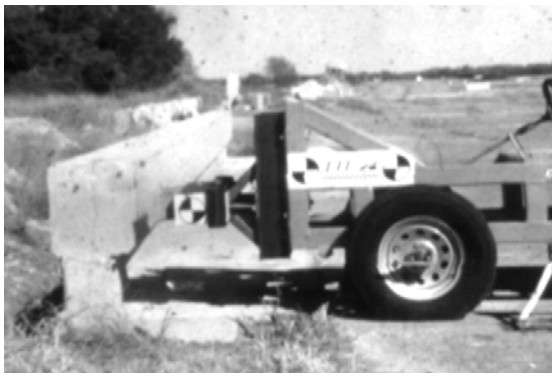

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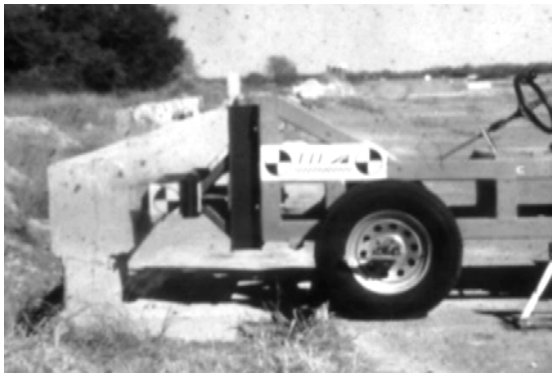

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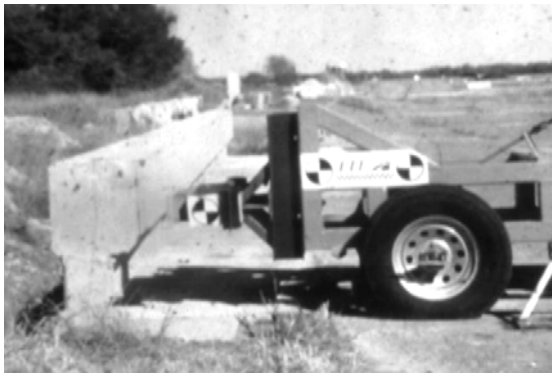

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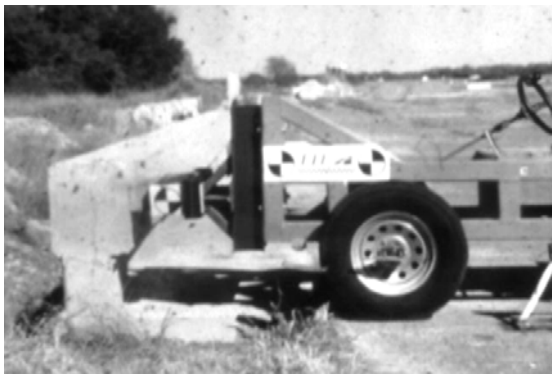

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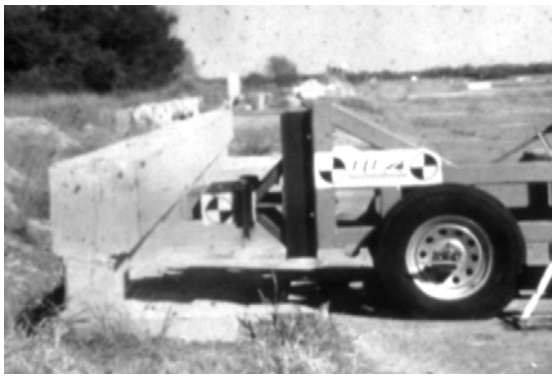

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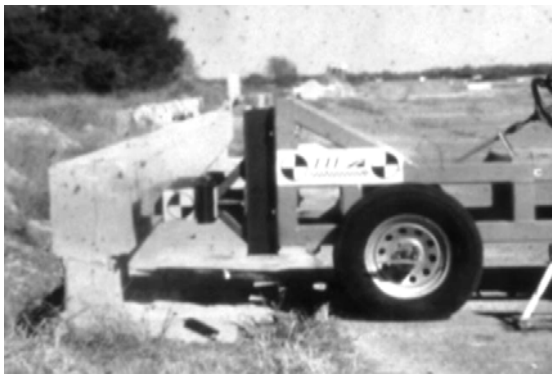

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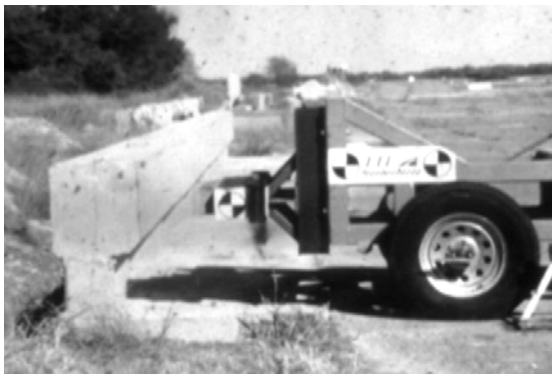

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Figure B1. Sequential Photographs for Test 452109-B1.

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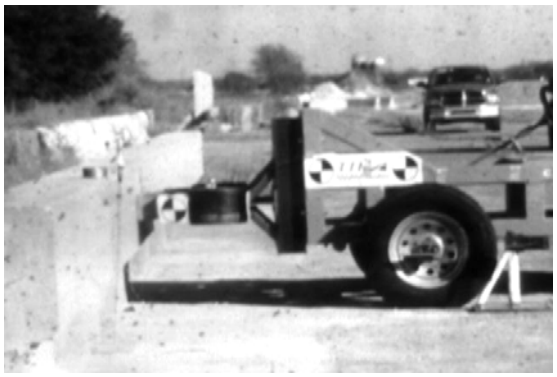
Figure B2. Sequential Photographs for Test 452109-B2.



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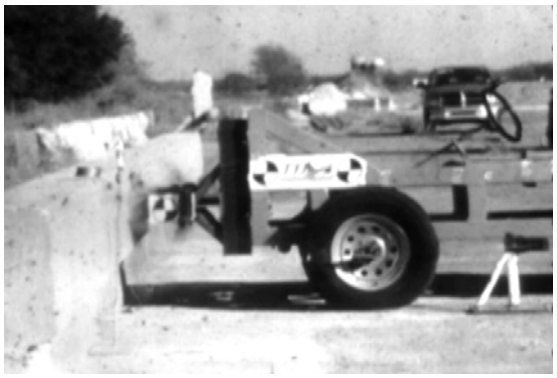

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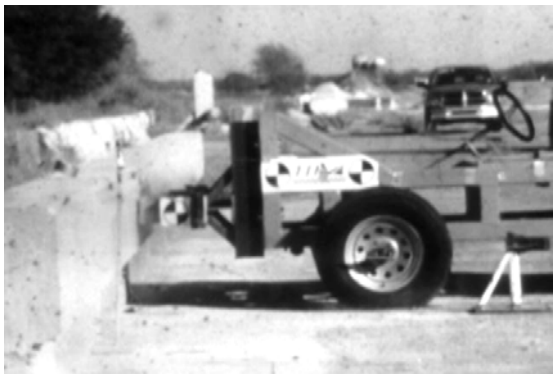

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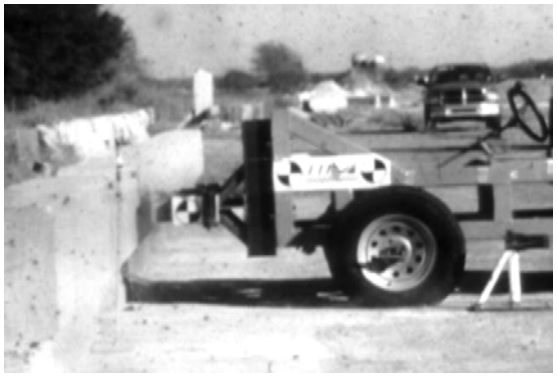

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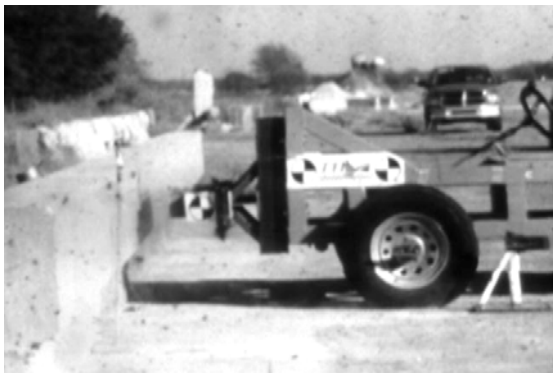

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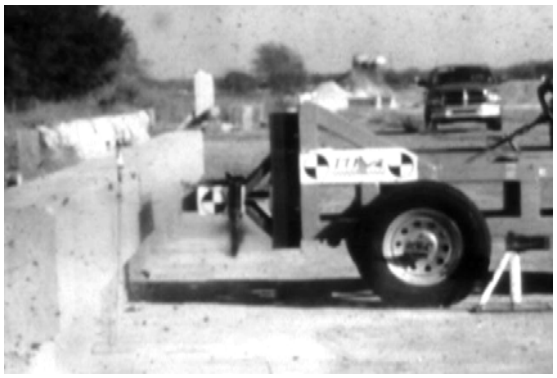

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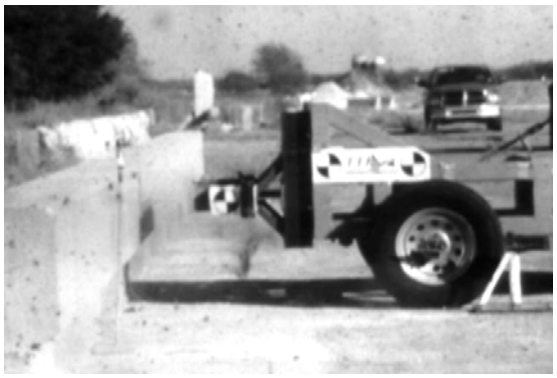

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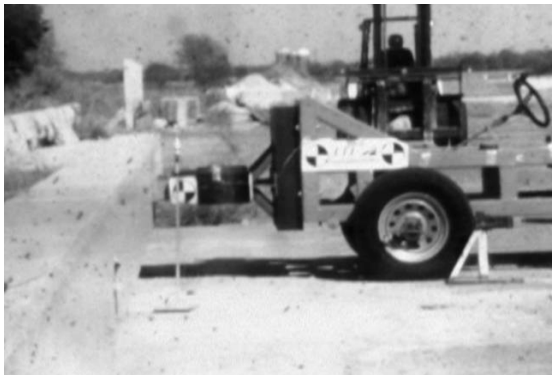

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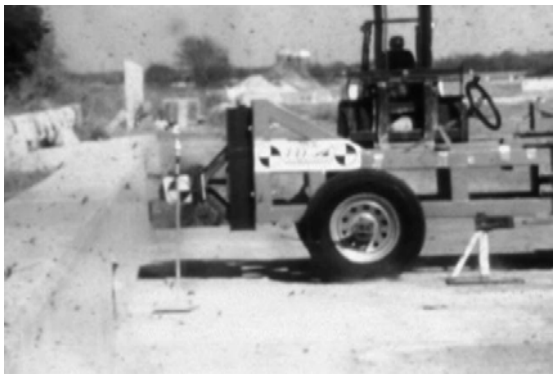

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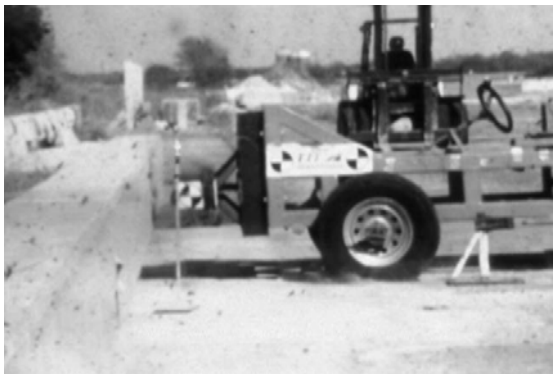

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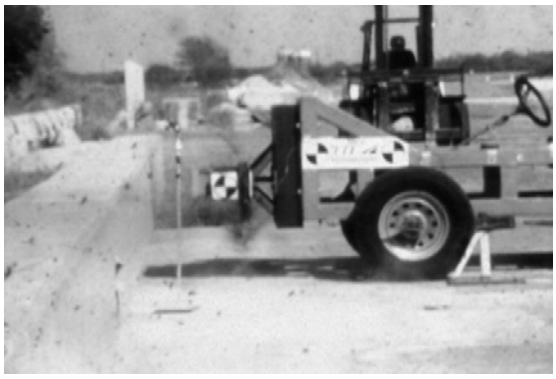

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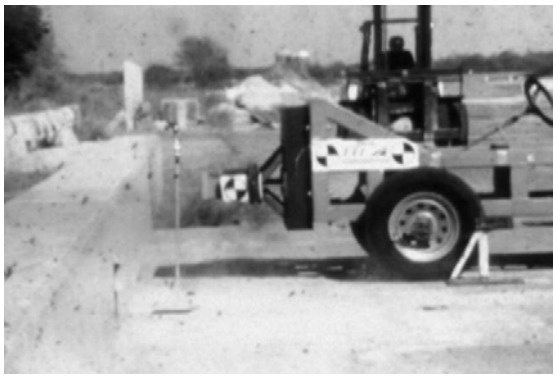

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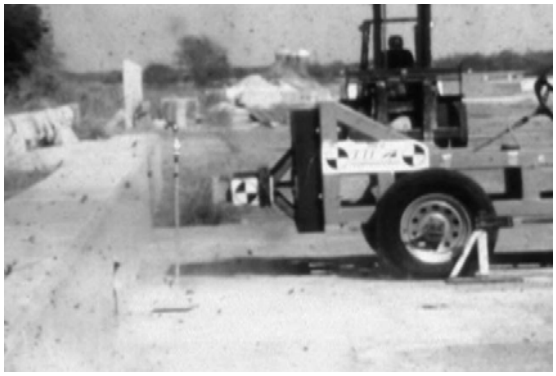

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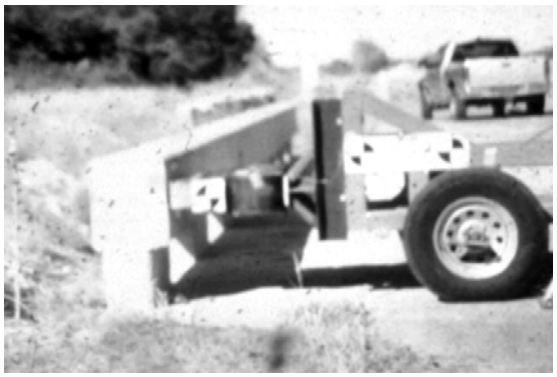

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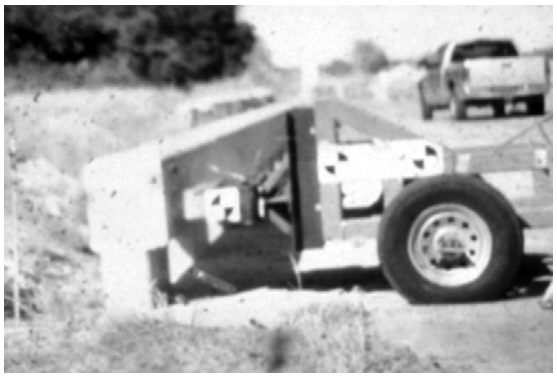

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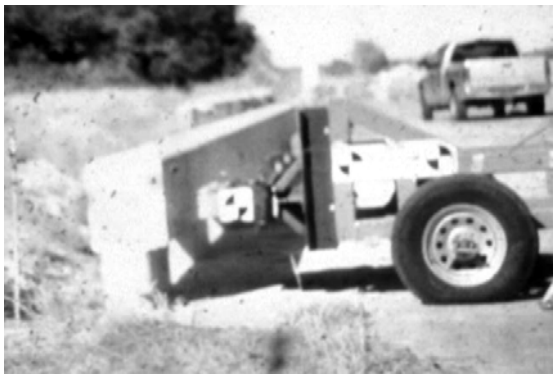

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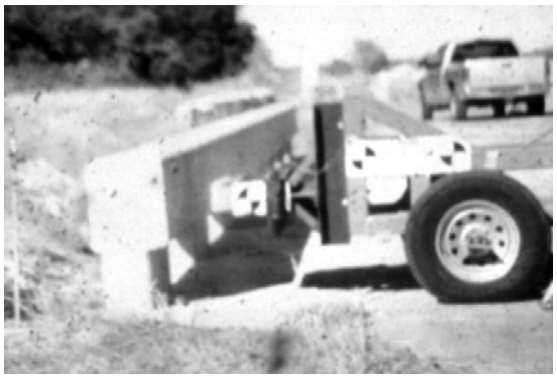

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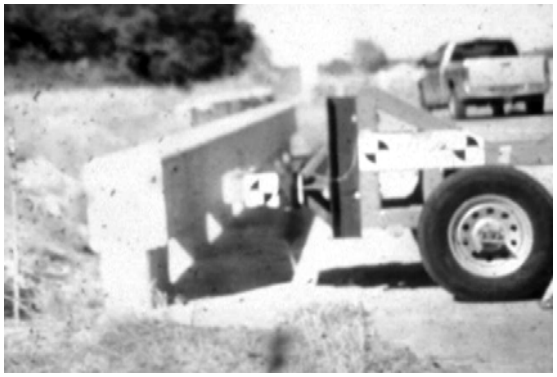

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Figure B5. Sequential Photographs for Test 452109-B5.