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# DEVELOPMENT OF A *MASH* TL-3 MEDIAN BARRIER GATE



Crash testing performed at:  
TTI Proving Ground  
3100 SH 47, Building 7091  
Bryan, TX 77807

**Research/Test Report 9-1002-2**

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  
<http://tti.tamu.edu/documents/9-1002-2.pdf>



1. Report No. FHWA/TX-11/9-1002-2		2. Government Accession No.		3. Recipient's Catalog No.	
4. Title and Subtitle <b>DEVELOPMENT OF A MASH TL-3 MEDIAN BARRIER GATE</b>				5. Report Date February 2011 Published June 2011	
				6. Performing Organization Code	
7. Author(s) Roger P. Bligh, Dusty R. Arrington, Nauman M. Sheikh, Chiara Silvestri, and Wanda L. Menges				8. Performing Organization Report No. Test Report 9-1002-2	
9. Performing Organization Name and Address Texas Transportation Institute Proving Ground The Texas A&M University System College Station, Texas 77843-3135				10. Work Unit No. (TRAIS)	
				11. Contract or Grant No. Project 9-1002	
12. Sponsoring Agency Name and Address Texas Department of Transportation Research and Technology Implementation Office P.O. Box 5080 Austin, Texas 78763-5080				13. Type of Report and Period Covered Technical/Test Report: September 2008–August 2010	
				14. Sponsoring Agency Code	
15. Supplementary Notes Project performed in cooperation with the Texas Department of Transportation and the Federal Highway Administration. Project Title: Roadside Safety Device Crash Testing Program URL: <a href="http://tti.tamu.edu/documents/9-1002-2.pdf">http://tti.tamu.edu/documents/9-1002-2.pdf</a>					
16. Abstract <p>Median barriers are commonly used to separate opposing lanes of traffic on divided highways and to separate managed lanes from general purpose lanes. Concrete median barriers (CMBs) are often preferred on urban freeways with narrow medians due to their minimal deflection and low maintenance. However, long, continuous runs of CMBs limit access of emergency and maintenance vehicles to the other side of a roadway or a managed lane. Implementation of crashworthy median barrier gates at these locations can maintain the desired level of median protection for motorists while offering improved cross-median access for emergency and/or maintenance vehicles.</p> <p>A new median barrier gate was developed and crash tested under this project. The gate spans a 30-ft opening in a concrete median barrier and consists of two vertically stacked 12-inch × 12-inch × ¼-inch steel tubes connected to steel end brackets with 2¼-inch diameter steel pins.</p> <p>The gate is economical to fabricate and install. It can be manually operated by a single person and is designed to accommodate reversible traffic flow on both sides of the median and be operable in both directions on each end. The median barrier gate satisfies <i>MASH</i> Test Level 3 (TL-3) impact performance criteria and is considered suitable for implementation on Texas highways where cross-median access is desired.</p>					
17. Key Words Median Barrier, Gate, Roadside Safety, Crash Test, <i>MASH</i>			18. Distribution Statement No restrictions. This document is available to the public through NTIS: National Technical Information Service Springfield, Virginia 22161 <a href="http://www.ntis.gov">http://www.ntis.gov</a>		
19. Security Classif.(of this report) Unclassified		20. Security Classif.(of this page) Unclassified		21. No. of Pages 170	22. Price



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MEDIAN BARRIER GATE**

by

Roger P. Bligh, P.E.  
Research Engineer  
Texas Transportation Institute

Dusty R. Arrington  
Engineering Research Associate  
Texas Transportation Institute

Nauman M. Sheikh, P.E.  
Assistant Research Engineer  
Texas Transportation Institute

Chiara Silvestri  
Post Doctoral Research Associate  
Texas Transportation Institute

and

Wanda L. Menges  
Research Specialist  
Texas Transportation Institute

Report 9-1002-2  
Project 9-1002

Project Title: Roadside Safety Device Crash Testing Program

Performed in cooperation with the  
Texas Department of Transportation  
and the  
Federal Highway Administration

February 2011  
Published: June 2011

TEXAS TRANSPORTATION INSTITUTE  
The Texas A&M University System  
College Station, Texas 77843-3135




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



  
Wanda L. Menges, Research Specialist  
Deputy Quality Manager

  
Richard A. Zimmer, Senior Research Specialist  
Test Facility Manager  
Quality Manager  
Technical Manager

## **ACKNOWLEDGMENTS**

This research project was conducted under a cooperative program between the Texas Transportation Institute, the Texas Department of Transportation, and the Federal Highway Administration. The TxDOT project director for this research was Rory Meza, P.E. Bobby Dye with the Design Division served as project advisor and was also actively involved in this research. The authors acknowledge and appreciate their guidance and assistance.



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# CHAPTER 1. INTRODUCTION

## 1.1 INTRODUCTION

This project was set up to provide Texas Department of Transportation (TxDOT) with a mechanism to quickly and effectively evaluate high priority issues related to roadside safety devices. Roadside safety devices shield motorists from roadside hazards such as non-traversable terrain and fixed objects. To maintain the desired level of safety for the motoring public, these safety devices must be designed to accommodate a variety of site conditions, placement locations, and a changing vehicle fleet. Periodically, there is a need to assess the compliance of existing safety devices with current vehicle testing criteria.

Under this project, roadside safety issues are identified and prioritized for investigation. Each roadside safety issue is addressed with a separate work plan, and the results are summarized in an individual test report.

## 1.2 BACKGROUND

Median barriers are commonly used to separate opposing lanes of traffic on divided highways. Concrete median barriers (CMBs) are often preferred on urban freeways with narrow medians. They are also used along heavily traveled highways to separate managed lanes from general purpose lanes. The rigid nature of concrete barriers results in little or no deflection and makes them relatively maintenance free. This reduces life-cycle cost, congestion due to lane closures, and exposure of maintenance personnel.

However, long, continuous runs of CMBs limit access of emergency and maintenance vehicles to the other side of the roadway or a managed lane. Periodic openings in the barrier can provide needed cross-median access. However, the exposed barrier ends resulting from openings in a concrete median barrier pose an impact hazard for traffic. Even if the exposed barrier ends are safety treated with crash attenuators, median protection is lost along the length of the opening. Implementation of crashworthy median barrier gates at these locations can maintain the desired level of median protection for motorists while offering improved cross-median access for emergency and/or maintenance vehicles.

A median barrier gate must be able to function as a median barrier to contain and redirect errant vehicles impacting along its length, be able to open and close, and be properly transitioned to the CMB on both ends. The Texas Transportation Institute (TTI) developed an emergency opening system (EOS) for the Texas State Department of Highways and Public Transportation (SDHPT) in the early 1980s (*1*). The system was comprised of two tubular steel beams mounted vertically on top of each other with a separation of 3 inches. A W-beam rail was attached to the face of the steel beams and terminated with W-beam end connectors to minimize snagging potential. The beams spanned 30 ft between free-standing CMB sections that were modified to transition from a New Jersey safety shape profile to a vertical face. Steel brackets with three 7/8-inch thick horizontal steel plates were anchored to the ends of the CMB sections using eight 1.5-inch diameter anchor bolts. The steel box beams were pinned to the brackets using a

3.25-inch diameter pin at each end. A jack and caster mechanism was used to raise the beams off of the horizontal bracket plates to permit it to be pushed open.

Three full-scale crash tests were conducted to evaluate the impact performance of the system under *NCHRP Report 230* (2). Two tests were performed to evaluate the transition of the steel beams to the CMB and the effects of vehicle snagging on the concrete barrier ends. One test involved an 1800-lb small passenger car impacting the EOS at a nominal speed of 60 mi/h and a nominal angle of 15 degrees. The other transition test involved a 4500-lb passenger sedan impacting the EOS at nominal speed of 60 mi/h and a nominal angle of 25 degrees. The impact point for both tests was 6 ft upstream of the downstream end of the system.

Another test was conducted 6 ft upstream of the midpoint of the gate to evaluate the strength and maximum deflection of the steel beams. A 4500-lb passenger sedan impacted the EOS at nominal speed of 60 mi/h and a nominal angle of 25 degrees. The crash tests were successful, and the design was implemented by the SDHPT on selected projects along Interstate 45 (1).

As traffic volumes have continued to increase, additional lanes have been added to increase capacity. This has resulted in narrower medians and the use of more concrete median barrier to separate traffic. The use of managed lanes has also increased significantly in recent years as another means of addressing growing congestion problems. Consequently, the need for median barrier gates to provide emergency and other authorized vehicles access to these lanes has also increased.

TTI conducted further testing of both the original and a modified version of the EOS for the TxDOT under research project 0-5210 (3). The objective of the testing was to determine if the EOS complies with the new *Manual for Assessing Safety Hardware (MASH)* that was published by the American Association of State Highway and Transportation Officials (AASHTO) in October 2009 (4). *MASH* has superseded *NCHRP Report 350* (5) as the recommended guidance for the safety performance evaluation of roadside safety features.

*MASH* test designation 3-10 was performed on the original EOS barrier design with some minor modifications incorporated to reduce the potential for vehicle snagging. The horizontal plates on the steel end bracket were tapered, and the curb protruding from the end of the concrete parapet was constructed with a straight taper rather than a rounded nose. Figure 1.1 shows the test installation. The test conditions were a 2420 lb vehicle (denoted 1100C) impacting the gate 3.6 ft upstream of the end of the concrete parapet at a nominal impact speed and angle of 62 mi/h and 25 degrees, respectively.

The 1100C test vehicle was contained and redirected. However, the gate failed to comply with *MASH* due to excessive occupant compartment deformation inside the vehicle (3).





**Figure 1.1. Emergency Opening System (EOS).**

Several modifications were made to the end of the EOS to help mitigate the severe vehicle snagging. These changes were developed with retrofit of the existing design as a goal. The horizontal steel plates on the end brackets were replaced with tapered sections of 2 inch  $\times$   $\frac{1}{4}$ -inch thick steel tubing. The ends of the tubular steel beams were cut off and tapered sections of tubing were added. These tubes tapered out 2 inches from the sides of the steel beams and then tapered back down to a width that was less than the width of the end of the concrete parapet to reduce snagging potential from a reverse direction impact. When assembled and installed, the tapered sections of tubing on the steel beams and end bracket overlapped each other to resemble

a finger joint. Other details of the median barrier gate, including the concrete parapet details, remained the same as in the previous tests.

*MASH* test 3-10 was performed on the modified design. Once again, the modified gate did not perform acceptably due to excessive occupant compartment deformation inside the vehicle (3). Further research was needed to develop a median barrier gate that satisfies *MASH* impact performance criteria.

### **1.3 OBJECTIVES/SCOPE OF RESEARCH**

The objective of this research was to develop a median barrier gate that meets the Test Level 3 (TL-3) impact performance requirements of *MASH*. TxDOT requested that the gate be designed to accommodate reversible traffic flow on both sides of the median and that the gate be operable in both directions on each end.

The research approach consisted of engineering analysis, finite element simulation, and full-scale crash testing. Three tests were performed to evaluate different aspects of the design. Test 3-11 evaluated the strength of the median barrier gate and its ability to function as a longitudinal barrier. Tests 3-20 and 3-21 assessed the transition of the median barrier gate to the adjacent concrete median barrier.

Reported herein are details of the design and analysis of the TxDOT median barrier gate, descriptions of the tests performed, assessment of the test results, and implementation recommendations.

## CHAPTER 2. MEDIAN BARRIER GATE DESIGN\*

A median barrier gate must function as a median barrier. Adequate strength is necessary to maintain continuity of protection between the sections of concrete median barrier it spans. The gate must be capable of containing and redirecting errant vehicles that impact along its length. Additionally, the stiffness of the gate must be properly transitioned to the adjacent concrete median barrier to prevent excessive vehicle snagging or vehicle “pocketing” into the more flexible gate in advance of the rigid barrier end.

As the name implies, the median barrier gate must also function as a gate. It must be capable of being readily opened and closed from both directions on either end. The gate must be sufficiently light to permit manual operation and the components, including any wheels or casters must be durable and suitable for operation in a highway environment. Key design considerations that must be addressed include vehicle snagging on exposed CMB surfaces, structural adequacy to accommodate the increased impact severity of the design impact conditions prescribed by the AASHTO *MASH*, and stability of the pickup truck design test vehicle.

### 2.1 DESIGN CONSIDERATIONS

#### 2.1.1 Snagging

As discussed in [Chapter 1](#), the original EOS failed to comply with *MASH*. Exposed surfaces on the CMB to which the gate was attached permitted severe vehicle snagging to occur. The snagging forces led to excessive occupant compartment deformation inside the vehicle.

Various design features were incorporated into the new median barrier gate to help mitigate snagging potential. The vertical spacing between the rail elements was eliminated. This not only reduced snagging, but also simplified fabrication. Stacking the two rails on top of one another eliminates the need for welded spacers. Thus, the rails can be individually galvanized and assembled with through bolts rather than being welded together with channel spacers and galvanized as a unit.

Additionally, the width of the tubular rail members was increased to match the width of the end of the concrete parapet to which it is attached. This decreases the ability of the vehicle to make direct contact with the end of the concrete parapet. When making this change, it was important to account for the tolerance in the pinned connection and any lateral shift that the connection permits in the rail members. Too much shift could expose the edge of the rail members and result in snagging in a reverse direction impact.

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\* The opinions/interpretations expressed in this section are outside the scope of TTI Proving Ground's A2LA accreditation.

Finally, the gap between the ends of the tubular rails and the concrete parapet was minimized. Some offset was required to accommodate the travel arc of the rails as they are opened and closed.

### 2.1.2 Rail Member Selection

The selection of a rail member to serve as the beams in the median barrier gate involved consideration of several factors. The bending capacity of the rails had to be sufficient to contain and redirect a pickup truck impacting at the design test conditions specified in *MASH*. The EOS was connected to free-standing barrier ends when it was crash tested. The resulting lateral barrier deflection reduced the impact forces compared to a system connected to a rigid barrier. Furthermore, the heavier design test vehicle specified in *MASH* increased the impact severity by 13 percent compared to the nominal test conditions used to evaluate the EOS.

Geometry of the rails was an important consideration in addition to strength. As mentioned in the previous section, it was desirable that the width of the rail match the width of the end of the concrete parapet to which it was attached to reduce snagging potential. Further, several constraints existed on the depth of the rail members. The combined height of the two rail members had to provide sufficient rail height to maintain vehicle stability during redirection while maintaining a clear opening from the ground to the bottom of the lower rail of no more than 11 inches. An empirical relationship between clear opening and post setback distance is presented in Section 13 “Railings” of the 2004 AASHTO *LRFD Bridge Design Specifications* (6). This guidance, which was based on crash test performance, recommends that the clear opening beneath a rail be no more than 11 inches when the post setback distance is zero. In the case of the median barrier gate, the “post” is the end of the concrete parapet and the setback distance is zero (i.e., the edge of the concrete parapet is aligned with the face of the tubular steel rail elements).

Weight, cost, and availability were other important factors in the selection of a rail member for use in the median barrier gate. If the tubular steel rails were too heavy, it would make their use in a manually operated gate impractical. Some districts have found the cost of proprietary gate systems in the market to be prohibitive. One of the design objectives for the new median barrier gate was to keep its cost comparable to that of the existing EOS. The availability of tubular steel members in large sizes can be very limited. Selection of a rail size with very limited availability could adversely affect fabrication and delivery schedules. The researchers contacted several steel suppliers in Texas to obtain cost information and verify availability of the members being considered for use in the median barrier gate system.

Table 2.1 shows the weight, cost, and plastic section modulus for the 8-inch × 8-inch × ½-inch steel tube used in the EOS and other sizes with possible application in the new median barrier gate. Tubular members with a width of 12 inches were selected to match the width of the concrete parapet needed to develop the strength of the barrier gate. The selection of member depth was a function of rail height. Stacked 12-inch × 10-inch steel tubes could provide a maximum height of 31 inches when constrained by a maximum clear opening of 11 inches. The 12-inch × 12-inch section could provide rail heights up to 35 inches.

Several thicknesses were available for these two sizes of steel tubes. The selection of a thickness is based on the required strength. Impact simulations were performed to aid in the selection of a rail height based on vehicle stability and a rail thickness based on strength.

**Table 2.1. Comparison of Tubular Rail Properties.**

Material Costs (04/2010)					
Section	Thickness	Cost/Foot	Weight/Foot	Cost/lb	Zx
12x12	1/4	\$28.91	39.4	\$0.73	47.6
	5/16	\$33.42	48.8	\$0.68	58.6
	3/8	\$35.90	58	\$0.62	69.2
12x10	1/4	\$38.80	36	\$1.08	42.1
	5/16	N/A	44.6	N/A	51.7
	3/8	\$58.35	52.9	\$1.10	61.1
8x8	1/2	\$38.09	48.7	\$0.78	37.5

## 2.2 FINITE ELEMENT ANALYSIS

Finite element models were developed for use in impact simulations to determine the optimal rail member size for the new median barrier gate. The objective was to meet strength and crashworthiness requirements while minimizing weight and cost. This was accomplished through a parametric study of the performance of different rail sizes and thicknesses.

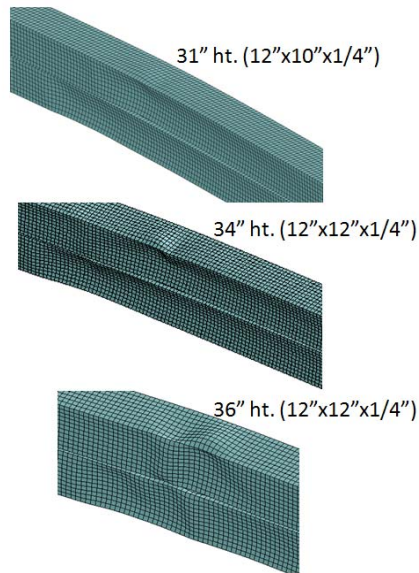
The LS-DYNA finite element code was used for the simulations (7). LS-DYNA is a general purpose explicit finite element code capable of simulating complex nonlinear dynamic impact problems. LS-DYNA incorporates state-of-the-art contact algorithms that can be used to model vehicular collisions with roadside objects and is widely used within the roadside safety research community for analyzing the impact performance of roadside safety hardware.

The analyses were performed using the impact conditions of *MASH* test 3-11. This test involves a 5000-lb pickup truck (denoted 2270P) impacting the barrier at a speed of 62 mi/h and an angle of 25 degrees. The impact point was approximately 4 ft upstream of the midpoint of the gate. The vehicle model used in the simulations was a 2007 Chevrolet Silverado 1500, 2-wheel drive (2WD), crew cab, short box, pickup truck (8). This model was developed by the National Crash Analysis Center (NCAC) under sponsorship of the Federal Highway Administration (FHWA) to represent the *MASH* design vehicle.

An initial simulation was performed on the EOS. This system incorporates two 8-inch × 8-inch × ½-inch steel tubes vertically separated 3 inches and mounted at a height of 28.5 inches. The pickup truck exhibited a high roll angle as shown in Figure 2.1, and rollover was the predicted outcome. It was concluded from the results of this simulation that the rail height needed to be increased to improve stability of the pickup truck.



Rail Height	Max. Dynamic Deflection	Max. Static Deflection
31" (12"x10"x1/4")	12.25"	9.5"
34" (12"x12"x1/4")	11.75"	9"
36" (12"x12"x1/4")	12"	9"

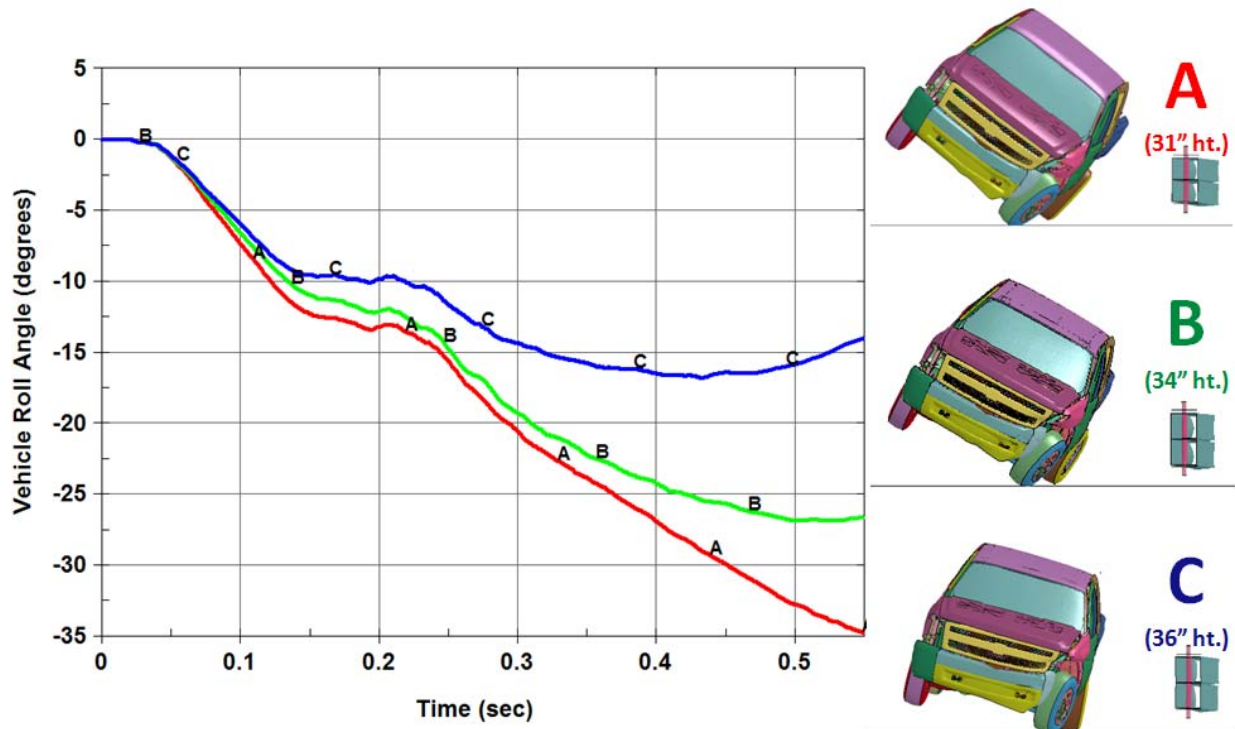


**Figure 2.3. Rail Deformation and Deflection Results.**

Figure 2.4 shows vehicle roll angle versus time. At time of termination of the simulation runs (0.55 seconds), the vehicle roll angle for the 31 inch rail height was 35 degrees and still increasing. Vehicle rollover for this configuration is likely. The vehicle was very stable in the impact with the 36 inch rail height, with a maximum roll angle of only 17 degrees. The vehicle was also successfully redirected in the simulation with the 34 inch rail height, but the vehicle had a higher roll angle of 27 degrees.

Results showed that a 12-inch  $\times$  10-inch tube section was not feasible as a rail member for the new median barrier gate. It was not capable of redirecting the pickup truck in a stable manner at its maximum height of 31 inches. Thus, further evaluation efforts focused on the 12-inch  $\times$  12-inch steel tube sections.

Two additional simulations were performed. One simulation evaluated vehicle stability associated with a 35 inch rail height. A 12-inch  $\times$  12-inch  $\times$  1/4 inch tube was used in this simulation. The final simulation was performed with a thicker 12-inch  $\times$  12-inch  $\times$  5/16-inch tube at a height of 34 inches. The purpose of this simulation was to evaluate if the local buckling phenomenon observed in the simulation of the thin-walled tube affected vehicle stability. In other words, would the reduced deformation of a thicker, stronger tube improve vehicle stability and enable a lower mounting height to be utilized.



**Figure 2.4. Vehicle Roll Angle Results.**

Figure 2.5 shows vehicle roll angle versus time for these additional simulations superimposed on the results from the previous simulations. Results from the two cases with different rail thickness (cases B and E) are similar in terms of vehicle roll angle, indicating that the increase in rail thickness did not affect vehicle stability. Consequently, there was no compelling reason to adopt a thicker, heavier, more costly rail section. It was concluded that the 12-inch  $\times$  12-inch  $\times$  1/4-inch tube section was the optimal choice as a rail member for the new median barrier gate. Not only does it provide adequate strength to contain and redirect the pickup truck, it is a lighter and less expensive section than the 8-inch  $\times$  8-inch  $\times$  1/2-inch tube section used in the EOS (refer to Table 2.1).

The rail height selected for the new median barrier gate was 35 inches. The pickup truck was stably redirected at this rail height as shown in Figure 2.5. Further, this is the maximum height that can be achieved with the stacked 12-inch  $\times$  12-inch  $\times$  1/4-tubes when constrained by a maximum clear opening of 11 inches between the ground and bottom of the rail to reduce potential for vehicle snagging.

The impact forces derived from the simulation of the selected rail configuration were used to size the connection pins, design the steel anchor bracket, and engineer the reinforcement in the concrete parapet ends. The design recommendations were reviewed and approved by TxDOT. Full-scale crash tests were performed to verify the impact performance of the median barrier gate. Details of the median barrier gate and crash tests are described in the following sections of this report.



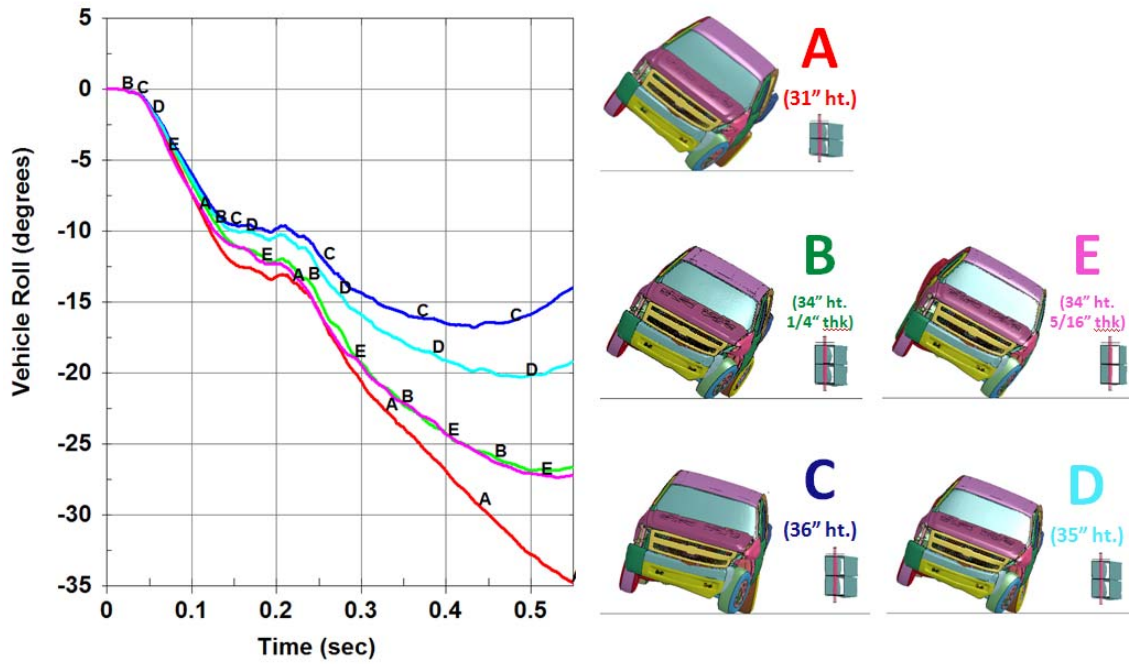


Figure 2.5. Predicted Vehicle Roll Outcomes for Different Rail Configurations.



## CHAPTER 3. MEDIAN BARRIER GATE DETAILS

### 3.1 TEST ARTICLE DESIGN AND CONSTRUCTION

The total length of the installation was 50 ft-0 inch and was comprised of two 10 ft cast-in-place concrete barrier sections with a 30 ft long median barrier gate spanning between them. The concrete parapets were cast in place on top of a 6-inch thick reinforced concrete slab. They were tied to the slab using fourteen #5 stirrups spaced at 8 inches, followed by three #5 stirrups spaced at 4 inches at the gate end of the parapet. The concrete parapets transitioned from a 32-inch tall F-shape that was 9½ inches wide on top and 24 inches wide on bottom to a vertical wall that was 36½ inches tall and 12 inches wide over a distance of 5 ft. A 9½-inch tall curb protruded 16 inches out from the end of the concrete parapet to support the steel end bracket and steel connection pin.

Horizontal reinforcement in the F-shape portion of the concrete parapets consisted of four pairs of #5 bars located 5 inches, 10 inches, 16 inches, and 30½ inches from the bottom of the parapet. These bars were symmetric about the vertical centerline of the parapet and followed its profile. In the transition section, the horizontal reinforcement included two pairs of #5 bars located 5 inches and 10 inches from the bottom of the parapet, and three pairs of #7 Richmond anchors located 14 inches, 20½ inches, and 25½ inches from the bottom of the parapet. Another set of #7 Richmond anchors were bent to follow the vertical taper of the transition and terminated at a height of 31 inches from the bottom of the parapet. The Richmond anchors formed a rectangular bolt pattern to which the steel anchor brackets were attached.

The vertical reinforcement in the 5-ft transition section of the parapet near the gate connection was comprised of pairs of #5 U-bars that created closed stirrups spaced on 4-inch centers. This was followed by four more pairs of U-bars spaced at 8 inches. These U-bars were positioned between #5 open stirrups that were bent to match the profile of the F-shape barrier and spaced on 8-inch centers along the 5-ft length of F-shape barrier.

A 16-inch long, 9½-inch high curb was cast on the inside face of each concrete parapet. A 9½-inch long section of 3-inch schedule 40 pipe that was cast inside the curb and reinforced with two #5 U-bars that extended out of the end of the parapet. The steel end brackets rested on top of the curb, and the connecting pins extended into the embedded pipe section.

The median barrier gate itself was comprised of two 29-ft long, 12-inch × 12-inch × ¼-inch A500 Grade B steel tubes. The tubes were stacked vertically on top of one another and bolted together using three ¾-inch diameter × 26-inch long ASTM A325 or equivalent grade bolts spaced on 80-inch centers. A 2½-inch schedule 40 pipe section was welded inside the ends of the tubes for the connecting pins. The ends of the tubes were reinforced with a tubing support bracket fabricated from ASTM A36 steel plate. The tubing support bracket slides into the end of the tubes around the pipe inserts and is secured in place using two ¾-inch diameter × 26-inch long ASTM A325 or equivalent grade bolts.

Steel end brackets were fabricated from ASTM A36 steel plate. The vertical plate of the end bracket that connected to the end of the concrete parapet was 12 inches wide and 2 inches thick. Two 1-inch thick tapered horizontal steel plates were welded to the top and bottom of the end plate. A 2½-inch × 3-inch slot was cut into each plate to accept the connecting pin.

The end brackets were bolted to the ends of the concrete parapets using eight 1-inch diameter × 3¾-inch long ASTM A325 high-strength bolts. The bolts threaded into the Richmond anchors that were cast inside the concrete parapet.

The median barrier gate was connected to the end brackets using 2¼-inch diameter × 32-inch long ASTM A36 cold rolled steel pins. The pins passed through the horizontal plates in the end bracket, the pipe sections inside the tubular steel rails, and inserted into the pipe sleeve embedded in the parapet curb.

The median barrier was supported by a heavy duty 8-inch diameter swivel caster wheel. The wheel provides a mounting height of 35 inches to the top of the upper steel tube. [Figure 3.1](#), [Figure 3.2](#), and [Appendix A](#) show details of the median barrier gate installation. [Figure 3.3](#) presents photographs of the completed test installation.

### **3.2 MATERIAL SPECIFICATIONS**

Concrete used for parapet portion of the barrier was specified to have a 28-day unconfined compressive strength of 3600 psi. All reinforcing steel was grade 60.

The rails that comprised the gate were ASTM A500 Grade B steel tubes. The end bracket, tubing support bracket, and caster mounting plate were fabricated from ASTM A36 steel plate.

The bolts used to connect the end bracket to the concrete parapet, secure the tubing support bracket inside the tubes, connect the tubes together, and connect the swivel caster were all ASTM A325 or equivalent grade. The connecting pin was specified to be ASTM A36 cold rolled steel. The handle on the pin was fabricated from ASTM A36 steel rod. [Appendix B](#) presents materials certifications related to the materials used to construct the median barrier gate.

### **3.3 SOIL CONDITIONS**

The test installation was installed on an existing concrete apron.

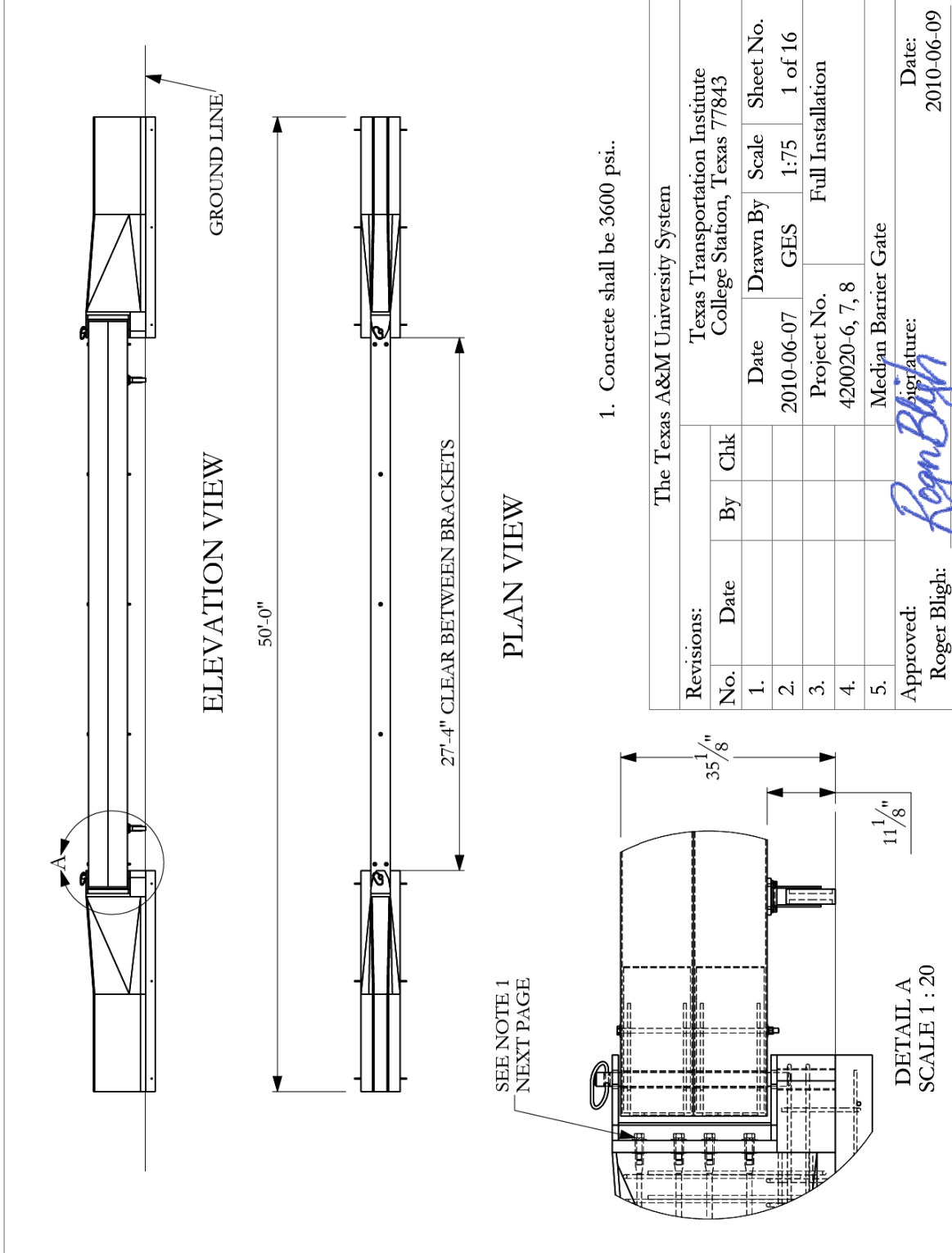


Figure 3.1. Details of the TxDOT Median Barrier Gate Installation.

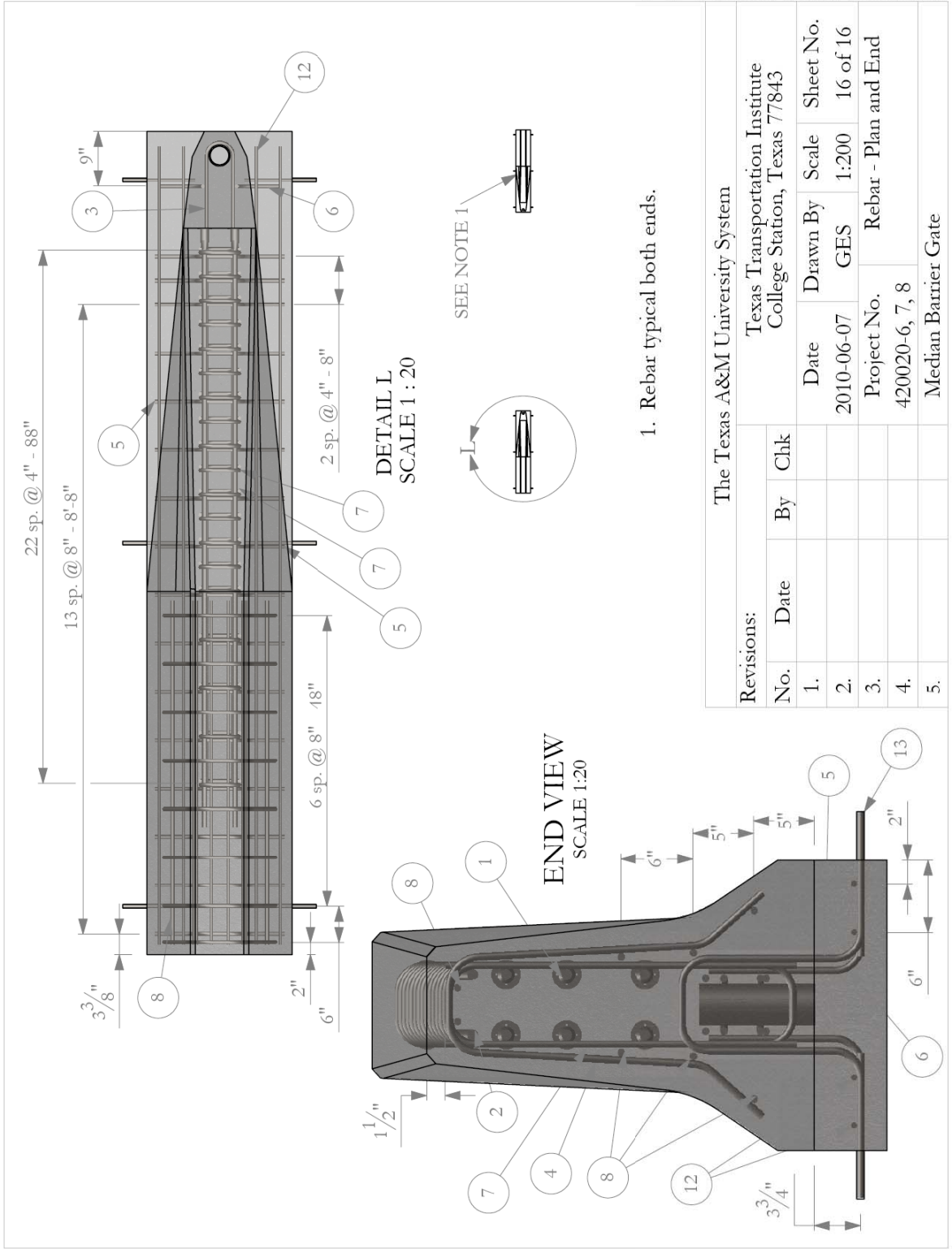


Figure 3.2. Details of the TxDOT Median Barrier Gate.



**Figure 3.3. TxDOT Median Barrier Gate Installation before Testing.**





## CHAPTER 4. TEST REQUIREMENTS AND EVALUATION CRITERIA

### 4.1 CRASH TEST MATRIX

Three full-scale crash tests were performed to evaluate the impact performance of the TxDOT median barrier gate and assess its compliance with *MASH* guidelines. The first test performed on the TxDOT median barrier gate was *MASH* test 3-20. This test involves a 2420-lb passenger car (denoted 1100C) impacting the median barrier gate upstream of its connection to the rigid concrete parapet at a nominal speed of 62 mi/h and an angle of 25 degrees. The intent of this test is to evaluate the transition of the median barrier gate to the concrete parapet and assesses the potential for vehicle snagging. The critical impact point (CIP) for this test was determined to be 3.6 ft upstream of the concrete parapet end.

The second test was *MASH* test 3-11. This test involves a 5000 lb pickup truck (denoted 2270P) impacting the CIP of the length of need (LON) of the median barrier at a nominal impact speed and angle of 62 mi/h and 25 degrees, respectively. This is a strength test that verifies the structural adequacy of the median barrier gate for impacts involving light trucks and sport utility vehicles (SUVs). Vehicle stability is also a primary evaluation criterion for this test. The CIP for this test was selected to be 4.3 ft upstream of the midpoint of the median barrier gate.

The third test performed on the median barrier gate was *MASH* test 3-21. This test involves a 5000 lb pickup truck impacting the median barrier gate upstream of its connection to the rigid concrete parapet at a nominal speed of 62 mi/h and angle 25 degrees. The purpose of this test is to evaluate the strength of the connection between the median barrier gate and concrete parapet as well as the potential for vehicle snagging in the transition section. The critical impact point (CIP) for this test was determined to be 4.3 ft upstream of the concrete parapet end.

The crash test and data analysis procedures followed for these tests were in accordance with guidelines presented in *MASH*. [Chapter 4](#) presents brief descriptions of these procedures.

### 4.2 EVALUATION CRITERIA

The crash tests were evaluated in accordance with the criteria presented in *MASH*. The performance of the TxDOT median barrier gate was judged on the basis of three factors: structural adequacy, occupant risk, and post impact vehicle trajectory. Structural adequacy criteria assess the median barrier gate's ability to contain and redirect the vehicle. Occupant risk criteria evaluate the potential risk of hazard to occupants in the impacting vehicle, and to some extent other traffic, pedestrians, or workers in construction zones, if applicable. Post impact vehicle trajectory is evaluated to determine potential for secondary impact with other vehicles or fixed objects that may create further risk of injury to occupants of the impacting vehicle and/or risk of injury to occupants in other vehicles. The appropriate safety evaluation criteria from table 5.1 of *MASH* were used to evaluate the crash tests reported herein. These criteria are described in further detail for each crash test.



## **CHAPTER 5. CRASH TEST PROCEDURES**

### **5.1 TEST FACILITY**

The full-scale crash tests reported herein were performed at TTI Proving Ground. TTI Proving Ground is an International Standards Organization (ISO) 17025 accredited laboratory with American Association for Laboratory Accreditation (A2LA) Mechanical Testing certificate 2821.01. The full-scale crash tests were performed according to TTI Proving Ground quality procedures and according to the *MASH* guidelines and standards.

The Texas Transportation Institute Proving Ground is a 2000-acre complex of research and training facilities located 10 miles 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. The site selected for construction and testing of the TxDOT median barrier gate evaluated under this project was on the surface of an out-of-service concrete apron. The apron consists of 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.

### **5.2 VEHICLE TOW AND GUIDANCE PROCEDURES**

The test vehicle was towed into the median barrier gate 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.

### **5.3 DATA ACQUISITION SYSTEMS**

#### **5.3.1 Vehicle Instrumentation and Data Processing**

The test vehicle was instrumented with a self-contained, on-board data acquisition system. The signal conditioning and acquisition system is a 16-channel, Tiny Data Acquisition System (TDAS) Pro produced by Diversified Technical Systems, Inc. The accelerometers, that measure the x, y, and z axis of vehicle acceleration, are strain gauge type with linear millivolt output proportional to acceleration. Angular rate sensors, measuring vehicle roll, pitch, and yaw rates, are ultra small size, solid state units designs for crash test service. The TDAS Pro

hardware and software conform to the latest SAE J211, Instrumentation for Impact Test. Each of the 16 channels is capable of providing precision amplification, scaling, and filtering based on transducer specifications and calibrations. During the test, data are recorded from each channel at a rate of 10,000 values per second with a resolution of one part in 65,536. Once recorded, the data are backed up inside the unit by internal batteries should the primary battery cable be severed. Initial contact of the pressure switch on the vehicle bumper provides a time zero mark as well as initiating the recording process. After each test, the data are downloaded from the TDAS Pro unit into a laptop computer at the test site. The raw data are then processed by the Test Risk Assessment Program (TRAP) software to produce detailed reports of the test results. Each of the TDAS Pro units is returned to the factory annually for complete recalibration. Accelerometers and rate transducers are also calibrated annually with traceability to the National Institute for Standards and Technology.

TRAP uses the data from the TDAS Pro to compute occupant/compartiment impact velocities, time of occupant/compartiment impact after vehicle impact, and the highest 10-millisecond (ms) average ridedown acceleration. TRAP 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.

### **5.3.2 Anthropomorphic Dummy Instrumentation**

An Alderson Research Laboratories Hybrid II, 50<sup>th</sup> percentile male anthropomorphic dummy, restrained with lap and shoulder belts, was placed in the driver's position of the 1100C vehicle. The dummy was uninstrumented. Use of a dummy in the 2270P vehicle is optional according to *MASH*, and there was no dummy used in the tests with the 2270P vehicle.

### **5.3.3 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 footage from these high-speed cameras was 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 camera and still cameras recorded and documented conditions of the test vehicle and median barrier gate installation before and after the test.

## CHAPTER 6. CRASH TEST 420020-6 (MASH TEST 3-20)

### 6.1 TEST DESIGNATION AND ACTUAL IMPACT CONDITIONS

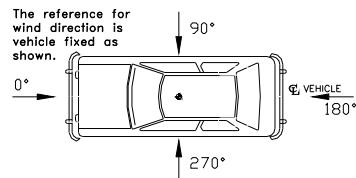
MASH test 3-20 involves an 1100C vehicle weighing 2420 lb  $\pm$ 55 lb impacting the median barrier gate at a speed of 62.2 mi/h  $\pm$ 2.5 mi/h and an angle of 25 degrees  $\pm$ 1.5 degrees. The target impact point was 3.6 ft upstream of the end of the concrete parapet. The 2003 Kia Rio used in the test weighed 2424 lb and the actual impact speed and angle were 62.6 mi/h and 24.6 degrees, respectively. The actual impact point was 4.1 ft upstream of the end of the concrete parapet.

### 6.2 TEST VEHICLE

A 2003 Kia Rio, shown in [Figures 6.1](#) and [6.2](#), was used for the crash test. Test inertial weight of the vehicle was 2424 lb, and its gross static weight was 2592 lb. The height to the lower edge of the vehicle bumper was 8.50 inches, and it was 22.75 inches to the upper edge of the bumper. [Figure C1](#) in [Appendix C](#) gives additional dimensions and information on the vehicle. 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.

### 6.3 WEATHER CONDITIONS

The test was performed on the morning of July 15, 2010. Eight days prior to test date, a total of 0.17 inch of rainfall was recorded. Weather conditions at the time of testing were as follows: wind speed: 6 mi/h; wind direction: 184 degrees with respect to the vehicle (vehicle was traveling in a northerly direction); temperature: 88°F, relative humidity: 66 percent.



### 6.4 TEST DESCRIPTION

The 2003 Kia Rio, traveling at a speed of 62.6 mi/h, impacted the TxDOT median barrier gate 49 inches upstream of the end of the concrete parapet at an angle of 24.6 degrees. At approximately 0.009 s after impact, the left front tire of the vehicle contacted the downstream caster wheel of the gate, and at 0.026 s, the left front tire contacted the toe of the concrete barrier. The vehicle began to redirect 0.037 s after impact. At 0.167 s, the vehicle was traveling parallel with the median barrier gate and traveling at a speed of 45.6 mi/h. The rear of the vehicle contacted the barrier 0.199 s after impact. At 0.300 s, the vehicle lost contact with the barrier and was traveling at an exit speed and angle of 49.3 mi/h and 11.6 degrees, respectively. Brakes on the vehicle were applied at 1.4 s after impact, and the vehicle subsequently came to rest 183 ft downstream of impact and 27 ft toward traffic lanes. [Figures D1](#) and [D2](#) in [Appendix D](#) show sequential photographs of the test period.



**Figure 6.1. Vehicle/Barrier Geometries for Test No. 420020-6.**



**Figure 6.2. Vehicle before Test No. 420020-6.**

## 6.5 DAMAGE TO TEST INSTALLATION

Damage to the gate itself was only cosmetic and consisted of scuff marks as shown in [Figures 6.3 and 6.4](#). The end of the upstream concrete parapet sustained two thin stress cracks on the field side. Minor concrete spalling was observed on the field side of the end of the downstream concrete parapet. No rebar was exposed and the spall was considered to be cosmetic in nature. The vehicle was in contact with the installation 10.2 ft. No measurable dynamic or permanent deflection was noted.

## 6.6 VEHICLE DAMAGE

As shown in [Figure 6.5](#), the vehicle sustained damage to the front and left side. The left front strut, strut tower, and A-post were deformed. Also damaged were the front bumper, hood, grill, radiator and support, left front fender, left front tire and wheel rim, left front door and glass, the left rear door, and left rear quarter panel. The roof was deformed and the windshield sustained stress cracking. Maximum exterior crush to the vehicle was 12.0 inches in the side plane at the left front corner at bumper height. Maximum occupant compartment deformation was 3.0 inches in the firewall area near the toe pan on the driver side. [Figure 6.6](#) shows photographs of the interior of the vehicle. Exterior crush and occupant compartment deformation measurements are provided in [Appendix C, Tables C1 and C2](#).

## 6.7 OCCUPANT RISK FACTORS

Data from the accelerometer, located at the vehicle center of gravity, were digitized for evaluation of occupant risk. In the longitudinal direction, the occupant impact velocity was 26.6 ft/s at 0.078 s, the highest 0.010-s occupant ridedown acceleration was  $-4.0$  Gs from 0.221 to 0.231 s, and the maximum 0.050-s average acceleration was  $-14.9$  Gs between 0.032 and 0.082 s. In the lateral direction, the occupant impact velocity was 31.2 ft/s at 0.078 s, the highest 0.010-s occupant ridedown acceleration was 6.4 Gs from 0.217 to 0.227 s, and the maximum 0.050-s average acceleration was 17.6 Gs between 0.023 and 0.073 s. Theoretical Head Impact Velocity (THIV) was 43.1 km/h or 12.0 m/s at 0.076 s; Post-Impact Head Decelerations (PHD) was 7.1 Gs between 0.218 and 0.228 s; and Acceleration Severity Index (ASI) was 2.28 between 0.028 and 0.078 s. [Figure 6.7](#) summarizes these data and other pertinent information from the test. Vehicle angular displacements and accelerations versus time traces are presented in [Appendix E, Figures E1 through E7](#).





**Figure 6.3. Vehicle/Barrier Positions after Test No. 420020-6.**



**Figure 6.4. TxDOT Median Barrier Gate after Test No. 420020-6.**



**Figure 6.5. Vehicle after Test No. 420020-6.**

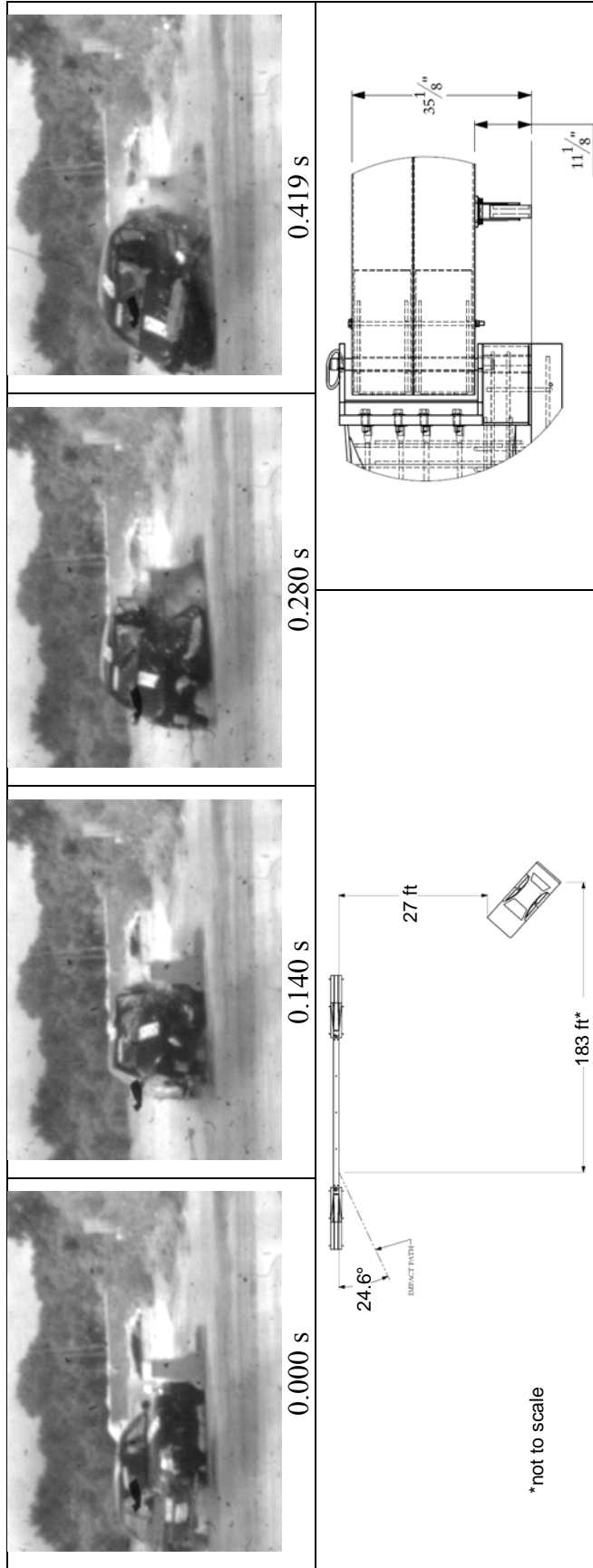


Before Test



After Test

**Figure 6.6. Interior of Vehicle for Test No. 420020-6.**



<b>General Information</b>	Texas Transportation Institute (TTI) MASH Test 3-20 420020-6 2010-07-15	<b>Impact Conditions</b>	Speed .....62.6 mi/h Angle .....24.6 degrees Location/Orientation .....4.1 ft upstrm of parapet end	<b>Post-Impact Trajectory</b>	Stopping Distance ..... 183 ft dwnstr 27 ft twd traffic
<b>Test Article</b>	Median Barrier Gate TxDOT Median Barrier Gate 50 ft 12-inch x 12-inch x 1/4-inch steel tubes connected to concrete parapets using 2 1/4-inch steel pins Anchored to existing concrete	<b>Exit Conditions</b>	Speed .....49.3 mi/h Angle .....11.6 degrees	<b>Vehicle Stability</b>	Maximum Yaw Angle..... -184 degrees Maximum Pitch Angle..... 10 degrees Maximum Roll Angle ..... -12 degrees Vehicle Snagging ..... No Vehicle Pocketing..... No
<b>Soil Type and Condition</b>	1100C 2003 Kia Rio 2357 lb 2424 lb 168 lb 2592 lb	<b>Occupant Risk Values</b>	Impact Velocity Longitudinal.....26.6 ft/s Lateral .....31.2 ft/s Ridedown Accelerations Longitudinal .....4.0 G Lateral .....6.4 G PHD .....43.1 km/h ASI .....7.1 G Max. 0.050-s Average Longitudinal.....-14.9 G Lateral .....17.6 G Vertical .....-3.9 G	<b>Test Article Deflections</b>	Dynamic ..... Nil Permanent..... Nil Working Width ..... Nil
<b>Test Vehicle</b>	1100C 2003 Kia Rio 2357 lb 2424 lb 168 lb 2592 lb			<b>Vehicle Damage</b>	VDS ..... 11LFQ6 CDC ..... 11FDEW4 Max. Exterior Deformation ..... 12.0 inches OCDI ..... LS1020120 Max. Occupant Compartment Deformation ..... 3.0 inches

Figure 6.7. Summary of Results for MASH Test 3-20 on the TxDOT Median Barrier Gate.

## 6.8 ASSESSMENT OF TEST RESULTS

An assessment of the test based on applicable *MASH* safety evaluation criteria is provided below.

### 6.8.1 Structural Adequacy

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

Results: The TxDOT median barrier gate contained and redirected the 1100C vehicle. The vehicle did not penetrate, underride, or over the installation. No measureable deformation was noted. (PASS)

### 6.8.2 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 should not exceed limits set forth in Section 5.3 and Appendix E of MASH. (roof  $\leq 102$  mm (4.0 inches); windshield =  $\leq 76$  mm (3.0 inches); side windows = no shattering by test article structural member; wheel/foot well/toe pan  $\leq 229$  mm (9.0 inches); forward of A-pillar  $\leq 305$  mm (12.0 inches); front side door area above seat  $\leq 229$  mm (9.0 inches); front side door below seat  $\leq 305$  mm (12.0 inches); floor pan/transmission tunnel area  $\leq 305$  mm (12.0 inches))*

Results: No detached elements, fragments, or other debris was present to penetrate or to show potential for penetrating the 1100C vehicle, nor to present hazard to others in the area. (PASS)  
Maximum occupant compartment deformation was 3.0 inches in the firewall area near the toe pan on the driver side. (PASS)

- F. *The vehicle should remain upright during and after collision. The maximum roll and pitch angles are not to exceed 75 degrees.*

Results: The 1100C vehicle remained upright during and after the collision event. Maximum roll and pitch angles were  $-12$  degrees and 10 degrees, respectively. (PASS)

- H. *Occupant impact velocities should satisfy the following:*

Longitudinal and Lateral Occupant Impact Velocity

Preferred  
30 ft/s

Maximum  
40 ft/s

Results: Longitudinal occupant impact velocity was 26.6 ft/s, and lateral occupant impact velocity was 31.2 ft/s. (PASS)

- I. *Occupant ridedown accelerations should satisfy the following:*  
*Longitudinal and Lateral Occupant Ridedown Accelerations*
- | <i><u>Preferred</u></i> | <i><u>Maximum</u></i> |
|-------------------------|-----------------------|
| <i>15.0 Gs</i>          | <i>20.49 Gs</i>       |

Results: Longitudinal ridedown acceleration was -4.0 G, and lateral ridedown acceleration was 6.4 G. (PASS)

### **6.8.3 Vehicle Trajectory**

*For redirective devices, the vehicle shall exit the barrier within the exit box.*

Result: The vehicle exited within the exit box. (PASS)





## CHAPTER 7. CRASH TEST 420020-7 (MASH TEST 3-11)

### 7.1 TEST DESIGNATION AND ACTUAL IMPACT CONDITIONS

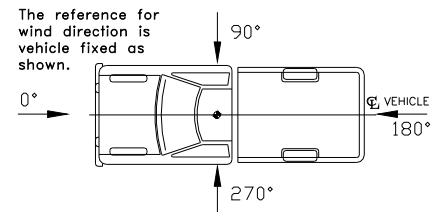
MASH test 3-11 involves a 2270P vehicle weighing 5000 lb  $\pm$ 100 lb impacting the TxDOT median barrier gate at a speed of 62.2 mi/h  $\pm$ 2.5 mi/h and an angle of 25 degrees  $\pm$ 1.5 degrees. The target impact point was 4.3 ft upstream of the mid-span of the gate. The 2003 Dodge Ram 1500 Quad-Cab pickup used in the test weighed 5015 lb and the actual impact speed and angle were 63.1 mi/h and 24.7 degrees, respectively. The actual impact point was 4.8 ft upstream of the mid-span of the gate.

### 7.2 TEST VEHICLE

A 2003 Dodge Ram 1500 Quad-Cab pickup, shown in [Figures 7.1 and 7.2](#), was used for the crash test. Test inertia weight of the vehicle was 5015 lb, and its gross static weight was 5015 lb. The height to the lower edge of the vehicle bumper was 13.5 inches, and it was 26.0 inches to the upper edge of the bumper. The vertical center of gravity (CG) height of the pickup truck was measured to be 28.12 inches. [Figure C2](#) and [Table C3](#) in [Appendix C](#) gives additional dimensions and information on the vehicle. 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.

### 7.3 WEATHER CONDITIONS

The test was performed on the morning of July 19, 2010. No rainfall was recorded for the 10 days prior to the test date. Weather conditions at the time of testing were as follows: wind speed: 6 mi/h; wind direction: 218 degrees with respect to the vehicle (vehicle was traveling in a northerly direction); temperature: 87°F, relative humidity: 69 percent.



### 7.4 TEST DESCRIPTION

The 2003 Dodge Ram 1500 Quad-Cab pickup, traveling at a speed of 63.1 mi/h, impacted the TxDOT median barrier gate 4.8 ft upstream of the mid-span of the gate at an angle of 24.7 degrees. At approximately 0.021 s, the left front tire contacted the gate and the left front tire aired out. The gate began to deflect 0.025 s after impact, and the vehicle began to redirect at 0.042 s. At 0.169 s after impact, the vehicle was traveling parallel with the barrier at a speed of 55.1 mi/h. Maximum deflection of the barrier of 1.1 ft occurred 0.223 s after impact. At 0.311 s, the 2270P vehicle lost contact with the barrier and was traveling at an exit speed and angle of 50.1 mi/h and 12.2 degrees, respectively. Brakes on the vehicle were applied at 1.2 s after impact, and the vehicle subsequently came to rest 100 ft downstream of impact and 25 ft toward traffic lanes. [Figures D3 and D4](#) in [Appendix D](#) show sequential photographs of the test period.



**Figure 7.1. Vehicle/Gate Geometrics for Test No. 420020-7.**



**Figure 7.2. Vehicle before Test No. 420020-7.**

## 7.5 DAMAGE TO TEST INSTALLATION

The steel barrier gate sustained moderate damage as shown in [Figures 7.3 and 7.4](#). The traffic faces of the steel tubes were deformed inward and the tubular rails were buckled near mid-span. There was no damage noted to the concrete parapets. The vehicle was in contact with the installation a distance of 14.9 ft. Working width was 1.1 ft. Maximum dynamic deflection of the median barrier gate during the test was 1.1 ft, and maximum permanent deformation was 0.8 ft.

## 7.6 VEHICLE DAMAGE

As shown in [Figure 7.5](#), the majority of the damage sustained by the 2270P vehicle was to the left front corner and above the top wheel line along the left side. The left upper A-arm was deformed. Also damaged were the front bumper, grill, left front fender, left front tire and wheel rim, left front and rear doors, rear of the cab, left exterior bed, left rear wheel rim (no loss of air in the tire), rear bumper, and tailgate. Maximum exterior crush to the vehicle was 12.0 inches in the side plane in the left front corner at bumper height. Maximum occupant compartment deformation was 0.5 inches across the cab at hip level on the driver side. [Figure 7.6](#) shows photographs of the interior of the vehicle. Exterior crush measurements and occupant compartment deformation are provided in [Appendix C, Tables C4 and C5](#).

## 7.7 OCCUPANT RISK FACTORS

Data from the accelerometer, located at the vehicle center of gravity, were digitized for evaluation of occupant risk. In the longitudinal direction, the occupant impact velocity was 11.5 ft/s at 0.090 s, the highest 0.010-s occupant ridedown acceleration was  $-7.4$  Gs from 0.101 to 0.111 s, and the maximum 0.050-s average acceleration was  $-5.0$  Gs between 0.015 and 0.065 s. In the lateral direction, the occupant impact velocity was 27.2 ft/s at 0.090 s, the highest 0.010-s occupant ridedown acceleration was 12.8 Gs from 0.104 to 0.114 s, and the maximum 0.050-s average acceleration was 12.9 Gs between 0.032 and 0.082 s. THIV was 32.2 km/h or 8.9 m/s at 0.088 s; PHD was 14.2 Gs between 0.103 and 0.113 s; and ASI was 1.49 between 0.028 and 0.078 s. [Figure 7.7](#) summarizes these data and other pertinent information from the test. Vehicle angular displacements and accelerations versus time traces are presented in [Appendix E, Figures E8 through E14](#).



**Figure 7.3. Vehicle/Gate Positions after Test No. 420020-7.**



**Figure 7.4. TxDOT Median Barrier Gate after Test No. 420020-7.**



**Figure 7.5. Vehicle after Test No. 420020-7.**

Before Test

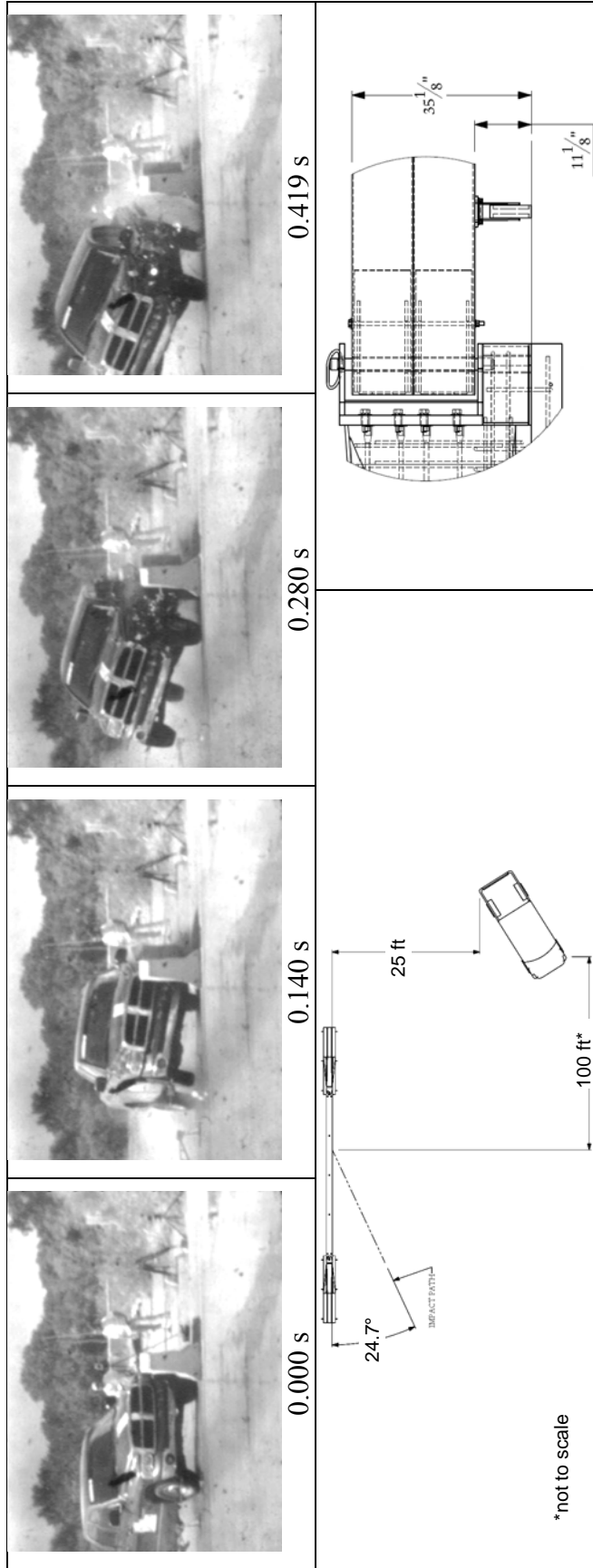


After Test



**Figure 7.6. Interior of Vehicle for Test No. 420020-7.**





<p><b>General Information</b></p> <p>Test Agency ..... Texas Transportation Institute (TTI)</p> <p>Test Standard Test No. .... MASH Test 3-11</p> <p>TTI Test No. .... 420020-7</p> <p>Date ..... 2010-07-19</p> <p><b>Test Article</b></p> <p>Type ..... Median Barrier Gate</p> <p>Name ..... TxDOT Median Barrier Gate</p> <p>Installation Length ..... 50.0 ft</p> <p>Material or Key Elements ..... 12-inch x 12-inch x 1/4-inch steel tubes connected to concrete parapets using 2 1/4-inch steel pins</p> <p><b>Soil Type and Condition</b></p> <p>Test Vehicle</p> <p>Type/Designation ..... 2270P</p> <p>Make and Model ..... 2003 Dodge Ram 1500 Quad-Cab</p> <p>Curb ..... 4699 lb</p> <p>Test Inertial ..... 5015 lb</p> <p>Dummy ..... No dummy</p> <p>Gross Static ..... 5015 lb</p>	<p><b>Impact Conditions</b></p> <p>Speed ..... 63.1 mi/h</p> <p>Angle ..... 24.7 degrees</p> <p>Location/Orientation ..... 4.8 ft upstream of mid-span</p> <p><b>Exit Conditions</b></p> <p>Speed ..... 50.1 mi/h</p> <p>Angle ..... 12.2 degrees</p> <p><b>Occupant Risk Values</b></p> <p>Impact Velocity</p> <p>Longitudinal ..... 11.5 ft/s</p> <p>Lateral ..... 27.2 ft/s</p> <p>Ridedown Accelerations</p> <p>Longitudinal ..... 7.4 G</p> <p>Lateral ..... 12.8 G</p> <p>PHD ..... 32.2 kmh</p> <p>PHD ..... 14.2 G</p> <p>ASI ..... 1.49</p> <p>Max. 0.050-s Average</p> <p>Longitudinal ..... -5.0 G</p> <p>Lateral ..... 12.9 G</p> <p>Vertical ..... -3.7 G</p>	<p><b>Post-Impact Trajectory</b></p> <p>Stopping Distance ..... 100 ft downstrm</p> <p>..... 25 ft twd traffic</p> <p><b>Vehicle Stability</b></p> <p>Maximum Yaw Angle ..... 38 degrees</p> <p>Maximum Pitch Angle ..... 6 degrees</p> <p>Maximum Roll Angle ..... -21 degrees</p> <p>Vehicle Snagging ..... No</p> <p>Vehicle Pocketing ..... No</p> <p><b>Test Article Deflections</b></p> <p>Dynamic ..... 1.1 ft</p> <p>Permanent ..... 0.8 ft</p> <p>Working Width ..... 1.1 ft</p> <p><b>Vehicle Damage</b></p> <p>VDS ..... 11LFQ4</p> <p>CDC ..... 11FLEW3</p> <p>Max. Exterior Deformation ..... 12.0 inches</p> <p>OCDI ..... LS0000000</p> <p>Max. Occupant Compartment Deformation ..... 0.5 inches</p>
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Figure 7.7. Summary of Results for MASH Test 3-11 on the TxDOT Median Barrier Gate.

## 7.8 ASSESSMENT OF TEST RESULTS

An assessment of the test based on the applicable *MASH* safety evaluation criteria is provided below.

### 7.8.1 Structural Adequacy

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

Results: The TxDOT median barrier gate contained and redirected the 2270P vehicle. The vehicle did not penetrate, underride, or override the installation. Maximum dynamic deflection during the test was 1.1 ft. (PASS)

### 7.8.2 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 should not exceed limits set forth in Section 5.3 and Appendix E of MASH. (roof  $\leq 102$  mm (4.0 inches); windshield =  $\leq 76$  mm (3.0 inches); side windows = no shattering by test article structural member; wheel/foot well/toe pan  $\leq 229$  mm (9.0 inches); forward of A-pillar  $\leq 305$  mm (12.0 inches); front side door area above seat  $\leq 229$  mm (9.0 inches); front side door below seat  $\leq 305$  mm (12.0 inches); floor pan/transmission tunnel area  $\leq 305$  mm (12.0 inches))*

Results: No detached elements, fragments, or other debris was present to penetrate or to show potential for penetrating the occupant compartment, nor to present undue hazard to others in the area. (PASS)  
Maximum occupant compartment deformation was 0.5 inches at the hip level on the driver side. (PASS)

- F. *The vehicle should remain upright during and after collision. The maximum roll and pitch angles are not to exceed 75 degrees.*

Results: The 2270P vehicle remained upright during and after the collision event. Maximum roll and pitch angles were  $-21$  degrees and 6 degrees, respectively. (PASS)

- H. *Occupant impact velocities should satisfy the following:*

Longitudinal and Lateral Occupant Impact Velocity

<u>Preferred</u>	<u>Maximum</u>
30 ft/s	40 ft/s

Results: Longitudinal occupant impact velocity was 11.5 ft/s, and lateral occupant impact velocity was 27.2 ft/s. (PASS)

I. *Occupant ridedown accelerations should satisfy the following:*  
Longitudinal and Lateral Occupant Ridedown Accelerations

<u>Preferred</u>	<u>Maximum</u>
15.0 Gs	20.49 Gs

Results: Longitudinal ridedown acceleration was  $-7.4$  G, and lateral ridedown acceleration was 12.8 G. (PASS)

### **7.8.3 Vehicle Trajectory**

*For redirective devices, the vehicle shall exit the barrier within the exit box.*

Result: The 2270P vehicle exited within the exit box. (PASS)



## CHAPTER 8. CRASH TEST 420020-8 (MASH TEST 3-21)

### 8.1 TEST DESIGNATION AND ACTUAL IMPACT CONDITIONS

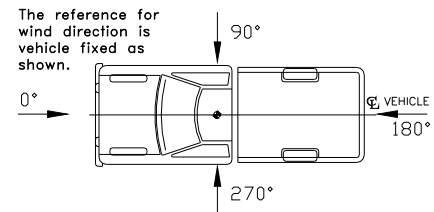
MASH test 3-21 involves a 2270P vehicle weighing 5000 lb  $\pm$ 100 lb impacting the TxDOT median barrier gate at a speed of 62.2 mi/h  $\pm$ 2.5 mi/h and an angle of 25 degrees  $\pm$ 1.5 degrees. The target impact point was 4.3 ft upstream of the end of the concrete parapet. The 2003 Dodge Ram 1500 Quad-Cab pickup used in the test weighed 5008 lb and the actual impact speed and angle were 63.1 mi/h and 25.5 degrees, respectively. The actual impact point was 3.9 ft upstream of the end of the concrete parapet.

### 8.2 TEST VEHICLE

A 2003 Dodge Ram 1500 Quad-Cab pickup, shown in [Figures 8.1 and 8.2](#), was used for the crash test. Test inertia weight of the vehicle was 5008 lb, and its gross static weight was 5008 lb. The height to the lower edge of the vehicle bumper was 13.5 inches, and it was 26.0 inches to the upper edge of the bumper. The vertical CG height of the pickup truck was 28.25 inches. [Figure C3](#) and [Table C6](#) in [Appendix C](#) gives additional dimensions and information on the vehicle. 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.

### 8.3 WEATHER CONDITIONS

The test was performed on the morning of July 21, 2010. Three days prior to the test date 0.41 inch of rain was recorded. Weather conditions at the time of testing were as follows: Wind speed: 5 mi/h; wind direction: 88 degrees with respect to the vehicle (vehicle was traveling in a southwesterly direction); temperature: 90°F, relative humidity: 65 percent.



### 8.4 TEST DESCRIPTION

The 2003 Dodge Ram 1500 Quad-Cab pickup, traveling at a speed of 63.1 mi/h, impacted the TxDOT median barrier gate 3.9 ft upstream of the end of the concrete parapet at an angle of 25.5 degrees. At approximately 0.49 s after impact, the right front corner of the vehicle contacted the concrete parapet, and at 0.054 s, the vehicle began to redirect. The caster wheel under the gate separated from the gate at 0.059 s. At 0.184 s after impact, the vehicle was traveling parallel with the barrier at a speed of 49.4 mi/h. The rear of the vehicle contacted the gate at 0.199 s after impact, and then the concrete barrier at 0.263 s. At 0.344 s, the vehicle lost contact with the barrier and was traveling at an exit speed and angle of 46.3 mi/h and 6.6 degrees, respectively. Brakes on the vehicle were applied 1.2 s after impact, and the vehicle subsequently came to rest 190 ft downstream of impact with the rear toward the field side of the installation. [Figures D5 and D6](#) in [Appendix D](#) show sequential photographs of the test period.



**Figure 8.1. Vehicle/Gate Geometrics for Test No. 420020-8.**



**Figure 8.2. Vehicle before Test No. 420020-8.**

## 8.5 DAMAGE TO TEST INSTALLATION

The lower toe and end of the concrete barrier sustained significant damage, as shown in [Figures 8.3](#) and [8.4](#). The concrete was cracked and fell away from the reinforcement in the toe of the concrete barrier and also from the field side of the barrier. The concrete on the end of the traffic face of the barrier was cracked, but remained in place. The end bracket was pushed toward the field side 1.0 inch. Tire marks were present along the traffic face of the steel gate and traffic face of the concrete barrier for a distance of 11.75 ft. Working width, maximum dynamic deflection, and maximum permanent deformation were 1.25 inches.

## 8.6 VEHICLE DAMAGE

[Figure 8.5](#) shows the damage to the vehicle, which was mostly in the right front quarter in the side plane. The right upper and lower ball joint, right tie rod end, right frame rail, right front upper and lower A-arms, drive shaft, rear axle, and rear U-bolts and springs were damaged. Also damaged were the front bumper, hood, grill, right front fender, right front tire and wheel rim, right front and rear doors, right rear cab, right rear exterior bed, right rear tire and wheel rim, rear bumper, and tailgate. The windshield sustained stress cracks. Maximum exterior crush to the vehicle was 19 inches in the side plane at the right front corner at bumper height. Maximum occupant compartment deformation was 5.25 inches in the right firewall area near the toe pan on the front passenger side. [Figure 8.6](#) shows photographs of the interior of the vehicle. Exterior crush and occupant compartment deformation are provided in [Appendix C, Tables C7](#) and [C8](#).

## 8.7 OCCUPANT RISK FACTORS

Data from the accelerometer, located at the vehicle center of gravity, were digitized for evaluation of occupant risk. In the longitudinal direction, the occupant impact velocity was 22.6 ft/s at 0.091 s, the highest 0.010-s occupant ridedown acceleration was  $-6.5$  Gs from 0.103 to 0.113 s, and the maximum 0.050-s average acceleration was  $-11.8$  Gs between 0.045 and 0.095 s. In the lateral direction, the occupant impact velocity was 27.9 ft/s at 0.091 s, the highest 0.010-s occupant ridedown acceleration was  $-9.4$  Gs from 0.104 to 0.114 s, and the maximum 0.050-s average acceleration was  $-14.9$  Gs between 0.034 and 0.084 s. THIV was 38.8 km/h or 10.8 m/s at 0.089 s; PHD was 11.1 Gs between 0.104 and 0.114 s; and ASI was 1.92 between 0.044 and 0.094 s. [Figure 8.7](#) summarizes these data and other pertinent information from the test. Vehicle angular displacements and accelerations versus time traces are presented in [Appendix E, Figures E15](#) through [E21](#).





**Figure 8.3. Position of Vehicle/Gate after Test No. 420020-8.**



Rear of barrier

**Figure 8.4. Installation after Test No. 420020-8.**



**Figure 8.5. Vehicle after Test No. 420020-8.**

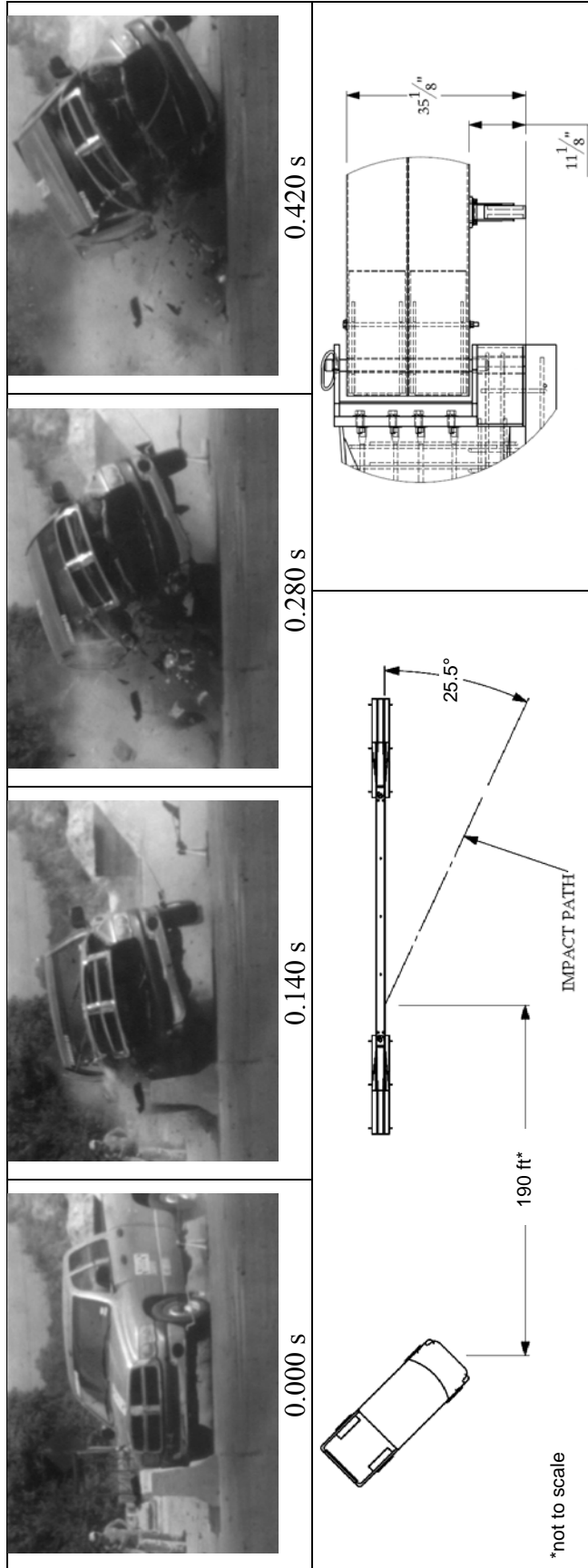


Before Test



After Test

**Figure 8.6. Interior of Vehicle for Test No. 420020-8.**



<b>General Information</b>		Texas Transportation Institute (TTI)
Test Agency	MASH Test 3-21	
Test Standard Test No.	420020-8	
TTI Test No.	2010-07-21	
Date		
<b>Test Article</b>		Median Barrier Gate
Type	TxDOT Median Barrier Gate	
Name	50.0 ft	
Installation Length	12-inch x 1/4-inch steel tubes	
Material or Key Elements	connected to concrete parapets using 2 1/4-inch steel pins	
<b>Soil Type and Condition</b>		Anchored on existing concrete apron
Test Vehicle	2270P	
Type/Designation	2003 Dodge Ram 1500 Quad-Cab	
Make and Model	4765 lb	
Curb	5008 lb	
Test Inertial	No dummy	
Dummy	5008 lb	
Gross Static		
<b>Impact Conditions</b>		Speed ..... 63.1 mi/h
Speed	Angle ..... 25.5 degrees	
Location/Orientation	<b>Exit Conditions</b>	
Speed	Angle	Speed ..... 46.3 mi/h
Angle		Angle ..... 6.6 degrees
<b>Occupant Risk Values</b>		<b>Impact Velocity</b>
Longitudinal	Lateral	Longitudinal ..... 22.6 ft/s
Lateral		Lateral ..... 27.9 ft/s
<b>Ridedown Accelerations</b>		Longitudinal
Longitudinal	Lateral	Longitudinal ..... -6.5 G
Lateral		Lateral ..... -9.4 G
<b>THIV</b>		THIV ..... 38.8 km/h
<b>PHD</b>		PHD ..... 11.1 G
<b>ASI</b>		ASI ..... 1.92
<b>Max. 0.050-s Average</b>		Max. Longitudinal ..... -11.8 G
<b>Longitudinal</b>		Max. Lateral ..... -14.9 G
<b>Lateral</b>		Max. Vertical ..... -4.9 G
<b>Vertical</b>		
<b>Post-Impact Trajectory</b>		Stopping Distance ..... 190 ft downstrm
<b>Vehicle Stability</b>		Maximum Yaw Angle ..... -32 degrees
		Maximum Pitch Angle ..... -8 degrees
		Maximum Roll Angle ..... 20 degrees
		Vehicle Snagging ..... Yes
		Vehicle Pocketing ..... No
<b>Test Article Deflections</b>		Dynamic ..... 1.25 inches
		Permanent ..... 1.25 inches
<b>Working Width</b>		Working Width ..... 1.25 inches
<b>Vehicle Damage</b>		VDS ..... 02RFQ5
		CDC ..... 02RFEW4
		Max. Exterior Deformation ..... 19.0 inches
		OCDI ..... RF0030000
		Max. Occupant Compartment Deformation ..... 5.25 inches

Figure 8.7. Summary of Results for MASH Test 3-21 on the TxDOT Median Barrier Gate.

## 8.8 ASSESSMENT OF TEST RESULTS

An assessment of the test based on the applicable *MASH* safety evaluation criteria is provided below.

### 8.8.1 Structural Adequacy

- B. Test article should contain and redirect the vehicle or bring the vehicle to a controlled stop; the vehicle should not penetrate, underride, or override the installation although controlled lateral deflection of the test article is acceptable.*

Results: The TxDOT median barrier gate contained and redirected the 2270P vehicle. The vehicle did not penetrate, underride, or override the installation. Maximum dynamic deflection during the test was 1.25 inches. (PASS)

### 8.8.2 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 should not exceed limits set forth in Section 5.3 and Appendix E of MASH. (roof  $\leq 102$  mm (4.0 inches); windshield =  $\leq 76$  mm (3.0 inches); side windows = no shattering by test article structural member; wheel/foot well/toe pan  $\leq 229$  mm (9.0 inches); forward of A-pillar  $\leq 305$  mm (12.0 inches); front side door area above seat  $\leq 229$  mm (9.0 inches); front side door below seat  $\leq 305$  mm (12.0 inches); floor pan/transmission tunnel area  $\leq 305$  mm (12.0 inches))*

Results: The toe and end of the concrete parapet cracked and pieces of concrete fell off in small pieces. This debris did not penetrate or show potential to penetrate the occupant compartment, nor to present undue hazard to others in the area. (PASS)

Maximum occupant compartment deformation was 5.25 inches in the firewall area near the toe pan on the front passenger side. (PASS)

- F. The vehicle should remain upright during and after collision. The maximum roll and pitch angles are not to exceed 75 degrees.*

Results: The 2270P vehicle remained upright during and after the collision event. Maximum roll and pitch angles were 20 degrees and -8 degrees, respectively. (PASS)

H. *Occupant impact velocities should satisfy the following:*  
Longitudinal and Lateral Occupant Impact Velocity

<u>Preferred</u>	<u>Maximum</u>
9.0 m/s (30 ft/s)	12.2 m/s (40 ft/s)

Results: Longitudinal occupant impact velocity was 22.6 ft/s, and lateral occupant impact velocity was 27.9 ft/s. (PASS)

I. *Occupant ridedown accelerations should satisfy the following:*  
Longitudinal and Lateral Occupant Ridedown Accelerations

<u>Preferred</u>	<u>Maximum</u>
15.0 Gs	20.49 Gs

Results: Longitudinal ridedown acceleration was -6.5 G, and lateral ridedown acceleration was -9.4 G. (PASS)

### **8.8.3 Vehicle Trajectory**

*For redirective devices, the vehicle shall exit the barrier within the exit box.*

Result: The vehicle exited within the exit box. (PASS)





## CHAPTER 9. SUMMARY AND CONCLUSIONS

Concrete median barrier is commonly used to separate opposing lanes of traffic on high-speed, urban freeways with high average daily traffic (ADT) and narrow medians. The resulting long, continuous runs of CMBs limit access of emergency and maintenance vehicles to the other side of the roadway or managed lane. Periodic implementation of crashworthy median barrier gates can maintain the desired level of median protection for motorists while offering improved cross-median access for authorized vehicles.

TxDOT has been using an Emergency Opening System developed in the early 1980s to satisfy this need. The EOS was recently crash tested in accordance with the latest guidelines for the impact performance of roadside safety features contained in the AASHTO *Manual for Assessing Safety Hardware*. The gate failed to comply with *MASH* due to excessive occupant compartment deformation inside the vehicle.

A new crashworthy median barrier gate was developed to replace the EOS and meet the continuing needs of TxDOT. Three crash tests were performed to evaluate the impact performance of different aspects of the median barrier gate. Test 3-11 evaluated the strength of the median barrier gate and its ability to function as a longitudinal barrier. Tests 3-20 and 3-21 assessed the transition of the median barrier gate to the adjacent concrete median barrier. As summarized in [Table 9.1](#) through [Table 9.3](#), the new median barrier gate passed all of the required evaluation criteria for each test and meets the Test Level 3 (TL-3) impact performance requirements of *MASH*.

**Table 9.1. Performance Evaluation Summary for MASH Test 3-20 on the TxDOT Median Barrier Gate.**

Test Agency: Texas Transportation Institute		Test No.: 420020-5	Test Date: 2010-07-15
<b>MASH Test 3-10 Evaluation Criteria</b>		<b>Test Results</b>	<b>Assessment</b>
Structural Adequacy			
A. <i>Test article should contain and redirect the vehicle or bring the vehicle to a controlled stop; the vehicle should not penetrate, underride, or override the installation although controlled lateral deflection of the test article is acceptable</i>		The TxDOT median barrier gate contained and redirected the 1100C vehicle. The vehicle did not penetrate, underride, or over the installation. No measureable deformation was noted.	Pass
Occupant Risk			
D. <i>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.</i>		No detached elements, fragments, or other debris was present to penetrate or to show potential for penetrating the 1100C vehicle, nor to present hazard to others in the area.	Pass
E. <i>Deformations of, or intrusions into, the occupant compartment should not exceed limits set forth in Section 5.3 and Appendix E of MASH.</i>		Maximum occupant compartment deformation was 3.0 inches in the firewall area near the toe pan on the driver side.	Pass
F. <i>The vehicle should remain upright during and after collision. The maximum roll and pitch angles are not to exceed 75 degrees.</i>		The 1100C vehicle remained upright during and after the collision event. Maximum roll and pitch angles were -12 degrees and 10 degrees, respectively.	Pass
H. <i>Longitudinal and lateral occupant impact velocities should fall below the preferred value of 30 ft/s, or at least below the maximum allowable value of 40 ft/s.</i>		Longitudinal occupant impact velocity was 26.6 ft/s, and lateral occupant impact velocity was 31.2 ft/s.	Pass
I. <i>Longitudinal and lateral occupant ridedown accelerations should fall below the preferred value of 15.0 Gs, or at least below the maximum allowable value of 20.49 Gs.</i>		Maximum longitudinal ridedown acceleration was -4.0 G, and maximum lateral ridedown acceleration was 6.4 G.	Pass
Vehicle Trajectory			
<i>For redirective devices, the vehicle shall exit the barrier within the exit box.</i>		The vehicle exited within the exit box.	Pass

**Table 9.2. Performance Evaluation Summary for MASH Test 3-11 on the TxDOT Median Barrier Gate.**

Test Agency: Texas Transportation Institute		Test No.: 420020-7	Test Date: 2010-07-19
<b>MASH Test 3-11 Evaluation Criteria</b>		<b>Test Results</b>	<b>Assessment</b>
<b>Structural Adequacy</b>			
<i>A. Test article should contain and redirect the vehicle or bring the vehicle to a controlled stop; the vehicle should not penetrate, underide, or override the installation although controlled lateral deflection of the test article is acceptable</i>		The TxDOT median barrier gate contained and redirected the 2270P vehicle. The vehicle did not penetrate, underide, or override the installation. Maximum dynamic deflection during the test was 1.1 ft.	Pass
<b>Occupant Risk</b>			
<i>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.</i>		No detached elements, fragments, or other debris was present to penetrate or to show potential for penetrating the occupant compartment, nor to present undue hazard to others in the area.	Pass
<i>Deformations of, or intrusions into, the occupant compartment should not exceed limits set forth in Section 5.3 and Appendix E of MASH.</i>		Maximum occupant compartment deformation was 0.5 inches at the hip level on the driver side.	Pass
<i>F. The vehicle should remain upright during and after collision. The maximum roll and pitch angles are not to exceed 75 degrees.</i>		The 2270P vehicle remained upright during and after the collision event. Maximum roll and pitch angles were -21 degrees and 6 degrees, respectively.	Pass
<i>H. Longitudinal and lateral occupant impact velocities should fall below the preferred value of 30 ft/s, or at least below the maximum allowable value of 40 ft/s.</i>		Longitudinal occupant impact velocity was 11.5 ft/s, and lateral occupant impact velocity was 27.2 ft/s.	Pass
<i>I. Longitudinal and lateral occupant ridedown accelerations should fall below the preferred value of 15.0 Gs, or at least below the maximum allowable value of 20.49 Gs.</i>		Longitudinal ridedown acceleration was -7.4 G, and lateral ridedown acceleration was 12.8 G.	Pass
<b>Vehicle Trajectory</b>			
<i>For redirective devices, the vehicle shall exit the barrier within the exit box.</i>		The 2270P vehicle exited within the exit box.	Pass

**Table 9.3. Performance Evaluation Summary for MASH Test 3-21 on the TxDOT Median Barrier Gate.**

Test Agency: Texas Transportation Institute		Test No.: 420020-8	Test Date: 2010-07-21
<b>MASH Test 3-21 Evaluation Criteria</b>		<b>Test Results</b>	
<b>Structural Adequacy</b>			
<i>A. Test article should contain and redirect the vehicle or bring the vehicle to a controlled stop; the vehicle should not penetrate, underide, or override the installation although controlled lateral deflection of the test article is acceptable</i>		The TxDOT median barrier gate contained and redirected the 2270P vehicle. The vehicle did not penetrate, underide, or override the installation. Maximum dynamic deflection during the test was 1.25 inches.	Pass
<b>Occupant Risk</b>			
<i>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.</i>		The toe and end of the concrete parapet cracked and pieces of concrete fell off in small pieces. This debris did not penetrate or show potential to penetrate the occupant compartment, nor to present undue hazard to others in the area.	Pass
<i>Deformations of, or intrusions into, the occupant compartment should not exceed limits set forth in Section 5.3 and Appendix E of MASH.</i>		Maximum occupant compartment deformation was 5.25 inches in the firewall area near the toe pan on the front passenger side.	Pass
<i>F. The vehicle should remain upright during and after collision. The maximum roll and pitch angles are not to exceed 75 degrees.</i>		The 2270P vehicle remained upright during and after the collision event. Maximum roll and pitch angles were 20 degrees and -8 degrees, respectively.	Pass
<i>H. Longitudinal and lateral occupant impact velocities should fall below the preferred value of 30 ft/s, or at least below the maximum allowable value of 40 ft/s.</i>		Longitudinal occupant impact velocity was 22.6 ft/s, and lateral occupant impact velocity was 27.9 ft/s.	Pass
<i>I. Longitudinal and lateral occupant ridedown accelerations should fall below the preferred value of 15.0 Gs, or at least below the maximum allowable value of 20.49 Gs.</i>		Longitudinal ridedown acceleration was -6.5 G, and lateral ridedown acceleration was -9.4 G.	Pass
<b>Vehicle Trajectory</b>			
<i>For redirective devices, the vehicle shall exit the barrier within the exit box.</i>		The vehicle exited within the exit box.	Pass

## CHAPTER 10. IMPLEMENTATION STATEMENT<sup>†</sup>

A new median barrier gate was developed and crash tested. The gate spans a 30-ft opening in a concrete median barrier. The gate consists of two vertically stacked 12-inch × 12-inch × ¼-inch steel tubes connected to steel and brackets with 2¼-inch diameter steel pins.

The 35-inch rail height dramatically improves vehicle stability during impacts along the length of the gate. The 12-inch width of the tubular steel rails matches the width of the concrete parapet to which the gate is attached. This significantly reduces snagging potential on the end of the rigid concrete parapet.

The weight and material cost of the tubular steel rails are less than those used in the existing EOS. Thus, it will be more economical to deploy and easier to operate. Testing with a prototype built for the full-scale crash test program demonstrated that the gate can be readily operated by one person. Bolted connections are used to reduce welding and decrease fabrication cost. It also permits the rail members and components to be individually galvanized and assembled rather than as a complete unit.

The gate is designed to accommodate reversible traffic flow on both sides of the median and be operable in both directions on each end. This versatility enables the gate to be used in the median of a divided highway or as a means of separating main lanes from managed lanes with changing traffic direction. The heavy duty swivel caster wheels support the weight of the gate and eliminate the need for a jack to raise and lower the gate as part of the operation sequence. This will expedite operations for authorized vehicles requiring access through the gate.

The median barrier gate satisfies *MASH* Test Level 3 (TL-3) impact performance criteria and is suitable for immediate implementation on Texas highways where cross-median access is desired. Statewide implementation can be achieved through the development and issuance of a standard detail sheet by the Design Division.

A few design changes and options are recommended for consideration. It is recommended to increase the height of the fabricated steel end bracket by 1 inch. This modification will provide an additional ½-inch tolerance between the upper and lower horizontal plates and the tubular steel rail members for gate operation.

A design option is the use of a fabricated steel curb rather than a concrete curb beneath the fabricated steel end bracket. Steel plates can be welded to the bottom of the lower horizontal plate of the end bracket to form a curb. If this option is used, the end bracket can be attached to the Richmond anchors and used as an end form for the concrete parapet. It eliminates the need to separately form, reinforce and cast a concrete curb, and eliminates the need for the pipe sleeve in the curb.

---

<sup>†</sup> *The opinions/interpretations expressed in this section are outside the scope of TTI Proving Ground's A2LA accreditation.*

Finally, an optional pry bar can be included in the design. During installation and operation, it is possible for the rails to shift longitudinally against the connecting pins. The resulting bearing pressure can make it difficult to extract the pin to operate the gate. A pry bar can be used between the end plate and the tubular steel rails to shift the rail and release the bearing pressure on the pin. This can be easily accomplished by a single person if necessary. The pry bar design option calls for the incorporation of a pry bar in the system that will be available to the gate operator if needed. The pry bar is stowed by inserting it vertically into prefabricated holes in the steel rails. [Appendix F](#) provides these recommended design changes and options.

## REFERENCES

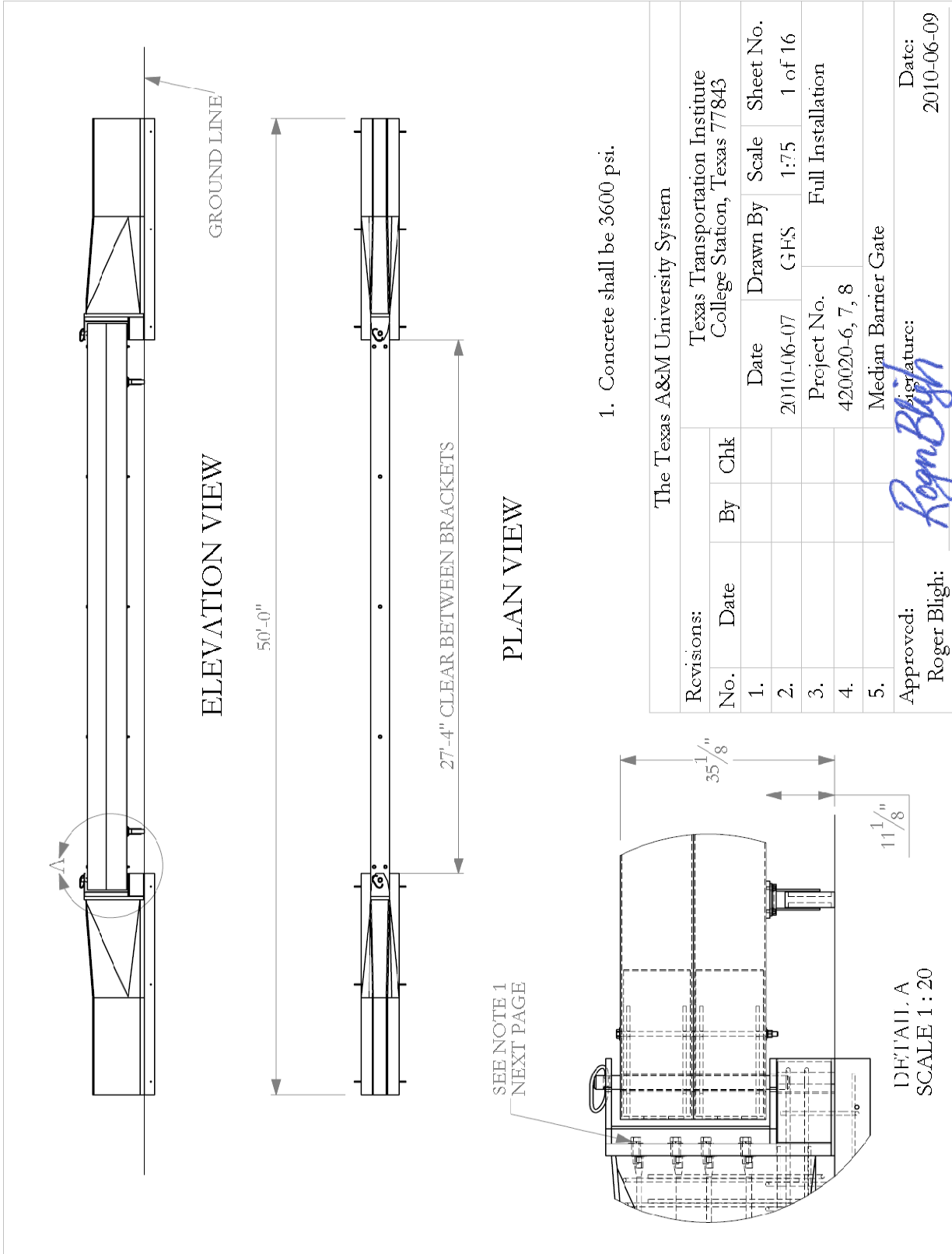
1. Strybos, J. W., Morgan, J. R., and Ross, Jr., H. E., "Emergency Opening System for an Authorized Vehicle Lane," Research Report TX-84/105-1F, Texas Transportation Institute, College Station, TX, March 1984.
2. Michie, J.D., "Recommended Procedures for the Safety Performance Evaluation of Highway Features," *NCHRP Report 230*, Transportation Research Board, National Research Council, Washington, D.C., March 1981.
3. Bligh, R. P. and Menges, W. L., "Median Barrier Gate, Technical Memorandum #0-5210-9," Texas Transportation Institute, College Station, TX, June 2010.
4. AASHTO, *Manual for Assessing Safety Hardware*, Washington, D.C., American Association of State Highway and Transportation Officials, 2009.
5. Ross, Jr., H.E., Sicking, D.L., Zimmer, R.A. and Michie, J.D., "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. AASHTO, *LRFD Bridge Design Specifications*, Washington, D.C., American Association of State Highway and Transportation Officials, 2004.
7. Hallquist, J. O., *LS-DYNA: Keyword User's Manual*, Version 971, Livermore Software Technology Corporation (LSTC), Livermore, California, 2007.
8. National Crash Analysis Center (NCAC) website for Silverado truck model: <http://www.ncac.gwu.edu/vml/archive/ncac/vehicle/silverado-v2.pdf>, Accessed February 7, 2011.

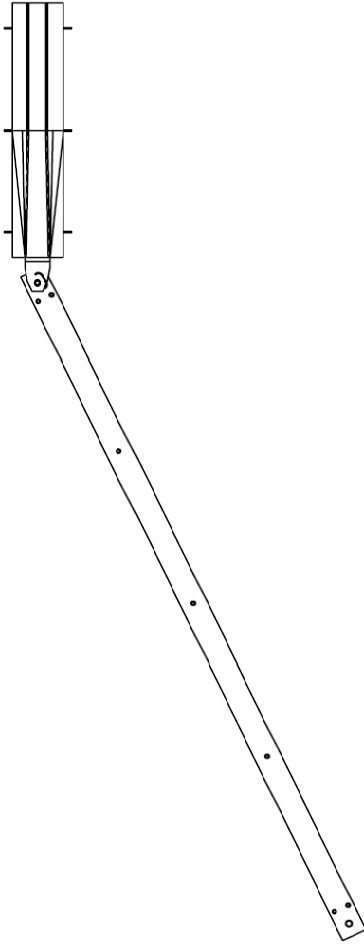




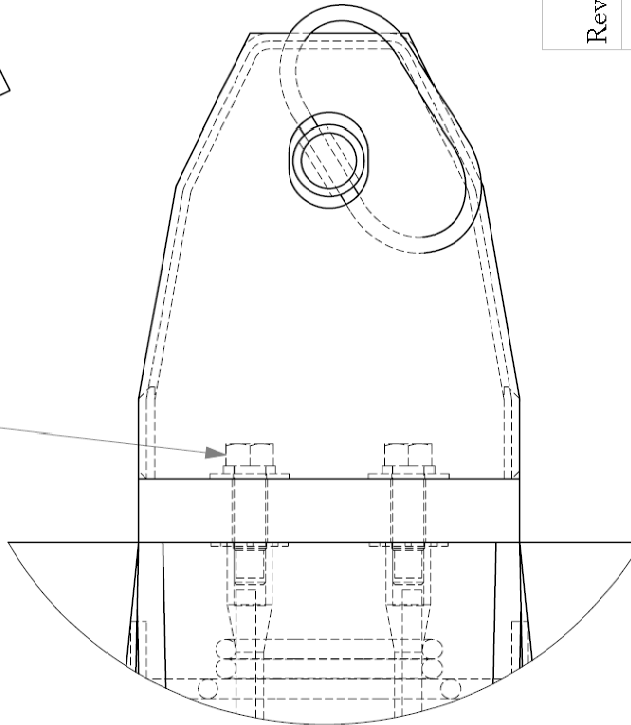
# APPENDIX A. DETAILS OF THE TXDOT MEDIAN BARRIER GATE

T:\2009-2010\420020 TxDOT\Median Barrier\Drawings\Final Design\Solidworks\Drawings\Median Barrier Gate Drawings





1. Mounting bracket attaches to Richmond anchors in concrete with 1" - 8 x 3-3/4" grade A325 bolts, flat washers, and lock washers. Eight needed per bracket.



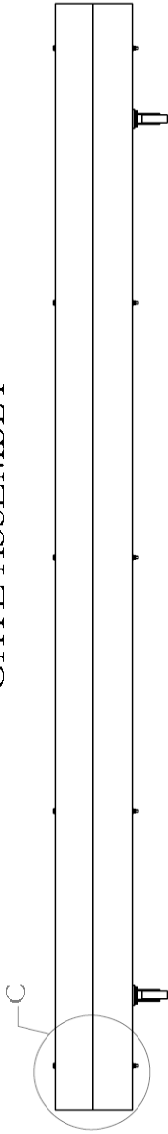
DETAIL B  
SCALE 1 : 5

The Texas A&M University System				
Texas Transportation Institute College Station, Texas 77843				
Revisions:	No.	Date	By	Chk
	1.			
	2.	2010-06-07	GES	
	3.			
	4.			
	5.			

Date	Drawn By	Scale	Sheet No.
2010-06-07	GES	1:75	2 of 16
Project No.		Open	
420020-6, 7, 8			
Median Barrier Gate			

# GATE ASSEMBLY



ELEVATION VIEW

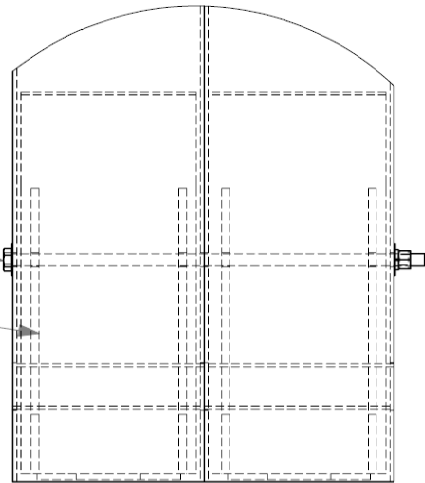


PLAN VIEW

SEE NOTE 1

TUBING SUPPORT BRACKET

SEE NOTE 1

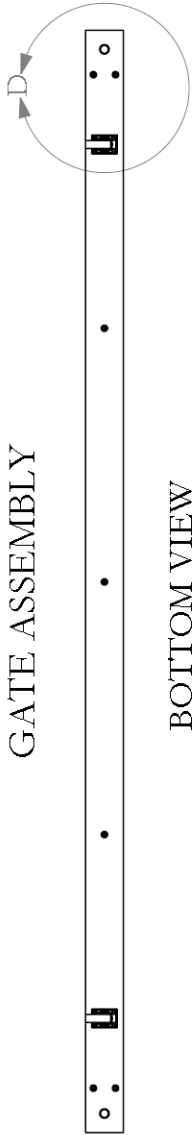


DETAIL C  
SCALE 1 : 10

1. 3/4" - 10 x 26" hex head bolt, A325 or grade 5, 2 flat washers, lock washer, and hex nut. 7 needed per installation. Bolts attach Tubes together and hold Support Brackets in Tubes

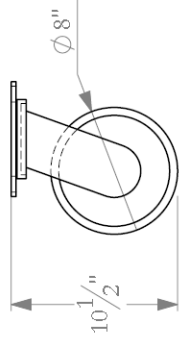
The Texas A&M University System					
Texas Transportation Institute College Station, Texas 77843					
Revisions:		Date	Drawn By	Scale	Sheet No.
No.	Date	By	Chk		
1.				1:50	3 of 16
2.	2010-06-07	GES			
3.					Gate Assembly
4.					420020-6, 7, 8
5.					Median Barrier Gate

# GATE ASSEMBLY

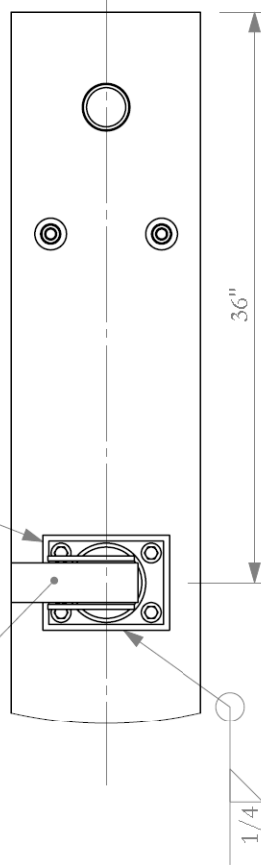


BOTTOM VIEW

SWIVEL CASTER  
SEE NOTE 1



SWIVEL CASTER  
SEE NOTE 1  
CASTER MOUNTING PLATE

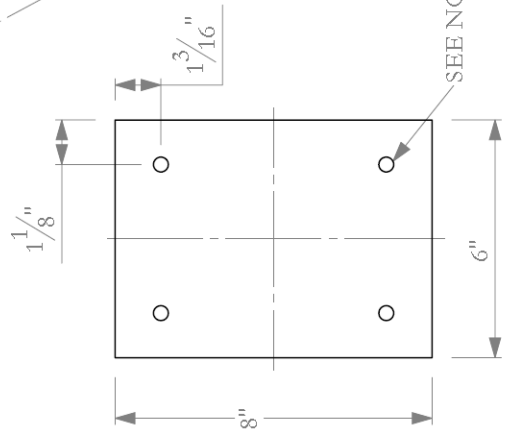


DETAIL D  
SCALE 1 : 10  
TYPICAL EACH END

1. Grainger Item # 1NVZ9 - 2 needed per installation. Attaches to Caster Mounting Plate with (4) 1/2" -13 x 1" hex head bolts and flat washers (A325 or gr. 5).
2. Drill and tap 4 holes for 1/2" -13 bolts. Plug holes prior to galvanizing or drill holes through tubing to prevent galvanizing build up in holes.



ELEVATION VIEW

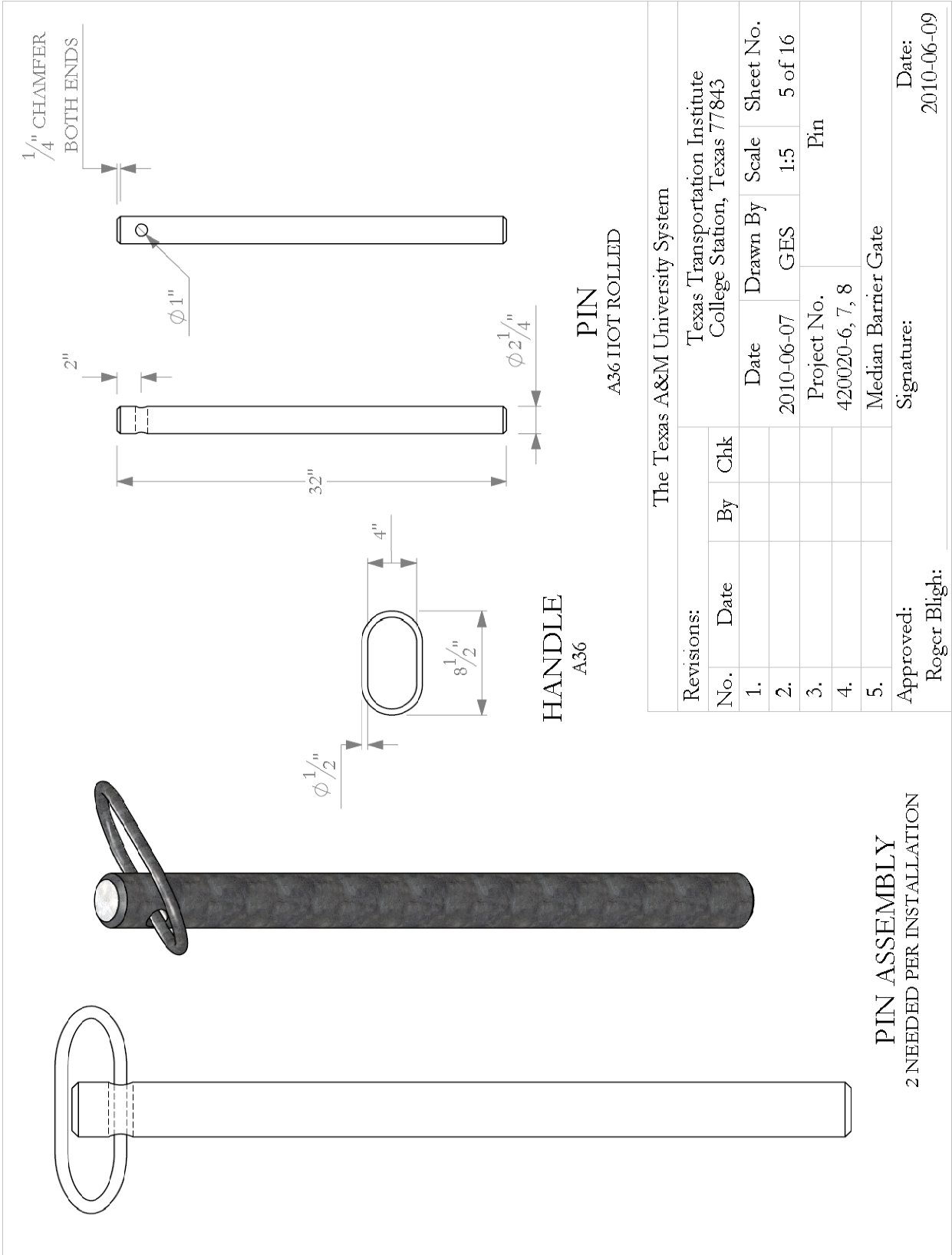


PLAN VIEW

CASTER MOUNTING PLATE  
A36 - SCALE 1:4  
SYMMETRICAL ABOUT  $\phi$ 'S

The Texas A&M University System

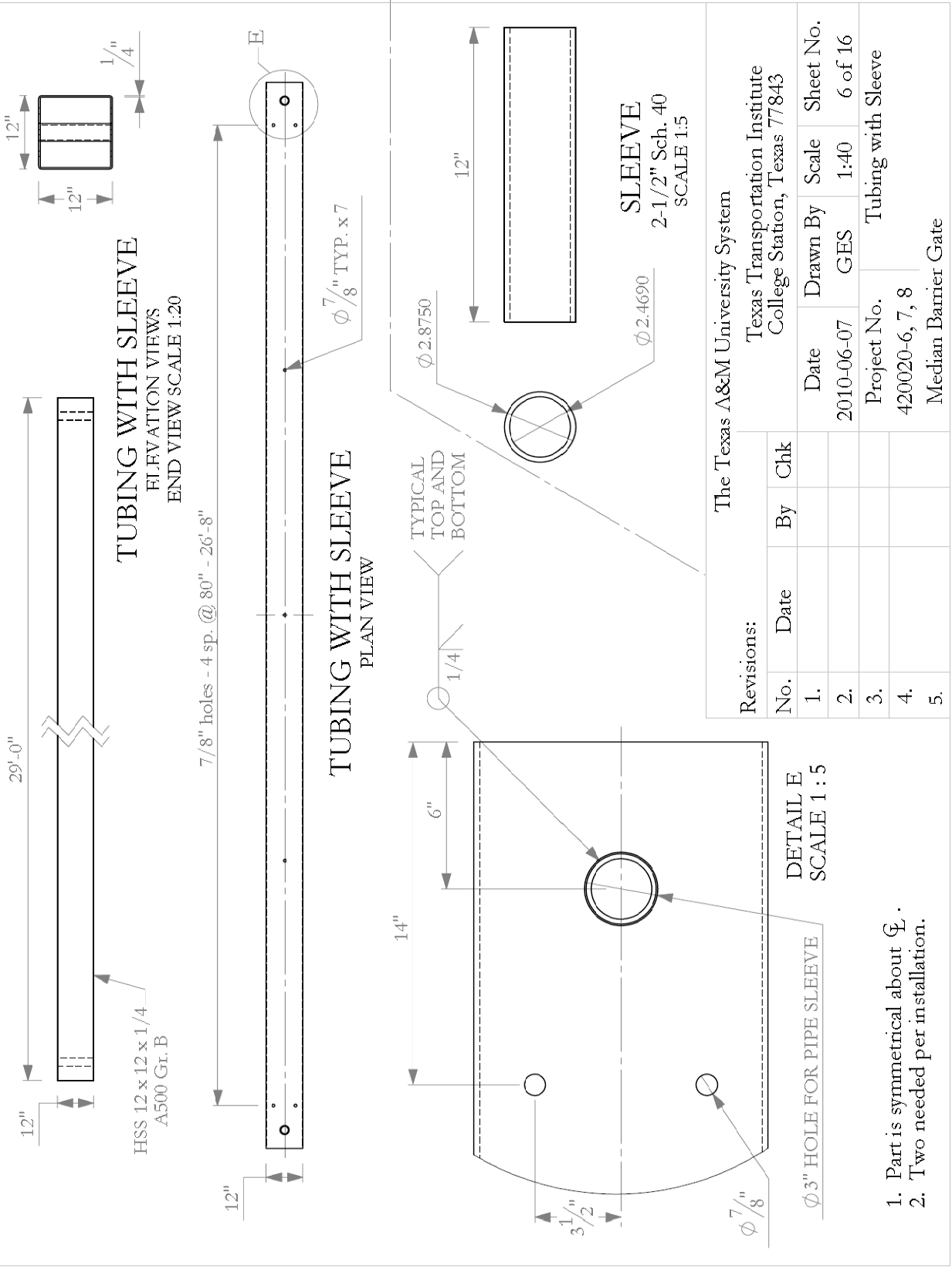
Revisions:		Texas Transportation Institute College Station, Texas 77843			
No.	Date	By	Chk	Scale	Sheet No.
1.				1:50	4 of 16
2.	2010-06-07	GES			
3.					Caster Details
4.					Project No. 420020-6, 7, 8
5.					Median Barrier Gate



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Revisions:		Texas Transportation Institute College Station, Texas 77843		
No.	Date	By	Chk	Sheet No.
1.				5 of 16
2.	2010-06-07	GES	1:5	5 of 16
3.				Pin
4.				Project No. 420020-6, 7, 8
5.				Median Barrier Gate

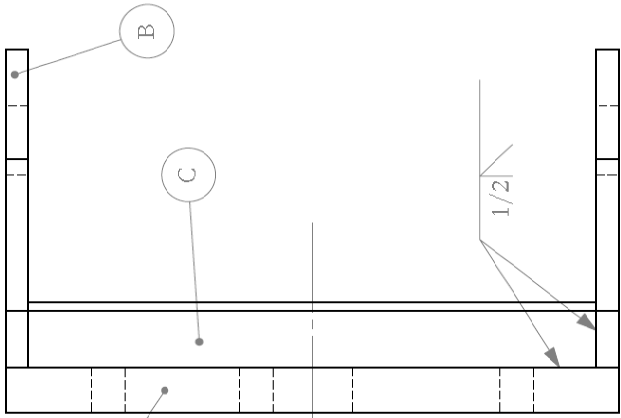
Approved: Roger Bligh: Signature: Date: 2010-06-09



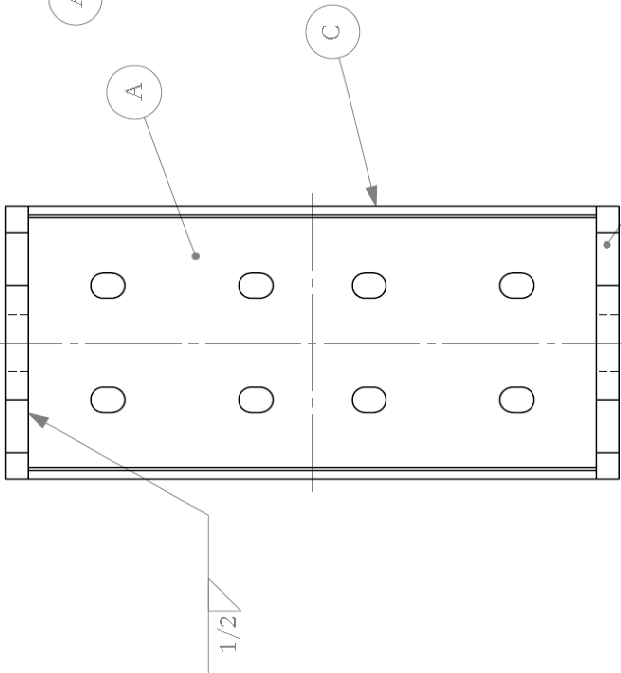
T:\2009-2010\420020 TYP\CT\Median Barrier\Solidworks\Final Design\Drawings\Drawings\Median Barrier Gate Drawing



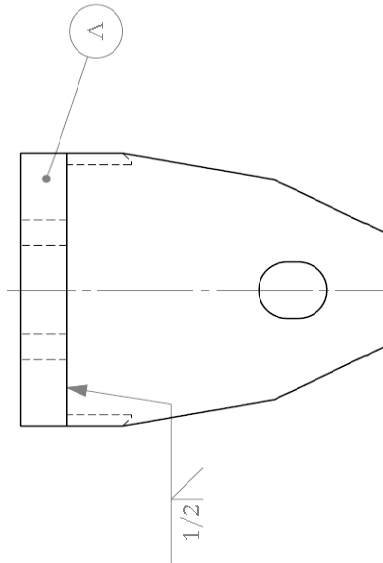
ISOMETRIC VIEW  
SCALE 1:10



ELEVATION VIEW  
FRONT



ELEVATION VIEW  
END

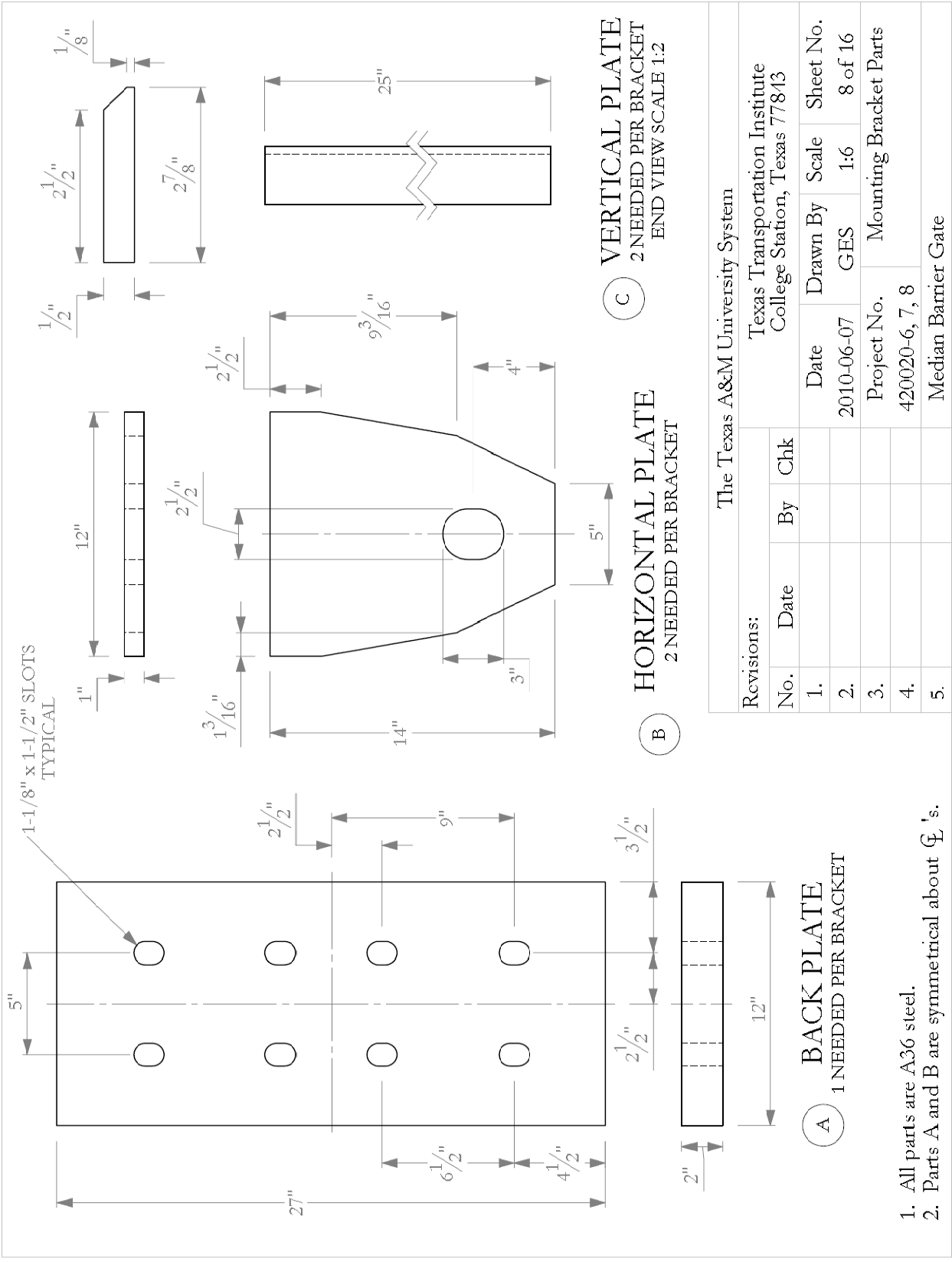


PLAN VIEW

MOUNTING BRACKET

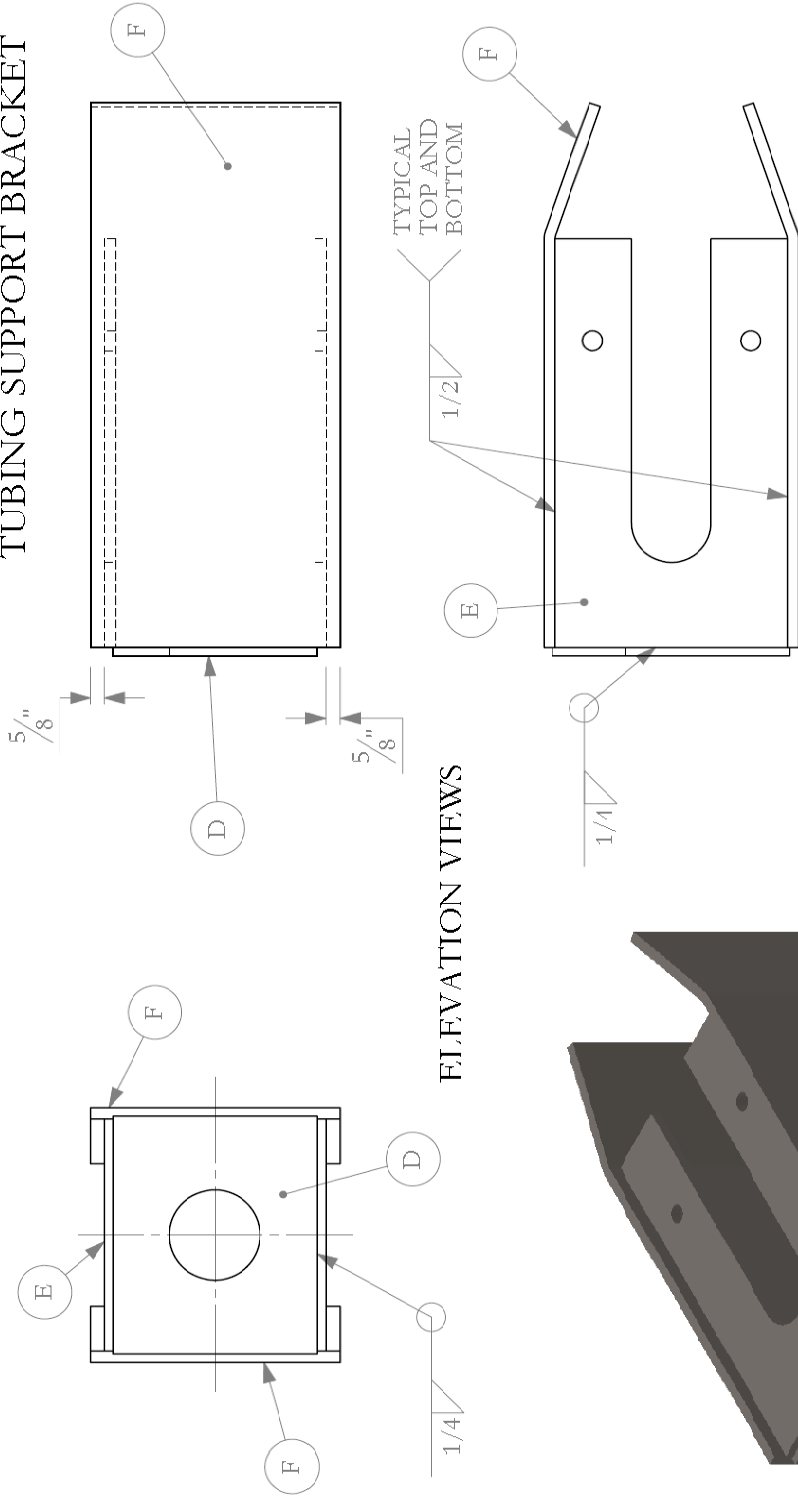
1. Part is symmetrical about  $\Phi$ 's.
2. Two needed per installation.

Revisions:		The Texas A&M University System		
No.	Date	By	Chk	
1.				Texas Transportation Institute College Station, Texas 77843
2.	2010-06-07	GES		Date Drawn By Scale Sheet No. 2010-06-07 GES 1:7 7 of 16
3.				Project No. Mounting Bracket 420020-6, 7, 8
4.				Median Barrier Gate
5.				



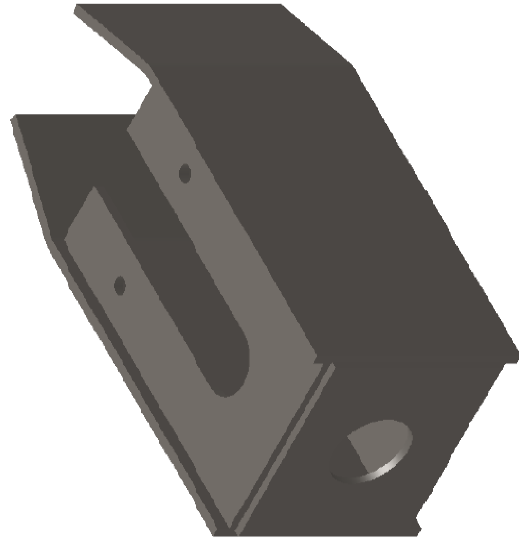


# TUBING SUPPORT BRACKET



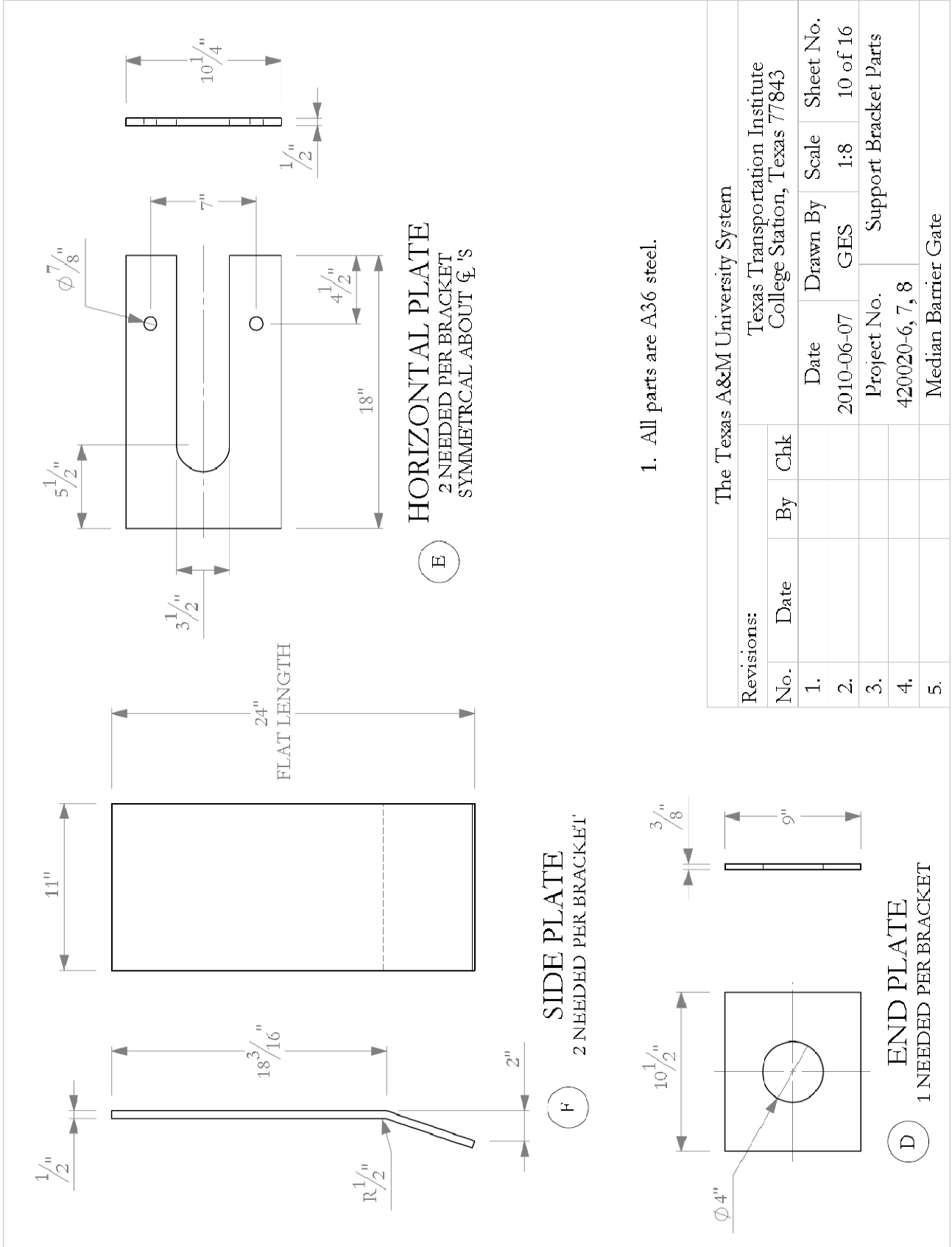
ELEVATION VIEWS

PLAN VIEW

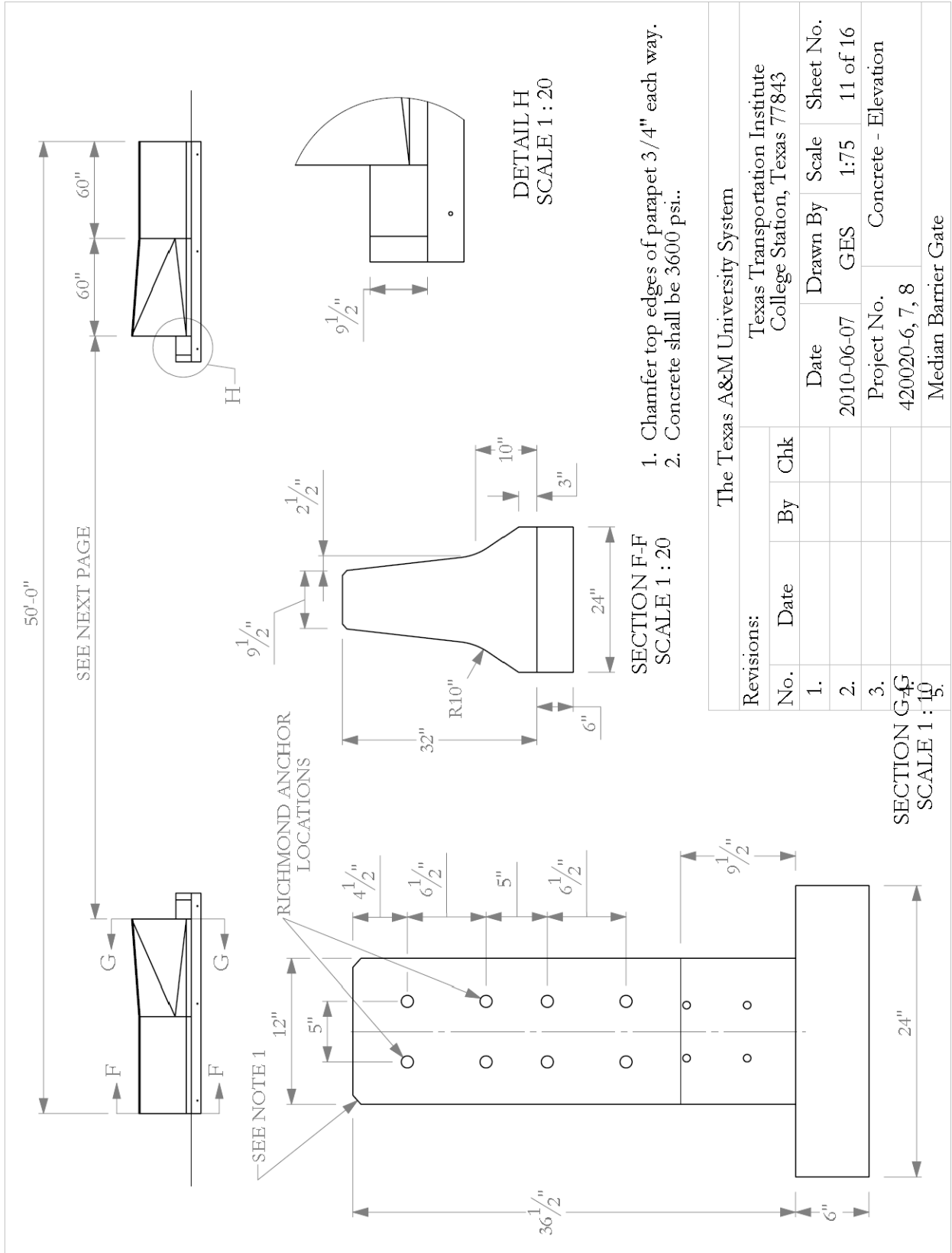


ISOMETRIC VIEW

Revisions:		The Texas A&M University System		
No.	Date	By	Chk	
1.				Texas Transportation Institute College Station, Texas 77813
2.	2010-06-07	GES	1:7	Date Drawn By Scale Sheet No. 2010-06-07 GES 1:7 9 of 16
3.				Project No. Tubing Support Bracket
4.				420020-6, 7, 8
5.				Median Barrier Gate

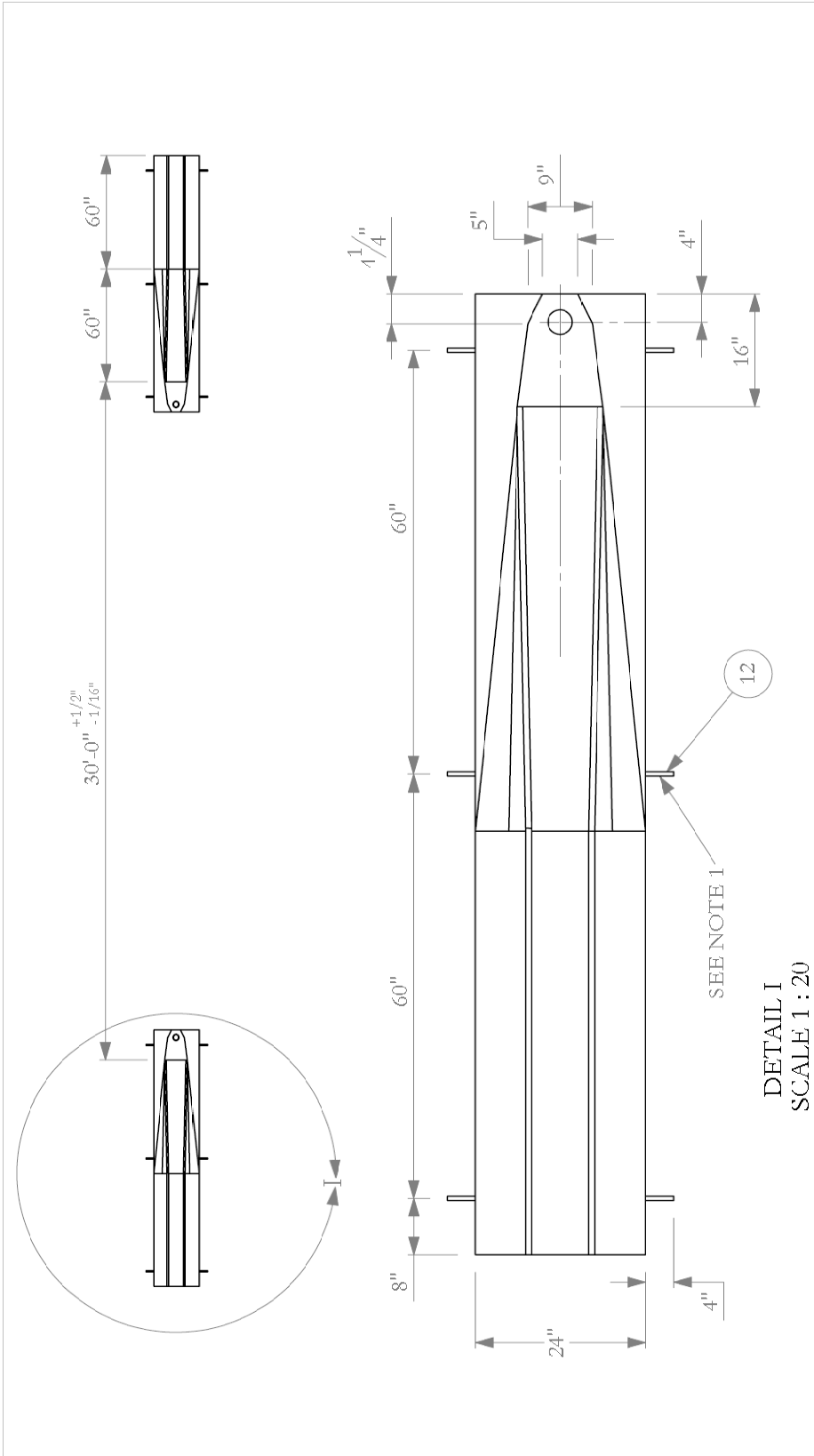


The Texas A&M University System					
Texas Transportation Institute College Station, Texas 77843					
Revisions:		Date	Drawn By	Scale	Sheet No.
No.	Date		By	Chk	
1.					10 of 16
2.		2010-06-07	GES	1:8	10 of 16
3.					Support Bracket Parts
4.					420020-6, 7, 8
5.					Median Barrier Gate



The Texas A&M University System

Revisions:		Texas Transportation Institute College Station, Texas 77843		
No.	Date	By	Chk	Sheet No.
1.				11 of 16
2.	2010-06-07	GES		11 of 16
3.				Concrete - Elevation
Project No.		420020-6, 7, 8		
Median Barrier Gate				



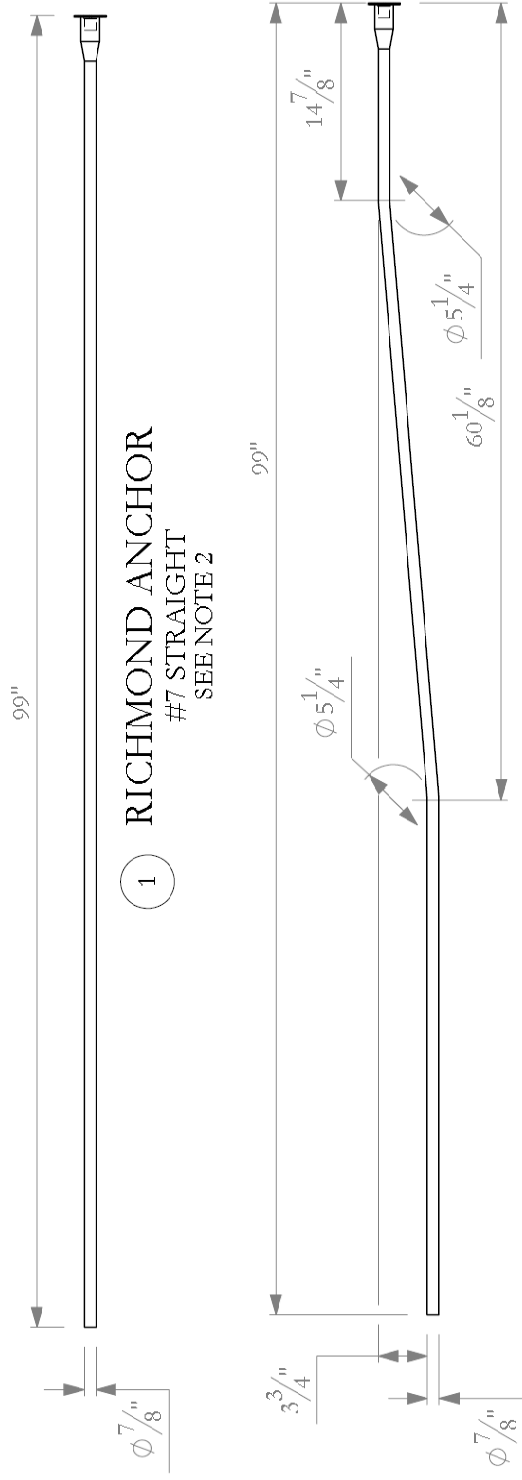
The Texas A&M University System				
Texas Transportation Institute College Station, Texas 77843				
Revisions:	No.	Date	By	Chk
	1.			
	2.	2010-06-07	GES	
	3.			
	4.			
	5.			

Date	Drawn By	Scale	Sheet No.
2010-06-07	GES	1:75	12 of 16

Project No.	Concrete - Plan
420020-6, 7, 8	Concrete - Plan

Project Name
Median Barrier Gate

1. Drill into existing concrete and insert #5 x 12" rebars.



1 RICHMOND ANCHOR  
#7 STRAIGHT  
SEE NOTE 2

2 RICHMOND ANCHOR  
#7 BENT  
SEE NOTE 2

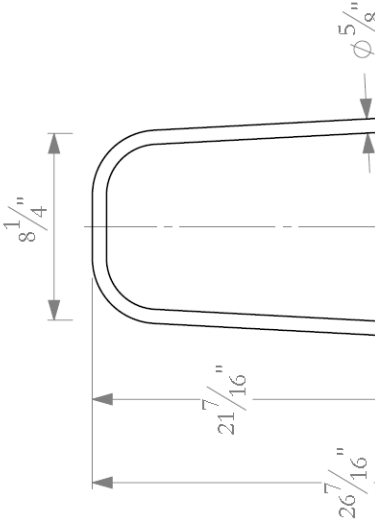
3 U-BAR  
TOE

1. All rebar is grade 60.
2. Dayton Superior D-101-A Dowel Bar Splicers, #7 rebar.

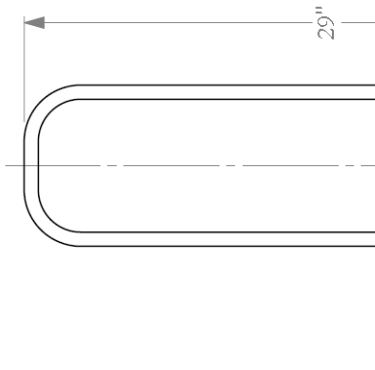
#	PART NUMBER	QTY.
1	Richmond Anchor, #7 straight	12
2	Richmond Anchor, #7 bent	4
3	U-bar, toe	4
4	Stirrup, parapet	16
5	Stirrup, foundation	32
6	L-bar, toe	4
7	U-bar, parapet	76
8	Rebar, #5 x 57"	16
9	Rebar, #5 x 93"	8
10	Pipe, 3" sch, 40 x 9-1/2"	2
11	Rebar, #4 x 11'	8
12	Rebar, #5 x 12"	12

Revisions:				
No.	Date	By	Chk	Scale
1.				Sheet No.
2.	2010-06-07	GES		1:12
3.				13 of 16
4.				Rebar List
5.				420020-6, 7, 8
				Median Barrier Gate

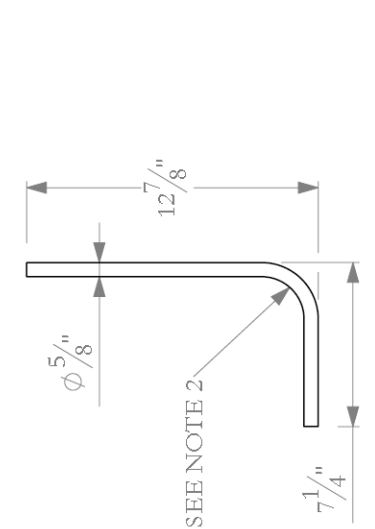
The Texas A&M University System  
Texas Transportation Institute  
College Station, Texas 77843



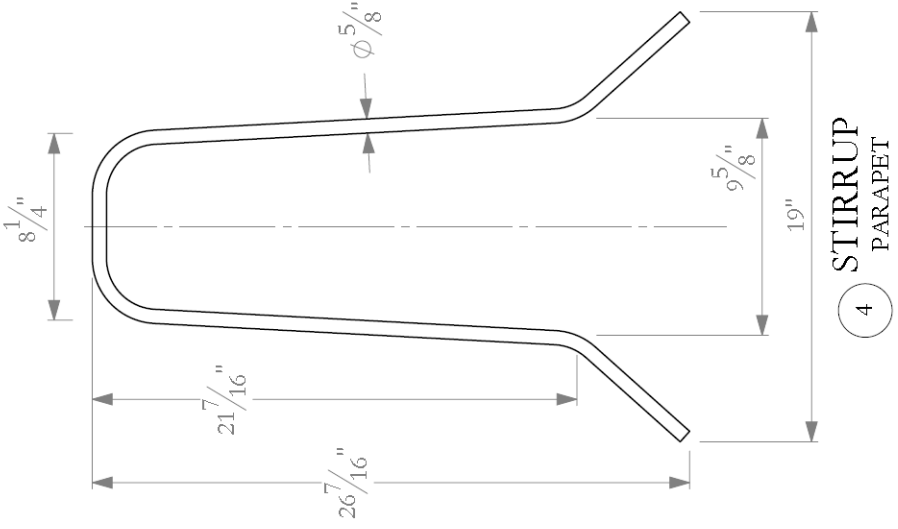
7 U-BAR



6 L-BAR



5 STIRRUP FOUNDATION

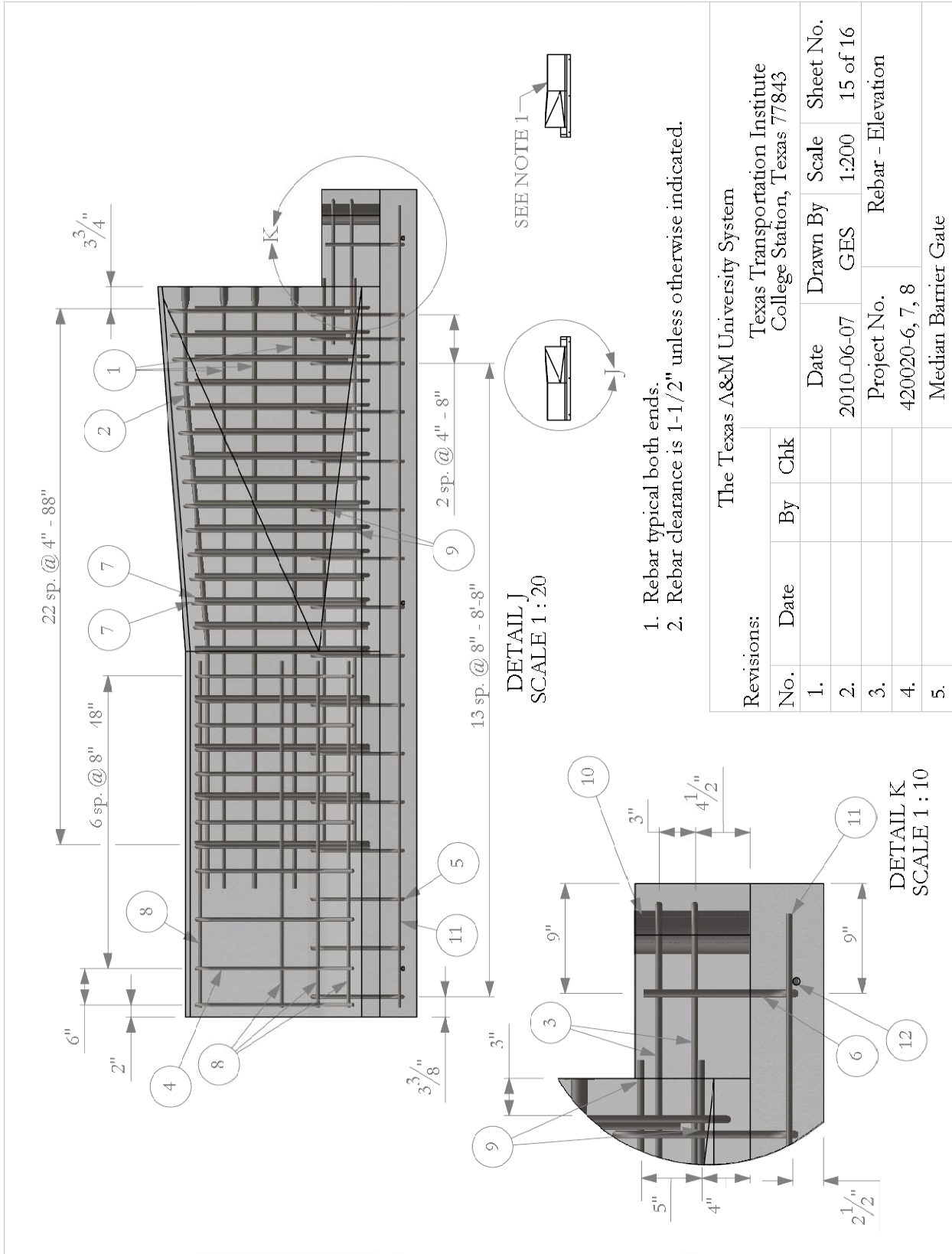


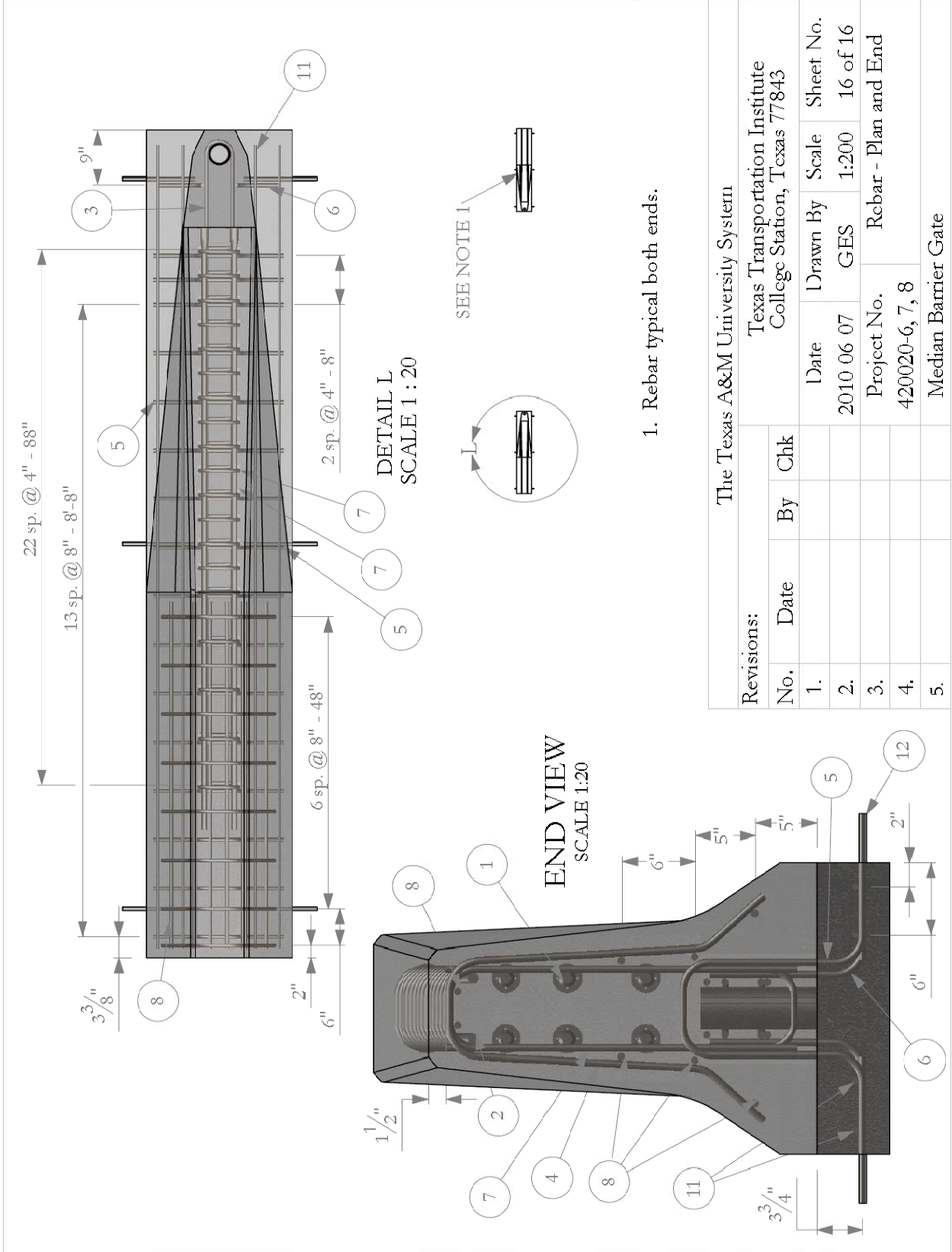
4 STIRRUP PARAPET

SEE NOTE 2

1. All rebar is grade 60.
2. Bends are  $\phi 3-3/4$ " (R 1-7/8") for all #5 stirrups.
3. Bars 4, 5, and 7 are symmetrical about  $\bar{C}$ 's.

The Texas A&M University System				
Revisions:		Texas Transportation Institute College Station, Texas 77843		
No.	Date	By	Chk	Sheet No.
1.				14 of 16
2.	2010-06-07	GES		1:7
3.				Rebar Details
4.				Project No. 420020-6, 7, 8
5.				Median Barrier Gate





1. Rebar typical both ends.

Revisions:		The Texas A&M University System		
No.	Date	By	Chk	
1.				Texas Transportation Institute College Station, Texas 77843
2.				Date Drawn By Scale Sheet No. 2010 06 07 GES 1:200 16 of 16
3.				Project No. Rcbar - Plan and End 420020-6, 7, 8
4.				Median Barrier Gate
5.				



## APPENDIX B. CERTIFICATION DOCUMENTATION

		MATERIAL USED		
TEST NUMBER	420020-7	420020-6	420020-8	
DATE	2010-07-15	2010-07-19	2010-07-21	
DATE RECEIVED	ITEM NUMBER	DESCRIPTION	SUPPLIER	HEAT #
2010-06-08	Rebar 05-10	5/8" x 20' grd 60	CMC-Sheplers	3016376
2010-06-08	Rich Anchor-1	#7 x 99" Richmond Anchor	CMC-Sheplers	
2010-07-07	Parts-7	Median Barrier Gate Parts	Brazos Industries	see file



CMC STEEL TEXAS  
 1 STEEL MILL DRIVE  
 SEGUIN TX 78155-7510

**CERTIFIED MILL TEST REPORT**  
 For additional copies call  
 830-372-8771

We hereby certify that the test results presented here  
 are accurate and conform to the reported grade specification

*Daniel J. Schacht*  
 Daniel J. Schacht

Quality Assurance Manager

HEAT NO.: 3016376 SECTION: REBAR 16MM (#5) 20'0" 420/60 GRADE: ASTM A615-09b Gr 420/60 ROLL DATE: 05/02/2010 MELT DATE: 04/30/2010	S O L D T O	CMC Construction Svcs College Stati 10650 State Hwy 30 College Station TX US 77845-7950 979 774 5900	S H I P T O	CMC Construction Svcs College Stati 10650 State Hwy 30 College Station TX US 77845-7950 979 774 5900	Delivery#: 80315040 BOL#: 70106603 CUST PO#: VERBAL CUST P/N: DLVRY LBS / HEAT: 39420.000 LB DLVRY PCS / HEAT: 1890 EA
Characteristic Value	Characteristic Value				
C 0.38%	Characteristic Value				
Mn 1.05%	Characteristic Value				
P 0.011%	Characteristic Value				
S 0.035%	Characteristic Value				
Si 0.26%	Characteristic Value				
Cu 0.39%	Characteristic Value				
Cr 0.16%	Characteristic Value				
Ni 0.21%	Characteristic Value				
Mo 0.061%	Characteristic Value				
V 0.001%	Characteristic Value				
Cb 0.002%	Characteristic Value				
Sn 0.013%	Characteristic Value				
Al 0.002%	Characteristic Value				
Yield Strength test 1 65.5ksi	Characteristic Value				
Tensile Strength test 1 105.5ksi	Characteristic Value				
Elongation test 1 13%	Characteristic Value				
Elongation Gage Lgth test 1 8IN	Characteristic Value				
Bend Test Diameter 2.188IN	Characteristic Value				
Bend Test Passed	Characteristic Value				

THIS MATERIAL IS FULLY KILLED, 100% MELTED AND MANUFACTURED IN THE USA, WITH NO WELD REPAIR OR MERCURY CONTAMINATION IN THE PROCESS.

REMARKS :

PO # 6271114



MILL TEST CERTIFICATE  
EN10204 3.1

Certificate No G0030836 K 2 Date 29.01.2010

Shipped .....: 30707603  
Product description: ERW-STEEL PIPES

Standard .....: ASTM A 53  
Customer name: SUNBELT GROUP, INC.

Dedwey Co.,  
Contract No: 2010

Material : ASTM A 53 GRA  
Order No: 002465  
Customer: 19,029

No	Od (inch)	WT (inch)	Length (Feet)	Pieces	Feet	Pipe Type	HT Psi	HT Sec	BD	DE	FB	NDT	VD	EL	NP	C
1	1.1/4"	0.140	21	252	5,291.34	GPE	1200	5	0	OK	OK	OK	OK	0,00	0	OK
2	1.1/2"	0.145	21	144	3,023.52	GPE	1200	5	0	OK	OK	OK	OK	0,00	0	OK
3	2"	0.154	21	130	2,729.58	GPE	2300	5	0	OK	OK	OK	OK	0,00	0	OK
4	2"	0.154	24	286	6,888.50	GPE	2300	5	0	OK	OK	OK	OK	0,00	0	OK
5	2.1/2"	0.203	24	180	4,322.83	GPE	2600	5	0	OK	OK	OK	OK	0,00	0	OK
6	4"	0.237	21	150	3,149.61	GPE	1900	5	0	OK	OK	OK	OK	0,00	0	OK
7	3"	0.216	21	42	881.88	GPE	2220	5	0	OK	OK	OK	OK	0,00	0	OK
8	2.1/2"	0.203	18	54	874.41	GPE	2500	5	0	OK	OK	OK	OK	0,00	0	OK
9	6"	0.280	24	42	1,008.66	GPE	1520	5	0	OK	OK	OK	OK	0,00	0	OK

No	Heat No	Ro Psi	Rm Psi	A %
1	922666	39,011	54,455	33

Description



*[Handwritten Signature]*

BORUSAN MANNESMANN BORU  
GEMLİK KALİTE  
Hisar Mah. Gemesiz Mevki



10Jun10 14:33 TEST CERTIFICATE No: HD 175340

Sold By:					
CARGILL STEEL SERVICE CENTERS		P/O No	AUS 6271157		
DEPARTMENT OF CARGILL, INCORPORATED		Rel			
8807 LIBERTY RD		S/O No	HD 135262-004		
HOUSTON TX 77028-5730		B/L No	HD 117162-006	Shp	10Jun10
Tel: 713-672-4200 Fax: 713 672-4292		Inv No		Inv	

Sold To: ( 20847)	Ship To: (011)
NAMASCO	NAMASCO
ATTN: A/P	SOUTH LOOP 4
SUITE 500	BUDA TX 78610
500 COLONIAL CENTER PKWY	
ROSWELL GA 30076	

Tel: 678-259-8800 Fax: 866 598-1572

-----

CERTIFICATE of ANALYSIS and TESTS	Cert. No: HD 175340
	10Jun10

Part No		Pcs	Wgt
HR PLATE SHEET ASTM-A36/ASME SA-36		30	19,604
1/2 X 48.0000" X 96.0000"			

Heat Number	Tag No	Pcs	Wgt
101815	152703	15	9,802
	YIELD=47.42-47.56/TENS=66.17-66.53/ELONG=45-46/MILL=<AHMSA>		
	VESSL=<UP242205>/CNTRY=<MEXICO>		
101815	152704	15	9,802
	YIELD=47.42-47.56/TENS=66.17-66.53/ELONG=45-46/MILL=<AHMSA>		
	VESSL=<UP242205>/CNTRY=<MEXICO>		

Heat Number	*** Chemical Analysis ***
101815	**<*> C=0.1610 Mn=0.5610 P=0.0140 S=0.0060 Si=0.1000 Cu=0.0200
	Al=0.0290 Ti=0.0030 V=0.0040 Nb=0.0020 Mo=0.0070 Cr=0.0230
	Ni=0.0240

ELEMENTS NOT LISTED TEST BELOW DETECTABLE LEVELS  
ALL ASTM PLATE PRODUCTS ARE PRODUCED FROM COIL  
CENTER TESTS AVAILABLE AT CARGILL

THIS IS TO CERTIFY THAT THE PRODUCT DESCRIBED  
HEREIN WAS SAMPLED AND TESTED IN ACCORDANCE  
WITH THE SPECIFICATION, TO OUR KNOWLEDGE,  
AND FULFILLS REQUIREMENTS IN SUCH RESPECT.

Україна  
Ukraine

Сертифікат якості  
CERTIFICATE

ОАО "ІЛІЧ ІЗІР І СТЕЛ ВОРКС ОФ МАРИУПОЛ"  
OSC "ILYICH IRON & STEEL WORKS OF MARIUPOЛ"

Сертифікат якості  
QUALITY CERTIFICATE

Лист 1  
OF 1

Листов  
Sheets

87504, г. Мариуполь, ул. Лавченко, 1. Телескоп 115157 DEPO SU  
Levchenko str. 1, Mariupol, 87504, Telex 115157 DEPO SU

Сертифікований тип Ілліч ІЗІР І СТЕЛ ВОРКС ОФ МАРИУПОЛ № 0045  
Сертифікований тип Ілліч ІЗІР І СТЕЛ ВОРКС ОФ МАРИУПОЛ № 0045

Сертифікований тип Ілліч ІЗІР І СТЕЛ ВОРКС ОФ МАРИУПОЛ № 0045  
Сертифікований тип Ілліч ІЗІР І СТЕЛ ВОРКС ОФ МАРИУПОЛ № 0045

Сертифікат якості CERTIFICATE		Лист 1 OF 1		Листов Sheets	
Сертифікований тип Ілліч ІЗІР І СТЕЛ ВОРКС ОФ МАРИУПОЛ № 0045		Сертифікований тип Ілліч ІЗІР І СТЕЛ ВОРКС ОФ МАРИУПОЛ № 0045		Сертифікований тип Ілліч ІЗІР І СТЕЛ ВОРКС ОФ МАРИУПОЛ № 0045	
Сертифікований тип Ілліч ІЗІР І СТЕЛ ВОРКС ОФ МАРИУПОЛ № 0045		Сертифікований тип Ілліч ІЗІР І СТЕЛ ВОРКС ОФ МАРИУПОЛ № 0045		Сертифікований тип Ілліч ІЗІР І СТЕЛ ВОРКС ОФ МАРИУПОЛ № 0045	
Сертифікований тип Ілліч ІЗІР І СТЕЛ ВОРКС ОФ МАРИУПОЛ № 0045		Сертифікований тип Ілліч ІЗІР І СТЕЛ ВОРКС ОФ МАРИУПОЛ № 0045		Сертифікований тип Ілліч ІЗІР І СТЕЛ ВОРКС ОФ МАРИУПОЛ № 0045	

Сертифікат якості CERTIFICATE	Лист 1 OF 1	Листов Sheets
Сертифікований тип Ілліч ІЗІР І СТЕЛ ВОРКС ОФ МАРИУПОЛ № 0045	Сертифікований тип Ілліч ІЗІР І СТЕЛ ВОРКС ОФ МАРИУПОЛ № 0045	Сертифікований тип Ілліч ІЗІР І СТЕЛ ВОРКС ОФ МАРИУПОЛ № 0045
Сертифікований тип Ілліч ІЗІР І СТЕЛ ВОРКС ОФ МАРИУПОЛ № 0045	Сертифікований тип Ілліч ІЗІР І СТЕЛ ВОРКС ОФ МАРИУПОЛ № 0045	Сертифікований тип Ілліч ІЗІР І СТЕЛ ВОРКС ОФ МАРИУПОЛ № 0045
Сертифікований тип Ілліч ІЗІР І СТЕЛ ВОРКС ОФ МАРИУПОЛ № 0045	Сертифікований тип Ілліч ІЗІР І СТЕЛ ВОРКС ОФ МАРИУПОЛ № 0045	Сертифікований тип Ілліч ІЗІР І СТЕЛ ВОРКС ОФ МАРИУПОЛ № 0045

Підпис  
Signature

АВАНКО  
AVANKO

Підпис  
Signature

АВАНКО  
AVANKO

Issuing Date : 05/27/2010 B/L No. : 263099 Load No. : 264806 Our Order No. : 81782/3 Cust. Order No. : 9525  
 Vehicle No: TTPX 80247  
 Specification : 1.0000" x 96.0000" x 240.0000"  
 ASTM A36-08/ASTM A709 Grade 36-09a/ASME SA36-03a .05 Max Si

Marking :

Heat No	C	Min	P	S	Si	Cu	Ni	Cr	Mo	Al(%)	V	Nb	Ti	N	Ca	B	Sn	CEQ	PCM	
0503684	0.18	0.83	0.017	0.001	0.03	0.25	0.06	0.11	0.02	0.024	0.005	0.001	0.001	0.001	0.0032	0.0001	0.012	0.36	0.24	
Plate Serial No		Places	Tons	Dlr.	Yield	Tensile	Elongation % in 2"	Elongation % in 8"	Dlr.	1	2	3	Ave.	shear	Temp	Min	Ave.			
		Charpy Impacts																		
		Dlr. 1 shear 2 shear 3 shear Ave. shear																		
		Dlr. 1 shear 2 shear 3 shear Ave. shear																		
0503684-02	4	13.06	T	43,300	70,100	20.9	20.9	20.9												
			T	43,700	70,400	18.7	18.7	18.7												
0503684-03	12	39.20	T	43,300	70,100	20.9	20.9	20.9												
			T	43,700	70,400	18.7	18.7	18.7												
0503684-04	9	29.40	T	43,300	70,100	20.9	20.9	20.9												
			T	43,700	70,400	18.7	18.7	18.7												

Manufactured to fully killed fine grain practice by Electric Arc Furnace. Welding or weld repair was not performed on this material. We hereby certify that the contents of this report are accurate and correct. All test results Mercury has not been used in the direct manufacturing of this material. Produced as continuous cast discrete plate as-rolled, unless otherwise noted in Specification.

Yield by 0.5EUL method unless otherwise specified. Ceq = C+(Mn/16)+(Cr+Mo\*0.05)+(Cu\*0.0175)  
 Pcm = C+(Si/30)+(Mn/20)+(Cu/20)+(Ni/60)+(Cr/20)+(Mo/15)+(V/10)+Sb  
 Melted and manufactured in the USA. ISO 9001-2000 certified (#006461) by SRI Quality System Registrar (#0985-09). PED 97/23/IEC 7/2 Annex 1, Para. 4.3 Compliant.  
 DIN 50049 3.1.B/EN 10204 3.1B(2004), DIN EN 10204 3.1(2005) compliant. For ABS grades only, Quality Assurance certificate 06-MM/POA-383

T. A. Depretis, Metallurgist  
 05/28/2010 9:53:28 AM

Issuing Date : 04/15/2010      BIL No. : 258864      Our Order No. : 810087      Cust. Order No. : 9480  
 Vehicle No: LW 82023      Sold To:  
 Specification : 2.0000" x 96.000" x 240.000"  
 ASTM A36-08/ASTM A709 Grade 36-08a/AASHTO M270 Grade 36/ASME  
 SA36-03a 2009 Addenda AASHTO M270 36

Marking :

Heat No	C	Mn	P	S	Si	Cu	Ni	Cr	Mo	A(%)	V	Nb	Ti	N	Ca	B	Sn	CEQ	PCM
0502639	0.19	0.86	0.024	0.001	0.18	0.29	0.07	0.12	0.01	0.005	0.006	0.003	0.001		0.0015	0.0001	0.015	0.36	0.26

Plate Serial No	Tensile Test		Elongation			Charpy Impacts			Mln Ave.						
	Pieces	Tons	Dir.	Yield (psi)	Tensile (psi)	% In 2"	% In 8"	Dir.		1	2	3	shear	Ave.	Temp
0502639-02	2	13.06	T	43,600	72,900	23.8									
			T	42,600	73,100	19.7									
0502639-03	6	39.20	T	43,600	72,900	23.8									
			T	42,600	73,100	19.7									
0502639-04	5	32.67	T	43,600	72,900	23.8									
			T	42,600	73,100	19.7									

Manufactured to fully killed practice by Electric Arc Furnace. Welding or weld repair was not performed on this material.  
 Mercury has not been used in the direct manufacturing of this material. Produced as continuous cast (discrete plate as-rolled, unless otherwise noted in Specification).  
 Yield by USEUL method unless otherwise specified.  $Ceq = C + (Mn/6) + ((Cr + Mo + V)/5) + (Cu/10) + 15$   
 Pcm =  $C/(Si/60) + (Mn/20) + (Cu/20) + (Ni/20) + (Cr/20) + (Nb/10) + (V/10) + 5B$   
 Milled and manufactured in the USA. ISO 9001:2000 certified (#006461) by SRI Quality System Registrar (#0985-08). PED 9723/EC 712 Annex 1, Para. 4.3 Compliant.  
 DIN 50049 3.1, EN 10204 3.1B(2004), DIN EN 10204 3.1(2005) compliant. For ABS grades only, Quality Assurance certificate 06-MMPOA-383

We hereby certify that the contents of this report are accurate and correct. All test results and operations performed by the material manufacturer are in compliance with the applicable specifications, including customer specifications.

T. A. Dopretis  
 T. A. Dopretis, Metallurgist

04/19/2010 11:15:56 AM





P. O. Box 911  
Seguin, Texas 78156-0911  
(830) 372-8200

**CERTIFIED MILL TEST REPORT**  
For additional copies call  
(830) 372-8485

are accurate and conform to the reported grade.  
*Daniel J. Schacht*  
Daniel J. Schacht  
Quality Assurance Manager

HEAT NO: 248838		SECTION: RD 2-1/4x20"		S NORTH SHORE SUPPLY CO		S NORTH SHORE SUPPLY CO		SHIP#: 10181030												
GRADE: ASTM A38-04 <td colspan="2">RD 57.15mm x6.056 <td colspan="2">P O BOX 8940 <td colspan="2">12829 MARKET ST. <td colspan="2">BOL #: 428361 </td></td></td></td>		RD 57.15mm x6.056 <td colspan="2">P O BOX 8940 <td colspan="2">12829 MARKET ST. <td colspan="2">BOL #: 428361 </td></td></td>		P O BOX 8940 <td colspan="2">12829 MARKET ST. <td colspan="2">BOL #: 428361 </td></td>		12829 MARKET ST. <td colspan="2">BOL #: 428361 </td>		BOL #: 428361												
				L HOUSTON, TX 77213 <td colspan="2">HOUSTON, TX 77015 <td colspan="2">INV #:</td> </td>		HOUSTON, TX 77015 <td colspan="2">INV #:</td>		INV #:												
								CUST PO#: 120201												
								CUST PIN:												
PROPERTIES																				
CHEMICAL ANALYSIS				MECHANICAL		TEST I		TEST		TEST										
%						IMPERIAL		METRIC		IMPERIAL		METRIC								
C	Mn	P	S	Si	Cu	Cr	Ni	Mo	Cb	V	Sn	B	Ti	C.Eq.						
0.20	0.80	0.009	0.026	0.20	0.31	0.09	0.08	0.023	0.002	0.002	0.012	0.0003	0.001	0.38						
Yield Strength				48.0 KSI		331.0 MPA														
Tensile Strength				74.6 KSI		514.4 MPA														
Elongation				32 %		32 %														
Gauge Length				8 INS		203 MM														
Reduction of Area				42 %		42 %														
Bend Test																				
Diameter																				
Charpy Impact				146		EBM														
Test Temp																				
Sample Size																				
Orientation																				
Hardness																				
JOMINY RESULTS - Rockwell C hardness at 1/16th inch increments										GRAIN SIZE		INCLUSION RATING								
1	2	3	4	5	6	7	8	9	10	11	12	METHOD	METHOD							
13	14	15	16	18	20	22	24	26	28	30	32	RESULT	TYPE							

100% MELTED AND MANUFACTURED IN THE USA AND FREE OF MERCURY CONTAMINATION IN THE PROCESS  
REMARKS:

01Jul10 9: 1 TEST CERTIFICATE No: DCR 696282

Sold By:  
INDEPENDENCE TUBE CORPORATION  
6226 W. 74TH STREET  
CHICAGO, IL 60638  
Tel: 708-496-0380 Fax: 708-563-1950

P/O No 6273761  
Rel  
S/O No DCR 23853-001  
B/L No DCR 16103-008 Shp 29Jun10  
Inv No Inv

Sold To: ( 144)  
NAMASCO-EAST  
500 COLONIAL PARKWAY  
SUITE 500  
ROSWELL, GA 30076

Ship To: ( 21)  
NAMASCO-BUDA  
2560 SOUTH LOOP 4  
BUDA, TX

Tel: 678-259-8845 Fax: 571 323-0613

-----  
CERTIFICATE of ANALYSIS and TESTS

Cert. No: DCR 696282  
29Jun10

Part No 001  
TUBING A500 GRADE B(C)  
12" SQ X 1/4" X 30'

Pcs Wgt  
4 4,732

Heat Number Tag No  
U81836 652592

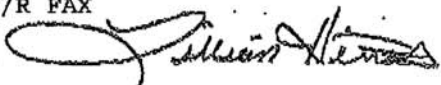
Pcs Wgt  
4 4,732

YLD=58500/TEN=72000/ELG=39.7

Heat Number  
U81836

\*\*\* Chemical Analysis \*\*\*  
C=0.2100 Mn=0.6900 P=0.0070 S=0.0120 Si=0.0130 Al=0.0410  
Cu=0.0300

T/R FAX

: 

Test Report Clerk  
MELTED IN U.S.A.

WE PROUDLY MANUFACTURE ALL OF OUR HSS IN THE USA.  
INDEPENDENCE TUBE PRODUCT IS MANUFACTURED, TESTED,  
AND INSPECTED IN ACCORDANCE WITH ASTM STANDARDS.  
\*\*\*\*\*

CURRENT STANDARDS:

- ..... A500/A500M-07
- ..... A513-07
- ..... A252-98 (2002)

**CERTIFIED MILL TEST REPORT**

**NUCOR**

BAR MILL GROUP  
NUCOR STEEL AUBURN, INC.

SOLD DAYTON SUPERIOR CORP (DIP)  
55 N PINE ST  
TO: TREMONT, PA 17981-

SHIP DAYTON SUPERIOR CORP (DIP)  
55 N PINE ST  
TO: TREMONT, PA 17981-

Ship from:

Nucor Steel - Auburn  
25 Quarry Road  
Auburn, NY 13021  
315-253-4561

Date: 5-Oct-2009  
B.L. Number: 368296  
Load Number: 117644

Material Safety Data Sheets are available at [www.nucorbar.com](http://www.nucorbar.com) or by contacting your incida sales representative.

NRMG-08 March 24, 2008

HEAT NUM. *	DESCRIPTION	PHYSICAL TESTS			CHEMICAL TESTS															
		YIELD P.S.I.	TENSILE P.S.I.	ELONG % IN 8"	BEND	WT% DEF	C	Ni	Mn	Cr	P	Mo	S	V	Si	Ch	Cu	Sn	C.E.	
PO# => 81775																				
AU0910019501	Nucor Steel - Auburn Inc	80,600	113,600	13.2%	OK		.35	1.10	.011	.030	.20	.36								
AU09100195	22#7 Rebar 20	556MPa	783MPa				.12	.14	.040	.026	.001									
	A615 Gr60 92K min tensile																			
PO# => 81775																				
AU0910089701	Nucor Steel - Auburn Inc	70,700	97,700	15.4%	OK		.33	1.14	.017	.040	.24	.37								
AU09100897	22#7 Rebar 20	487MPa	674MPa				.10	.16	.029	.028	.001									
	A615 Gr60 92K min tensile																			
PO# => 81775																				
AU0910163201	Nucor Steel - Auburn Inc	70,500	100,600	13.8%	OK		.34	1.06	.011	.035	.21	.36								
AU09101632	22#7 Rebar 20	486MPa	694MPa				.13	.16	.033	.032	.002									
	A615 Gr60 92K min tensile																			
PO# => 81773																				
AU0910170701	Nucor Steel - Auburn Inc	72,100	99,700	18.3%	OK		.34	1.01	.018	.045	.22	.38								
AU09101707	25#8 Rebar 20	497MPa	687MPa				.15	.25	.045	.028	.001									
	A615 Gr60 92K min tensile																			
	ASTM A615/A615M-08b GR 60(420)																			

I HEREBY CERTIFY THAT THE ABOVE FIGURES ARE CORRECT AS CONTAINED IN THE RECORDS OF THE CORPORATION.

ALL MANUFACTURING PROCESSES OF THE STEEL MATERIALS IN THIS PRODUCT INCLUDING HOT-ROLLING, FINISH ROLLING, PICKLING, COILING, SHEARING, AND CUTTING, HAVE BEEN PERFORMED IN ACCORDANCE WITH THE REQUIREMENTS OF THE ASTM SPECIFICATION FOR THIS MATERIAL. ALL MANUFACTURING PROCESSES OF THE STEEL MATERIALS IN THIS PRODUCT INCLUDING HOT-ROLLING, FINISH ROLLING, PICKLING, COILING, SHEARING, AND CUTTING, HAVE BEEN PERFORMED IN ACCORDANCE WITH THE REQUIREMENTS OF THE ASTM SPECIFICATION FOR THIS MATERIAL. ALL MANUFACTURING PROCESSES OF THE STEEL MATERIALS IN THIS PRODUCT INCLUDING HOT-ROLLING, FINISH ROLLING, PICKLING, COILING, SHEARING, AND CUTTING, HAVE BEEN PERFORMED IN ACCORDANCE WITH THE REQUIREMENTS OF THE ASTM SPECIFICATION FOR THIS MATERIAL.

QUALITY ASSURANCE  
Jim Bierat





## APPENDIX C. TEST VEHICLE PROPERTIES AND INFORMATION

Date: 2010-07-15 Test No.: 420020-5 VIN No.: KNADC125736268923

Year: 2003 Make: Kia Model: Rio

Tire Inflation Pressure: 32 psi Odometer: 120942 Tire Size: P175/65R14

Describe any damage to the vehicle prior to test: \_\_\_\_\_

• Denotes accelerometer location.

NOTES: \_\_\_\_\_

Engine Type: 4 cylinder

Engine CID: 1.6 Liter

Transmission Type: \_\_\_\_\_

     Auto or   x   Manual

  x   FWD      RWD      4WD

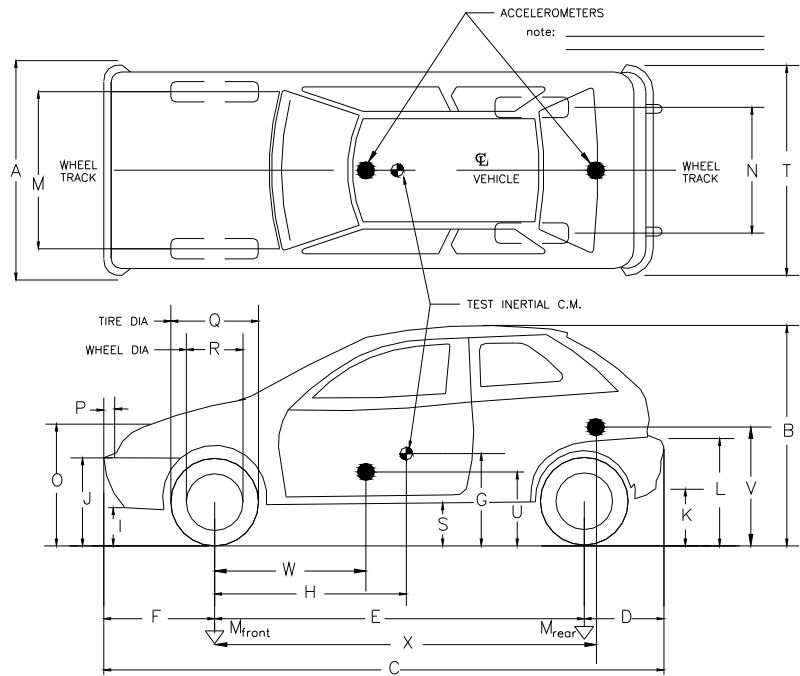
Optional Equipment: \_\_\_\_\_

Dummy Data: \_\_\_\_\_

Type: 50<sup>th</sup> percentile male

Mass: 168 lb

Seat Position: Frt Passenger Seat



**Geometry:** inches

A	<u>62.50</u>	F	<u>32.00</u>	K	<u>12.00</u>	P	<u>3.25</u>	U	<u>15.50</u>
B	<u>56.12</u>	G	<u>    </u>	L	<u>24.25</u>	Q	<u>22.50</u>	V	<u>20.00</u>
C	<u>164.25</u>	H	<u>36.27</u>	M	<u>56.50</u>	R	<u>15.50</u>	W	<u>39.50</u>
D	<u>37.00</u>	I	<u>8.50</u>	N	<u>57.00</u>	S	<u>8.62</u>	X	<u>103.25</u>
E	<u>95.25</u>	J	<u>22.75</u>	O	<u>28.00</u>	T	<u>63.00</u>		

Wheel Center Ht Front 10.75 Wheel Center Ht Rear 11.12

RANGE LIMIT: A = 65 ±3 inches; C = 168 ±8 inches; E = 98 ±5 inches; F = 35 ±4 inches; G = 39 ±4 inches;  
O = 24 ±4 inches; M+N/2 = 56 ±2 inches

GVWR Ratings:	Mass: lb	Curb	Test Inertial	Gross Static
Front <u>1808</u>	$M_{front}$	<u>1475</u>	<u>1501</u> Allowable	<u>1586</u> Allowable
Back <u>1742</u>	$M_{rear}$	<u>882</u>	<u>923</u> Range	<u>1006</u> Range =
Total <u>3379</u>	$M_{Total}$	<u>2357</u>	<u>2424</u> 2420 ±55 lb	<u>2592</u> 2585 ±55 lb

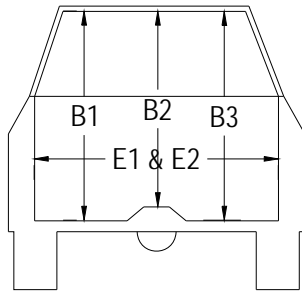
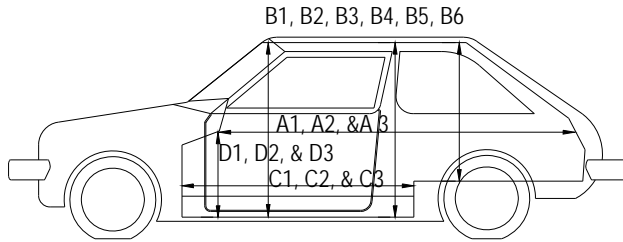
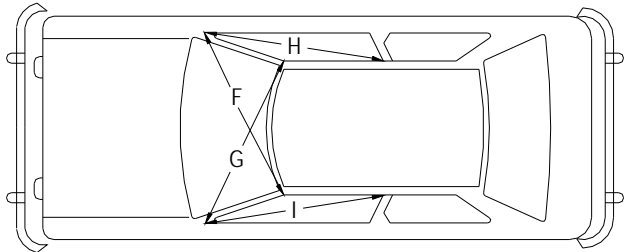
**Mass Distribution:**  
lb LF: 780 RF: 721 LR: 445 RR: 478

**Figure C1. Vehicle Properties for Test No. 420020-6.**



**Table C2. Occupant Compartment Measurements for Test No. 420020-6.**

Date: 2010-07-15 Test No.: 420020-5 VIN No.: KNADC125736268923  
 Year: 2003 Make: Kia Model: Rio



**OCCUPANT COMPARTMENT DEFORMATION MEASUREMENT**

	<b>Before</b> ( inches )	<b>After</b> ( inches )
A1	67.25	64.50
A2	64.50	63.50
A3	62.25	62.25
B1	39.12	43.12
B2	36.00	35.50
B3	39.12	39.50
B4	34.75	34.75
B5	34.75	34.75
B6	34.75	34.75
C1	27.00	24.00
C2	----	----
C3	27.00	27.00
D1	9.88	10.75
D2	5.88	6.00
D3	9.12	9.25
E1	49.50	52.00
E2	51.00	53.00
F	50.00	45.00
G	50.00	50.75
H	36.50	34.00
I	36.50	36.50
J*	50.50	48.00

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

Date: 2010-07-19 Test No.: 420020-7 VIN No.: 1D7HA18N43525276

Year: 2003 Make: Dodge Model: Ram 1500 Quad-Cab

Tire Size: 245/70R17 Tire Inflation Pressure: 35 psi

Tread Type: Highway Odometer: 147224

Note any damage to the vehicle prior to test: \_\_\_\_\_

- Denotes accelerometer location.

NOTES: \_\_\_\_\_

Engine Type: V8

Engine CID: 4.7 Liter

Transmission Type:

Auto or  Manual  
 FWD  RWD  4WD

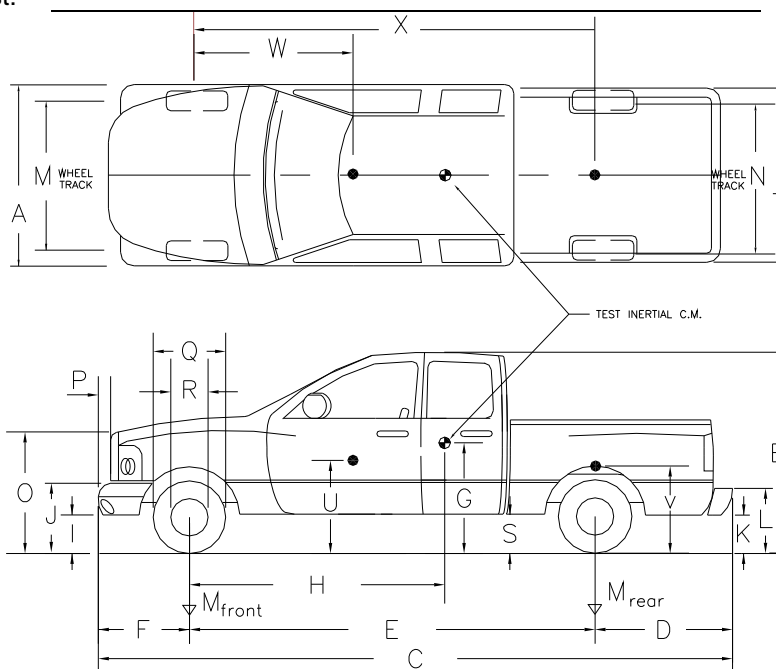
Optional Equipment: \_\_\_\_\_

Dummy Data:

Type: No dummy

Mass: \_\_\_\_\_

Seat Position: \_\_\_\_\_



**Geometry:** inches

A	<u>77.00</u>	F	<u>39.00</u>	K	<u>20.50</u>	P	<u>3.00</u>	U	<u>27.50</u>
B	<u>73.25</u>	G	<u>28.12</u>	L	<u>28.75</u>	Q	<u>29.50</u>	V	<u>34.00</u>
C	<u>227.00</u>	H	<u>63.23</u>	M	<u>68.25</u>	R	<u>18.50</u>	W	<u>59.50</u>
D	<u>47.50</u>	I	<u>13.5</u>	N	<u>67.25</u>	S	<u>14.25</u>	X	<u>140.50</u>
E	<u>140.50</u>	J	<u>26.00</u>	O	<u>44.75</u>	T	<u>75.50</u>		

Wheel Center Ht Front 14.12 Wheel Well Clearance (FR) 6.12 Frame Ht (FR) 16.62

Wheel Center Ht Rear 14.25 Wheel Well Clearance (RR) 11.25 Frame Ht (RR) 24.25

RANGE LIMIT: A=78 ±2 inches; C=237 ±13 inches; E=148 ±12 inches; F=39 ±3 inches; G = > 28 inches; H = 63 ±4 inches; O=43 ±4 inches; M+N/2=67 ±1.5 inches

GVWR Ratings:	Mass: lb	Curb	Test Inertial	Gross Static
Front <u>3650</u>	$M_{front}$	<u>2750</u>	<u>2758</u> Allowable	Allowable
Back <u>3900</u>	$M_{rear}$	<u>1949</u>	<u>2257</u> Range	Range
Total <u>6650</u>	$M_{Total}$	<u>4699</u>	<u>5015</u> 5000 ±110 lb	5000 ±110 lb

**Mass Distribution:**

lb LF: 1380 RF: 1378 LR: 1110 RR: 1147

**Figure C2. Vehicle Properties for Test No. 420020-7.**



**Table C3. Vehicle Parametric Measurements for Vertical CG for Test No. 420020-7.**

Date: 2010-07-19 Test No.: 420020-7 VIN: 1D7HA18N43525276

Year: 2003 Make: Dodge Model: Ra, 1500

Body Style: Quad Cab Mileage: 147224

Engine: 4.7 liter Transmission: Automatic

Fuel Level: Empty Ballast: 235 + 418 lb at front of bed (440 lb max)

Tire Pressure: Front: 35 psi Rear: 35 psi Size: 245/70R17

**Measured Vehicle Weights:** (lb)

LF: 1400 RF: 1334 Front Axle: 2734

LR: 1114 RR: 1122 Rear Axle: 2236

Left: 2514 Right: 2456 Total: 4970

5000 ±110 lb allowed

Wheel Base: 140.5 inches Track: F: 68.25 inches R: 67.25 inches

148 ±12 inches allowed

Track = (F+R)/2 = 67 ±1.5 inches allowed

**Center of Gravity, SAE J874 Suspension Method**

X: 63.21 in Rear of Front Axle (63 ±4 inches allowed)

Y: -0.40 in Left - Right + of Vehicle Centerline

Z: 28.125 in Above Ground (minumum 28.0 inches allowed)

Hood Height: 44.75 inches Front Bumper Height: 26.0 inches

43 ±4 inches allowed

Front Overhang: 39.0 inches Rear Bumper Height: 28.75 inches

39 ±3 inches allowed

Overall Length: 227.0 inches

237 ±13 inches allowed

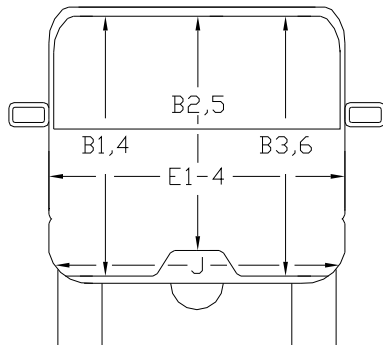
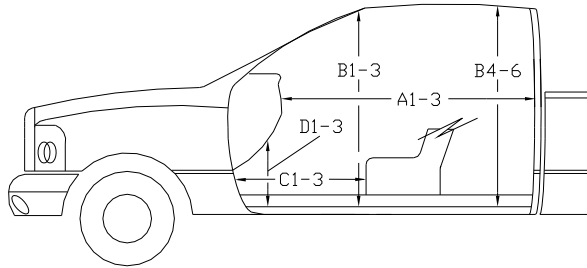
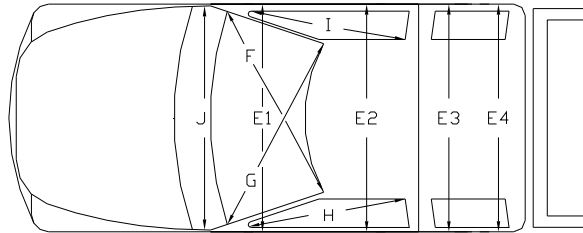


**Table C5. Occupant Compartment Measurements for Test No. 420020-7.**

Date: 2010-07-19 Test No.: 420020-7 VIN No.: 1D7HA18N43525276

Year: 2003 Make: Dodge Model: Ram 1500 Quad-Cab

**OCCUPANT COMPARTMENT DEFORMATION MEASUREMENT**



	<b>Before ( inches )</b>	<b>After ( inches )</b>
A1	64.25	64.25
A2	64.50	64.50
A3	65.25	65.25
B1	44.75	44.75
B2	39.25	39.25
B3	45.50	45.50
B4	42.12	42.12
B5	42.50	42.50
B6	42.12	42.12
C1	29.50	29.50
C2	----	----
C3	27.25	27.25
D1	12.62	12.62
D2	2.50	2.50
D3	11.50	11.50
E1	62.50	62.38
E2	64.50	64.50
E3	63.88	63.88
E4	64.00	64.00
F	60.00	60.00
G	60.00	60.00
H	39.75	39.75
I	39.75	39.75
J*	62.50	62.50

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

Date: 2010-07-21 Test No.: 420020-8 VIN No.: 1D7HA18N235509534

Year: 2003 Make: Dodge Model: Ram 1500 Quad-Cab

Tire Size: 245/70R17 Tire Inflation Pressure: 35 psi

Tread Type: Highway Odometer: 153319

Note any damage to the vehicle prior to test: \_\_\_\_\_

- Denotes accelerometer location.

NOTES: \_\_\_\_\_

Engine Type: V8

Engine CID: 4.7 Liter

Transmission Type:

Auto or  Manual  
 FWD  RWD  4WD

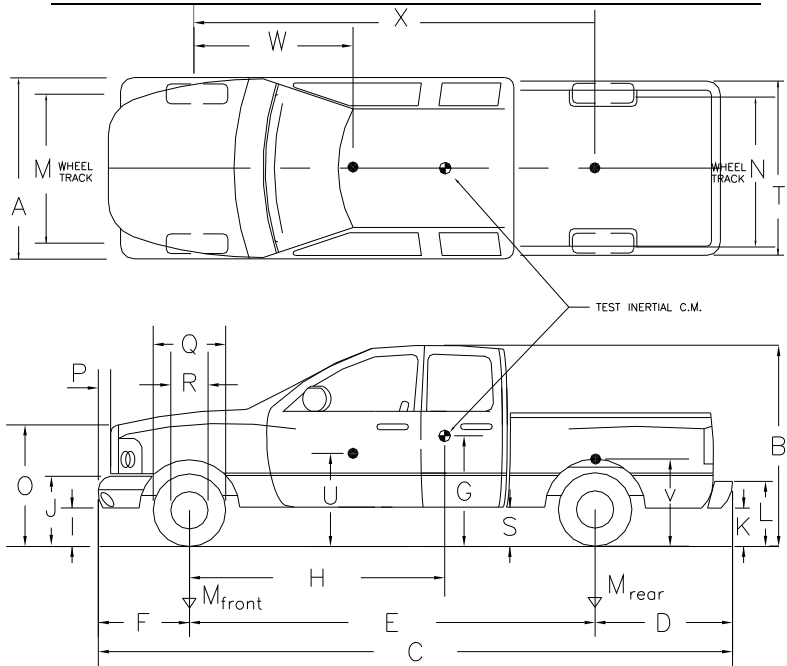
Optional Equipment: \_\_\_\_\_

Dummy Data:

Type: No dummy

Mass: \_\_\_\_\_

Seat Position: \_\_\_\_\_



**Geometry:** inches

A	<u>77.00</u>	F	<u>39.00</u>	K	<u>20.50</u>	P	<u>3.00</u>	U	<u>27.50</u>
B	<u>73.25</u>	G	<u>28.25</u>	L	<u>28.75</u>	Q	<u>29.50</u>	V	<u>34.00</u>
C	<u>227.00</u>	H	<u>62.34</u>	M	<u>68.25</u>	R	<u>18.50</u>	W	<u>59.50</u>
D	<u>47.50</u>	I	<u>13.5</u>	N	<u>67.25</u>	S	<u>14.25</u>	X	<u>140.50</u>
E	<u>140.50</u>	J	<u>26.00</u>	O	<u>44.75</u>	T	<u>75.50</u>		

Wheel Center Ht Front 14.12 Wheel Well Clearance (FR) 6.12 Frame Ht (FR) 16.62

Wheel Center Ht Rear 14.25 Wheel Well Clearance (RR) 11.25 Frame Ht (RR) 24.25

RANGE LIMIT: A=78 ±2 inches; C=237 ±13 inches; E=148 ±12 inches; F=39 ±3 inches; G = > 28 inches; H = 63 ±4 inches; O=43 ±4 inches; M+N/2=67 ±1.5 inches

GVWR Ratings:	Mass: lb	Curb	Test Inertial	Gross Static
Front <u>3650</u>	$M_{front}$ <u>2769</u>	<u>2769</u>	<u>2786</u> Allowable	Allowable
Back <u>3900</u>	$M_{rear}$ <u>1994</u>	<u>1994</u>	<u>2222</u> Range	Range
Total <u>6650</u>	$M_{Total}$ <u>4763</u>	<u>4763</u>	<u>5008</u> 5000 ±110 lb	5000 ±110 lb

**Mass Distribution:**

lb LF: 1420 RF: 1366 LR: 1110 RR: 1112

**Figure C3. Vehicle Properties for Test No. 420020-8.**

**Table C6. Vehicle Parametric Measurements for Vertical CG for Test No. 420020-7.**

Date: 2010-07-21 Test No.: 420020-8 VIN: 1D7HA18N235509534

Year: 2003 Make: Dodge Model: Ram 1500

Body Style: Quad Cab Mileage: 153319

Engine: 4.7 liter Transmission: Automatic

Fuel Level: Empty Ballast: 255 + 315 lb at front of bed (440 lb max)

Tire Pressure: Front: \_\_\_\_\_ psi Rear: \_\_\_\_\_ psi Size: \_\_\_\_\_

**Measured Vehicle Weights:** (lb)

LF: 1408 RF: 1368 Front Axle: 2776

LR: 1132 RR: 1132 Rear Axle: 2264

Left: 2540 Right: 2500 Total: 5040

5000 ±110 lb allowed

Wheel Base: 140.5 inches Track: F: 68.25 inches R: 67.25 inches

148 ±12 inches allowed

Track = (F+R)/2 = 67 ±1.5 inches allowed

**Center of Gravity, SAE J874 Suspension Method**

X: 63.11 in Rear of Front Axle (63 ±4 inches allowed)

Y: -0.27 in Left - Right + of Vehicle Centerline

Z: 28.25 in Above Ground (minumum 28.0 inches allowed)

Hood Height: 44.75 inches Front Bumper Height: 26.0 inches

43 ±4 inches allowed

Front Overhang: 39.0 inches Rear Bumper Height: 28.75 inches

39 ±3 inches allowed

Overall Length: 227.0 inches

237 ±13 inches allowed

**Table C7. Exterior Crush Measurements for Test No. 420020-8.**

Date: 2010-07-19 Test No.: 420020-7 VIN No.: 1D7HA18N43525276  
 Year: 2003 Make: Dodge Model: Ram 1500 Quad-Cab

**VEHICLE CRUSH MEASUREMENT SHEET<sup>1</sup>**

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

Note: Measure C<sub>1</sub> to C<sub>6</sub> 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 <sub>1</sub>	C <sub>2</sub>	C <sub>3</sub>	C <sub>4</sub>	C <sub>5</sub>	C <sub>6</sub>	±D
		Width** (CDC)	Max*** Crush								
1	Front plane at bumper ht	20	18	27	0	1	3.5	7	12	18	+13.5
2	Side plane at bumper ht	20	19	67	0	5	9	13	15	19	+56
	Measurements recorded										
	<b>in inches mm</b>										

<sup>1</sup>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.

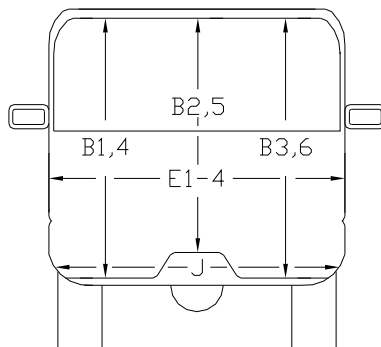
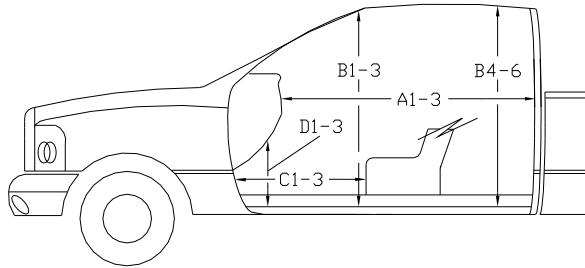
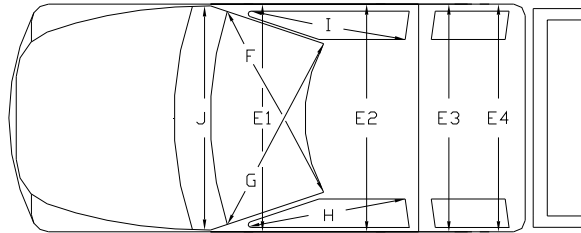
Note: Use as many lines/columns as necessary to describe each damage profile.

**Table C8. Occupant Compartment Measurements for Test No. 420020-8.**

Date: 2010-07-19 Test No.: 420020-7 VIN No.: 1D7HA18N43525276

Year: 2003 Make: Dodge Model: Ram 1500 Quad-Cab

**OCCUPANT COMPARTMENT DEFORMATION MEASUREMENT**



	<b>Before ( inches )</b>	<b>After ( inches )</b>
A1	64.25	64.50
A2	64.75	64.50
A3	65.25	64.75
B1	45.50	44.50
B2	39.12	38.25
B3	45.50	46.00
B4	42.12	42.12
B5	42.50	42.50
B6	42.12	42.12
C1	29.12	29.12
C2	----	----
C3	26.25	21.00
D1	12.75	12.75
D2	2.50	2.25
D3	11.75	10.75
E1	62.62	63.00
E2	64.25	65.12
E3	64.00	64.12
E4	64.00	64.00
F	39.50	39.50
G	39.50	39.50
H	60.00	59.00
I	60.00	60.25
J*	62.00	60.00

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





## APPENDIX D. SEQUENTIAL PHOTOGRAPHS



0.000 s



0.071 s



0.140 s



0.211 s



**Figure D1. Sequential Photographs for Test No. 420020-6 (Overhead and Frontal Views).**



0.280s



0.351 s



0.420 s



0.491 s



**Figure D1. Sequential Photographs for Test No. 420020-6 (Overhead and Frontal Views) (Continued).**



0.000 s



0.280 s



0.071 s



0.351 s



0.140 s



0.420 s



0.294 s



2.303 s

**Figure D2. Sequential Photographs for Test No. 420020-6  
(Rear View).**



0.000 s



0.071 s



0.140 s



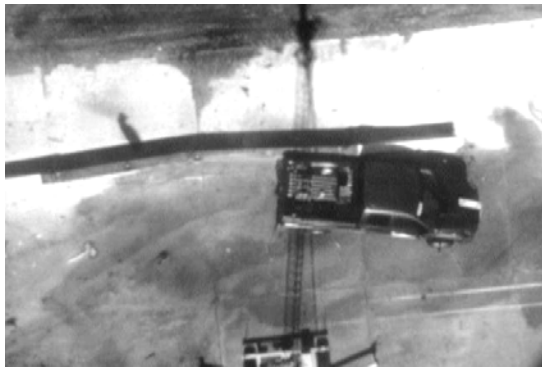
0.211 s



**Figure D3. Sequential Photographs for Test No. 420020-7  
(Overhead and Frontal Views).**



0.280 s



0.351 s



0.419 s



0.490 s



**Figure D3. Sequential Photographs for Test No. 420020-7  
(Overhead and Frontal Views) (Continued).**



0.000 s



0.280 s



0.071 s



0.351 s



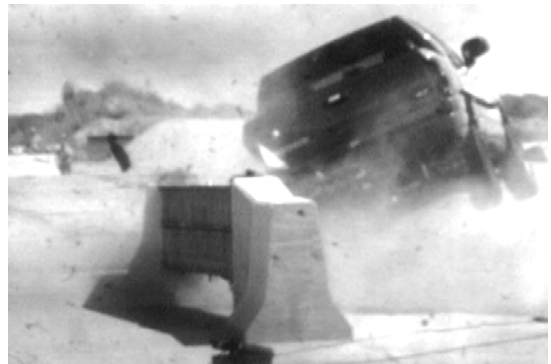
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0.419 s

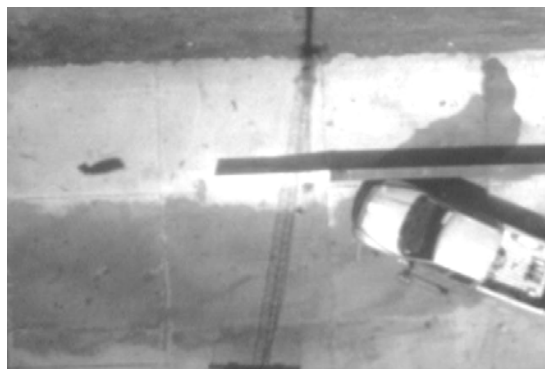


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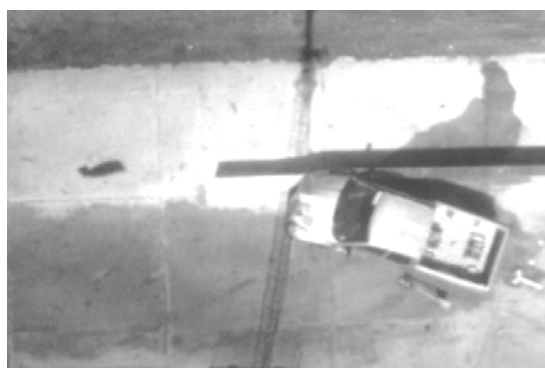


0.490 s

**Figure D4. Sequential Photographs for Test No. 420020-7  
(Rear View).**



0.000 s



0.071 s



0.140 s



0.211 s



**Figure D5. Sequential Photographs for Test No. 420020-8 (Overhead and Frontal Views).**



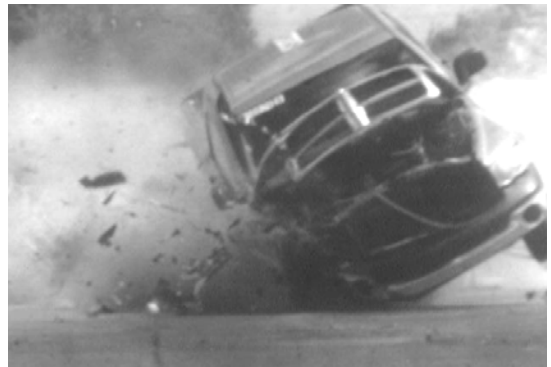
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0.351 s



0.420 s



0.490 s



**Figure D5. Sequential Photographs for Test No. 420020-8  
(Overhead and Frontal Views) (Continued).**





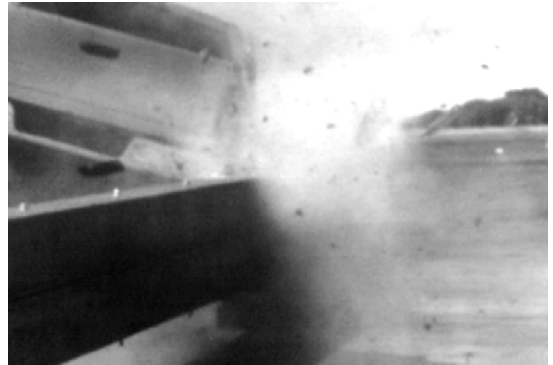
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0.280 s



0.071 s



0.351 s



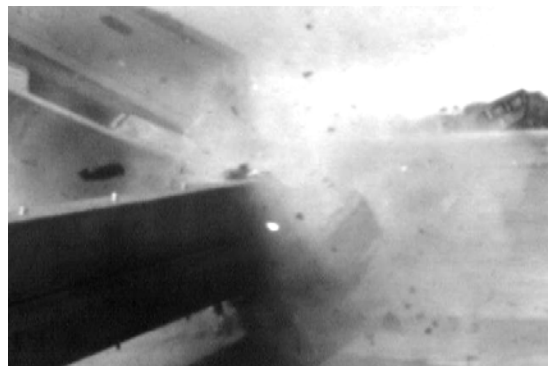
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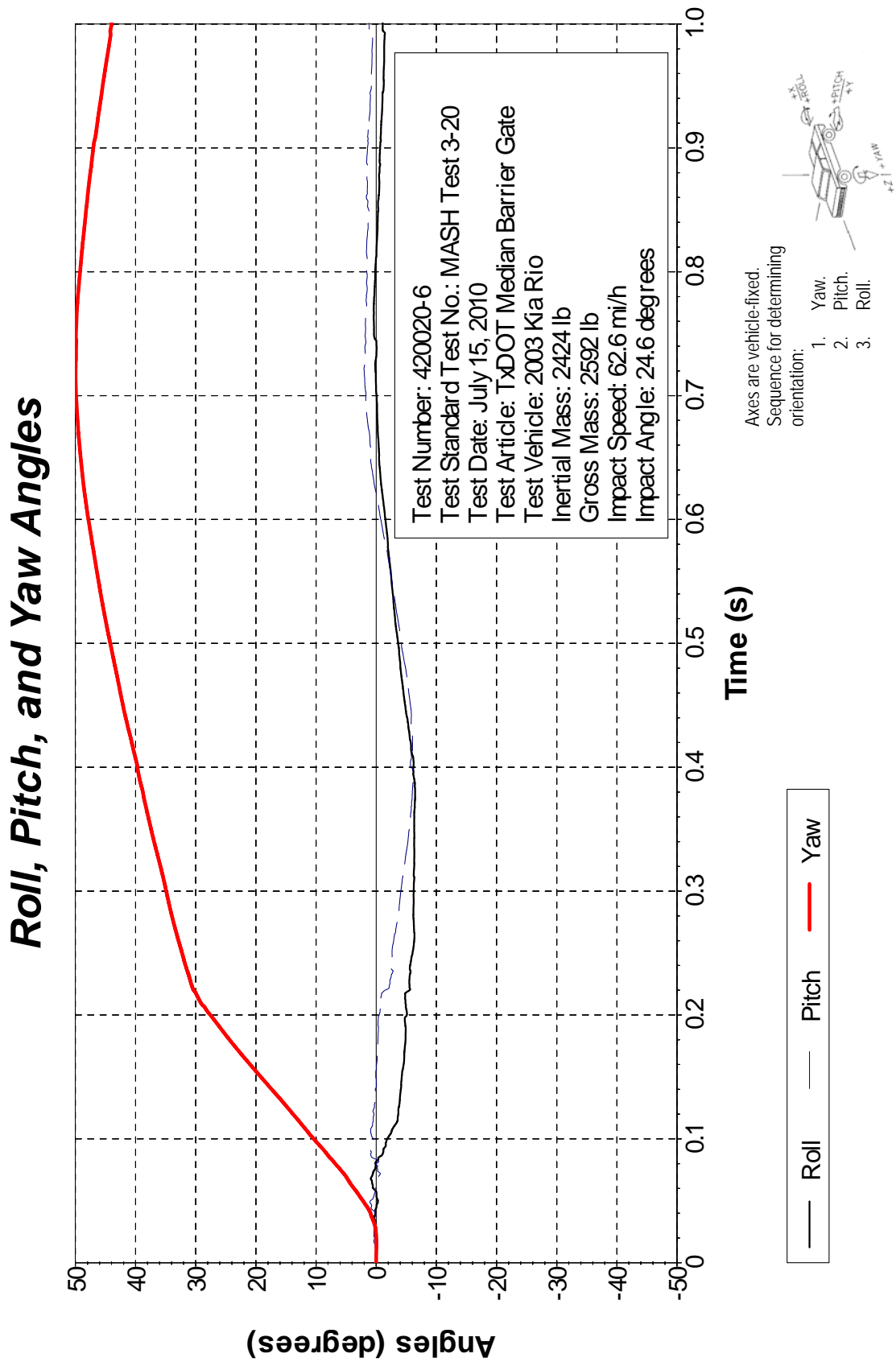


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**Figure D6. Sequential Photographs for Test No. 420020-8  
(Rear View).**

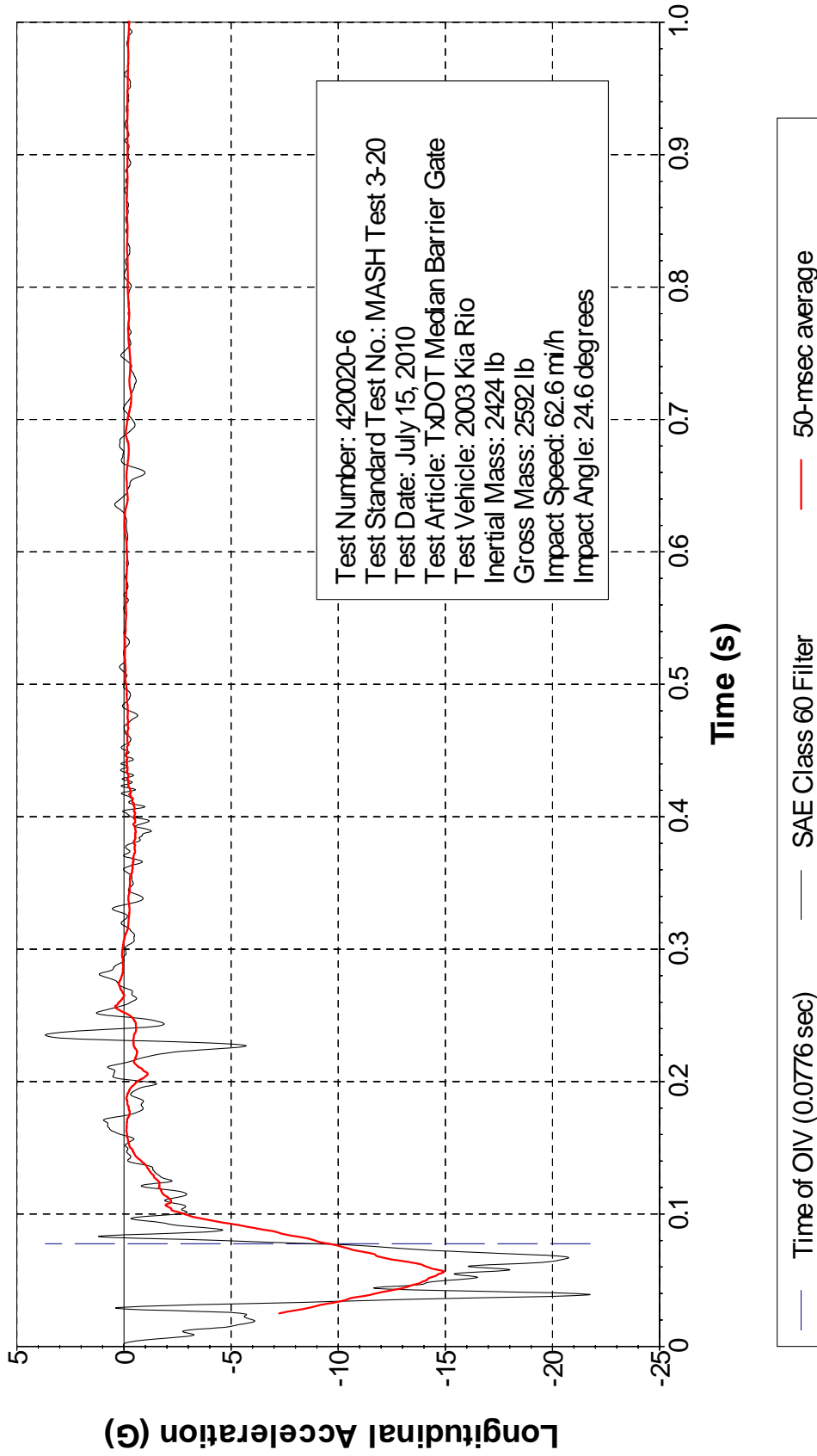


**APPENDIX E. VEHICLE ANGULAR DISPLACEMENTS  
AND ACCELERATIONS**



**Figure E1. Vehicle Angular Displacements for Test No. 420020-6.**

# X Acceleration at CG



**Figure E2. Vehicle Longitudinal Accelerometer Trace for Test No. 420020-6 (Accelerometer Located at Center of Gravity).**

# Y Acceleration at CG

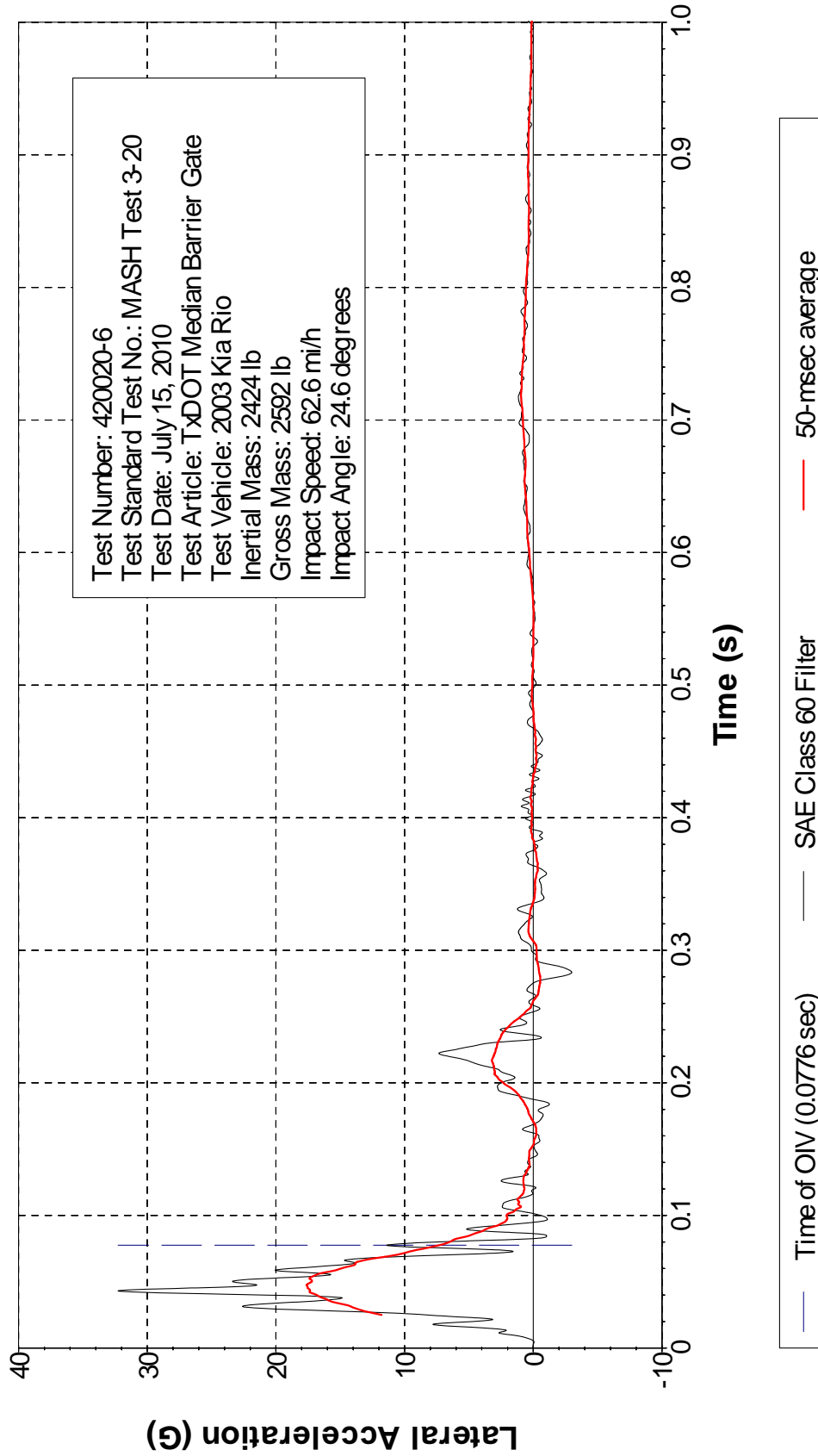


Figure E3. Vehicle Lateral Accelerometer Trace for Test No. 420020-6 (Accelerometer Located at Center of Gravity).

# Z Acceleration at CG

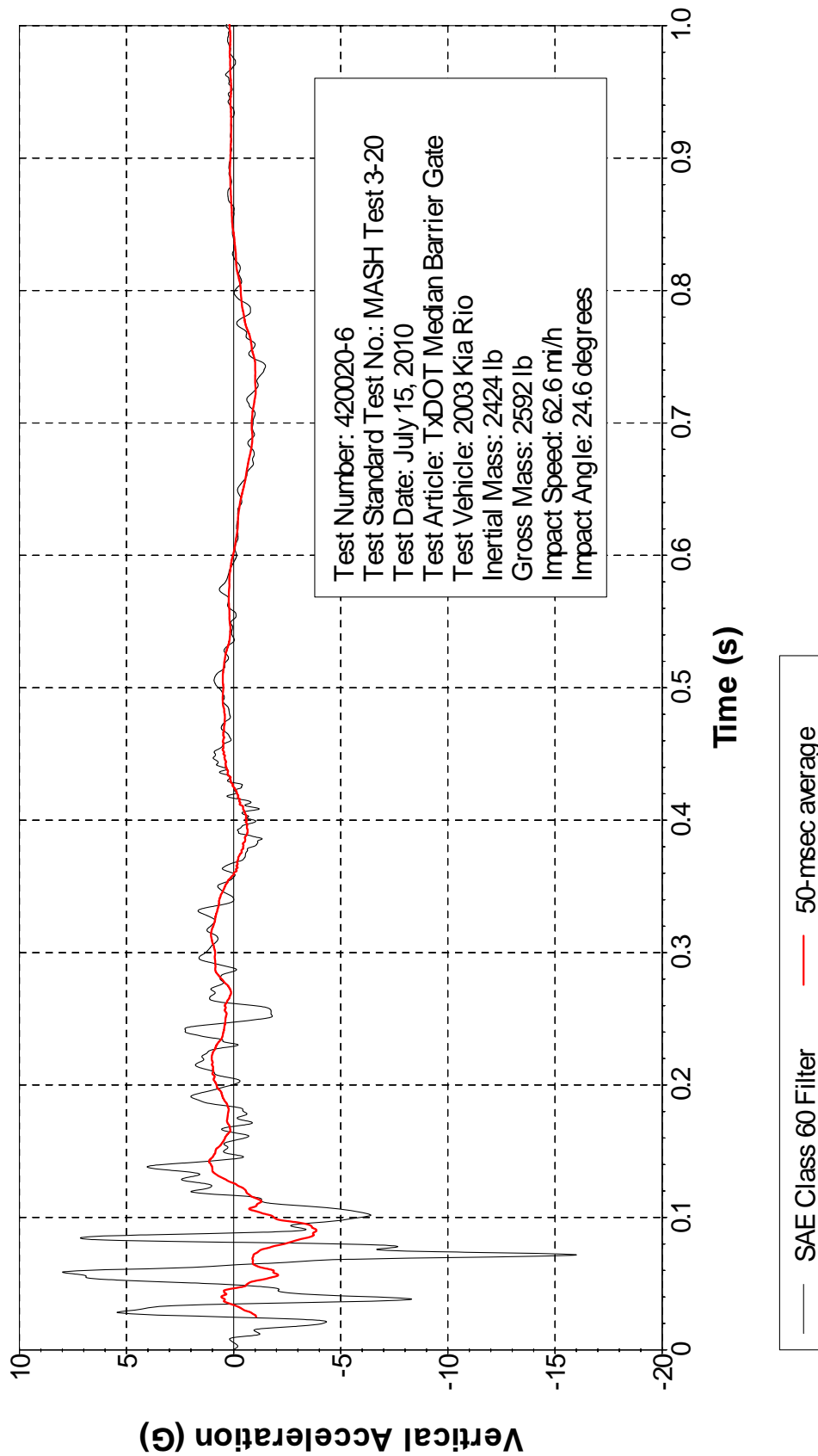


Figure E4. Vehicle Vertical Accelerometer Trace for Test No. 420020-6 (Accelerometer Located at Center of Gravity).

# X Acceleration over Rear Axle

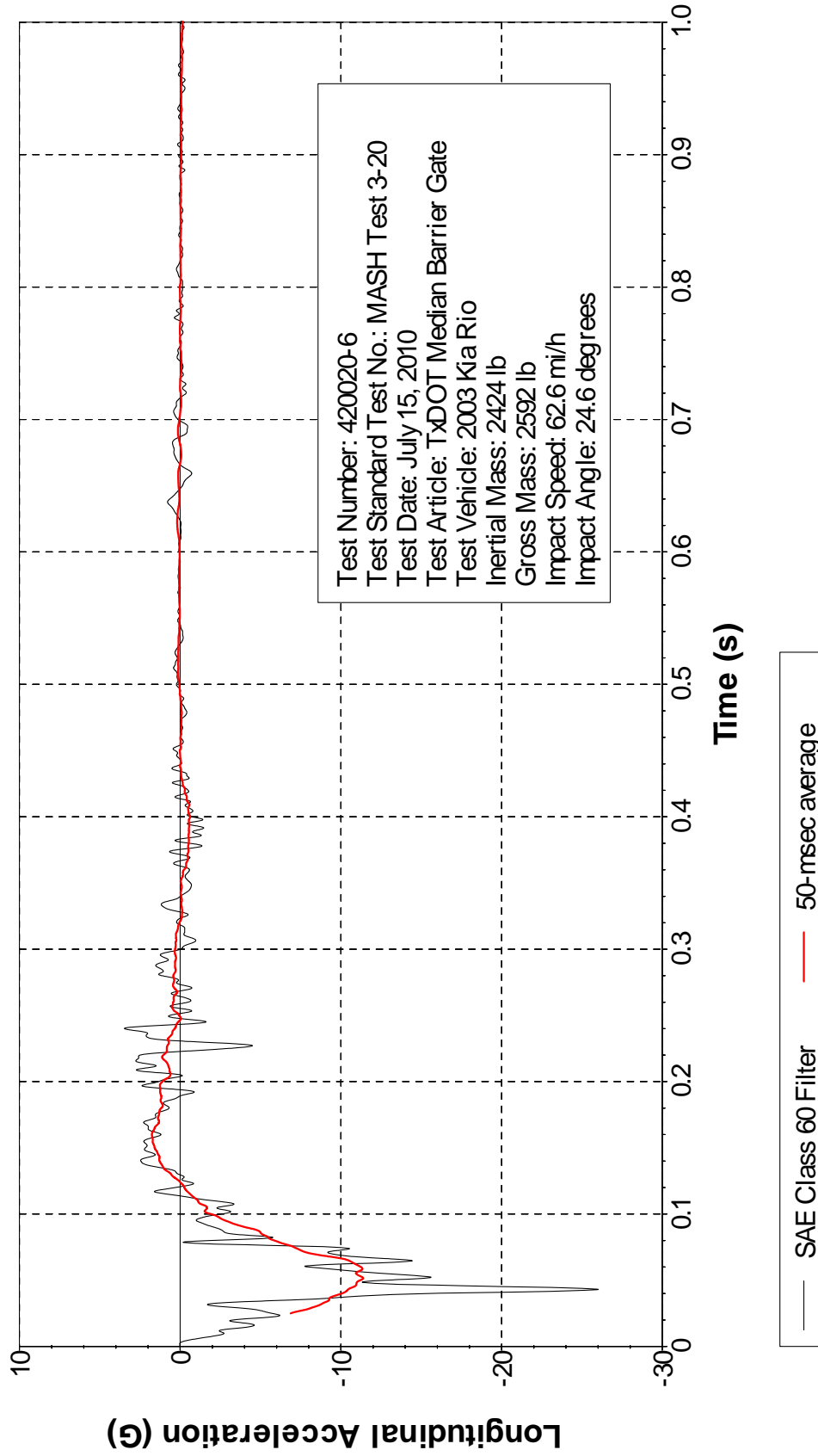


Figure E5. Vehicle Longitudinal Accelerometer Trace for Test No. 420020-6 (Accelerometer Located over Rear Axle).

# Y Acceleration over Rear Axle

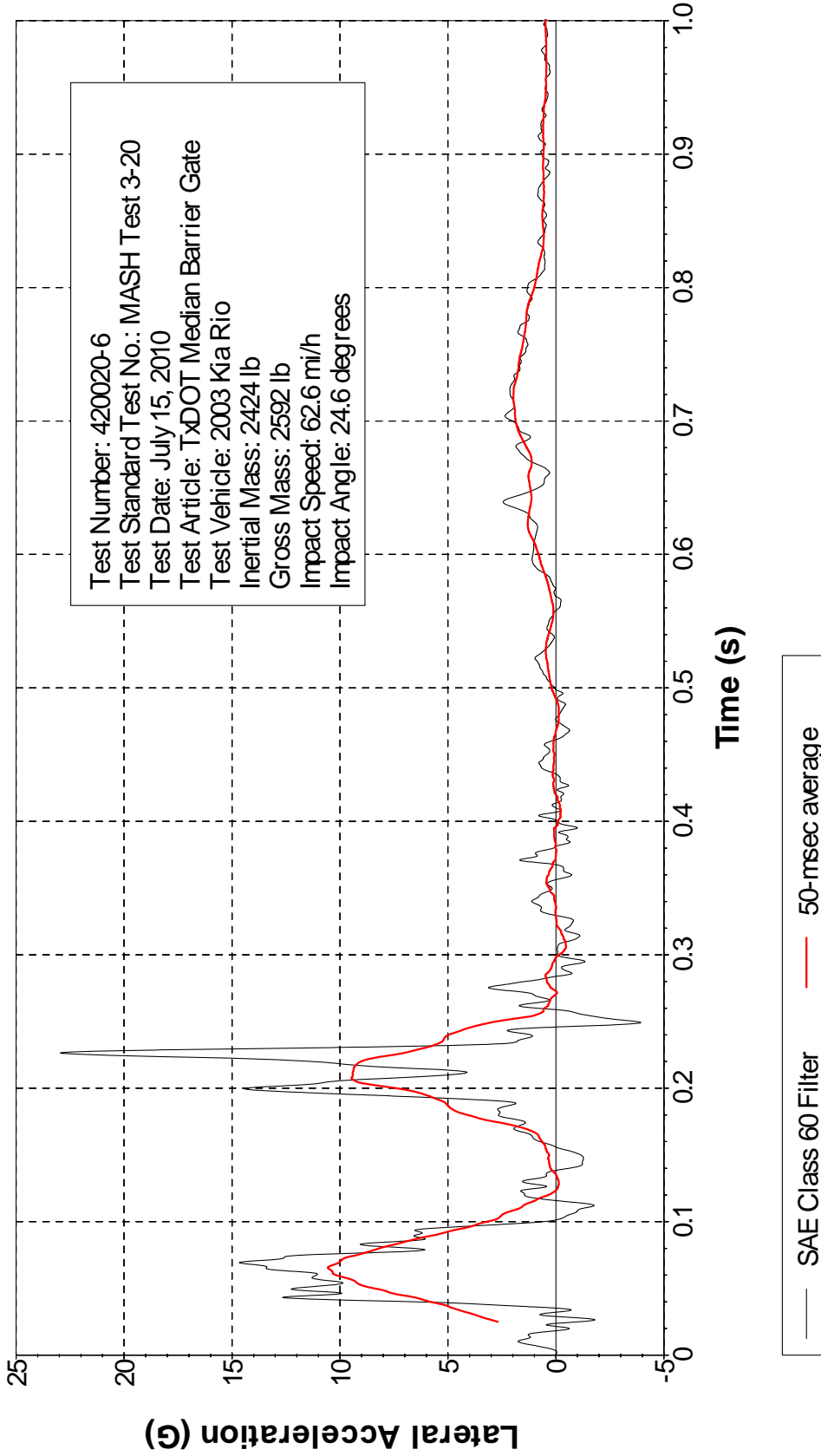
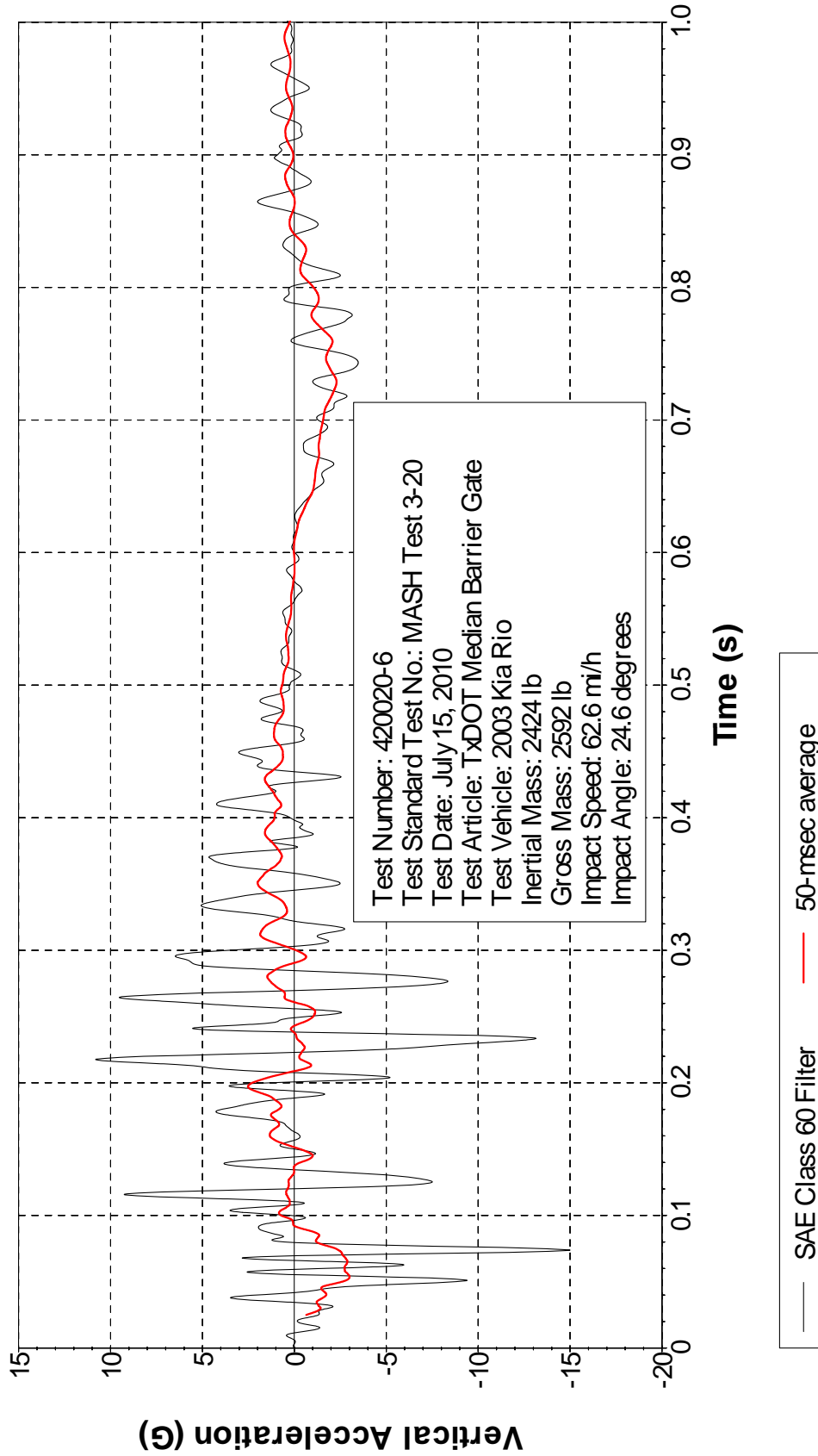


Figure E6. Vehicle Lateral Accelerometer Trace for Test No. 420020-6  
(Accelerometer Located over Rear Axle).



# Z Acceleration over Rear Axle



**Figure E7. Vehicle Vertical Accelerometer Trace for Test No. 420020-6 (Accelerometer Located over Rear Axle).**

# Roll, Pitch, and Yaw Angles

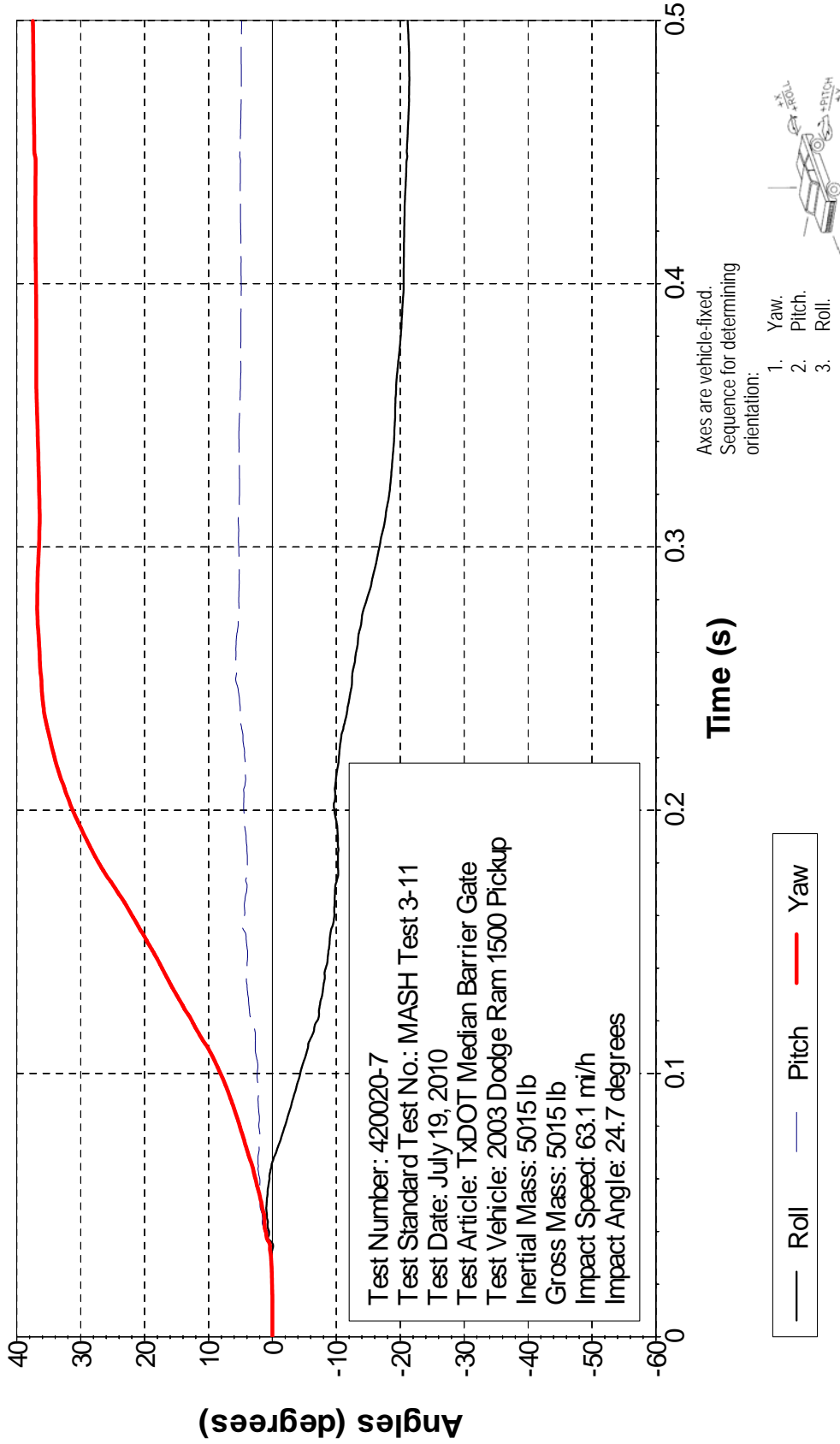
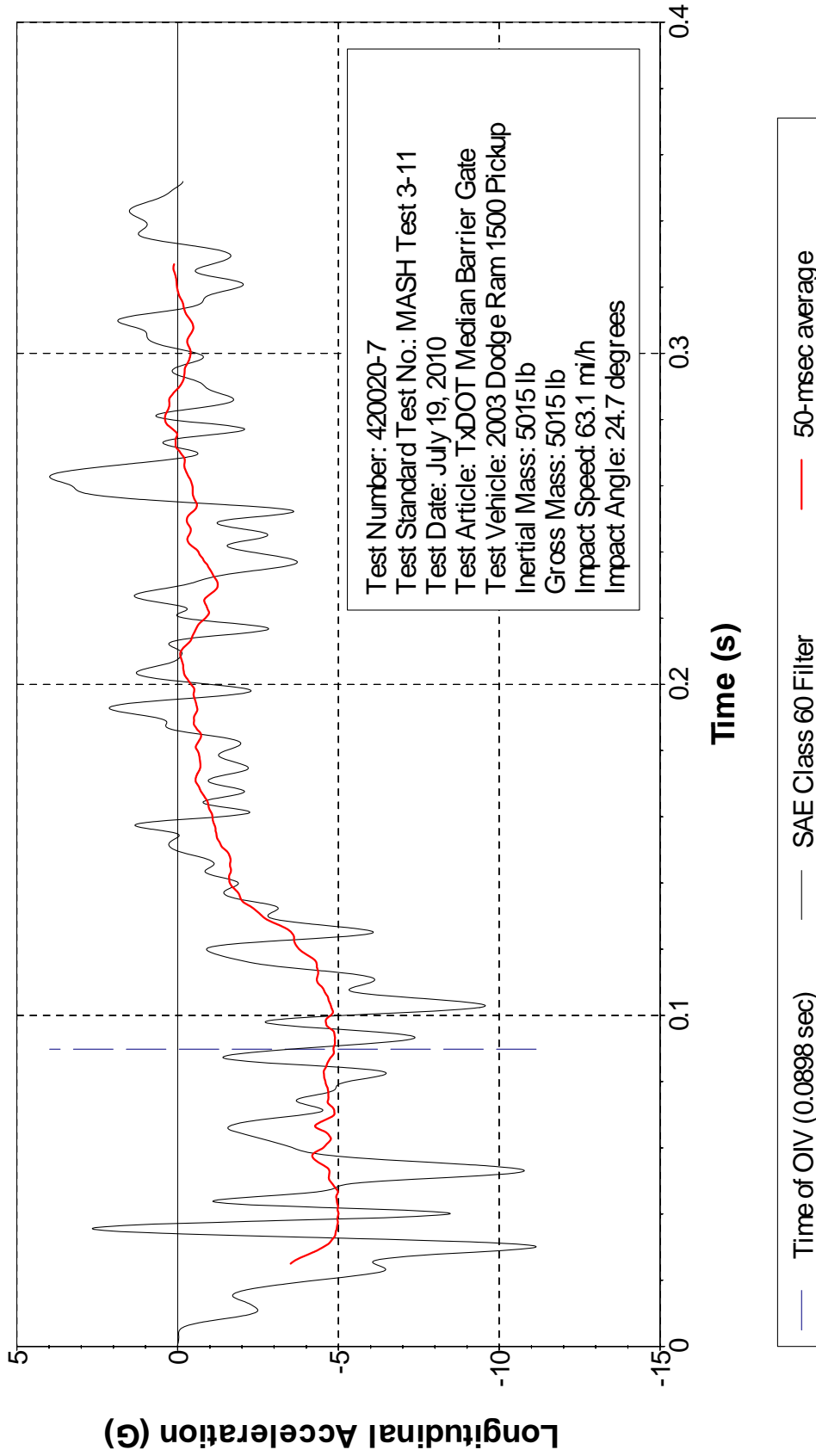


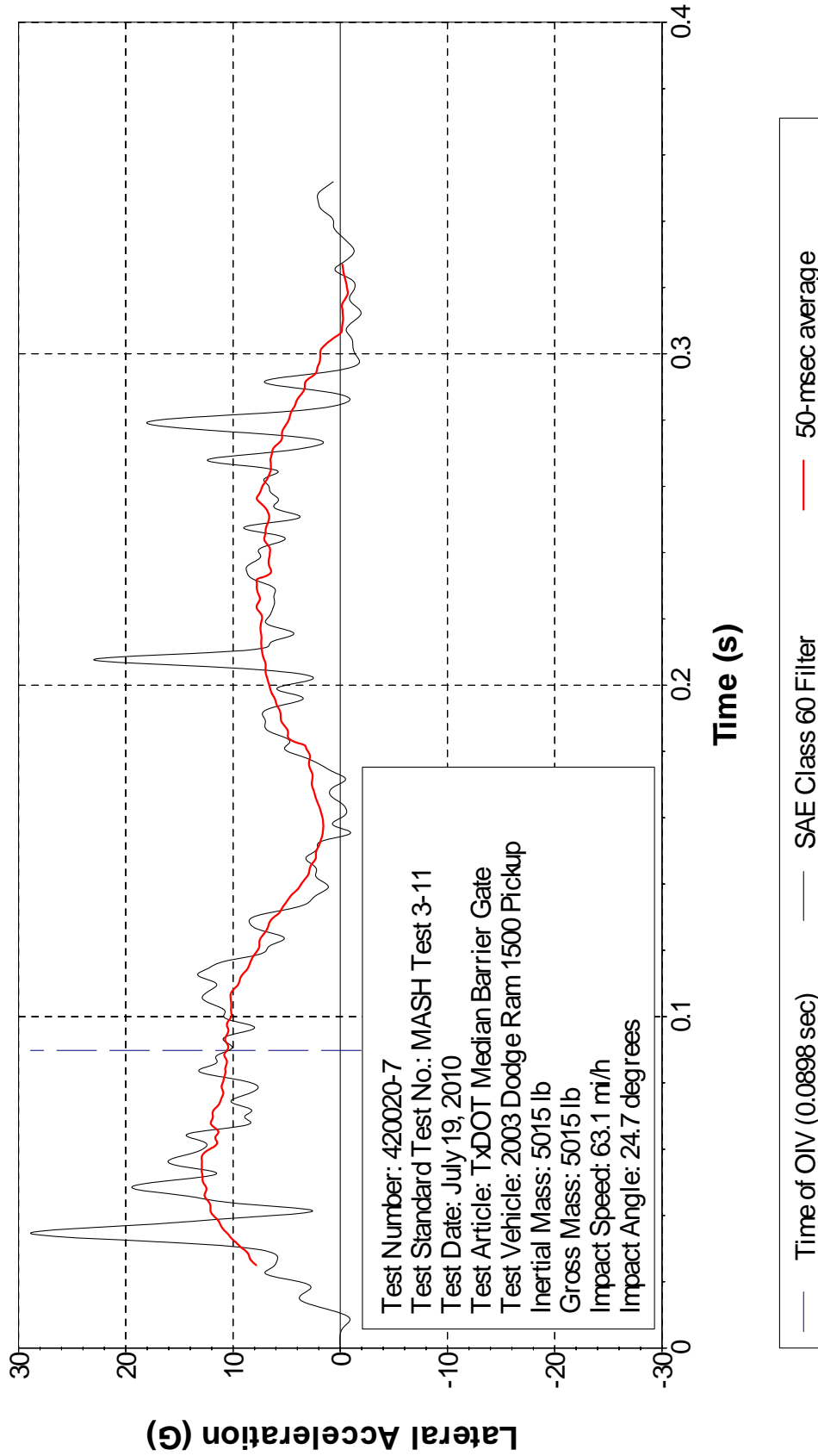
Figure E8. Vehicle Angular Displacements for Test No. 420020-7.

# X Acceleration at CG



**Figure E9. Vehicle Longitudinal Accelerometer Trace for Test No. 420020-7 (Accelerometer Located at Center of Gravity).**

# Y Acceleration at CG



**Figure E10. Vehicle Lateral Accelerometer Trace for Test No. 420020-7 (Accelerometer Located at Center of Gravity).**

# Z Acceleration at CG

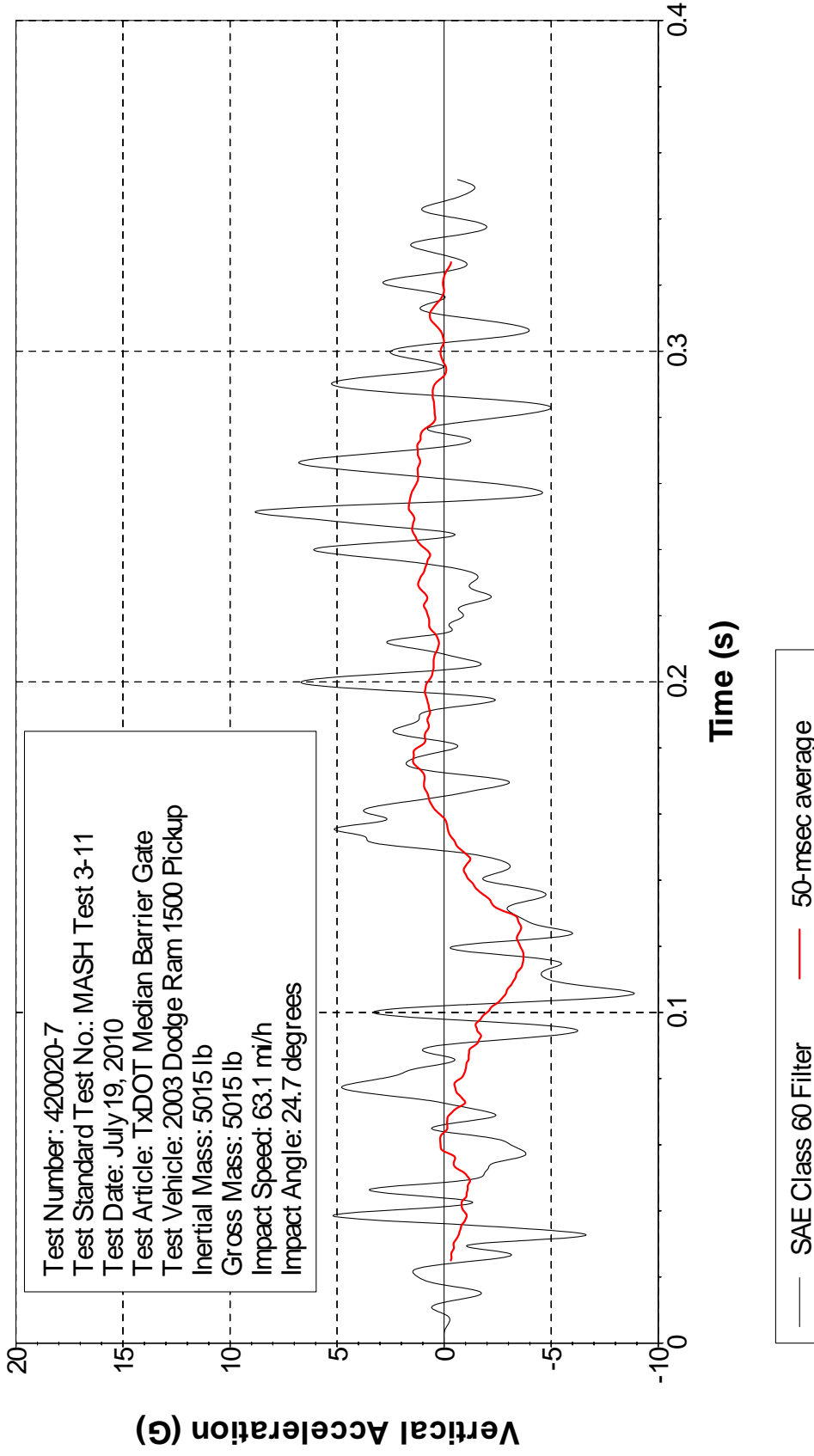


Figure E11. Vehicle Vertical Accelerometer Trace for Test No. 420020-7 (Accelerometer Located at Center of Gravity).

# X Acceleration over Rear Axle

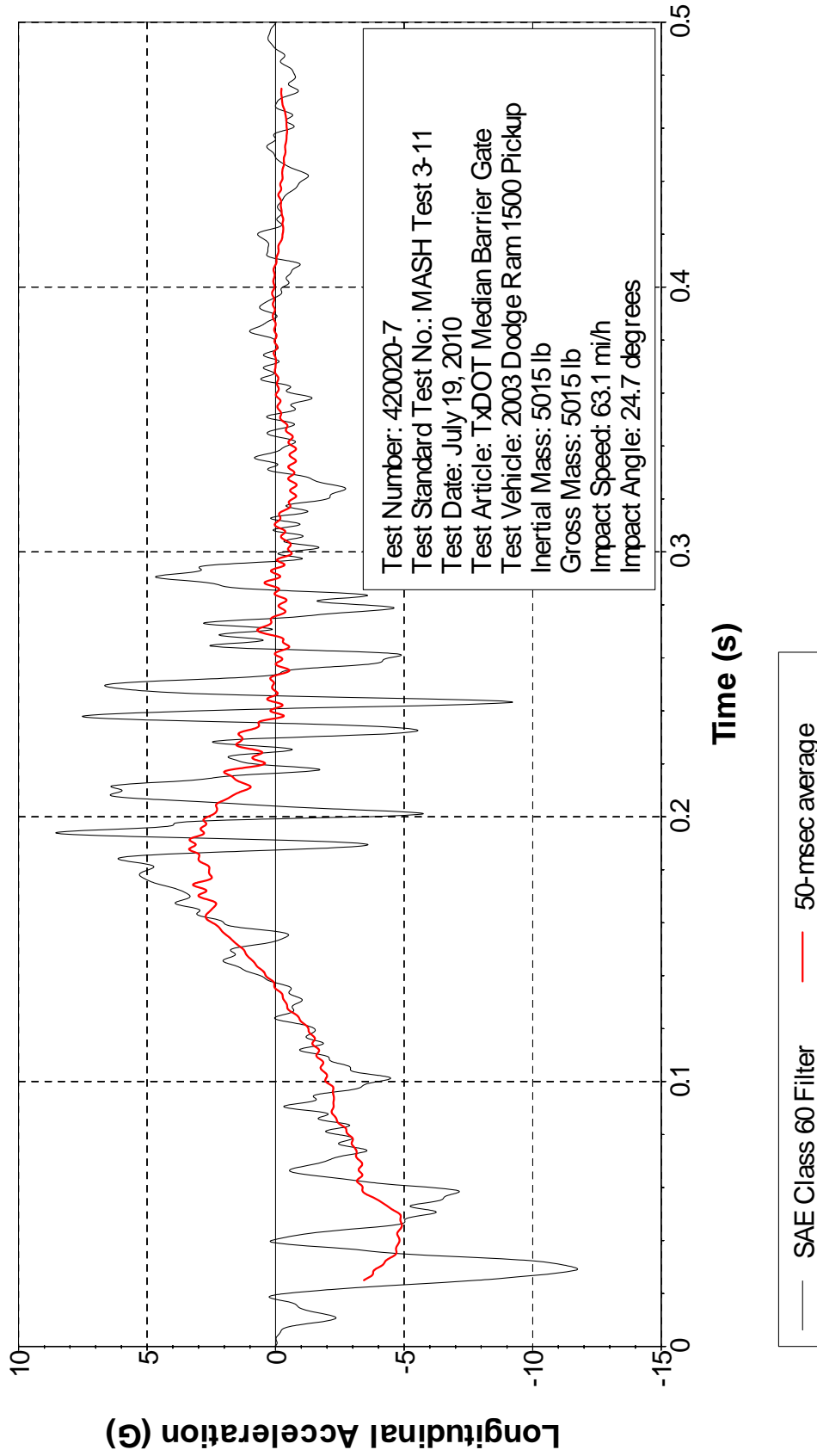


Figure E12. Vehicle Longitudinal Accelerometer Trace for Test No. 420020-7 (Accelerometer Located over Rear Axle).

# Y Acceleration over Rear Axle

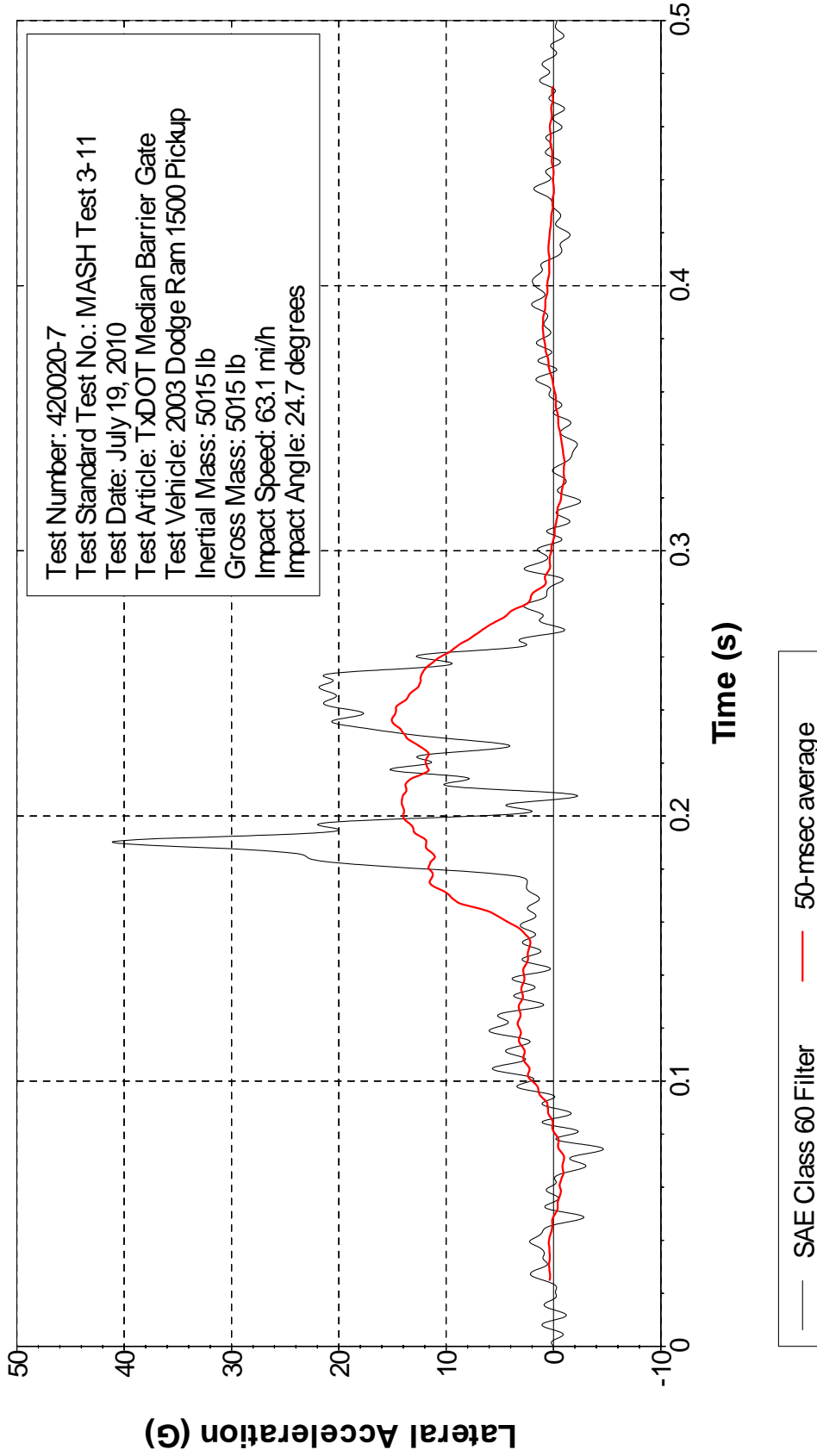


Figure E13. Vehicle Lateral Accelerometer Trace for Test No. 420020-7 (Accelerometer Located over Rear Axle).

# Z Acceleration over Rear Axle

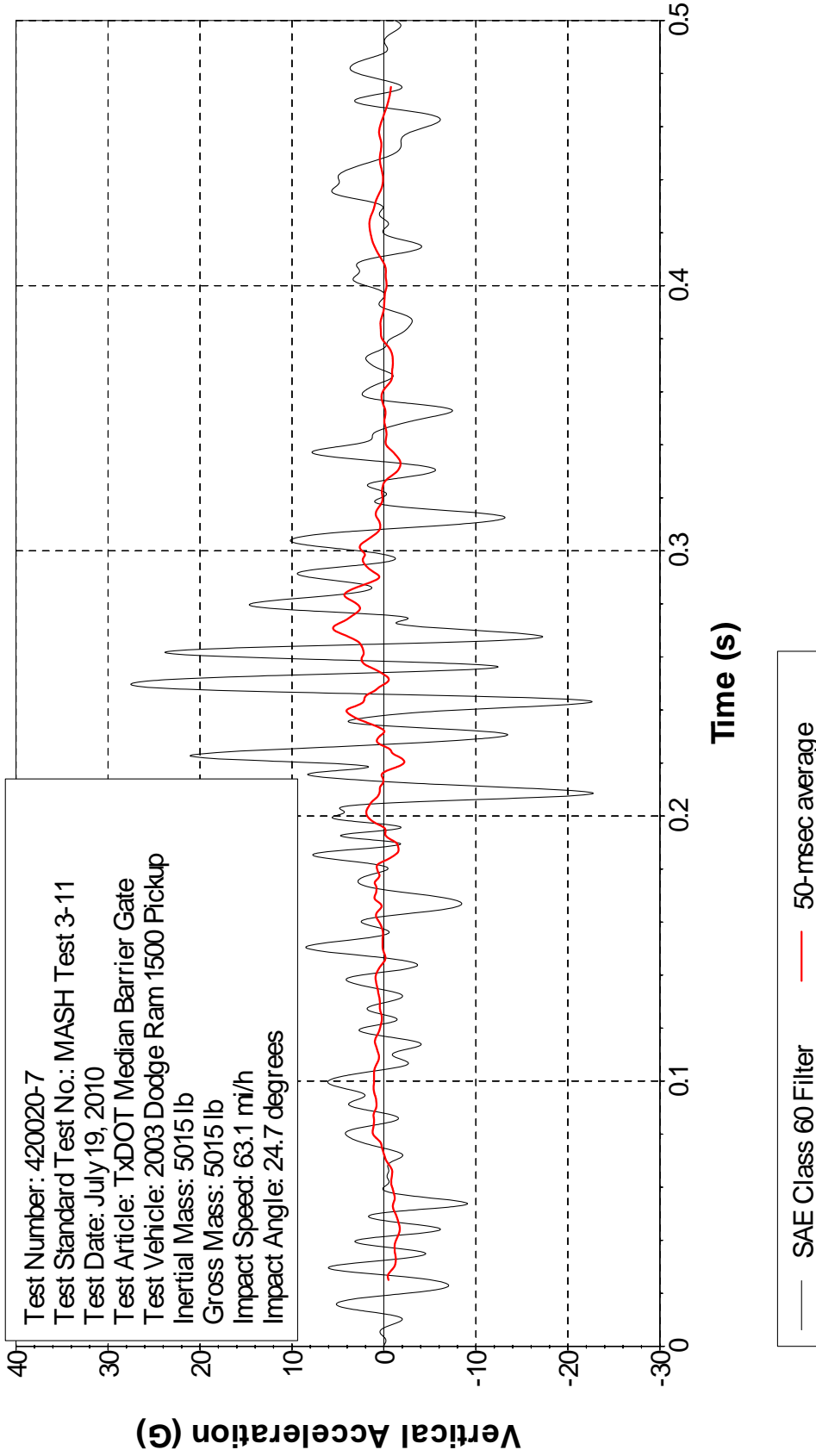
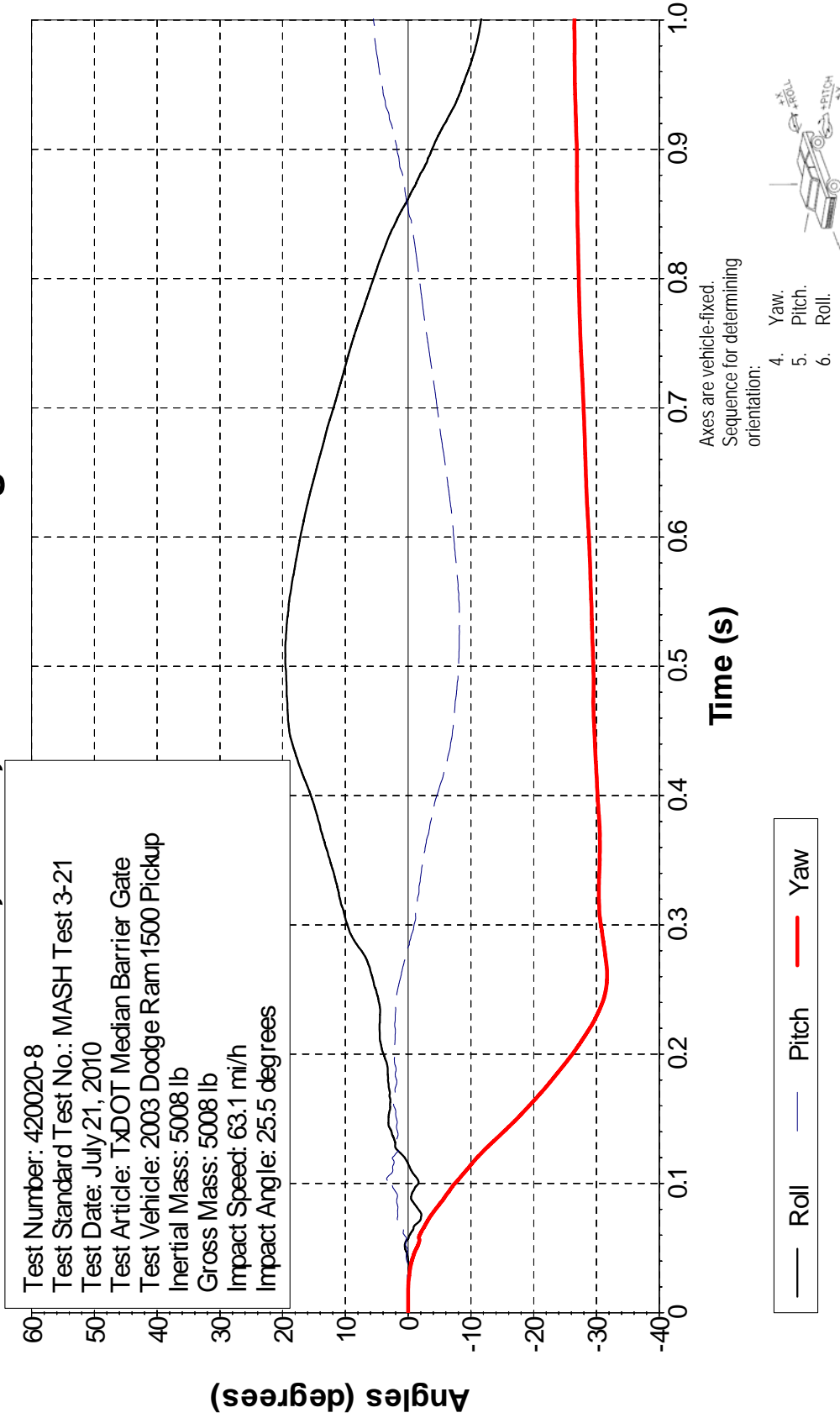


Figure E14. Vehicle Vertical Accelerometer Trace for Test No. 420020-7 (Accelerometer Located over Rear Axle).



# Roll, Pitch, and Yaw Angles



**Figure E15. Vehicle Angular Displacements for Test No. 420020-8.**

# X Acceleration at CG

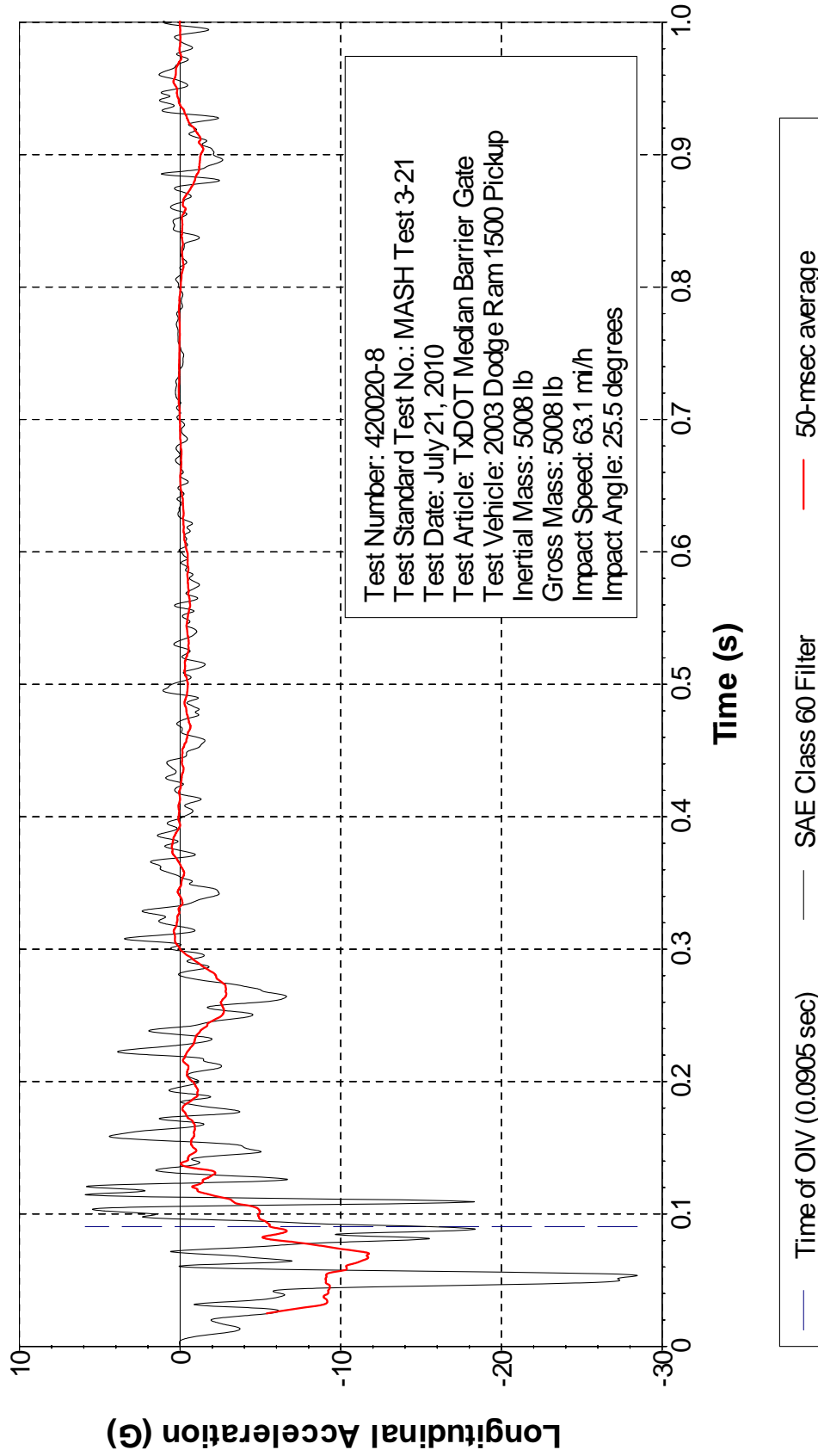
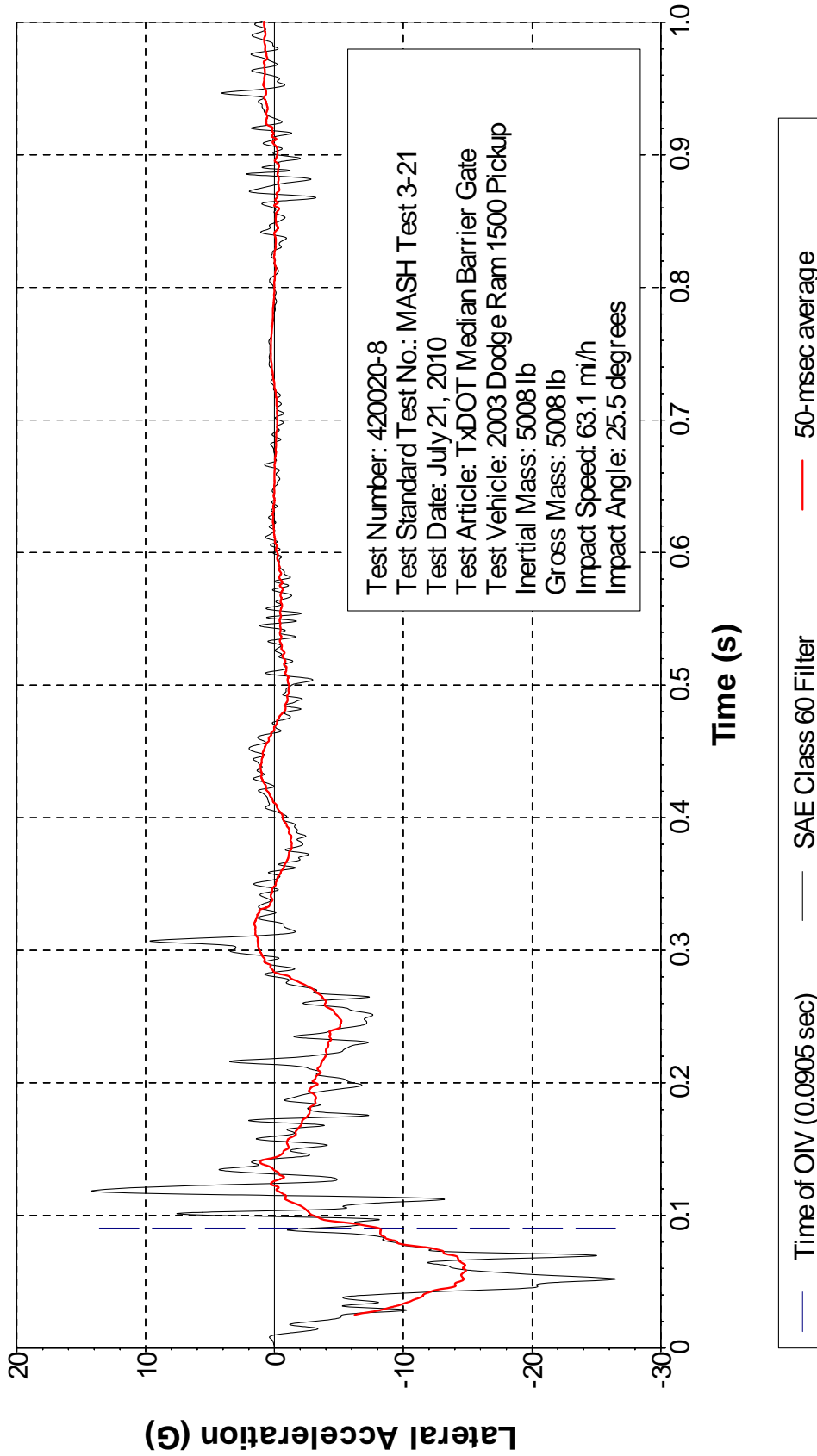


Figure E16. Vehicle Longitudinal Accelerometer Trace for Test No. 420020-8 (Accelerometer Located at Center of Gravity).

# Y Acceleration at CG



**Figure E17. Vehicle Lateral Accelerometer Trace for Test No. 420020-8 (Accelerometer Located at Center of Gravity).**

# Z Acceleration at CG

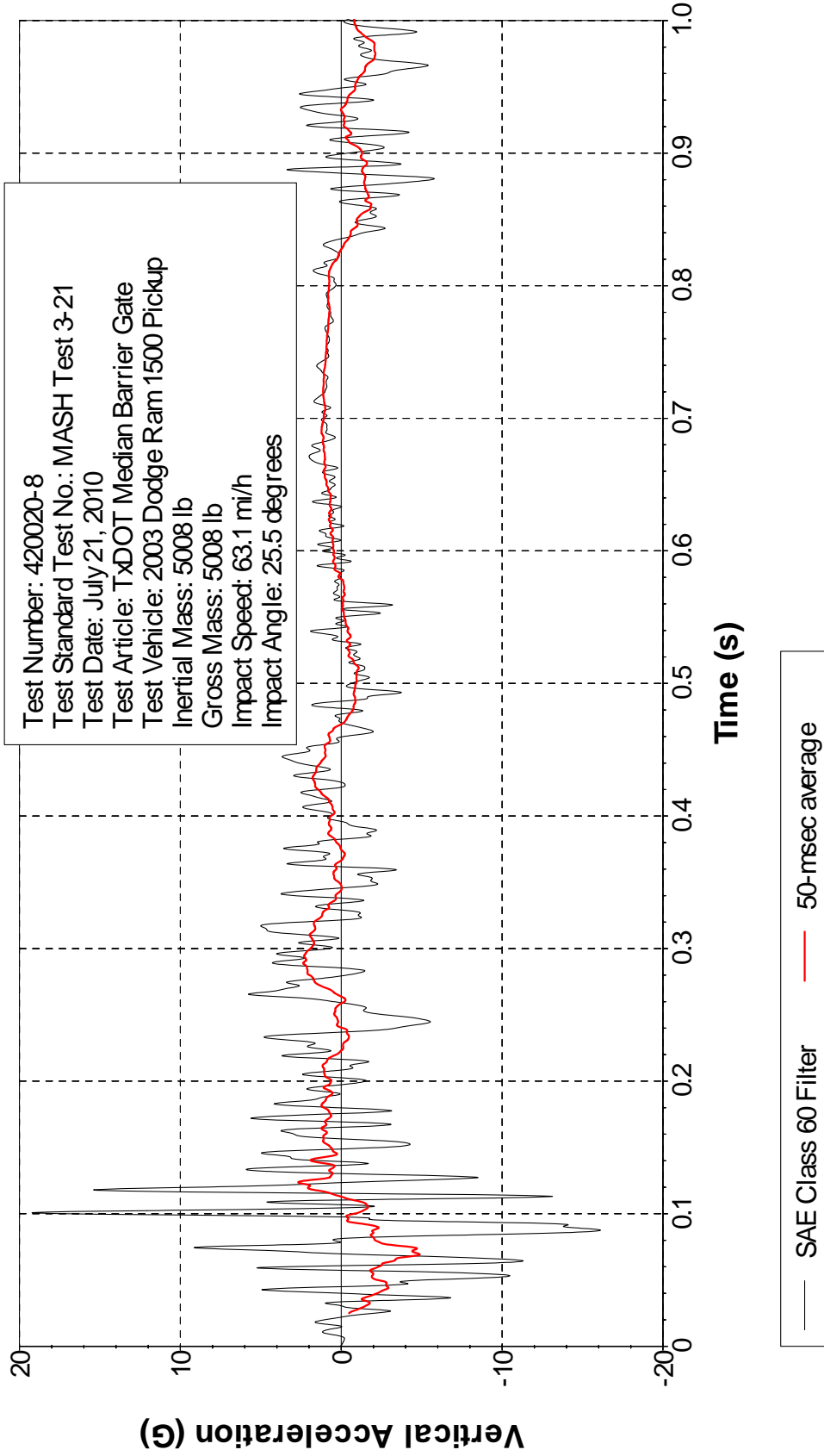


Figure E18. Vehicle Vertical Accelerometer Trace for Test No. 420020-8 (Accelerometer Located at Center of Gravity).

# X Acceleration over Rear Axle

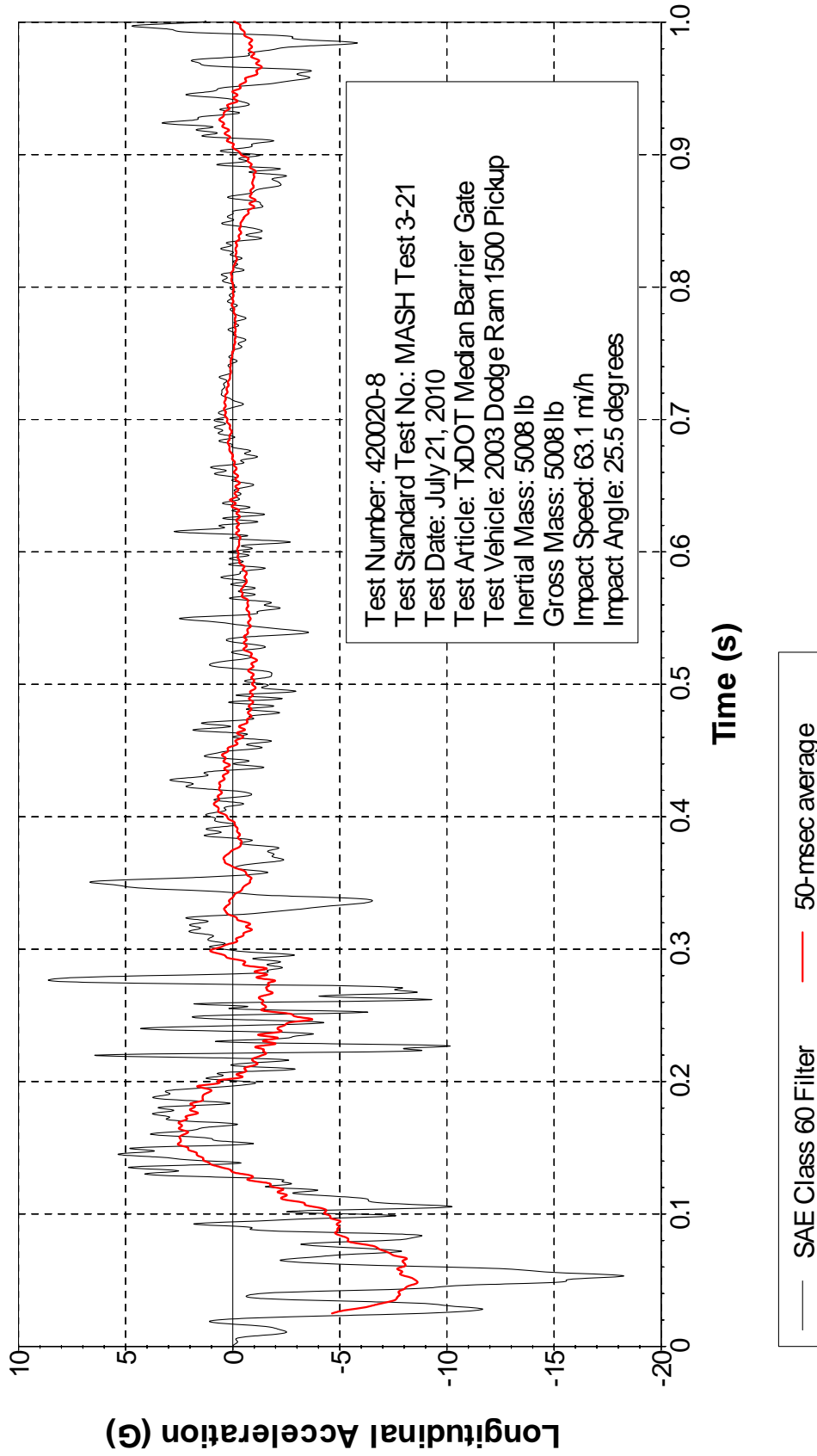


Figure E19. Vehicle Longitudinal Accelerometer Trace for Test No. 420020-8 (Accelerometer Located over Rear Axle).

# Y Acceleration over Rear Axle

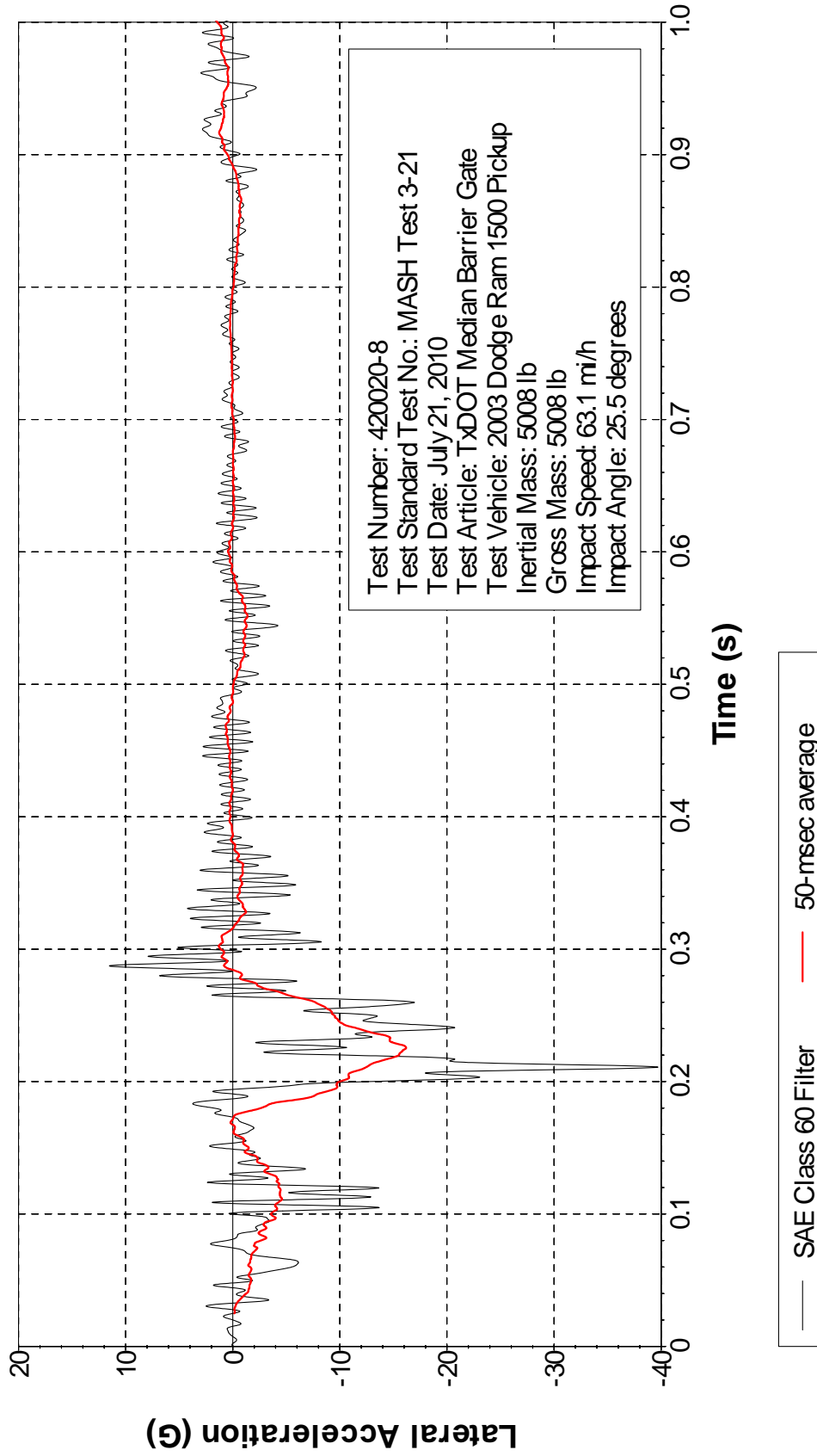


Figure E20. Vehicle Lateral Accelerometer Trace for Test No. 420020-8 (Accelerometer Located over Rear Axle).

# Z Acceleration over Rear Axle

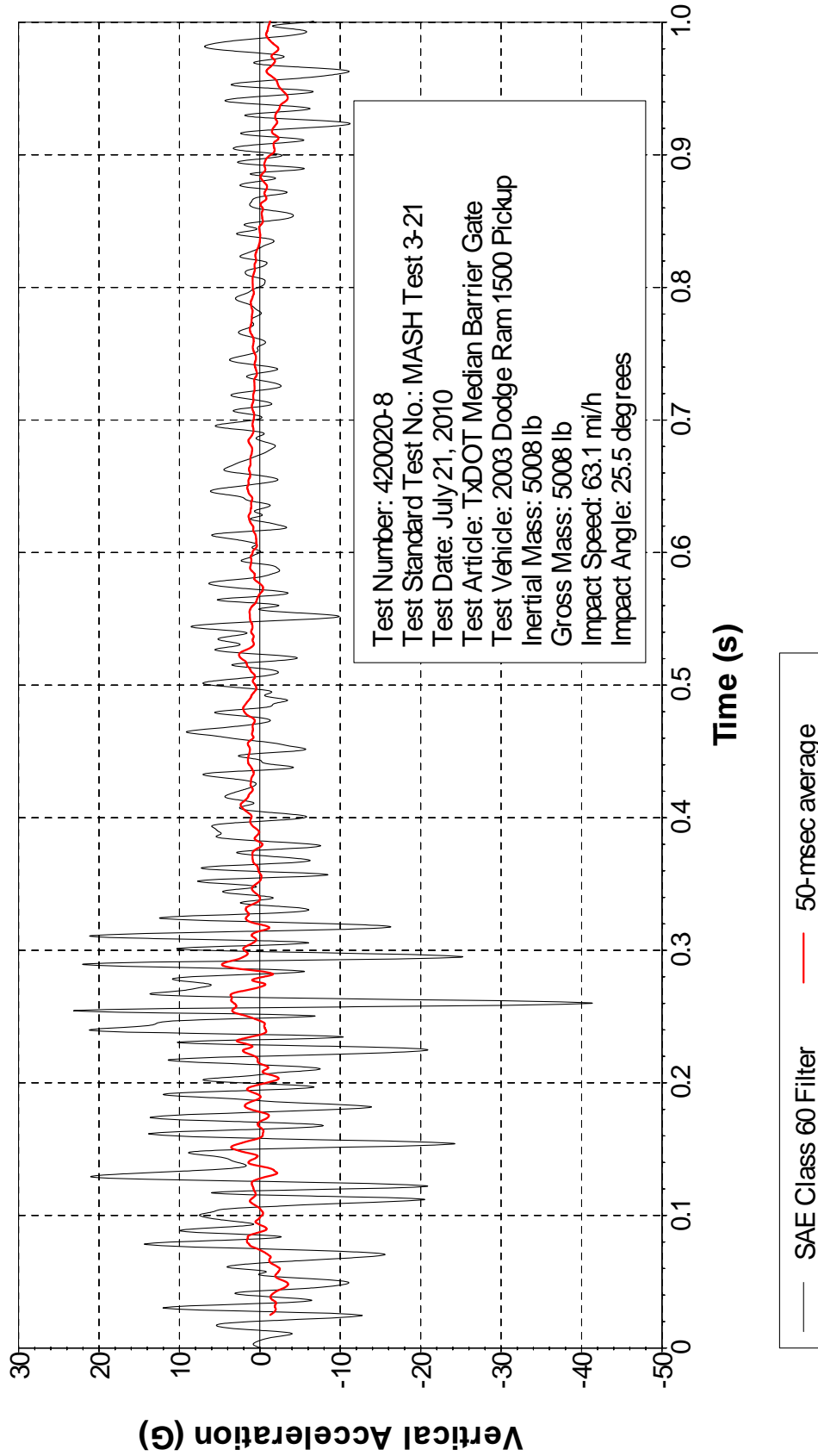


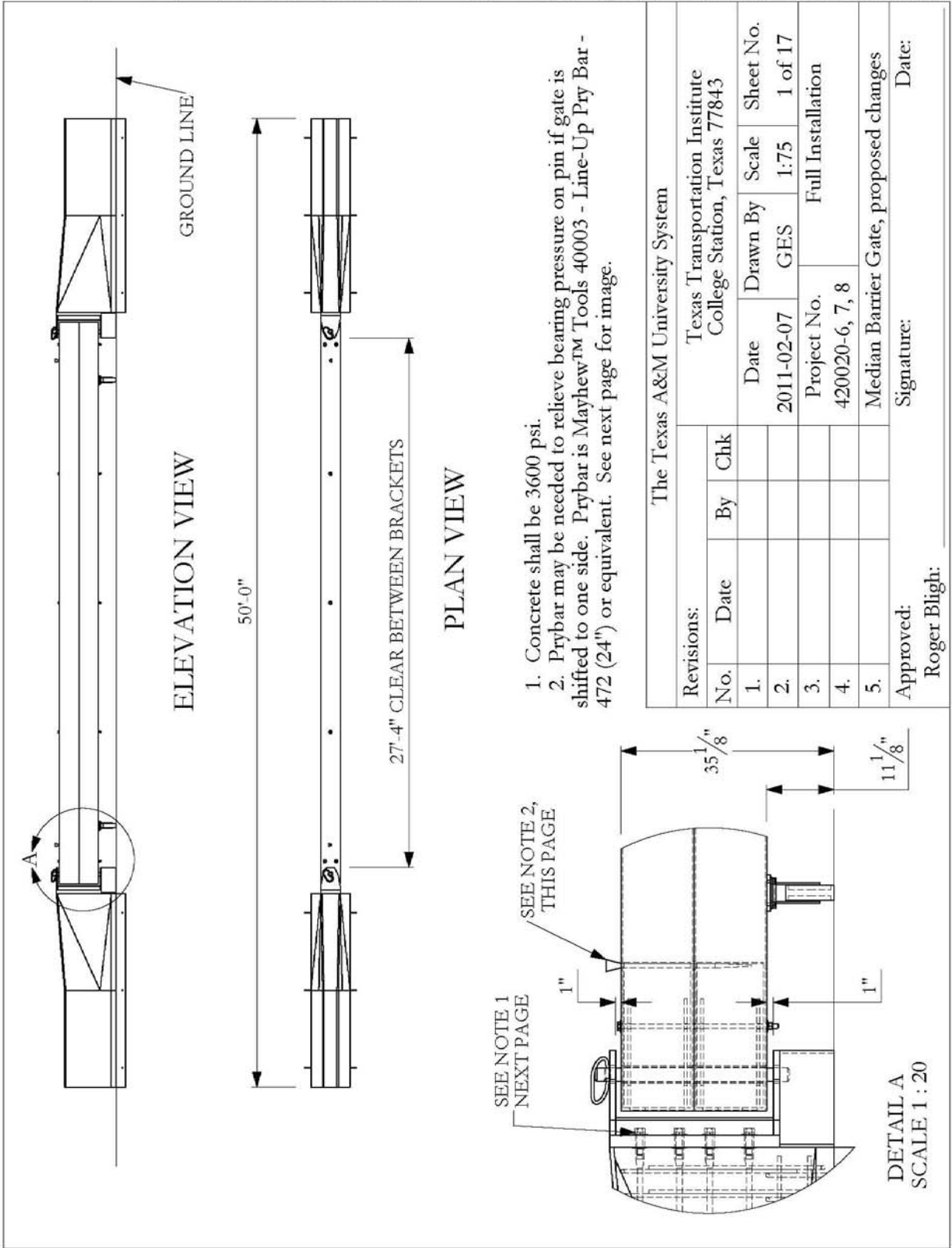
Figure E21. Vehicle Vertical Accelerometer Trace for Test No. 420020-8 (Accelerometer Located over Rear Axle).





# APPENDIX F. RECOMMENDED MEDIAN BARRIER GATE DETAILS

T:\2009-2010\420020 TXDOT\Median Barrier\Solidworks\Proposed Changes after Test\Median Barrier Gate Drawing, proposed



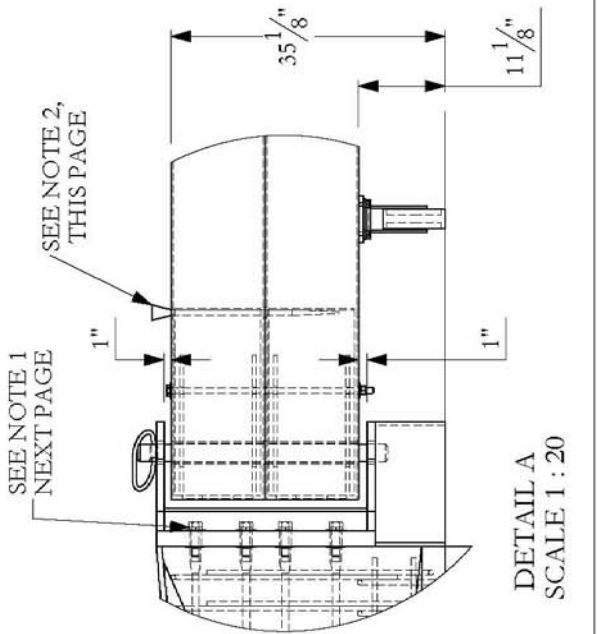
ELEVATION VIEW

PLAN VIEW

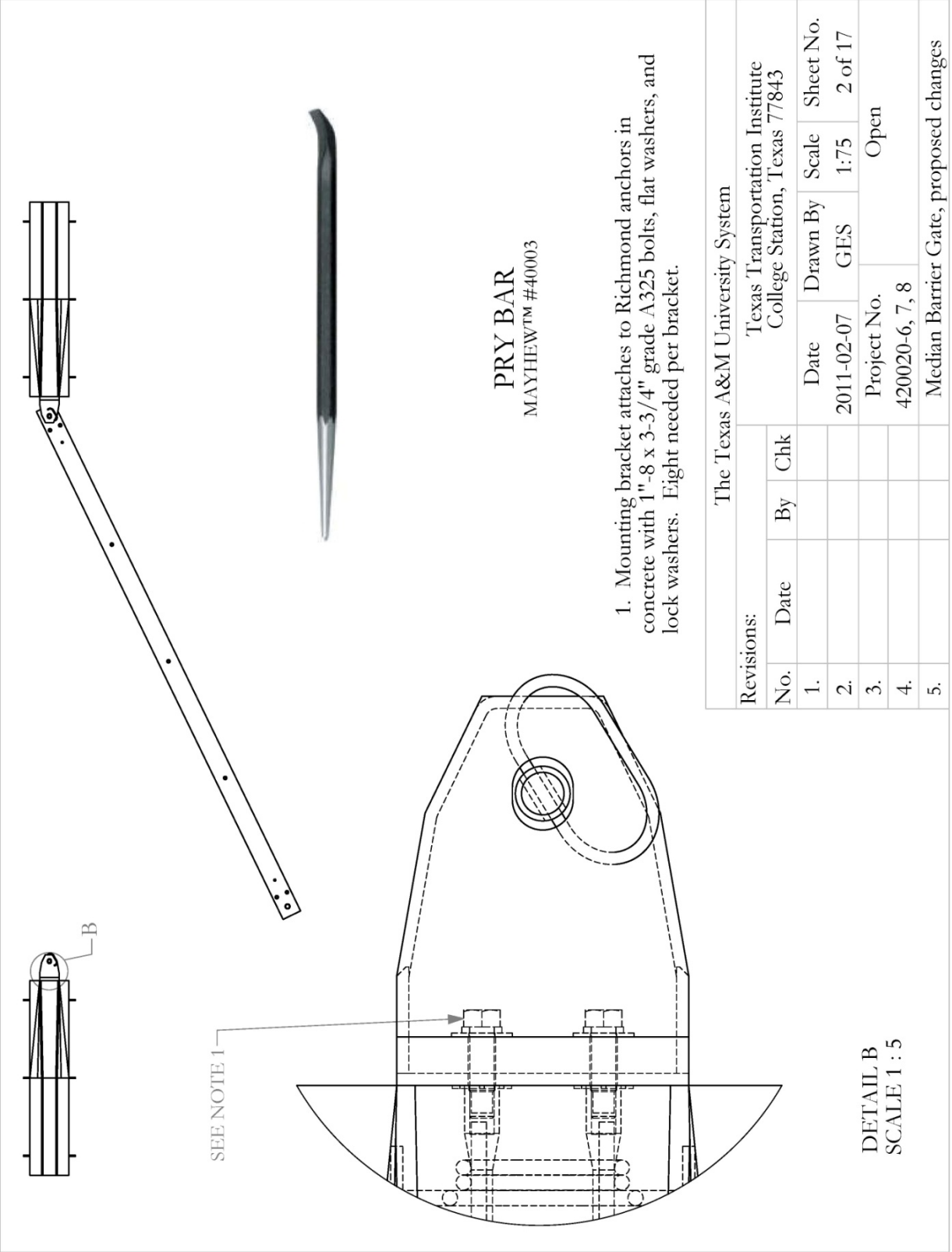
1. Concrete shall be 3600 psi.
2. Prybar may be needed to relieve bearing pressure on pin if gate is shifted to one side. Prybar is Mayhew™ Tools 40003 - Line-Up Pry Bar - 472 (24") or equivalent. See next page for image.

The Texas A&M University System				
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1.				1 of 17
2.	2011-02-07	GES		1:75
3.				Full Installation
4.				Project No. 420020-6, 7, 8
5.				Median Barrier Gate, proposed changes

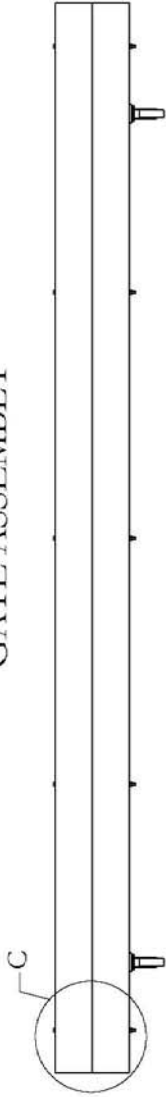
Approved: Roger Bligh: \_\_\_\_\_ Date: \_\_\_\_\_  
Signature: \_\_\_\_\_



DETAIL A  
SCALE 1 : 20



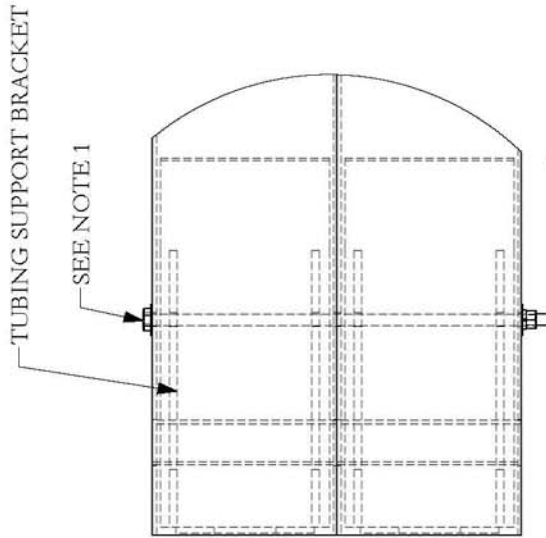
# GATE ASSEMBLY



ELEVATION VIEW



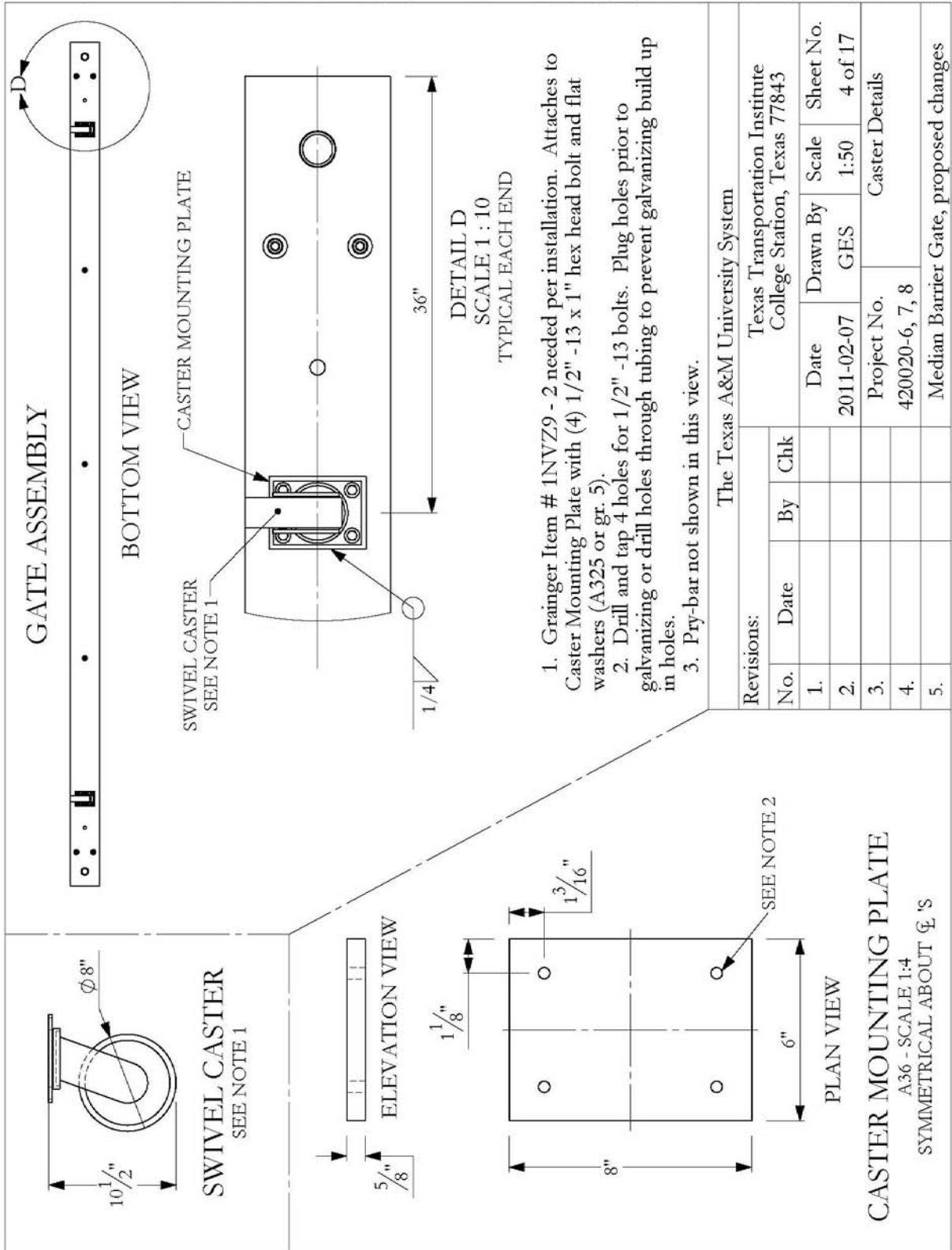
PLAN VIEW

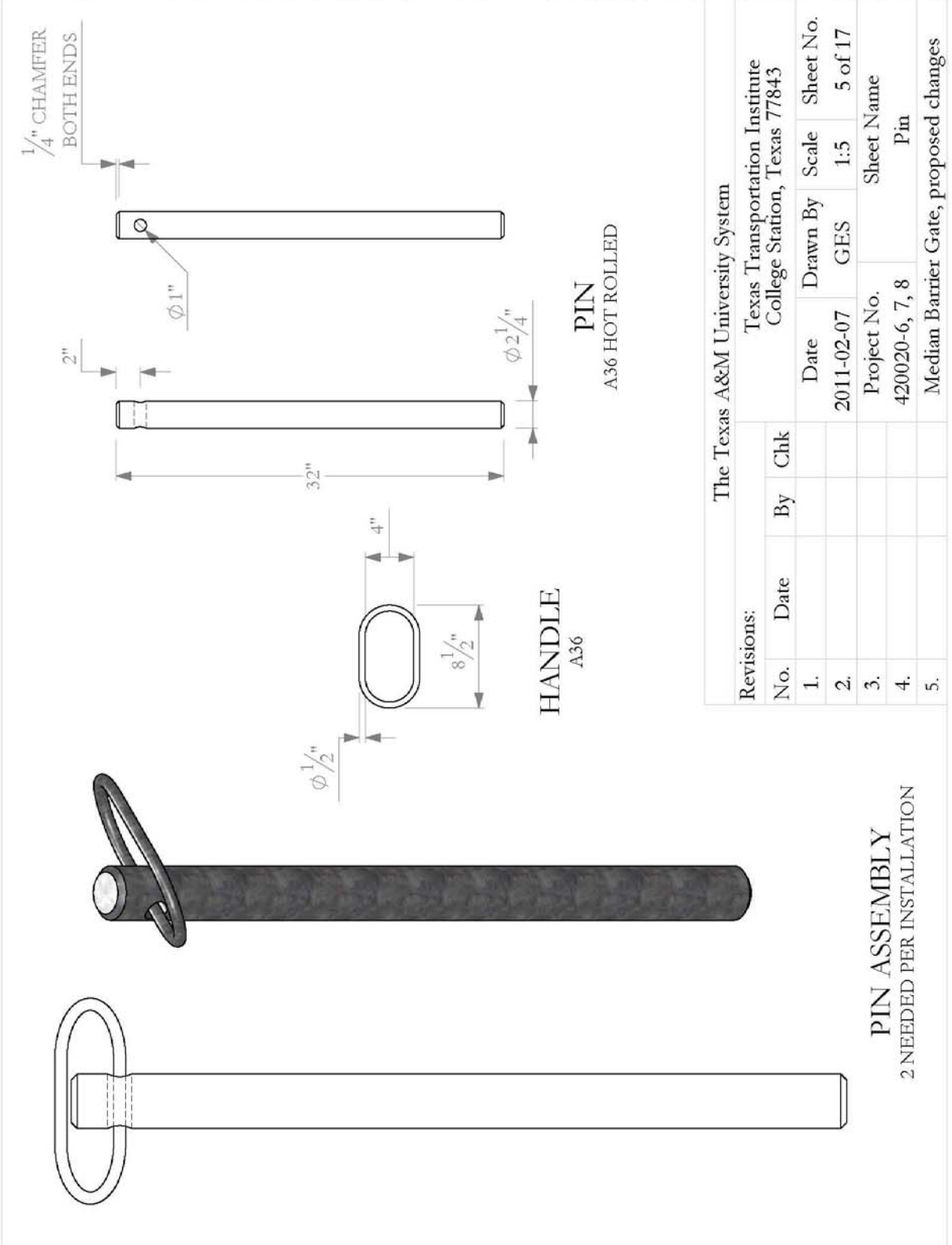


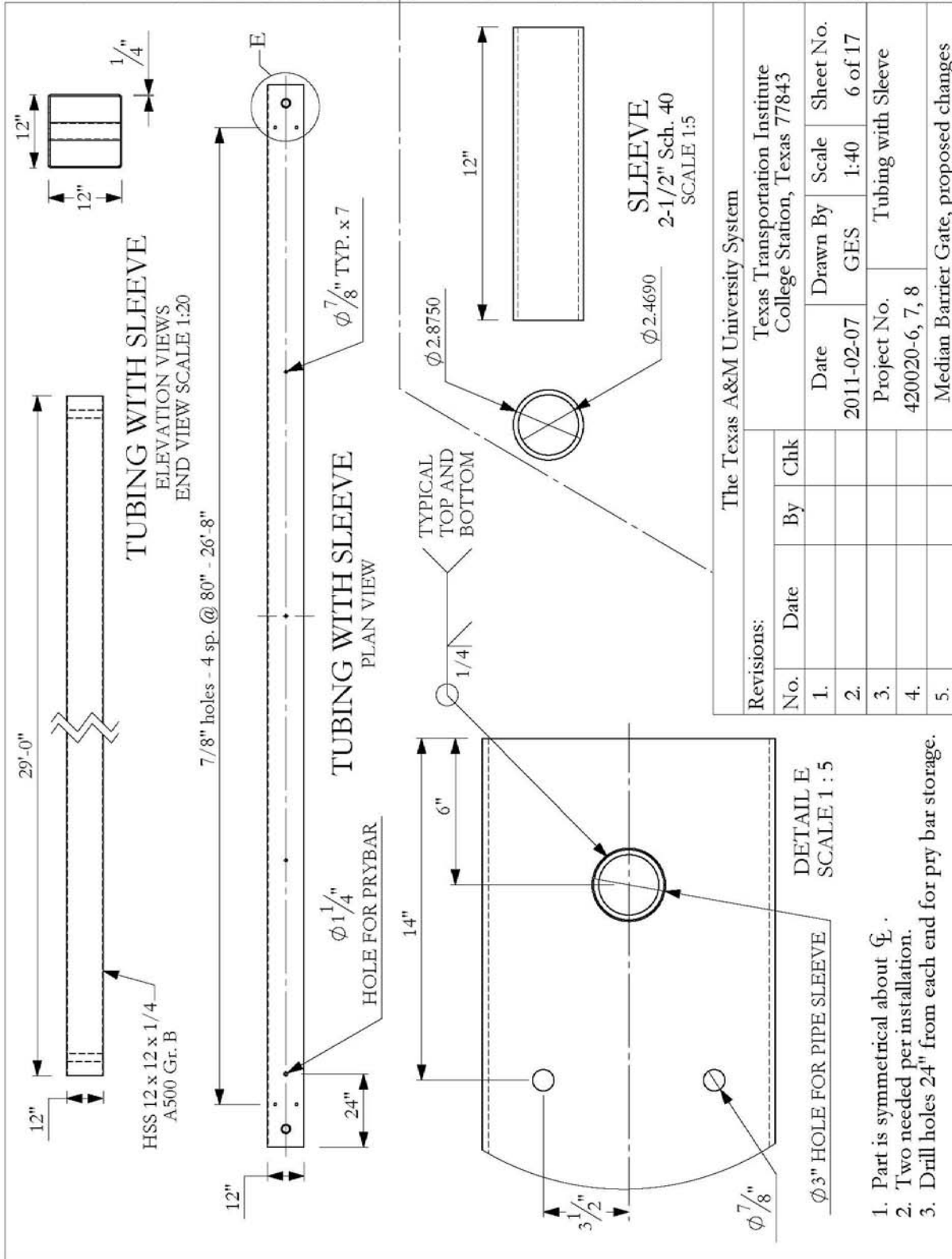
DETAIL C  
SCALE 1 : 10

1. 3/4" -10 x 26" hex head bolt, A325 or grade 5, 2 flat washers, lock washer, and hex nut. 7 needed per installation. Bolts attach Tubes together and hold Support Brackets in Tubes.
2. Pry-bar not shown in this view.

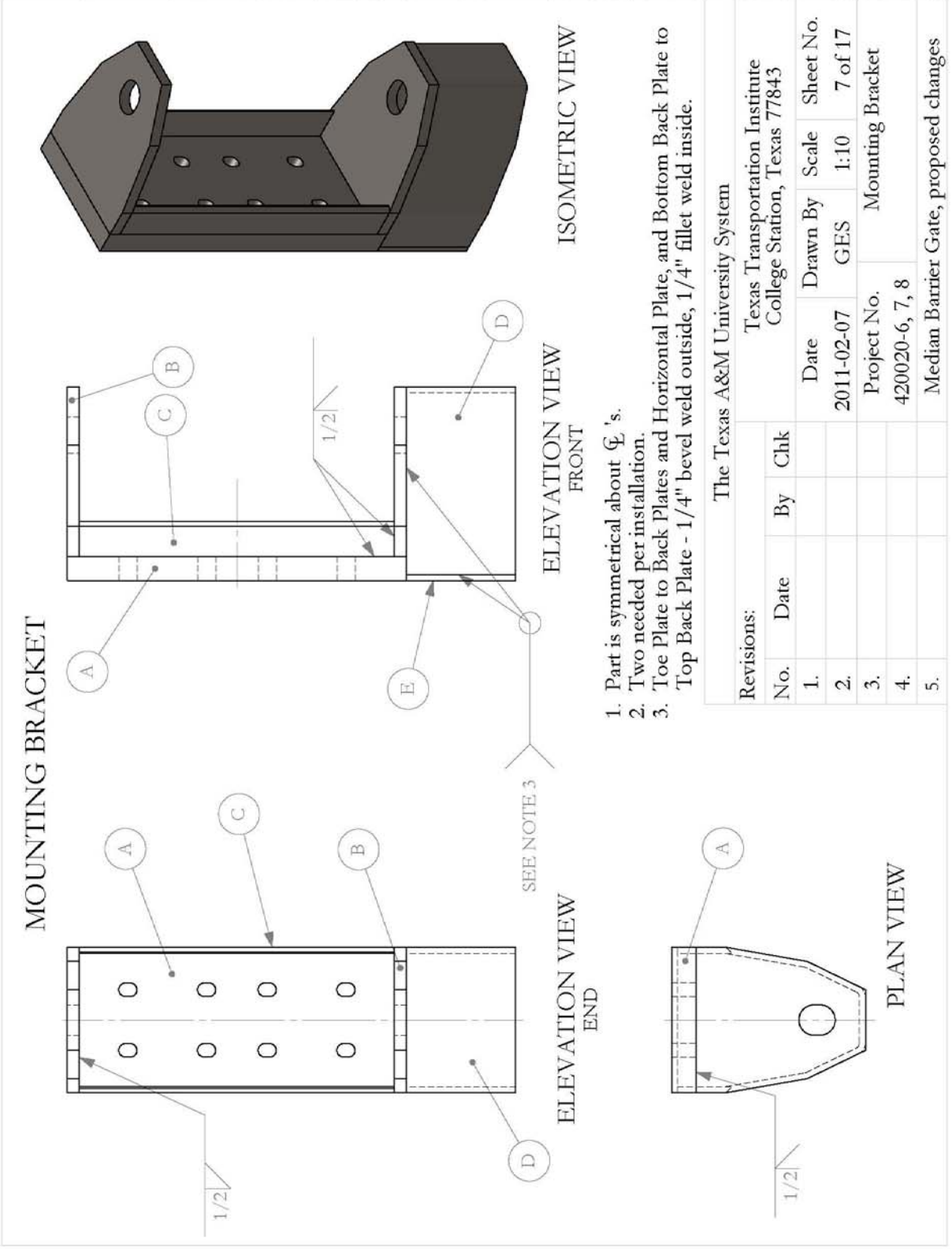
The Texas A&M University System				
Revisions:				
No.	Date	By	Chk	
1.				Texas Transportation Institute College Station, Texas 77843
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3.				Project No. 420020-6, 7, 8 Gate Assembly
4.				Median Barrier Gate, proposed changes
5.				





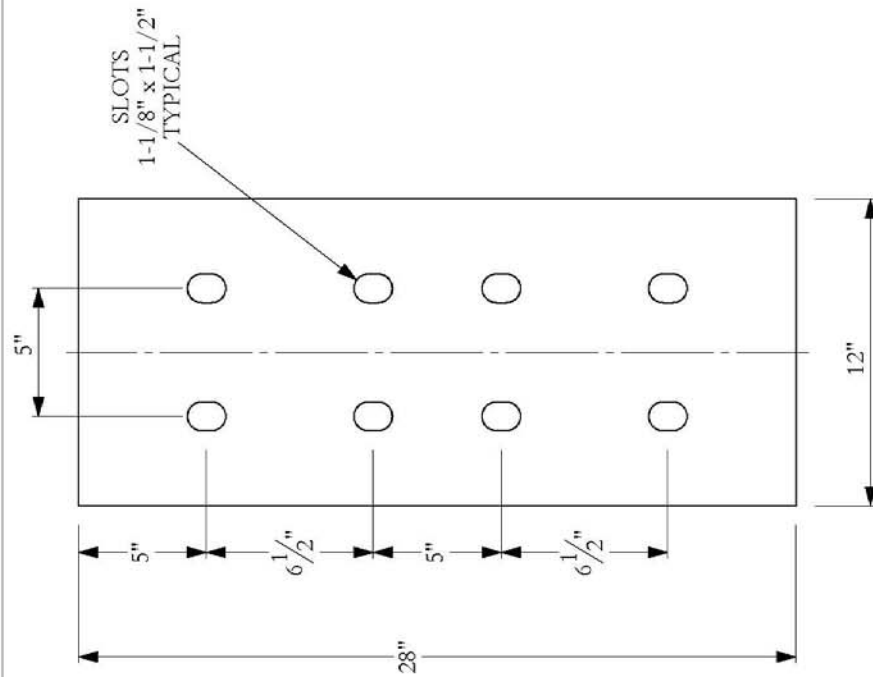


1. Part is symmetrical about  $\phi$ .
2. Two needed per installation.
3. Drill holes 24" from each end for pry bar storage.



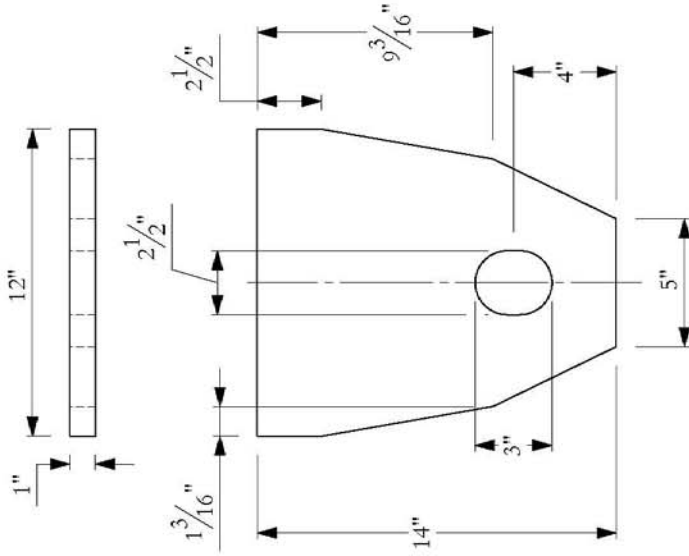
1. Part is symmetrical about  $\Phi$ 's.
2. Two needed per installation.
3. Toe Plate to Back Plates and Horizontal Plate, and Bottom Back Plate to Top Back Plate - 1/4" bevel weld outside, 1/4" fillet weld inside.

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1.				
2.	2011-02-07	GES		Scale 1:10 Sheet No. 7 of 17
3.				Project No. Mounting Bracket
4.				420020-6, 7, 8
5.				Median Barrier Gate, proposed changes



**BACK PLATE**

2" THICK  
1 NEEDED PER BRACKET



**HORIZONTAL PLATE**

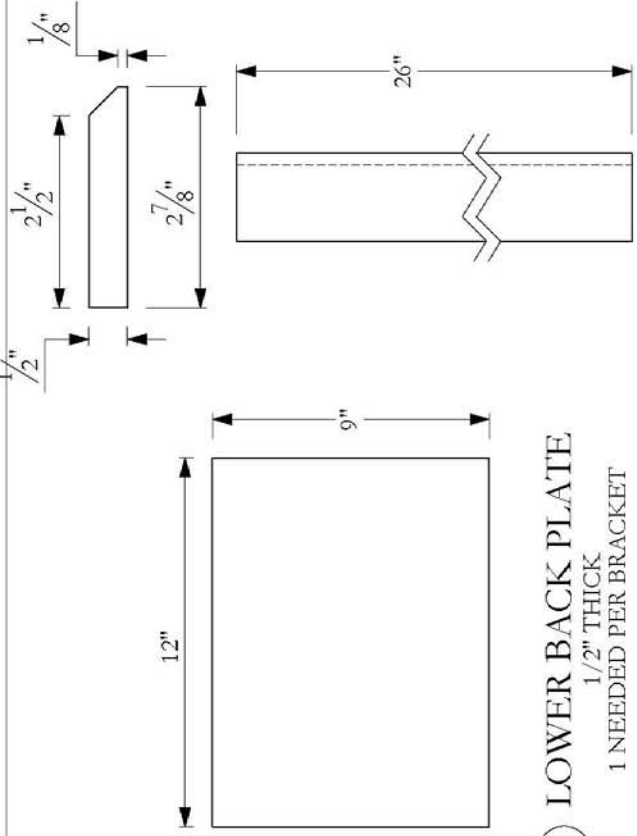
2 NEEDED PER BRACKET

1. All parts are A36 steel.
2. Parts A and B are symmetrical about  $\Phi$ 's.

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1.				Sheet No.
2.	2011-02-07	GES		1:6
3.				8 of 17
4.				Project No. Mounting Bracket Parts - 1
5.				420020-6, 7, 8
				Median Barrier Gate, proposed changes

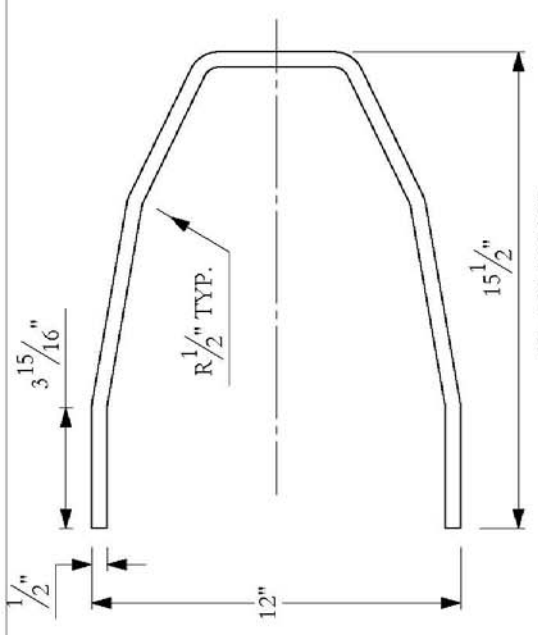




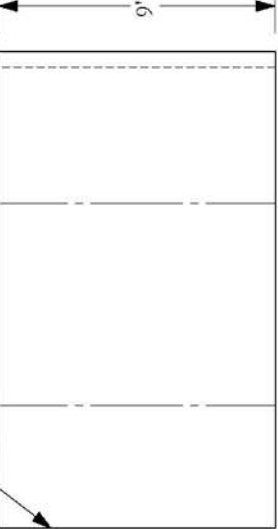
**(E) LOWER BACK PLATE**  
 1/2" THICK  
 1 NEEDED PER BRACKET

**(C) VERTICAL PLATE**  
 2 NEEDED PER BRACKET  
 END VIEW SCALE 1:2

1. All parts are A36 steel.
2. Toe Plate may be made from multiple pieces. If so, weld pieces together with full penetration bevel welds.
3. 1/4" chamfer top and back edges for bevel welds.



**(D) TOE PLATE**  
 BEND TO FIT HORIZONTAL PLATE  
 SEE NOTE 2



**ELEVATION VIEW**

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1.				Texas Transportation Institute College Station, Texas 77843
2.	2011-02-07	GES		Scale 1:5 Sheet No. 9 of 17
3.				Project No. Mounting Bracket Parts - 2
4.				420020-6, 7, 8
5.				Median Barrier Gate, proposed changes

### TUBING SUPPORT BRACKET

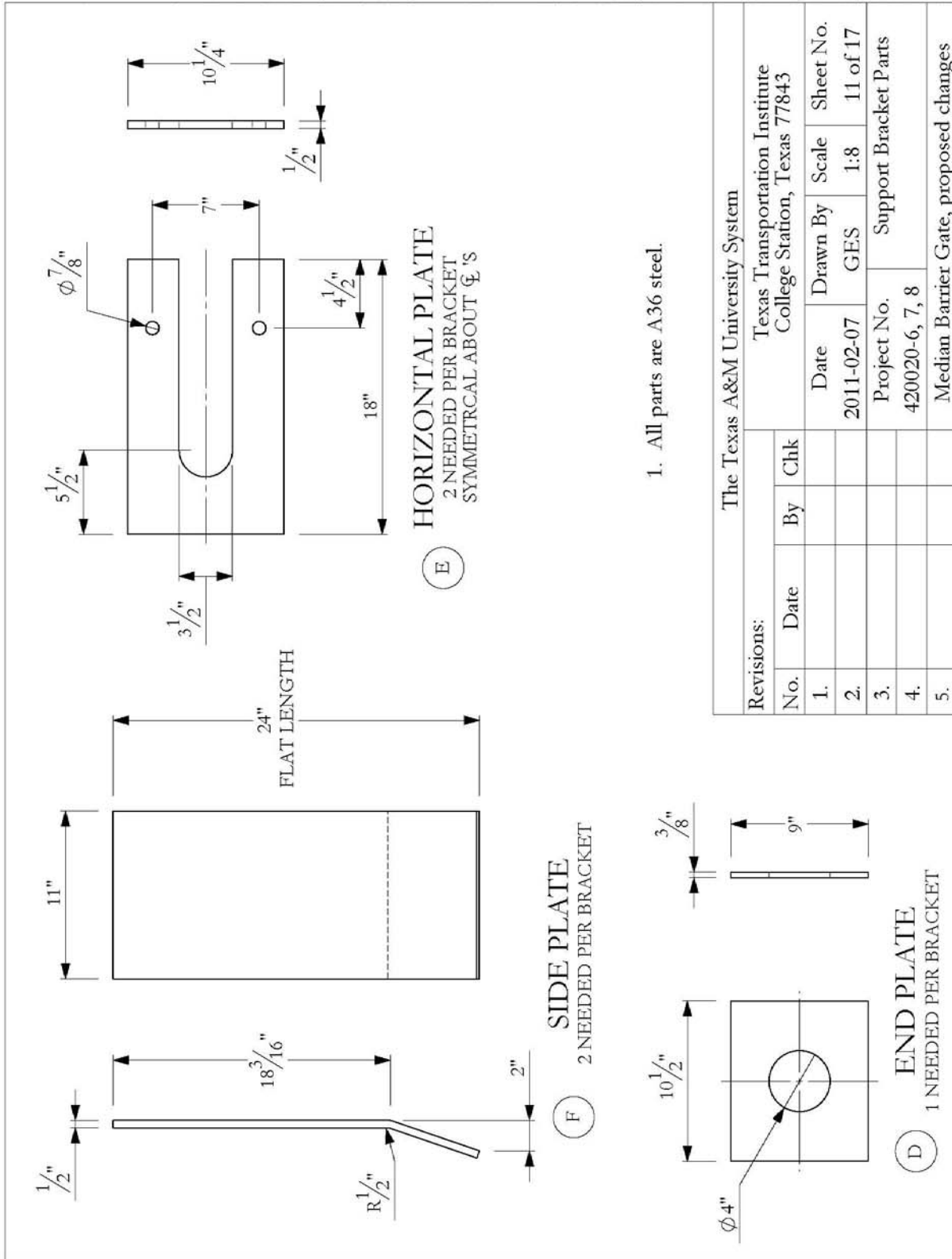
ELEVATION VIEWS

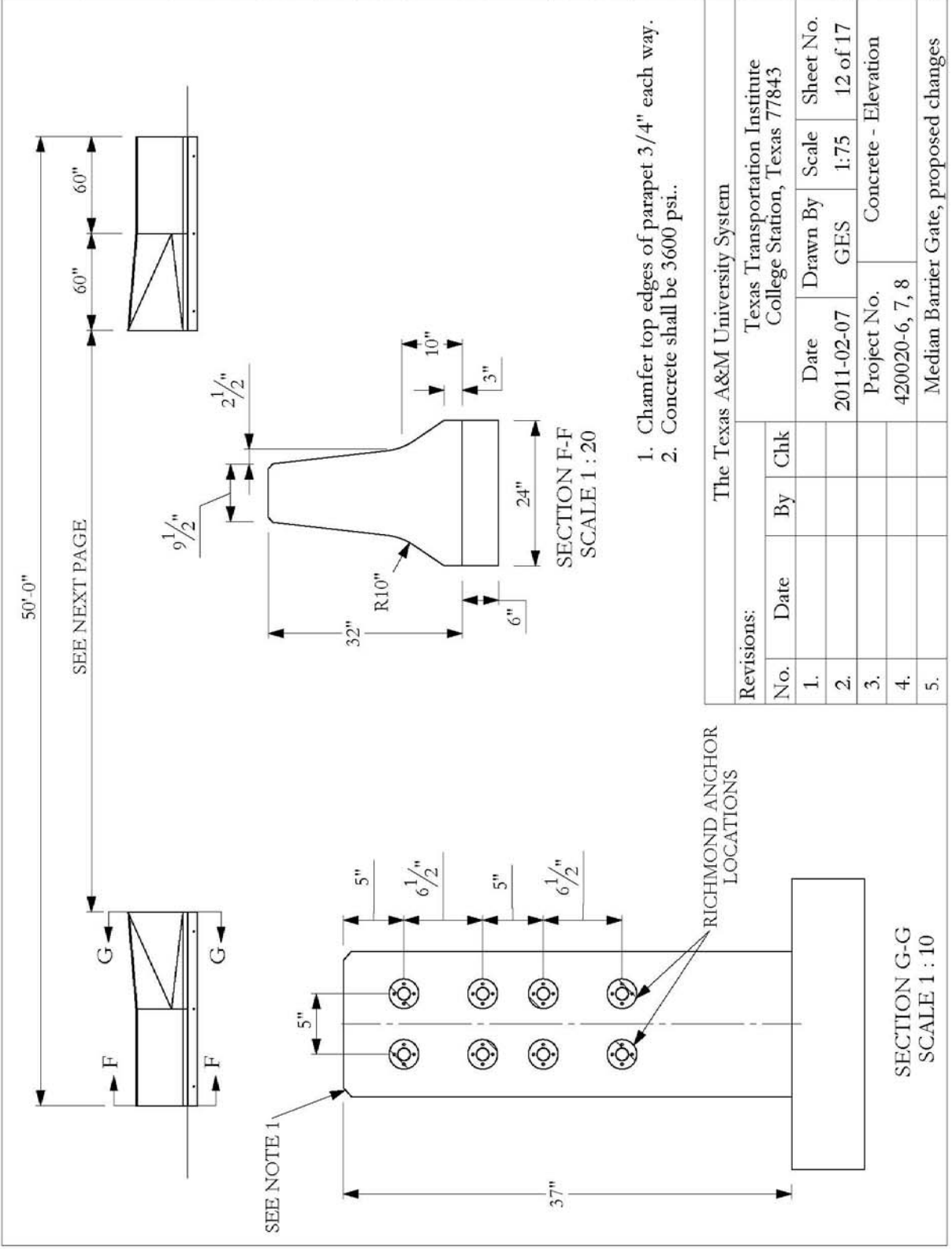
PLAN VIEW

ISOMETRIC VIEW

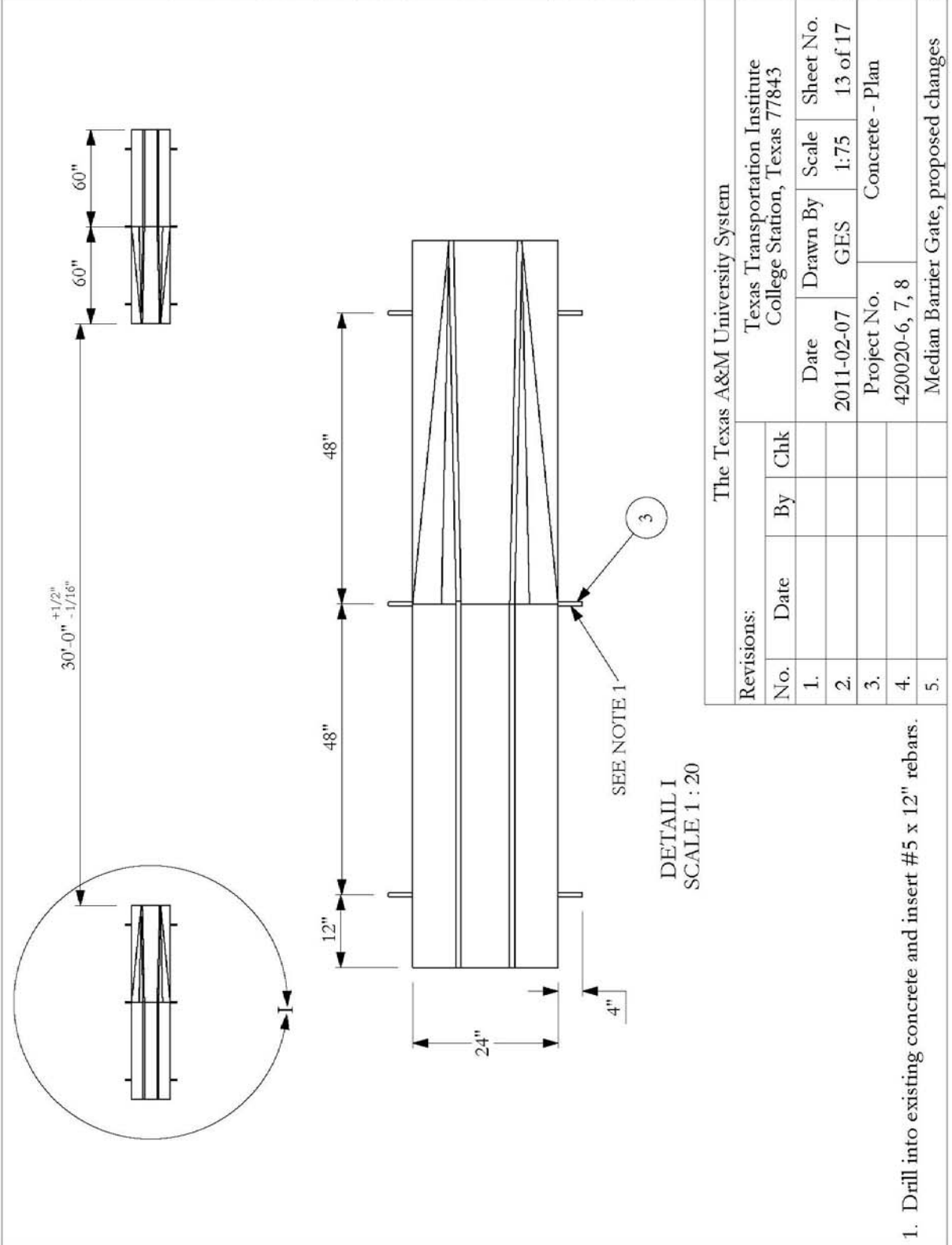
The Texas A&M University System				
Texas Transportation Institute College Station, Texas 77843				
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1.				
2.		2011-02-07	GES	
3.				
4.				
5.				

Date	Drawn By	Scale	Sheet No.
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Project No.		Tubing Support Bracket	
420020-6, 7, 8			
Median Barrier Gate, proposed changes			





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No.	Date	By	Chk	
1.				
2.	2011-02-07	GES		Sheet No. 12 of 17
3.				Concrete - Elevation
4.				Project No. 420020-6, 7, 8
5.				Median Barrier Gate, proposed changes

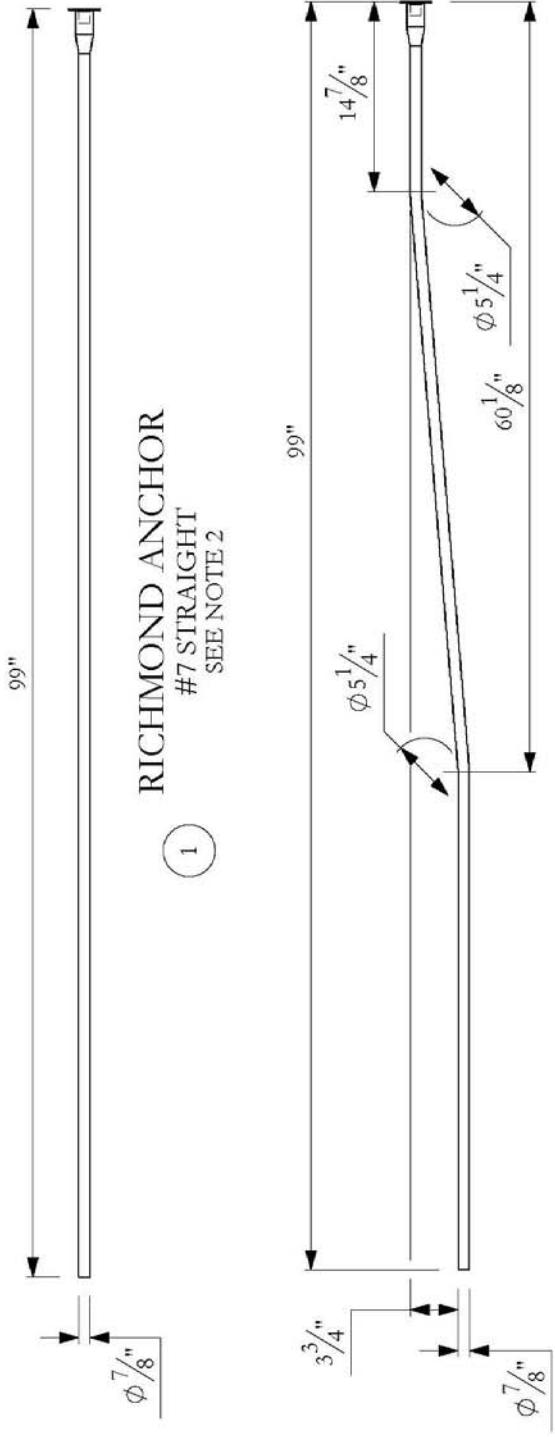


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No.	Date	By	Chk	Sheet No.
1.				13 of 17
2.	2011-02-07	GES		Concrete - Plan
3.				
4.				
5.				

Project No. 420020-6, 7, 8  
Median Barrier Gate, proposed changes

1. Drill into existing concrete and insert #5 x 12" rebars.



1  
**RICHMOND ANCHOR**  
 #7 STRAIGHT  
 SEE NOTE 2

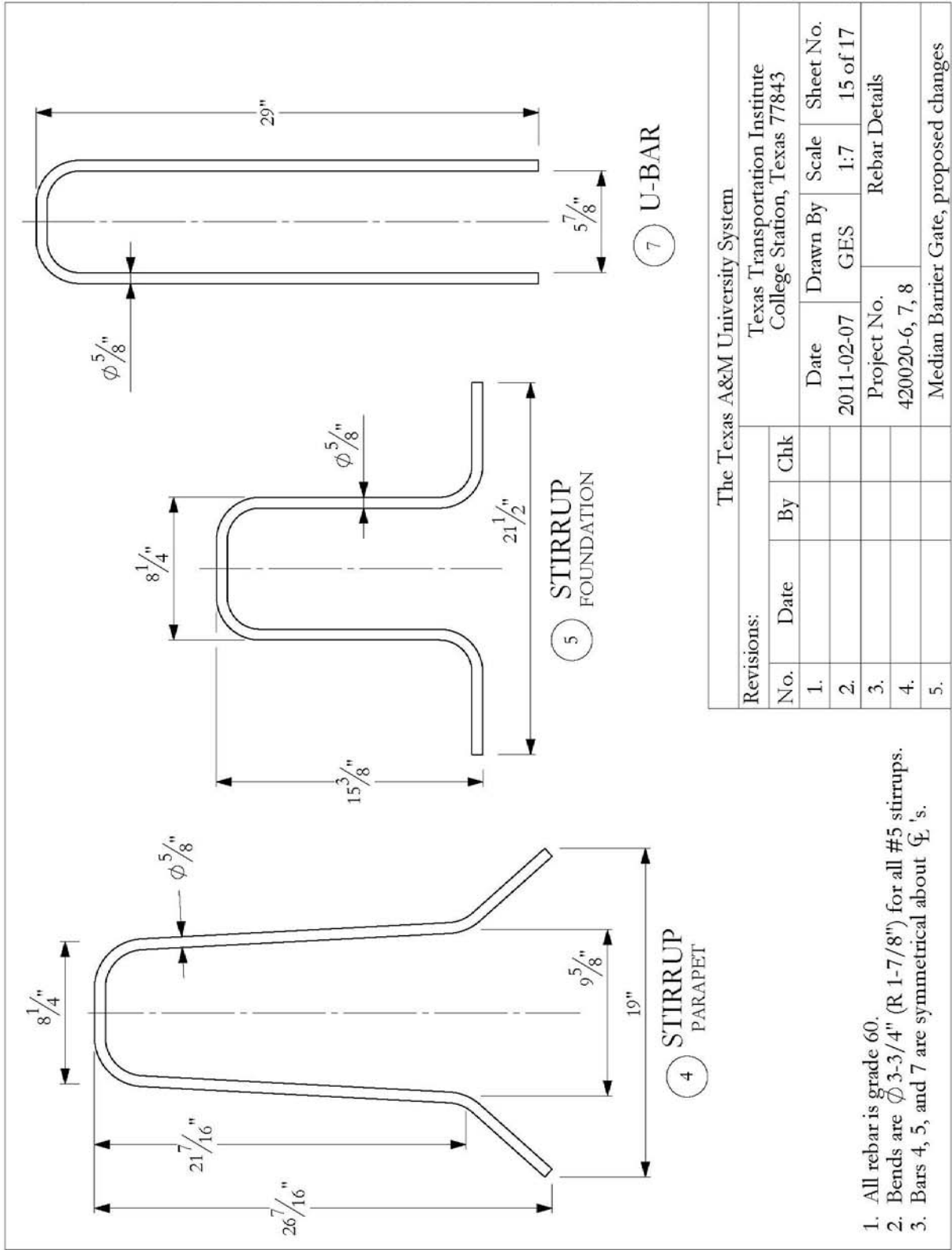
2  
**RICHMOND ANCHOR**  
 #7 BENT  
 SEE NOTE 2

1. All rebar is grade 60.
2. Dayton Superior D-101-A Dowel Bar Splicers, #7 rebar.

#	PART NUMBER	QTY.
1	Richmond Anchor, #7 straight	12
2	Richmond Anchor, #7 bent	4
3	Rebar, #5 x 12"	18
4	Stirrup, parapet	16
5	Stirrup, foundation	32
6	Rebar, #5 x 57"	16
7	U-bar, parapet	76
8	Rebar, #5 x 93"	8
9	Rebar, #4 x 9' 8"	12

The Texas A&M University System

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1.				Sheet No.
2.	2011-02-07	GES		1:12
3.				14 of 17
4.				Project No.
5.				420020-6, 7, 8
				Rebar List
				Median Barrier Gate, proposed changes



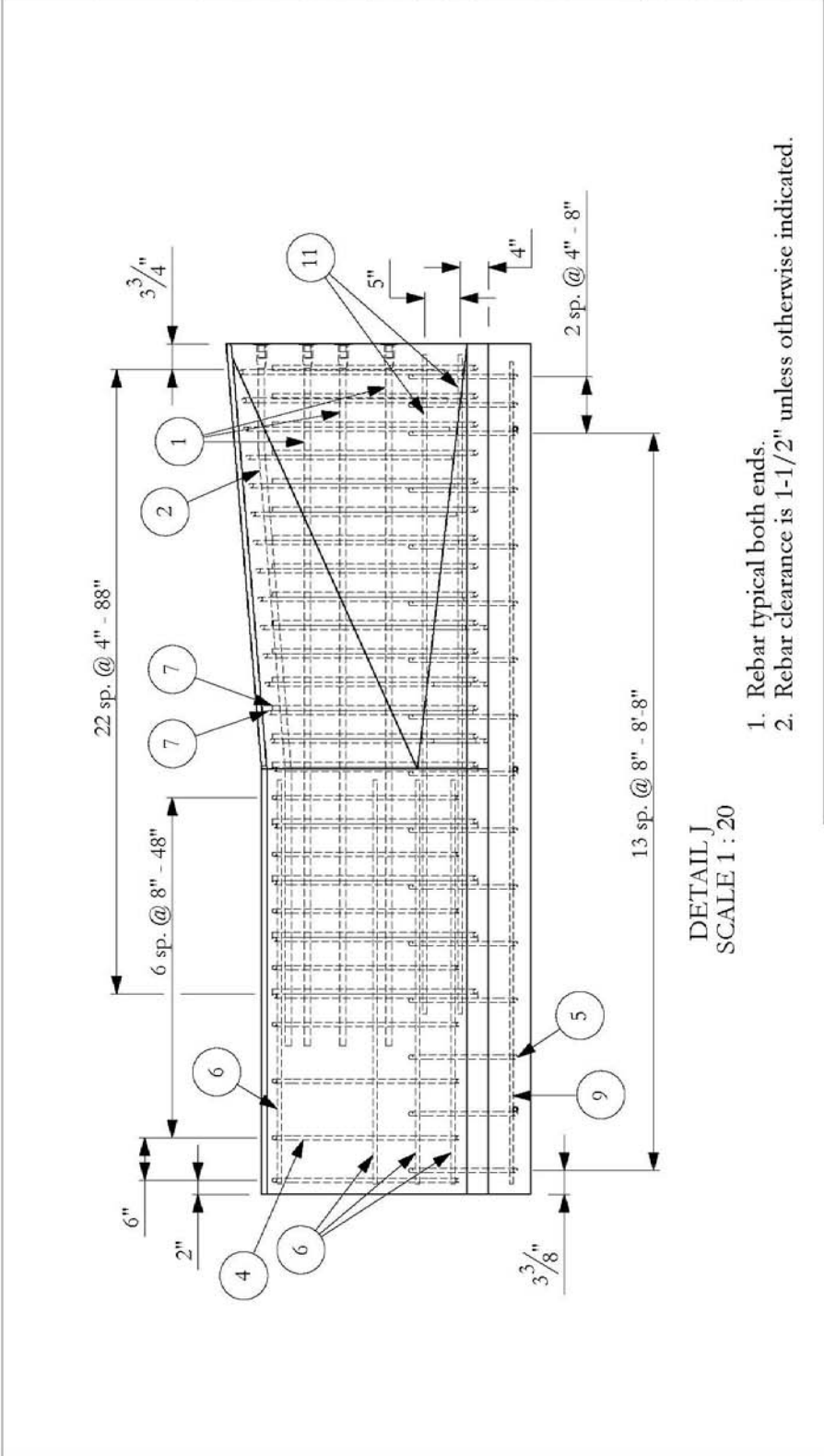
1. All rebar is grade 60.
2. Bends are  $\phi$  3-3/4" (R 1-7/8") for all #5 stirrups.
3. Bars 4, 5, and 7 are symmetrical about  $\phi$ 's.

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2.	2011-02-07	GES	
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4.			
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Date	Drawn By	Scale	Sheet No.
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Project No. 420020-6, 7, 8  
 Rebar Details  
 Median Barrier Gate, proposed changes



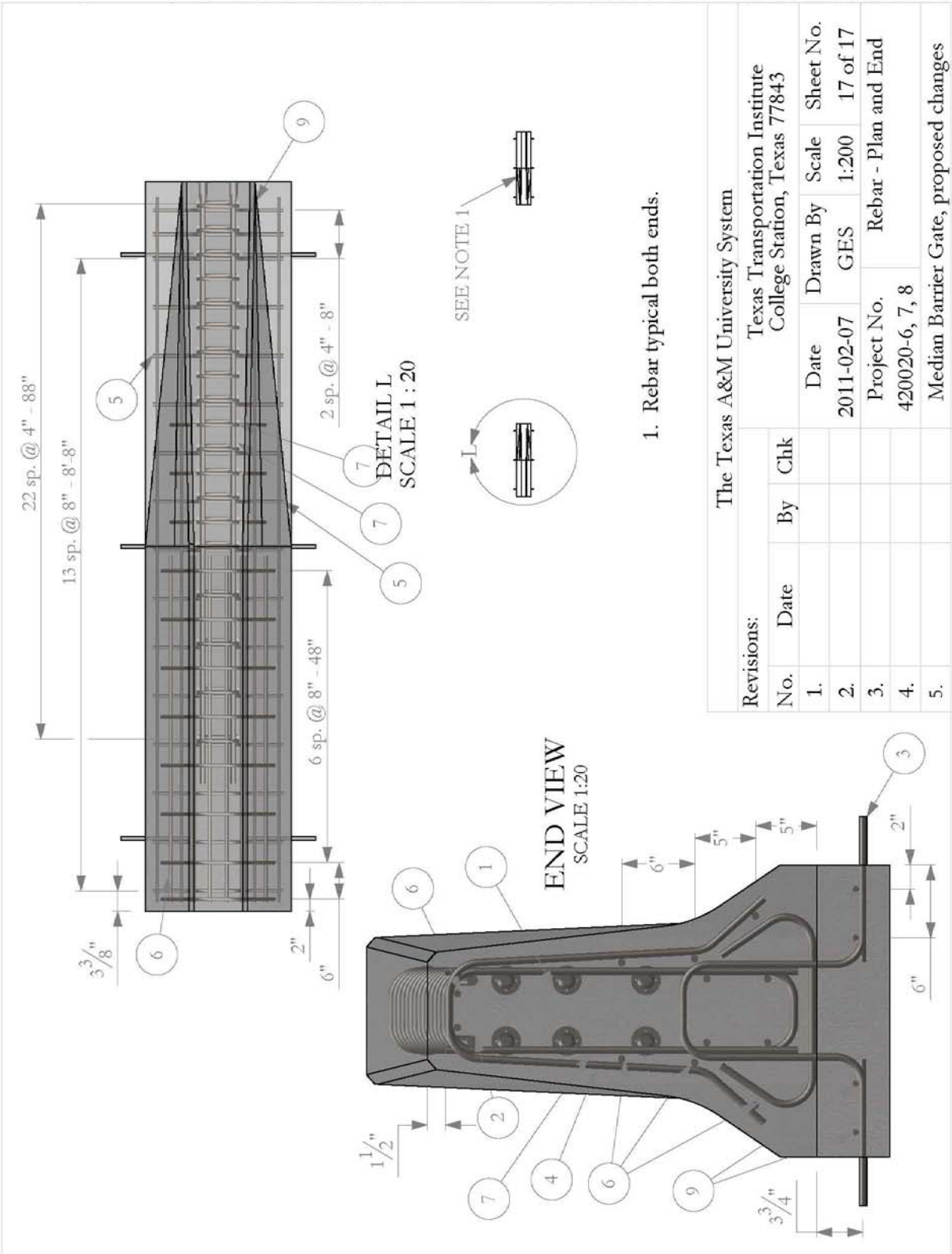
DETAIL J  
SCALE 1 : 20

1. Rebar typical both ends.
2. Rebar clearance is 1-1/2" unless otherwise indicated.



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1.				16 of 17
2.	2011-02-07	GES		1:200
3.				Rebar - Elevation
4.				420020-6, 7, 8
5.				Median Barrier Gate, proposed changes





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	4.			
	5.			

Date	Drawn By	Scale	Sheet No.
2011-02-07	GES	1:200	17 of 17

Project No.	Rebar - Plan and End
420020-6, 7, 8	

Median Barrier Gate, proposed changes

