Transportation Pooled Fund Program

Texas Transportation Institute
Proving Ground

DEVELOPMENT AND TESTING OF A CONCRETE BARRIER DESIGN FOR USE IN FRONT OF SLOPE OR ON MSE WALL

by

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The bogie testing and the full-scale crash test reported herein were performed at Texas Transportation Institute (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 bogie testing and the full-scale crash test were performed according to TTI Proving Ground quality procedures and according to the *MASH08* guidelines and standards, herein referred to as MASH.[3,4]

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1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.

4. Title and Subtitle	5. Report Date
DEVELOPMENT AND TESTING OF A CONCRETE BARRIER DESIGN FOR USE IN FRONT OF SLOPE OR ON MSE WALL	August 2009
	6. Performing Organization Code

7. Author(s)	8. Performing Organization Report No.
Nauman M. Sheikh, Roger P. Bligh, and Wanda L. Menges	405160-13-1

9. Performing Organization Name and Address	10. Work Unit No. (TRAIS)
Texas Transportation Institute Proving Ground The Texas A&M University System College Station, Texas 77843-3135	
	11. Contract or Grant No.
	T4541

12. Sponsoring Agency Name and Address	13. Type of Report and Period Covered
Washington State Department of Transportation Transportation Building, MS 47372 Olympia, Washington 98504-7372	Test Report March 2008 – August 2009
	14. Sponsoring Agency Code

15. Supplementary Notes

Research Study Title: Task Order #13 – Concrete Barrier Design for Use in Front of a Slope or on MSE Wall
Name of Contacting Representative: Dave Olson

16. Abstract

The objective of this research was to restrict lateral deflection of a concrete barrier when placed adjacent to steep slopes or on top of Mechanically Stabilized Earth (MSE) walls, without using a concrete moment slab. The final design was required to incorporate 20-ft long single slope barrier segments with grouted rebar grid connection. The researchers first evaluated the performance of the free-standing barrier with grouted rebar-grid connection using a smaller scale bogie impact test and simulation analysis. It was determined that the grouted rebar-grid connection did not provide enough strength to restrict lateral deflections.

The researchers then evaluated restricting the deflection of the barrier by embedding it 10 inches in soil. The barrier was placed in front of a 1.5H:1V slope. The offset of the barrier from the slope break point was restricted to 2 ft. Another phase of bogie testing and simulation analysis was performed to evaluate the performance of the grouted rebar grid connection in the embedded configuration. Results of the simulation analysis showed that the embedded barrier system will result in acceptably reduced lateral deflections.

A 100-ft long installation of the embedded single-slope barrier in front of a 1.5H:1V slope was subsequently crash tested under *Manual for Assessing Safety Hardware* (*MASH*) criteria. The design performed acceptably according to the requirements of *MASH* and the maximum static barrier deflection was 5.5 inches. While the barrier was tested in front of a 1.5H:1V slope, due to a relatively small lateral deflection, it is also recommended for use on top of MSE walls as long as a minimum 2-ft lateral offset is maintained between the back of the barrier and the wall.

17. Key Words	18. Distribution Statement
Concrete barrier, embedded barrier, restrained barrier, slope, MSE wall, soil, single slope barrier, rebar grid	

19. Security Classif.(of this report)	20. Security Classif.(of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	80	

Form DOT F 1700.7 (8-72)   Reproduction of completed page authorized

SI* (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

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

APPROXIMATE CONVERSIONS FROM SI UNITS

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

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

ACKNOWLEDGMENTS

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Revised December 2008

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TABLE OF CONTENTS

TABLE OF CONTENTS (CONTINUED)

LIST OF FIGURES

LIST OF TABLES

1. INTRODUCTION

1.1 PROBLEM

When concrete barriers are installed adjacent to steep slopes or on top of Mechanically Stabilized Earth (MSE) walls, a concrete moment slab is usually constructed underneath the barrier to restrict lateral barrier movement and provide barrier stability. By resisting the lateral deflection and rotation of the barrier, the moment slab prevents the barrier from toppling over the adjacent slope or the edge of the MSE wall. Moment slabs are expensive to construct and significantly increase the cost of installation. In addition to using the moment slab, several feet of soil embankment behind the barrier is generally recommended. This reduces the travel space available in front of the barrier. There is a need to develop a cost effective design for restraining the barrier and to minimize the embankment width behind the barrier.

1.2 BACKGROUND

In 1989, Texas Transportation Institute (TTI) developed the single-slope barrier for the Texas State Department of Highways and Public Transportation. *(1)* The development of the single-slope barrier was done under National Cooperative Highway Research Program (NCHRP) *Report 230* criteria. *(2)* Several full-scale crash tests were performed to evaluate the performance of the barrier. Two of the tests were conducted with the barrier in a temporary configuration. Thirty-foot, free-standing, single-slope barrier segments were connected using a rebar-grid connection (without grout) in one test and an angle-splice connection in the other test. The barriers were impacted with a 4504-lb large passenger car at a speed of 62 mph and an angle of 15 degrees in both tests. The barrier deflection in the tests with the rebar-grid connection and the angle-splice connection was 6 and 7 inches, respectively. Two more tests were performed with the single-slope barrier segments in a permanent configuration. In these tests, the 30-ft barrier segments were keyed into a 1-inch thick asphalt layer. The asphalt layer was 5 ft wide on the field side of the barrier and 1 ft wide on the traffic side. The rebar-grid connection was used to connect adjacent barriers. The connection was grouted to provide more resistance to barrier movement. The barrier was impacted with a 4504-lb large passenger car at 63.1 mph and 26.5 degrees in one test, and with an 1801-lb small passenger car at 60.7 mph and 19.9 degrees in another test. No barrier deflection was observed in either test.

It should be noted that the impact severity, which is the measure of the kinetic energy being imparted on the barrier laterally, was significantly less in the tests with the free-standing barriers when compared to the impact severity prescribed in National Cooperative Highway Research Program (NCHRP) *Report 350* and the American Association of State Highway and Transportation Officials (AASHTO) *Manual for Assessing Safety Hardware* (*MASH*). *(3, 4)* Thus, higher deflections should be expected for the same barrier system if crash tested under *MASH* criteria. It should also be noted that most pooled fund states use barrier segments that are less than 30 ft in length. Reducing segment length is also expected to increase lateral barrier

deflection. This is because shorter segments have less mass and allow greater relative rotation of adjacent segments due to the presence of more connections.

1.3   OBJECTIVES AND SCOPE OF RESEARCH

The main objective of this research project was to develop and test a design for a restrained concrete barrier that can be placed in front of slopes as steep as 1.5H:1V, or on top of MSE walls. The design would not require a moment slab and would reduce soil embankment width behind the barrier to 2 ft or less. Further, the design feature should incorporate Washington Department of Transportation's (WSDOT) precast single slope barrier with 20-ft long barrier segments. The design was required to meet Test Level 3 (TL-3) requirements of *MASH*.

The existing WSDOT single slope barrier uses a grouted rebar-grid connection to connect the 20-ft long barrier segments. The performance of this barrier connection was not known in a free standing condition. It was suggested that if the free standing barrier with grouted rebar-grid connection resulted in small lateral deflection under vehicle impact, it would render the simplest and most cost effective solution to the design problem. The researchers evaluated the performance of this connection in a free-standing single-slope barrier using a surrogate bogie vehicle impact test and finite element analysis. It was determined that using the barrier with existing connection in a free-standing mode would result in large lateral deflections.

The researchers then evaluated restraining the barrier by embedding it 10 inches in soil and providing a 2 ft offset from the slope breakpoint. Another phase of bogie testing and finite element analysis was performed and it was determine that the design would result in acceptable lateral deflection. Subsequently, the new embedded barrier design was crash tested and it successfully met *MASH* TL-3 requirements. The maximum static deflection of the barrier was 5.5 inches.

Details of the design and analysis are presented in chapter 2 of this report. Chapter 3 presents the description of the test article. Details of the testing criteria and crash test results are presented in chapters 4 through 6. Chapter 7 presents a summary of the results, conclusions, and recommendations emanating from this project.

2. DESIGN AND ANALYSIS

2.1 INTRODUCTION

The primary objective of this research was to develop a design for a precast concrete barrier that can be placed in front of slopes as steep as 1.5H:1V or on top of MSE walls, without using a moment slab. The design was required to use 20-ft long single-slope barrier segments, and to restrict the soil embankment behind the barrier to two feet or less.

The pooled-fund states typically use the grouted rebar-grid slot connection to connect single-slope barrier segments. To date, there has been no testing performed with the single slope barrier using the grouted rebar-grid slot connection in a free-standing condition. As a first step, the researchers evaluated the performance of the free-standing single slope barrier. The objective of this evaluation was to determine if the grouted rebar-grid connection provided sufficient connection strength to cause adjacent barriers segments to deflect as a single body during vehicle impact, without significant rotation at the joints. If this could be achieved, it was believed that the impacting vehicle can be contained and redirected without significant barrier deflection simply using the weight of the concrete barrier. This would have also rendered the easiest solution to the design problem and allowed maximum flexibility in the use of the barrier. However, subsequent evaluation of the grouted rebar-grid slot connection in a free-standing condition showed that it is not strong enough to transfer moments between adjacent barrier segments and results in large rotations at the joints, thus resulting in a large overall lateral barrier deflection.

The researchers then considered use of different methods for restraining the barrier to prevent large lateral deflection. Among the methods considered were using a stronger barrier connection, pinning or staking the barrier segments with steel pins, using straps or angles to tie adjacent barriers together, etc. However, the participating states expressed interest in keeping the same connection methods and avoiding use of additional hardware if possible. To fulfill these requirements, the researchers evaluated restraining the barriers by embedding them in soil. The height of a typical single-slope barrier is 42 inches. The researchers suggested embedding the single slope barrier 10 inches in soil. This reduces the height of the barrier to 32 inches, which is typical of the common New Jersey and F-shape barrier profiles. The researchers used a combination of component level bogie impact testing, simulation analysis, and full-scale crash testing[1] to successfully develop a restraint mechanism for the single slope barrier by embedding it 10 inches in soil. The design uses existing grouted rebar-grid slot connection and requires a 2-ft offset from the slope breakpoint. Details of the analysis are presented in later sections of this chapter. Details of the final design and the results of the full-scale crash testing are presented in subsequent chapters of this report.

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[1] The bogie testing and the full-scale crash test reported herein were performed at TTI Proving Ground. TTI Proving Ground is an ISO 17025 accredited laboratory with A2LA Mechanical Testing certificate 2821.01. This certificate does not include simulation analysis.

2.2   VEHICLE MODEL

In *MASH*, which is a recent update to the *NCHRP Report 350*, the pickup truck design vehicle has been changed from a 4409-lb, ¾-ton, standard cab pickup truck to a 5000-lb, ½-ton, 4-door pickup truck. While a public domain finite element model of the 4409-lb pickup truck was available to researchers in the roadside safety community, no such model was available for the 5000-lb, ½-ton, 4-door pickup truck during the period of this research. The Federal Highway Administration (FHWA) had funded the development of a finite element model for a ½-ton, Chevrolet Silverado, 4-door, pickup truck, which meets the design test vehicle requirements of *MASH*.   However, the work on developing this new model was underway but was not completed within the timeframe of this research.

In the past, TTI researchers have made simple modifications to the existing 4409-lb pickup truck model for use in studies where the dynamics of the vehicle were not very critical compared to the higher mass required by *MASH*. These modifications involve increasing the mass of the existing 4409-lb pickup truck model by distributing additional mass over different parts of the vehicle and bringing the total vehicle mass to 5000-lb. The original 4409-lb pickup truck model was developed by the National Crash Analysis Center with further modifications and improvements by TTI researchers.

In the absence of a pickup truck model that met *MASH* requirements, the researchers employed the above mentioned methodology of using a surrogate 5000-lb pickup truck model for evaluating the single-slope barrier design. Doing so enabled the researchers to impart the same level of impact energy into the barrier system as required by *MASH*. It was expected that the vehicle dynamics response of the surrogate 5000-lb vehicle will not match the response measured in a crash test. However, previous testing of the single-slope barrier has shown that the vehicle remains fairly stable during the impact. *(1)* Thus the vehicle dynamic characteristics were not deemed as critical and accounting for the increased vehicle mass was expected to enable a successful evaluation of the barrier system for the *MASH* criteria.

2.3   FREE-STANDING BARRIER WITH GROUTED REBAR-GRID SLOT CONNECTION

To evaluate the performance of the free-standing single slope barrier with grouted rebar-grid connection, the researchers first determined the dynamic response of a single barrier connection using bogie testing. Two 42-inch tall, 20-ft long single-slope barrier segments were connected using the WSDOT grouted rebar-grid connection. The free ends of the barrier segments were constrained from moving laterally by a 5-inch diameter pipe that was anchored to the concrete pavement as shown in figure 2.1. A 5000-lb surrogate bogie vehicle impacted the barrier connection at a 90 degree angle. The purpose of this bogie test was to evaluate the strength of the grouted rebar-grid connection when used with the single-slope barrier in a free-standing condition. The test results were later used to calibrate a model of the grouted rebar-grid slot connection for further evaluation of the overall barrier system performance.
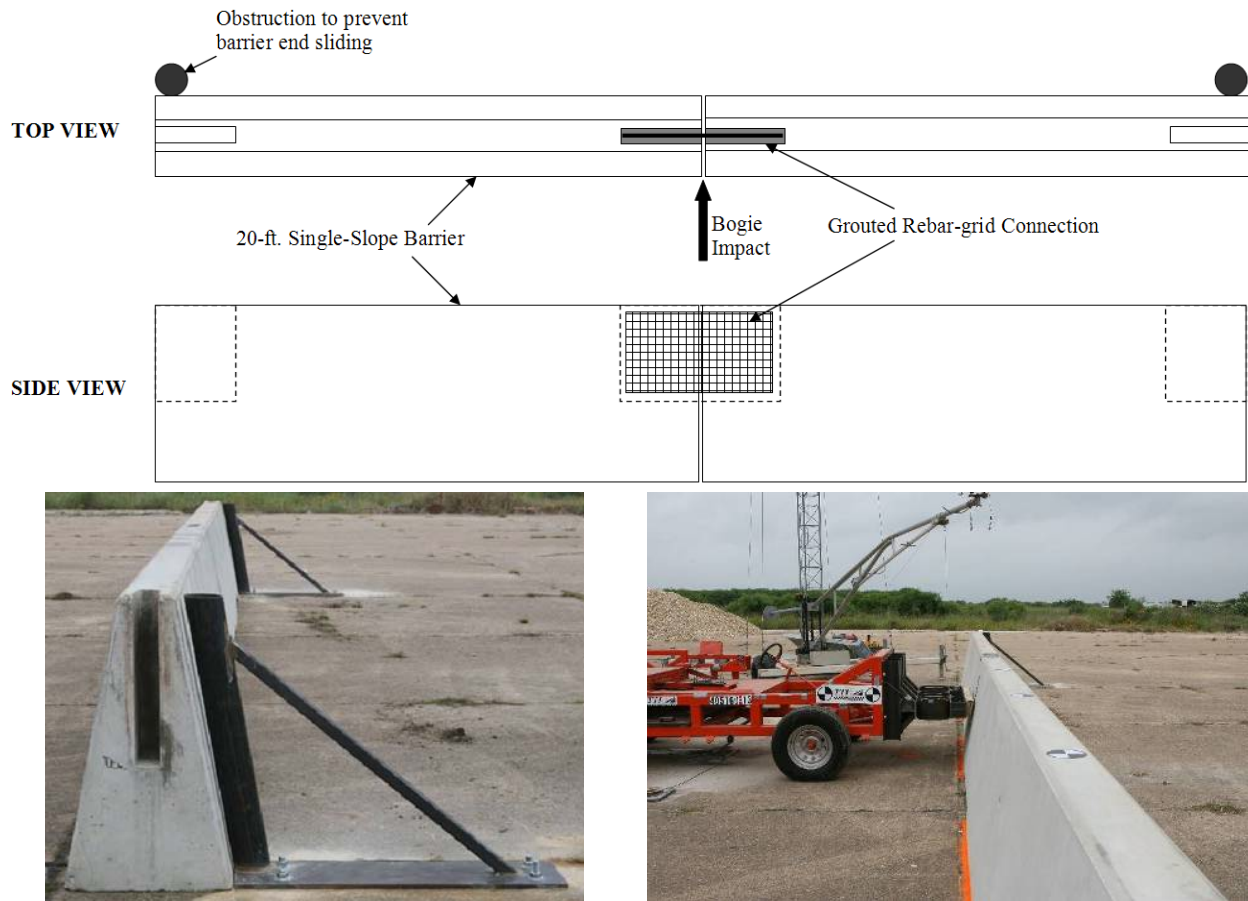
Figure 2.1. Test installation to evaluate strength of the grouted rebar-grid connection.

An appropriate impact speed of the bogie vehicle was determined using simulation analysis. A simulation was performed with the 5000-lb pickup truck vehicle impacting a rigid single slope barrier at 62 mi/h and 25 degree angle (as required by test 3-11 of *MASH*. See figure 2.2). The force of contact between the vehicle and rigid barrier were measured. Another set of simulations was performed where a finite element model of the 5000-lb surrogate bogie vehicle impacted a rigid single slope barrier at 90 degrees (as shown in figure 2.2). The contact force between the bogie vehicle and the rigid barrier were measured for several impact speeds and then compared to the forces resulting from the pickup truck impact with the barrier (as shown in figure 2.3). The comparison revealed that a 15 mi/h impact at 90 degrees provided forces that were approximately equivalent to those resulting from a 62 mi/h impact of the pickup at 25 degrees. Thus, the impact speed of the bogie vehicle in the test was selected to be 15 mi/h.

The 5000-lb bogie vehicle impacted the barriers at the center of the joint at an impact speed of 14 mi/h. The impact in the test resulted in a maximum permanent lateral deflection of 22 inches. The grouted rebar-grid connection cracked near the centerline of the connection (see figure 2.4).
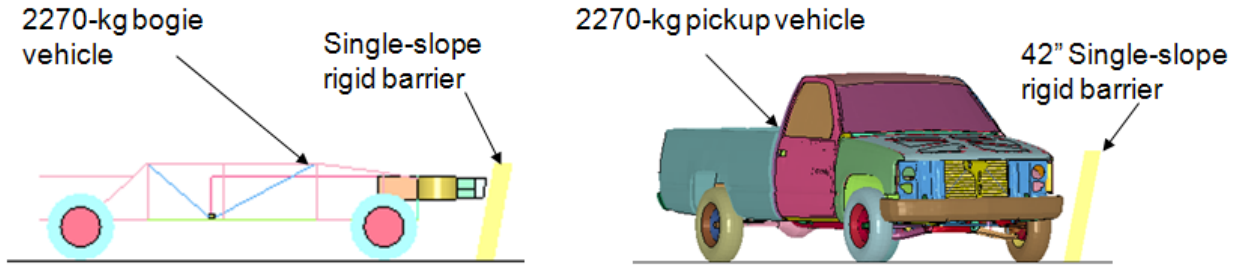
Figure 2.2. Simulation setup for determining lateral force levels for impacts with rigid single slope barrier.
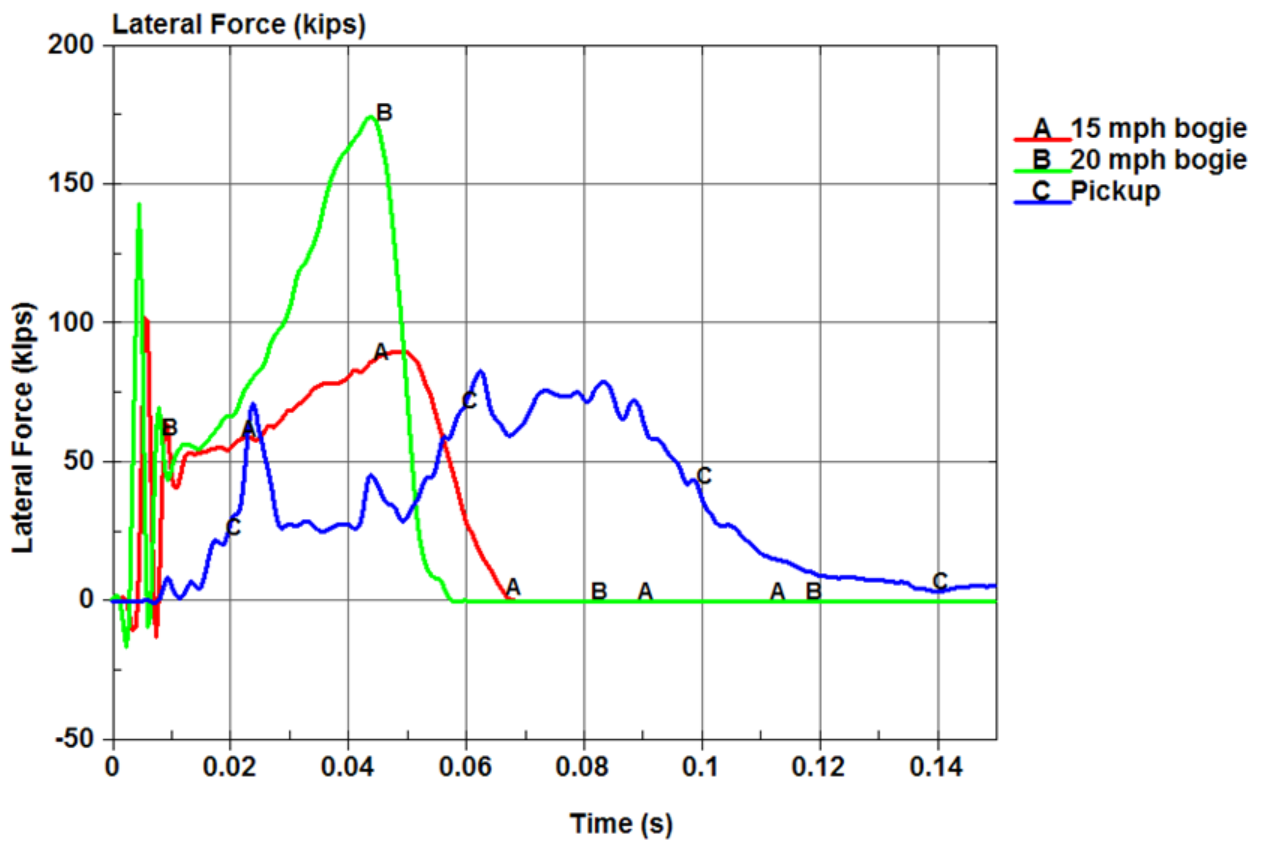
Figure 2.3. Lateral force comparison of pickup truck and bogie vehicle impacts on rigid single slope barrier.

6

Figure 2.4. Barrier after impact from bogie vehicle.

The researchers then developed a finite element model of the barrier installation used in the bogie test. The single slope barrier segments were modeled with mostly rigid material representation. To improve the distribution of forces at interfaces between adjacent barriers and between the barrier and the ground, elastic material representation was used in these regions. The grouted rebar-grid connection was modeled using bi-linear elastic-plastic material and a rebar-grid comprised of beam elements. A 5000-lb bogie vehicle model impacted the barrier modle at the test speed and location. The model of the barrier bogie test setup is shown in figure 2.5.
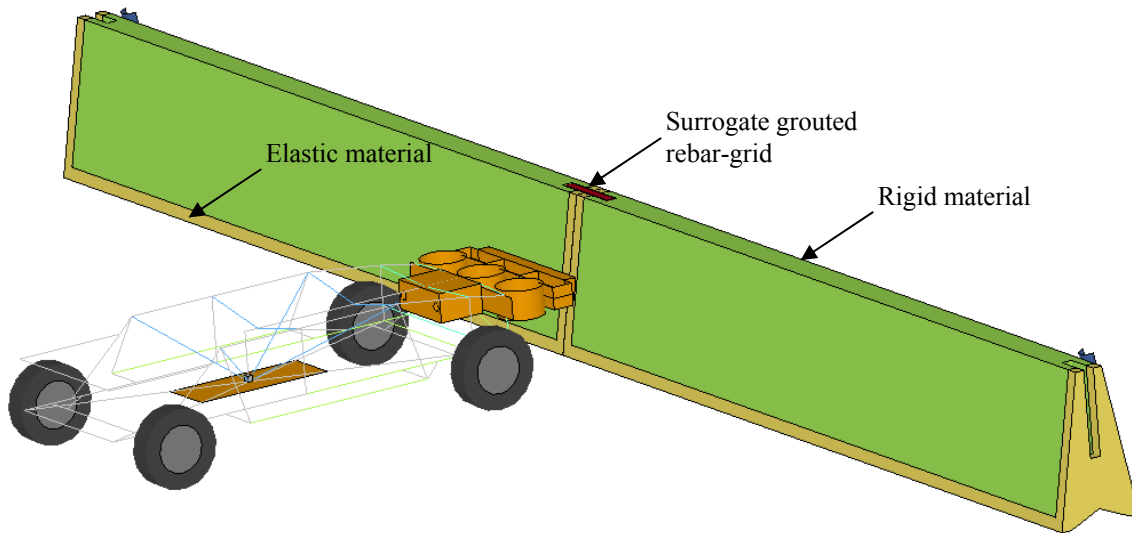
Figure 2.5. Finite element model of the bogie test.

The properties of the surrogate grouted rebar-grid connection in the simulation model were calibrated to match the lateral deflection of the barrier observed in the test. Figure 2.6 shows the calibrated simulation results compared to the crash test results.

Once the response of a single grouted rebar-grid connection was calibrated, the researchers developed a 100-ft long full-scale barrier system model to evaluate the free-standing single slope barrier under *MASH* TL-3 impact conditions (i.e. impact with a 5000-lb vehicle at 62 mi/h and 25 degrees). The objective of this simulation was to determine if the overall lateral deflection of the free-standing barrier installation was small enough to allow its use adjacent to slopes or on MSE walls without requiring any restraining mechanisms. The barrier system model was comprised of five 20-ft long single slope barrier segments that were connected using the calibrated grouted rebar-grid slot connection model. The 5000-lb vehicle impacted the barrier 4 ft upstream of the connection between the second and the third barrier segment as shown in figure 2.7.

In the simulated impact, the free standing barrier had a deflection greater than 30 inches. This deflection was much higher than acceptable as per the objectives of this research. Hence, the researchers started investigating ways of restraining the barrier to limit lateral deflections.
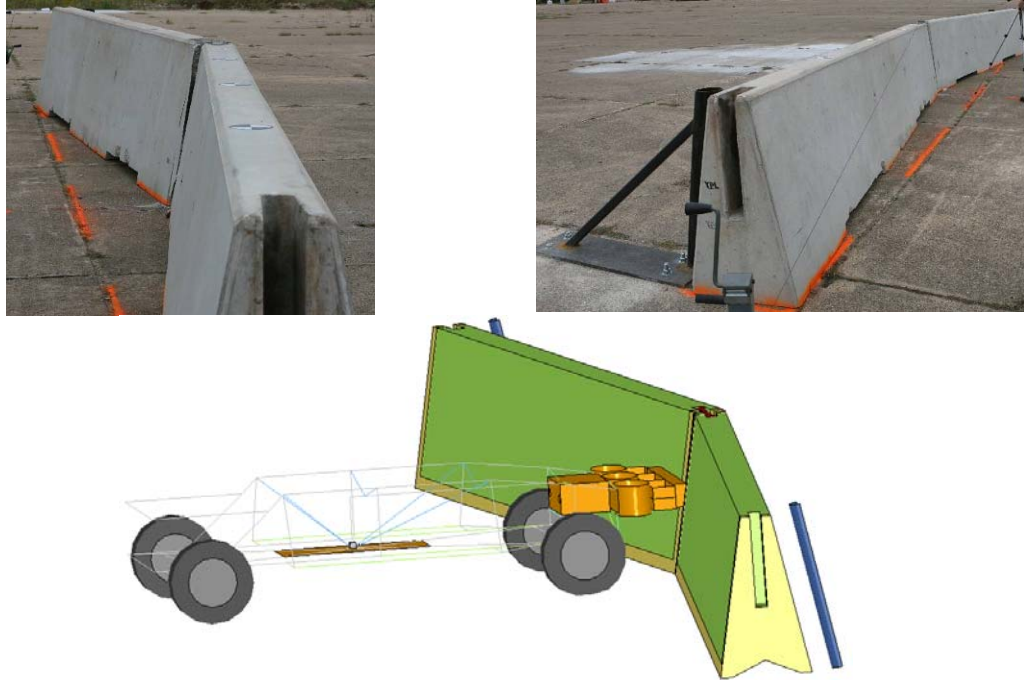
Figure 2.6. Results of the bogie crash test and simulation analysis.
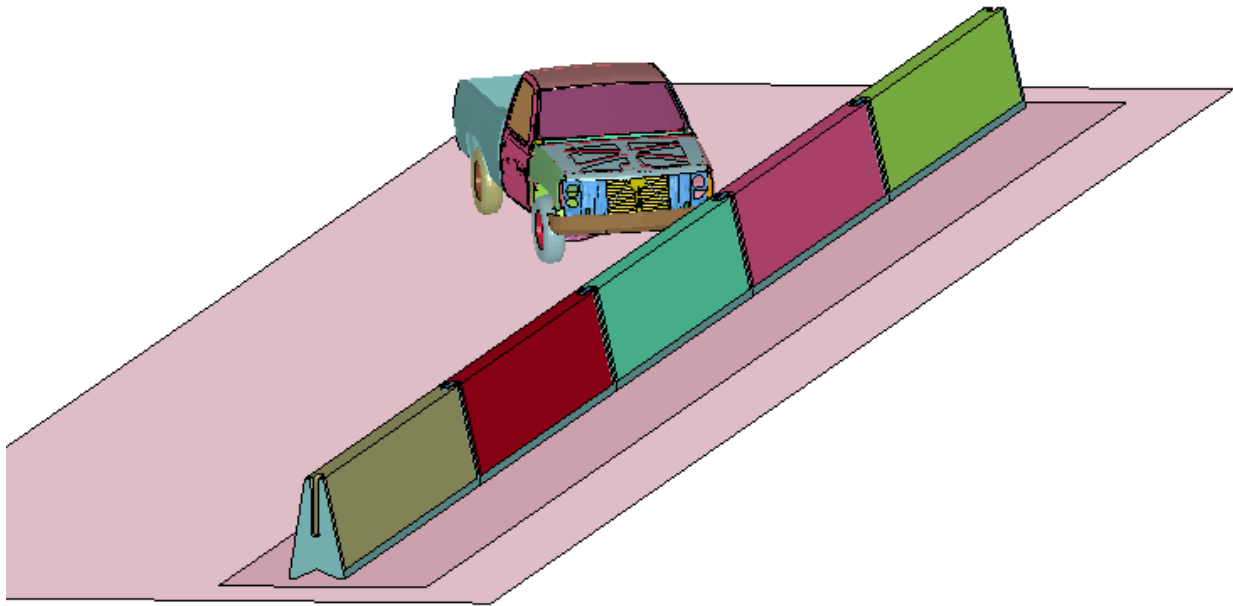
**Figure 2.7. Finite element model of the 100-ft installation
of free-standing single slope barrier.**

2.4   EMBEDDED BARRIER WITH GROUTED REBAR-GRID SLOT CONNECTION

Various methods of restraining the barriers were considered, such as anchoring with steel pins, using steel straps to tie barrier segments, etc. In consultation with the technical representatives of the participating pooled fund states, it was decided to investigate direct embedment of the barrier in soil. This method allowed the use of existing hardware inventory without any modifications. The embedment depth was 10 inches. A typical single slope barrier used by the sponsoring pooled fund states is 42 inches tall. The states did not perceive any related problems with reducing the effective height of the single slope barrier to 32 inches as a result of the 10-inch embedment. The 32-inch barrier height is typical for other commonly used safety shape barriers such as the New Jersey and the F-shape barriers.

The researchers conducted another bogie impact test with two single-slope barrier segments connected via grouted rebar-grid slot connection and embedded 10 inches in soil. The width of the soil behind the barrier was 24 inches behind the barrier. A 1.5H:1V slope was used for the soil cut, as shown in the test setup in figure 2.8. The type of soil and the compaction method used were as specified in the *MASH* gudielines. The 5004-lb bogie vehicle impacted the barrier at the joint at a speed of 14.4 mi/h. The maximum permanent barrier deflection was 4.45 inches at the joint. The researchers then incorporated a 10-inch soil layer into the finite element model and calibrated the soil properties by conducted bogie vehicle impact simulations until the results matched the barrier deflection observed in the test (see figure 2.9).
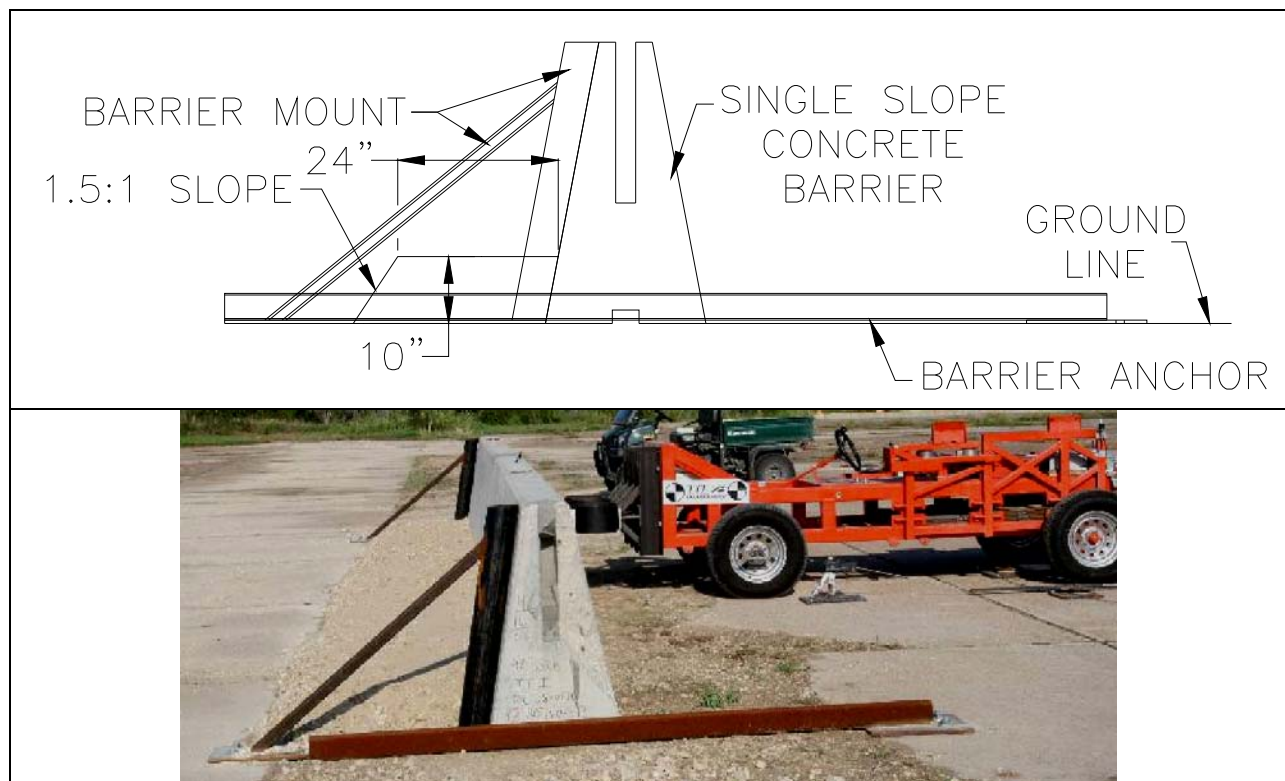
Figure 2.8. Bogie test setup for embedded barriers.
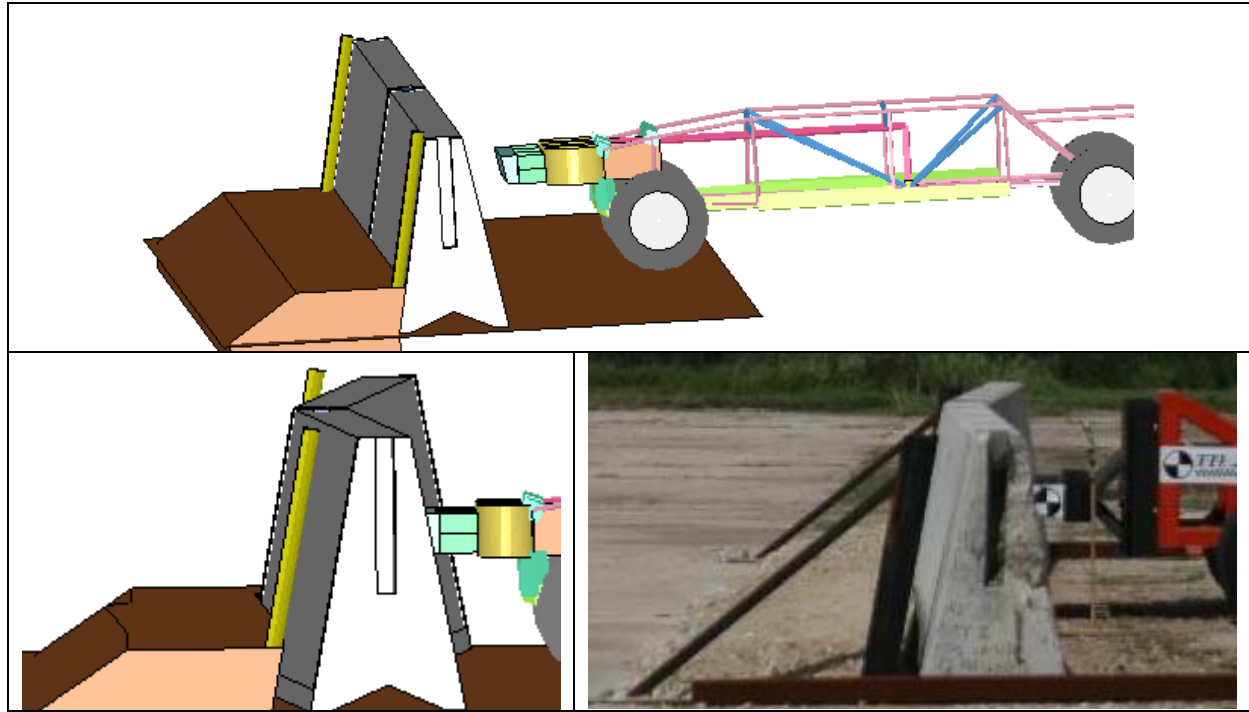
Figure 2.9: Simulation and test results of bogie impacted with embedded barriers.

The researchers used the calibrated embedded barrier to develop a 100-ft long full-scale barrier system model. The installation was comprised of five 20-ft long single-slope barrier segments, connected using grouted rebar-grid connection and embedded 10 inches in soil behind the barrier (i.e. on the field side). The field side of the barriers was offset 2 ft from the 1.5H:1V slope. A simulation was performed with a 5000-lb vehicle impacting the barrier at 25 degrees and 62 mi/h (see figure 2.10). The vehicle impacted the barrier 4 ft upstream of the connection between the second and the third barrier segment. The vehicle was successfully contained and redirected by the embedded barrier system. The maximum permanent deflection of the barrier was 10 inches. The deflection of the barrier after the impact is shown in figure 2.10.
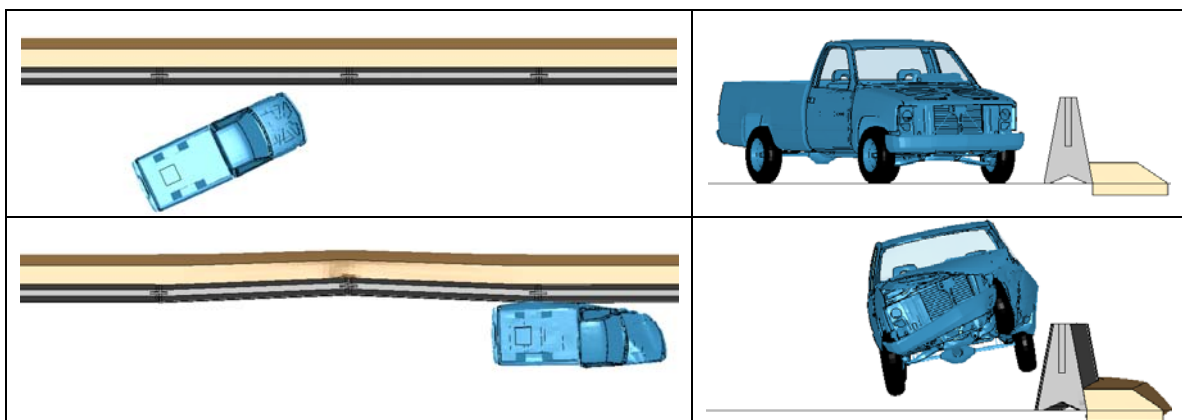
Figure 2.10: Simulation results with soil behind the barrier
(initial (top) and final (bottom) states).

11

As mentioned above, in the initial simulation the soil was present only behind the barrier, to match the bogie test configuration. Thus, the effective height of the barrier remained 42 inches for the impacting vehicle. A field installation of the embedded barrier can involve scenarios when the barrier is embedded in soil both in front and back of the barrier. In this case, the effective height of the barrier for the impacting vehicle is reduced to 32 inches, which could result in greater vehicular instability. Presence of the soil in front and back of the barrier is expected to lower the lateral barrier deflection slightly, which would be desirable for this design. To quantify the differences between the two installation scenarios, the researchers performed another simulation where soil was added to the front of the barrier as well. The mass of the vehicle and the impact conditions remained the same. Simulation results showed that the maximum permanent deflection of the barrier in this case was 9.75 inches (see figure 2.11). When compared to the previous simulation, the reduction in lateral barrier deflection was insignificant. Even though the vehicle was redirected successfully in both simulations, slightly greater vehicle roll was observed when the barrier was installed with soil on both sides (i.e. when the effective barrier height was reduced to 32 inches).
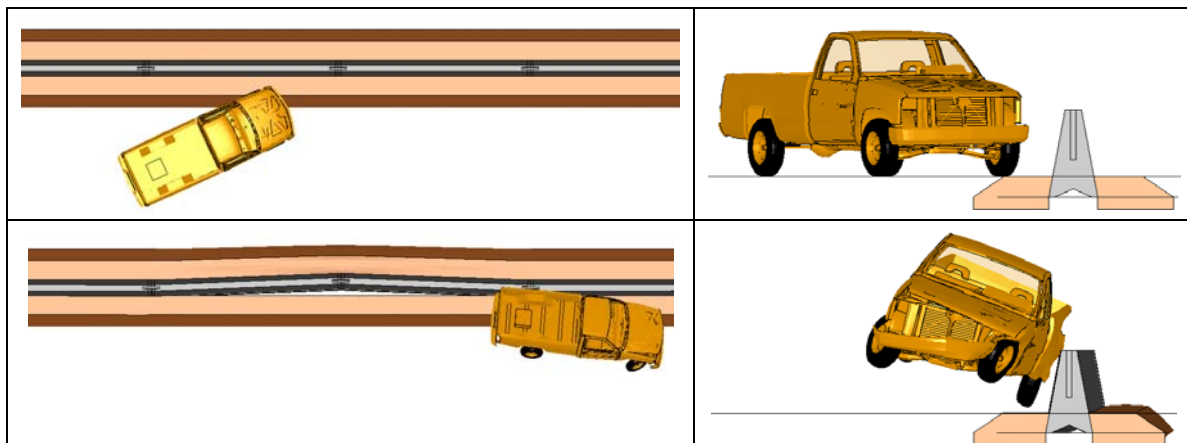
Figure 2.11. Simulation results with soil on both sides of barrier (initial (top) and final (bottom) states).

2.5   CONCLUSIONS

Using a combination of bogie testing and simulation analysis, the researchers determined that the free standing single slope barrier with the grouted rebar-grid slot connection cannot provide adequate lateral resistance to allow its use adjacent to 1.5H:1V slopes or on MSE walls when the offset behind the barrier is 2 ft or less. Simulation results indicated that the free-standing barrier is likely to result in lateral deflection of greater than 30 inches, which is significantly more than the desired deflection for this project.

The researchers then evaluated a single slope barrier embedded 10 inches in soil. In this case, the lateral deflection of the barrier was significantly reduced. The embedded barrier was evaluated both with the soil present in front and behind the barrier, and with soil present only behind the barrier. Simulation results indicated that the vehicle was successfully contained and

redirected in both cases and the requirement of reduced lateral deflection was met. In the case when soil was present on both sides of the barrier, higher vehicle roll was observed. This was expected because the barrier embedment reduced the height of the barrier from 42 inches to 32 inches. Based on these results, the researchers recommended that the crash test be performed on a single slope barrier using grouted rebar-grid connection embedded 10 inches in soil on both sides. This was considered to be the more critical configuration in regard to impact performance. Thus, a successful test could validate the use of both configurations.

3. SYSTEM DETAILS

3.1   TEST ARTICLE DESIGN AND CONSTRUCTION

The test article was comprised of a 100-ft long installation of single-slope concrete barrier embedded 10 inches in soil. Five 20-ft long barrier segments were connected using the grouted rebar-grid slot connections to achieve the 100-ft installation length.

The single-slope barrier segments were 42 inches tall, 24 inches wide at the base and 8 inches wide at the top. At each end of the barrier segments, a 3-inch wide, 24-inch deep, and 10.5-inch long slot was cast into the barrier to accommodate the grouted rebar-grid connection. The concrete reinforcement of the barrier segments was comprised of #4 vertical bars that were bent to approximately match the profile of the barrier faces and were spaced 12 inches apart along the length of the barrier. The spacing of the vertical bars was reduced around the slot cast at each end for the grouted rebar-grid connection. The vertical bars, ten #5 longitudinal bars were located along the height of the barrier. A 4-inch wide, 2-inch high slot was cast at the bottom of the segments along their centerline.

The barrier was embedded in crushed limestone road base material that conforms to *MASH* standard soil. To embed the barrier to a depth of 2-ft, the native soil adjacent to the testing facility's concrete pavement was excavated. The excavated area was then backfilled with standard *MASH* soil and compacted in approximately 6-inch lifts. Once the backfill soil reached a level of 10 inches below the concrete pavement surface, the barrier was set in place and further soil was added and compacted in front and back of the barrier. As the soil was backfilled, a 1.5H:1V slope was built into the embankment with the breakpoint located 2 ft from the field side of the barrier.

A rebar-grid was then dropped into the slot at each barrier connection location. It was comprised of two vertical #6 bars that were spaced 10 inches apart, and three longitudinal #8 bars that were spaced eight inches apart. With the rebar-grid in place, the connection was grouted using a non-shrink grout.

Details of the test article are shown in figures 3.1 and 3.2, and Appendix A.

3.2   MATERIAL SPECIFICATIONS

The barrier concrete was specified to have a minimum 28-day compressive strength of 4000 psi. The reinforcing steel was specified to be grade 60. The steel material used for manufacturing the rebar-grid was also specified to be grade 60 (see appendix B for MIL certificates). The grout used for making the connection was Shelper #1107 non-shrink grout which had a minimum compressive strength of 4000 psi (see appendix C for compressive strength test results). The soil used for embedding the barriers was a crushed limestone road base material that conforms to standard *MASH* soil. The moisture content of the soil on the day of the test was 8.5%.

SINGLE SLOPE
CONCRETE
BARRIER
DETAIL A

GROUND
LINE

SLOT FOR
REBAR GRID

24"

1.5:1 SLOPE

12"

10"

24"

AVG. 8" THK.
CONCRETE
APRON

END VIEW

MASH 2008
STD. SOIL
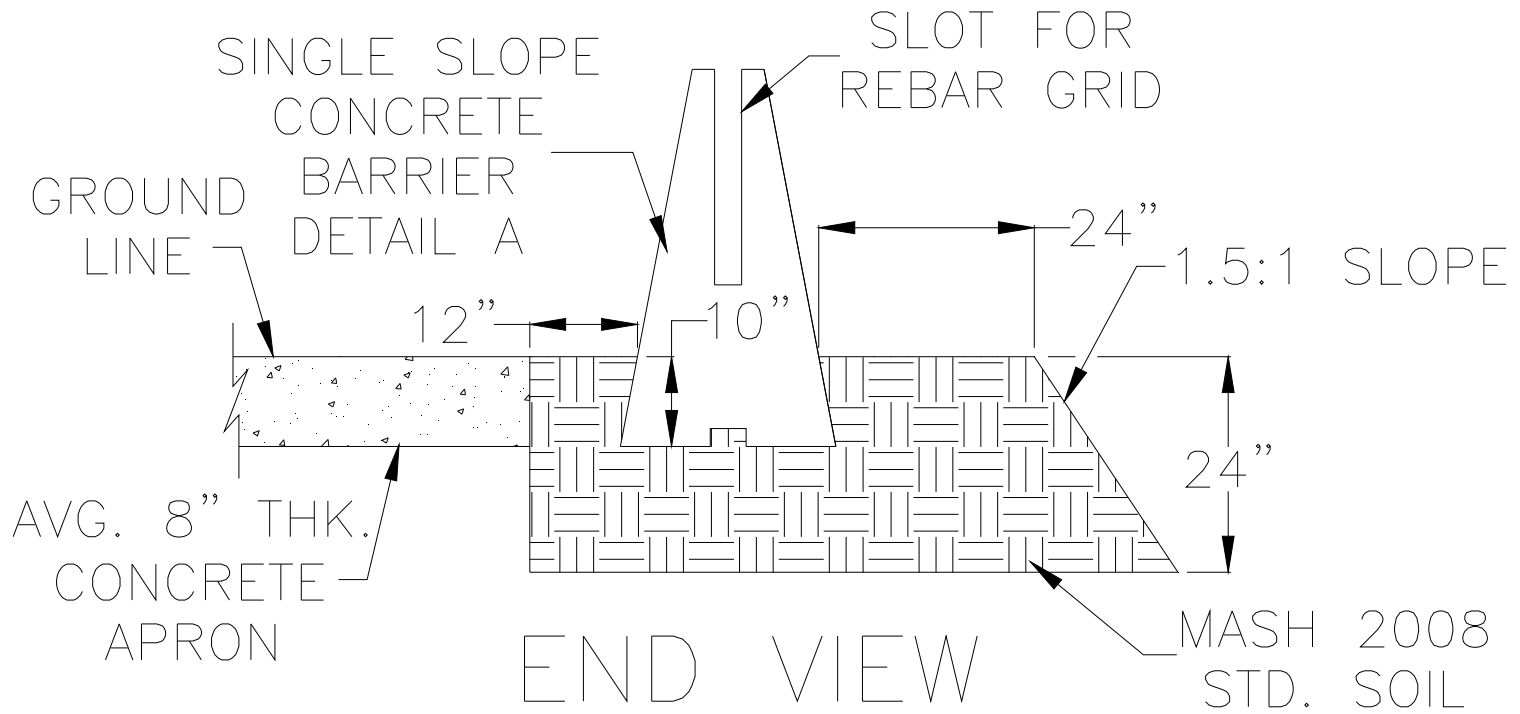
Figure 3.1. Layout of the single-slope barrier in front of 1.5:1 slope.

Figure 3.2. Single-slope barrier in front of 1.5:1 slope prior to testing.

4. TEST REQUIREMENTS AND EVALUATION CRITERIA

4.1   CRASH TEST MATRIX

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

> *MASH* **Test Designation 3-10:** A 2425 lb vehicle impacting the critical impact point (CIP) of the length of need section at a speed of 62 mi/h and an angle of 25 degrees.

> *MASH* **Test Designation 3-11:** A 5000 lb pickup truck impacting the CIP of the length of need section at a speed of 62 mi/h and an angle of 25 degrees.

The researchers performed test 3-11 of *MASH* (5000 lb vehicle, 62 mi/h, 25 degrees) on the embedded single-slope barrier system. It is argued that this is the critical test for this design and the test with smaller 2425 lb vehicle is not needed. Due to higher impact energy, the test with the 5000 lb pickup truck will result in greater impact load on the connections and greater lateral deflection. An impact resulting from the lighter 2425 lb passenger car under same impact speed and angle will not result in any increase in lateral deflection of the barrier nor will it impart a higher force on the barrier to evaluate connection strength and barrier rotation. Due to the small deflection expected in the test, the small car impact with the embedded single-slope barrier is expected to be similar to an impact into a rigid single-slope barrier. Thus, the test was conducted with the 5000 lb pickup only.

The crash test and data analysis procedures were in accordance with guidelines presented in *MASH*. Chapter 5 presents brief descriptions of these procedures.

4.2   EVALUATION CRITERIA

The crash test was evaluated in accordance with the criteria presented in *MASH*. The performance of the barrier is judged on the basis of three factors: structural adequacy, occupant risk, and post impact vehicle trajectory. Structural adequacy is judged upon the barrier's ability to contain and redirect the vehicle, or bring the vehicle to a controlled stop in a predictable manner. 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 assessed to determine potential for secondary impact with other vehicles or fixed objects, creating 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 test reported herein, and are listed in further detail under the assessment of the crash test.

5. TEST CONDITIONS

5.1   TEST FACILITY

The full-scale crash test was performed at Texas Transportation Institute (TTI) Proving Ground. TTI Proving Ground is an International Standards Organization (ISO) 17025 accredited laboratory with American Association for Laboratory Accreditation (A2LA) Mechanic Testing certificate 2821.01. The full-scale crash test was performed according to TTI Proving Ground quality procedures and according to the *MASH* guidelines and standards.

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

5.2   VEHICLE TOW AND GUIDANCE SYSTEM

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

5.3   DATA ACQUISITION SYSTEMS

5.3.1   Vehicle Instrumentation and Data Processing

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

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

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

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

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

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

5.3.2 Anthropomorphic Dummy Instrumentation

Use of a dummy in the 2270P vehicle is optional according to *MASH*, and there was no dummy used in the test 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 films from these high-speed cameras were analyzed on a computer-linked motion analyzer to observe phenomena occurring during the collision and to obtain time-event, displacement, and angular data. A mini-DV camera and still cameras recorded and documented conditions of the test vehicle and installation before and after the test.

6. CRASH TEST 405160-13-1 (*MASH* TEST NO. 3-11)

6.1   TEST DESIGNATION AND ACTUAL IMPACT CONDITIONS

MASH test 3-11 involves a 2270P vehicle weighing 5000 lb ±100 lb and impacting the barrier at an impact speed of 62.2 mi/h ±2.5 mi/h and an angle of 25 degrees ±1.5 degrees. The target impact point was 4 ft upstream of the centerline of the joint located between segments 2 and 3. The 2002 Dodge pickup used in the test weighed 4953 lb and the actual impact speed and angle were 63.1 mi/h and 24.2 degrees, respectively. The actual impact point was 62.0 inches upstream of the joint between segments 2 and 3.

6.2   TEST VEHICLE

A 2002 Dodge Ram 1500 quad-cab pickup, shown in figures 6.1 and 6.2, was used for the crash test. Test inertia weight of the vehicle was 4953 lb. The height to the lower edge of the vehicle's front bumper was 13.5 inches, and the height to the upper edge of the front bumper was 26.0 inches. The height to the center of gravity was 28.12 inches. Additional dimensions and information on the vehicle are given in appendix D, figure D1. 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 crash test was performed the morning of April 16, 2009. Weather conditions at the time of testing were: Wind speed: 7 mi/h; wind direction: 90 degrees with respect to the vehicle (vehicle was traveling in a southwesterly direction); temperature: 70 ºF; relative humidity: 71 percent.

6.4   TEST DESCRIPTION

The 2270P vehicle, traveling at an impact speed of 63.1 mi/h, impacted the single-slope barrier 62 inches upstream of the joint between segments 2 and 3, at an impact angle of 24.2 degrees. At approximately 0.042 s, the right front tire began to climb the face of the barrier and the vehicle began to redirect. At 0.169 s, the vehicle was parallel to the barrier and was traveling at a speed of 58.7 mi/h. At 0.173 s, the right rear of the vehicle contacted the barrier, and at 0.176 s, the vehicle began to roll clockwise. The right rear corner of the bed of the vehicle contacted the top of the barrier at 0.616 s, and after that, dust obscured the view in all camera views. Brakes on the vehicle were applied 1.5 s after impact, and the vehicle came to rest 247 ft downstream of impact and 10 ft toward traffic lanes. Sequential photographs of the test period are shown in appendix D, figures D2 and D3.

Figure 6.1. Vehicle/installation geometrics for test 405160-13-1.

Figure 6.2. Vehicle before test 405160-13-1.

6.5　TEST ARTICLE AND COMPONENT DAMAGE

Damage to the barrier is shown in figures 6.3 and 6.4. Tire marks were observed on the traffic face of the barrier and there was no evidence of cracking in the barrier. Length of contact of the vehicle with the barrier was 14.0 ft. Maximum permanent deflection of the barrier was 5.5 inches. Working width was 19.6 inches. Maximum dynamic deflection during the test was 5.6 inches.

6.6　TEST VEHICLE DAMAGE

The 2270P vehicle sustained damage to the right front corner and along the right side, as shown in figure 6.5. The right upper A-arm, right tie rod end, and sway bar were deformed. Also damaged were the front bumper, grill, right front fender, right front and rear doors, right exterior side of bed, rear bumper, and tailgate. The right front and rear wheel rims were deformed and the right front tire was deflated. Maximum exterior crush to the vehicle was 14.0 inches in the side plane at the right front corner at bumper height. Maximum occupant compartment deformation was 0.5 inches in the right front door at hip height. Photographs of the interior of the vehicle are shown in figure 6.6. Exterior vehicle crush and occupant compartment measurements are shown in appendix D, tables D1 and D2.

6.7　OCCUPANT RISK VALUES

Data from the accelerometer, located at the vehicle's center of gravity, were digitized for evaluation of occupant risk. In the longitudinal direction, the occupant impact velocity was 12.1 ft/s (3.7 m/s) at 0.090 s, the highest 0.010-s occupant ridedown acceleration was -2.4 Gs from 0.173 to 0.183 s, and the maximum 0.050-s average acceleration was -6.5 Gs between 0.009 and 0.059 s. In the lateral direction, the occupant impact velocity was 24.6 ft/s (7.5 m/s) at 0.090 s, the highest 0.010-s occupant ridedown acceleration was -11.3 Gs from 0.187 to 0.197 s, and the maximum 0.050-s average was -13.0 Gs between 0.026 and 0.076 s. Theoretical Head Impact Velocity (THIV) was 29.6 km/h or 8.2 m/s at 0.089 s; Post-Impact Head Decelerations (PHD) was 11.3 Gs between 0.187 and 0.197 s; and Acceleration Severity Index (ASI) was 1.56 between 0.020 and 0.070 s. These data and other pertinent information from the test are summarized in figure 6.7. Vehicle angular displacements and accelerations versus time traces are presented in appendix D, figures D4 through D10.

Figure 6.3. Vehicle trajectory path after test 405160-13-1.

Figure 6.4. Installation after test 405160-13-1.

Figure 6.5. Vehicle after test 405160-13-1.

Before Test

After Test

Figure 6.6. Interior of vehicle for test 405160-13-1.

| 0.000 s | 0.098 s | 0.296 s | 0.393 s |
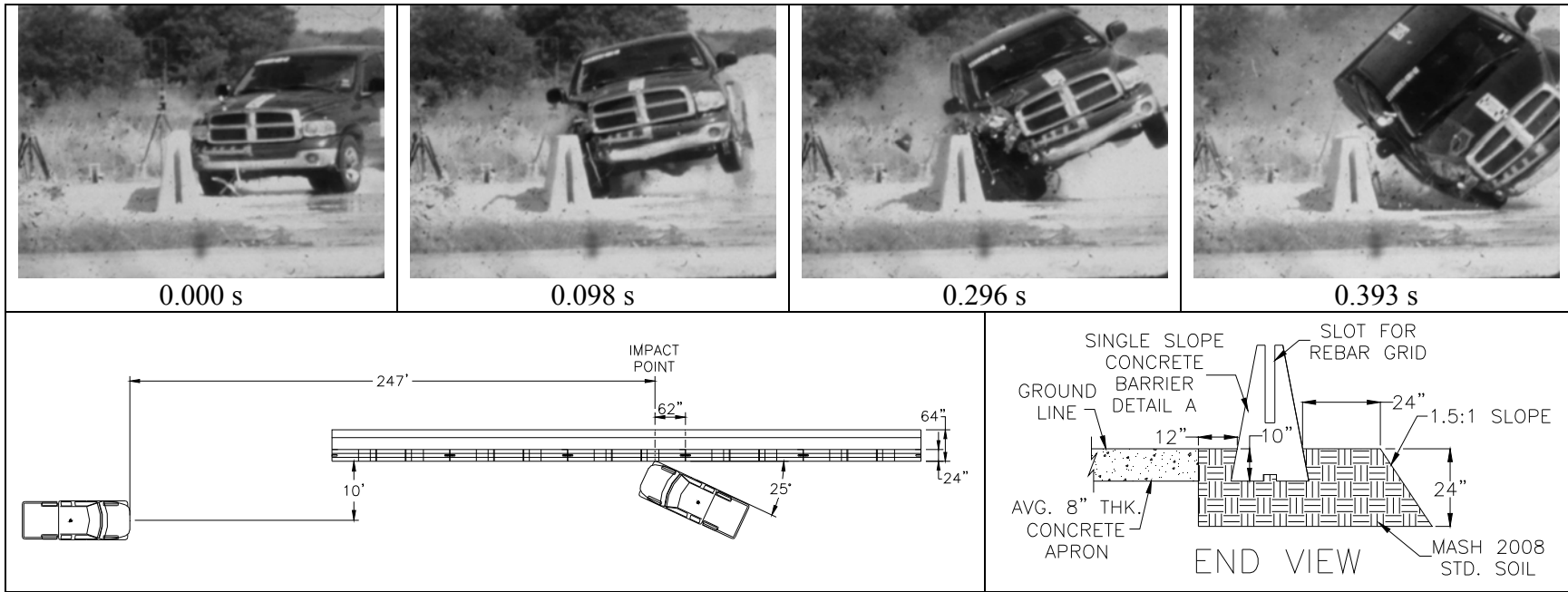
General Information
Test Agency............................ Texas Transportation Institute
Test No. 405160-13-1
Date .... April 16, 2009

Test Article
Type.. Concrete Barrier
Name .... Single-Slope Barrier offset 2 ft from 1.5:1 Slope
Installation Length .... 100 ft
Material or Key Elements .... 42-inch tall x 20 ft long single-slope concrete barrier embedded 10 inches in soil in front of 1.5H:1V slope
Soil Type and Condition........... Standard Soil, Dry

Test Vehicle
Type/Designation...................... 2270P
Make and Model .... 2002 Dodge Ram 1500 Pickup
Curb.. 4630 lb
Test Inertial.............................. 4953 lb
Dummy .... No Dummy
Gross Static .... 4953 lb

Impact Conditions
Speed ....63.1 mi/h
Angle ....24.2 degrees
Location/Orientation ....62 inch upstrm Joint 2-3
Exit Conditions
Speed ....Out of view
Angle ....Out of view
Occupant Risk Values
Impact Velocity
Longitudinal........................12.1 ft/s
Lateral ....24.6 ft/s
Ridedown Accelerations
Longitudinal........................ -2.4 G
Lateral ....-11.3 G
THIV .... 29.6 km/h
PHD .... 11.3 G
Max. 0.050-s Average
Longitudinal........................ -6.5 G
Lateral ....-13.0 G
Vertical .... -4.2 G

Post-Impact Trajectory
Stopping Distance .... 247 ft dwnstrm
10 ft fwd
Vehicle Stability
Maximum Yaw Angle.....................-42 degrees
Maximum Pitch Angle....................-11 degrees
Maximum Roll Angle...................... 44 degrees
Vehicle Snagging...........................No
Vehicle Pocketing ....No

Test Article Deflections
Dynamic..5.6 inches
Permanent ....5.5 inches
Working Width ....19.6 inches

Vehicle Damage
VDS 01RFQ5
CDC..01RFEW4
Max. Exterior Deformation............. 14.0 inches
Max. Occupant Compartment
Deformation..............................0.56 inch

Figure 6.7. Summary of results for *MASH* test 3-11 on the single-slope barrier on 1.5:1 slope.

6.8   ASSESSMENT OF TEST RESULTS

An assessment of the test was made based on the following applicable *MASH* safety evaluation criteria.

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 single-slope barrier in front of 1.5H:1V slope contained and redirected the 2270P vehicle. The vehicle did not penetrate, underride, or override the installation. Maximum dynamic deflection during the test was 5.6 inches. (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.*

Results: No detached elements, fragments, or other debris were present to penetrate or show potential to penetrate the occupant compartment, or to present undue hazard to others in the area. (PASS)
Maximum occupant compartment deformation was 5.5 inches. (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 was 44 degrees. (PASS)

H.   *Occupant impact velocities should satisfy the following:*
     Longitudinal and Lateral Occupant Impact Velocity
          Preferred   *Maximum*
          9.0 m/s (30 ft/s)   *12.2 m/s (40 ft/s)*

Results: Longitudinal occupant impact velocity was 12.1 ft/s, and lateral occupant impact velocity was 24.6 ft/s. (PASS)

I.   *Occupant ridedown accelerations should satisfy the following:*
     Longitudinal and Lateral Occupant Ridedown Accelerations
          Preferred   *Maximum*
          15.0 Gs   *20.49 Gs*

Results: Longitudinal ridedown acceleration was -2.4 G, and lateral ridedown acceleration was -11.3 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)

7. SUMMARY AND CONCLUSIONS

7.1   SUMMARY

To restrict the lateral deflection of a single slope barrier when placed adjacent to 1.5H:1V slope or on top of an MSE wall, a 100-ft installation of the barrier was embedded 10 inches in soil. The effective height of the single slope barrier was thus reduced to 32 inches due to the 10 inch embedment. The barrier was placed at a 2-ft lateral offset from the 1.5H:1V slope break point of the soil embankment. The concrete barrier was comprised of five 20-ft long barrier segments that were connected using the grouted rebar-grid connection. The embedded barrier was crash tested using *MASH* test level 3 criteria.

The embedded single-slope barrier successfully contained and redirected the 2270P vehicle. The vehicle did not penetrate, underride, or override the installation. Maximum dynamic and static deflections of the barrier during the test were 5.6 inches and 5.5 inches, respectively. No detached elements, fragments, or other debris were present to penetrate or show potential to penetrate the occupant compartment, or to present undue hazard to others in the area. Maximum occupant compartment deformation was 5.5 inches. The 2270P vehicle remained upright during and after the collision event. Maximum roll was 44 degrees. Occupant risk factors were within the limits specified in *MASH*. The vehicle remained within the exit box.

7.2   CONCLUSIONS

The objective of the this research was to restrict lateral deflection of the barrier when placed adjacent to steep slopes such as 1.5H:1V or on top of MSE walls, without using a concrete moment slab.

The final design was required to incorporate 20-ft long single slope barrier segments with grouted rebar grid connection. Since the performance of the grouted rebar-grid connection in a free-standing single slope barrier was not known under *MASH* evaluation criteria, the researchers evaluated its performance using a smaller scale bogie impact test and simulation analysis. It was determined that the grouted rebar grid connection did not provide enough strength to restrict lateral deflections to acceptable levels for this application. Results of the simulation analysis showed that large lateral deflection was expected with the grouted rebar-grid connection when used with the single slope barrier in a free-standing mode.

The researchers then evaluated restricting the deflection of the barrier by embedding it 10 inches in soil. The barrier was placed in front of a 1.5H:1V slope. The offset of the barrier from the slope break point of the soil embankment was restricted to two feet. Another phase of bogie testing and simulation analysis was performed to evaluate the performance of the grouted rebar grid connection in the embedded barrier configuration. Results of the simulation analysis showed that the embedded barrier system will result in acceptably reduced lateral deflections.

The researchers performed simulations of the 100-ft long installation of the embedded barrier with soil present in front and behind the barrier, and with soil present only behind the barrier. Both configurations resulted in a successful redirection of the vehicle. It was determined that there were no significant differences in the lateral barrier deflection resulting from these two configurations. However, simulation results indicated that due the reduced effective height of the barrier when soil layer is present in front of the barrier, the vehicle exhibited slightly higher climb and roll. Thus the researchers recommended performing the crash test in the configuration where soil is present in front and behind the barrier.

A full-scale crash test was subsequently performed to validate the design. The embedded single-slope barrier in front of 1.5H:1V slope performed acceptably according to the requirements of *MASH*, as shown in table 7.1. The permanent lateral deflection of the barrier was 5.5 inches.

Based on the successful test of the embedded barrier with soil present in front and behind the barrier, the configuration with soil present only behind the barrier is also considered acceptable provided proper placement and compaction of the soil behind the barrier is achieved. While the embedded barrier design was tested in front of a 1.5H:1V slope, due to the small lateral barrier deflection, it is also considered suitable for use on top of an MSE wall.

Table 7.1. Performance evaluation summary for *MASH* test 3-11 on the single-slope barrier on slope.

Test Agency: Texas Transportation Institute   Test No.: 405160-13-1   Test Date: 2009-04-16

MASH Evaluation Criteria	Test Results	Assessment
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*	The single-slope barrier in front of 1.5H:1V slope contained and redirected the 2270P vehicle. The vehicle did not penetrate, underride, or override the installation. Maximum dynamic deflection during the test was 5.6 inches.	Pass
Occupant Risk D. *Detached elements, fragments, or other debris from the test article should not penetrate or show potential for penetrating the occupant compartment, or present an undue hazard to other traffic, pedestrians, or personnel in a work zone.*	No detached elements, fragments, or other debris were present to penetrate or show potential to penetrate the occupant compartment, or to present undue hazard to others in the area.	Pass
Deformations of, or intrusions into, the occupant compartment should not exceed limits set forth in Section 5.3 and Appendix E of MASH.	Maximum occupant compartment deformation was 5.5 inches.	Pass
F. *The vehicle should remain upright during and after collision. The maximum roll and pitch angles are not to exceed 75 degrees.*	The 2270P vehicle remained upright during and after the collision event. Maximum roll was 44 degrees.	Pass
H. *Longitudinal and lateral occupant impact velocities should fall below the preferred value of 9.1 m/s (30 ft/s), or at least below the maximum allowable value of 12.2 m/s (40 ft/s).*	Longitudinal occupant impact velocity was 12.1 ft/s, and lateral occupant impact velocity was 24.6 ft/s.	Pass
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.*	Longitudinal ridedown acceleration was -2.4 G, and lateral ridedown acceleration was -11.3 G.	Pass
Vehicle Trajectory		
For redirective devices, the vehicle shall exit the barrier within the exit box.	The vehicle remained within the exit box.	Pass

*Criterion K and M are preferable, not required.

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GROUTED
REBAR GRID
DETAIL C

SLOT FOR
REBAR GRID

DRAINAGE SLOT

24"

PLAN

100'

20' | 20' | 20' | 20' | 20'

42"

DRAINAGE SLOT

GROUND
LINE

ELEVATION

STL. PIPE SLEEVE
FOR LIFTING RODS

SINGLE SLOPE
CONCRETE BARRIER
DETAIL A TYP.

SINGLE SLOPE
CONCRETE
BARRIER
DETAIL A

SLOT FOR
REBAR GRID

GROUND
LINE

12"

10"

24"

1.5:1 SLOPE

24"

AVG. 8" THK.
CONCRETE
APRON

END VIEW A—A

MASH 2008
STD. SOIL
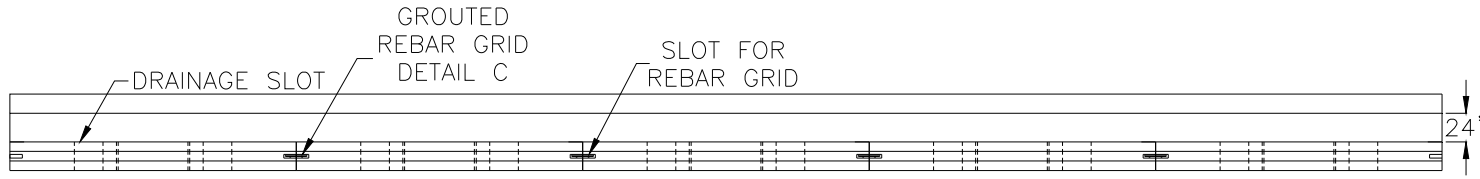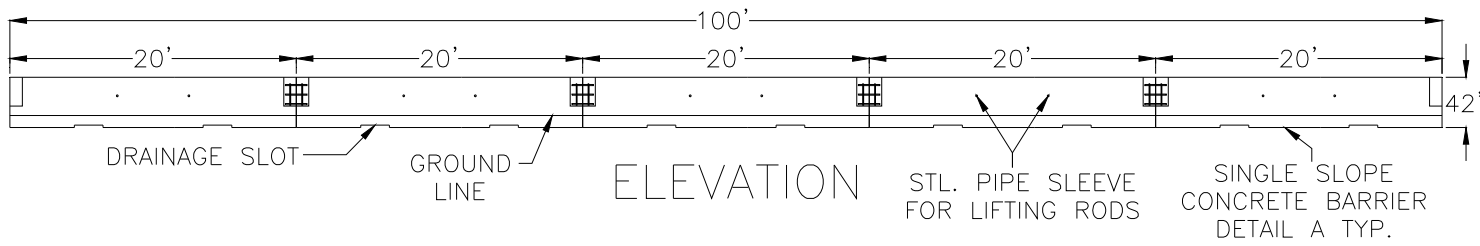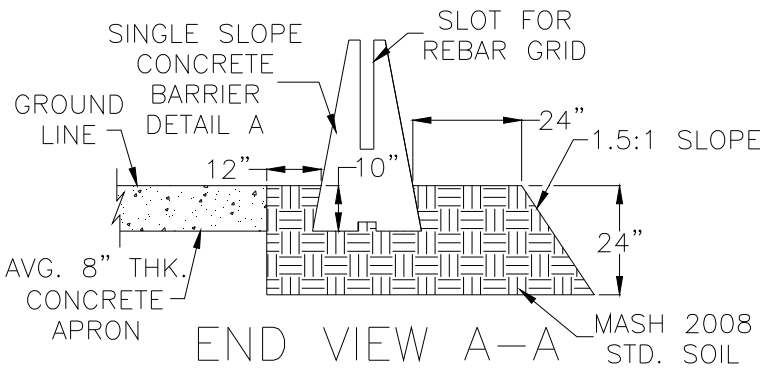
NOTE:
—SHEP 1107 PREMIUM GROUT
IS USED IN BARRIER CONNECTIONS

The Texas A&M University System				
REVISIONS			TEXAS TRANSPORTATION INSTITUTE	
NO.	DATE	BY	CHK.	COLLEGE STATION, TEXAS 77843
1.	2009/01/22	NDE	GG	Project No. / Date / Drawn By / Scale
2.	2009/01/22	NDE	NS	405160-13 / 2009/01/20 / NDE
3.				
4.				EMBEDDED BARRIERS
5.				Sheet No. 1 of 5

APPROVED:
NAUMAN SHEIKH:_____

2009/01/21

Jul 15, 2009 — 9:53am

20'

PLAN

SLOT FOR—
REBAR GRID

GROUTED—
REBAR GRID
DETAIL C

STL. PIPE SLEEVE
FOR LIFTING RODS

DETAIL A—A

ELEVATION

DETAIL A
SINGLE SLOPE
CONCRETE BARRIER

PLAN

3 SPACES @ 4"=12"

90"

$4\frac{1}{2}$" 6" 6" 6" 6" $7\frac{1}{2}$"

12" O.C. SPACINGS

SLOT FOR REBAR GRID

2"

H1 BARS (#5)
DETAIL E

DRAINAGE SLOT = 24"

54"

1 1/2" NOMINAL DIA.
GALV. STEEL PIPE SLEEVE
FOR PRECAST SECTIONS
(7.5' FROM EA. END)

ELEVATION

$10\frac{1}{2}$"

B

V1 BARS (#4)
DETAIL F

C

V2 BARS
DETAIL D

1 1/2" NOMINAL DIA.
GALV. STEEL PIPE SLEEVE
FOR PRECAST SECTIONS
(7.5' FROM EA. END)

H1 BARS (#5)
DETAIL E

B

DRAINAGE SLOT

2" MAX

C

V1 BARS (#4)
DETAIL F

DETAIL A-A

The Texas A&M University System				
REVISIONS			TEXAS TRANSPORTATION INSTITUTE	
NO.	DATE	BY	CHK.	COLLEGE STATION, TEXAS 77843
1.	2009/01/22	NDE	GG	
2.				Project No. 405160-13 / Date 2009/01/20 / Drawn By NDE / Scale
3.				
4.				EMBEDDED BARRIERS / Sheet No. 3 of 5
5.				

T:\2008-2009\405160_PooledFund\405160-13-1 SSB\405160-13-1SSB.dwg

Jul 15, 2009 - 9:57am

8"

V1 BAR
DETAIL F

$15\frac{1}{2}$"

H1 BAR
DETAIL E

1 1/2" NOMINAL DIA.
GALV. STEEL PIPE SLEEVE
FOR PRECAST SECTIONS
(7.5' FROM EA. END)

36"

21"

$28\frac{1}{2}$"

$13\frac{1}{2}$"

6"

4"

2"

24"

SECTION C-C

8"

3"

REBAR GRID
DETAIL C

V2 BAR
DETAIL D

H1 BAR
DETAIL E

1 3/4" TYP. COVER

24"

$33\frac{1}{2}$"

4"

2"

24"

SECTION B-B

The Texas A&M University System

	REVISIONS			TEXAS TRANSPORTATION INSTITUTE
NO.	DATE	BY	CHK.	COLLEGE STATION, TEXAS 77843

TEXAS TRANSPORTATION INSTITUTE
COLLEGE STATION, TEXAS 77843

NO.	DATE	BY	CHK.
1.	2009/01/22	NDE	GG
2.			
3.			
4.			
5.			

Project No.	Date	Drawn By	Scale
405160-13	2009/01/20	NDE	

EMBEDDED BARRIERS

Sheet No.
4 of 5

Jul 15, 2009 - 9:59am

DETAIL C
REBAR GRID

18"
4" — 10" — 4"
#8 BARS
8"
8"
1"
#6 BARS

DETAIL D
V2 BAR (#4)

$4\frac{3}{8}$"
$3\frac{1}{4}$"
$33\frac{1}{4}$"
R2"
$7\frac{7}{16}$"
7"
$9\frac{1}{4}$"
15"

DETAIL F
V1 BAR (#4)

$R2\frac{1}{4}$"
36"
R2"
$7\frac{7}{16}$"
7"
$9\frac{1}{4}$"
15"

DETAIL E
H1 BAR (#5)

19'–8"

MATERIAL USED

TEST NUMBER   405160-13-1

DATE   2009-04-16

Date received	Item number	Description	Supplier	Heat #	Quantity used
2009-03-09	CMB 1	20' single slope	Bexar Pre-cast		5
2009 01 26	REBAR8-3	1" REBAR	CMC-SHEPLERS	250430	
2009 01 26	REBAR6-5	3/4" REBAR	CMC-SHEPLERS	402-6581	

Barriers were provided by Bexar Pre-cast. No paperwork was provided.

Rebar 8-3 and Rebar 6-5 was used for connection grids in joints.

B/L# 428754

JEWETT, TEXAS 75846   PH (903) 626-4461   Date   3/27/07

CERTIFIED MILL TEST REPORT

74118
CMC CONSTRUCTION SERVICES
777 NORTH ELDRIDGE PARKWAY
SUITE 500
HOUSTON   TX   77079

74121
CMC CONSTRUCTION SERVICES
10650 STATE HWY 30

COLLEGE STATION TX

SIZE GRADE	HEAT NUMBER	CUSTOMER PO NUMBER	C	Mn	Si	S	P	V	Nb	Cu	Cr	Ni	Mo	Sn	Bend Test
NO.6 REBAR / 19 MM METRIC ASTM A615-06/GR60/420MPA	402-6581	275674	.42	1.08	.22	.050	.011	.004	.002	.41	.14	.14	.040	.016	OK

Tensile 1: 108300 Yield 1: 69000 Elong% 1: 14
Tensile 2: 105200 Yield 2: 67200 Elong% 2: 14

405160-13

#6 20'

ELONGATION IN 8 INCH SCALE/TENSILE & YIELD SHOWN IN PSI
MELTED AND MANUFACTURED IN U.S.A.   ALL MATERIAL STRAND CAST AND HOT ROLLED

CHIEF METALLURGIST
By Traffic

405160-13

#8

CERTIFIED MILL TEST REPORT

CMC Steel Texas

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

For additional copies call
(830) 372-8485

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

Daniel J. Schacht

Daniel J. Schacht
Quality Assurance Manager

HEAT NO.: 250430	SOLD TO: CMC HOUSTON STEEL 7077 FAIRBANKS NORTH HOUSTON HOUSTON, TX 77040-4201	SHIP TO: CMC HOUSTON STEEL 7077 FAIRBANKS NORTH HOUSTON (NEW H.S.S. LOCATION) HOUSTON, TX 77040-
SECTION: Rebar 25mmx64'0" Rebar 25mmx19.507		
GRADE: ASTM A615-05a GRADE 60 ASTM A615M-05a GRADE 420		

SHIP#: 101796/131
BOL #: 427257
INV #:
CUST PO#:
CUST P/N:

CHEMICAL ANALYSIS

	%
C	0.39
Mn	0.81
P	0.009
S	0.021
Si	0.18
Cu	0.47
Cr	0.20
Ni	0.19
Mo	0.056
Cb	0.002
V	0.000
Sn	0.015
B	0.0003
Ti	0.001
C.Eq.	

PROPERTIES

MECHANICAL	TEST I IMPERIAL	TEST I METRIC	TEST IMPERIAL	TEST METRIC	TEST IMPERIAL	TEST METRIC
Yield Strength	62.6 KSI	431.6 MPA				
Tensile Strength	102.9 KSI	709.5 MPA				
Elongation	16 %	16 %				
Gauge Length	8 INS	203 MM				
Reduction of Area						
Bend Test	OK					
Diameter	5.00 INS	126.90 MM				
Charpy Impact						
Test Temp						
Sample Size						
Orientation						
Hardness						

JOMINY RESULTS - Rockwell C hardness at 1/16th inch increments

1	2	3	4	5	6	7	8	9	10	11	12
13	14	15	16	18	20	22	24	26	28	30	32

GRAIN SIZE
METHOD
RESULT

INCLUSION RATING

METHOD							
TYPE							
	T	H	T	H	T	H	T	H
SIZE							

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

AASHTO M 31M/M 31-95

APPENDIX C. CONCRETE INFORMATION

GROUT COMPRESSIVE STRENGTH TEST REPORT

Report Number: A1071059.0013
Service Date: 03/16/09
Report Date: 04/13/09
Task: PO No. 405160-13

Terracon
6198 Imperial Loop
College Station, TX 77845
979-846-3767

Client

Texas Transportation Institute
Attn: Gary Gerke
TTI Business Office
3135 TAMU
College Station, TX 77843-3135

Project

Riverside Campus
Riverside Campus
Bryan, TX

Project Number: A1071059

Material Information

Specified Strength: 4,000 psi @ 3 days

Mix ID:	Sheplers #1 107 Nonshrink Grout		
Supplier:	Client		
Batch Time:	1345	**Plant:**	Mixed on site
Truck No.:	N/A	**Ticket No.:**	N/A

Field Test Data

Test	Result	Specification
Slump (in):		
Grout Temp. (F):		
Ambient Temp. (F):	75	

Sample Information

Sample Date:	03/16/09	**Sample Time:** 1350
Sampled By:	Randolph E. Rohrbach	
Weather Conditions:	Partly cloudy, light wind	
Accumulative Yards:		**Batch Size:**
Sample Size:	2 X 2 Cubes	
Sample Location:	Concrete barriers on west side of runway	
Placement Location:	Single slope barrier	
Form Material:	Plastic Mold	**No. Units:** 6
Samples Plumb:	Yes	
Temperature Range:		

Laboratory Test Data

Set No.	Specimen ID	Measured Slump (in)	Measured Flow (sec)	Date Received	Date Tested	Age (days)	Area (sq in)	Maximum Load (lbs)	Compressive Strength (psi)
1	A	NP		.	03/19/09	3	4.00	20,630	5,160
1	B	NP			03/19/09	3	4.00	21,490	5,370
1	C	NP			03/19/09	3	4.00	22,920	5,730
								Average (3 days)	5,420
1	D	NP			04/13/09	28	4.00	31,800	7,950
1	E	NP			04/13/09	28	4.00	24,060	6,020
1	F	NP			04/13/09	28	4.00	29,560	7,390
								Average (28 days)	7,120

Comments: Average compressive strength of 28 day Cube complies with the specified strength. **NP = Not Performed

Samples Made By: Terracon
Services:

Terracon Rep.: Randolph E. Rohrbach
Reported To: Gary Gerke
Contractor:
Report Distribution:
    (1) Texas Transportation Institute

Started: 1300   **Lunch / Non-Chargeable:**
Finished: 1430

Reviewed By: _Don H. Kopetsky_
Don H. Kopetsky
Senior Project Manager

Test Methods: ASTM C1019
The tests were performed in general accordance with applicable ASTM, AASHTO, or DOT test methods. This report is exclusively for the use of the client indicated above and shall not be reproduced except in full without the written consent of our company. Test results transmitted herein are only applicable to the actual samples tested at the location(s) referenced and are not necessarily indicative of the properties of other apparently similar or identical materials.

CR-0000   Page 1 of 1   Created 8/14/2007
                                                                            Revised 4/13/2009

SAMPLE PICK-UP REPORT

Terracon
6198 Imperial Loop
College Station, TX 77845
979-846-3767

Report Number:	A1071059.0013A
Service Date:	03/17/09
Report Date:	03/18/09
Task:	PO No. 405160-13

Client

Texas Transportation Institute
Attn: Gary Gerke
TTI Business Office
3135 TAMU
College Station, TX 77843-3135

Project

Riverside Campus
Riverside Campus
Bryan, TX

Project Number: A1071059

On March 17, 2009, a Terracon Consultants, Inc., representative was present at the above referenced project to obtain 2 sets of 3 grout cubes cast on March 16, 2009. The samples were returned to the laboratory for processing and curing.

TTI SAFETY
AND STRUCTURAL

MAR 2 7 2009

SYSTEMS
DIVISION

Services:

Terracon Rep.: Mohammed Mobeen
Reported To:
Contractor:
Report Distribution:
(1) Texas Transportation Institute

Started: 1100
Finished: 1200

Lunch / Non-Chargeable:

Reviewed By: Don H. Kopetsky
Don H. Kopetsky
Senior Project Manager

The tests were performed in general accordance with applicable ASTM, AASHTO, or DOT test methods. This report is exclusively for the use of the client indicated above and shall not be reproduced except in full without the written approval of Terracon. Test results transmitted herein are only applicable to the actual samples tested at the location(s) referenced and are not necessarily indicative of the properties of other apparently similar or identical materials.

APPENDIX D. CRASH TEST NO. 405160-13-1

D1. VEHICLE PROPERTIES AND INFORMATION

Date: 2009-04-16   Test No.: 405160-13-1   VIN No.: 1D7HA18N82S629430

Year: 2002   Make: Dodge   Model: Ram 1500 Quad-Cab

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

Tread Type: Highway   Odometer: 174085

Note any damage to the vehicle prior to test:

• Denotes accelerometer location.

NOTES:

Engine Type: V-8
Engine CID: 4.7 liter

Transmission Type:
  x Auto   or   Manual
     FWD   x RWD   4WD

Optional Equipment:

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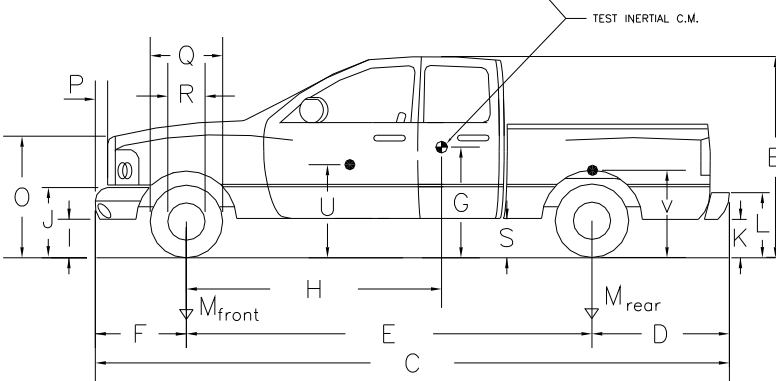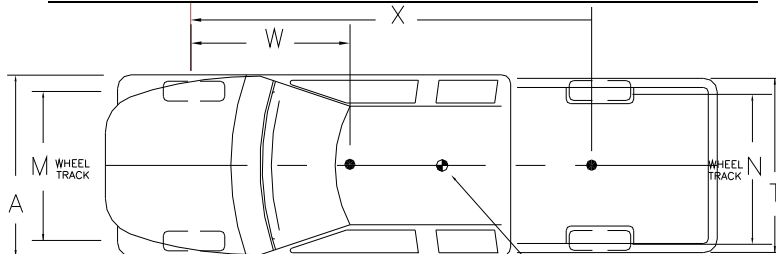
Geometry: inches

A	77.00	F	39.00	K	20.50	P	3.00	U	27.50
B	73.25	G	28.12	L	28.75	Q	29.50	V	33.00
C	227.00	H	62.69	M	68.25	R	18.50	W	59.50
D	140.50	I	13.50	N	67.25	S	14.25	X	140.5
E	47.50	J	26.00	O	44.75	T	75.50		

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 3650	M_{front}	2621	2743	Allowable		Allowable
Back 3900	M_{rear}	2009	2210	Range		Range
Total 6650	M_{Total}	4630	4953	5000 ±110 lb		5000 ±110 lb

Mass Distribution:

lb	LF: 1368	RF: 1375	LR: 1072	RR: 1138

Figure D1. Vehicle properties for test 405160-13-1.

Table D1. Exterior crush measurements for test 405160-13-1.

Date: 2009-04-16   Test No.: 405160-13-1   VIN No.: 1D7HA18N82S629430

Year: 2002   Make: Dodge   Model: Ram 1500 Quad-Cab

VEHICLE CRUSH MEASUREMENT SHEET[1]

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

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

Specific Impact Number	Plane* of C-Measurements	Direct Damage		Field L**	C_1	C_2	C_3	C_4	C_5	C_6	±D
		Width** (CDC)	Max*** Crush								
1	Front plane at bumper ht	15	10.5	30	0	0.5	1.5	3	5	10.5	+15
2	Side plane at bumper ht	15	14	54	0	1.5	---	---	9.75	14	+76.5
	Measurements recorded										
	in inches										

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

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

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

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

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

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

Table D2. Occupant compartment measurements for test 405160-13-1.

Date: 2009-04-16   Test No.: 405160-13-1   VIN No.: 1D7HA18N82S629430

Year: 2002   Make: Dodge   Model: Ram 1500 Quad-Cab

OCCUPANT COMPARTMENT DEFORMATION MEASUREMENT
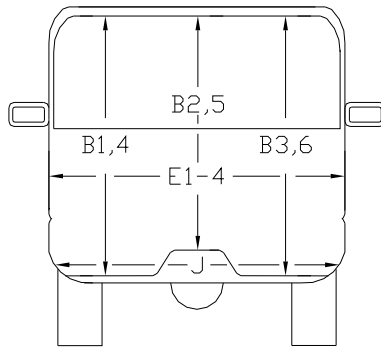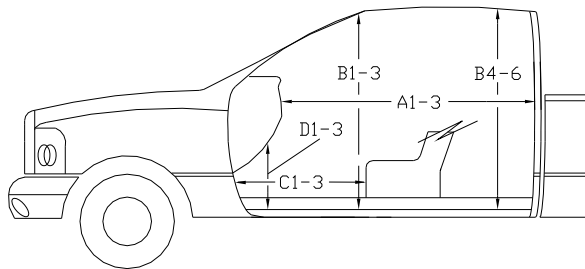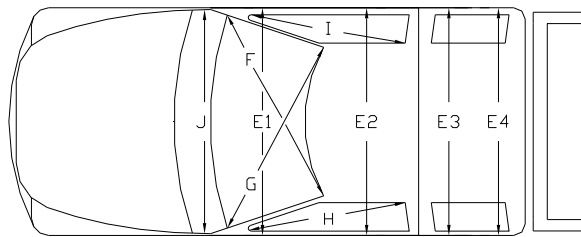
	Before (inches)	After (inches)
A1	64.50	64.50
A2	64.62	64.62
A3	65.25	65.25
B1	45.56	45.56
B2	39.50	39.50
B3	45.56	45.56
B4	49.19	49.19
B5	45.56	45.56
B6	49.18	49.18
C1	29.75	29.75
C2	----	----
C3	27.56	27.56
D1	12.69	12.69
D2	2.50	2.50
D3	11.69	11.69
E1	64.44	64.25
E2	64.31	64.25
E3	64.00	63.50
E4	64.00	63.88
F	60.00	60.00
G	60.00	60.00
H	39.50	39.50
I	39.5	39.5
J*	23.62	23.62

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

D2. SEQUENTIAL PHOTOGRAPHS

0.000 s

0.098 s

0.198 s

0.296 s

**Figure D2. Sequential photographs for test 405160-13-1
(overhead and frontal views).**

0.393 s

0.491 s

0.591 s

0.689 s

**Figure D2. Sequential photographs for test 405160-13-1
(overhead and frontal views) (continued).**

D-5

0.000 s

0.393 s

0.098 s

0.491 s

0.198 s

0.591 s

0.296 s

0.689 s

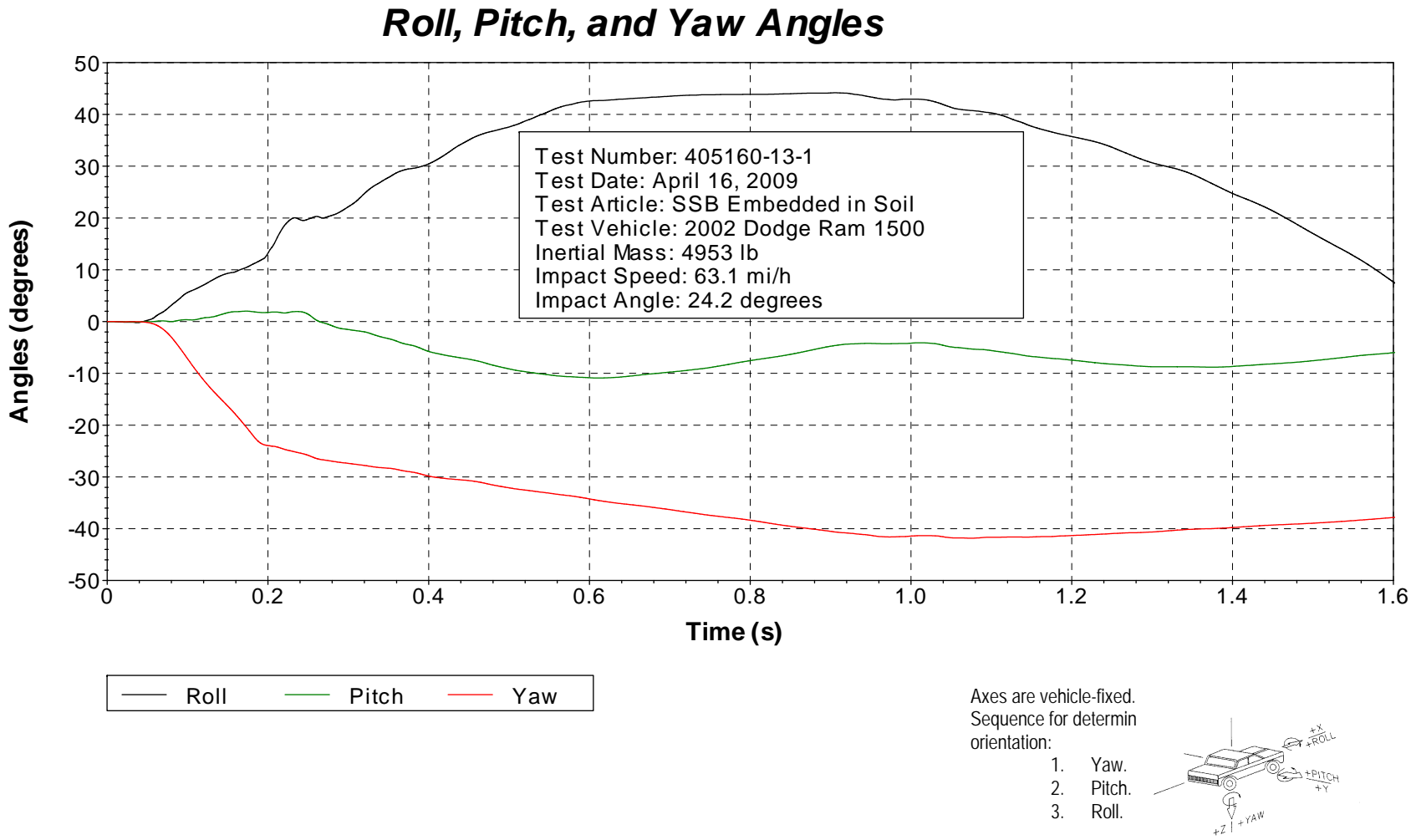**Figure D3. Sequential photographs for test 405160-13-1
(rear view).**

Figure D4. Vehicle angular displacements for test 405160-13-1.

X Acceleration at CG

Test Number: 405160-13-1
Test Date: April 16, 2009
Test Article: SSB Embedded in Soil
Test Vehicle: 2002 Dodge Ram 1500
Inertial Mass: 4953 lb
Impact Speed: 63.1 mi/h
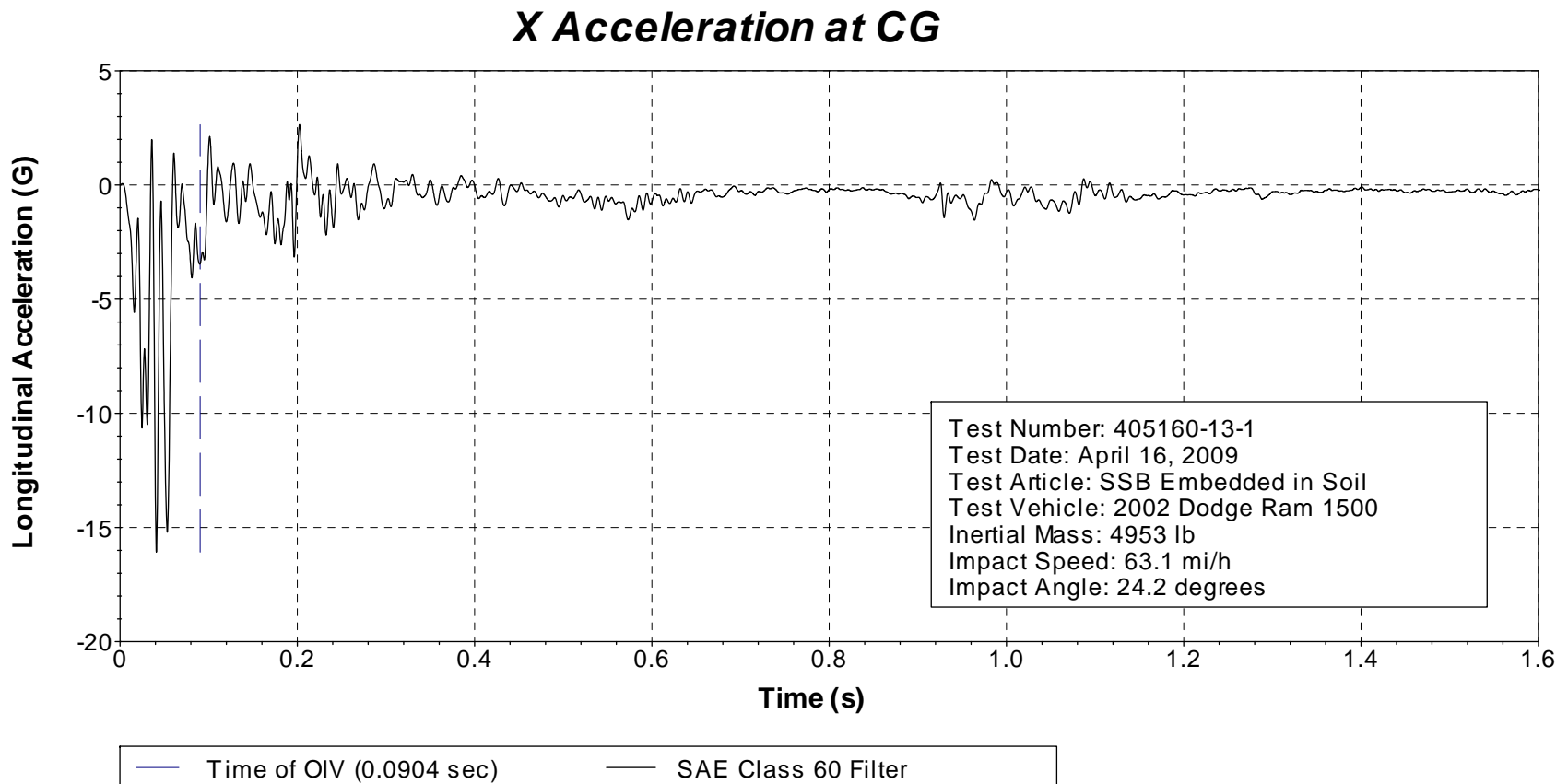Impact Angle: 24.2 degrees

Time of OIV (0.0904 sec) — SAE Class 60 Filter

Figure D5. Vehicle longitudinal accelerometer trace for test 405160-13-1 (accelerometer located at center of gravity).

Y Acceleration at CG
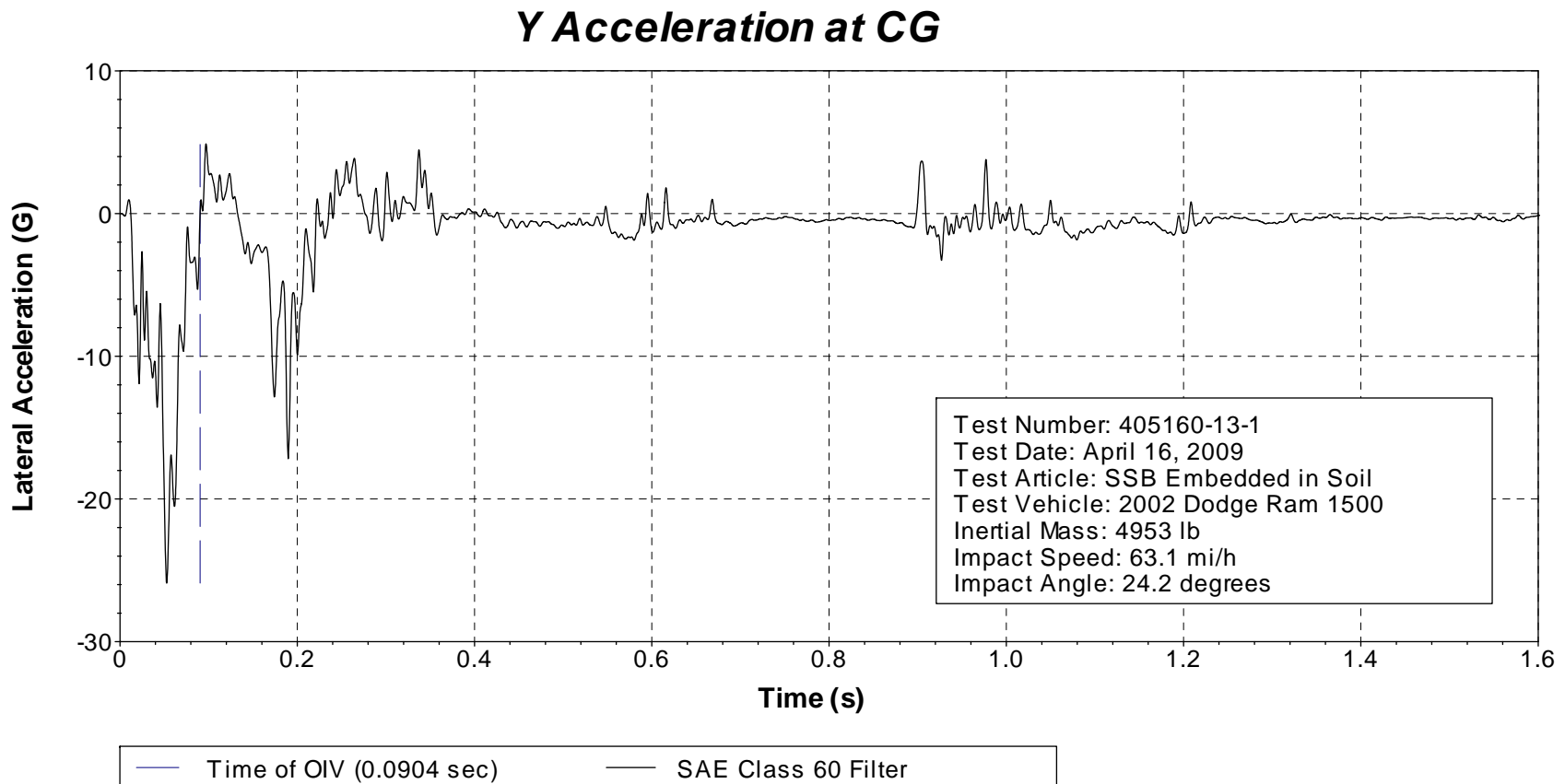

Test Number: 405160-13-1
Test Date: April 16, 2009
Test Article: SSB Embedded in Soil
Test Vehicle: 2002 Dodge Ram 1500
Inertial Mass: 4953 lb
Impact Speed: 63.1 mi/h
Impact Angle: 24.2 degrees

Time of OIV (0.0904 sec)   SAE Class 60 Filter

**Figure D6. Vehicle lateral accelerometer trace for test 405160-13-1
(accelerometer located at center of gravity).**

Z Acceleration at CG

Test Number: 405160-13-1
Test Date: April 16, 2009
Test Article: SSB Embedded in Soil
Test Vehicle: 2002 Dodge Ram 1500
Inertial Mass: 4953 lb
Impact Speed: 63.1 mi/h
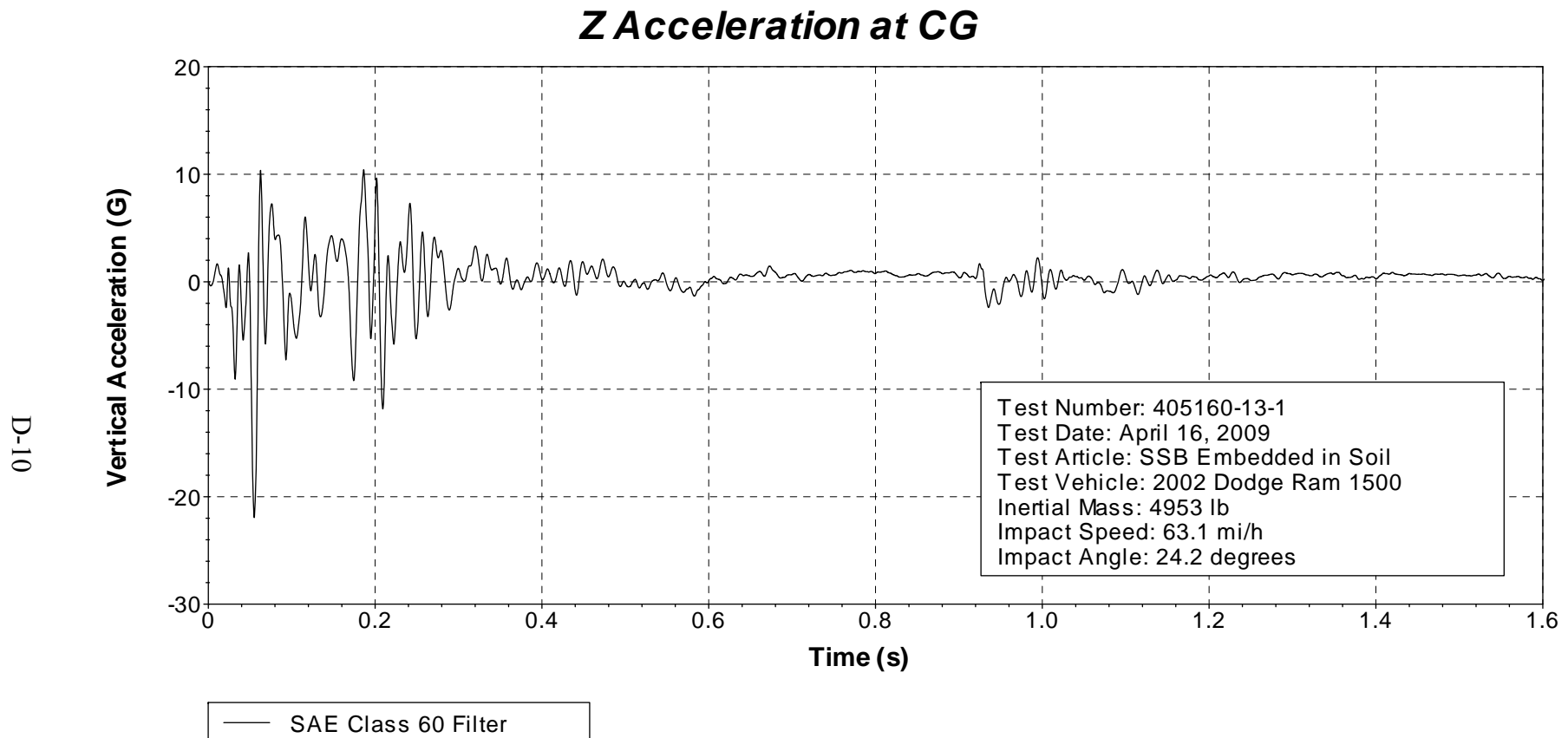Impact Angle: 24.2 degrees

—— SAE Class 60 Filter

Figure D7. Vehicle vertical accelerometer trace for test 405160-13-1 (accelerometer located at center of gravity).
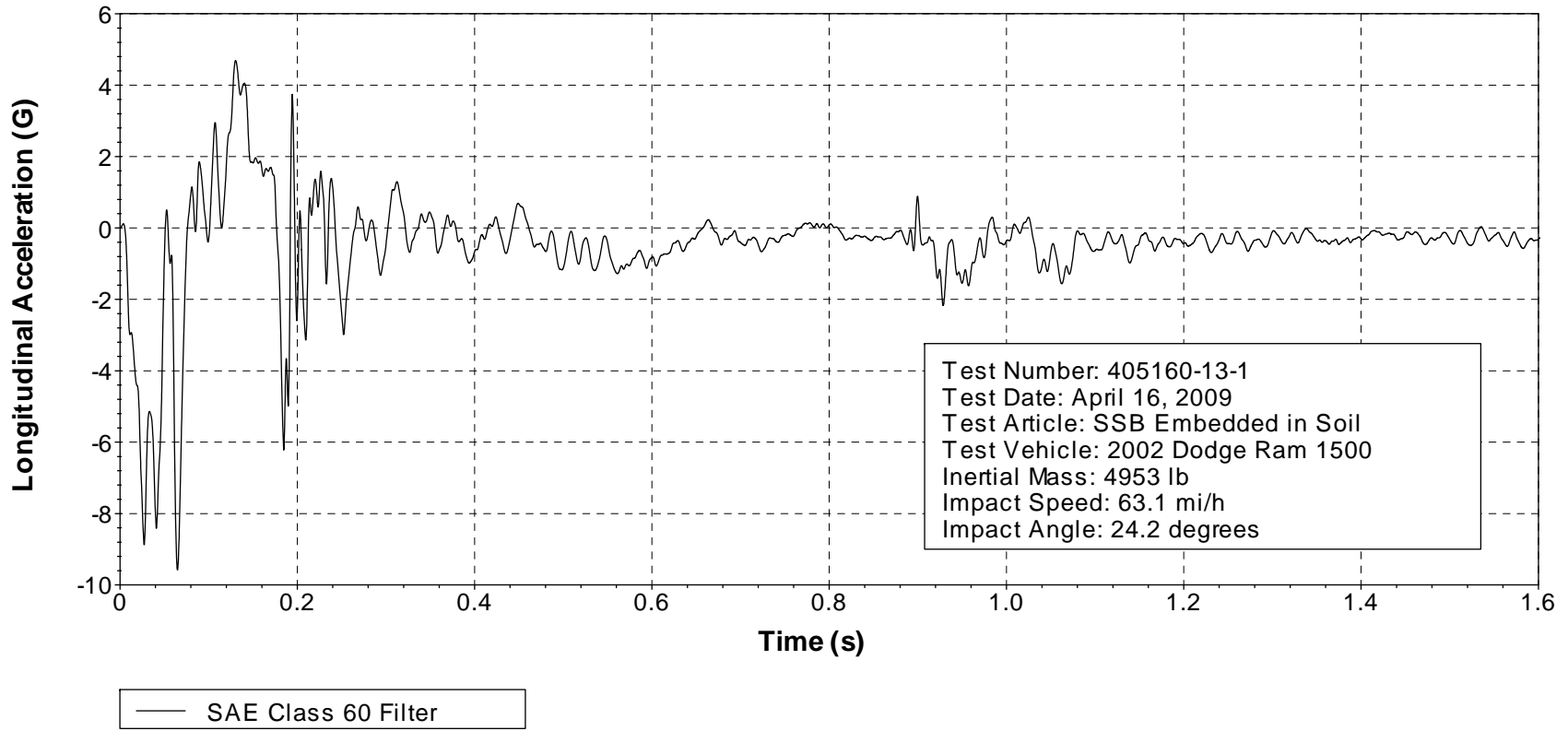
X Acceleration over Rear Axle

Test Number: 405160-13-1
Test Date: April 16, 2009
Test Article: SSB Embedded in Soil
Test Vehicle: 2002 Dodge Ram 1500
Inertial Mass: 4953 lb
Impact Speed: 63.1 mi/h
Impact Angle: 24.2 degrees

SAE Class 60 Filter

Figure D8. Vehicle longitudinal accelerometer trace for test 405160-13-1 (accelerometer located over rear axle).

Y Acceleration over Rear Axle

Test Number: 405160-13-1
Test Date: April 16, 2009
Test Article: SSB Embedded in Soil
Test Vehicle: 2002 Dodge Ram 1500
Inertial Mass: 4953 lb
Impact Speed: 63.1 mi/h
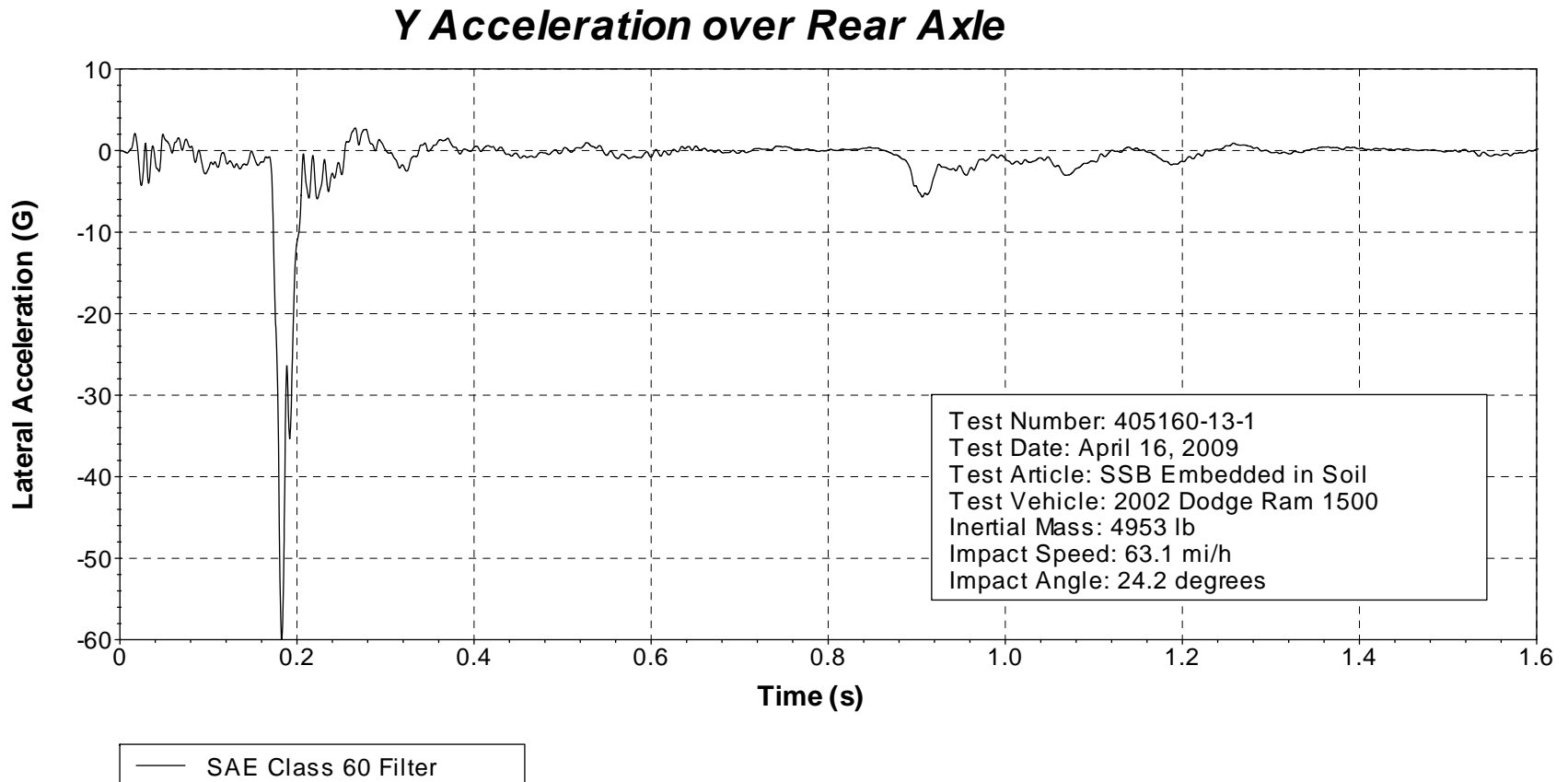Impact Angle: 24.2 degrees

SAE Class 60 Filter

**Figure D9. Vehicle lateral accelerometer trace for test 405160-13-1
(accelerometer located over rear axle).**

Z Acceleration over Rear Axle

Test Number: 405160-13-1
Test Date: April 16, 2009
Test Article: SSB Embedded in Soil
Test Vehicle: 2002 Dodge Ram 1500
Inertial Mass: 4953 lb
Impact Speed: 63.1 mi/h
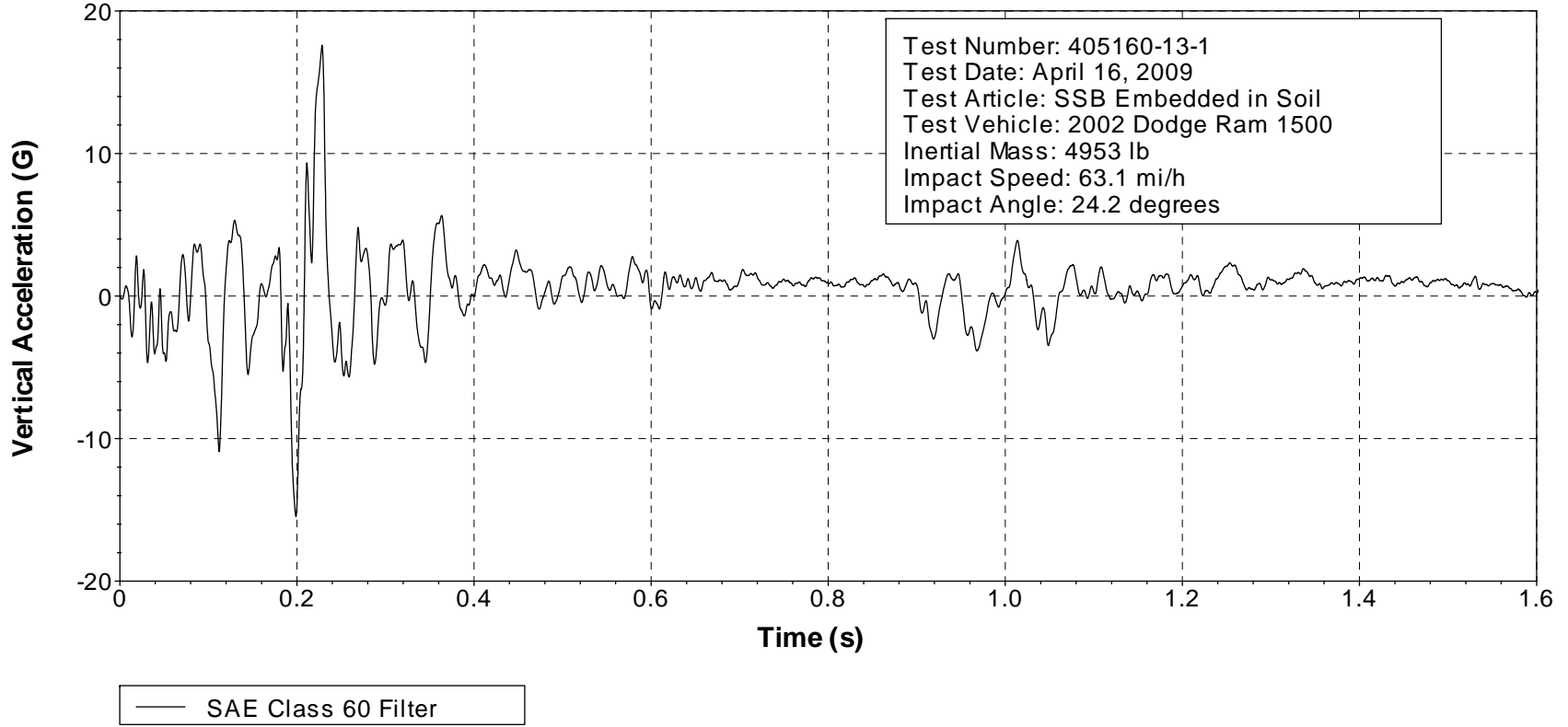Impact Angle: 24.2 degrees

SAE Class 60 Filter

**Figure D10. Vehicle vertical accelerometer trace for test 405160-13-1
(accelerometer located over rear axle).**