Texas A&M Transportation Institute
Proving Ground

Test Report No. 440862-03 3-4

EVALUATION OF ALLOWABLE TAPER RATES OF FREESTANDING SINGLE-SLOPE CONCRETE BARRIERS

COOPERATIVE RESEARCH PROGRAM

Texas Department of Transportation
https://tti.tamu.edu/documents/0-7086-R2.pdf

TEXAS A&M TRANSPORTATION INSTITUTE PROVING GROUND
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ACCREDITED
ISO 17025 Laboratory
Testing Certificate # 2821.01

Technical Report Documentation Page

1. Report No. FHWA/TX-23/0-7086-R2	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle EVALUATION OF ALLOWABLE TAPER RATES OF FREESTANDING SINGLE-SLOPE CONCRETE BARRIERS		5. Report Date Published: August 2023 6. Performing Organization Code
7. Author(s) Roger P. Bligh, Sofokli Cakalli, Nauman M. Sheikh, William J. L. Schroeder, and Darrell L. Kuhn		8. Performing Organization Report No. Report 440862-03 3-4
9. Performing Organization Name and Address Texas A&M Transportation Institute Proving Ground 3135 TAMU College Station, Texas 77843-3135		10. Work Unit No. (TRAIS) 11. Contract or Grant No. Project 0-7086-R2
12. Sponsoring Agency Name and Address Texas Department of Transportation Research and Technology Implementation Office 6230 E Stassney Lane Austin, Texas 78744		13. Type of Report and Period Covered Technical Report: June 2022–August 2022 14. Sponsoring Agency Code

15. Supplementary Notes

Project sponsored by the Texas Department of Transportation and the Federal Highway Administration.
Project Title: Roadside Safety Device Analysis, Testing, and Evaluation Program
URL: https://tti.tamu.edu/documents/0-7086-R2.pdf

16. Abstract

The Texas Department of Transportation desires to flare the ends of its freestanding single-slope concrete barrier system so the system can be terminated outside the clear zone. Currently, limited guidance exists on the acceptable flare rate for the single-slope portable concrete barrier under the American Association of State Highway and Transportation Officials (AASHTO) *Manual for Assessing Safety Hardware* (*MASH*) 2016 guidelines. This project evaluated flare rates for portable, freestanding, single-slope concrete barriers through finite element impact simulations and full-scale crash testing. This report presents details of the simulation work and the full-scale crash testing performed under the project.

The purpose of the tests reported herein was to assess the performance of the freestanding flared single-slope portable concrete barriers according to the safety-performance evaluation guidelines included in the AASHTO *MASH*, Second Edition (*1*). The crash tests were performed in accordance with *MASH* Test Level 3 (TL-3), which requires two crash tests:

1. ***MASH* Test 3-10:** An 1100C vehicle weighing 2420 lb, impacting the longitudinal barrier while traveling at 62 mi/h and 25 degrees.
2. ***MASH* Test 3-11:** A 2270P vehicle weighing 5000 lb, impacting the longitudinal barrier while traveling at 62 mi/h and 25 degrees.

This report provides details on the flared single-slope portable concrete barriers, the crash tests and results, and the performance assessment of the flared single-slope portable concrete barriers for *MASH* TL-3 longitudinal barrier evaluation criteria. The flared single-slope portable concrete barriers met the performance criteria for *MASH* TL-3 longitudinal barriers.

17. Key Words Longitudinal Barrier, Portable Concrete Barrier, *MASH*, Crash Test, Finite Element Simulation, Finite Element Analysis (FEA)	18. Distribution Statement No restrictions. This document is available to the public through NTIS: National Technical Information Service Alexandria, Virginia https://www.ntis.gov

19. Security Classif. (of this report) Unclassified	20. Security Classif. (of this page) Unclassified	21. No. of Pages 100	22. Price

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Report 440862-03 3-4
Project 0-7086-R2
Project Title: Roadside Safety Device Analysis, Testing, and Evaluation Program

Sponsored by the
Texas Department of Transportation
and the
Federal Highway Administration

Published: August 2023

TEXAS A&M TRANSPORTATION INSTITUTE
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DISCLAIMER

This research was sponsored by the Texas Department of Transportation (TxDOT) and the Federal Highway Administration (FHWA). The contents of this report reflect the views of the authors, who are responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official view or policies of FHWA or TxDOT. This report does not constitute a standard, specification, or regulation.

This report is not intended for construction, bidding, or permit purposes. The engineer (researcher) in charge of the project was Roger P. Bligh, P.E. # 78550.

TTI PROVING GROUND DISCLAIMER

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

REPORT AUTHORIZATION

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ACKNOWLEDGMENTS

This project was sponsored by TxDOT and FHWA. The authors thank Ken Mora and Christopher Lindsey, Design Division, and Wade Odell, project manager, for their guidance and assistance. The authors also thank the Texas A&M University High Performance Research Computing Department for providing advance computing resources needed for computer simulations performed under the project.

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SI* (MODERN METRIC) CONVERSION FACTORS				
APPROXIMATE CONVERSIONS TO SI UNITS				
Symbol	**When You Know**	**Multiply By**	**To Find**	**Symbol**
		LENGTH		
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
		AREA		
in^2	square inches	645.2	square millimeters	mm^2
ft^2	square feet	0.093	square meters	m^2
yd^2	square yards	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 1000L 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)		
°F	Fahrenheit	5(F-32)/9 or (F-32)/1.8	Celsius	°C
		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	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 (2000lb)	T
		TEMPERATURE (exact degrees)		
°C	Celsius	1.8C+32	Fahrenheit	°F
		FORCE and PRESSURE or STRESS		
N	newtons	0.225	poundforce	lbf
kPa	kilopascals	0.145	poundforce per square inch	lb/in^2

*SI is the symbol for the International System of Units

Chapter 1. INTRODUCTION

1.1. BACKGROUND AND PROBLEM STATEMENT

Portable concrete barriers (PCBs) are commonly used to provide positive protection in work zones. This protection includes shielding motorists from encountering non-traversable terrain or cuts behind the barrier as well as construction equipment. PCBs additionally perform the important function of shielding work-zone personnel from errant motorists when activities are being performed in close proximity to the edge of the travel way.

As with other types of longitudinal barrier systems, the exposed ends of PCBs can pose a hazard to motorists if left untreated. One mean of mitigating this hazard is to install a suitable crash attenuator at the end of the barrier. This can be costly and time consuming, often involving the installation of numerous anchors in the underlying pavement to permit the crash attenuator to function as designed.

Another alternative, if space permits, is to flare the PCB away from traffic to a point where the exposed end is outside the clear zone for opposing traffic. This practice can significantly reduce the probability of an errant motorist impacting the barrier end. Other work-zone layouts may require a flared portion of barrier to create an offset from one line of barrier to another.

When a barrier is flared in such a manner, the flare rate creates an increase in the effective impact angle of the vehicle, which increases overall impact severity. The Texas Department of Transportation (TxDOT) Design Standards currently limit the flare rate of a cast-in-place concrete barrier to 20:1. There is no specific guidance regarding the acceptable flare rates of PCBs. Research was requested to determine applicable flare rates for PCBs.

TxDOT standards contain two different types of PCBs: a 32-inch-tall F-shape profile PCB and a 42-inch-tall single-slope PCB. Both barriers can have different connection types that provide positive attachment between the barrier segments. TxDOT requested that this research evaluate the single-slope PCB with J-J Hooks® connections. Based on the geometry of the barrier and this connection, the maximum angle that can be achieved between two adjacent barrier segments is approximately 7 degrees.

1.2. OBJECTIVE AND RESEARCH APPROACH

The objective of this research was to determine a range of acceptable flare rates for the single-slope PCB with J-J Hooks connections. Finite element (FE) modeling and simulation were used to evaluate the impact performance of the barrier when installed on different flare rates. A detailed model of the barrier with concrete material failure capability was developed and validated against available dynamic impact tests of the barrier. The simulations were performed following impact conditions for *Manual for Assessing Safety Hardware* (*MASH*) Test Level 3 (TL-3) (*1*). Results of the simulations were used to recommend a flare rate for crash testing that was considered to have a reasonable probability of achieving *MASH* compliance. The impact performance of the barrier installed with the selected flare rate was then verified through full-scale crash testing conducted according to *MASH* criteria. This report documents details of this research.

Chapter 2. FINITE ELEMENT COMPUTER SIMULATIONS

2.1. INTRODUCTION

This chapter presents details of the FE analysis performed to assist in determining a *MASH*-compliant flare rate for single-slope PCBs. First, a detailed FE model of a 30-ft single-slope PCB segment with J-J Hooks connections was developed using a commercially available FE preprocessor called HyperMesh® (*2*). Model verification was then performed for the single-slope PCB profile using bogie tests previously conducted by the Texas A&M Transportation Institute (TTI) under TxDOT Project 0-7059 (*3*). All simulations were performed using LS-DYNA, which is a commercially available general-purpose FE analysis software (*4*).

A full-scale FE model was developed using six 30-ft single-slope PCB segments. Three of the end segments were flared at the maximum achievable angle of 7 degrees. Two different points of impact were investigated to select the most critical one for full-scale crash testing.

The impact performance of the system was evaluated following *MASH* Test 3-11 conditions with a *MASH* 2270P pickup truck model. The vehicle was successfully contained and redirected. The occupant risk metrics were all within *MASH* limits. However, the occupant compartment deformation in the toe pan area of the pickup truck model was marginal.

After discussions about these results, TxDOT decided to proceed more conservatively and evaluate a shallower flare rate of 12:1. The FE model was modified accordingly, and a *MASH* Test 3-11 simulation was performed. The single-slope PCB system on a 12:1 flare satisfied all relevant *MASH* criteria in the simulation. Based on these results, TxDOT decided to move forward with full-scale crash testing of the system with the 12:1 flare rate.

Details of the FE modeling and simulation of the flared single-slope PCB system are provided in the sections below.

2.2. FINITE ELEMENT MODELING

A detailed FE model of the single-slope PCB with J-J Hooks connections was developed using standard drawings provided by TxDOT. The single-slope PCB segment was modeled with solid elements with an average mesh size of 1 inch, as shown in Figure 2.1. To capture concrete damage from vehicle impact, barrier segment ends were modeled as deformable solid elements using a continuous surface cap model in LS-DYNA. This material model has the capability to capture concrete damage. The interior portion of the barrier segments was modeled with non-deformable rigid material.

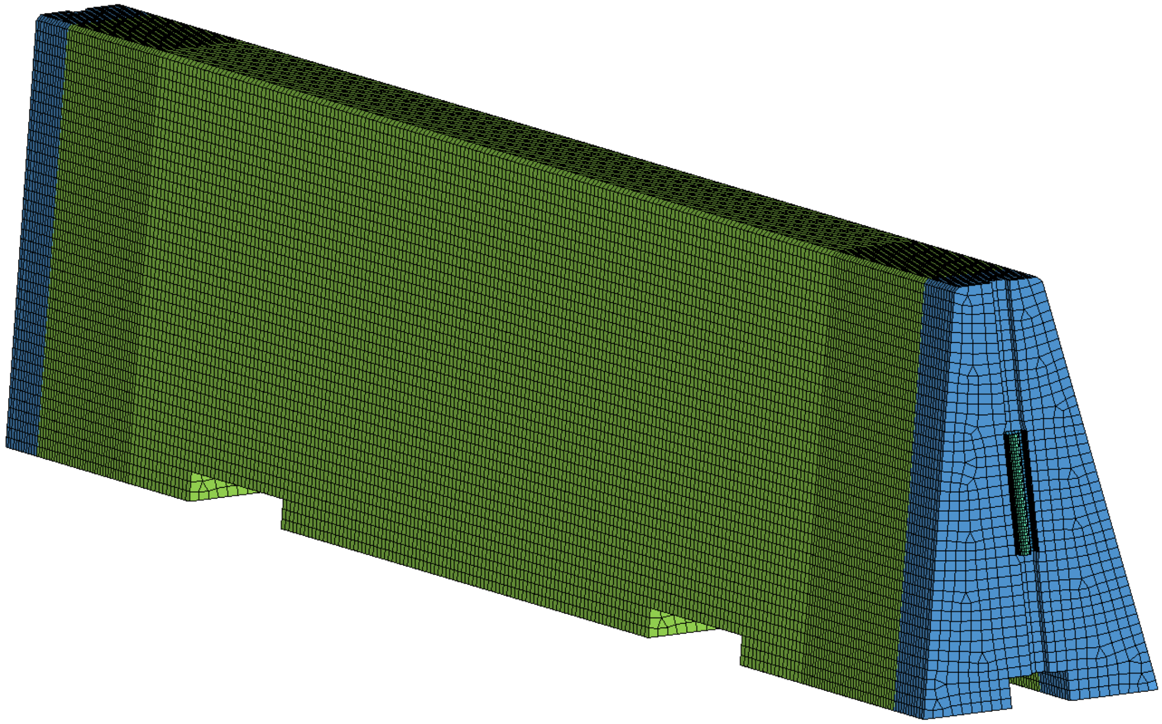


Figure 2.1. FE Model of Single-Slope PCB with J-J Hooks.

The longitudinal and vertical reinforcements within the deformable portions of the single-slope PCB segments were modeled with beam elements, as shown in Figure 2.2. The J-J Hooks connection plates were modeled with shell elements. The rebar and the connection plates were modeled using elastic-plastic material representation.

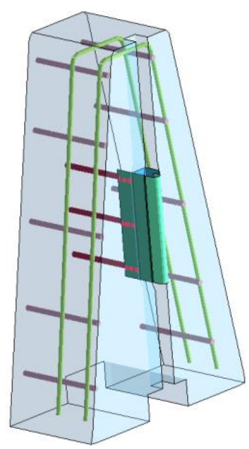


Figure 2.2. Reinforcement Modeled with Beam Elements.

The FE vehicle models used in the simulations were originally developed by the Center for Collision Safety and Analysis and were further improved in-house by TTI over the course of use under various projects. A Chevrolet Silverado pickup truck and a Toyota Yaris passenger car FE models were used to represent the *MASH* design vehicles in *MASH* Test 3-11 and Test 3-10 simulations, respectively.

2.3. SINGLE-SLOPE PCB FE MODEL VERIFICATION

The single-slope PCB FE model was validated using the dynamic impact test 440591-01-B2 performed previously under TxDOT Project 0-7059 (*3*). This test involved a surrogate, or bogie, vehicle impacting a single-slope PCB system with J-J Hooks connections head-on at a joint between two adjacent segments. The bogie vehicle was outfitted with a crushable nose assembly comprised of a series of steel pipes aligned with a vertical axis.

A simplified FE model of the collapsible bogie nose was developed by the researchers to capture the overall impact energy and force-deflection characteristics of the bogie vehicle. The weight of the bogie vehicle was 4980 lb in the simulations and the crash test.

Replicating the bogie test, the single-slope PCB FE model consisted of four barrier segments for a total length of 120 ft, as shown in Figure 2.3. The impact simulation conditions used in the simulation matched the actual impact conditions reported for test 440591-01-B2. Specifically, the bogie nose model impacted the centerline of the middle barrier joint at a speed of 18.5 mi/h and an angle of 89.4 degrees.

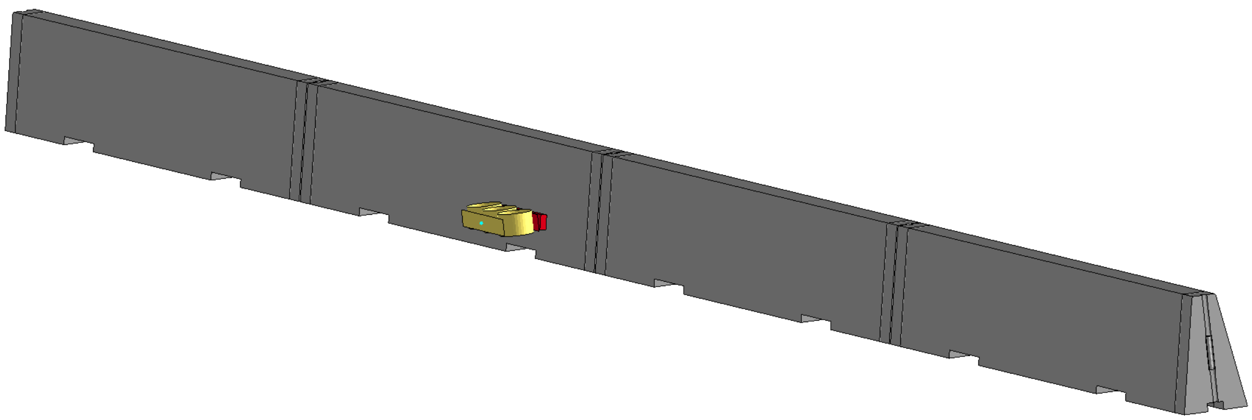
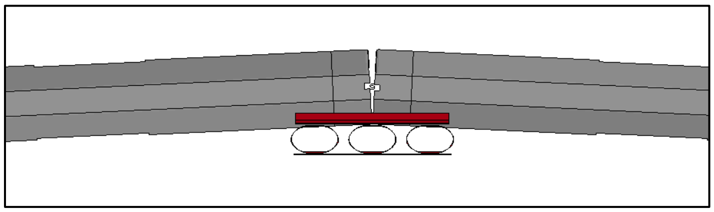


Figure 2.3. Bogie Test Simulation Setup.

The dynamic behavior and permanent deflection of the simulated single-slope PCB bogie impact reasonably matched the results of bogie test 440591-01-B2, as shown in Figure 2.4 and Table 2.1. Therefore, the validation of the single-slope PCB FE model was considered satisfactory to move forward with predictive *MASH* TL-3 impact simulations.

a. TTI Bogie Test No. 440591-01-B2



b. FE Simulation with Bogie Nose Model

Figure 2.4. Comparison of the Simulation Model with Bogie Field Test.

Table 2.1. Comparison of Permanent Deflections.

Test	Permanent Deflection
TTI Bogie Test No. 440591-01-B2	15.25 inches
FE Simulation	16.1 inches

2.4. *MASH* TEST LEVEL 3 SIMULATIONS

A full-scale FE model for the flared single-slope PCB system with J-J Hooks connections was developed using six 30-ft segments providing a total length of 180 ft. Three of the barrier segments were modeled on a straight, tangent section, and three were modeled on a 7-degree flare. This flare represented the maximum achievable flare angle based on the geometrics of the barrier and the J-J Hooks connections. The 7-degree angle corresponded to a flare rate of 8.14:1. A barrier system with a more conservative 12:1 flare rate was also modeled and simulated.

Vehicle impact simulations following *MASH* Test 3-11 and Test 3-10 conditions were performed on the barrier system models. Both test conditions involve impacting the barrier system at a speed of 62 mi/h and an angle of 25 degrees. Test 3-11 involves the *MASH* 2270P pickup truck, while Test 3-10 involves the *MASH* 1100C passenger car. The impact points for the *MASH* pickup truck (Test 3-11) and small car (Test 3-10) simulations were selected to be 4.3 ft and 3.6 ft upstream of the joint between barrier 2 and barrier 3, respectively. These impact points correspond to recommendations in *MASH* Table 2-7 (*1*). The *MASH* Test 3-11 simulation setup and the barrier numbering are shown in Figure 2.5.

An alternative point of impact (POI B) was investigated for Test 3-11 with the pickup truck model to determine which one was more critical. The alternate location was 4.3 ft upstream of the joint where the flared barrier started between segments 3 and 4. Comparison of the results of the simulations performed at both impact points indicated that the original point of impact (POI A) was more critical, and it was used in all subsequent simulations.

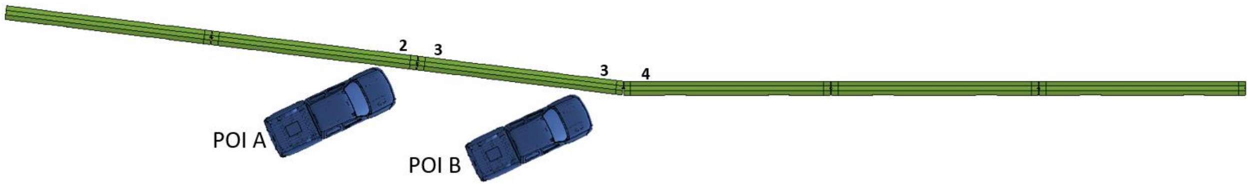


Figure 2.5. Two Points of Impact Investigated for *MASH* Test 3-11.

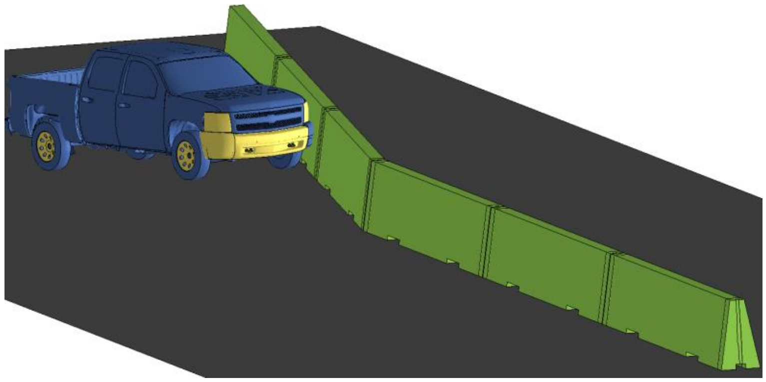
2.4.1. Single-Slope PCB System at Maximum Flare Rate

The single-slope PCB FE model with 7-degree flare was impacted with the pickup truck model under *MASH* Test 3-11 conditions. The *MASH* pickup truck model impacted the system at 62 mi/h and a resultant angle of 32 degrees (i.e., 25 degrees for *MASH* Test 3-11 plus a 7-degree flare). The impact point (POI A) was 4.3 ft upstream of the joint between barrier 2 and barrier 3, as shown in Figure 2.5.

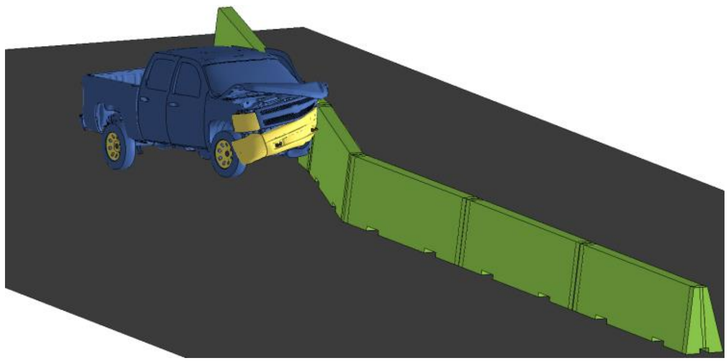
Key results of the *MASH* Test 3-11 simulation are presented in Table 2.2. Images from the simulation are shown in Figure 2.6. The vehicle was successfully contained and redirected, and the occupant risk metrics were all within *MASH* limits. However, the occupant compartment deformation (OCD) in the toe pan area of the pickup truck model was 9.4 inches, which slightly exceeds the *MASH* threshold of 9 inches. Even though the FE model of the pickup truck has not been validated for OCD, and there are several limitations of the model (e.g., lack of suspension and material failure), the high OCD value in the simulation indicated high probability of marginal performance in the crash test. Taking a more conservative approach that still met the project goals, TxDOT decided to select a shallower flare rate of 12:1 for evaluating the single-slope PCB system.

Table 2.2. Results for *MASH* Test 3-11 on Single-Slope PCB System Flared at 7 Degrees.

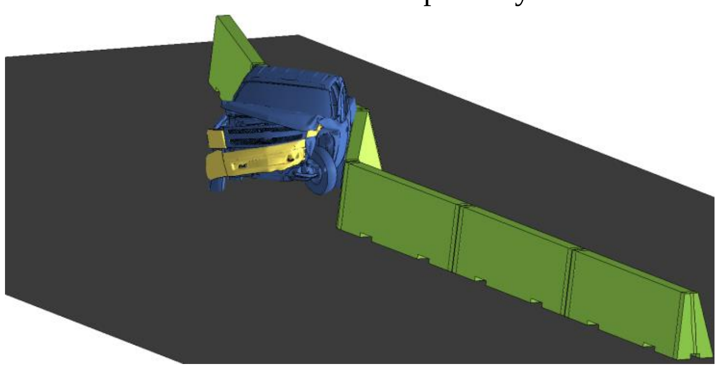
Occupant Risk Parameters	Absolute Values	*MASH* Criteria
Occupant Impact Velocity (OIV)	8.8 m/s	≤ 12.2 m/s
Ridedown Acceleration (RDA)	16.7 g	≤ 20.49 g
Occupant Compartment Deformation (OCD)	9.4 inches	≤ 9 inches



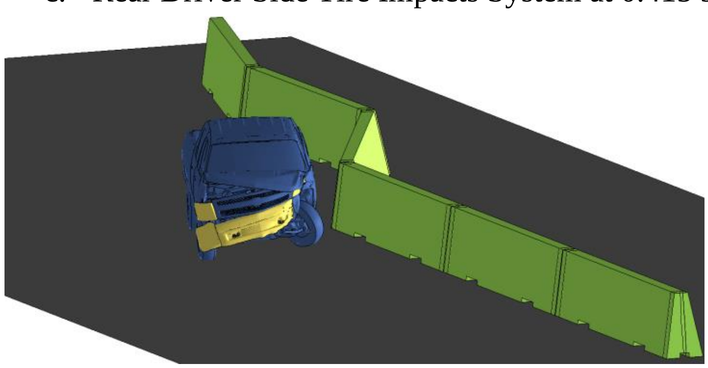
a. First Impact of Vehicle with System at 0.045 s



b. Front Driver Side Tire Impacts System at 0.135 s



c. Rear Driver Side Tire Impacts System at 0.415 s



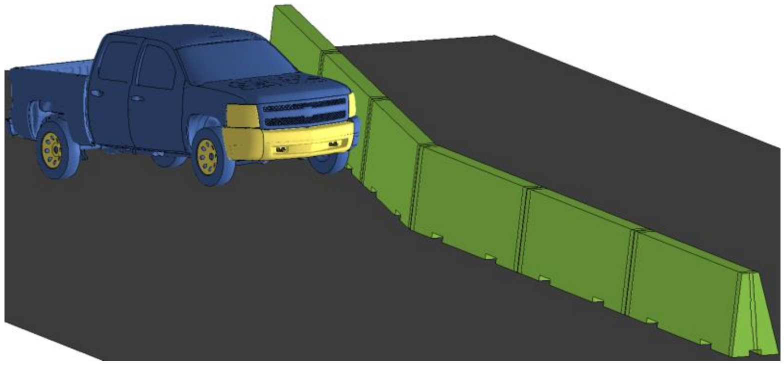
d. Vehicles Redirects in Stable State at 0.9 s

Figure 2.6. Frames of Test 3-11 for Single-Slope PCB System Flared at 7 Degrees.

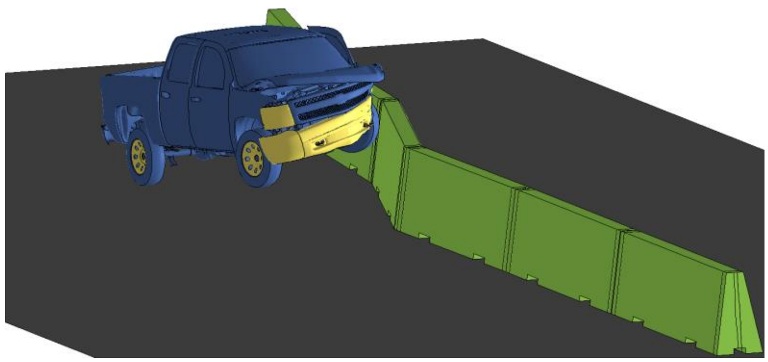
2.4.2. Single-Slope PCB System with 12:1 Flare Rate

Impact simulations for *MASH* Test 3-11 and Test 3-10 conditions were performed on the single-slope PCB model with a 12:1 flare rate. The *MASH* pickup truck model impacted the system at 62 mi/h and a resultant angle of 29.76 degrees (i.e., 25 degrees for *MASH* Test 3-11, plus a 4.76-degree flare). The impact point was 4.3 ft upstream of the joint between barrier 2 and barrier 3.

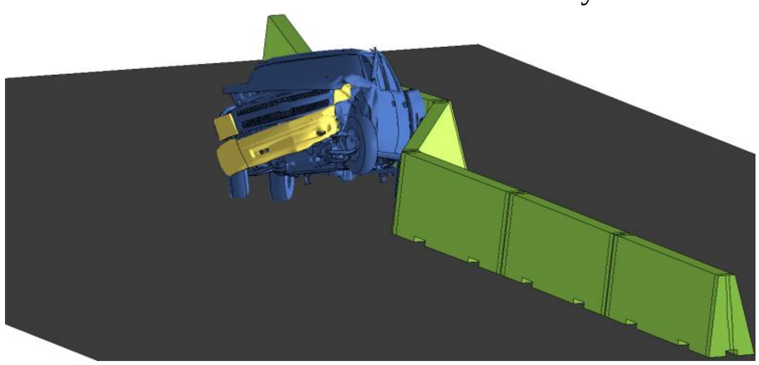
Isometric- and top-view images from the *MASH* Test 3-11 simulation with the pickup truck model are shown in Figure 2.7 and Figure **2.8**, respectively. Isometric- and top-view images from the *MASH* Test 3-10 simulation with the small car model are shown in Figure 2.9 and Figure 2.10, respectively. Both vehicles were successfully contained and redirected in a stable manner.



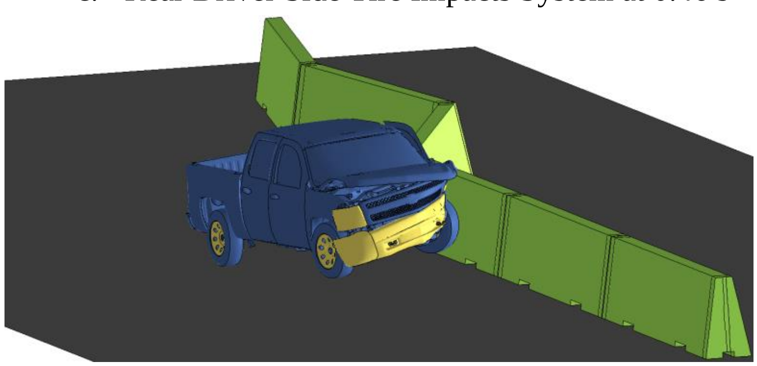
a. First Impact of Vehicle with System at 0.025 s



b. Front Driver Side Tire Interacts with System at 0.14 s

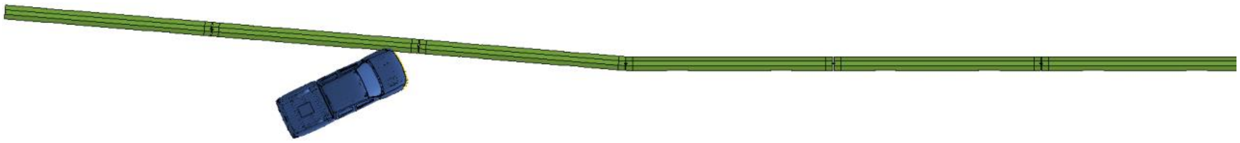


c. Rear Driver Side Tire Impacts System at 0.46 s

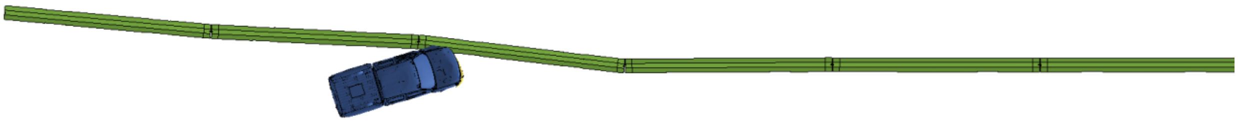


d. Vehicles Redirects in Stable State at 1.1 s

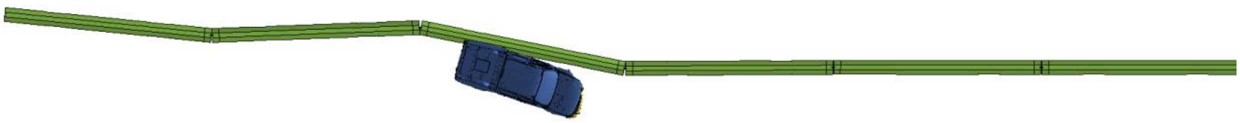
Figure 2.7. Isometric-View Simulation Frames of *MASH* Test 3-11 for Single-Slope PCB System with a 12:1 Flare Rate.



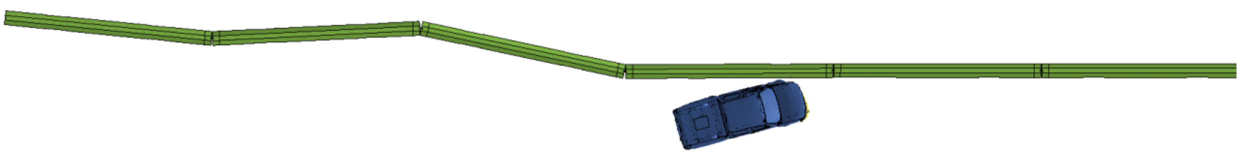
a. First Impact of Vehicle with System at 0.025 s



b. Front Driver Side Tire Interacts with System at 0.14 s

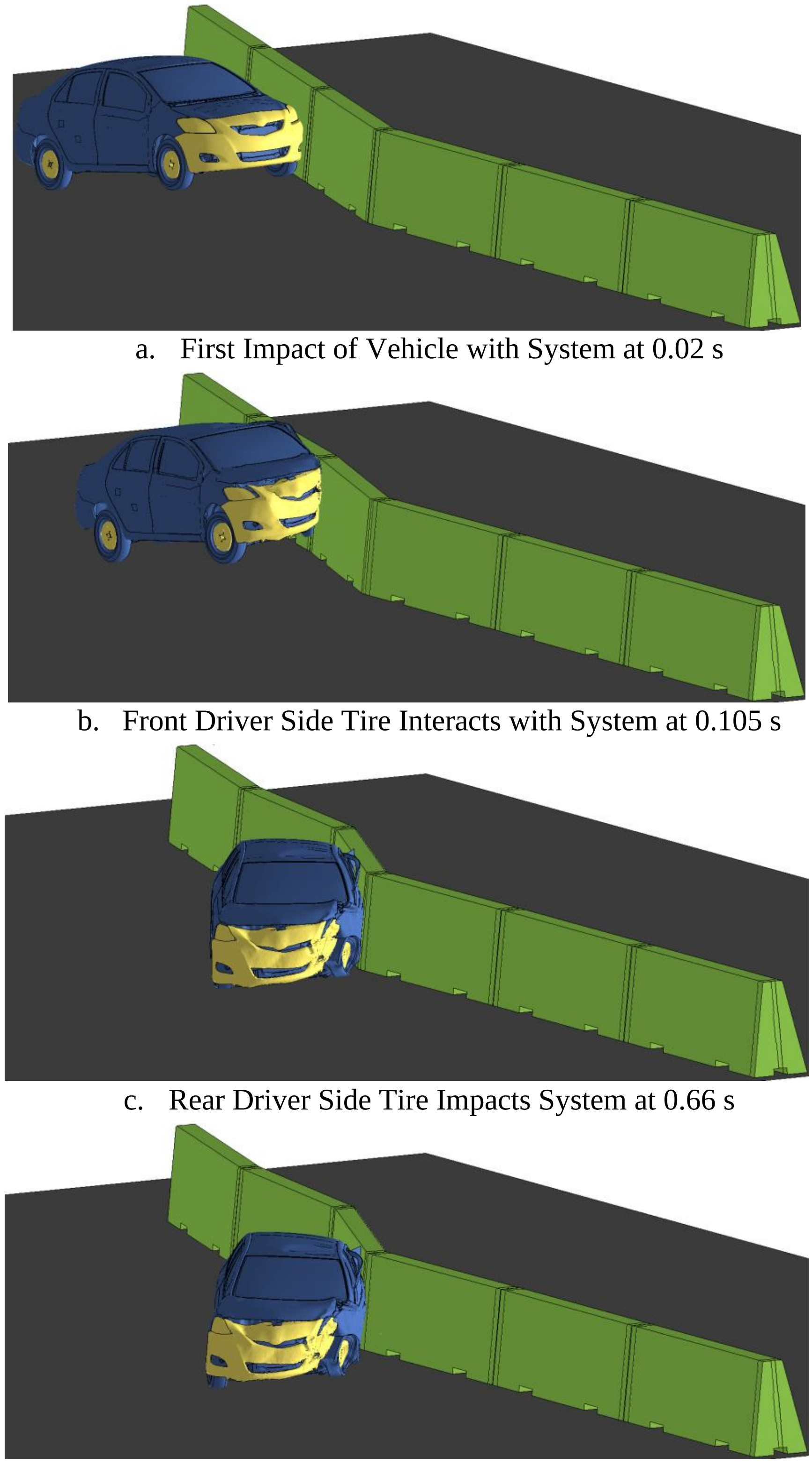


c. Rear Driver Side Tire Impacts System at 0.46 s



d. Vehicles Redirects in Stable State at 1.1 s

Figure 2.8**. Top-View Simulation Frames of *MASH* Test 3-11 for Single-Slope PCB System with a 12:1 Flare Rate.**



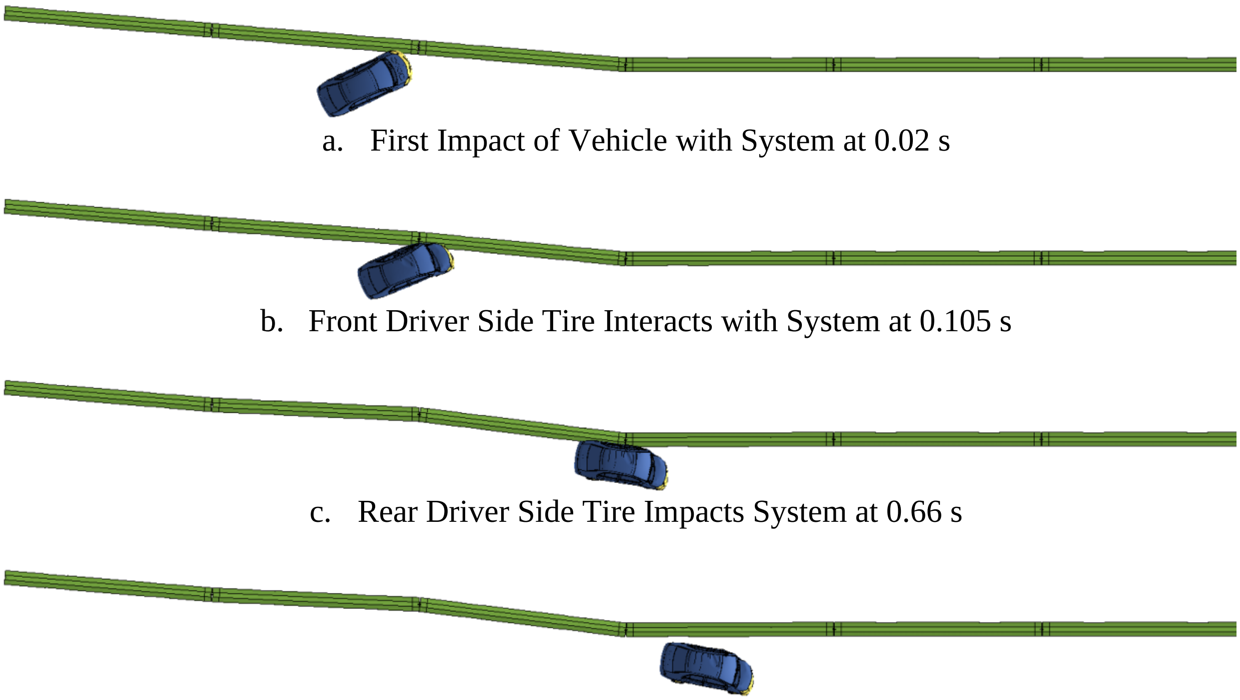
a. First Impact of Vehicle with System at 0.02 s

b. Front Driver Side Tire Interacts with System at 0.105 s

c. Rear Driver Side Tire Impacts System at 0.66 s

d. Vehicles Redirects in Stable State at 0.9 s

Figure 2.9. Isometric-View Simulation Frames of *MASH* Test 3-10 for Single-Slope PCB System with a 12:1 Flare Rate.



a. First Impact of Vehicle with System at 0.02 s

b. Front Driver Side Tire Interacts with System at 0.105 s

c. Rear Driver Side Tire Impacts System at 0.66 s

d. Vehicles Redirects in Stable State at 0.9 s

Figure 2.10. Top-View Simulation Frames of *MASH* Test 3-10 for Single-Slope PCB System with a 12:1 Flare Rate.

Key results of the simulations are presented in Table 2.3. All occupant risk metrics, including the occupant compartment deformations, were within *MASH* limits. The maximum occupant compartment deformation of the pickup truck was 7.7 inches in the toe pan area, which was under the *MASH* limit of 9 inches. Figure 2.11 shows the occupant compartment deformation occurred in the driver's side toe pan area of the vehicle floor.

Table 2.3. Results for *MASH* Test 3-11 and 3-10 on Single-Slope PCB System with 12:1 Flare Rate.

Parameter	*MASH* Test 3-10	*MASH* Test 3-11	*MASH* Limit
OIV (ft/s)	38.1	28.9	40
RDA (g)	9.3	16.7	20.49
Permanent Deflection (inch)	13.15	45.52	N/A

Note: N/A = not applicable.

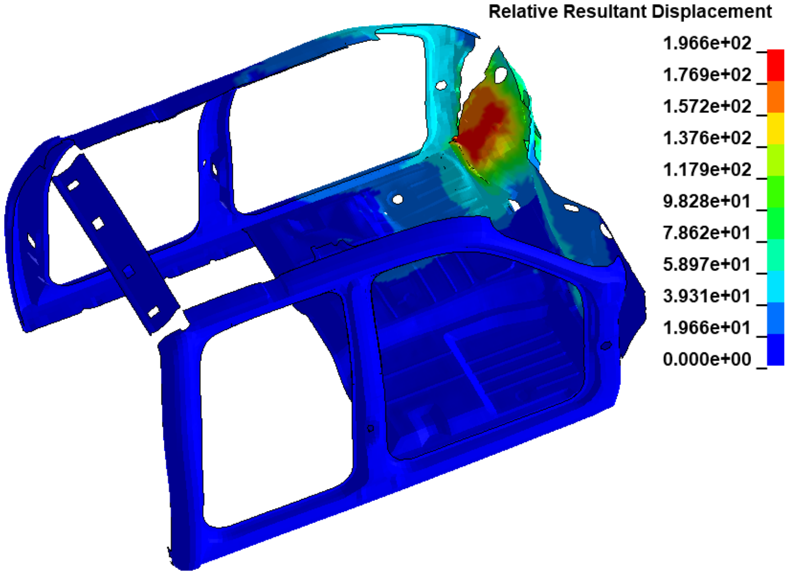


Figure 2.11. Maximum Deformation in Toe Pan Area of Pickup Truck was 7.7 inches (Fringe Scale in Millimeters).

2.5. CONCLUSIONS

The single-slope PCB system with 12:1 flare rate met *MASH* requirements in the TL-3 simulations performed with the pickup truck and passenger car. Given these satisfactory results, TTI proceeded with the full-scale crash testing of the single-slope PCB system with a 12:1 flare rate.

Chapter 3. SYSTEM DETAILS

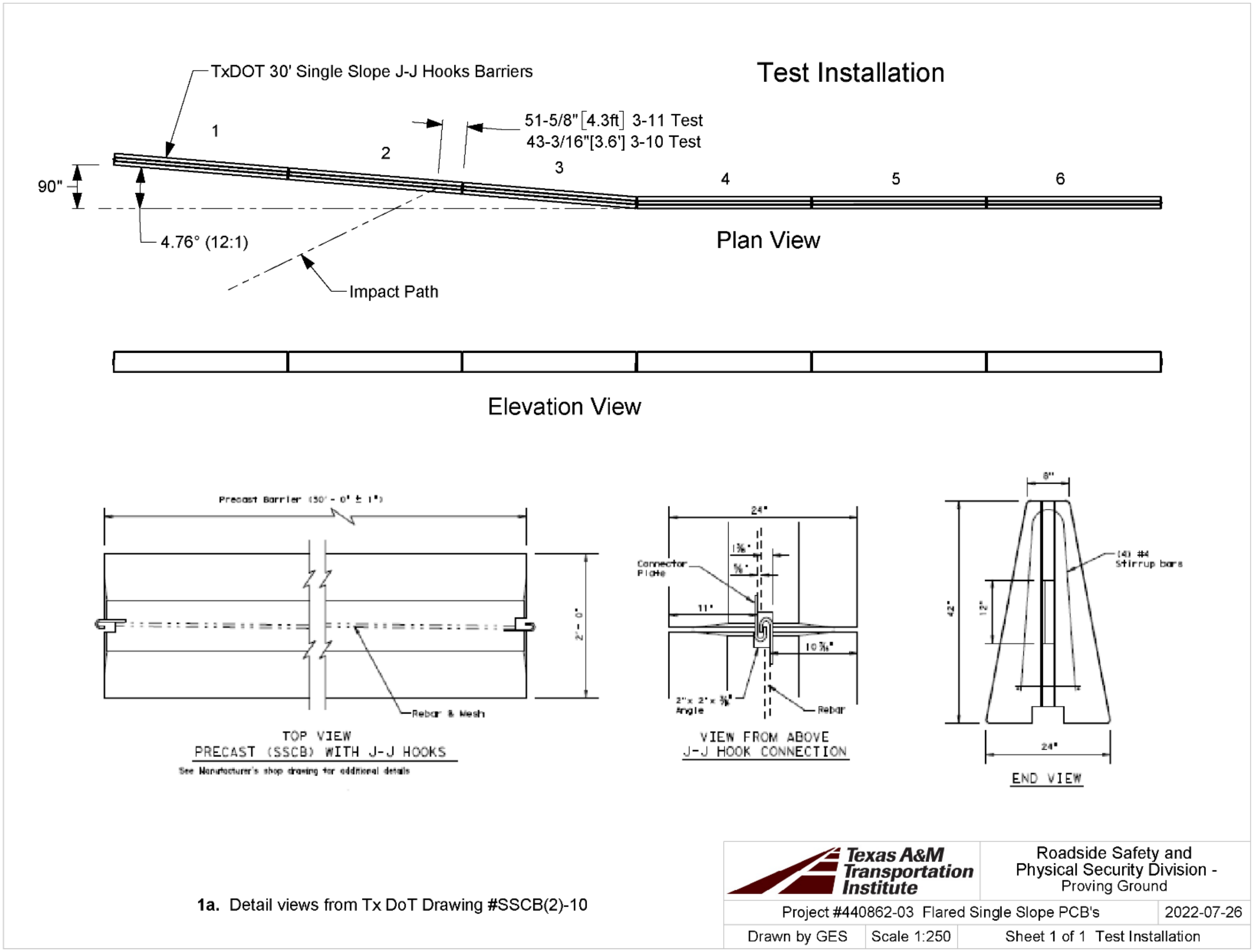
3.1. TEST ARTICLE AND INSTALLATION DETAILS

The test installation consisted of six 30-ft long single-slope steel-reinforced concrete barriers with J-J Hooks connections. The barriers were 8 inches wide at the top, 24 inches wide at the bottom, and 42 inches tall. The first three barriers on the upstream end were offset from the other three by 4.62 degrees (12:1) so that the upstream end of the first barrier was offset from the last three by approximately 90 inches. The barriers were set directly on the concrete apron without any restraints that would restrict movement.

Figure 3.1 presents the overall information on the flared single-slope PCBs, and Figure 3.2 through Figure 3.7 provide photographs of the installation. Appendix A provides further details on the flared single-slope PCBs. Drawings were provided by the TTI Proving Ground, and assembly of the installation was performed by TTI Proving Ground personnel.

3.2. DESIGN MODIFICATIONS DURING TESTS

No modifications were made to the installation during the testing phase.



Q:\Accreditation-17025-2017\EIR-000 Project Files\440862-01 - TxDOT FY2022\440862-03, Flared Portable Concrete Barrier - Bligh\Drafting, 440862-03\440862-03 Single Slope Drawing

Figure 3.1. Details of Flared Single-Slope Portable Concrete Barriers.

Figure 3.2. Flared Single-Slope Portable Concrete Barriers Prior to Testing.

Figure 3.3. Flared Single-Slope Portable Concrete Barriers at Impact Prior to Testing.

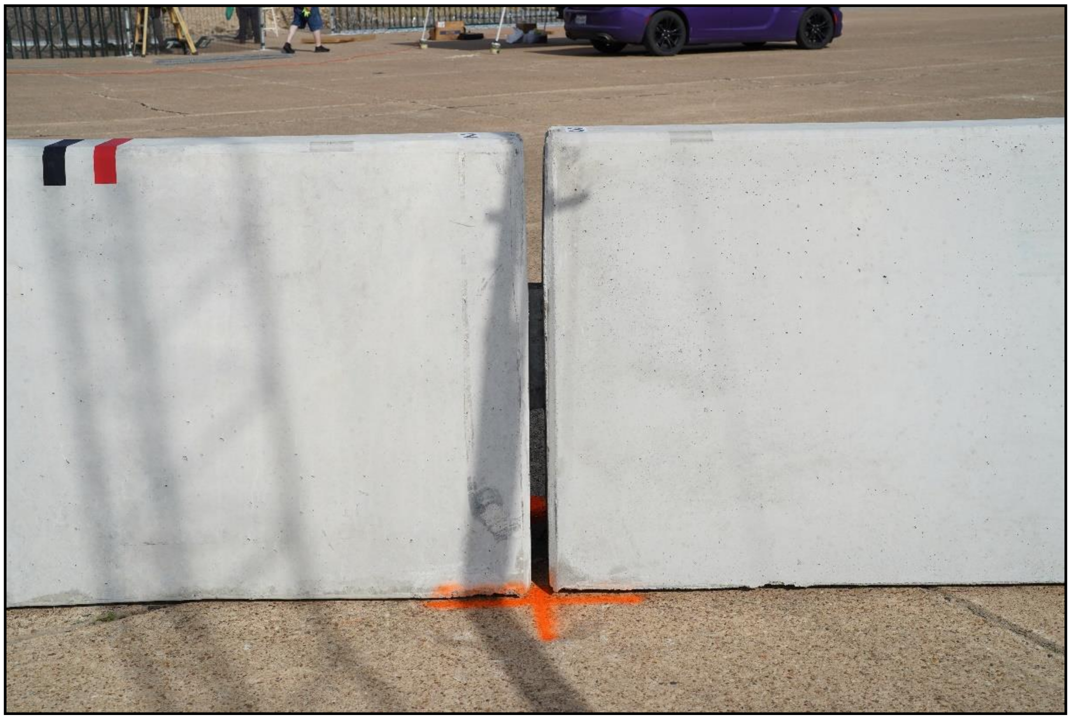


Figure 3.4. Flared Single-Slope Portable Concrete Barriersat the Joint Between Barriers 2 and 3 Prior to Testing.

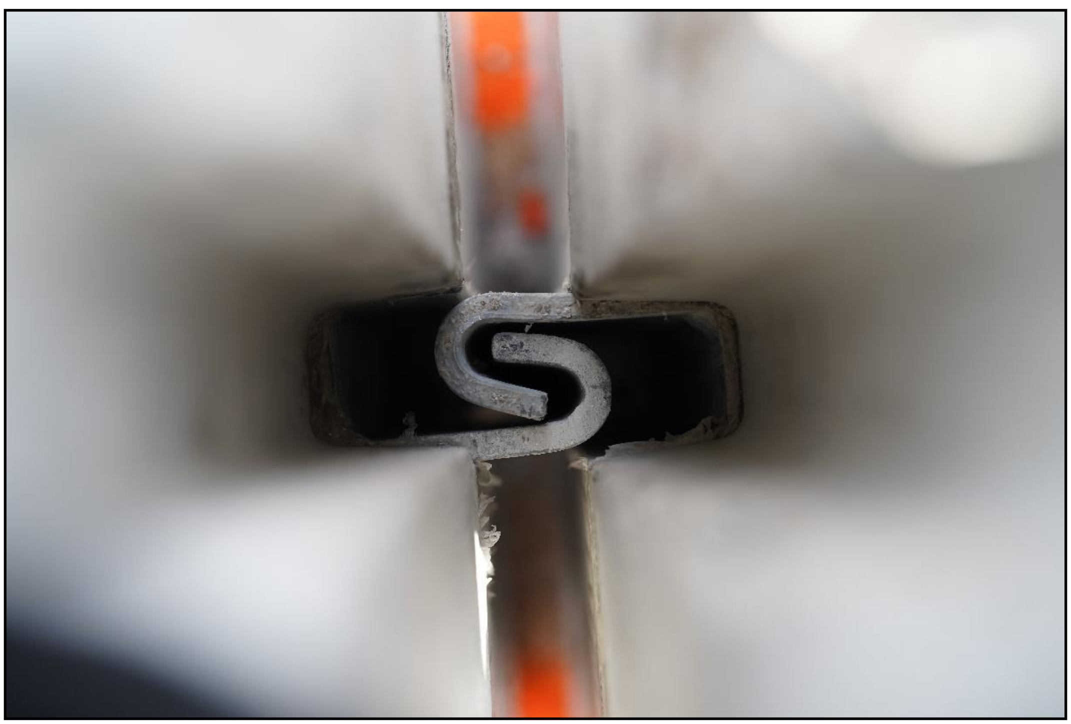


Figure 3.5. The Barrier Connections at the Joint of Barriers 2 and 3 Prior to Testing.

Figure 3.6. Downstream View of the Flared Single-Slope Portable Concrete Barriers prior to Testing.

Figure 3.7. Downstream View in Line with the Length of Need of the Flared Single-Slope Portable Concrete Barriers prior to Testing.

Chapter 4. TEST REQUIREMENTS AND EVALUATION CRITERIA

4.1. CRASH TEST PERFORMED/MATRIX

Table 4.1 shows the test conditions and evaluation criteria for *MASH* TL-3 for longitudinal barriers. The target critical impact points (CIPs) for each test were determined using *MASH* Table 2-7 and the simulation analysis presented in Chapter 2. Figure 4.1 shows the target CIP for *MASH* Tests 3-10 and 3-11 on the flared single-slope PCBs.

Table 4.1. Test Conditions and Evaluation Criteria Specified for *MASH* TL-3 Longitudinal Barriers.

Test Designation	Test Vehicle	Impact Speed	Impact Angle[a]	Evaluation Criteria
3-10	1100C	62 mi/h	25°	A, D, F, H, I
3-11	2270P	62 mi/h	25°	A, D, F, H, I

[a] Impact angle noted in the table is relative to the tangent barrier segments.

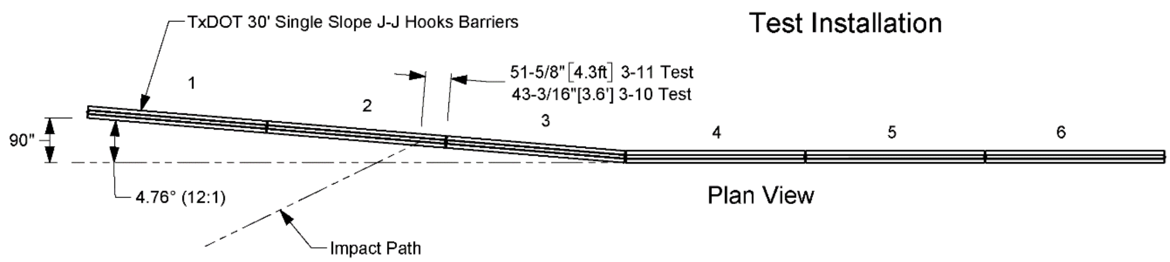


Figure 4.1. Target CIP for *MASH* TL-3 Tests on Flared Single-Slope PCBs.

The crash tests 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 appropriate safety evaluation criteria from Tables 2.2 and 5.1 of *MASH* were used to evaluate the crash tests reported herein. Table 4.1 lists the test conditions and evaluation criteria required for *MASH* TL-3, and Table 4.2 provides detailed information on the evaluation criteria.

Table 4.2. Evaluation Criteria Required for *MASH* Testing.

Evaluation Factors	Evaluation Criteria	*MASH* Test
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.	10, 11
D.	Detached elements, fragments, or other debris from the test article should not penetrate or show potential for penetrating the occupant compartment, or present undue hazard to other traffic, pedestrians, or personnel in a work zone. Deformations of, or intrusions into, the occupant compartment should not exceed limits set forth in Section 5.2.2 and Appendix E of *MASH*.	10, 11
F.	The vehicle should remain upright during and after collision. The maximum roll and pitch angles are not to exceed 75 degrees.	10, 11
H.	Occupant impact velocities (OIV) should satisfy the following limits: Preferred value of 30 ft/s, or maximum allowable value of 40 ft/s. Occupant impact velocities (OIV) should satisfy the following limits: Preferred value of 10 ft/s, or maximum allowable value of 16 ft/s.	10, 11
I.	The occupant ridedown accelerations should satisfy the following: Preferred value of 15.0 g, or maximum allowable value of 20.49 g.	10, 11

Chapter 5. TEST CONDITIONS

5.1. TEST FACILITY

The full-scale crash tests reported herein were performed at the TTI Proving Ground, an International Standards Organization (ISO)/International Electrotechnical Commission (IEC) 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, as well as *MASH* guidelines and standards.

The test facilities of the TTI Proving Ground are located on The Texas A&M University System RELLIS Campus, which consists of a 2000-acre complex of research and training facilities situated 10 mi northwest of the flagship campus of Texas A&M University. The site, formerly a United States Army Air Corps 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, highway pavement durability and efficacy, and roadside safety hardware and perimeter protective device evaluation. The site selected for construction and testing was on an out-of-service apron/runway. The apron/runway consists of an unreinforced jointed-concrete pavement in 12.5-ft × 15-ft blocks nominally 6 inches deep. The aprons were built in 1942, and the joints have some displacement but are otherwise flat and level.

5.2. VEHICLE TOW AND GUIDANCE SYSTEM

For the testing utilizing the 1100C and 2270P vehicles, each 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 and 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 2:1 speed ratio between the test and tow vehicle existed with this system. Just prior to impact with the installation, the test vehicle was released and ran unrestrained. The vehicle remained freewheeling (i.e., no steering or braking inputs) until it cleared the immediate area of the test site.

5.3. DATA ACQUISITION SYSTEMS

5.3.1. Vehicle Instrumentation and Data Processing

Each test vehicle was instrumented with a self-contained onboard data acquisition system. The signal conditioning and acquisition system is a multi-channel data acquisition system (DAS) produced by Diversified Technical Systems Inc. The accelerometers, which 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, solid-state units designed for crash test service. The data acquisition hardware and software conform to the latest SAE J211, Instrumentation for Impact Test. Each of the 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 samples per second with a resolution of one part in 65,536. Once data are recorded, internal batteries back these up inside the unit in case the primary battery cable is severed. Initial contact of the pressure switch on the vehicle bumper provides a time zero mark and initiates the recording process. After each test, the data are downloaded from the DAS unit into a laptop computer at the test site. The Test Risk Assessment Program (TRAP) software then processes the raw data to produce detailed reports of the test results.

Each DAS is returned to the factory annually for complete recalibration and to ensure that all instrumentation used in the vehicle conforms to the specifications outlined by SAE J211. All accelerometers are calibrated annually by means of an ENDEVCO® 2901 precision primary vibration standard. This standard and its support instruments are checked annually and receive a National Institute of Standards Technology (NIST) traceable calibration. The rate transducers used in the data acquisition system receive calibration via a Genisco Rate-of-Turn table. 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 also made anytime data are suspect. Acceleration data are measured with an expanded uncertainty of ±1.7 percent at a confidence factor of 95 percent (k = 2).

TRAP uses the DAS-captured data to compute the occupant/compartment impact velocities, time of occupant/compartment impact after vehicle impact, and 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 an SAE Class 180-Hz low-pass 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 being initial impact. Rate of rotation data is measured with an expanded uncertainty of ±0.7 percent at a confidence factor of 95 percent (k = 2).

5.3.2. Anthropomorphic Dummy Instrumentation

An Alderson Research Laboratories Hybrid II, 50th percentile male anthropomorphic dummy, restrained with lap and shoulder belts, was placed in the front seat on the impact side of the 1100C vehicle. The dummy was not instrumented.

According to *MASH*, use of a dummy in the 2270P vehicle is optional. However, *MASH* recommends that a dummy be used when testing “any longitudinal barrier with a height greater than or equal to 33 inches.” More specifically, use of the dummy in the 2270P vehicle is recommended for tall barriers to evaluate the “potential for an occupant to extend out of the vehicle and come into direct contact with the test article.” Although this information is reported, it is not part of the impact performance evaluation. Since the barrier height of the flared single-slope PCBs was 42 inches, a dummy was placed in the front seat of the 2270P vehicle on the impact side and restrained with lap and shoulder belts.

5.3.3. Photographic Instrumentation Data Processing

Photographic coverage of each test included three digital high-speed cameras:

- One located overhead with a field of view perpendicular to the ground and directly over the impact point.
- One placed downstream from the impact on the field side of the installation at an angle to have a field of view of the movement of the barrier.
- A third placed with a field of view parallel to and aligned with the installation at the downstream end.

A flashbulb on the impacting vehicle was activated by a pressure-sensitive tape switch to indicate the instant of contact with the flared single-slope PCBs. The flashbulb was visible from each camera. The video files from these digital high-speed cameras were analyzed to observe phenomena occurring during the collision and to obtain time-event, displacement, and angular data. A digital camera recorded and documented conditions of each test vehicle and the installation before and after the test.

Chapter 6. *MASH* TEST 3-11 (CRASH TEST NO. 440862-03-3)

6.1. TEST DESIGNATION AND ACTUAL IMPACT CONDITIONS

See Table 6.1 for details on the *MASH* impact conditions and Table 6.2 for the exit parameters of Test 440862-03-3. Figure 6.1 and Figure 6.2 depict the target impact setup.

Table 6.1. Impact Conditions for *MASH* Test 3-11, Crash Test 440862-03-3.

Test Parameter	Specification	Tolerance	Measured
Impact Speed (mi/h)	62	±2.5 mi/h	60.9
Impact Angle (deg)	25	±1.5°	25.2
Impact Severity (kip-ft)	106	≥106 kip-ft	113.4
Impact Location	51.6 inches upstream of center of joint between barrier 2 and 3	±1 ft	52.6 inches upstream of center of joint between barrier 2 and 3

Table 6.2. Exit Parameters for *MASH* Test 3-11, Crash Test 440862-03-3.

Exit Parameter	Measured
Speed (mi/h)	46.3
Trajectory (deg)	8
Heading (deg)	8
Brakes applied post impact (s)	2.7
Vehicle at rest position	236 ft downstream of impact point 51 ft to the traffic side 15° right
Comments:	Vehicle remained upright and stable. Vehicle crossed exit box[a] 71 ft downstream from loss of contact.

[a] Not less than 32.8 ft downstream from loss of contact for cars and pickups is optimal.

Figure 6.1. Flared Single-Slope Portable Concrete Barriers/Test Vehicle Geometrics for Test 440862-03-3.

Figure 6.2. Flared Single-Slope Portable Concrete Barriers/Test Vehicle Impact Location for Test 440862-03-3.

6.2. WEATHER CONDITIONS

Table 6.3 provides the weather conditions for Test 440862-03-3.

Table 6.3. Weather Conditions for Test 440862-03-3.

Date of Test	August 17, 2022 AM
Temperature (°F)	89
Relative Humidity (%)	68
Wind Direction (deg)	210
Vehicle Traveling (deg)	350
Wind Speed (mi/h)	8

6.3. TEST VEHICLE

Figure 6.3 and Figure 6.4 show the 2016 RAM 1500 used for the crash test. Table 6.4 shows the vehicle measurements. Figure B.1 in Appendix B.1 gives additional dimensions and information on the vehicle.

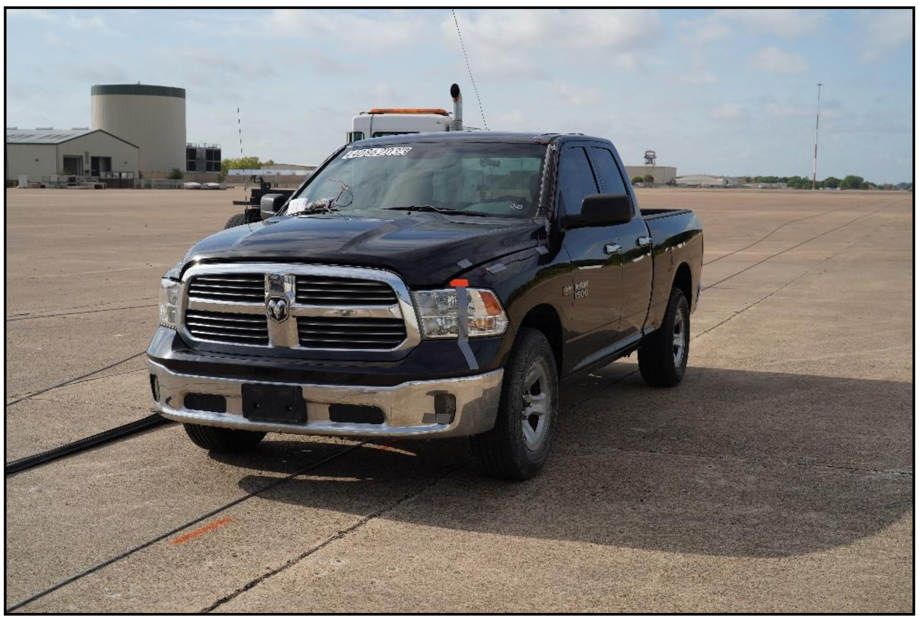


Figure 6.3. Impact Side of Test Vehicle before Test 440862-03-3.

Figure 6.4. Opposite Impact Side of Test Vehicle before Test 440862-03-3.

Table 6.4. Vehicle Measurements for Test 440862-03-3.

Test Parameter	***MASH***	**Allowed Tolerance**	**Measured**
Dummy (if applicable)[a] (lb)	165	N/A	165
Curb Weight (lb)	5000	±110	5080
Vehicle Inertial Weight (lb)	5000	±110 lb	5046
Gross Static[a] (lb)	5165	N/A	5211
Wheelbase (inches)	148	±12	140.5
Front Overhang (inches)	39	±3	40
Overall Length (inches)	237	±13	227.5
Overall Width (inches)	78	±2	78.5
Hood Height (inches)	43	±4	46
Track Width[b] (inches)	67	±1.5	68.25
CG aft of Front Axle[c] (inches)	63	±4	60.2
CG above Ground[c,d] (inches)	28	≥28	28.4

[a] If a dummy is used, the gross static vehicle mass should be increased by the mass of the dummy.
[b] Average of front and rear axles.
[c] For test inertial mass.
[d] 2270P vehicle must meet minimum center of gravity (CG) height requirement.

6.4. TEST DESCRIPTION

Table 6.5 lists events that occurred during Test No. 440862-03-3. Figures B.4 through B.6 in Appendix B.2 present sequential photographs during the test.

Table 6.5. Events during Test 440862-03-3.

Time (s)	Events
0.0000	Vehicle impacted the installation
0.0350	Vehicle began to redirect
0.0440	Barrier began to displace toward field side
0.0970	Front passenger side tire lifted off the pavement
0.2310	Vehicle was parallel with the installation
0.5730	Front driver side tire contacted the pavement
0.5870	Vehicle exited the installation traveling 46.3 mi/h with an exit angle of 8 degrees
0.7120	Front passenger side tire contacted the pavement

6.5. DAMAGE TO TEST INSTALLATION

There was concrete scuffing and spalling at impact. There was concrete spalling at the joint between barriers 2 and 3, with exposed rebar on barrier 2. There were cracks in barriers 2 and 3. The concrete was also spalled on the field side at the joint between barriers 3 and 4.

Table 6.6 and Table 6.7 describe the damage to the flared single-slope PCBs. Figure 6.5 and Figure 6.6 show the damage to the flared single-slope PCBs.

Table 6.6. Movement of the Flared Single-Slope Portable Concrete Barriers in Test 440862-03-3.

Location	Longitudinal Movement	Lateral Movement
Upstream end of B1	8 inches d/s	6 inches f/s
Joint 1–2	8 inches d/s	8 inches t/s
Joint 2–3	0	58 inches f/s
Joint 3–4	1 inch u/s	2 inches f/s
Joint 4–5	½ inch u/s	0
Joint 5–6	½ inch u/s	0
Downstream end of B6	0	0

Note: d/s = downstream; u/s = upstream; t/s = traffic side; f/s = field side.

Table 6.7. Damage to Flared Single-Slope Portable Concrete Barriers in Test 440862-03-3.

Test Parameter	Measured
Permanent Deflection/Location	58 inches toward field side, at the joint of barriers 2 and 3
Dynamic Deflection	58.7 inches toward field side at the traffic side toe of the joint of barriers 2 and 3
Working Width[a] and Height	82.7 inches, at a height of 1 inch, at the base of the barrier

[a] Per *MASH*, "The working width is the maximum dynamic lateral position of any major part of the system or vehicle. These measurements are all relative to the pre-impact traffic face of the test article." In other words, working width is the total barrier width plus the maximum dynamic intrusion of any portion of the barrier or test vehicle past the field side edge of the barrier.

Figure 6.5. Flared Single-Slope Portable Concrete Barriers after Test 440862-03-3.

Figure 6.6. Flared Single-Slope Portable Concrete Barriers after Test at Impact Location, Test 440862-03-3.

6.6. DAMAGE TO TEST VEHICLE

Figure 6.7 and Figure 6.8 show the damage sustained by the vehicle. Figure 6.9 and Figure 6.10 show the interior of the test vehicle. Table 6.8 and Table 6.9 provide details on the occupant compartment deformation and exterior vehicle damage. Figures B.2 and B.3 in Appendix B.1 provide exterior crush and occupant compartment measurements.

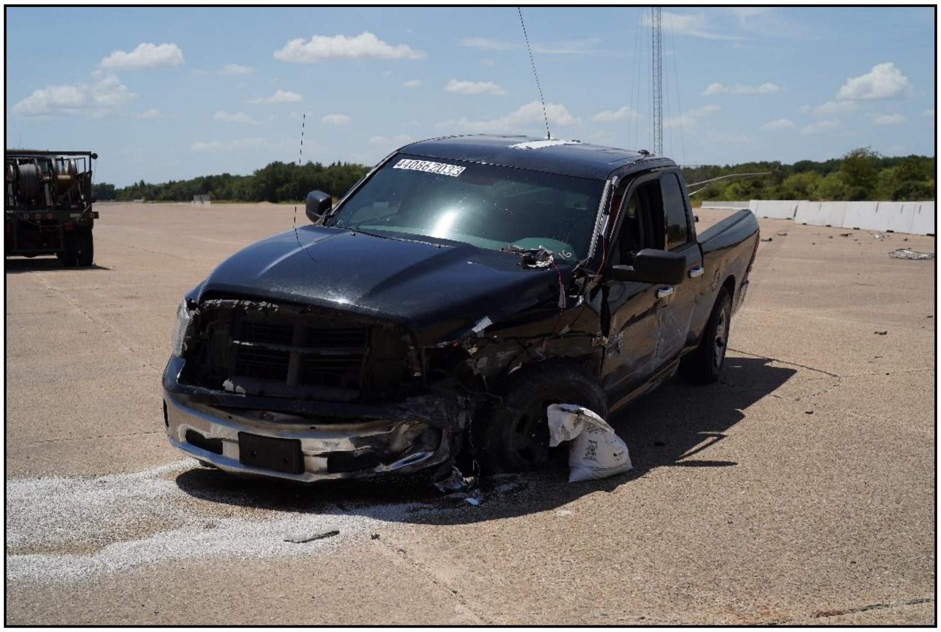


Figure 6.7. Impact Side of Test Vehicle after Test 440862-03-3.

Figure 6.8. Rear Impact Side of Test Vehicle after Test 440862-03-3.

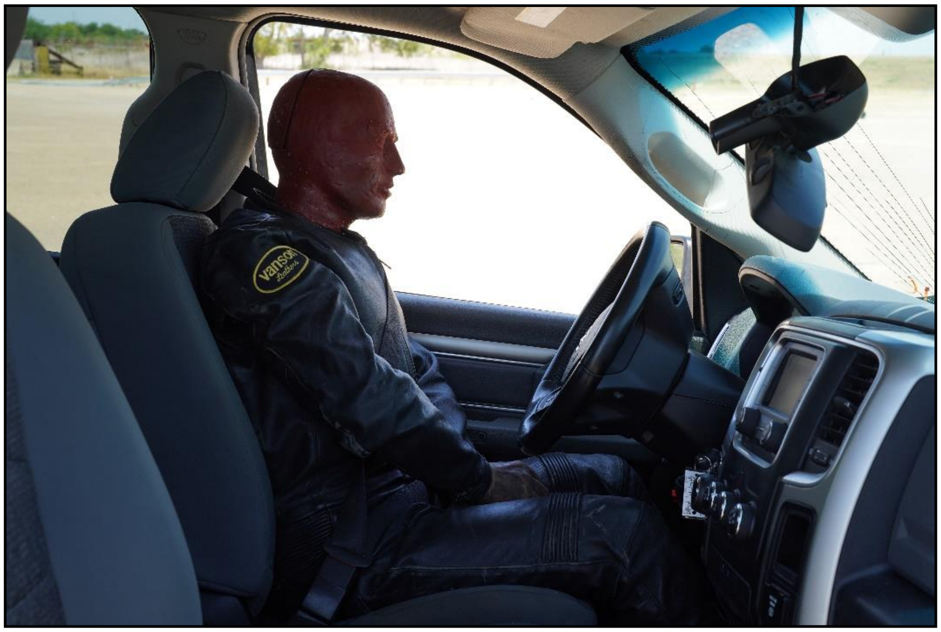


Figure 6.9. Overall Interior of Test Vehicle after Test 440862-03-3.

Figure 6.10. Interior of Test Vehicle on Impact Side after Test 440862-03-3.

Table 6.8. Occupant Compartment Deformation for Test 440862-03-3.

Test Parameter	Specification	Measured
Roof	≤4.0 inches	0 inches
Windshield	≤3.0 inches	0 inches
A and B Pillars	≤5.0 overall/≤3.0 inches lateral	0 inches
Foot Well/Toe Pan	≤9.0 inches	2 inches
Floor Pan/Transmission Tunnel	≤12.0 inches	0 inches
Side Front Panel	≤12.0 inches	1 inch
Front Door (above Seat)	≤9.0 inches	1 inch
Front Door (below Seat)	≤12.0 inches	0 inches

Table 6.9. Exterior Vehicle Damage for Test 440862-03-3.

Side Windows	The left side window shattered due to deformation of the door.
Maximum Exterior Deformation	9 inches in the front plane at the left front corner at bumper height.
VDS	11LFQ4
CDC	11FLEW5
Fuel Tank Damage	None
Description of Damage to Vehicle:	The front bumper, hood, grill, left headlight, left front quarter fender, left front tire and rim, windshield, left front door and glass, floor pan, left rear door, left rear cab corner, left rear quarter fender, left rear rim, left taillight, and rear bumper were damaged. The windshield had some cracking (caused by flexing of the body), and the left front door had a 2.5-inch gap at the top of the door.

6.7. OCCUPANT RISK FACTORS

Data from the accelerometers were digitized for evaluation of occupant risk, and the results are shown in Table 6.10. Figure B.7 in Appendix B.3 shows the vehicle angular displacements, and Figures B.8 through B.10 in Appendix B.4 show acceleration versus time traces.

Table 6.10. Occupant Risk Factors for Test 440862-03-3.

Test Parameter	*MASH*	Measured	Time
OIV, Longitudinal (ft/s)	≤40.0 *30.0*	18.0	0.0984 s on left side of interior
OIV, Lateral (ft/s)	≤40.0 *30.0*	23.0	0.0984 s on left side of interior
RDA, Longitudinal (g)	≤20.49 *15.0*	4.3	0.0984–0.1084 s
RDA, Lateral (g)	≤20.49 *15.0*	14.1	0.2474–0.2574 s
Theoretical Head Impact Velocity (THIV) (m/s)	N/A	8.9	0.0952 s on left side of interior
Acceleration Severity Index (ASI)	N/A	1.7	0.0579–0.1079 s
50-ms Moving Average Accelerations (MA) Longitudinal (g)	N/A	−8.7	0.0252–0.0752 s
50-ms MA Lateral (g)	N/A	12.6	0.0249–0.0749 s
50-ms MA Vertical (g)	N/A	−3.7	0.0311–0.0811 s
Roll (deg)	≤75	12	0.5457 s
Pitch (deg)	≤75	7	0.7642 s
Yaw (deg)	N/A	39	0.5272 s

Note: Values in italics are the preferred *MASH* values.

6.8. TEST SUMMARY

Figure 6.11, Table 6.11, and Table 6.12 summarize the results of *MASH* Test 440862-03-3. Figure 6.12 shows the sequential photographs from the crash test. Figure 6.13 shows the summary drawing for the crash test.

0.000 s

0.200 s

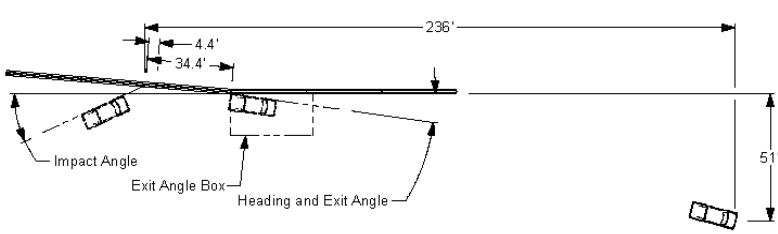
0.400 s

0.600 s

Test Agency	Texas A&M Transportation Institute (TTI)
Test Standard/Test No.	*MASH* 2016, Test 3-11
TTI Project No.	440862-03-3
Test Date	2022-08-17
TEST ARTICLE	
Type	Longitudinal Barrier
Name	Flared Single-Slope Portable Concrete Barriers
Length	180 ft
Key Materials	TxDOT 30-ft Single-Slope J-J Hooks Barriers
Soil Type and Condition	Concrete, Damp
TEST VEHICLE	
Type/Designation	2270P
Year, Make and Model	2016 RAM 1500
Curb Weight (lb)	5080
Inertial Weight (lb)	5046
Dummy (lb)	165
Gross Static (lb)	5211
IMPACT CONDITIONS	
Impact Speed (mi/h)	60.9
Impact Angle (deg)	25.2
Impact Location	52.6 inches upstream of center of joint between barrier 2 and 3
Impact Severity (kip-ft)	113.4
EXIT CONDITIONS	
Exit Speed (mi/h)	46.3
Trajectory/Heading Angle (deg)	8/8
Exit Box Criteria	Vehicle crossed 71 ft downstream from loss of contact
Stopping Distance	236 ft downstream of impact point 51 ft to the traffic side
TEST ARTICLE DEFLECTIONS	
Dynamic (inches)	58.7
Permanent (inches)	58.0
Working Width/Height (inches)	82.7/1
VEHICLE DAMAGE	
VDS	11LFQ4
CDC	11FLEW5
Max. Ext. Deformation	9 inches
Max. Occupant Compartment Deformation	2 inches in the toe pan

OCCUPANT RISK VALUES

Long. OIV (ft/s)	18.0	Long. Ridedown (g)	4.3	Max. 50-ms Long. (g)	−8.7	Max. Roll (deg)	12
Lat. OIV (ft/s)	23.0	Lat. Ridedown (g)	14.1	Max. 50-ms Lat. (g)	12.6	Max. Pitch (deg)	7
THIV (m/s)	8.9	ASI	1.7	Max. 50-ms Vert. (g)	−3.7	Max. Yaw (deg)	39



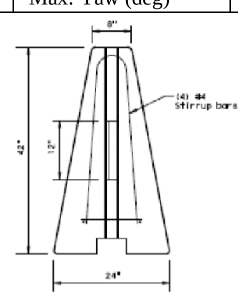


Figure 6.11. Summary of Results for *MASH* Test 3-11 on Flared Single-Slope Portable Concrete Barriers.

Table 6.11. Summary of Results for Test 440862-03-3, General Information, Impact and Exit Conditions.

General Information	Test Agency	Texas A&M Transportation Institute
	Test Standard Test No.	*MASH* 2016, Test 3-11
	TTI Test No.	440862-03-3
	Test Date	2022-08-17
Test Article	Type	Longitudinal Barrier
	Name	Flared Single-Slope Portable Concrete Barriers
	Installation Length	180 ft
	Material or Key Elements	TxDOT 30-ft Single-Slope J-J Hooks Barriers
	Foundation Type/ Condition	Concrete, Damp
Test Vehicle	Type/Designation	2270P
	Make and Model	2016 RAM 1500
	Curb	5080 lb
	Test Inertial	5046 lb
	Dummy	165 lb
	Gross Static	5211 lb
Impact Conditions	Speed	60.9 mi/h
	Angle	25.2 degrees
	Location	52.6 inches upstream of center of joint between barrier 2 and 3
	Impact Severity	113.4 kip-ft
Exit Conditions	Speed	46.3 mi/h
	Exit Trajectory/Heading	8 degrees/8 degrees

Table 6.12. Summary of Results for Test 440862-03-3, Occupant Risk, Vehicle and Test Article Damage.

Occupant Risk Values	Longitudinal OIV	18.0 ft/s
	Lateral OIV	23.0 ft/s
	Longitudinal RDA	4.3 g
	Lateral RDA	14.1 g
	THIV	8.9 m/s
	ASI	1.7
Max. 0.050-s Average	Longitudinal	−8.7 g
	Lateral	12.6 g
	Vertical	−3.7 g
Post-Impact Trajectory	Stopping Distance	236 ft downstream of impact point 51 ft to the traffic side
Vehicle Stability	Maximum Roll Angle	12 degrees
	Maximum Pitch Angle	7 degrees
	Maximum Yaw Angle	39 degrees
	Vehicle Snagging	No
	Vehicle Pocketing	No
Test Article Deflections	Dynamic	58.7 inches
	Permanent	58 inches
	Working Width	82.7 inches
	Height of Working Width	1 inch
Vehicle Damage	VDS	11LFQ4
	CDC	11FLEW5
	Max. Exterior Deformation	9 inches
	Max. Occupant Compartment Deformation	2 inches

(a) 0.000 s

(b) 0.200 s

Figure 6.12. Summary of Results for Test 440862-03-3, Sequential Test Pictures.

(c) 0.400 s

(d) 0.600 s

Figure 6.12. Summary of Results for Test 440862-03-3, Sequential Test Pictures (Continued).

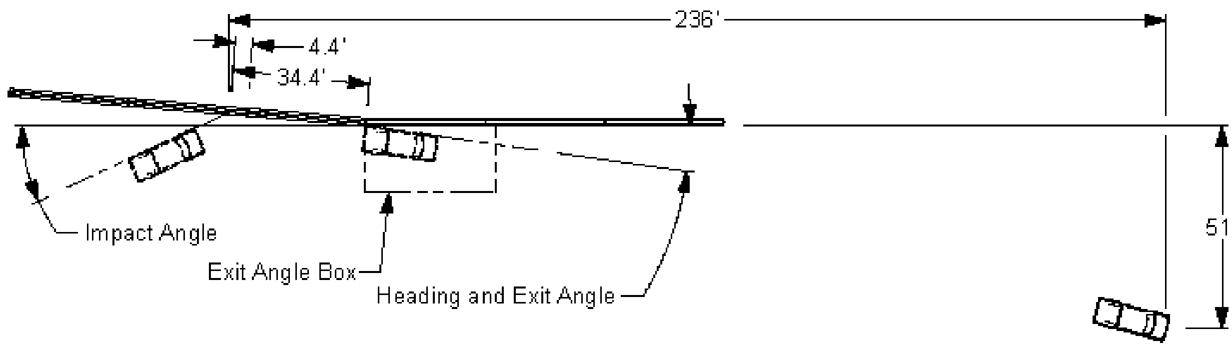


Figure 6.13. Summary of Results for Test 440862-03-3, Summary Drawing.

Chapter 7. *MASH* TEST 3-10 (CRASH TEST NO. 440862-03-4)

7.1. TEST DESIGNATION AND ACTUAL IMPACT CONDITIONS

See Table 7.1 for details on the *MASH* impact conditions and Table 7.2 for the exit parameters for Test 440862-03-4. Figure 7.1 and Figure 7.2 depict the target impact setup.

Table 7.1. Impact Conditions for *MASH* Test 3-10, Crash Test 440862-03-4.

Test Parameter	Specification	Tolerance	Measured
Impact Speed (mi/h)	62	±2.5 mi/h	61.6
Impact Angle (deg)	25	±1.5°	25.7
Vehicle Inertial Weight (lb)	2420	±55 lb	2443
Impact Severity (kip-ft)	51	≥51 kip-ft	58.3
Impact Location	43.2 inches upstream of the center of the joint between barriers 2 and 3	±12 inches	44.8 inches upstream of the center of the joint between barriers 2 and 3

Table 7.2. Exit Parameters for *MASH* Test 3-10, Crash Test 440862-03-4.

Exit Parameter	Measured
Speed (mi/h)	44.9
Trajectory (deg)	10
Heading (deg)	24
Brakes applied post impact (s)	2.75
Vehicle at rest position	179 ft downstream of impact point 84 ft to the traffic side 90° right
Comments:	Vehicle remained upright and stable. Vehicle crossed exit box[a] 40 ft downstream from loss of contact.

[a] Not less than 32.8 ft downstream from loss of contact for cars and pickups is optimal.

Figure 7.1. Flared Single-Slope Portable Concrete Barriers/Test Vehicle Geometrics for Test 440862-03-4.

Figure 7.2. Flared Single-Slope Portable Concrete Barriers/Test Vehicle Impact Location for Test 440862-03-4.

7.2. WEATHER CONDITIONS

Table 7.3 provides the weather conditions for Test 440862-03-4.

Table 7.3. Weather Conditions for Test 440862-03-4.

Date of Test	August 19, 2022 AM
Temperature (°F)	83
Relative Humidity (%)	83
Wind Direction (deg)	319
Vehicle Traveling (deg)	350
Wind Speed (mi/h)	2

7.3. TEST VEHICLE

Figure 7.3 and Figure 7.4 show the 2016 Nissan Versa used for the crash test. Table 7.4 shows the vehicle measurements. Figure C.1 in Appendix C.1 gives additional dimensions and information on the vehicle.

Figure 7.3. Impact Side of Test Vehicle before Test 440862-03-4.

Figure 7.4. Opposite Impact Side of Test Vehicle before Test 440862-03-4.

Table 7.4. Vehicle Measurements for Test 440862-03-4.

Test Parameter	***MASH***	**Allowed Tolerance**	**Measured**
Dummy (if applicable)[a] (lb)	165	N/A	165
Curb Weight (lb)	2420	±55	2382
Gross Static[a] (lb)	2585	±55	2608
Wheelbase (inches)	98	±5	102.4
Front Overhang (inches)	35	±4	32.5
Overall Length (inches)	169	±8	175.4
Overall Width (inches)	65	±3	66.7
Hood Height (inches)	28	±4	30.5
Track Width[b] (inches)	59	±2	58.4
CG aft of Front Axle[c] (inches)	39	±4	41.1
CG above Ground[c,d] (inches)	N/A	N/A	N/A

[a] If a dummy is used, the gross static vehicle mass should be increased by the mass of the dummy.
[b] Average of front and rear axles.
[c] For test inertial mass.
[d] 2270P vehicle must meet minimum CG height requirement.

7.4. TEST DESCRIPTION

Table 7.5 lists events that occurred during Test No. 440862-03-4. Figures C.4 through C.6 in Appendix C.2 present sequential photographs during the test.

Table 7.5. Events during Test 440862-03-4.

Time (s)	Events
0.0000	Vehicle impacted the installation
0.0340	Vehicle began to redirect
0.0390	Barrier began to displace toward field side
0.0650	Front passenger side tire lifted off the pavement
0.1800	Rear driver side tire impacted barrier
0.1860	Vehicle was parallel with the installation
0.4350	Front driver side tire contacted the pavement
0.4960	Vehicle exited the installation traveling 44.9 mi/h with an exit heading of 24 degrees
0.7180	Front passenger side tire contacted the pavement

7.5. DAMAGE TO TEST INSTALLATION

There was minor gouging and scuffing at impact, as well as a small crack on the downstream end of barrier 2 and the upstream end of barrier 3 at the top on the field side.

Table 7.6 and Table 7.7 describe the damage to the flared single-slope PCBs. Figure 7.5 and Figure 7.6 show the damage to the flared single-slope PCBs.

Table 7.6. Movement of the Flared Single-Slope Portable Concrete Barriers in Test 440862-03-4.

Location	Longitudinal Movement	Lateral Movement
Upstream end of B1	0	½ inch f/s
Joint 1–2	0	¼ inch t/s
Joint 2–3	0	17 inches f/s
Joint 3–4	0	¾ inch t/s
Joint 4–5	0	½ inch f/s
Joint 5–6	0	0
Downstream end of B6	0	0

Note: t/s = traffic side; f/s = field side.

Table 7.7. Damage to Flared Single-Slope Portable Concrete Barriers in Test 440862-03-4.

Test Parameter	Measured
Permanent Deflection/Location	17 inches toward field side at the joint of barriers 2 and 3
Dynamic Deflection	17.8 inches toward field side
Working Width[a] and Height	41.8 inches, at a height of 1 inch, at the base of the barrier

[a] Per *MASH*, "The working width is the maximum dynamic lateral position of any major part of the system or vehicle. These measurements are all relative to the pre-impact traffic face of the test article." In other words, working width is the total barrier width plus the maximum dynamic intrusion of any portion of the barrier or test vehicle past the field side edge of the barrier.

Figure 7.5. Flared Single-Slope Portable Concrete Barriers after Test at Impact Location, Test 440862-03-4.

Figure 7.6. Flared Single-Slope Portable Concrete Barriers after Test at the Joint of Barriers 2 and 3, Test 440862-03-4.

7.6. DAMAGE TO TEST VEHICLE

Figure 7.7 and Figure 7.8 show the damage sustained by the vehicle. Figure 7.9 and Figure 7.10 show the interior of the test vehicle. Table 7.8 and Table 7.9 provide details on the occupant compartment deformation and exterior vehicle damage. Figures C.2 and C.3 in Appendix C.1 provide exterior crush and occupant compartment measurements.

Figure 7.7. Impact Side of Test Vehicle after Test 440862-03-4.

Figure 7.8. Rear Impact Side of Test Vehicle after Test 440862-03-4.

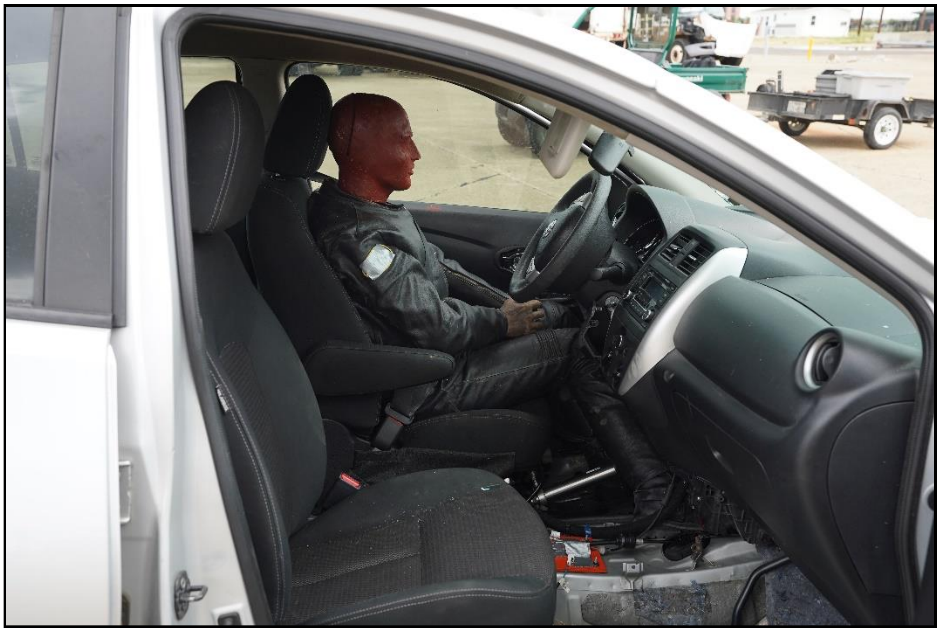


Figure 7.9. Overall Interior of Test Vehicle after Test 440862-03-4.

Figure 7.10. Interior of Test Vehicle on Impact Side after Test 440862-03-4.

Table 7.8. Occupant Compartment Deformation for Test 440862-03-4.

Test Parameter	Specification	Measured
Roof	≤4.0 inches	0 inches
Windshield	≤3.0 inches	4 inches (see Table 7.9)
A and B Pillars	≤5.0 overall/≤3.0 inches lateral	0 inches
Foot Well/Toe Pan	≤9.0 inches	3 inches
Floor Pan/Transmission Tunnel	≤12.0 inches	1 inch
Side Front Panel	≤12.0 inches	4 inches
Front Door (above Seat)	≤9.0 inches	3 inches
Front Door (below Seat)	≤12.0 inches	2 inches

Table 7.9. Exterior Vehicle Damage for Test 440862-03-4.

Side Windows	Intact
Maximum Exterior Deformation	12 inches in the front plane at the left front corner at bumper height
VDS	11LFQ5
CDC	11FLEW5
Fuel Tank Damage	None
Description of Damage to Vehicle:	The front bumper, hood, grill, left headlight, radiator and support, left front quarter fender, left front strut and tower, left front tire and rim, windshield, left front floor pan, roof, rear door, left rear rim, left rear quarter fender, left taillight, and rear bumper were damaged. There was a tear in the laminate on the windshield measuring 38 inches long and 4 inches wide, which was caused by a separation of body parts on the vehicle and was not due to intrusion of the test article. Similarly, the windshield deformation was caused by the break and the separation of the body parts on the vehicle and not due to any intrusion from the test article.

7.7. OCCUPANT RISK FACTORS

Data from the accelerometers were digitized for evaluation of occupant risk, and the results are shown in Table 7.10. Figure C.7 in Appendix C.3 shows the vehicle angular displacements, and Figures C.8 through C.10 in Appendix C.4 show acceleration versus time traces.

Table 7.10. Occupant Risk Factors for Test 440862-03-4.

Test Parameter	*MASH*	Measured	Time
OIV, Longitudinal (ft/s)	≤40.0 *30.0*	22.0	0.0785 s on left side of interior
OIV, Lateral (ft/s)	≤40.0 *30.0*	29.7	0.0785 s on left side of interior
RDA, Longitudinal (g)	≤20.49 *15.0*	4.2	0.1961–0.2061 s
RDA, Lateral (g)	≤20.49 *15.0*	14.3	0.1960–0.2060 s
THIV (m/s)	N/A	11.3	0.0764 s on left side of interior
ASI	N/A	2.6	0.0466–0.0966 s
50-ms MA Longitudinal (g)	N/A	−12.8	0.0129–0.0629 s
50-ms MA Lateral (g)	N/A	18.0	0.0206–0.0706 s
50-ms MA Vertical (g)	N/A	−9.3	0.0511–0.1011 s
Roll (deg)	≤75	21	0.5792 s
Pitch (deg)	≤75	7	0.7780 s
Yaw (deg)	N/A	58	2.0000 s

Note: Values in italics are the preferred *MASH* values.

7.8. TEST SUMMARY

Figure 7.11, Table 7.11, and Table 7.12 summarize the results of *MASH* Test 440862-03-3. Figure 7.12 shows the sequential photographs from the crash test. Figure 7.13 shows the summary drawing for the crash test.

0.000 s

0.200 s

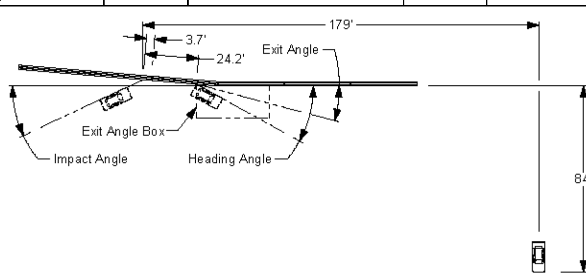
0.400 s

0.600 s

Test Agency	Texas A&M Transportation Institute (TTI)
Test Standard/Test No.	*MASH* 2016, Test 3-10
TTI Project No.	440862-03-4
Test Date	2022-08-19
TEST ARTICLE	
Type	Longitudinal Barrier
Name	Flared Single-Slope Portable Concrete Barriers
Length	180 ft
Key Materials	TxDOT 30-ft Single-Slope J-J Hooks Barriers
Soil Type and Condition	Concrete, Damp
TEST VEHICLE	
Type/Designation	1100C
Year, Make and Model	2016 Nissan Versa
Curb Weight (lb)	2382
Inertial Weight (lb)	2443
Dummy (lb)	165
Gross Static (lb)	2608
IMPACT CONDITIONS	
Impact Speed (mi/h)	61.6
Impact Angle (deg)	25.7
Impact Location	44.8 inches upstream of the center of the joint between barriers 2 and 3
Impact Severity (kip-ft)	58.3
EXIT CONDITIONS	
Exit Speed (mi/h)	44.9
Trajectory/Heading Angle (deg)	10/24
Exit Box Criteria	Vehicle crossed 40 ft downstream from loss of contact
Stopping Distance	179 ft downstream of impact point 84 ft to the traffic side
TEST ARTICLE DEFLECTIONS	
Dynamic (inches)	17.8
Permanent (inches)	17.0
Working Width/Height (inches)	41.8/1
VEHICLE DAMAGE	
VDS	11LFQ5
CDC	11FLEW5
Max. Ext. Deformation	12 inches
Max. Occupant Compartment Deformation	4 inches in side front panel

OCCUPANT RISK VALUES

Long. OIV (ft/s)	22.0	Long. Ridedown (g)	4.2	Max. 50-ms Long. (g)	−12.8	Max. Roll (deg)	21
Lat. OIV (ft/s)	29.7	Lat. Ridedown (g)	14.3	Max. 50-ms Lat. (g)	18.0	Max. Pitch (deg)	7
THIV (m/s)	11.3	ASI	2.6	Max. 50-ms Vert. (g)	−9.3	Max. Yaw (deg)	58



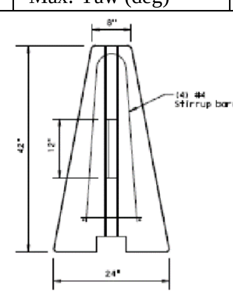


Figure 7.11. Summary of Results for *MASH* Test 3-10 on Flared Single-Slope Portable Concrete Barriers.

Table 7.11. Summary of Results for Test 440862-03-4, General Information, Impact and Exit Conditions.

General Information	Test Agency	Texas A&M Transportation Institute (TTI)
	Test Standard Test No.	*MASH* 2016, Test 3-10
	TTI Test No.	440862-03-4
	Test Date	2022-08-19
Test Article	Type	Longitudinal Barrier
	Name	Flared Single-Slope Portable Concrete Barriers
	Installation Length	180 ft
	Material or Key Elements	TxDOT 30-ft Single-Slope J-J Hooks Barriers
	Foundation Type/ Condition	Concrete, Damp
Test Vehicle	Type/Designation	1100C
	Make and Model	2016 Nissan Versa
	Curb	2382 lb
	Test Inertial	2443 lb
	Dummy	165 lb
	Gross Static	2608 lb
Impact Conditions	Speed	61.6 mi/h
	Angle	25.7 degrees
	Location	44.8 inches upstream of the center of the joint between barriers 2 and 3
	Impact Severity	58.3 kip-ft
Exit Conditions	Speed	44.9 mi/h
	Exit Trajectory/ Heading	10 degrees/24 degrees

Table 7.12. Summary of Results for Test 440862-03-4, Occupant Risk, Vehicle and Test Article Damage.

Occupant Risk Values	Longitudinal OIV	22.0 ft/s
	Lateral OIV	29.7 ft/s
	Longitudinal RDA	4.2 g
	Lateral RDA	14.3 g
	THIV	11.3 m/s
	ASI	2.6
Max. 0.050-s Average	Longitudinal	−12.8 g
	Lateral	18.0 g
	Vertical	−9.3 g
Post-Impact Trajectory	Stopping Distance	179 ft downstream of impact point; 84 ft to the traffic side
Vehicle Stability	Maximum Roll Angle	21 degrees
	Maximum Pitch Angle	7 degrees
	Maximum Yaw Angle	58 degrees
	Vehicle Snagging	No
	Vehicle Pocketing	No
Test Article Deflections	Dynamic	17.8 inches
	Permanent	17.0 inches
	Working Width	41.8 inches
	Height of Working Width	1 inch
Vehicle Damage	VDS	11LFQ5
	CDC	11FLEW5
	Max. Exterior Deformation	12 inches
	Max. Occupant Compartment Deformation	4 inches side front panel

(a) 0.000 s

(b) 0.200 s

Figure 7.12. Summary of Results for Test 440862-03-4, Sequential Test Pictures.

(c) 0.400 s

(d) 0.600 s

Figure 7.12. Summary of Results for Test 440862-03-4, Sequential Test Pictures (Continued).

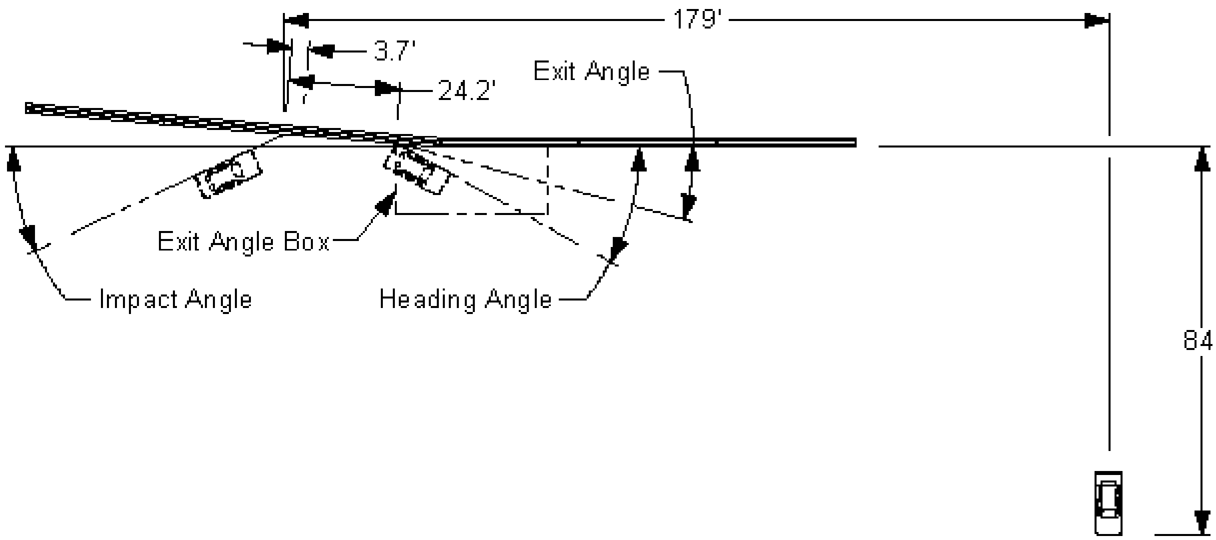


Figure 7.13. Summary of Results for Test 440862-03-4, Summary Drawing.

Chapter 8. SUMMARY AND CONCLUSIONS

8.1. ASSESSMENT OF TEST RESULTS AND CONCLUSION

The crash tests reported herein were performed in accordance with *MASH* TL-3, which involves two tests, on the flared single-slope PCBs.

Table 8.1 and Table 8.2 show that the flared single-slope PCBs met the performance criteria for *MASH* TL-3 longitudinal barriers. Table 8.3 provides an assessment of results from both tests.

Table 8.1. Performance Evaluation Summary for *MASH* Test 3-11 on Flared Single-Slope Portable Concrete Barriers, Test 440862-03-3, August 17, 2022.

Evaluation Criteria	*MASH* Description	Assessment
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.	Pass
D.	Detached elements, fragments, or other debris from the test article should not penetrate or show potential for penetrating the occupant compartment, or present an undue hazard to other traffic, pedestrians, or personnel in a work zone. Deformations of, or intrusions into, the occupant compartment should not exceed limits set forth in Section 5.2.2 and Appendix E of *MASH*.	Pass
F.	The vehicle should remain upright during and after collision. The maximum roll and pitch angles are not to exceed 75 degrees.	Pass
H.	Occupant impact velocities (OIV) should satisfy the following limits: Preferred value of 30 ft/s, or maximum allowable value of 40 ft/s.	Pass
I.	The occupant ridedown accelerations should satisfy the following limits: Preferred value of 15.0 g, or maximum allowable value of 20.49 g.	Pass

Table 8.2. Performance Evaluation Summary for *MASH* Test 3-10 on Flared Single-Slope Portable Concrete Barriers, Test 440862-03-4, August 19, 2022.

Evaluation Criteria	*MASH* Description	Assessment
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.	Pass
D.	Detached elements, fragments, or other debris from the test article should not penetrate or show potential for penetrating the occupant compartment, or present an undue hazard to other traffic, pedestrians, or personnel in a work zone. Deformations of, or intrusions into, the occupant compartment should not exceed limits set forth in Section 5.2.2 and Appendix E of *MASH*.	Pass
F.	The vehicle should remain upright during and after collision. The maximum roll and pitch angles are not to exceed 75 degrees.	Pass
H.	Occupant impact velocities (OIV) should satisfy the following limits: Preferred value of 30 ft/s or maximum allowable value of 40 ft/s.	Pass
I.	The occupant ridedown accelerations should satisfy the following limits: Preferred value of 15.0 g, or maximum allowable value of 20.49 g.	Pass

Table 8.3. Assessment Summary for *MASH* TL-3 Tests on Flared Single-Slope Portable Concrete Barriers.

Evaluation Criteria	Test No. 440862-03-3 Test 3-11	Test No. 440862-03-4 Test 3-10
A	S	S
D	S	S
F	S	S
G	N/A	N/A
H	S	S
I	S	S
Overall	Pass	Pass

Note: S = Satisfactory; N/A = Not Applicable.

Chapter 9. IMPLEMENTATION

The freestanding 42-inch-tall single-slope portable concrete barrier with J-J Hooks connections was investigated to determine a range of acceptable flare rates. Finite element simulation indicated that the impact performance of the single-slope PCB system on its maximum 7-degree (8.13H:1V) flare was marginal due to high occupant compartment deformation in the pickup truck model. Subsequent simulation and full-scale crash testing demonstrated that the single-slope PCB installed on a 12:1 flare was *MASH* compliant. Both *MASH* Test 3-10 and Test 3-11 were successfully performed on the single-slope PCB installed on a 12:1 flare. Consequently, any flare rate for the single-slope PCB with J-J Hooks connections up to and including 12:1 is considered suitable for implementation where needed.

TxDOT standards for the single-slope PCB permit the use of different connection systems to attach the precast concrete barrier segments to each other. The J-J Hooks connection was selected for evaluation in consultation with TxDOT. The J-J Hooks connection is commonly used and represents a more critical connection type than the X-bolt connection system because the X-bolt connection provides a stronger moment connection that results in less barrier deflection. Thus, the successful test of the flared single-slope PCB system with J-J Hooks connections indicates that the same flare rate used with similar single-slope barriers with the less critical X-bolt barrier connections is also *MASH* TL-3 compliant.

The successful *MASH* crash testing was performed on an installation that had three 30-ft long flared barrier segments. This should represent the minimum flare length utilized when a free, unrestrained end exists on the upstream end of the barrier installation. If barrier continuity exists beyond the flared portion of an installation, there is no restriction on the minimum flare length, only the 12:1 flare rate.

It is important to note that barrier deflections are likely to increase along the flared portion of the barrier. The barrier flare rate increases the effective impact angle and, hence, the overall impact severity.

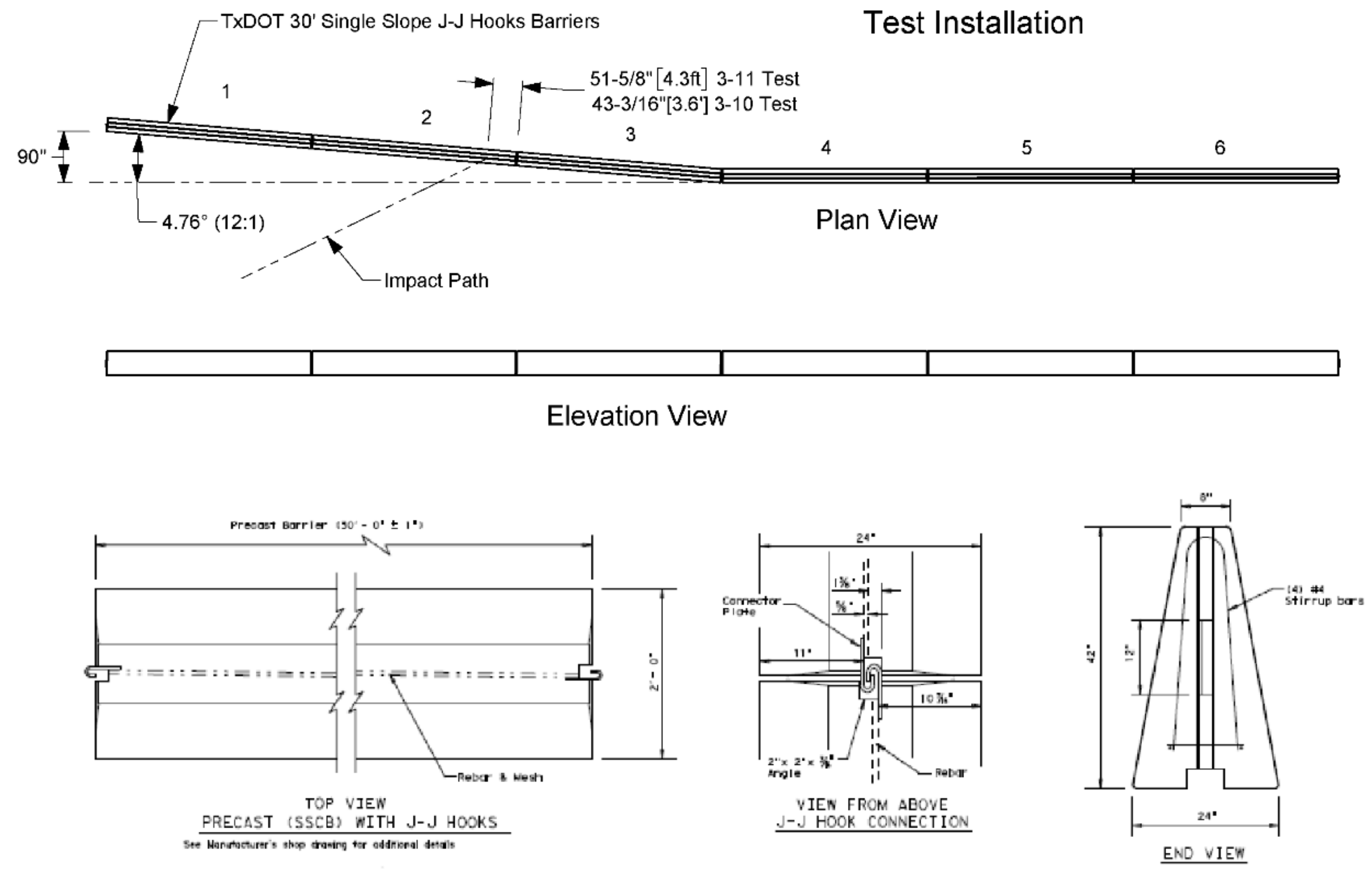
TxDOT standards also include a portable 32-inch F-shape concrete barrier. Due to its lower height and mass, the F-shape barrier requires further investigation to verify acceptable flare rates.

Implementation of the flared single-slope PCB system can be achieved by the Design Division through revision of its respective standard sheets to reflect the acceptable flare rates found to be *MASH* compliant through this research.

REFERENCES

1. AASHTO. *Manual for Assessing Roadside Safety Hardware*, Second Edition. American Association of State Highway and Transportation Officials, Washington, DC, 2016.
2. Altair Engineering Inc. *HyperMesh*®. CAE Altair HyperWorks, Troy, MI, 2019.
3. Chiara Silvestri Dobrovolny, Shristi Bhutani, Aniruddha Zalani, Roger P. Bligh, Stefan Hurlebaus, Husain Aldahlki, William Schroeder, and Darrell L. Kuhn. *Development of Guidelines for Inspection, Repair, and Use of Portable Concrete Barriers—Volume 1: Technical Report*. Research Report 0-7059-R1-Vol1. Texas A&M Transportation Institute, College Station, TX, October 2022.
4. ANSYS. *LS-DYNA Keyword User's Manual*. Livermore Software Technology Corporation, Livermore, CA, 2021.

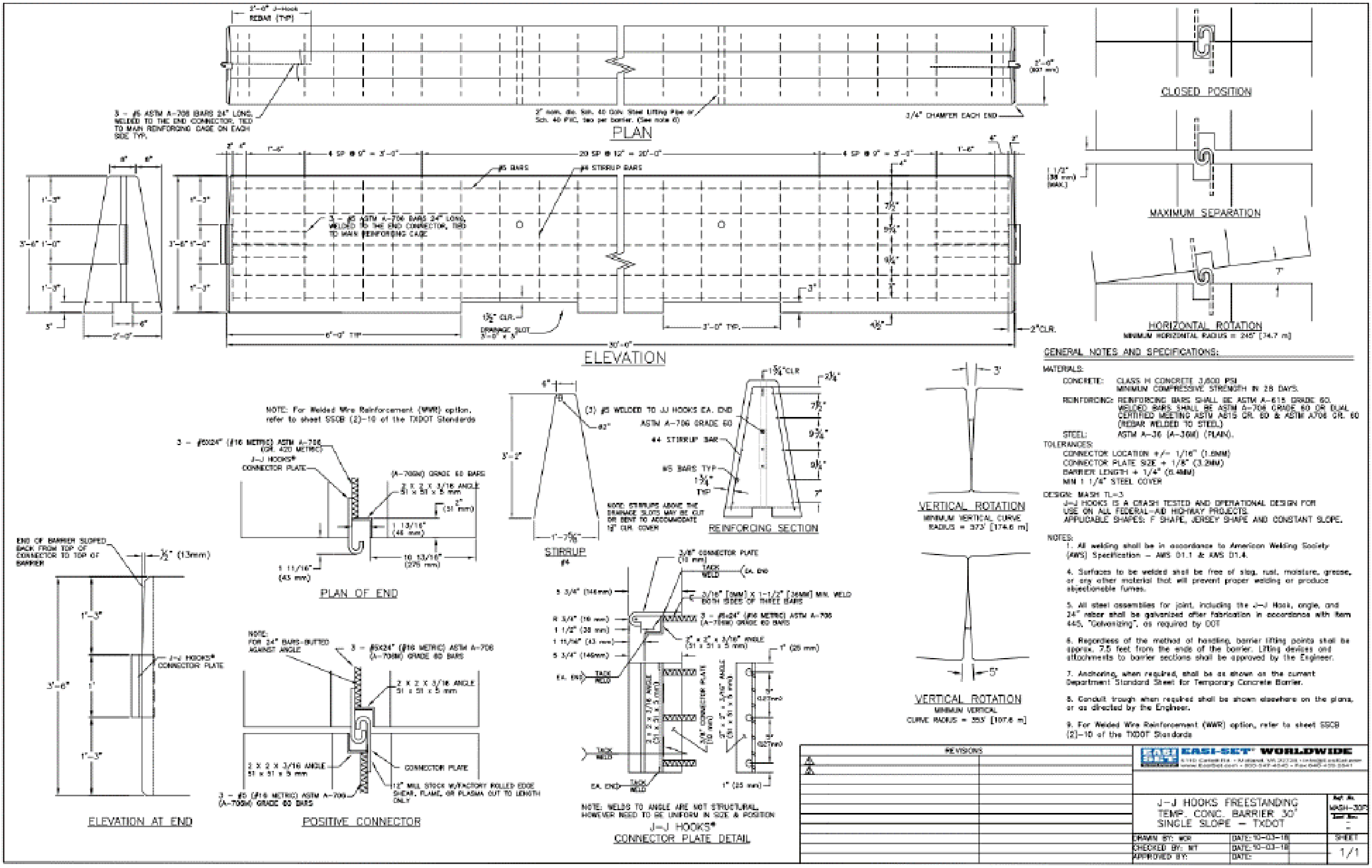
APPENDIX A. DETAILS OF FLARED SINGLE-SLOPE PORTABLE CONCRETE BARRIERS



1a. Detail views from Tx DoT Drawing #SSCB(2)-10

Texas A&M Transportation Institute	Roadside Safety and Physical Security Division - Proving Ground	
Project #440862-03 Flared Single Slope PCB's		2022-07-26
Drawn by GES	Scale 1:250	Sheet 1 of 1 Test Installation

Q:\Accreditation-17025-2017\EIR-000 Project Files\440862-01 - TxDOT FY2022\440862-03, Flared Portable Concrete Barrier - Bligh\Drafting, 440862-03\440862-03 Single Slope Drawing


PLAN
ELEVATION
PLAN OF END
STIRRUP
#4
REINFORCING SECTION
ELEVATION AT END
POSITIVE CONNECTOR
J-J HOOKS®
CONNECTOR PLATE DETAIL
CLOSED POSITION
MAXIMUM SEPARATION
HORIZONTAL ROTATION
MINIMUM HORIZONTAL RADIUS = 245' [74.7 m]
VERTICAL ROTATION
MINIMUM VERTICAL CURVE RADIUS = 573' [174.6 m]
VERTICAL ROTATION
MINIMUM VERTICAL CURVE RADIUS = 353' [107.6 m]
NOTE: For Welded Wire Reinforcement (WWR) option, refer to sheet SSCB (2)-10 of the TXDOT Standards
NOTE: WELDS TO ANGLE ARE NOT STRUCTURAL. HOWEVER NEED TO BE UNIFORM IN SIZE & POSITION
GENERAL NOTES AND SPECIFICATIONS:
MATERIALS:
CONCRETE: CLASS H CONCRETE 3,600 PSI MINIMUM COMPRESSIVE STRENGTH IN 28 DAYS.
REINFORCING: REINFORCING BARS SHALL BE ASTM A-615 GRADE 60. WELDED BARS SHALL BE ASTM A-706 GRADE 60 OR DUAL CERTIFIED MEETING ASTM A615 GR. 60 & ASTM A706 GR. 60 (REBAR WELDED TO STEEL)
STEEL: ASTM A-36 (A-36M) (PLAIN).
TOLERANCES:
CONNECTOR LOCATION +/- 1/16" (1.6MM)
CONNECTOR PLATE SIZE + 1/8" (3.2MM)
BARRIER LENGTH + 1/4" (6.4MM)
MIN 1 1/4" STEEL COVER
DESIGN: MASH TL=3
J-J HOOKS IS A CRASH TESTED AND OPERATIONAL DESIGN FOR USE ON ALL FEDERAL-AID HIGHWAY PROJECTS.
APPLICABLE SHAPES: F SHAPE, JERSEY SHAPE AND CONSTANT SLOPE.
NOTES:
1. All welding shall be in accordance to American Welding Society (AWS) Specification – AWS D1.1 & AWS D1.4.
4. Surfaces to be welded shall be free of slag, rust, moisture, grease, or any other material that will prevent proper welding or produce objectionable fumes.
5. All steel assemblies for joint, including the J-J Hook, angle, and 24" rebar shall be galvanized after fabrication in accordance with Item 445, "Galvanizing", as required by DOT
6. Regardless of the method of handling, barrier lifting points shall be approx. 7.5 feet from the ends of the barrier. Lifting devices and attachments to barrier sections shall be approved by the Engineer.
7. Anchoring, when required, shall be as shown on the current Department Standard Sheet for Temporary Concrete Barrier.
8. Conduit trough when required shall be shown elsewhere on the plans, or as directed by the Engineer.
9. For Welded Wire Reinforcement (WWR) option, refer to sheet SSCB (2)-10 of the TXDOT Standards
REVISIONS
EASI-SET® WORLDWIDE
J-J HOOKS FREESTANDING TEMP. CONC. BARRIER 30' SINGLE SLOPE – TXDOT
DRAWN BY: WOR DATE: 10-03-18
CHECKED BY: MT DATE: 10-03-18
APPROVED BY: DATE:
SHEET 1/1

APPENDIX B. *MASH* TEST 3-11 (CRASH TEST NO. 440862-03-3)

B.1. VEHICLE PROPERTIES AND INFORMATION

Date: 2022-08-17 Test No.: 440862-03-3 VIN No.: 1C6RR6GT3GS361034

Year: 2016 Make: RAM Model: 1500

Tire Size: 265/70 R 17 Tire Inflation Pressure: 35 psi

Tread Type: Highway Odometer: 132518

Note any damage to the vehicle prior to test: None

● Denotes accelerometer location.

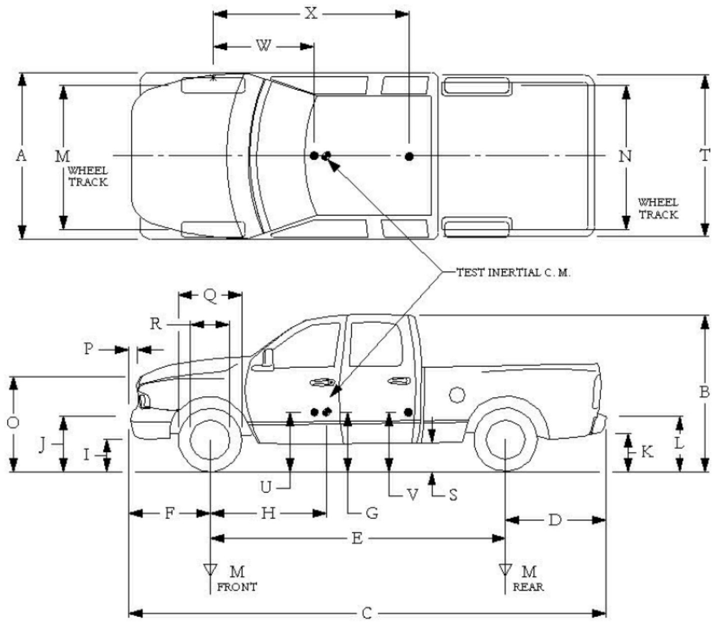
NOTES: None

Engine Type: V-8
Engine CID: 5.7 liter

Transmission Type:
☑ Auto or ☐ Manual
☐ FWD ☑ RWD ☐ 4WD

Optional Equipment:
None

Dummy Data:
Type: 50th Percentile Male
Mass: 165 lb
Seat Position: IMPACT SIDE



Geometry: inches

A	78.50	F	40.00	K	20.00	P	3.00	U	26.75
B	74.00	G	28.40	L	30.00	Q	30.50	V	30.25
C	227.50	H	60.22	M	68.50	R	18.00	W	60.25
D	44.00	I	11.75	N	68.00	S	13.00	X	79.00
E	140.50	J	27.00	O	46.00	T	77.00		

Wheel Center Height Front	14.75	Wheel Well Clearance (Front)	6.00	Bottom Frame Height - Front	12.50
Wheel Center Height Rear	14.75	Wheel Well Clearance (Rear)	9.25	Bottom Frame Height - Rear	22.50

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	3700	M_{front}	2881	2883	2968
Back	3900	M_{rear}	2199	2163	2243
Total	6700	M_{Total}	5080	5046	5211

(Allowable Range for TIM and GSM = 5000 lb ±110 lb)

Mass Distribution:
lb LF: 1493 RF: 1390 LR: 1077 RR: 1086

Figure B.1. Vehicle Properties for Test No. 440862-03-3.

Date:	2022-08-17	Test No.:	440862-03-3	VIN No.:	1C6RR6GT3GS361034
Year:	2016	Make:	RAM	Model:	1500

VEHICLE CRUSH MEASUREMENT SHEET[1]

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

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

Specific Impact Number	Plane* of C-Measurements	Direct Damage		Field L**	C_1	C_2	C_3	C_4	C_5	C_6	±D
		Width** (CDC)	Max*** Crush								
1	AT FT BUMPER	16	9	48							-12
2	ABOVE FT BUMPER	16	9	60							80
	Measurements recorded										
	☑ **inches or** ☐ **mm**										

[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.

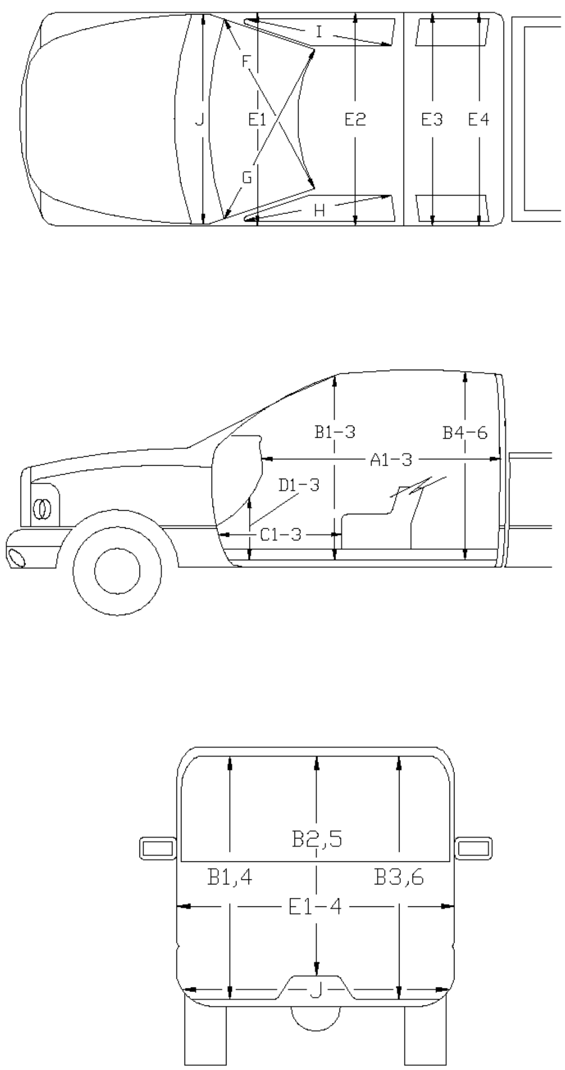
**Measure and document on the vehicle diagram the beginning or end of the direct damage width and field L (e.g., side damage with respect to undamaged axle).

***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.

Figure B.2. Exterior Crush Measurements for Test No. 440862-03-3.

Date:	2022-08-17	Test No.:	440862-03-3	VIN No.:	1C6RR6GT3GS361034
Year:	2016	Make:	RAM	Model:	1500



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

OCCUPANT COMPARTMENT DEFORMATION MEASUREMENT

	Before	After (inches)	Differ.
A1	65.00	65.00	0.00
A2	63.00	63.00	0.00
A3	65.50	65.50	0.00
B1	45.00	45.00	0.00
B2	38.00	38.00	0.00
B3	45.00	45.00	0.00
B4	39.50	39.50	0.00
B5	43.00	43.00	0.00
B6	39.50	39.50	0.00
C1	26.00	24.00	-2.00
C2	0.00	0.00	0.00
C3	26.00	26.00	0.00
D1	11.00	11.00	0.00
D2	0.00	0.00	0.00
D3	11.50	11.50	0.00
E1	58.50	57.50	-1.00
E2	63.50	64.50	1.00
E3	63.50	63.50	0.00
E4	63.50	63.50	0.00
F	59.00	59.00	0.00
G	59.00	59.00	0.00
H	37.50	37.50	0.00
I	37.50	37.50	0.00
J*	25.00	24.00	-1.00

Figure B.3. Occupant Compartment Measurements for Test No. 440862-03-3.

B.2. SEQUENTIAL PHOTOGRAPHS

(a) 0.000 s

(b) 0.100 s

(c) 0.200 s

(d) 0.300 s

(e) 0.400 s

(f) 0.500 s

(g) 0.600 s

(h) 0.700 s

Figure B.4. Sequential Photographs for Test No. 440862-03-3 (Overhead Views).

(a) 0.000 s

(b) 0.100 s

(c) 0.200 s

(d) 0.300 s

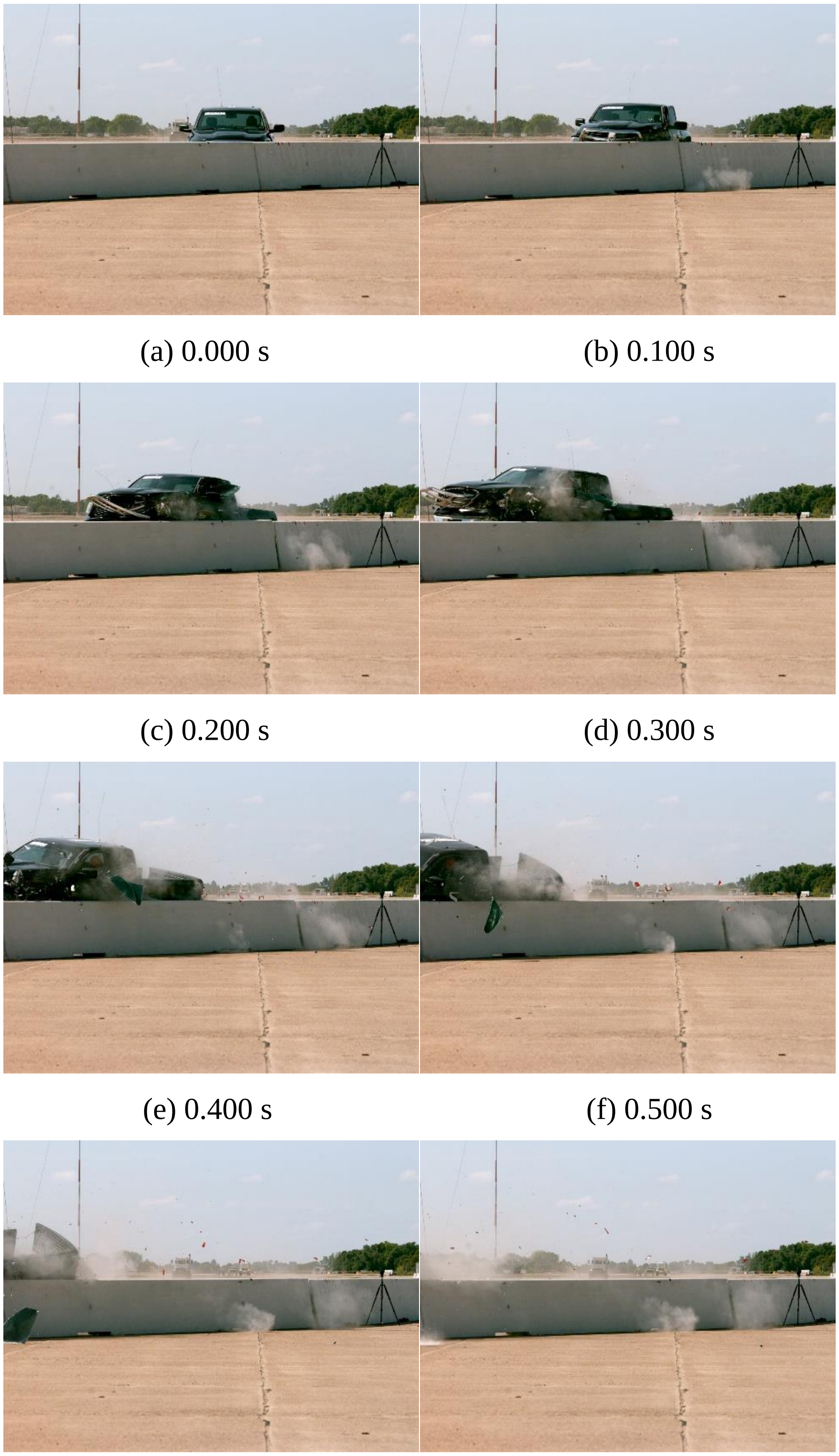
(e) 0.400 s

(f) 0.500 s

(g) 0.600 s

(h) 0.700 s

Figure B.5. Sequential Photographs for Test No. 440862-03-3 (Frontal Views).



(a) 0.000 s (b) 0.100 s

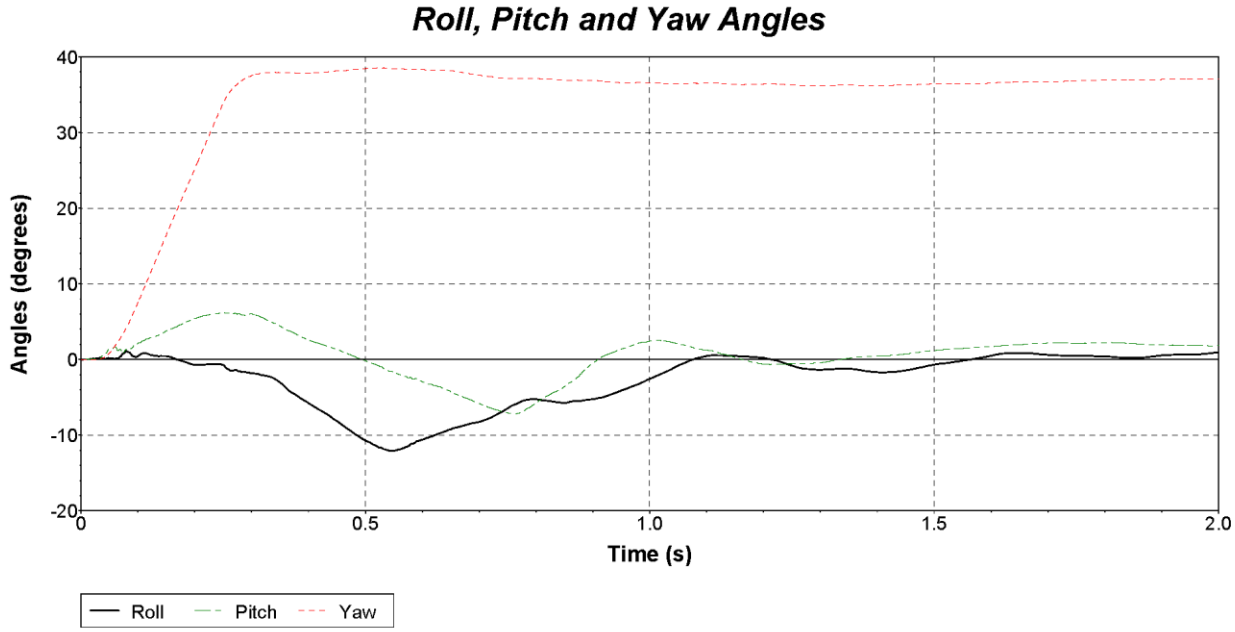
(c) 0.200 s (d) 0.300 s

(e) 0.400 s (f) 0.500 s

(g) 0.600 s (h) 0.700 s

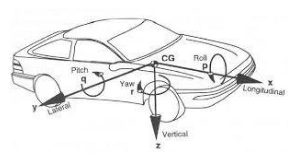
Figure B.6. Sequential Photographs for Test No. 440862-03-3 (Oblique Views).

B.3. VEHICLE ANGULAR DISPLACEMENTS



Axes are vehicle-fixed.
Sequence for determining orientation:

1. Yaw.
2. Pitch.
3. Roll.



Test Number: 440862-03-3
Test Standard Test Number: *MASH* Test 3-11
Test Article: Flared Portable Concrete Barrier
Test Vehicle: 2016 RAM 1500
Inertial Mass: 5046 lb
Gross Mass: 5211 lb
Impact Speed: 60.9 mi/h
Impact Angle: 25.2°

Figure B.7. Vehicle Angular Displacements for Test No. 440862-03-3.

B.4. VEHICLE ACCELERATIONS

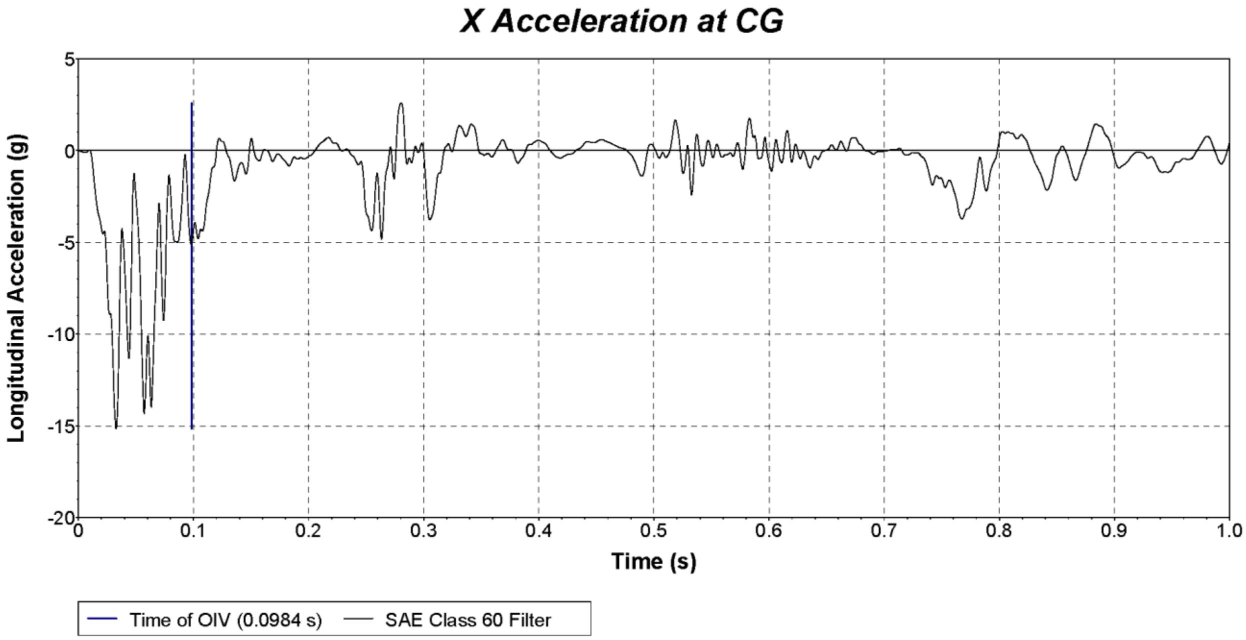


Figure B.8. Vehicle Longitudinal Accelerometer Trace for Test No. 440862-03-3 (Accelerometer Located at Center of Gravity).

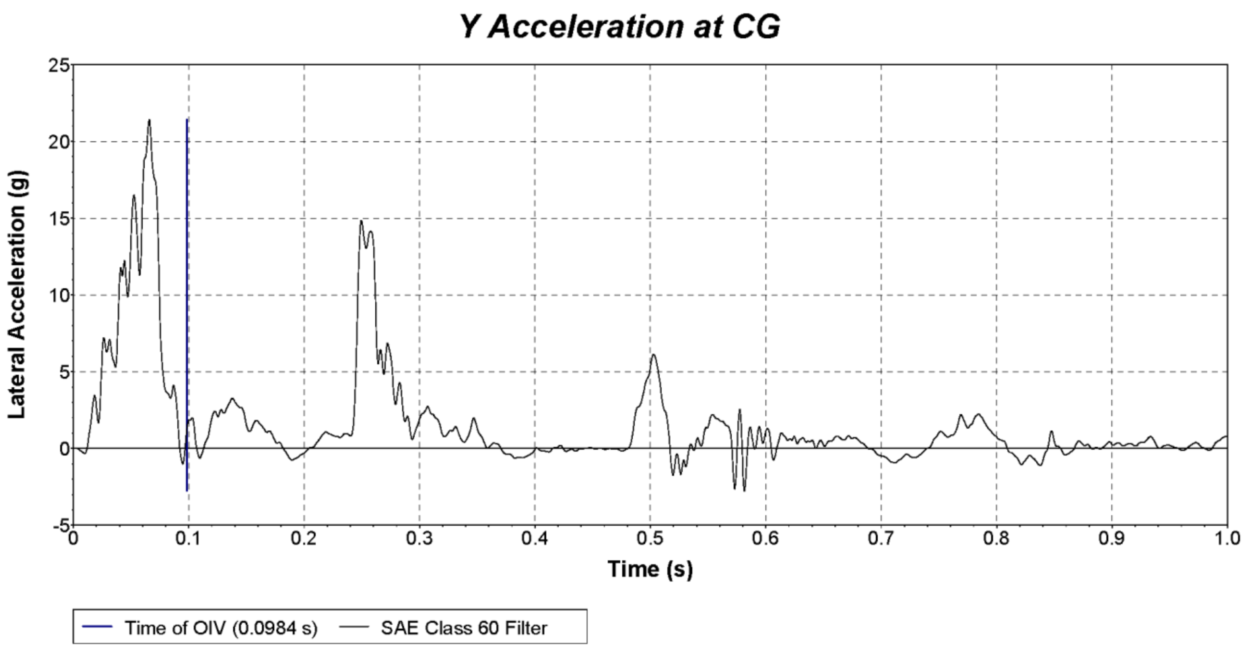


Figure B.9. Vehicle Lateral Accelerometer Trace for Test No. 440862-03-3 (Accelerometer Located at Center of Gravity).

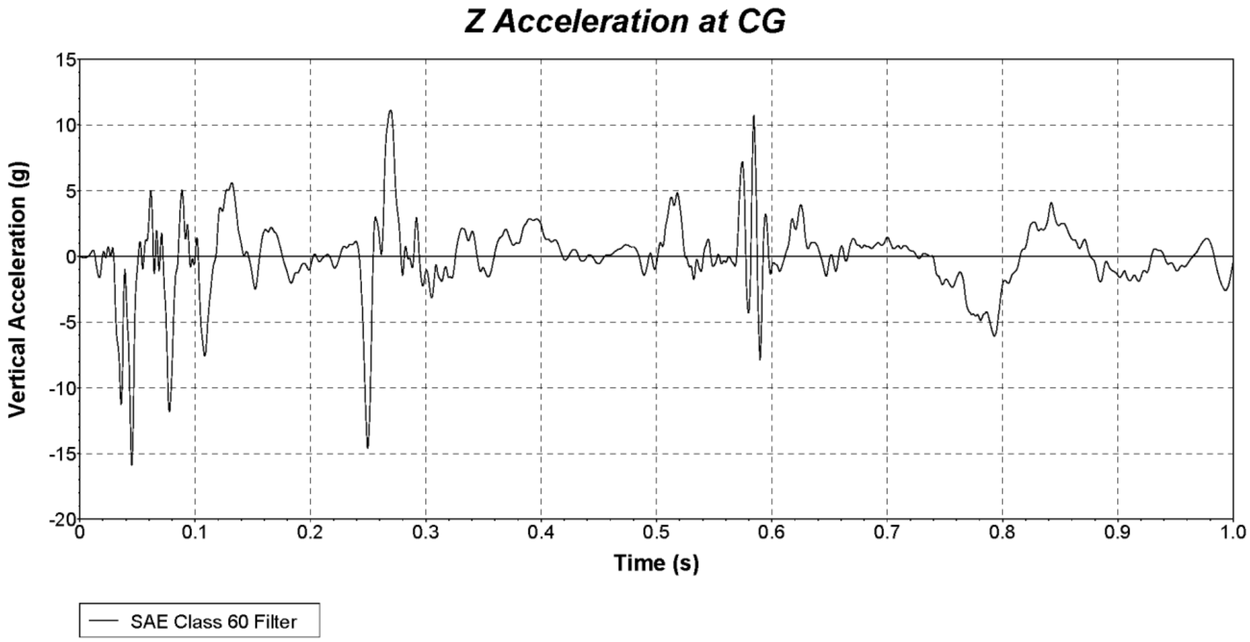


Figure B.10. Vehicle Vertical Accelerometer Trace for Test No. 440862-03-3 (Accelerometer Located at Center of Gravity).

APPENDIX C. *MASH* TEST 3-10 (CRASH TEST NO. 440862-03-4)

C.1. VEHICLE PROPERTIES AND INFORMATION

Date: 2022-08-19 Test No.: 440862-03-4 VIN No.: 3N1CN7AP2GL861134

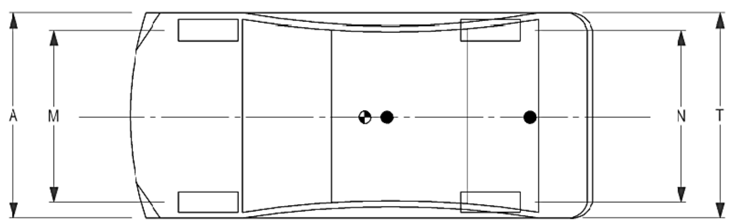
Year: 2016 Make: Versa Model: Nissan

Tire Inflation Pressure: 36 PSI Odometer: 109867 Tire Size: P185/65R15

Describe any damage to the vehicle prior to test: None

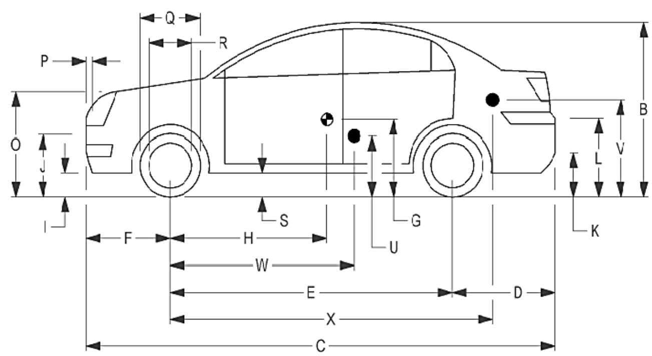
● Denotes accelerometer location.

NOTES: None



Engine Type: 4 CYL
Engine CID: 1.6 L
Transmission Type:
☑ Auto or ☐ Manual
☑ FWD ☐ RWD ☐ 4WD
Optional Equipment:
None

Dummy Data:
Type: 50th Percentile Male
Mass: 165 lb
Seat Position: IMPACT SIDE



Geometry: inches

A	66.70	F	32.50	K	12.50	P	4.50	U	15.50
B	59.60	G		L	26.00	Q	24.00	V	21.25
C	175.40	H	41.11	M	58.30	R	16.25	W	41.00
D	40.50	I	7.00	N	58.50	S	7.50	X	79.75
E	102.40	J	22.50	O	30.50	T	64.50		

Wheel Center Ht Front 11.50 Wheel Center Ht Rear 11.50 W-H -0.11

RANGE LIMIT: A = 65 ±3 inches; C = 169 ±8 inches; E = 98 ±5 inches; F = 35 ±4 inches; H = 39 ±4 inches; O (Top of Radiator Support) = 28 ±4 inches
(M+N)/2 = 59 ±2 inches; W-H < 2 inches or use MASH Paragraph A4.3.2

GVWR Ratings:		**Mass:** lb	Curb	Test Inertial	Gross Static
Front	1750	M_{front}	1432	1462	1547
Back	1687	M_{rear}	950	981	1061
Total	3389	M_{Total}	2382	2443	2608

Allowable TIM = 2420 lb ±55 lb | Allowable GSM = 2585 lb ± 55 lb

Mass Distribution:
lb LF: 747 RF: 715 LR: 483 RR: 498

Figure C.1. Vehicle Properties for Test No. 440862-03-4.

Date:	2022-08-19	Test No.:	440862-03-4	VIN No.:	3N1CNAAP2GL861134
Year:	2016	Make:	Versa	Model:	Nissan

VEHICLE CRUSH MEASUREMENT SHEET[1]

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

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

Specific Impact Number	Plane* of C-Measurements	Direct Damage Width** (CDC)	Direct Damage Max*** Crush	Field L**	C_1	C_2	C_3	C_4	C_5	C_6	±D
1	AT FT BUMPER	16	11	40							-11
2	SAME	16	12	42							54
	Measurements recorded										
	☑ **inches** or ☐ **mm**										

[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).

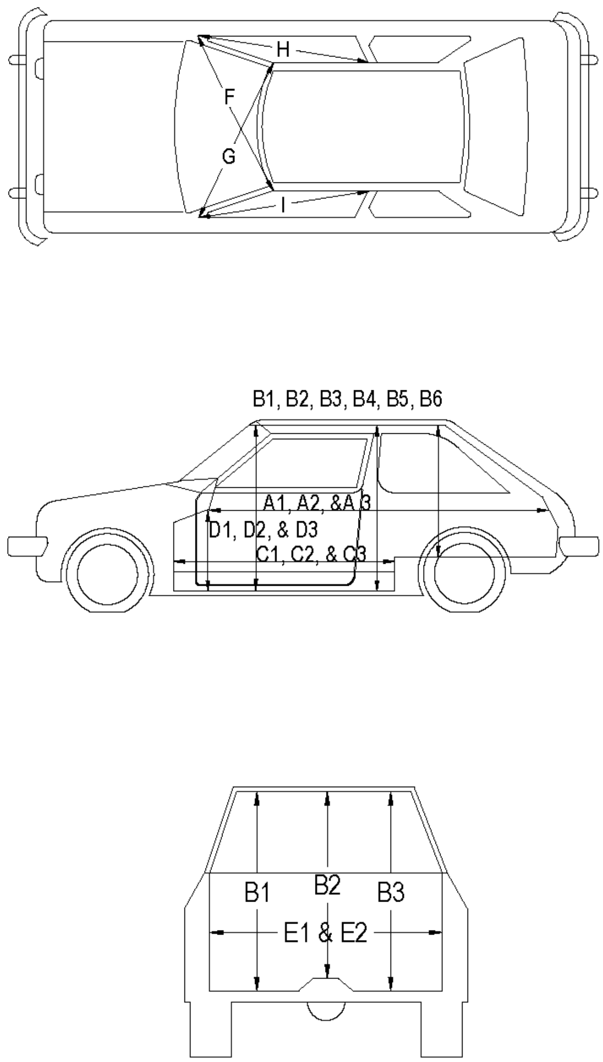
***Measure and document on the vehicle diagram the location of the maximum crush.

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

Figure C.2. Exterior Crush Measurements for Test No. 440862-03-4.

Date: 2022-08-19 Test No.: 440862-03-4 VIN No.: 3N1CNAAP2GL861134

Year: 2016 Make: Versa Model: Nissan



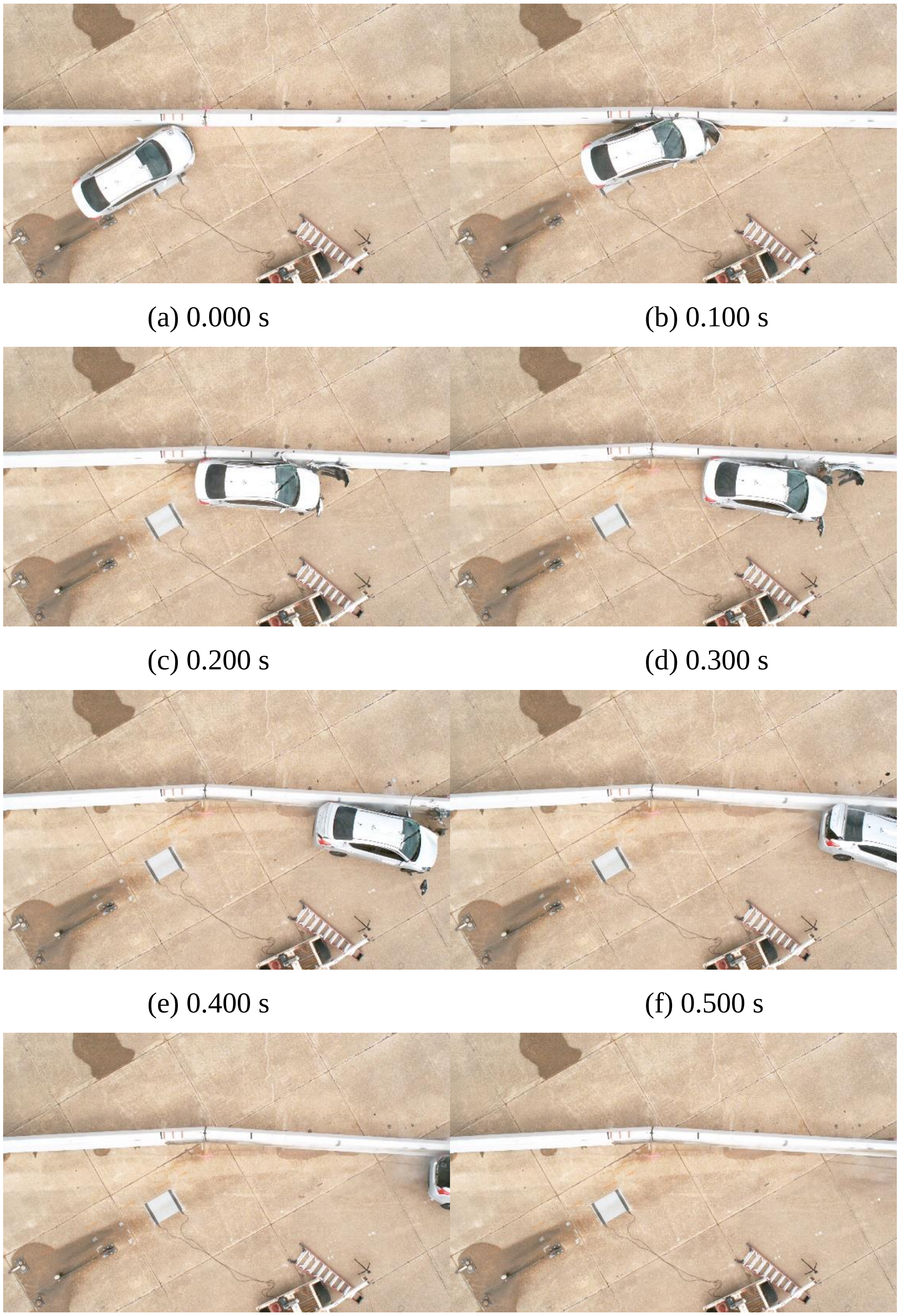
OCCUPANT COMPARTMENT DEFORMATION MEASUREMENT

	Before	After (inches)	Differ.
A1	67.50	67.50	0.00
A2	67.25	67.25	0.00
A3	67.75	67.75	0.00
B1	40.50	40.50	0.00
B2	39.00	39.00	0.00
B3	40.50	40.50	0.00
B4	36.25	36.25	0.00
B5	36.00	36.00	0.00
B6	36.25	36.25	0.00
C1	26.00	23.00	-3.00
C2	0.00	0.00	0.00
C3	26.00	26.00	0.00
D1	9.50	8.50	-1.00
D2	0.00	0.00	0.00
D3	9.50	9.50	0.00
E1	51.50	48.50	-3.00
E2	51.00	49.00	-2.00
F	51.00	51.00	0.00
G	51.00	51.00	0.00
H	37.50	37.50	0.00
I	37.50	37.50	0.00
J*	51.00	47.00	-4.00

*Lateral area across the cab from driver’s side kick panel to passenger’s side kick panel.

Figure C.3. Occupant Compartment Measurements for Test No. 440862-03-4.

C.2. SEQUENTIAL PHOTOGRAPHS



(a) 0.000 s (b) 0.100 s

(c) 0.200 s (d) 0.300 s

(e) 0.400 s (f) 0.500 s

(g) 0.600 s (h) 0.700 s

Figure C.4. Sequential Photographs for Test No. 440862-03-4 (Overhead Views).

(a) 0.000 s (b) 0.100 s

(c) 0.200 s (d) 0.300 s

(e) 0.400 s (f) 0.500 s

(g) 0.600 s (h) 0.700 s

Figure C.5. Sequential Photographs for Test No. 440862-03-4 (Frontal Views).

(a) 0.000 s (b) 0.100 s

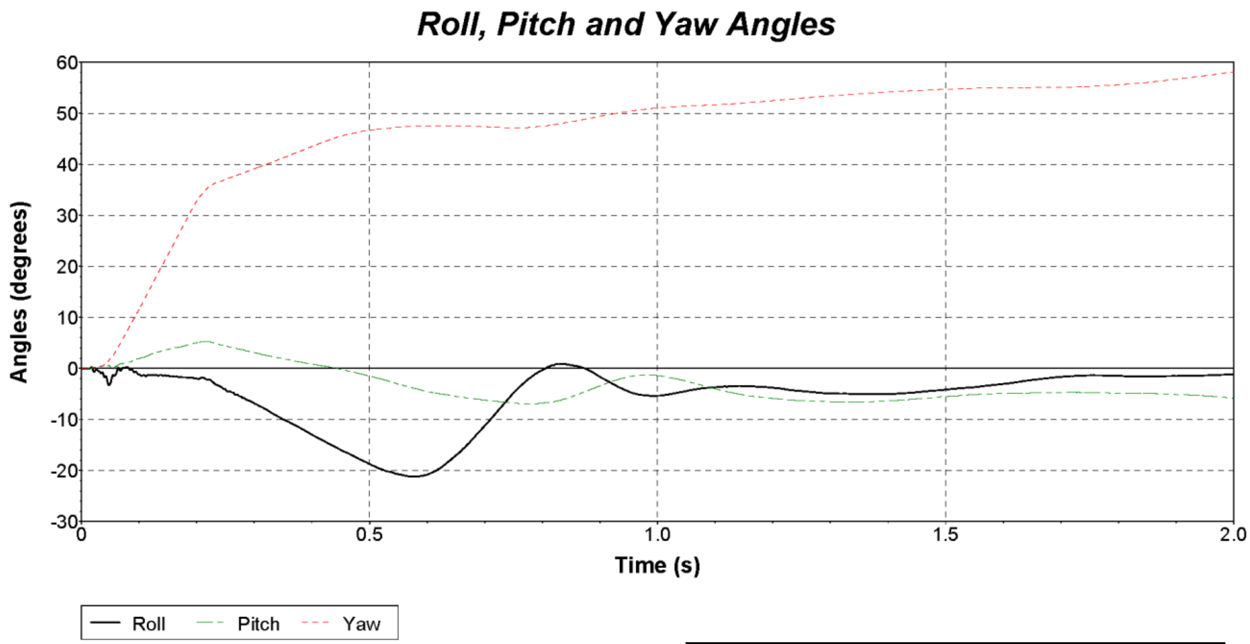
(c) 0.200 s (d) 0.300 s

(e) 0.400 s (f) 0.500 s

(g) 0.600 s (h) 0.700 s

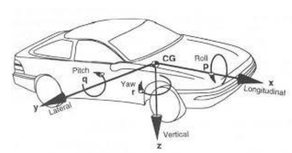
Figure C.6. Sequential Photographs for Test No. 440862-03-4 (Rear Views).

C.3. VEHICLE ANGULAR DISPLACEMENTS



Axes are vehicle-fixed.
Sequence for determining orientation:

4. Yaw.
5. Pitch.
6. Roll.



Test Number: 440862-03-4
Test Standard Test Number: *MASH* Test 3-10
Test Article: Flared Portable Concrete Barrier
Test Vehicle: 2016 Nissan Versa
Inertial Mass: 2443 lb
Gross Mass: 2608 lb
Impact Speed: 61.6 mi/h
Impact Angle: 25.7°

Figure C.7. Vehicle Angular Displacements for Test No. 440862-03-4.

C.4. VEHICLE ACCELERATIONS

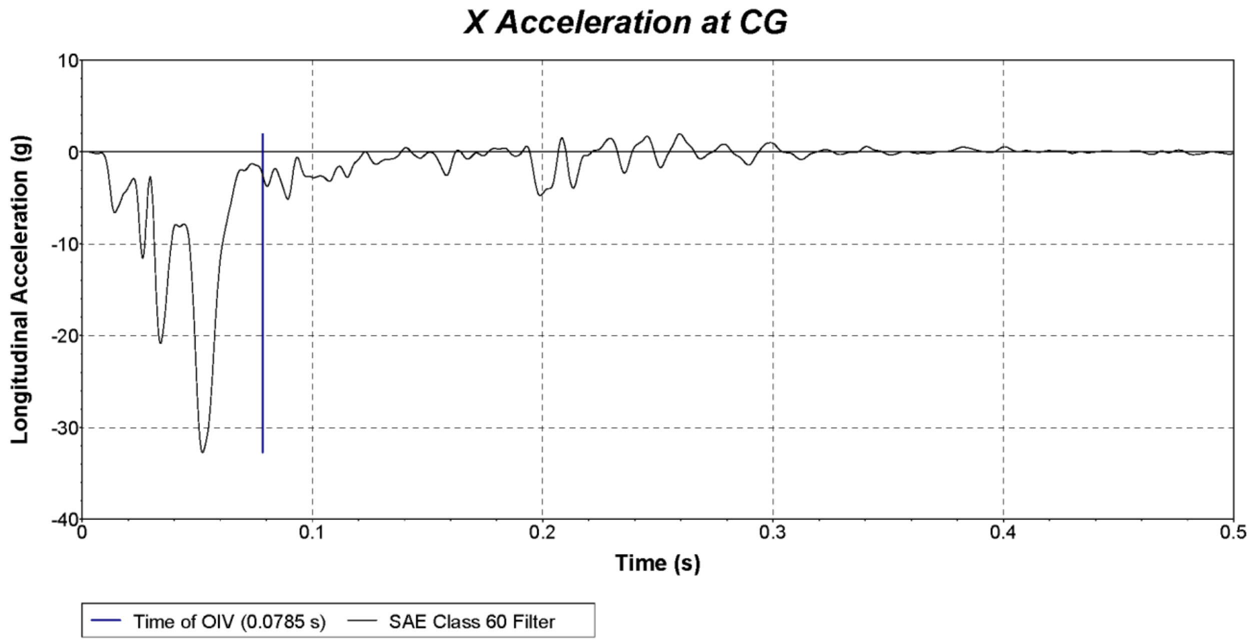


Figure C.8. Vehicle Longitudinal Accelerometer Trace for Test No. 440862-03-4 (Accelerometer Located at Center of Gravity).

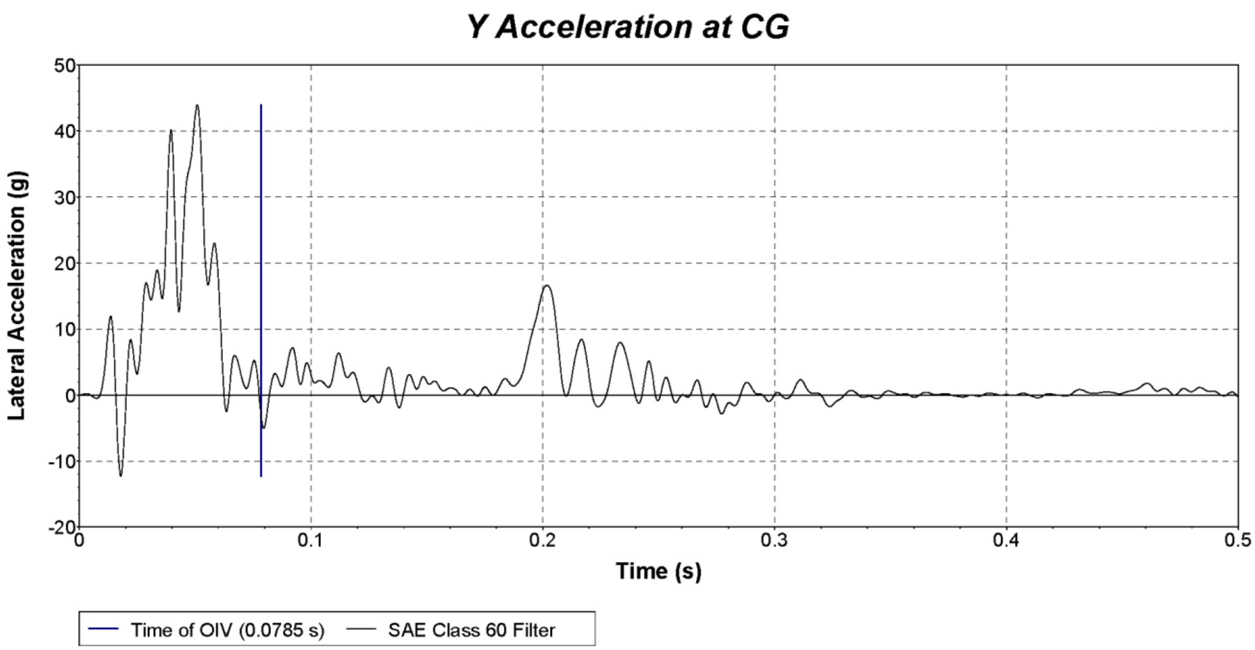


Figure C.9. Vehicle Lateral Accelerometer Trace for Test No. 440862-03-4 (Accelerometer Located at Center of Gravity).

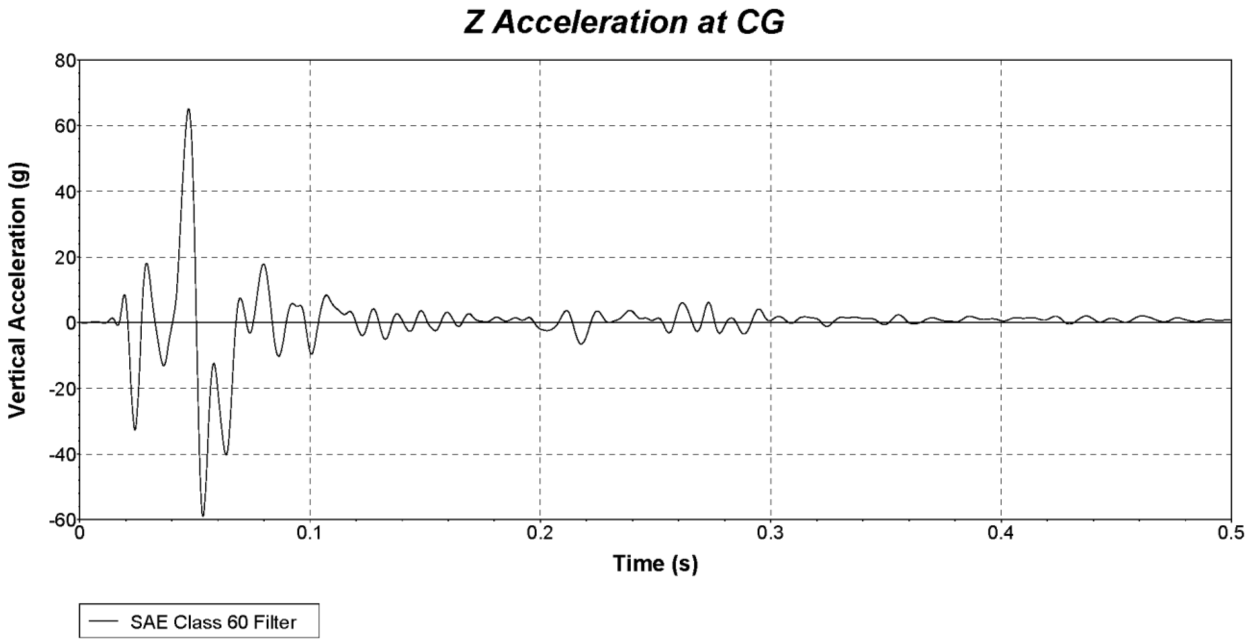


Figure C.10. Vehicle Vertical Accelerometer Trace for Test No. 440862-03-4 (Accelerometer Located at Center).