GEORGIA DOT RESEARCH PROJECT 17-33

FINAL REPORT

FINITE ELEMENT ANALYSIS OF VEHICLE DYNAMICS ON SINGLE SLOPE BARRIERS UNDER MASH TESTING

Georgia Department of Transportation

OFFICE OF PERFORMANCE-BASED MANAGEMENT AND RESEARCH
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FOREST PARK, GA 30297-2534

TECHNICAL REPORT DOCUMENTATION PAGE

1. Report No.: FHWA-GA-18-1733	2. Government Accession No.:	3. Recipient's Catalog No.:

4. Title and Subtitle: Finite Element Analysis of Vehicle Dynamics on Single Slope Barriers Under MASH Testing	5. Report Date: August 2018 6. Performing Organization Code:
7. Author(s): D.W. Scott and L.K. Stewart	8. Performing Organ. Report No.: 17-33
9. Performing Organization Name and Address: Georgia Institute of Technology School of Civil and Environmental Engineering 790 Atlantic Drive NW Atlanta, GA 30332	10. Work Unit No.: 11. Contract or Grant No.: A180401
12. Sponsoring Agency Name and Address: Georgia Department of Transportation Office of Performance-based Management and Research 15 Kennedy Drive Forest Park, GA 30297-2534	13. Type of Report and Period Covered: Final; June 2018 – August 2018 14. Sponsoring Agency Code:

15. Supplementary Notes:
Prepared in cooperation with the U.S. Department of Transportation, Federal Highway Administration.

16. Abstract: The Georgia Tech research team utilized the commercially available finite element program LS-DYNA to simulate impacts of a number of vehicles with two sloped barriers under specific impact conditions from the AASHTO Manual for Assessing Safety Hardware (MASH). The vehicle categories chosen for the analysis were a standard passenger car, light pickup truck, and heavy single unit truck. The concrete barriers were modeled with rigid material representation in all of the analyses. Two MASH criteria were used to evaluate the FEA simulation results: (1) MASH Structural Adequacy Criteria 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; and (2) MASH Occupant Risk Criteria F - The vehicle should remain upright during and after collision, and the maximum roll and pitch angles are not to exceed 75 degrees. For each impact condition and vehicle type, the simulations indicated that the barriers will satisfy the two pertinent MASH evaluation criteria.

17. Key Words: Barriers, finite element analysis, crash simulation		18. Distribution Statement:	
19. Security Class (this report): Unclassified	20. Security Class (this page): Unclassified	21. Number of Pages: 27	22. Price:

Form DOT 1700.7 (8-69)

GDOT Research Project 17-33

Final Report

FINITE ELEMENT ANALYSIS OF VEHICLE DYNAMICS ON SINGLE SLOPE BARRIERS UNDER MASH TESTING

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Georgia Department of Transportation

In cooperation with

U.S. Department of Transportation
Federal Highway Administration

August 17, 2018

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EXECUTIVE SUMMARY

The Georgia Tech research team utilized the commercially available finite element program LS-DYNA to simulate impacts of a number of vehicles with two sloped barriers under specific impact conditions from the AASHTO Manual for Assessing Safety Hardware (MASH). The vehicle categories chosen for the analysis were a standard passenger car, light pickup truck, and heavy single unit truck. The concrete barriers were modeled with rigid material representation in all of the analyses. Two MASH criteria were used to evaluate the FEA simulation results: (1) MASH Structural Adequacy Criteria 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; and (2) MASH Occupant Risk Criteria F - The vehicle should remain upright during and after collision, and the maximum roll and pitch angles are not to exceed 75 degrees. For each impact condition and vehicle type, the simulations indicated that the barriers will satisfy the two pertinent MASH evaluation criteria.

ACKNOWLEDGEMENTS

Mr. Brent Story, State Design Policy Engineer; Mr. Frank Flanders, Assistant State Design Policy Engineer; Mr. Daniel Pass, Assistant State Design Policy Engineer; Ms. Holly Cross, Senior Design Engineer; Mr. Douglas Franks, Bridge Design Group Manager; and Mr. David Jared, Assistant Office Head - Research at GDOT provided many valuable suggestions throughout this study. The opinions and conclusions expressed herein are those of the authors and do not represent the opinions, conclusions, policies, standards or specifications of the GDOT or of other cooperating organizations.

At the Georgia Institute of Technology, Dr. Esmaeel Bakhitary assisted in the development and validation of the vehicle finite element models.

The authors express their profound gratitude to all of these individuals for their assistance and support during the completion of this research project.

1.0 INTRODUCTION

The Georgia Tech research team utilized the commercially available finite element program LS-DYNA [1] to simulate impacts of a number of vehicles with two sloped barriers under Test Level 4 (TL-4) impact conditions from the AASHTO *Manual for Assessing Safety Hardware* (MASH) [2]. The barriers, vehicles and test conditions simulated are found in Table 1 below:

Table 1. FEA simulations performed using GDOT barriers

Barrier Type*	MASH Test Designation	Vehicle
Median Barrier	TL 4-10	Passenger Car
	TL 4-11	Pickup Truck
	TL 4-12	Single Unit Truck
Side Barrier	TL 4-10	Passenger Car
	TL 4-11	Pickup Truck
	TL 4-12	Single Unit Truck

*Barrier details found in Appendix A

The following criteria were used to evaluate the FEA simulation results:

1. MASH Structural Adequacy Criteria 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."* [2, pg. 102]
2. MASH Occupant Risk Criteria F – *"The vehicle should remain upright during and after collision. The maximum roll and pitch angles are not to exceed 75 degrees."* [2, pg. 103]

The concrete barriers were modeled with rigid material representation in all of the analyses. This approach has been used by previous researchers performing numerical simulations of vehicle impacts on concrete barriers [3]. The practice is considered acceptable when no significant failure or deflection of the barrier is expected due to the vehicle impact.

2.0 FINITE ELEMENT MODEL DEVELOPMENT

The vehicles and test conditions used for the simulations were selected based on MASH requirements, and are given in Table 2:

Table 2. Vehicles and test conditions used in FEA simulations performed using GDOT barriers

Test Designation	Vehicle Classification	Vehicle Type	Impact Speed (mph)	Impact Angle (degrees)
TL 4-10	Passenger Car – 1100C	Dodge Neon	62	25
TL 4-11	Pickup Truck – 2270P	Chevrolet Silverado	62	25
TL 4-12	Single Unit Truck – 10000S	Ford F800	56	15

2.1 Passenger Car – Test Vehicle 1100C

MASH recommends Test Vehicle 1100C have a target gross static weight of approximately 2600 pounds among other criteria [2, pg. 85]. Based on this criteria, the passenger car selected for simulation was the Dodge Neon. The model used was obtained from a publically available database [4]; no modifications were made to the model for the present work. The basic model setup is shown in Figure 1.

2.2 Pickup Truck – Test Vehicle 2270P

MASH recommends Test Vehicle 2270P have a target gross static weight of approximately 5000 pounds among other criteria [2, pg. 85]. Based on this criteria, the pickup truck selected for simulation was the Chevrolet Silverado. The model used was obtained from a publically available database [5]; no modifications were made to the model for the present work. The basic model setup is shown in Figure 2.

2.3 Single Unit Truck – Test Vehicle 10000S

MASH recommends Test Vehicle 10000S have a target test inertial weight of approximately 22,000 pounds among other criteria [2, pg. 86]. Based on this criteria, a Ford F800 single unit truck model was obtained from a publically available database [6]. The density of the "added mass" part in the box of the truck was modified to bring the total inertial weight to 22,000 pounds as recommended by the 2nd edition of MASH. No other modifications were made to the model. The basic model setup is shown in Figure 3.

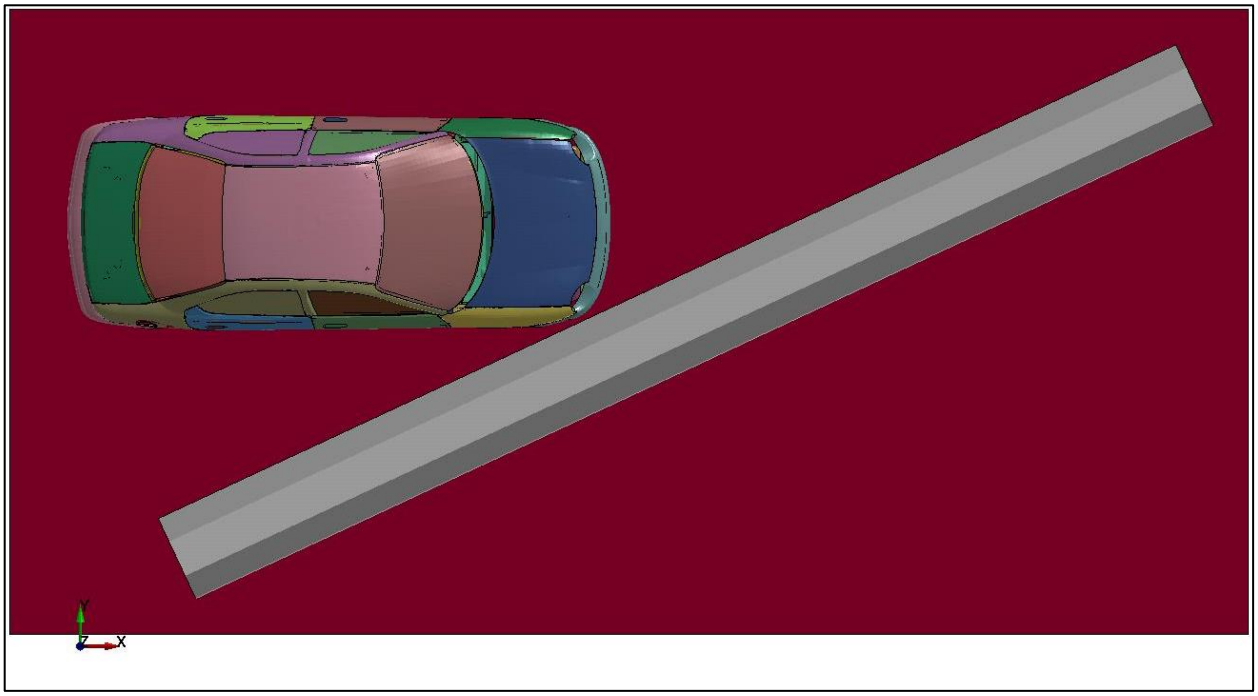


Figure 1. Finite element model of Dodge Neon used for simulation of Test 4-10

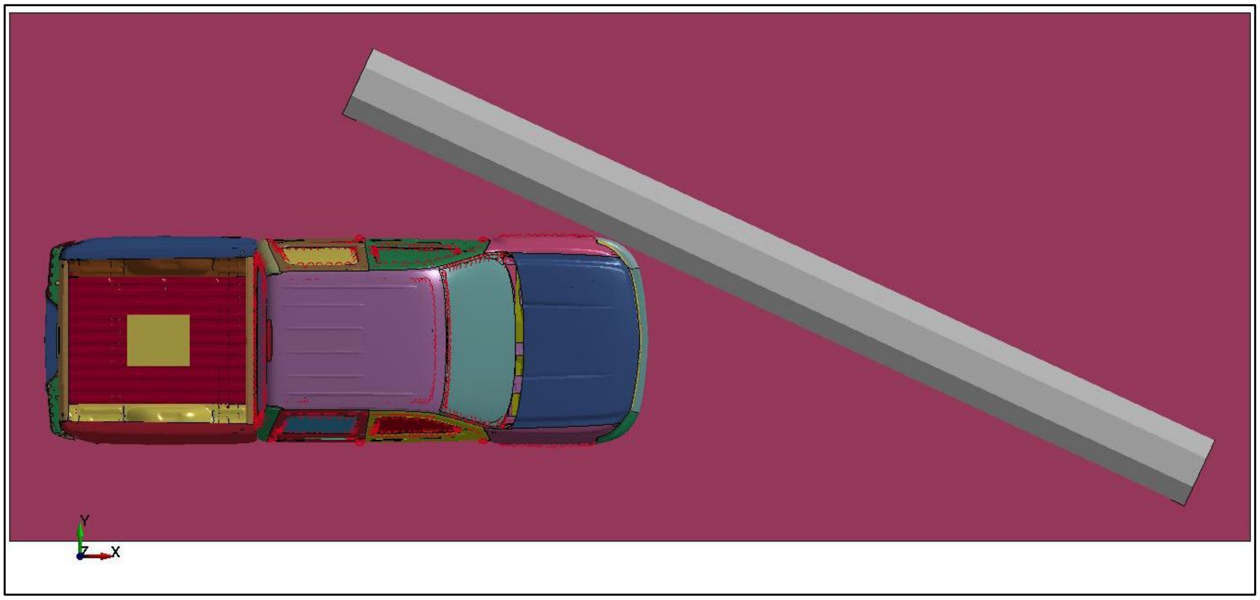


Figure 2. Finite element model of Chevy Silverado used for simulation of Test 4-11.

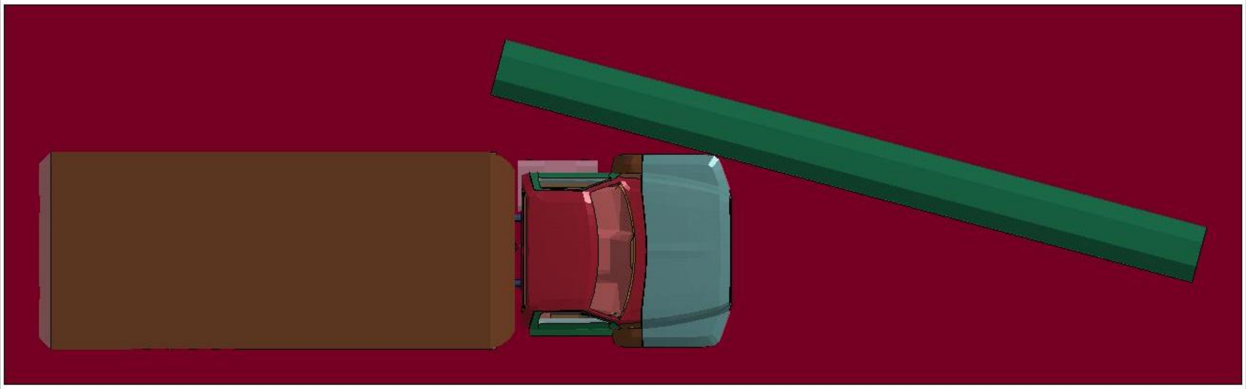


Figure 3. Finite element model of Ford F800 used for simulation of Test 4-12.

3.0 FINITE ELEMENT SIMULATION RESULTS

3.1.1 Test 4-10 Passenger Car - Median Barrier

The FEA simulation of MASH Test 4-10 on the median barrier indicated that barrier would satisfy MASH Structural Adequacy Criteria A - the GDOT single slope median barrier contained and redirected the 1100C vehicle. The vehicle did not penetrate, underride, or override the SSTR installation. In addition, the simulation indicated that the barrier satisfied MASH Occupant Risk Criteria F – the roll and pitch angles were 10 degrees and 17 degrees, respectively, for the passenger car after striking the median barrier. The simulation progression for the TL 4-10 test is shown in Figure 4. The roll, pitch, and yaw angles for the TL 4-10 test simulation are found in Figures 5, 6, and 7, respectively.

3.1.2 Test 4-10 Passenger Car - Side Barrier

The GDOT single slope side barrier has the same height and slope on the traffic-facing side as the median barrier. Given that the barrier is modeled using a rigid material with fixed boundary conditions, the simulation results are dependent only on the height and slope of the impacting side. As such, the results from the simulations of MASH tests on the side barrier will be identical to those for the median barrier. This is demonstrated by performing a simulation of the TL 4-10 passenger car test using a side barrier. The model for the TL 4-10 test using the side barrier is shown in Figure 8. The roll, pitch, and yaw angles are found in Figures 9, 10, and 11, respectively.

A comparison of the results between the TL 4-10 test on the GDOT median barrier and the GDOT side barrier is given in Table 3. As can be seen from the values presented, there is no difference in the simulation results for the median and side barriers. As such, there is no reason to perform the simulations for the TL 4-11 and TL 4-12 tests using the GDOT side barrier.

Table 3. Comparison of FEA simulation results on GDOT median and side barrier for test TL 4-10

Barrier Type	Structural Adequacy A	Max Roll Angle (degrees)	Max Pitch Angle (degrees)	Max Yaw Angle (degrees)
Median	Satisfied	10	17	55
Side	Satisfied	10	17	55
% diff	-	0.0	0.0	0.0

3.2 Test 4-11 Pickup Truck

The FEA simulation of MASH Test 4-11 on the median barrier indicated that barrier would satisfy MASH Structural Adequacy Criteria A - the GDOT single slope median barrier contained and redirected the 2270P vehicle. The vehicle did not penetrate, underride, or override the SSTR installation. In addition, the simulation indicated that the barrier satisfied MASH Occupant Risk Criteria F – the maximum roll and pitch angles were 23 degrees and 18 degrees, respectively, for the pickup truck after striking the median barrier. The simulation progression for the TL 4-11 test is shown in Figure 12. The roll, pitch, and yaw angles for the TL 4-11 test simulation are found in Figures 13, 14, and 15, respectively. As discussed in Section 3.1.2, these results are the same for the side barrier.

3.3 Test 4-12 – Single Unit Truck

The FEA simulation of MASH Test 4-12 on the median barrier indicated that barrier would satisfy MASH Structural Adequacy Criteria A - the GDOT single slope median barrier contained and redirected the 10000S vehicle. The vehicle did not penetrate, underride, or override the SSTR installation. In addition, the simulation indicated that the barrier satisfied MASH Occupant Risk Criteria F – the maximum roll and pitch angles for the passenger car were 17 degrees and 6 degrees, respectively, for the single unit truck after striking the median barrier. The simulation progression for the TL 4-12 test is shown in Figure 16. The roll, pitch, and yaw angles for the TL 4-12 test simulation are found in Figures 17, 18, and 19, respectively.

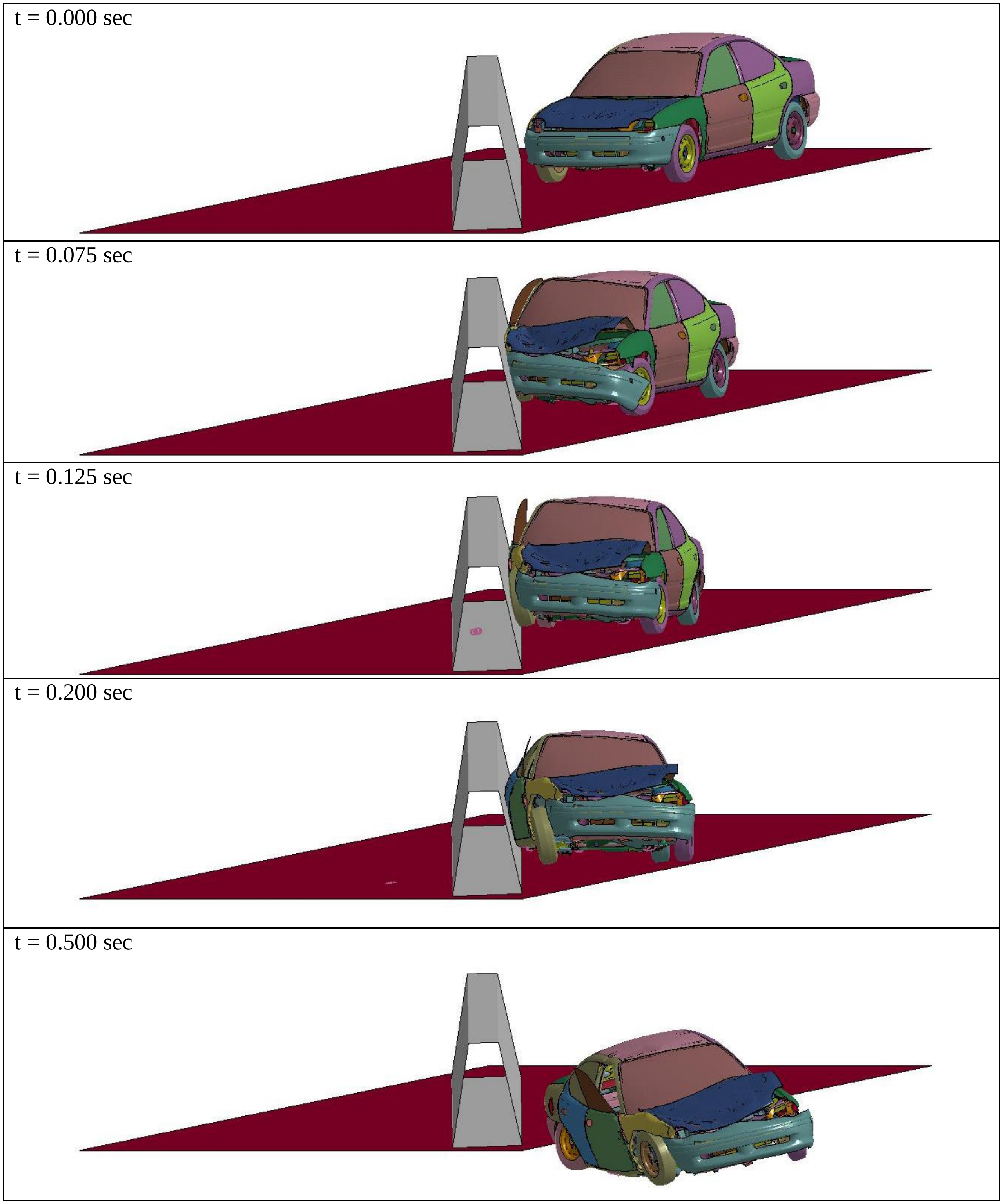


Figure 4. Progression of simulated TL 4-10 passenger car test on GDOT median barrier

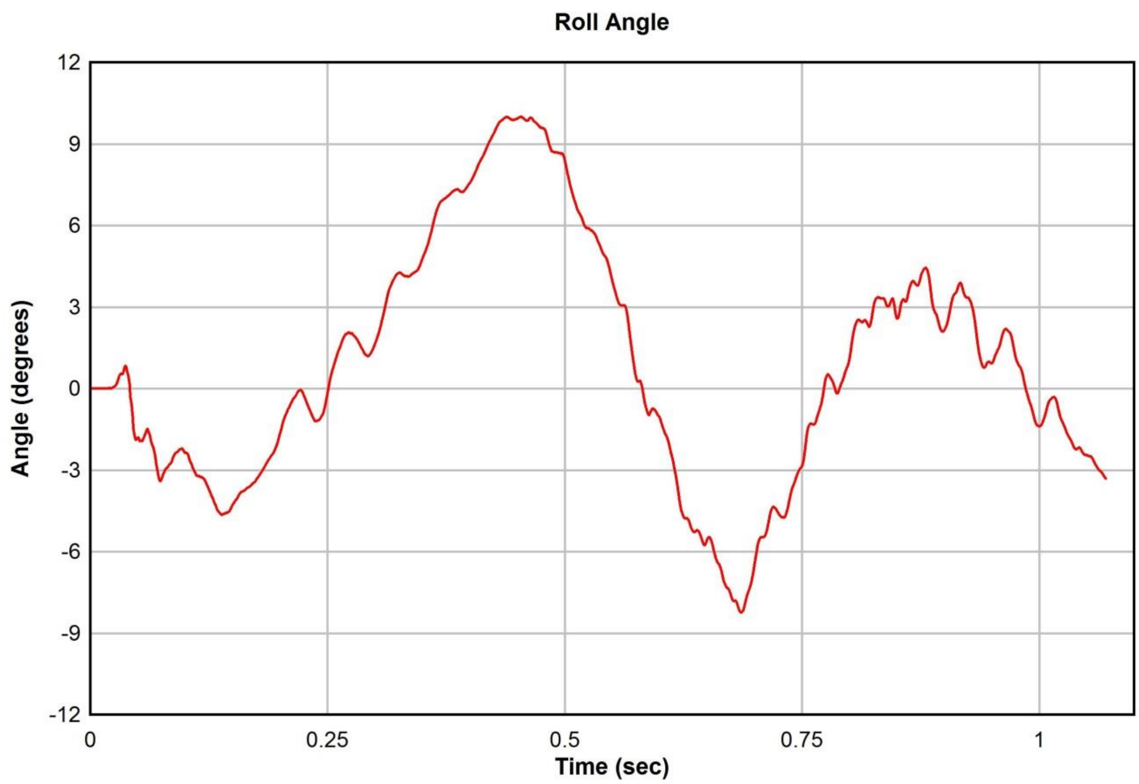


Figure 5. Roll angles from simulated TL 4-10 passenger car test on GDOT median barrier

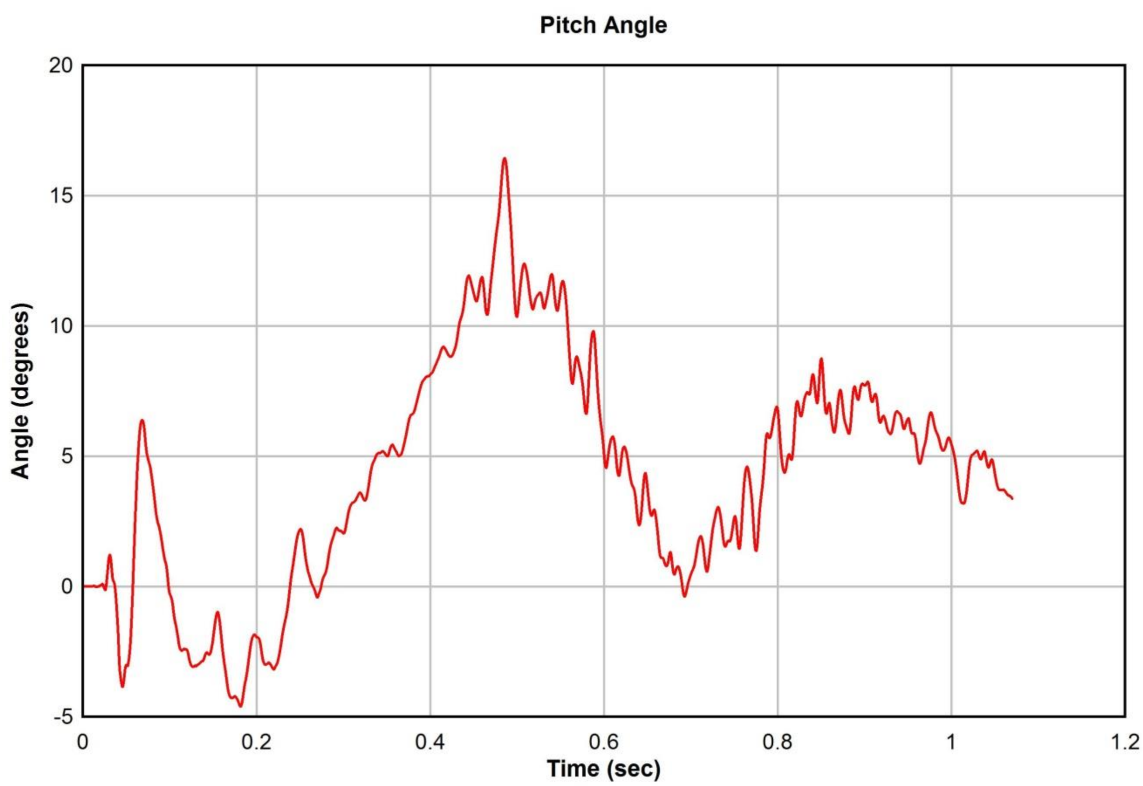


Figure 6. Pitch angles from simulated TL 4-10 passenger car test on GDOT median barrier

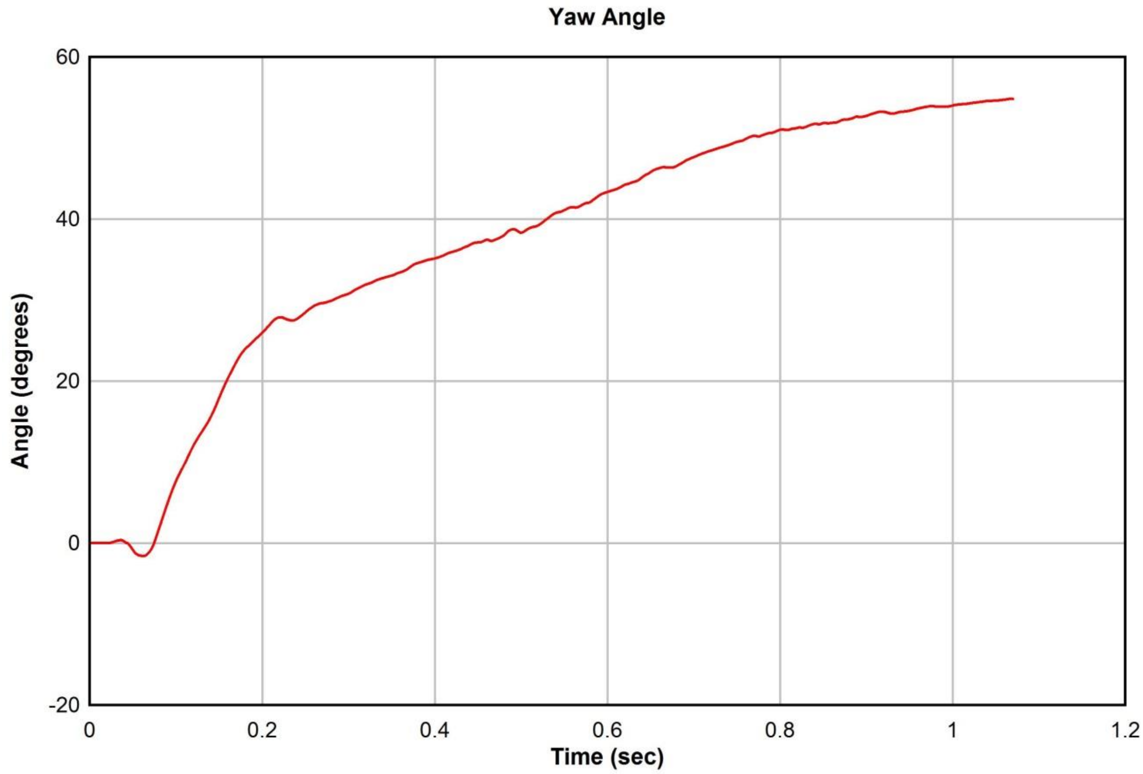


Figure 7. Yaw angles from simulated TL 4-10 passenger car test on GDOT median barrier

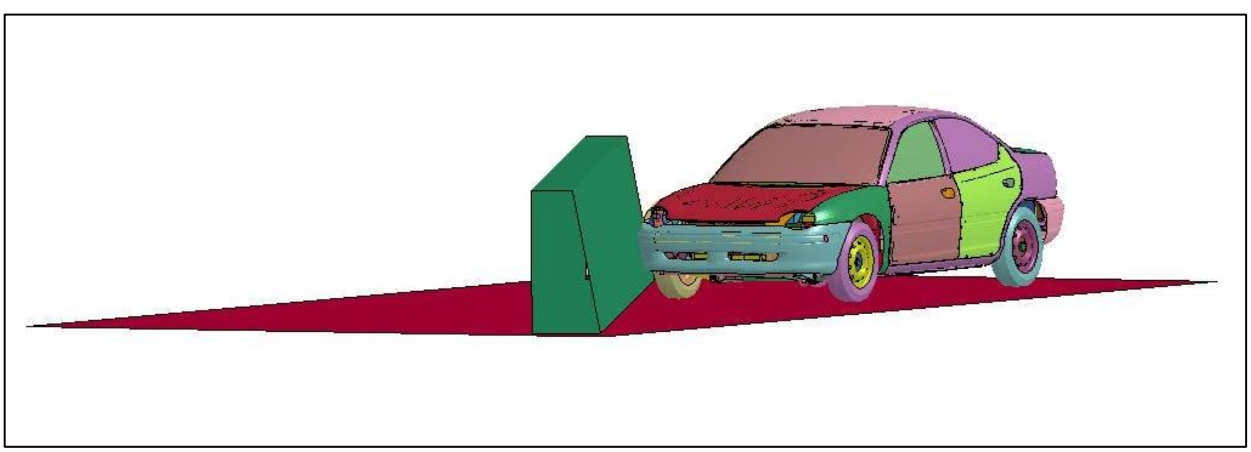


Figure 8. TL 4-10 passenger car test model on GDOT side barrier

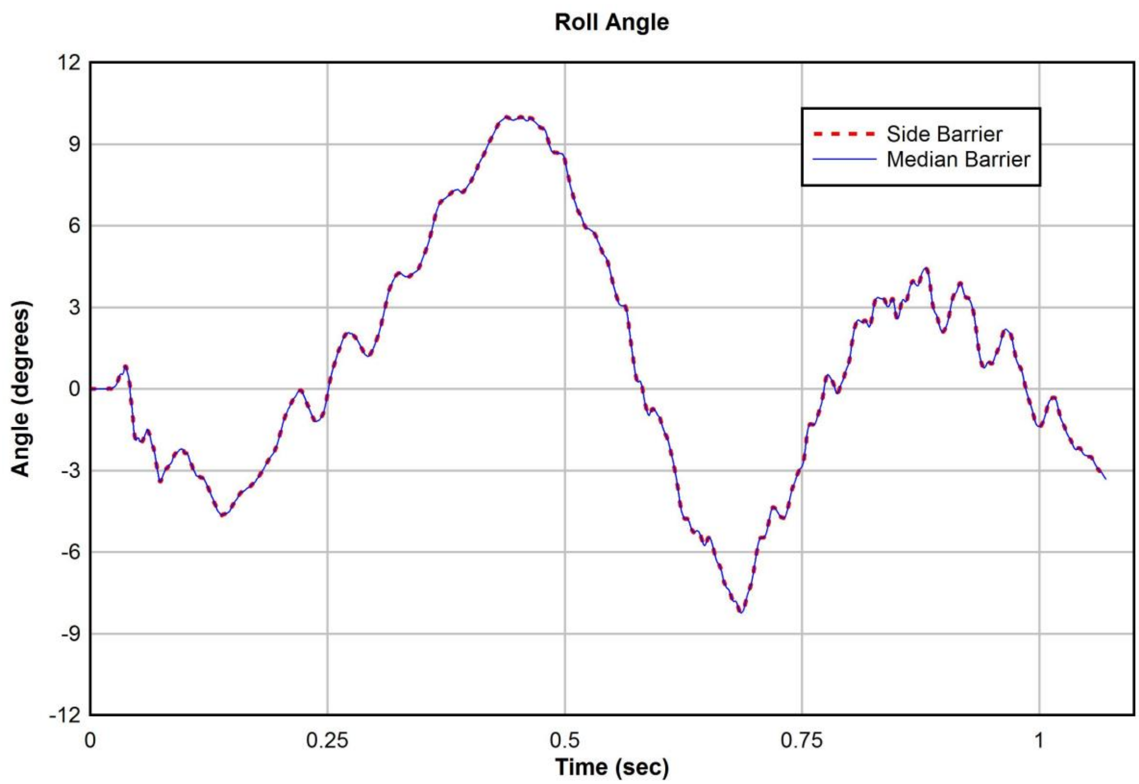


Figure 9. Roll angles from simulated TL 4-10 passenger car test on GDOT side barrier

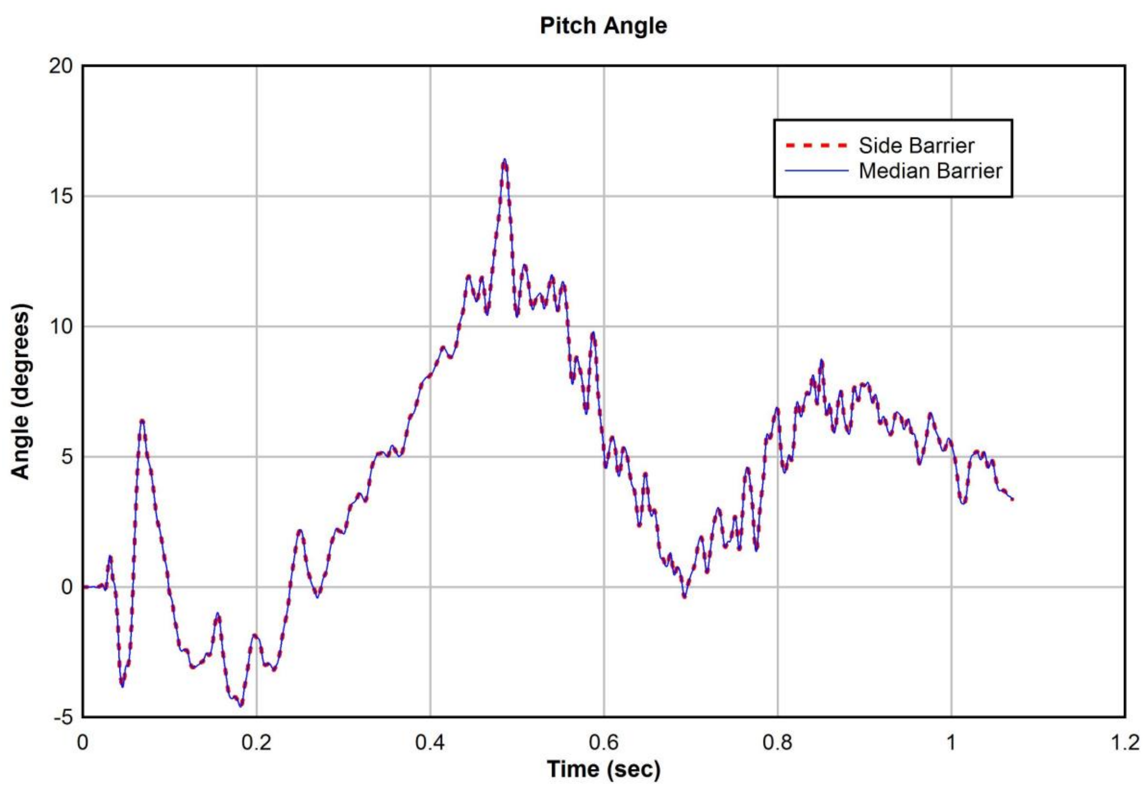


Figure 10. Pitch angles from simulated TL 4-10 passenger car test on GDOT side barrier

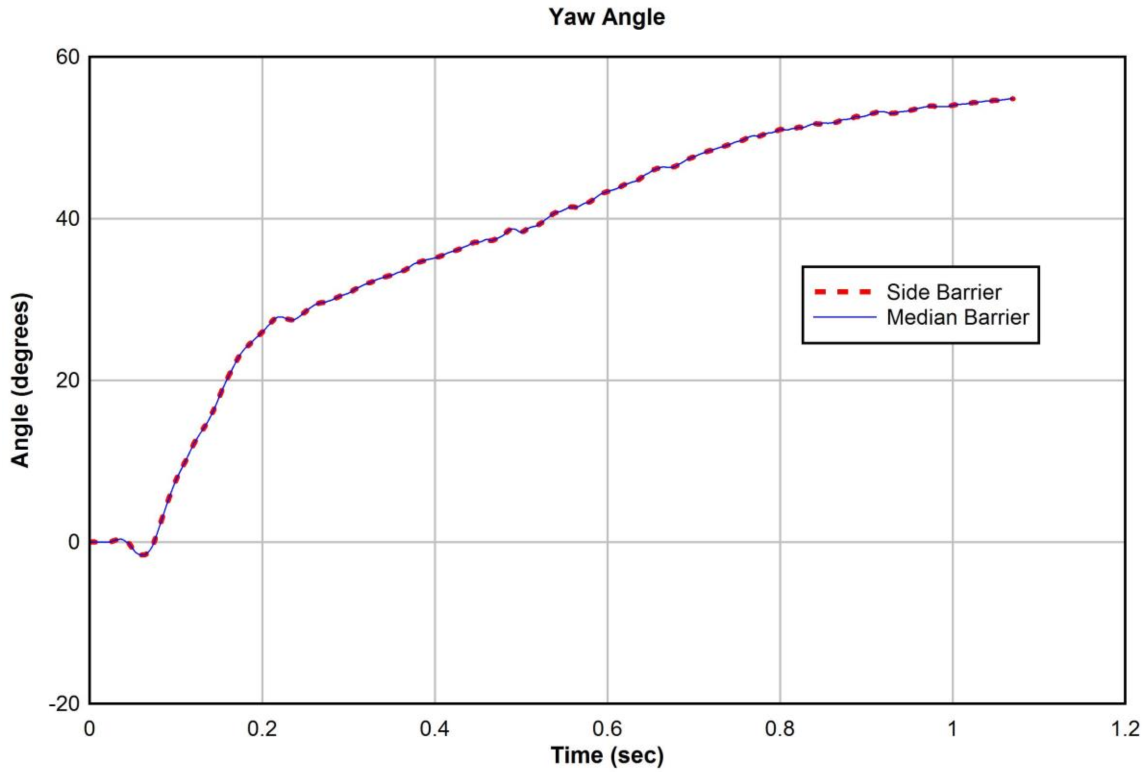


Figure 11. Yaw angles from simulated TL 4-10 passenger car test on GDOT side barrier

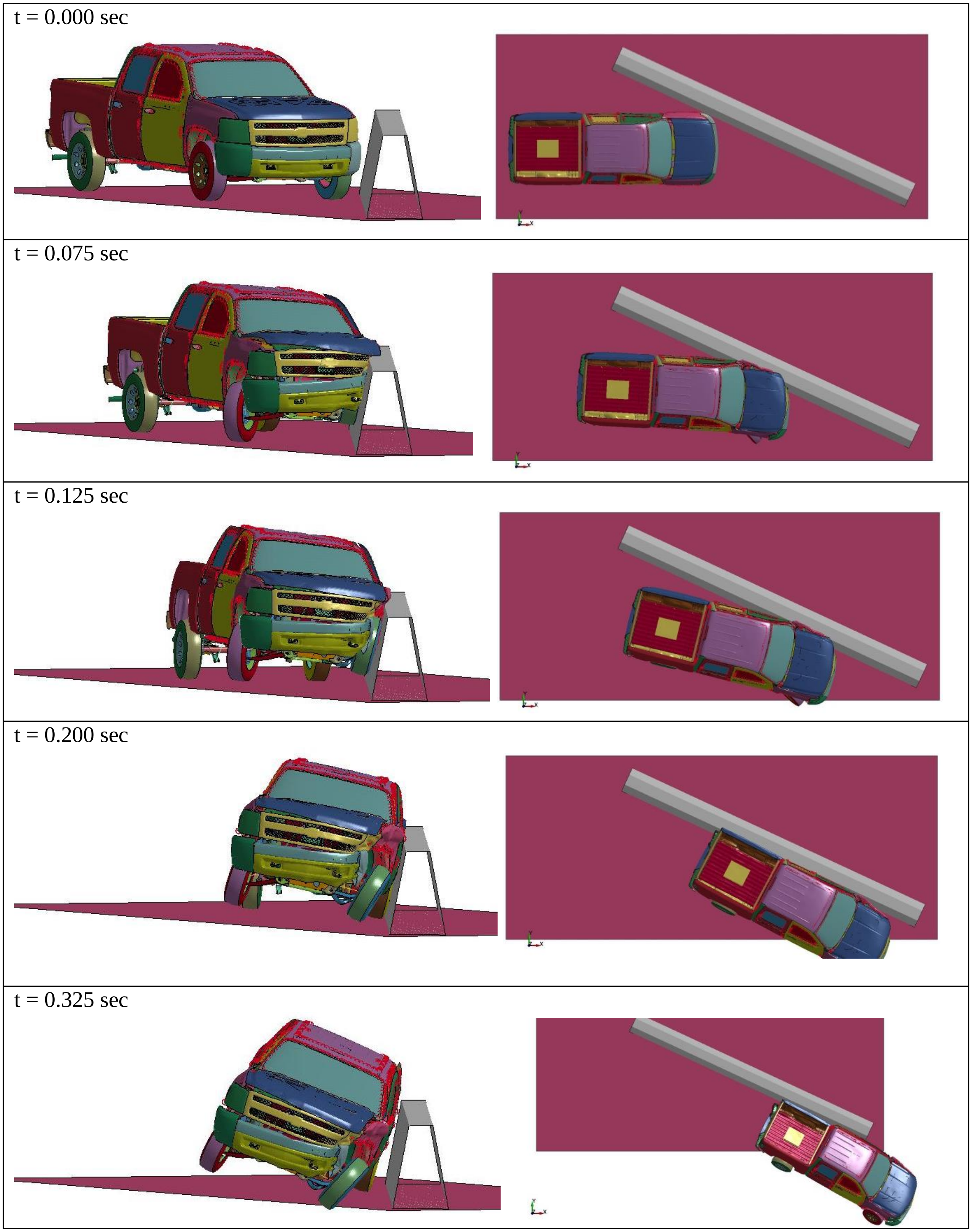


Figure 12. Progression of simulated TL 4-11 pickup truck test on GDOT median barrier

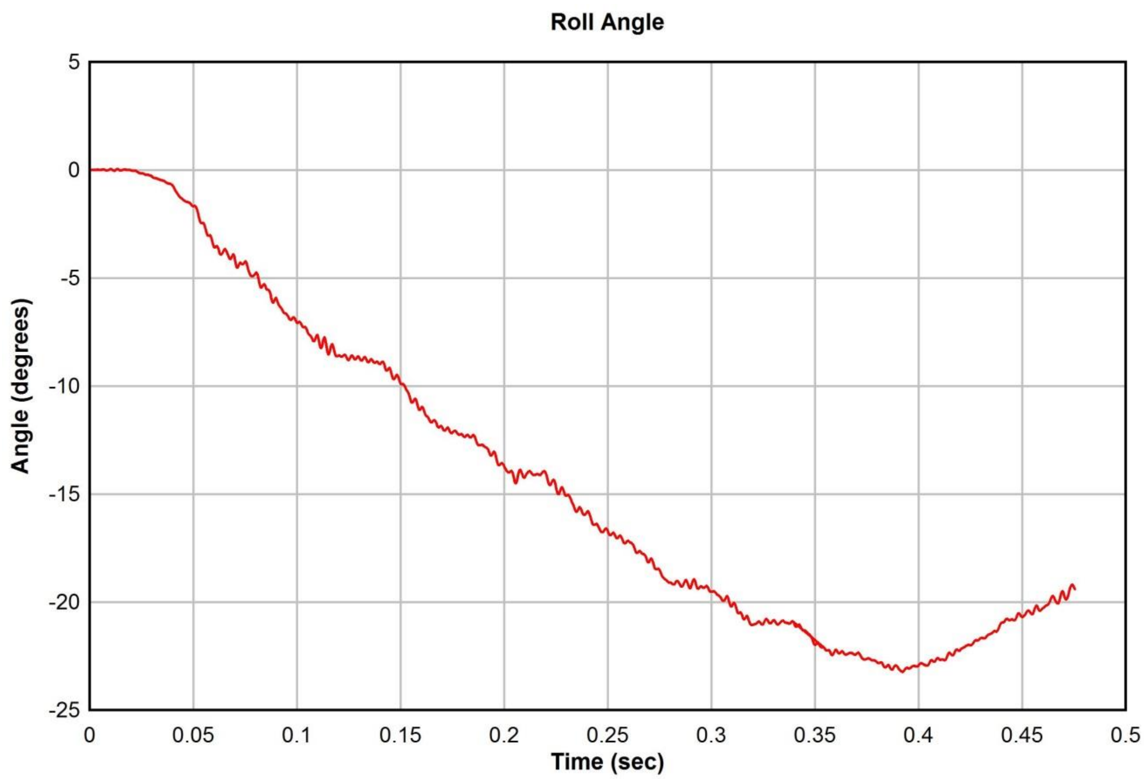


Figure 13. Roll angles from simulated TL 4-11 pickup truck test on GDOT median barrier

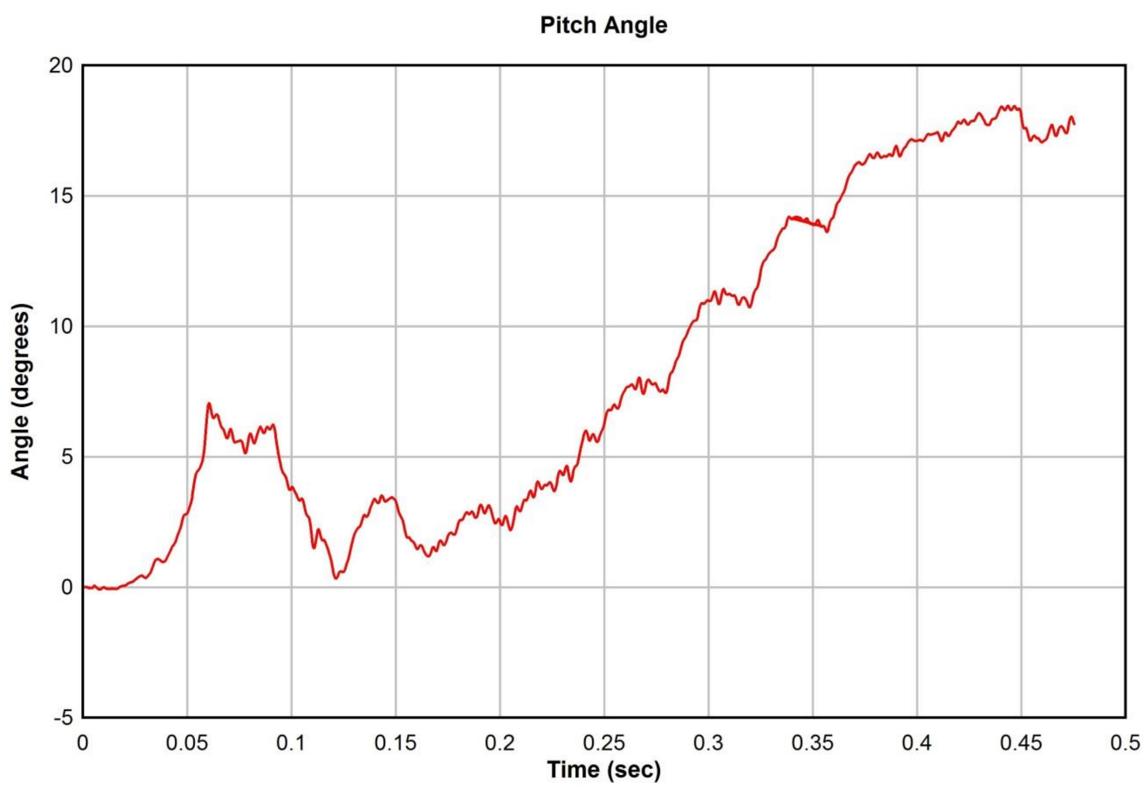


Figure 14. Pitch angles from simulated TL 4-11 pickup truck test on GDOT median barrier

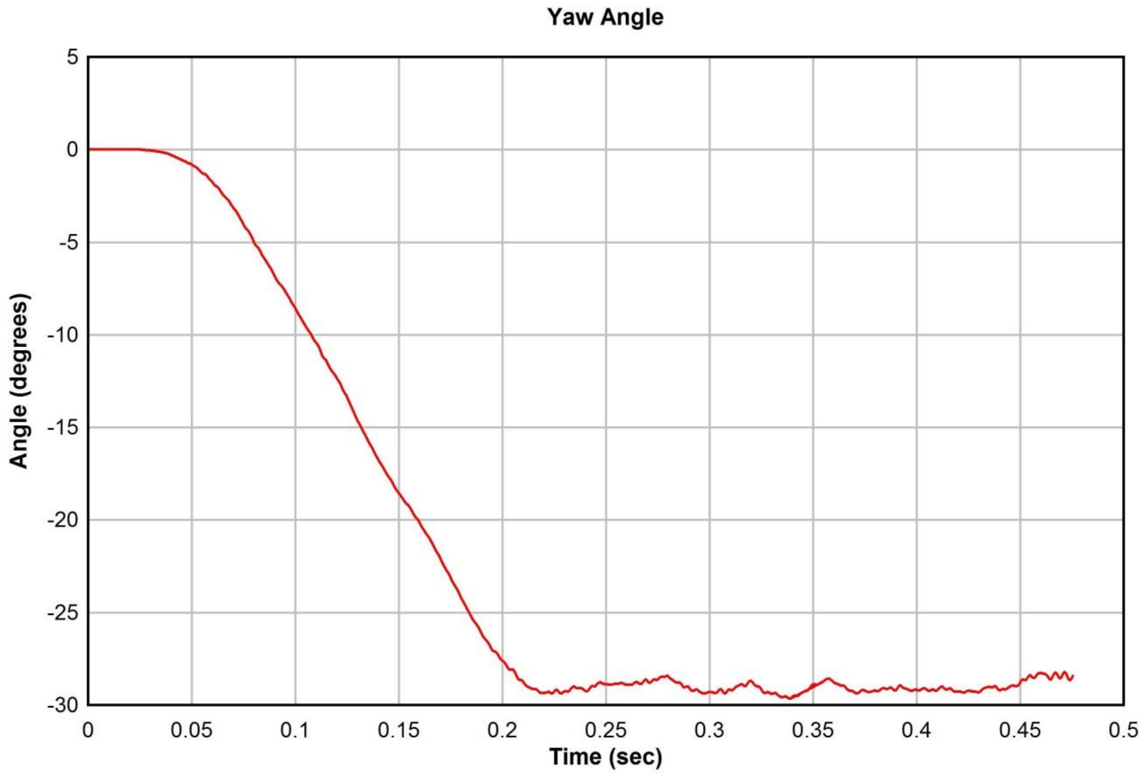


Figure 15. Yaw angles from simulated TL 4-11 pickup truck test on GDOT median barrier

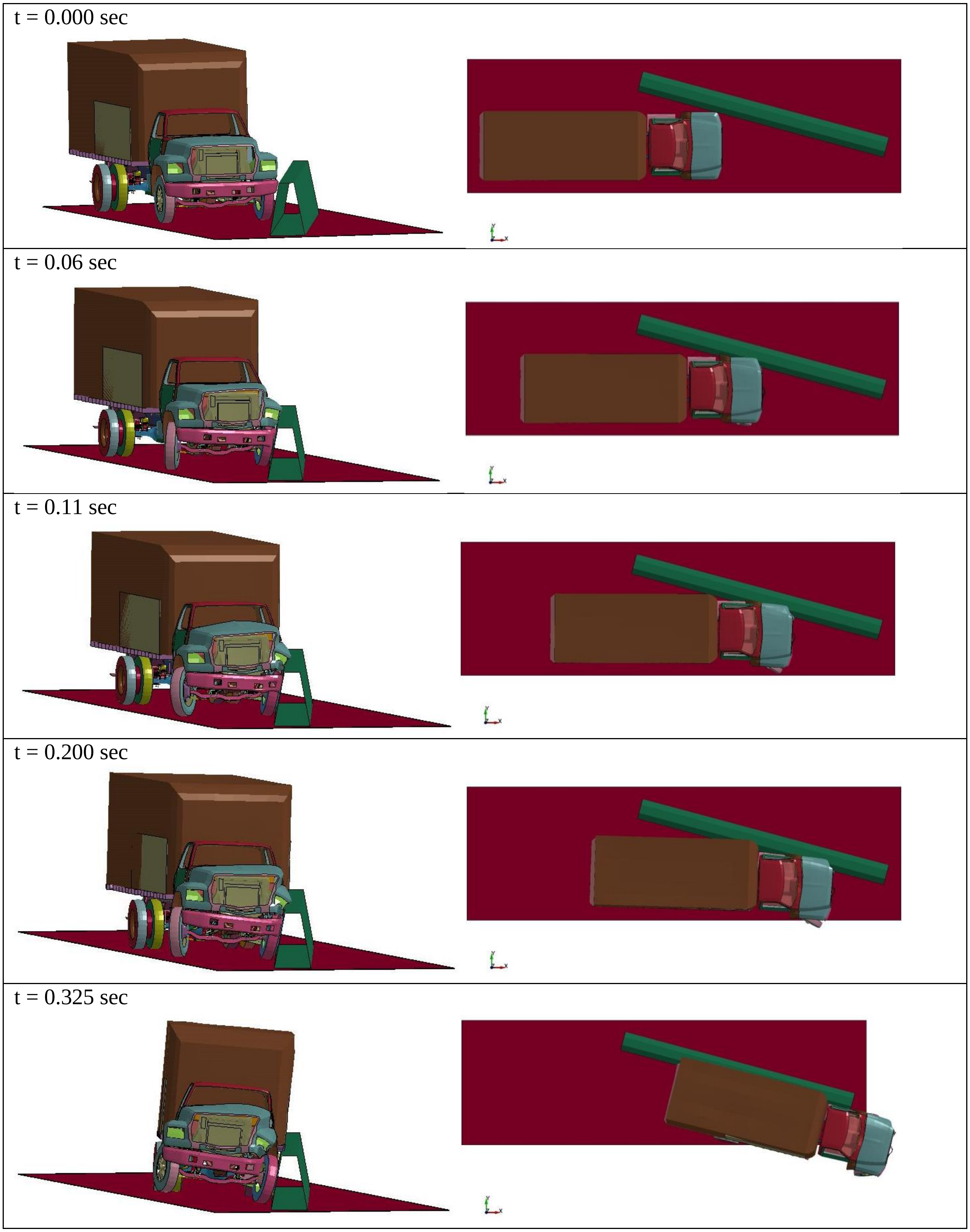


Figure 16. Progression of simulated TL 4-12 single unit truck test on GDOT median barrier

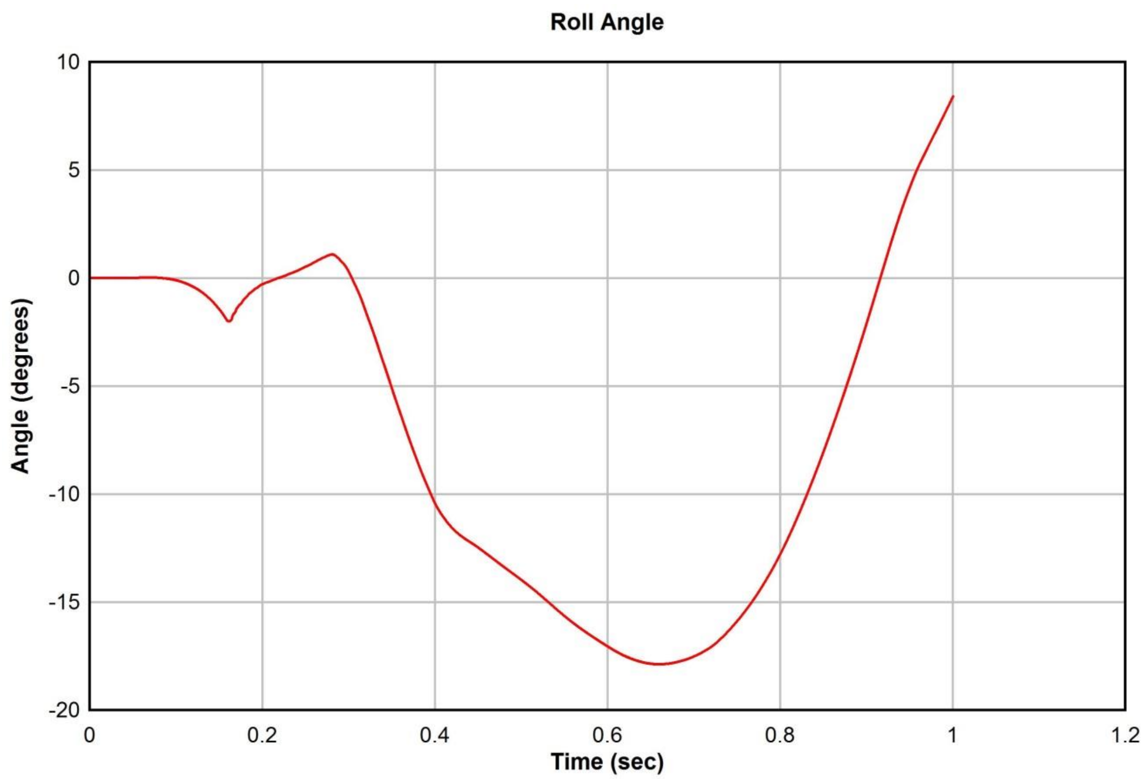


Figure 17. Roll angles from simulated TL 4-12 single unit truck test on GDOT median barrier

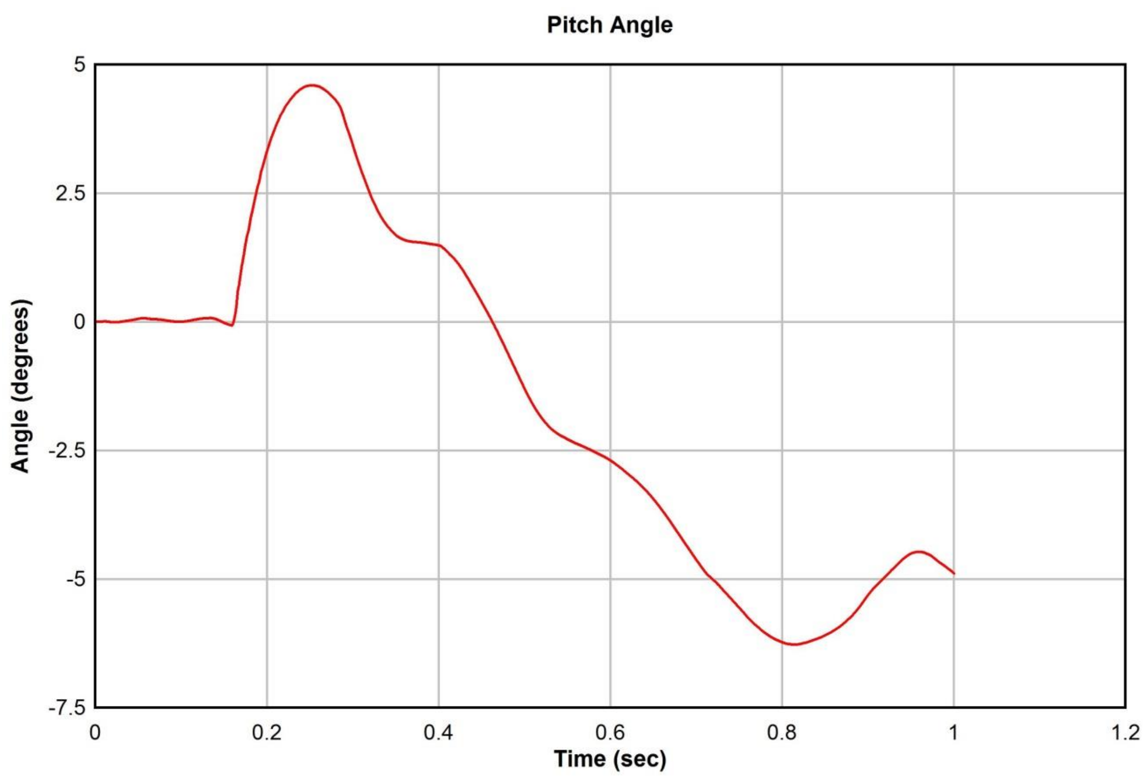


Figure 18. Pitch angles from simulated TL 4-12 single unit truck test on GDOT median barrier

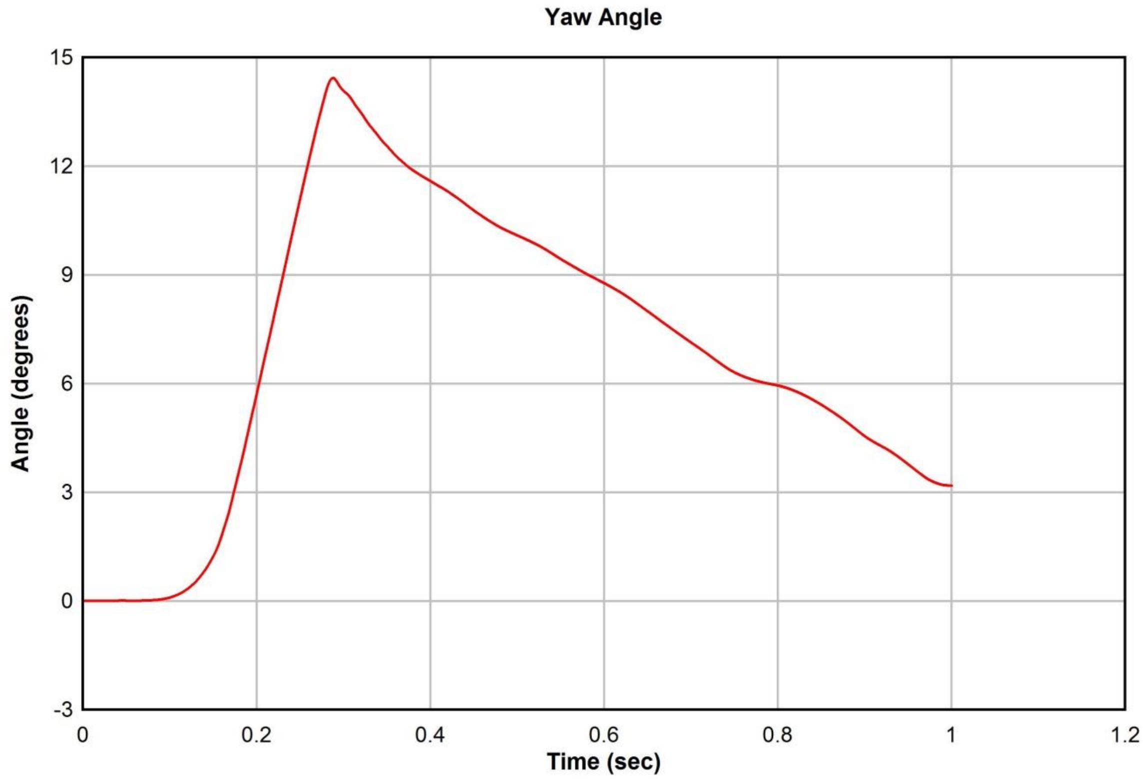


Figure 19. Yaw angles from simulated TL 4-12 single unit truck test on GDOT median barrier

3.4 Summary of Simulation Results for Median and Side Barrier and Conclusions

The results from the FEA simulations of MASH tests on the GDOT Median and Side Barriers are summarized in Table 4. Overall, the simulations indicated the barrier will satisfy pertinent MASH evaluation criteria.

Table 4. Summary of FEA simulation results on GDOT median and side barriers

Test Designation	Structural Adequacy A	Max Roll Angle (degrees)	Max Pitch Angle (degrees)	Max Yaw Angle (degrees)
TL 4-10	Satisfied	10	17	55
TL 4-11	Satisfied	23	18	29
TL 4-12	Satisfied	17	6	14

4.0 REFERENCES

1. "LS-DYNA Version R7.1." Livermore Software Technology Corporation (LSTC), Livermore, CA, 2014.

2. American Association of State Highway and Transportation Officials. *Manual for Assessing Safety Hardware, 2ND Edition*, AASHTO Subcommittee on Bridges and Structures, Washington, D.C., 2016.

3. Sheikh, N.M, Bligh, R.P., and Menges, W. L., "Determination of Minimum Height and Lateral Design Load for Test Level 4 Bridge Rails," Test Report 9-1002-5, Texas Transportation Institute, 2011.

4. https://www.nhtsa.gov/crash-simulation-vehicle-models, accessed 11/10/2017.

5. https://www.ccsa.gmu.edu/models/, accessed 10/15/2017.

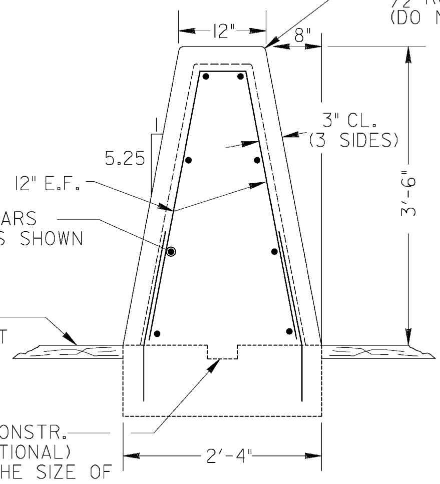
6. http://thyme.ornl.gov/fhwa/f800webpage/description/desc1.html, accessed 10/6/2017.

APPENDIX A

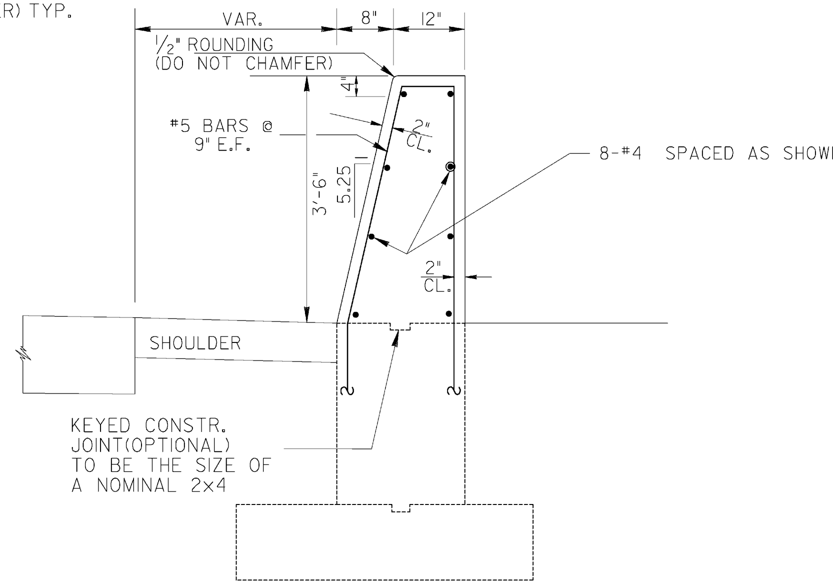
GDOT MEDIAN AND SIDE BARRIERS

STANDARD DETAILS

STATE	PROJECT NUMBER	SHEET NO.	TOTAL SHEETS
GA.			



MEDIAN BARRIER



SIDE BARRIER

GENERAL NOTES:

1. SPECIFICATIONS: GEORGIA STANDARD CURRENT EDITION, AND SUPPLEMENTS THERETO.

2. ALL CONCRETE SHALL BE CLASS "AA" (3500 PSI). REINFORCING STEEL SHALL BE GRADE 60. EXPOSED CONCRETE SURFACES SHALL RECEIVE A TYPE III FINISH. SEE SECTION 500.

3. REINFORCEMENT STEEL, WHERE REQUIRED
   A. BARRIER: ALL LONGITUDINAL STEEL SHALL BE CONTINUOUS EXCEPT: REQUIRED STOPS AT EXPANSION JOINTS; AND OPTIONAL STOPS NOT CLOSER THAN 100 FT. AT SELECTED CONTRACTION JOINTS.
   B. LONGITUDINAL OR VERTICAL REINFORCEMENT MAY BE LAP SPLICED 1'-6" AS APPROVED BY THE ENGINEER.

4. SIDE BARRIER IS USED AS STAND-ALONE BARRIER.

ALTERNATE:
WIRE FABRIC REINFORCING MAY BE USED INSTEAD OF SPECIFIED REBARS IF DETAILS ARE SUBMITTED TO & APPROVED BY THE GA. D.O.T. PRIOR TO USE.

DATE	DEPARTMENT OF TRANSPORTATION STATE OF GEORGIA
REVISION	CONCRETE MEDIAN BARRIER CONCRETE SIDE BARRIER
	NO SCALE — DECEMBER 2017
BY	DRAFT