Texas A&M Transportation Institute
Proving Ground

Test Report No. 614031-01-1&2

MASH TL-3 TESTING OF A THRIE-BEAM GUARDRAIL SYSTEM AT A FIXED OBJECT

Sponsored by

Roadside Safety Pooled Fund

TEXAS A&M TRANSPORTATION INSTITUTE PROVING GROUND
Roadside Safety & Physical Security
Texas A&M University System RELLIS Campus
Building 7091
1254 Avenue A
Bryan, TX 77807

ACCREDITED

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16. Abstract

The objective of this project was to develop a stiffened thrie-beam system, which could be implemented in close proximity to fixed objects. In pursuit of this goal, the research team performed numerous computer simulations to determine the minimum required offset to limit the interaction between an impacting vehicle and the fixed object. The research team developed both half-post spacing and quarter-post spacing alternative systems with a 75-inch gap between posts through computer simulations. The critical alternative, the quarter-post spacing system with 75-inch gap, was evaluated through physical crash testing. This system successfully met *MASH* evaluation criteria for tests 3-11 and 3-10. With positive correlation between the computer simulations and physical crash testing, the research team concluded both the quarter-post spacing and half-post spacing alternatives were suitable for implementation on the roadside. Lastly, the research team recommended a transition option for connecting the stiffened systems developed in this project to standard MGS.

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MASH TL-3 TESTING OF A THRIE-BEAM GUARDRAIL SYSTEM AT A FIXED OBJECT

by

James C. Kovar
Assistant Research Scientist
Texas A&M Transportation Institute

Maysam Kiani, Ph.D., P.E., PMP
Former Assistant Research Engineer

Sumedh Khair
Former Graduate Assistant Researcher

Heath Buttery
Former Student Technician

Daniel Curran
Student Technician
Texas A&M Transportation Institute

and

William J. L. Schroeder
Research Engineering Associate
Texas A&M Transportation Institute

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

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		
in2	square inches	645.2	square millimeters	mm2
ft2	square feet	0.093	square meters	m2
yd2	square yards	0.836	square meters	m2
ac	acres	0.405	hectares	ha
mi2	square miles	2.59	square kilometers	km2
		VOLUME		
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft3	cubic feet	0.028	cubic meters	m3
yd3	cubic yards	0.765	cubic meters	m3
	NOTE: volumes greater than 1000L shall be shown in m3			
		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/in2	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		
mm2	square millimeters	0.0016	square inches	in2
m2	square meters	10.764	square feet	ft2
m2	square meters	1.195	square yards	yd2
ha	hectares	2.47	acres	ac
km2	Square kilometers	0.386	square miles	mi2
		VOLUME		
mL	milliliters	0.034	fluid ounces	oz
L	liters	0.264	gallons	gal
m3	cubic meters	35.314	cubic feet	ft3
m3	cubic meters	1.307	cubic yards	yd3
		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/in2

*SI is the symbol for the International System of Units

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Roadside Safety Research Pooled Fund Committee
Revised April 2024

ALABAMA
Wade Henry, P.E.
Assistant State Design Engineer
Design Bureau, Final Design Division
Alabama Dept. of Transportation
1409 Coliseum Boulevard, T-205
Montgomery, AL 36110
(334) 242-6464
henryw@dot.state.al.us

Stanley (Stan) C. Biddick, P.E.
State Design Engineer
Alabama Dept. of Transportation
1409 Coliseum Boulevard, T-205
Montgomery, AL 36110
(334) 242-6488
biddicks@dot.state.al.us

ALASKA
Mary F. McRae
Assistant State Traffic & Safety Engineer
Alaska Depart. of Transportation & Public Facilities
3132 Channel Drive
P.O. Box 112500
Juneau, AK 99811-2500
(907) 465-6963
mary.mcrae@alaska.gov

Micheal Hills
Alaska Depart. of Transportation & Public Facilities
micheal.hills@alaska.gov

CALIFORNIA
Bob Meline, P.E.
Caltrans
Office of Materials and Infrastructure
Division of Research and Innovation
5900 Folsom Blvd
Sacramento, CA 95819
(916) 227-7031
Bob.Meline@dot.ca.gov

John Jewell, P.E.
Senior Crash Testing Engineer
Office of Safety Innovation & Cooperative Research
(916) 227-5824
John_Jewell@dot.ca.gov

COLORADO
David Kosmiski, P.E.
Miscellaneous (M) Standards Engineer
Division of Project Support, Construction Engineering Services (CES) Branch
Colorado Dept. of Transportation (CDOT)
2829 W. Howard Pl.
Denver, CO 80204
303-757-9021
david.kosmiski@state.co.us

Andy Pott, P.E.
Senior Bridge Design and Construction Engineer
Division of Project Support, Staff Bridge Design and Construction Management
Colorado Dept. of Transportation (CDOT)
4201 E Arkansas Ave, 4th Floor

Denver, CO 80222
303-512-4020
andrew.pott@state.co.us

Shawn Yu, P.E.
Miscellaneous (M) Standards and Specifications Unit Manager
Division of Project Support, Construction Engineering Services (CES) Branch
Colorado Dept. of Transportation (CDOT)
4201 E Arkansas Ave, 4th Floor
Denver, CO 80222
303-757-9474
shawn.yu@state.co.us

Amin Fakhimalizad
Assistant Miscellaneous (M) Standards Engineer
Division of Project Support, Construction Engineering Services (CES) Branch
Colorado Dept. of Transportation (CDOT)
303-757-9229
amin.fakhimalizad@state.co.us

Man (Steven) Yip
Division of Project Support, Construction Engineering Services (CES) Branch
Colorado Dept. of Transportation (CDOT)
man.yip@state.co.us

CONNECTICUT

David Kilpatrick
Transportation Supervising Engineer
State of Connecticut Depart. of Transportation
2800 Berlin Turnpike
Newington, CT 06131-7546
(806) 594-3288
David.Kilpatrick@ct.gov

Todd Ingarra
todd.ingarra@ct.gov

DELAWARE

Cassidy Blowers
Construction Resource Engineer
Construction Section
Delaware DOT
(302)760-2336
Cassidy.Blowers@delaware.gov

James Osborne
Traffic Safety Programs Manager
Traffic Operations
Delaware DOT
(302)659-4651
James.Osborne@delaware.gov

FLORIDA

Richard Stepp
Florida Department of Transportation
Richard.Stepp@dot.state.fl.us

Derwood C. Sheppard, Jr., P.E.
State Roadway Design Engineer
Florida Depart. of Transportation
Roadway Design Office
605 Suwannee Street, MS-32
Tallahassee, FL 32399-0450
(850) 414-4334
Derwood.Sheppard@dot.state.fl.us

IDAHO

Marc Danley, P.E.
Technical Engineer
(208) 334-8558
Marc.danley@itd.idaho.gov

Kevin Sablan
Design/Traffic Engineer
Idaho Transportation Department
(208) 334-8558
Kevin.sablan@itd.idaho.gov

ILLINOIS

Martha A. Brown, P.E.
Safety Design Bureau Chief
Bureau of Safety Programs and Engineering
Illinois Depart. of Transportation
2300 Dirksen Parkway, Room 005
Springfield, IL 62764
(217) 785-3034
Martha.A.Brown@illinois.gov

Edgar A. Galofre, MSCE, P.E.
Safety Design Engineer
Bureau of Safety Programs and Engineering
Illinois Department of Transportation
2300 S. Dirksen Parkway, Room 007
Springfield, IL 62764
(217) 558-9089
Edgar.Galofre@illinois.gov

IOWA

Daniel Harness
Design Bureau – Methods Section
Iowa Department of Transportation
Daniel.Harness@iowadot.us

Chris Poole
State Traffic Engineer
Traffic and Safety Bureau
Iowa Department of Transportation
Chris.Poole@iowadot.us

LOUISIANA

Carl Gaudry
Bridge Design Manager
Louisiana Department of Transportation and Development
Bridge & Structural Design Section
P.O. Box 94245
Baton Rouge, LA 70804-9245
(225) 379-1075
Carl.Gaudry@la.gov

Chris Guidry
Assistant Bridge Design Administrator
Louisiana Department of Transportation and Development
Bridge & Structural Design Section
P.O. Box 94245
Baton Rouge, LA 79084-9245
(225) 379-1328
Chris.Guidry@la.gov

MARYLAND

Philip Brentlinger
Maryland State Highway Administration
pbrentlinger@mdot.maryland.gov

MASSACHUSETTS

James Danila
Assistant State Traffic Engineer
Massachusetts Depart. of Transportation
(857) 368-9640
James.danila@state.ma.us

Alex Bardow
Director of Bridges and Structure
Massachusetts Depart. of Transportation
10 Park Plaza, Room 6430
Boston, MA 02116
(857) 368-9430
Alexander.Bardow@state.ma.us

MICHIGAN

Carlos Torres, P.E.
Roadside Safety Engineer
Geometric Design Unit, Design Division
Michigan Depart. of Transportation
P. O. Box 30050
Lansing, MI 48909
(517) 335-2852
TorresC@michigan.gov

MINNESOTA

Khamsai Yang
Design Standards Engineer
Office of Project Management and Technical Support
(612) 322-5601
Khamsai.Yang@state.mn.us

Brian Tang
Assistant Design Standards Engineer
Office of Project Management and Technical Support
Minnesota Department of Transportation
brian.tang@state.mn.us

MISSOURI

Gidget Koestner
Policy & Innovations Engineer
Central Office- Design
Missouri Department of Transportation
(573) 751-6905
gidget.koestner@modot.mo.gov

Kirby Woods
Roadside Design Engineer
Missouri Department of Transportation
(573) 472-5333
kirby.woodsjr@modot.mo.gov

NEW MEXICO

Brad Julian
New Mexico Department of Transportation
Traffic Technical Support Engineer
(505) 469-1405
Brad.Julian@dot.nm.gov

NEVADA

David Fox, P.E.
Specifications Engineer
Roadway Design Division
Nevada Dept. of Transportation
1263 S. Stewart St.
Carson City, NV 89712
(775) 888-7053
DWFox@dot.nv.gov

Tim Rudnick
Standards and Manuals Supervisor
Roadway Design Division
Nevada Dept. of Transportation
1263 S. Stewart St.
Carson City, NV 89712
(775) 888-7598
TRudnick@dot.nv.gov

OHIO

Don P. Fisher, P.E.
Ohio Depart. of Transportation
1980 West Broad Street

Mail Stop 1230
Columbus, OH 43223
(614) 387-2614
Don.fisher@dot.ohio.gov

OREGON
Christopher Henson
Senior Roadside Design Engineer
Oregon Depart. of Transportation
Technical Service Branch
4040 Fairview Industrial Drive, SE
Salem, OR 97302-1142
(503) 986-3561
Christopher.S.Henson@odot.state.or.us

PENNSYLVANIA
James A. Borino, Jr., P.E.
Chief, Standards and Criteria Unit
Highway Design and Technology Division
Pennsylvania DOT
(717) 612-4791
jborino@pa.gov

Evan Pursel
Senior Civil Engineer
Highway Design and Technology Division
Pennsylvania DOT
(717) 705-8535
epursel@pa.gov

Nina Ertel
Project Development Engineer
Highway Design and Technology Division
Pennsylvania DOT
(717) 425-7679
nertel@pa.gov

TENNESSEE
Laura Chandler
Engineering Production Support Manager
Engineering Division
Tennessee Dept. of Transportation
(615) 253-4769
Laura.Chandler@tn.gov

Ali Hangul M.S., P.E
State Standards Transportation Engineer
Engineering Production Support, Engineering Division
Tennessee Dept. of Transportation
(615) 741-0840
Ali.Hangul@tn.gov

TEXAS
Chris Lindsey
Transportation Engineer
Design Division
Texas Department of Transportation
125 East 11th Street
Austin, TX 78701-2483
(512) 416-2750
Christopher.Lindsey@txdot.gov

Taya Retterer
TxDOT Bridge Standards Engineer
Bridge Division
Texas Department of Transportation
(512) 993-0330
Taya.Retterer@txdot.gov

Wade Odell
Research Project Manager
Research & Technology Implementation Division
Texas Department of Transportation
(512) 416-4737
wade.odell@txdot.gov

UTAH

Clint McCleery
Barrier and Attenuation Specialist
Traffic and Safety Operations
Utah Department of Transportation
(801)712-8685
cmccleery@utah.gov

WASHINGTON

Tim Moeckel
Roadside Safety Engineer
Washington State Department of Transportation
Development Division
P.O. Box 47329
Olympia, WA 98504-7246
(360) 704-6377
moecket@wsdot.wa.gov

Mustafa Mohamedali
Research Manager/Engineering
Transportation Safety & System Analysis
Research & Library Services
(360) 704-6307
mohamem@wsdot.wa.gov

Kevin Burch
Policy Support Engineer
Washington State Department of Transportation
Development Division
burchk@wsdot.wa.gov

WEST VIRGINIA

Donna J. Hardy, P.E.
Mobility, ITS & Safety Engineer
West Virginia Depart. of Transportation – Traffic Engineering
Building 5, Room A-550
1900 Kanawha Blvd E.
Charleston, WV 25305-0430
(304) 414-7338
Donna.J.Hardy@wv.gov

Ted Whitmore
Traffic Services Engineer
Traffic Engineering
WV Division of Highways
(304)414-7373
Ted.J.Whitmore@wv.gov

WISCONSIN

Erik Emerson, P.E.
Standards Development Engineer – Roadside Design
Wisconsin Department of Transportation
Bureau of Project Development
4802 Sheboygan Avenue, Room 651
P. O. Box 7916
Madison, WI 53707-7916
(608) 266-2842
Erik.Emerson@wi.gov

CANADA – ONTARIO

Kenneth Shannon, P. Eng.
Senior Engineer, Highway Design (A)
Ontario Ministry of Transportation
301 St. Paul Street
St. Catharines, ON L2R 7R4
CANADA
(904) 704-3106
Kenneth.Shannon@ontario.ca

FEDERAL HIGHWAY ADMINISTRATION (FHWA)

Website: safety.fhwa.dot.gov

Eduardo Arispe
Research Highway Safety Specialist
U.S. Department of Transportation
Federal Highway Administration
Turner-Fairbank Highway Research Center
Mail Code: HRDS-10
6300 Georgetown Pike
McLean, VA 22101
(202) 493-3291
Eduardo.arispe@dot.gov

Richard B. (Dick) Albin, P.E.
Senior Safety Engineer
Office of Innovation Implementation, Safety & Design Team
(303) 550-8804
Dick.Albin@dot.gov

Paul LaFleur, P.E.
Safety Design Team - Roadway Departure Program Manager
FHWA Office of Safety
U.S. Department of Transportation
(515) 233-7308
paul.lafleur@dot.gov

Christine Black
Highway Safety Engineer
Central Federal Lands Highway Division
12300 West Dakota Ave.
Lakewood, CO 80228
(720) 963-3662
Christine.black@dot.gov

Isbel Ramos-Reyes
Lead Safety and Transportation Operations Engineer
Eastern Federal Lands Highway Division
(703) 948-1442
isbel.ramos-reyes@dot.gov

TEXAS A&M TRANSPORTATION INSTITUTE (TTI)
Website: tti.tamu.edu
www.roadsidepooledfund.org

D. Lance Bullard, Jr., P.E.
Senior Research Engineer
Roadside Safety & Physical Security Div.
Texas A&M Transportation Institute
3135 TAMU
College Station, TX 77843-3135
(979) 317-2855
L-Bullard@tti.tamu.edu

Roger P. Bligh, Ph.D., P.E.
Senior Research Engineer
Roadside Safety and Physical Security Division
(979) 317-2703
R-Bligh@tti.tamu.edu

Nauman Sheikh, P.E.
Research Engineer
Roadside Safety and Physical Security
Texas A&M Transportation Institute
(979) 317-2703
n-sheikh@tti.tamu.edu

Ariel Sheil
Research Assistant
Roadside Safety and Physical Security
Texas A&M Transportation Institute
(979) 317-2250
A-Sheil@tti.tamu.edu

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REPORT AUTHORIZATION

REPORT REVIEWED BY:

Glenn Schroeder, Research Specialist
Drafting & Reporting

Ken Reeves, Research Specialist
Electronics Instrumentation

Adam Mayer, Research Specialist
Construction

Richard Badillo, Research Specialist
Photographic Instrumentation

Robert Kocman, Research Engineering Associate
Mechanical Instrumentation

William J. L. Schroeder, Research Engineering Associate
Research Evaluation and Reporting

Bill L. Griffith, Research Specialist
Quality Manager

Matthew N. Robinson, Research Specialist
Test Facility Manager & Technical Manager

James C. Kovar
Assistant Research Scientist

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CHAPTER 1. INTRODUCTION

1.1. BACKGROUND

The Roadside Safety Pooled Fund prioritized a research effort to develop a stiff guardrail system that could mitigate risks of fixed objects in close proximity to the guardrail system. The close proximity required this system to provide significantly reduced deflections compared to standard Midwest Guardrail Systems (MGS). One of the common methods for minimizing deflections is to install a rigid concrete barrier system. However, concrete barriers are often a costly option for roadside obstacle mitigation. Therefore, the barrier developed in this project aimed to be more cost effective than a concrete solution.

The origin of this research need arose from a Washington Department of Transportation (WSDOT) design standard (*1*). Their original design included a thrie-beam guardrail system which could be utilized in close proximity to fixed objects. In fact, the fixed objects could be installed with blockouts in locations where steel posts would not fit. Figure 1.1 details this thrie-beam in close proximity to a fixed object design.

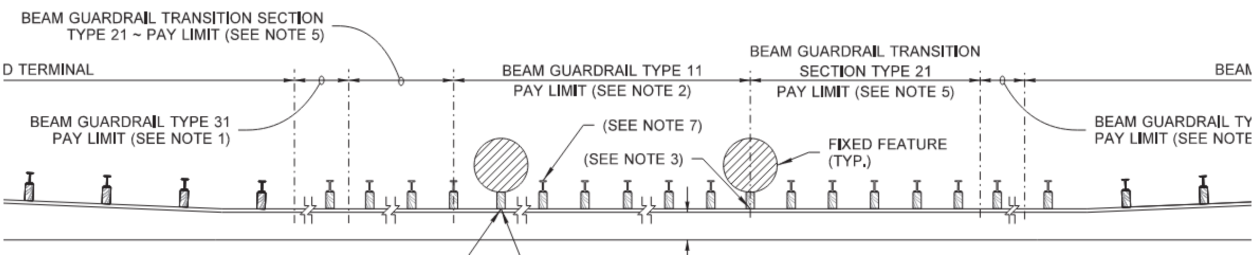

Figure 1.1 WSDOT Thrie-beam at Fixed Object Detail (*1*)

1.2. OBJECTIVE

The objective of this project was to develop an American Association of State Highway and Transportation Officials (AASHTO) *Manual for Assessing Safety Hardware*, Second Edition (*MASH*) compliant guardrail system which could be utilized in close proximity to fixed objects (*2*). This project involved a simulation effort to aid in the design and development of the new barrier system, which was then evaluated with full-scale crash testing. The purpose of the tests reported herein was to assess the performance of the Thrie-Beam Guardrail System at a Fixed Object according to the safety-performance evaluation guidelines included in *MASH*. The crash tests were performed in accordance with *MASH* Test Level 3 (TL-3).

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CHAPTER 2. COMPUTER SIMULATION

2.1. INTRODUCTION

The simulation effort evaluated a variety of design options prior to full-scale crash testing. At the start of the simulation effort, the research team investigated the crashworthiness of thrie-beam systems with reduced post spacing. These systems did not have additional space between posts to accommodate a larger fixed object or foundation. Both quarter- (18-¾ inches) and half- (37-½ inches) post spacings were evaluated in this effort. The early simulations did not include any fixed or rigid object behind the guardrail system. The latter simulations included a fixed object located behind the guardrail to evaluate any vehicle interaction with the rigid object.

During the simulation effort, the Roadside Safety Pooled Fund decided to alter the scope of the simulations. The new design options incorporated a larger gap or space between posts to accommodate the size of the fixed object and appropriate foundation. These options were evaluated with both quarter- and half-post spacing.

The research team utilized LS-DYNA, a commercial non-linear finite element analysis code, to perform the simulations (*3*). The models of the individual system components were developed and verified through previous research projects. Likewise, the material cards, boundary conditions, and other modeling assumptions were also developed and verified through previous research projects. The vehicle model was originally developed by the Center for Collision Safety and Analysis at George Mason University, and has been modified by TTI researchers through a number of research efforts. The researchers reviewed the results of preliminary simulations and accepted the predictive capability of the models and simulations.

Figure 2.1 below shows an elevation cross-section view. Based on the positive results of other thrie-beam research projects, shortened blockouts were utilized in this evaluation. These blockouts were 8-inch laterally deep blockouts and 14-inches tall. The models incorporated 12-gauge thrie-beam rail sections and W6x15 posts. The following sections summarize the results of the individual computer simulation evaluations.

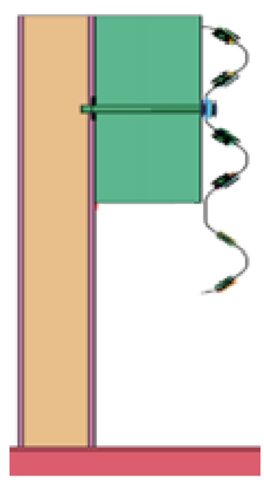


Figure 2.1. Elevation Cross-Section of Thrie-Beam System

2.2. DESIGN OPTIONS WITHOUT ADDITIONAL SPACE BETWEEN POSTS

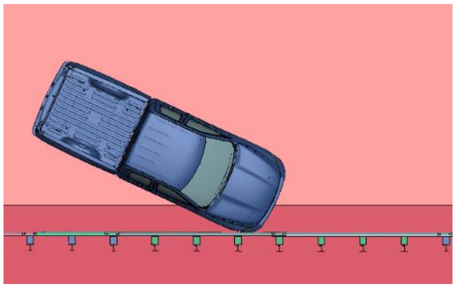
The following simulations evaluate the crashworthiness of thrie-beam systems with consistent post spacings. In other words, no additional space was added between posts to accommodate a fixed object and appropriate foundation.

2.2.1. Models without Fixed Objects

The following simulations evaluate the crashworthiness of thrie-beam systems without a rigidized fixed object behind the barrier.

2.2.1.1. MASH Test 3-11 Simulation of Half-Post Spacing Thrie-Beam System

This simulation evaluated the crashworthiness of a half-post spacing thrie-beam system. This barrier incorporated two 12 ½-ft thrie-beam rail sections. Figure 2.2 through Figure 2.4 show the sequential frames of the simulated *MASH* test 3-11. The maximum post deflection was measured as 12.75 inches. The occupant impact velocity (OIV) was calculated to be 8.0 m/s (preferred limit is 9.1 m/s). The ridedown acceleration (RDA) was calculated to be 13.6 g's (preferred limit is 15.0 g's). This configuration passed *MASH* test 3-11 by successfully containing and redirecting the vehicle.



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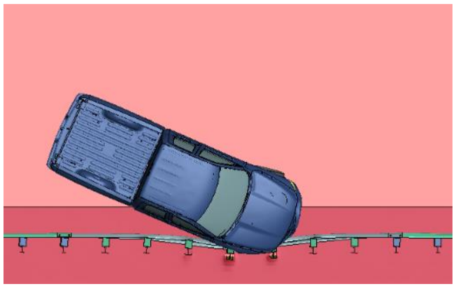

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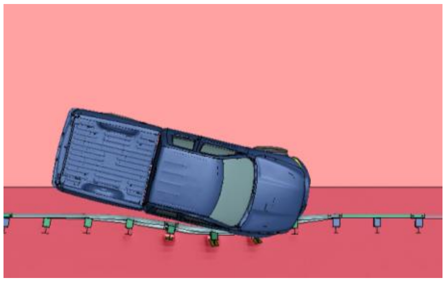

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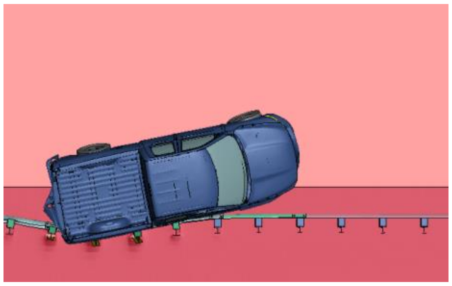

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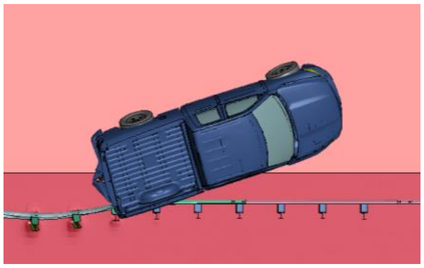

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Figure 2.2. *MASH* Test 3-11 Simulation of Half-Post Spacing Thrie-Beam System– Overhead View

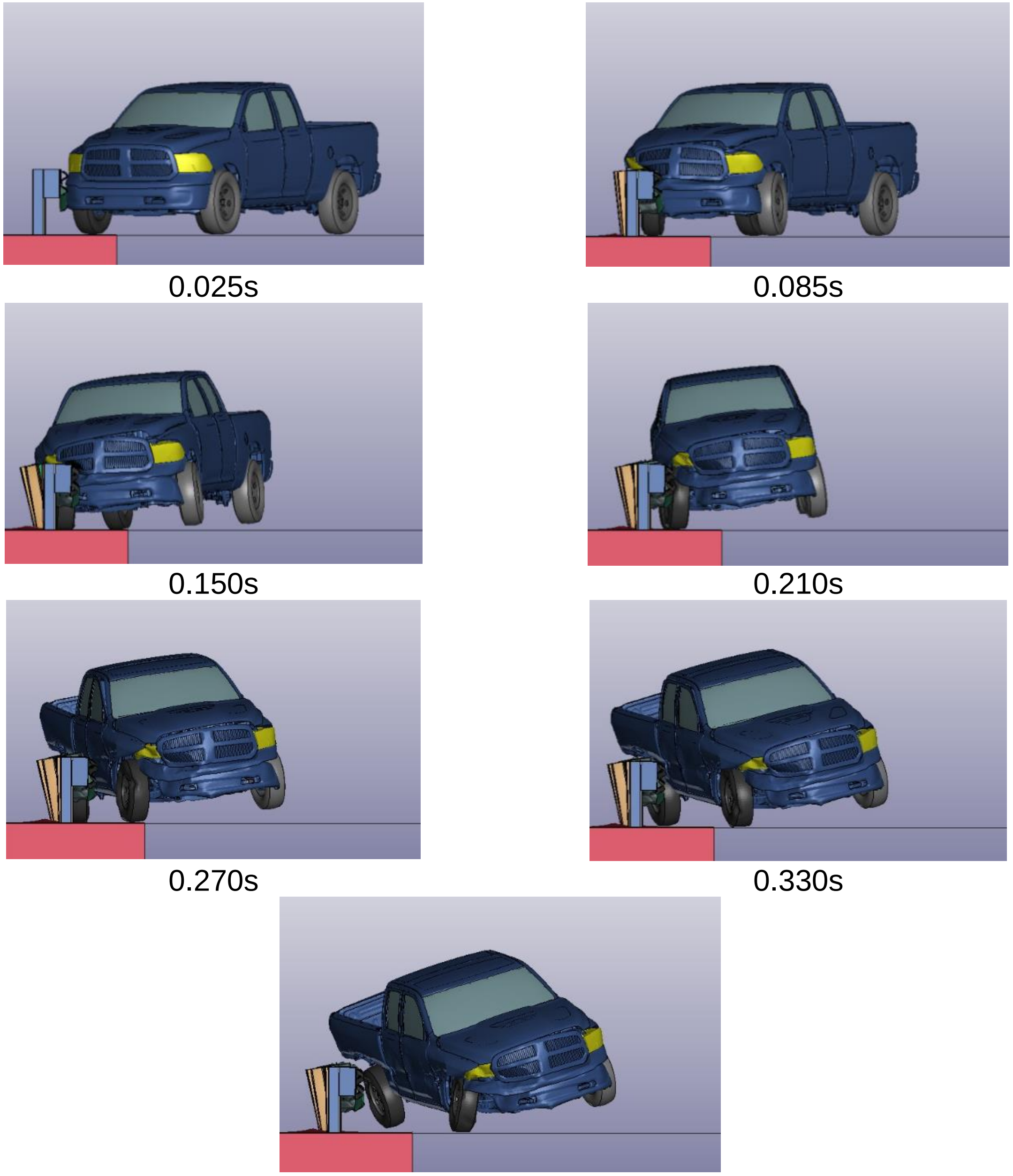
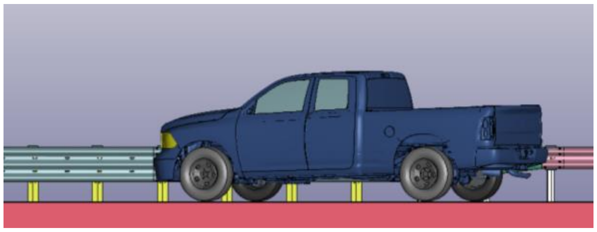


Figure 2.3. *MASH* Test 3-11 Simulation of Half-Post Spacing Thrie-Beam System – Downstream View



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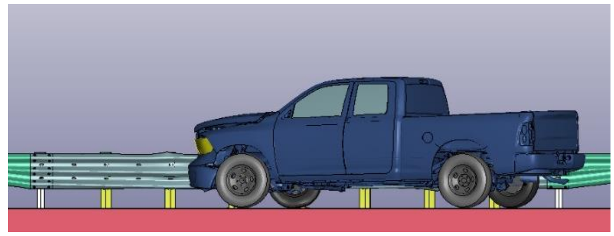

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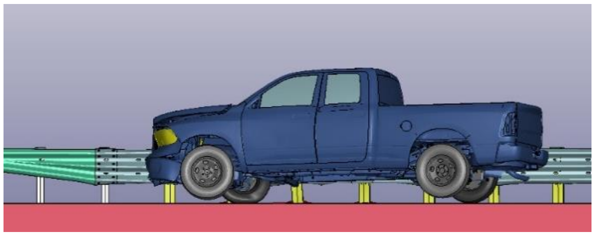

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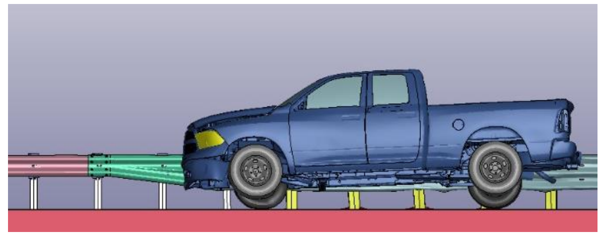

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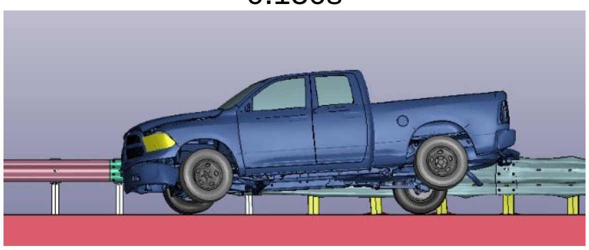

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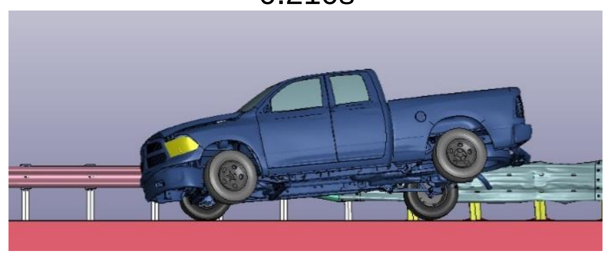

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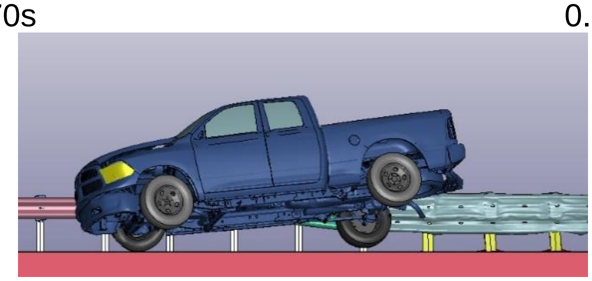

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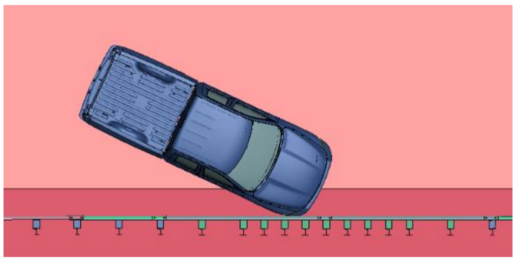
Figure 2.4. *MASH* Test 3-11 Simulation of Half-Post Spacing Thrie-Beam System – Rear View of MASH Test 3-11

2.2.1.2. MASH Test 3-11 Simulation of Quarter-Post Spacing Thrie-Beam System

This simulation evaluated the crashworthiness of a quarter-post spacing thrie-beam system. This barrier incorporated two 12 ½-ft thrie-beam rail sections. Figure 2.5 through Figure 2.7 show the sequential frames of the simulated *MASH* test 3-11. The occupant impact velocity was calculated to be 9.1 m/s (maximum limit is 12.2 m/s). The ridedown acceleration was calculated to be 11.2 g's (preferred limit is 15.0 g's). This configuration passed *MASH* test 3-11 by successfully containing and redirecting the vehicle.



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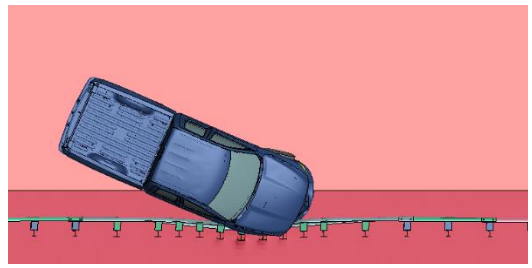

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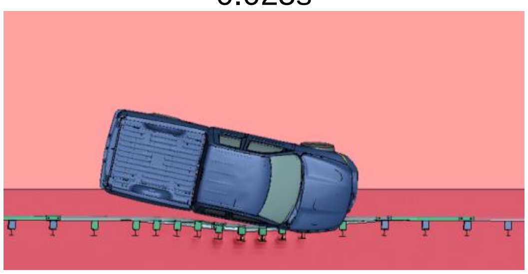

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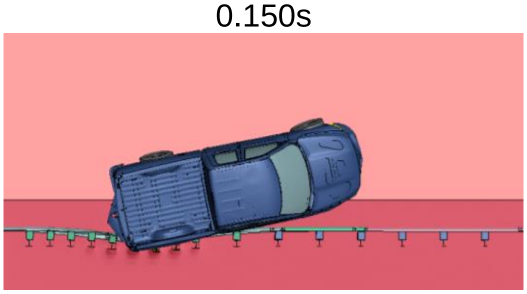

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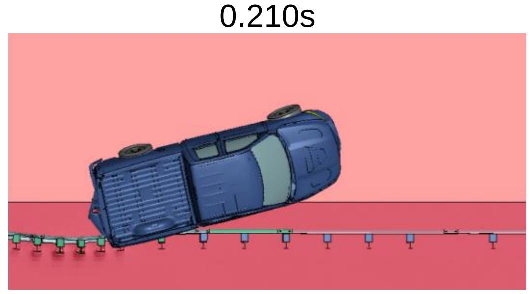

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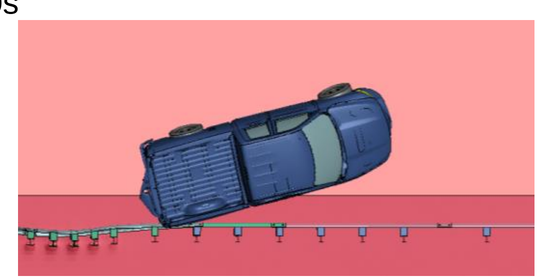

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Figure 2.5. *MASH* Test 3-11 Simulation of Quarter-Post Spacing Thrie-Beam System – Overhead View

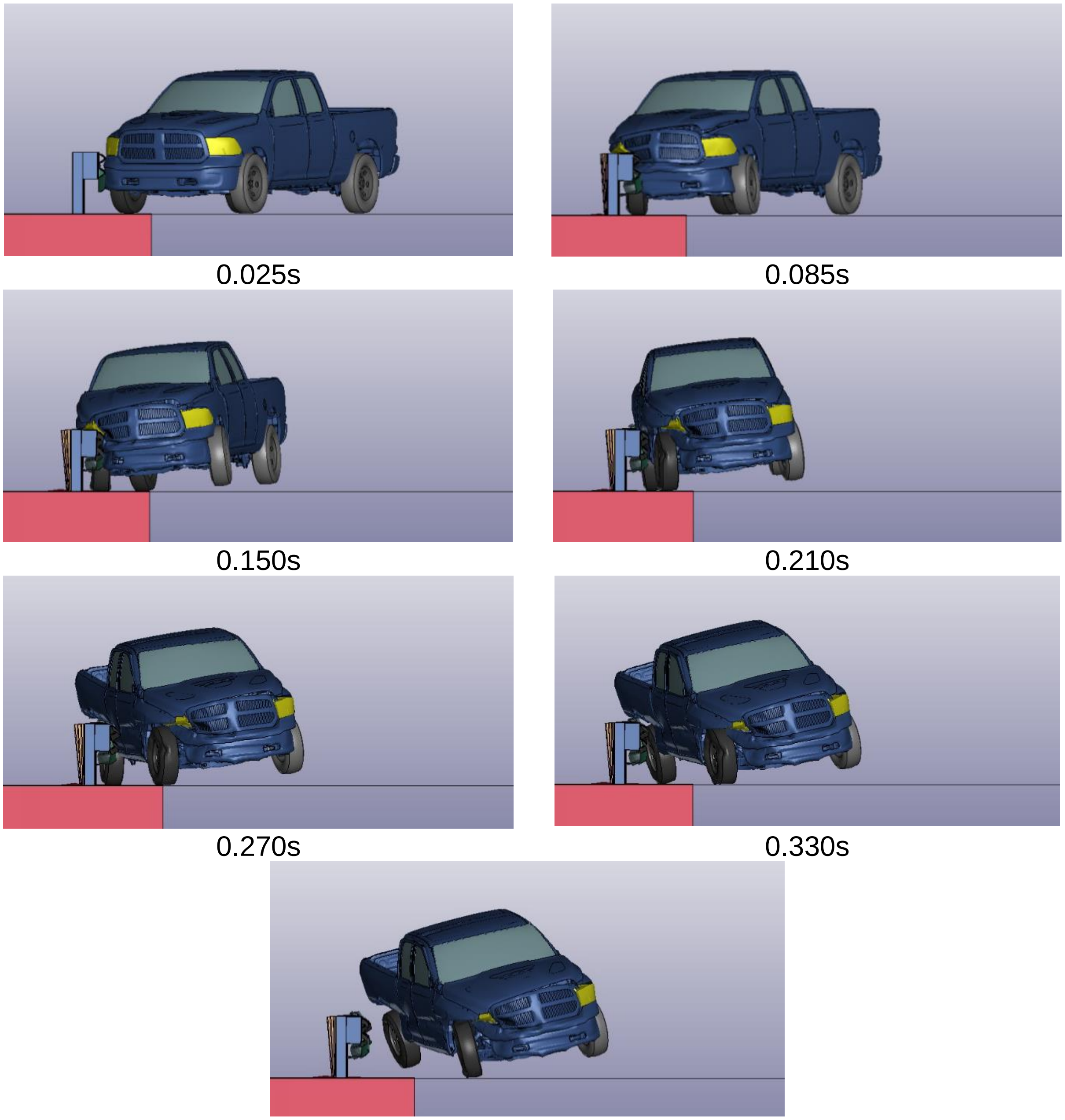
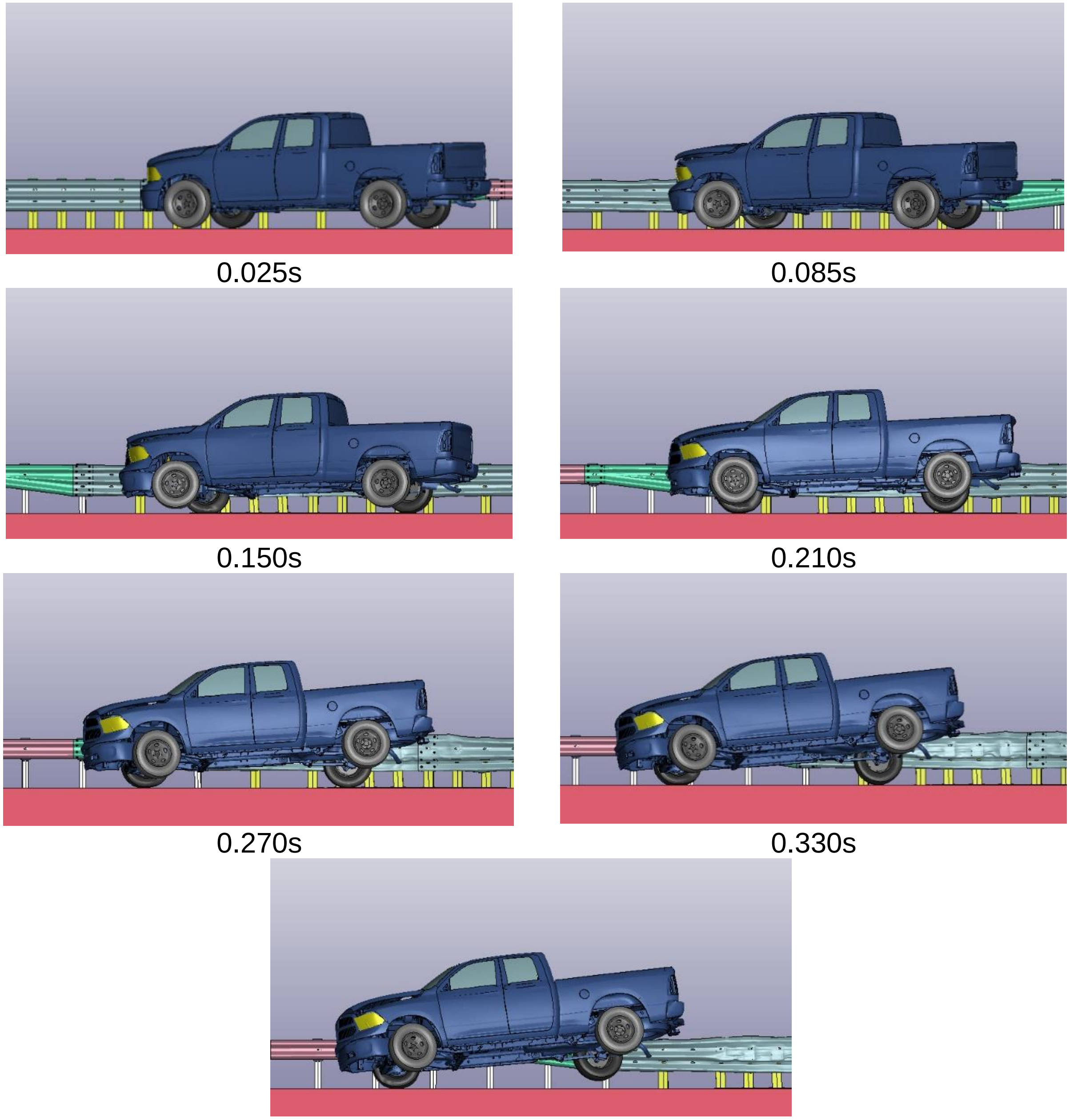


Figure 2.6. *MASH* Test 3-11 Simulation of Quarter-Post Spacing Thrie-Beam System – Downstream View



0.025s 0.085s

0.150s 0.210s

0.270s 0.330s

0.395s

Figure 2.7. *MASH* Test 3-11 Simulation of Quarter-Post Spacing Thrie-Beam System – Rear View

2.2.1.3. MASH Test 3-11 Simulation of Quarter-Post Spacing Thrie-Beam System with Additional Thrie-Beam Rails

This simulation evaluated the crashworthiness of a quarter-post spacing thrie-beam system. This barrier incorporated three 12 ½-ft thrie-beam rail sections with the objective of minimizing the influence of other conditions beyond the thrie-beam design under evaluation. Figure 2.8 through Figure 2.10 show the sequential frames of the simulated *MASH* test 3-11. The occupant impact velocity was calculated to be 8.8 m/s (preferred limit is 9.1 m/s). The ridedown acceleration was calculated to be 12.5 g's (preferred limit is 15.0 g's). This configuration passed *MASH* test 3-11 by successfully containing and redirecting the vehicle.

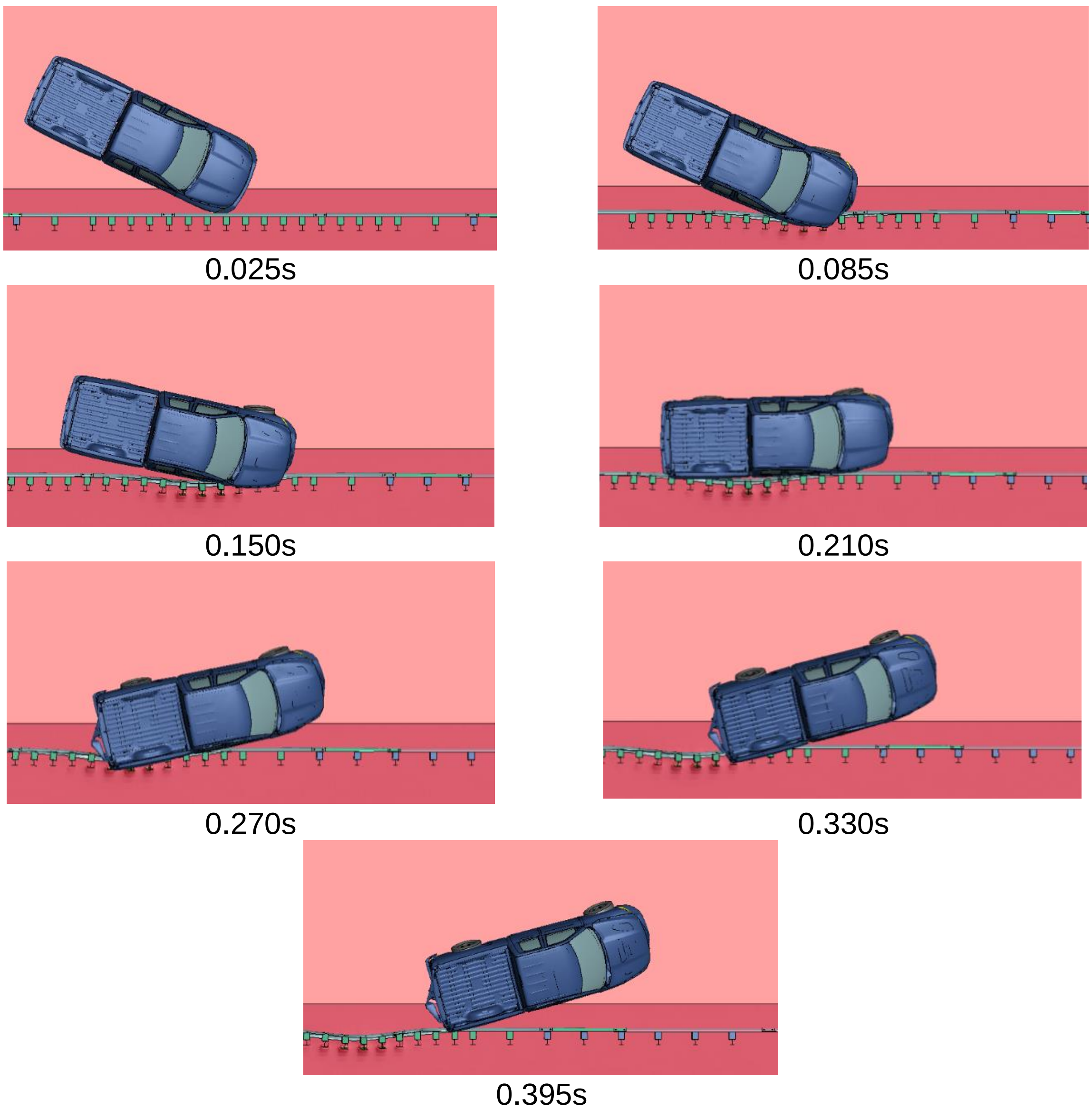


Figure 2.8. *MASH* Test 3-11 Simulation of Quarter-Post Spacing Thrie-Beam System with Additional Thrie-Beam Rails – Overhead View

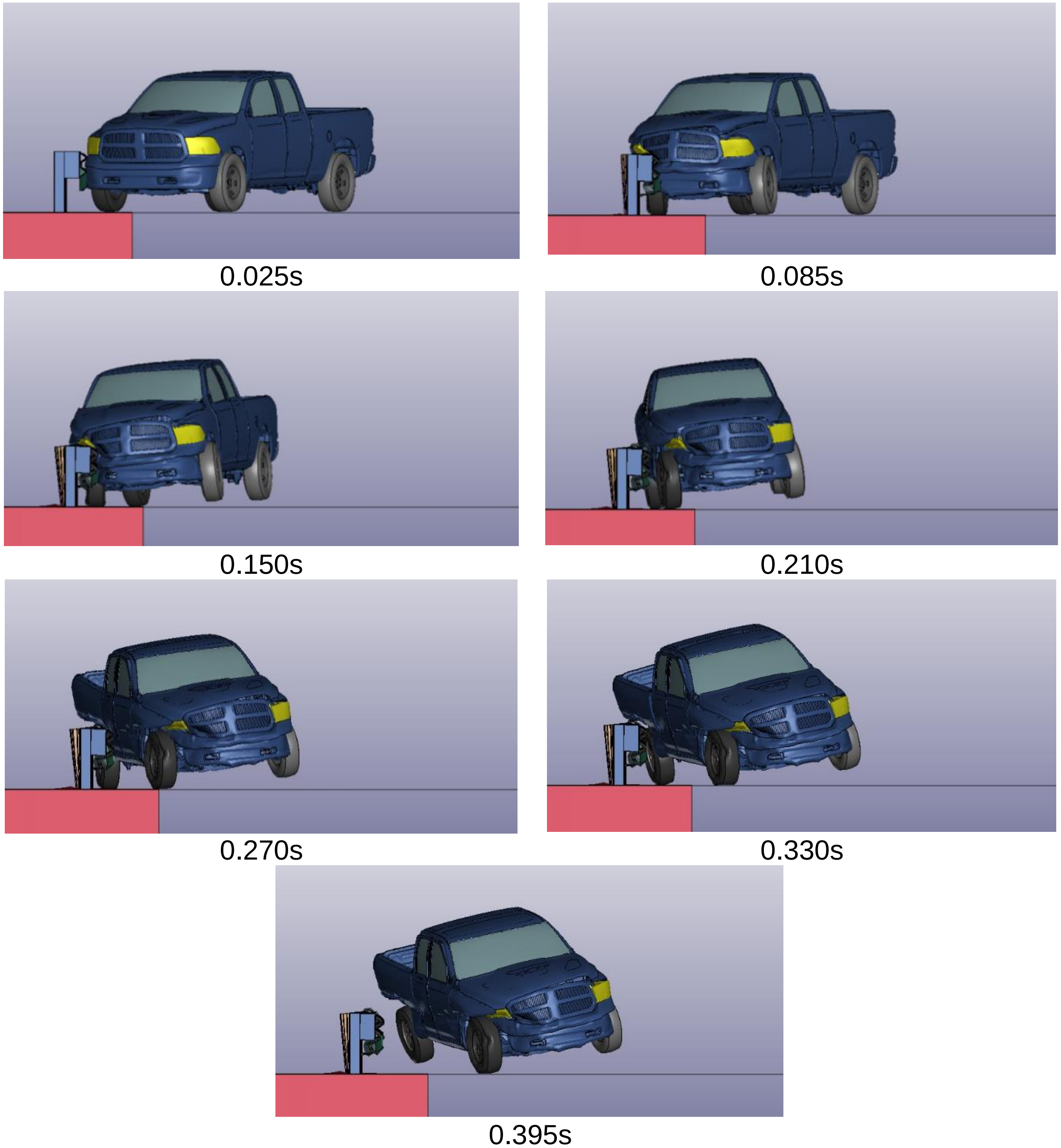
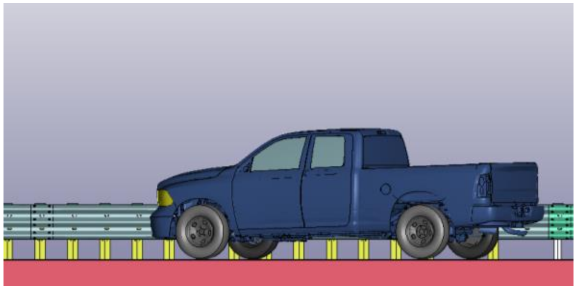


Figure 2.9. *MASH* Test 3-11 Simulation of Quarter-Post Spacing Thrie-Beam System with Additional Thrie-Beam Rails – Downstream View



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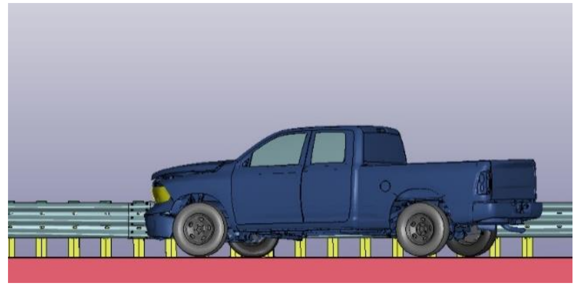

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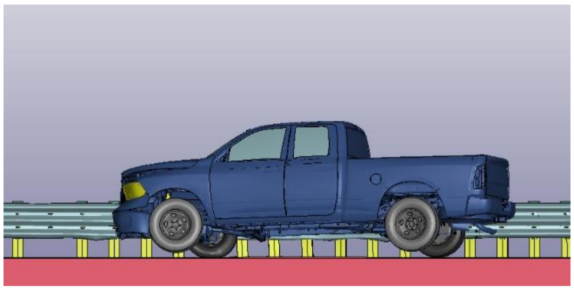

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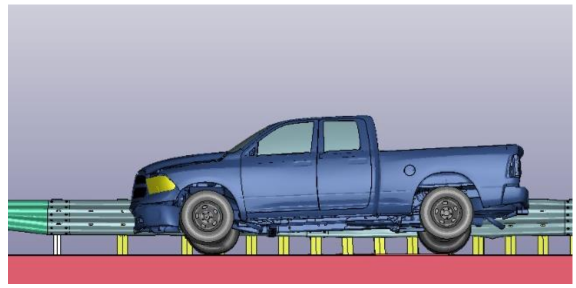

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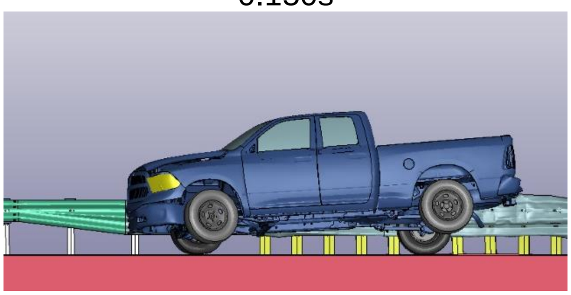

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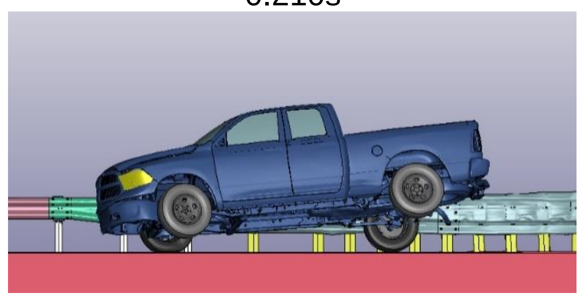

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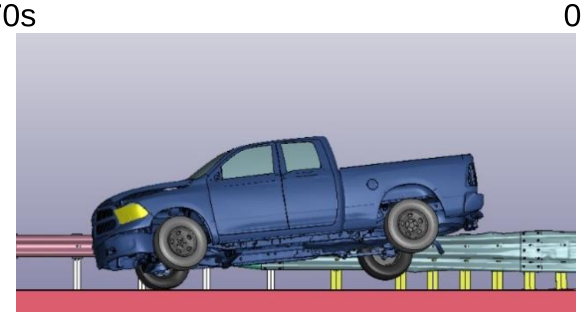


0.395s

Figure 2.10. *MASH* Test 3-11 Simulation of Quarter-Post Spacing Thrie-Beam System with Additional Thrie-Beam Rails – Rear View

2.2.1.4. *MASH Test 3-11 Simulation of Half-Post Spacing Thrie-Beam System with Additional Thrie-Beam Rails*

This simulation evaluated the crashworthiness of a half-post spacing thrie-beam system. This barrier incorporated three 12 ½-ft thrie-beam rail sections. Figure 2.11 through Figure 2.13 show the sequential frames of the simulated *MASH* test 3-11. The occupant impact velocity was calculated to be 7.8 m/s (preferred limit is 9.1 m/s). The ridedown acceleration was calculated to be 11.5 g's (preferred limit is 15.0 g's). This configuration passed *MASH* test 3-11 by successfully containing and redirecting the vehicle.

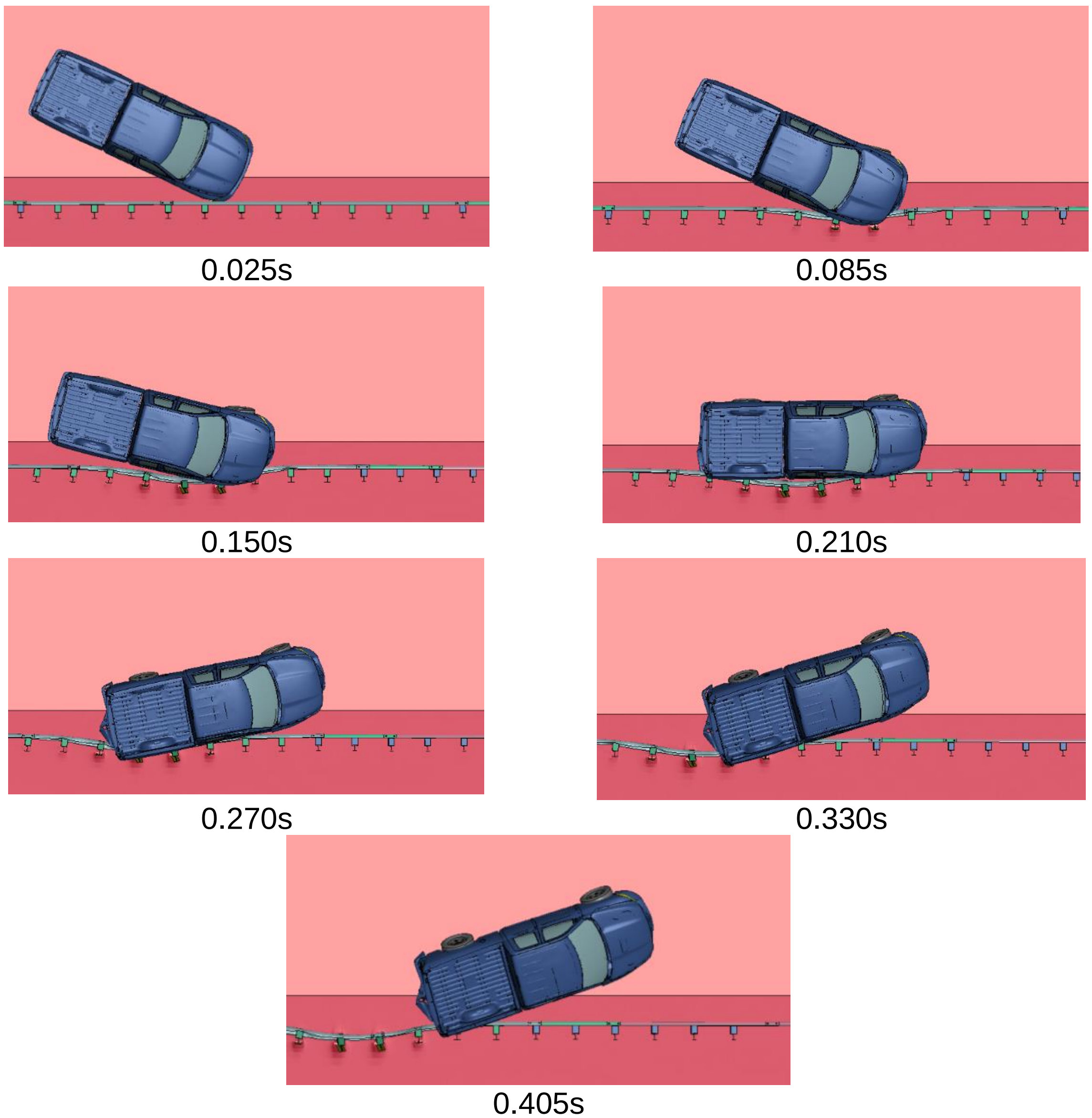


Figure 2.11. *MASH* Test 3-11 Simulation of Half-Post Spacing Thrie-Beam System with Additional Thrie-Beam Rails – Overhead View

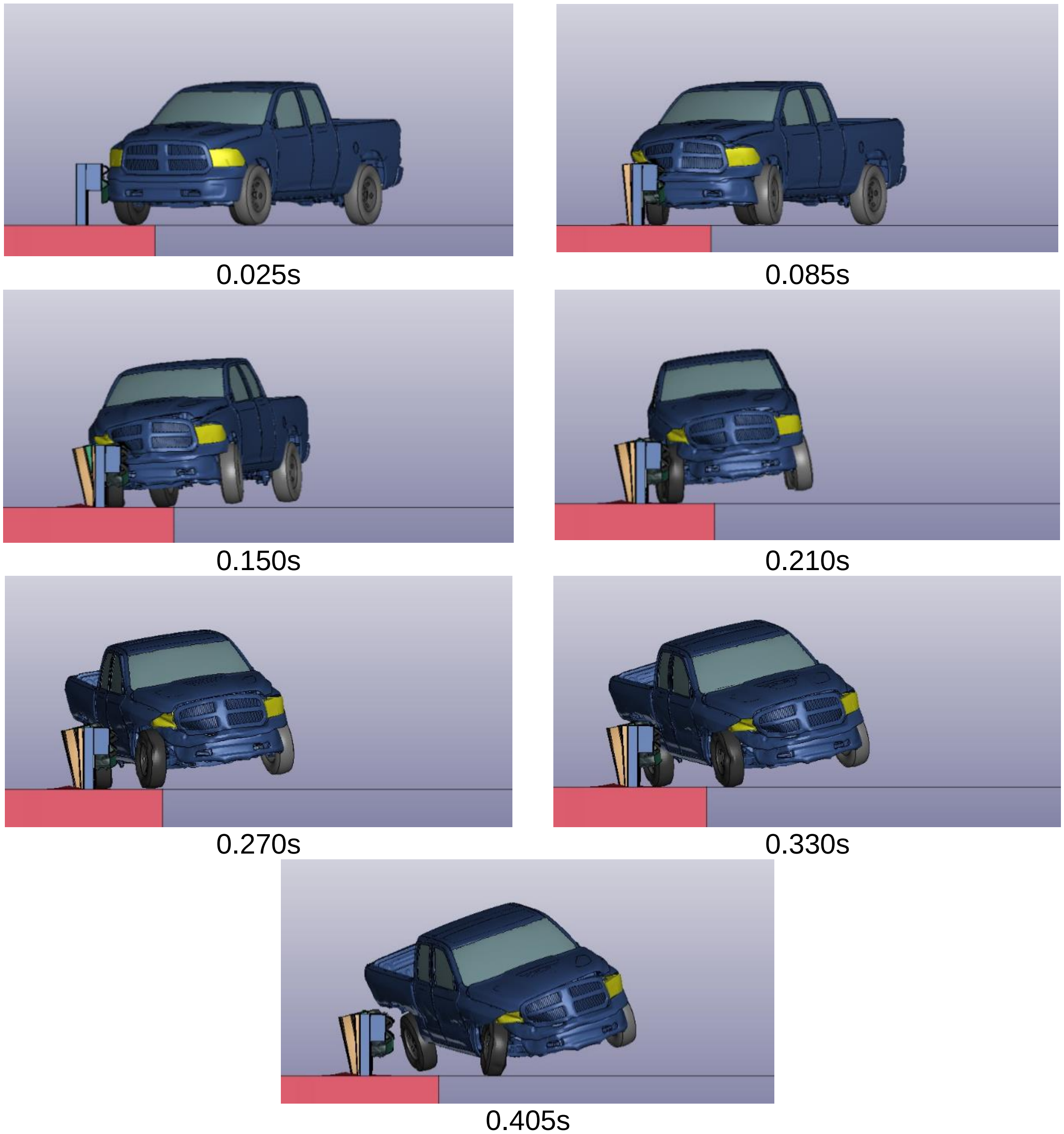
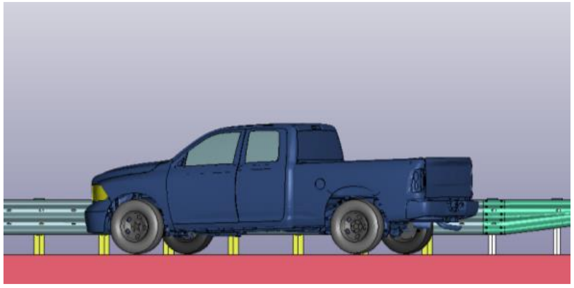


Figure 2.12. *MASH* Test 3-11 Simulation of Half-Post Spacing Thrie-Beam System with Additional Thrie-Beam Rails – Downstream View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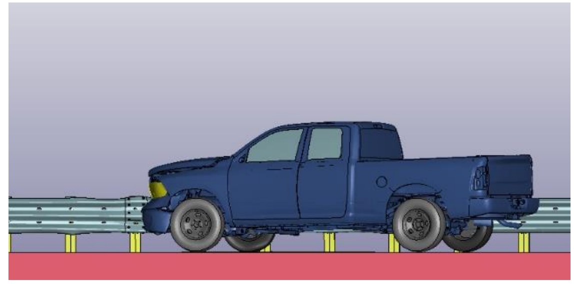
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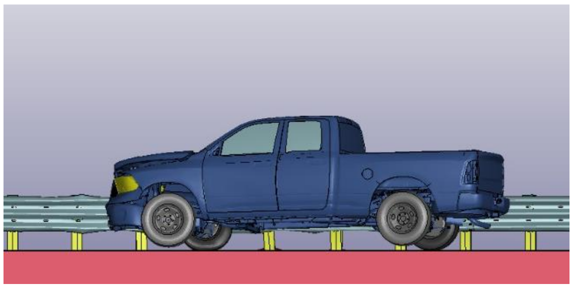
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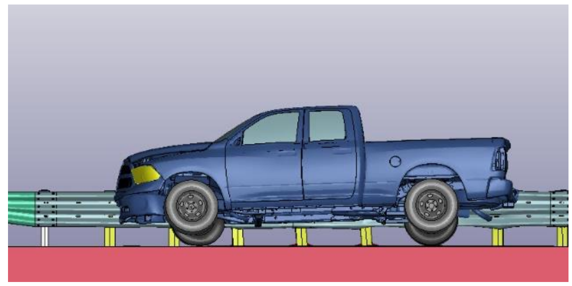
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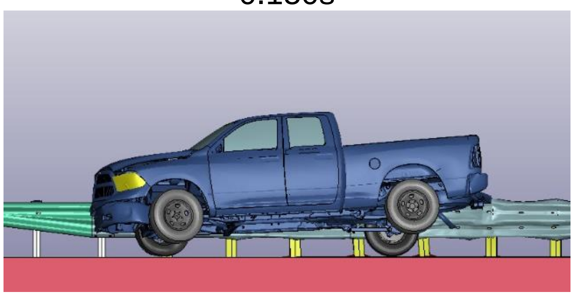
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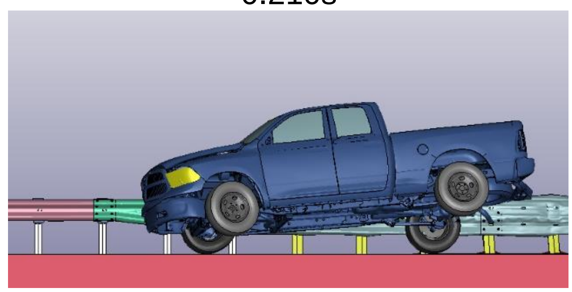
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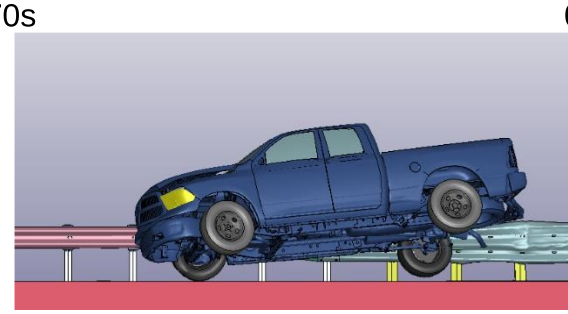
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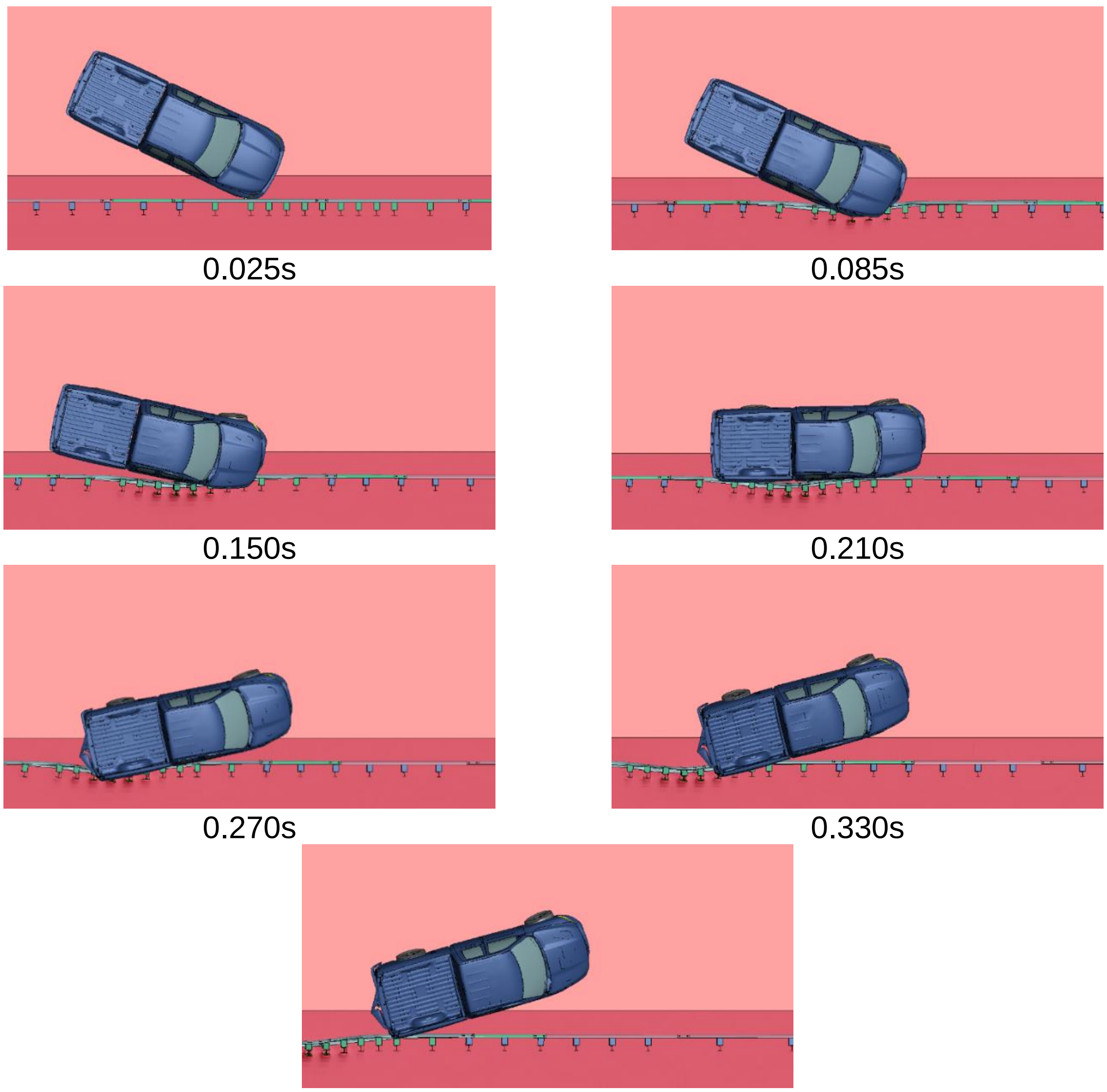
Figure 2.13. *MASH* Test 3-11 Simulation of Half-Post Spacing Thrie-Beam System with Additional Thrie-Beam Rails – Rear View

2.2.1.5. MASH Test 3-11 Simulation of Quarter-Post Spacing Thrie-Beam System Varied Impact Point 4 feet Upstream.

Figure 2.14 through Figure 2.16 show the sequential frames of *MASH* test 3-11 on the quarter-post spacing with a varied impact point of 4 feet upstream. The impact location was targeted at the first quarter spacing post on the upstream end of the system. The variation in impact point was executed as a start to the sensitivity analysis for impact points. The occupant impact velocity was calculated to be 8.7 m/s (preferred limit is 9.1 m/s). The ridedown acceleration was calculated to be 14.4 g's (preferred limit is 15.0 g's). This configuration passed *MASH* test 3-11 by successfully containing and redirecting the vehicle



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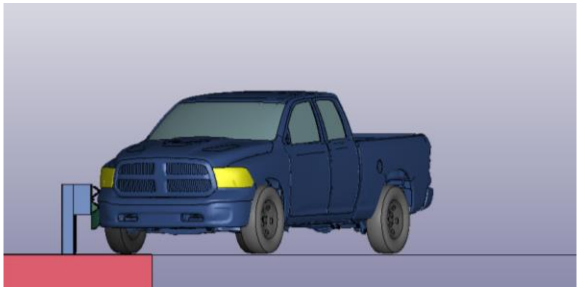
0.150s 0.210s

0.270s 0.330s

0.395s

Figure 2.14. *MASH* Test 3-11 Simulation of Quarter-Post Spacing Thrie-Beam System with Varied Impact Point 4 feet Upstream – Overhead View



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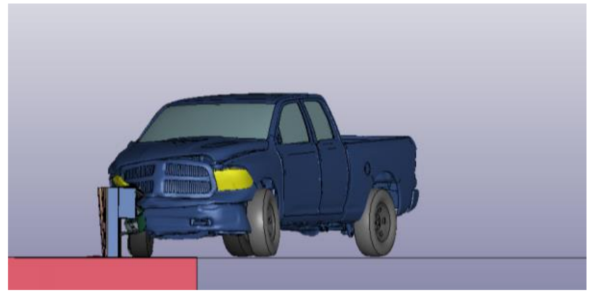

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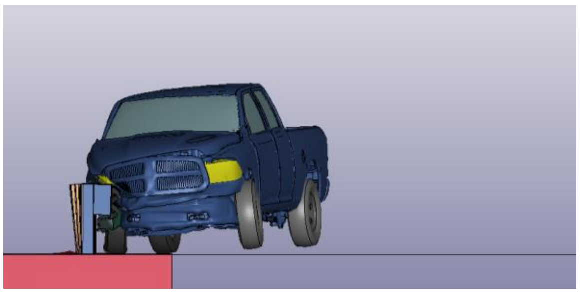

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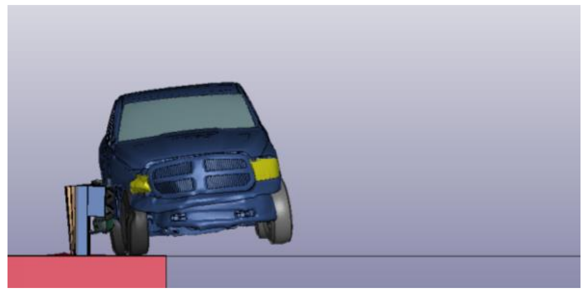

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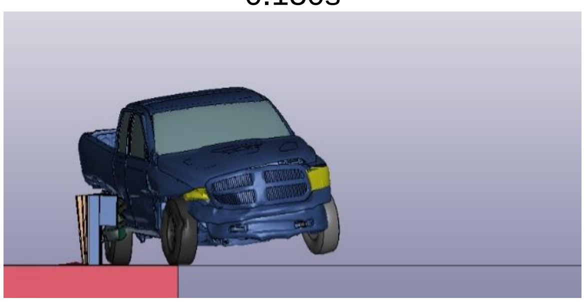

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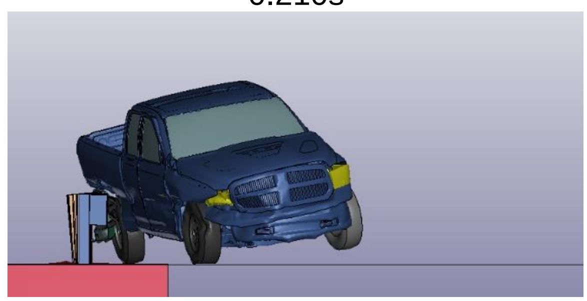

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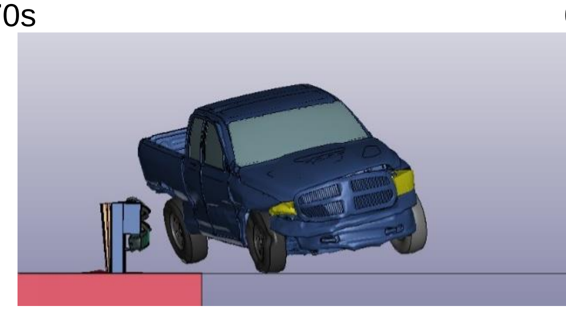

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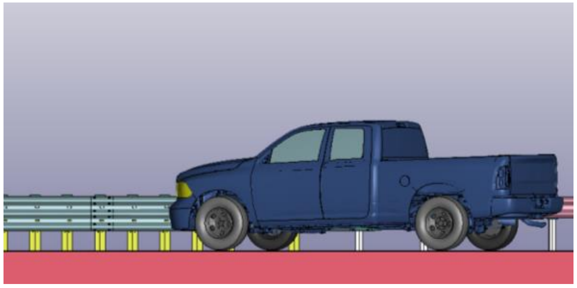
Figure 2.15. *MASH* Test 3-11 Simulation of Quarter-Post Spacing Thrie-Beam System with Varied Impact Pont 4 feet Upstream – Downstream View



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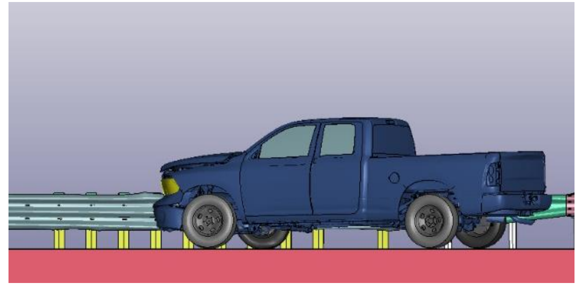

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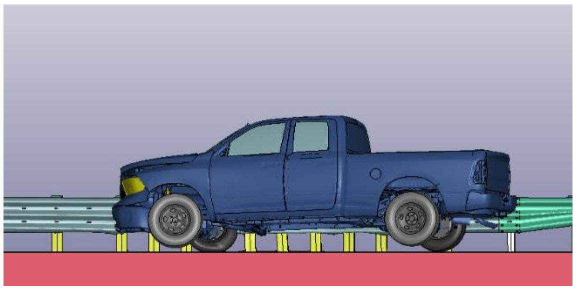

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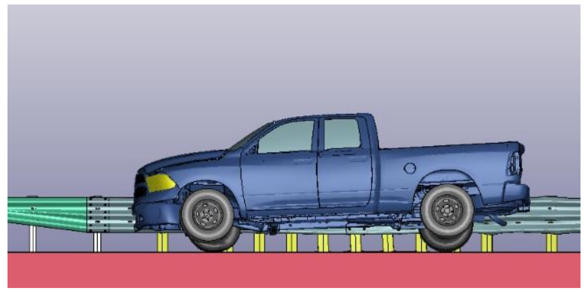

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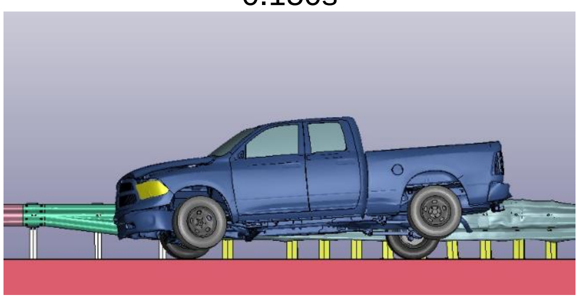

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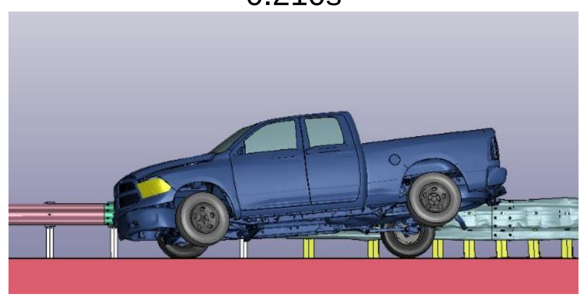

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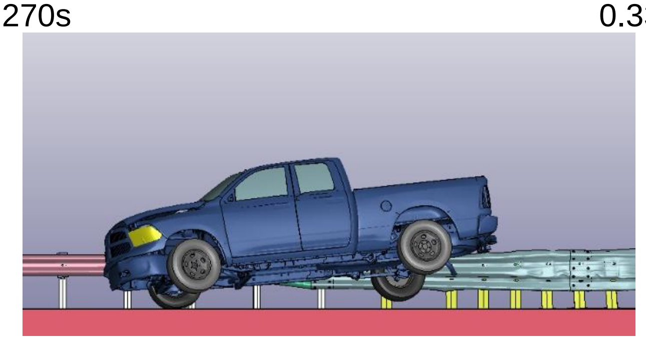


0.395s

Figure 2.16. *MASH* Test 3-11 Simulation of Quarter-Post Spacing Thrie-Beam System with Varied Impact Pont 4 feet Upstream – Rear View

2.2.2. Models with Fixed Objects

The following simulations evaluated the crashworthiness of thrie-beam systems with a rigidized fixed object behind the barrier. The simulations incorporated the rigidized fixed object to evaluate the snagging potential of the test vehicles on the fixed object itself during an impact with the barrier system. The fixed object was modeled as a 19.5-inch by 19.5-inch structure with rigidized material properties. The square shape with discrete corners represented a critical shape for evaluating impacting vehicle snagging potential. Iterations of this configuration were simulated with a variety of offset distances between the field-side face of the thrie-beam and the traffic-side face of the fixed object.

2.2.2.1. MASH Test 3-11 Simulation of Half-Post Spacing Thrie-Beam System with Fixed Object – 8 inch Offset.

Figure 2.17 through Figure 2.19 show the sequential frames of *MASH* test 3-11 with the fixed object offset 8 inches and located between posts. The occupant impact velocity was calculated to be 9.3 m/s (maximum limit is 12.2 m/s). The ridedown acceleration was calculated to be 10.6 g’s (preferred limit is 15.0 g’s). This configuration passed *MASH* test 3-11 by successfully containing and redirecting the vehicle.

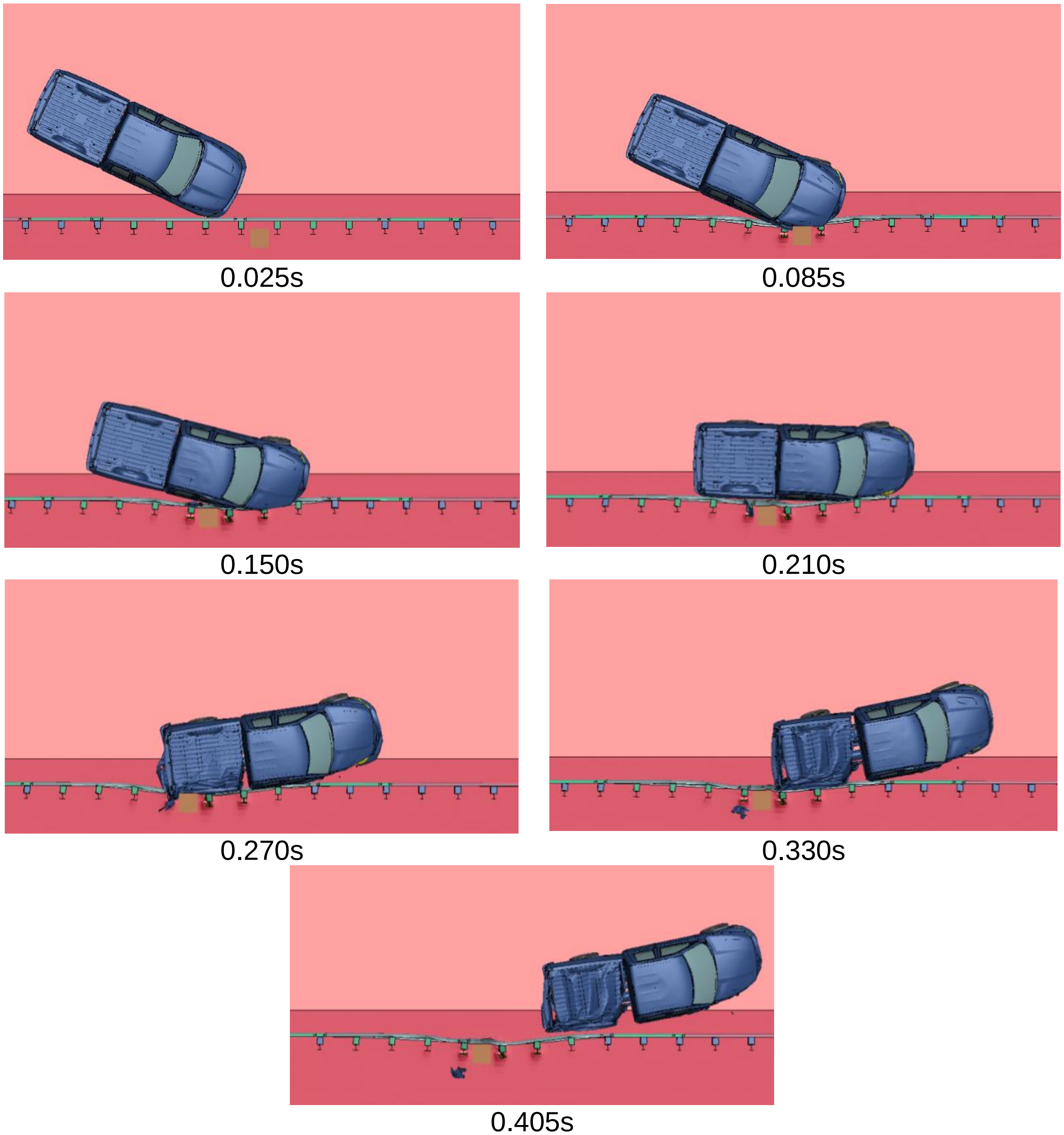
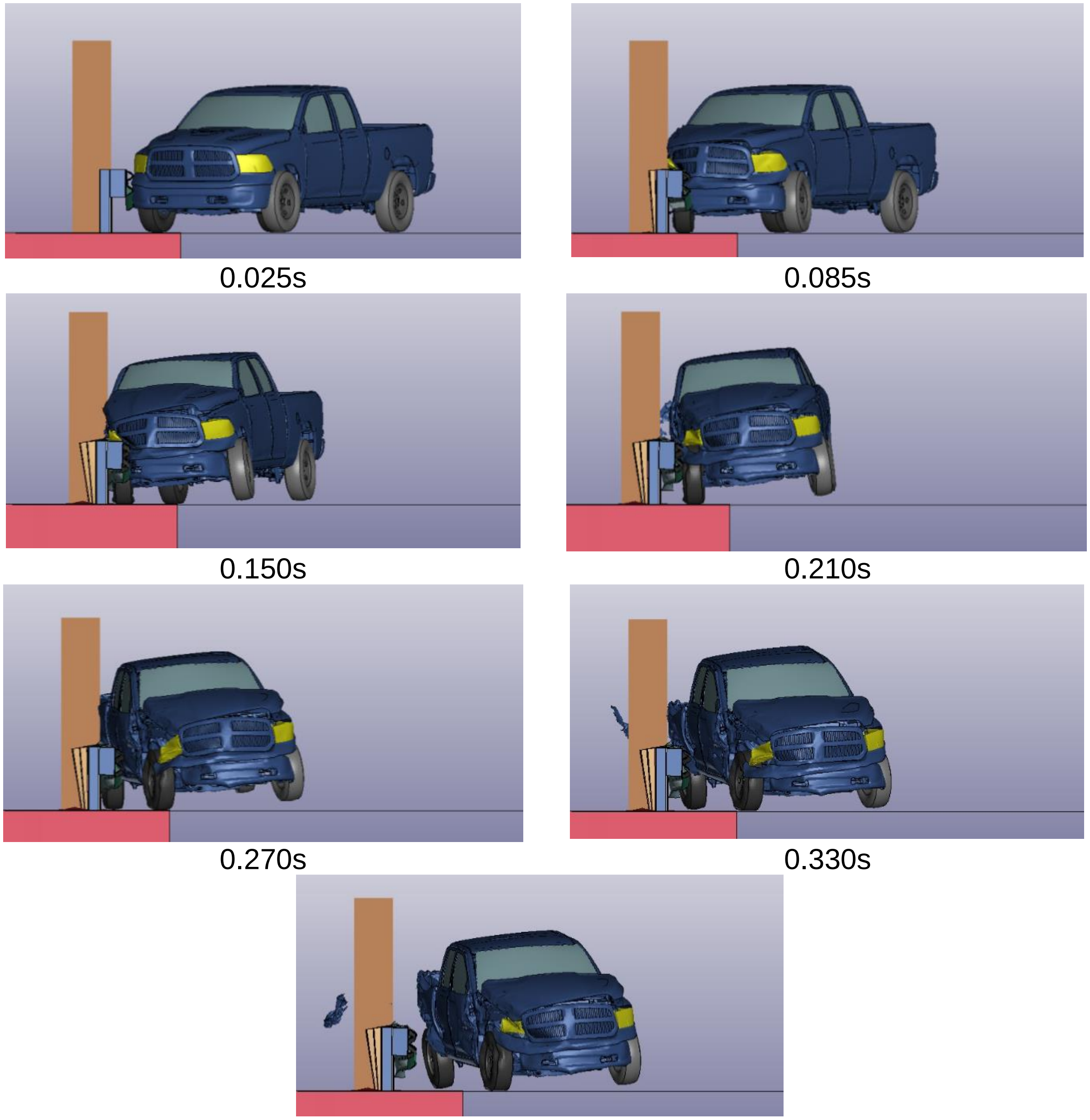


Figure 2.17. *MASH* Test 3-11 Simulation of Half-Post Spacing Thrie-Beam System with Fixed Object 8 inch Offset – Overhead View



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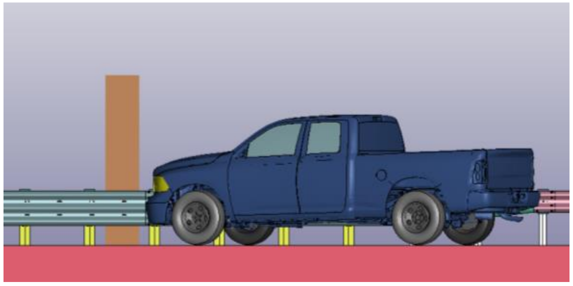
0.150s 0.210s

0.270s 0.330s

0.405s

Figure 2.18. *MASH* Test 3-11 Simulation of Half-Post Spacing Thrie-Beam System with Fixed Object 8 inch Offset – Downstream View



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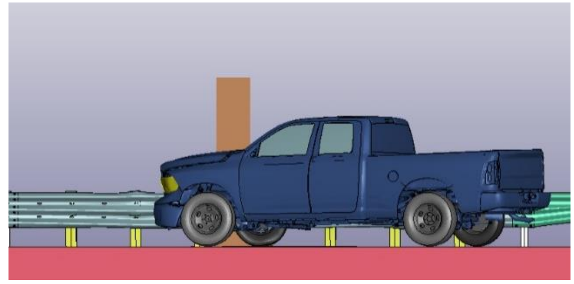

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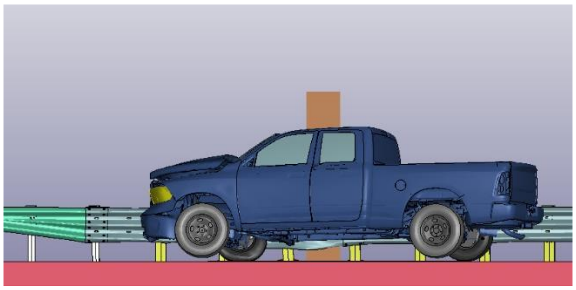

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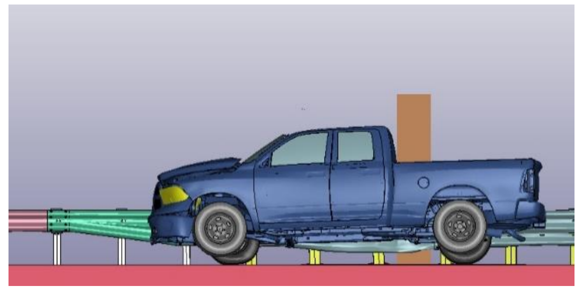

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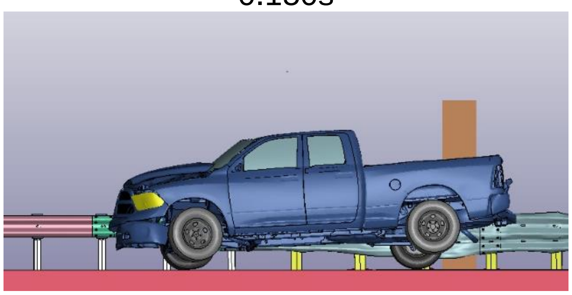

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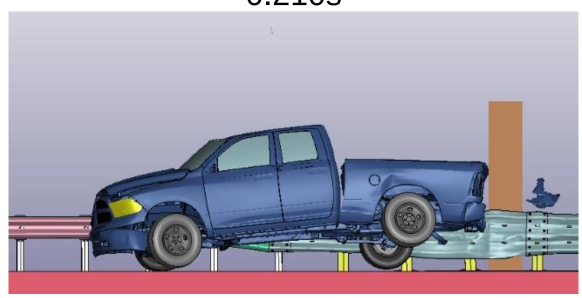
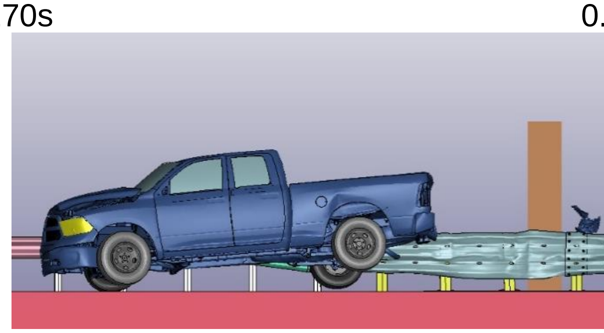


0.330s

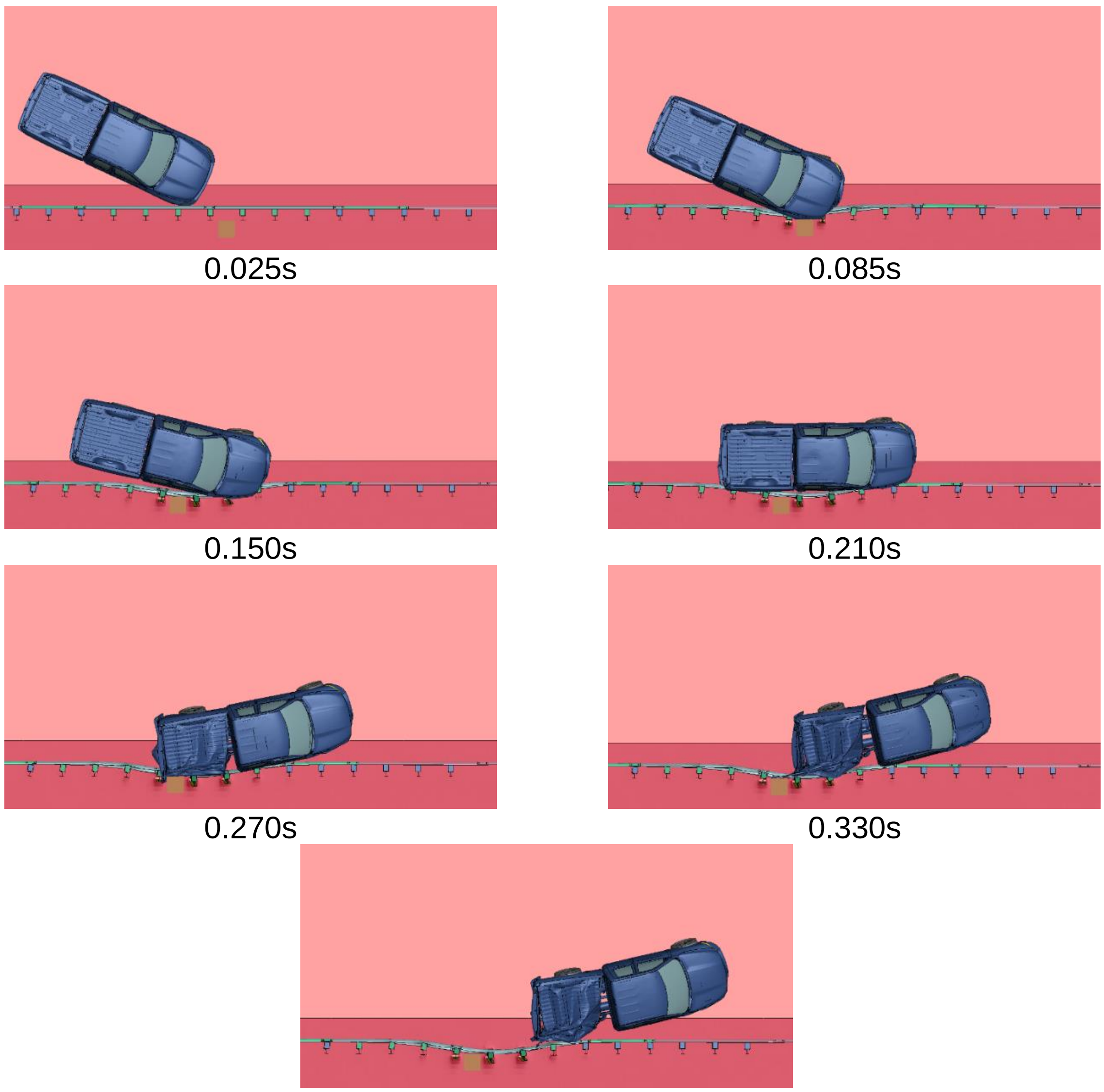


0.405s

Figure 2.19. ***MASH*** **Test 3-11 Simulation of Half-Post Spacing Thrie-Beam System with Fixed Object 8 inch Offset – Rear View**

2.2.2.2. MASH Test 3-11 Simulation of Half-Post Spacing Thrie-Beam System with Fixed Object – 14 inch Offset

Figure 2.20 through Figure 2.22 show the sequential frames of *MASH* test 3-11 with the fixed object offset 14 inches and located between posts. The occupant impact velocity was calculated to be 6.9 m/s (preferred limit is 9.1 m/s). The ridedown acceleration was calculated to be 14.4 g's (preferred limit is 15.0 g's). This configuration passed *MASH* test 3-11 by successfully containing and redirecting the vehicle. However, the simulation showed significant and possibly unrealistic snagging of the pickup truck bed on the fixed object. Therefore, the research team modified the models to mitigate this behavior in the subsequent simulation.



0.025s 0.085s

0.150s 0.210s

0.270s 0.330s

0.405s

Figure 2.20. *MASH* Test 3-11 Simulation of Half-Post Spacing Thrie-Beam System with Fixed Object 14 inch Offset – Overhead View

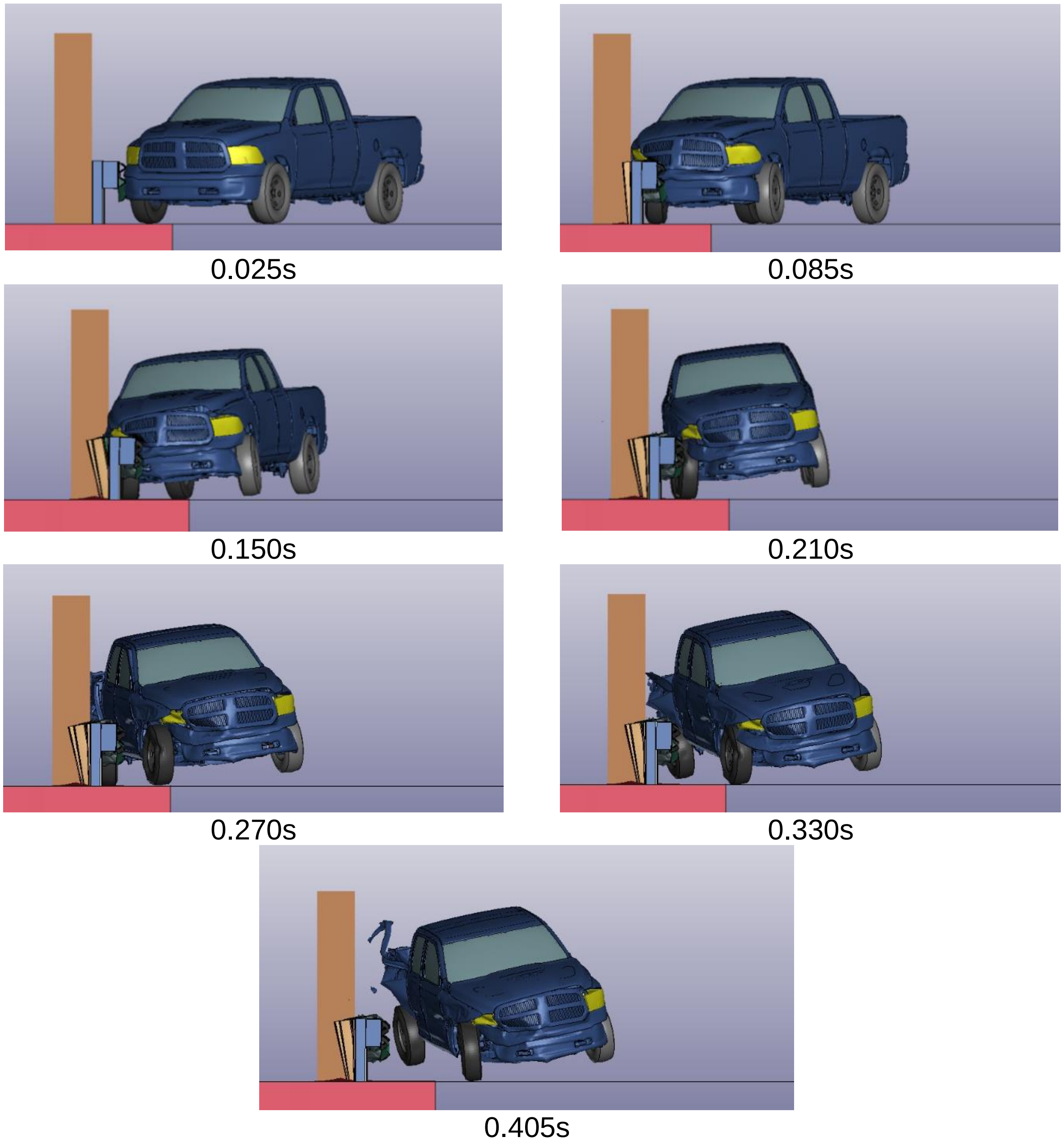


Figure 2.21. ***MASH*** **Test 3-11 Simulation of Half-Post Spacing Thrie-Beam System with Fixed Object 14 inch Offset – Downstream View**

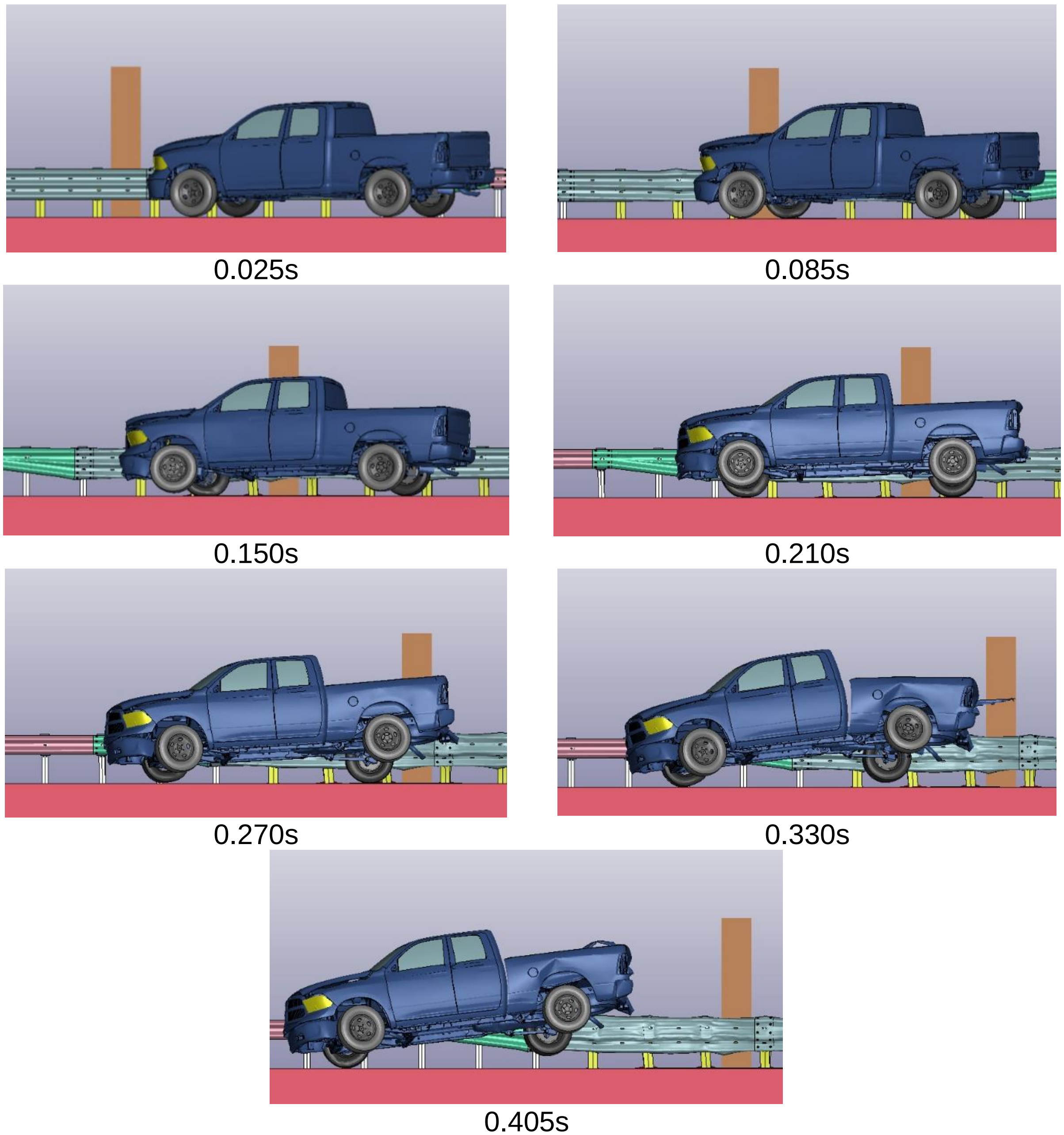


Figure 2.22. *MASH* Test 3-11 Simulation of Half-Post Spacing Thrie-Beam System with Fixed Object 14 inch Offset – Rear View

2.2.2.3. MASH Test 3-11 Simulation of Quarter-Post Spacing Thrie-Beam System with Fixed Object 8 inch Offset & Erosion Components

Figure 2.23 through Figure 2.25 show the sequential frames of *MASH* test 3-11 with the fixed object offset 8 inches and located between posts. The previous simulations showed significant and possibly unrealistic snagging of the pickup truck bed on the fixed object. Therefore, the research team added an erosion card to components of the pickup truck bed. The occupant impact velocity was calculated to be 7.4 m/s (preferred limit is 9.1 m/s). The ridedown acceleration was calculated to be 10.1 g’s (preferred limit is 15.0 g’s). This configuration passed *MASH* test 3-11 by successfully containing and redirecting the vehicle.

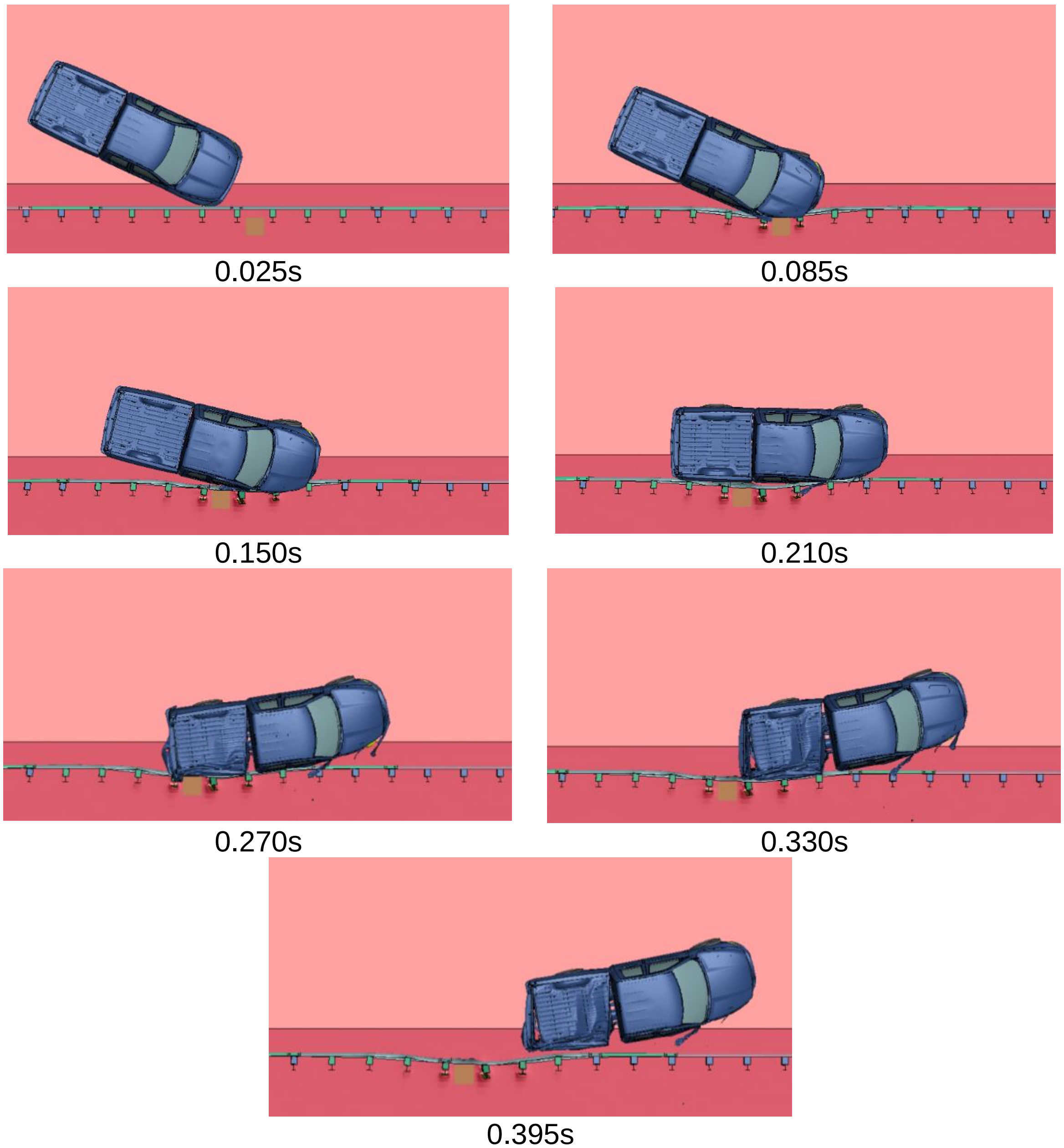


Figure 2.23. *MASH* Test 3-11 Simulation of Quarter-Post Spacing Thrie-Beam System with Fixed Object 8 inch Offset & Erosion Components – Overhead View

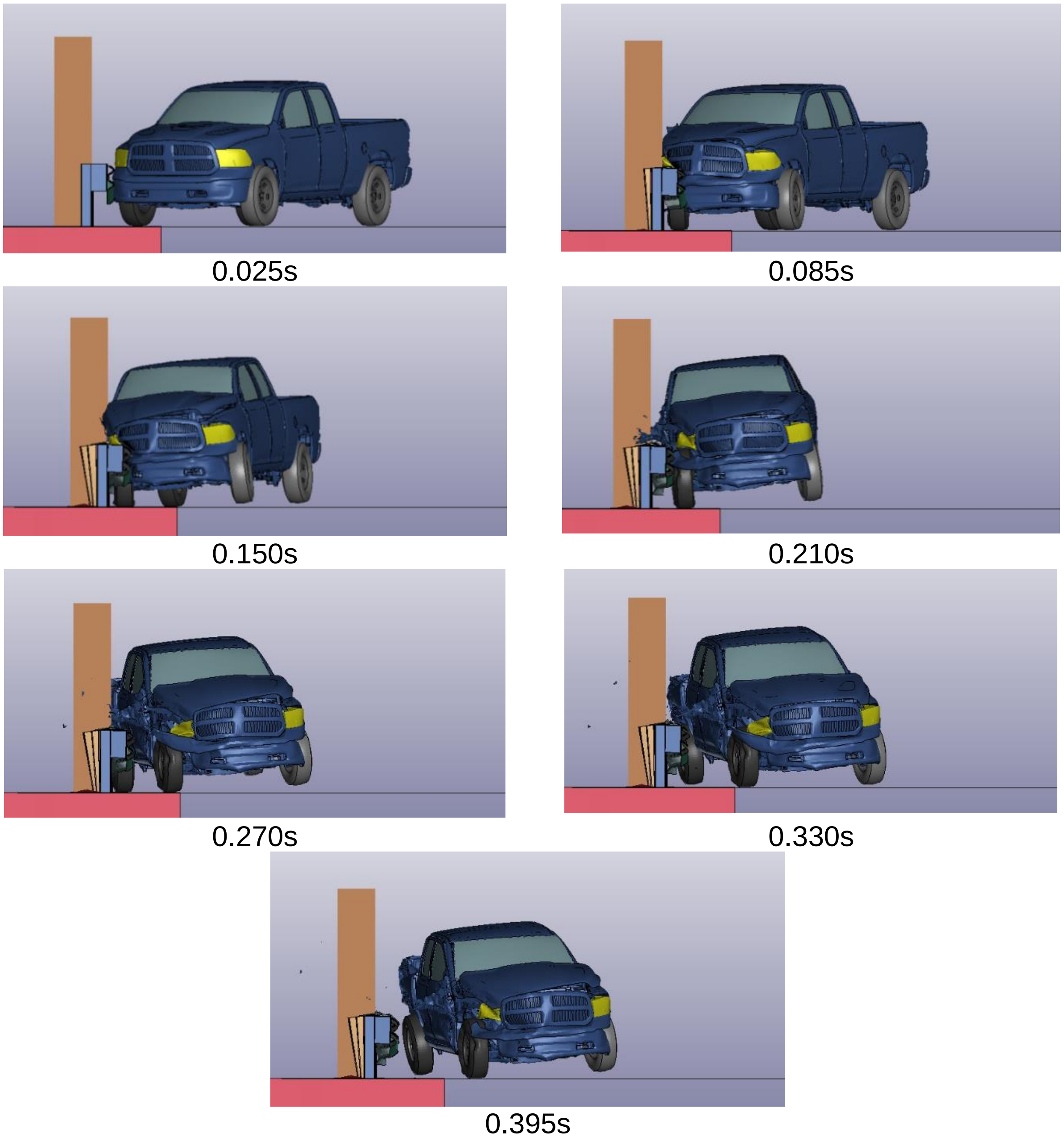
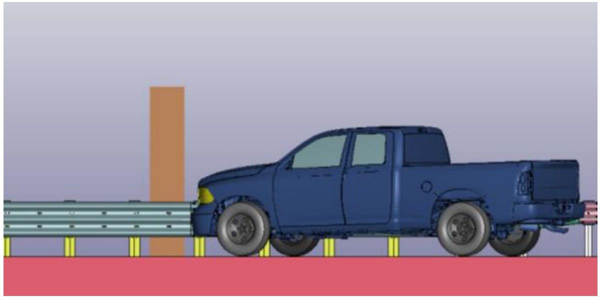


Figure 2.24. *MASH* Test 3-11 Simulation of Quarter-Post Spacing Thrie-Beam System with Fixed Object 8 inch Offset & Erosion Components – Downstream View



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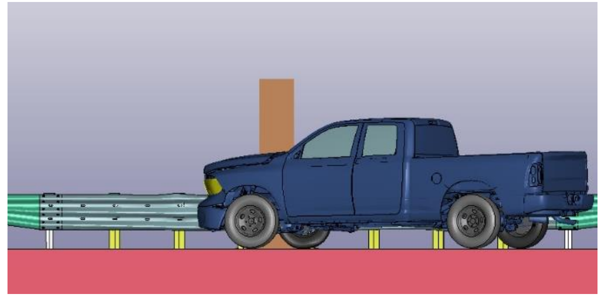

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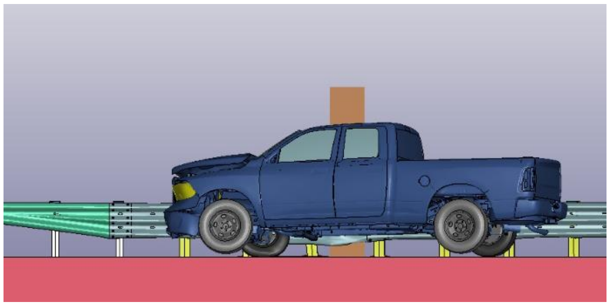

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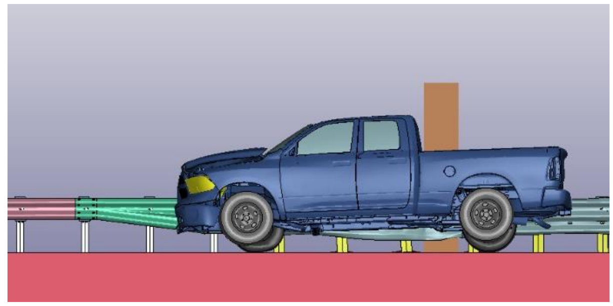
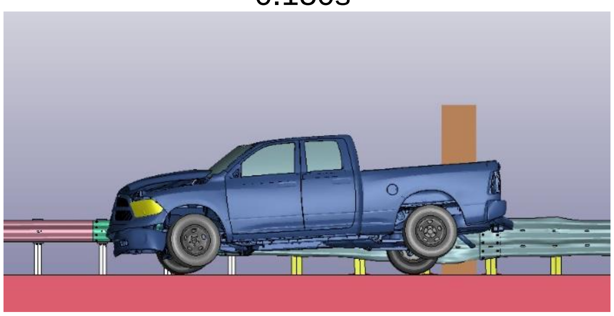


0.210s



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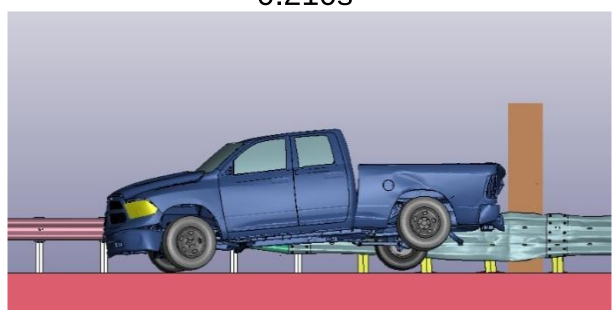

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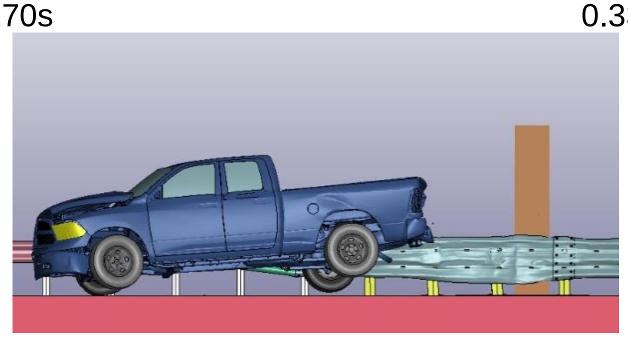


0.395s

Figure 2.25. *MASH* Test 3-11 Simulation of Quarter-Post Spacing Thrie-Beam System with Fixed Object 8 inch Offset & Erosion Components – Rear View

2.2.2.4. MASH Test 3-11 Simulation of Half-Post Spacing Thrie-Beam System with Fixed Object 3 inch Offset from Behind Posts

Figure 2.26 through Figure 2.28 show the sequential frames of *MASH* test 3-11 with the fixed object located 3 inches behind the posts. The occupant impact velocity was calculated to be 7.6 m/s (preferred limit is 9.1 m/s). The ridedown acceleration was calculated to be 12.7 g's (preferred limit is 15.0 g's). This configuration passed *MASH* test 3-11 by successfully containing and redirecting the vehicle.

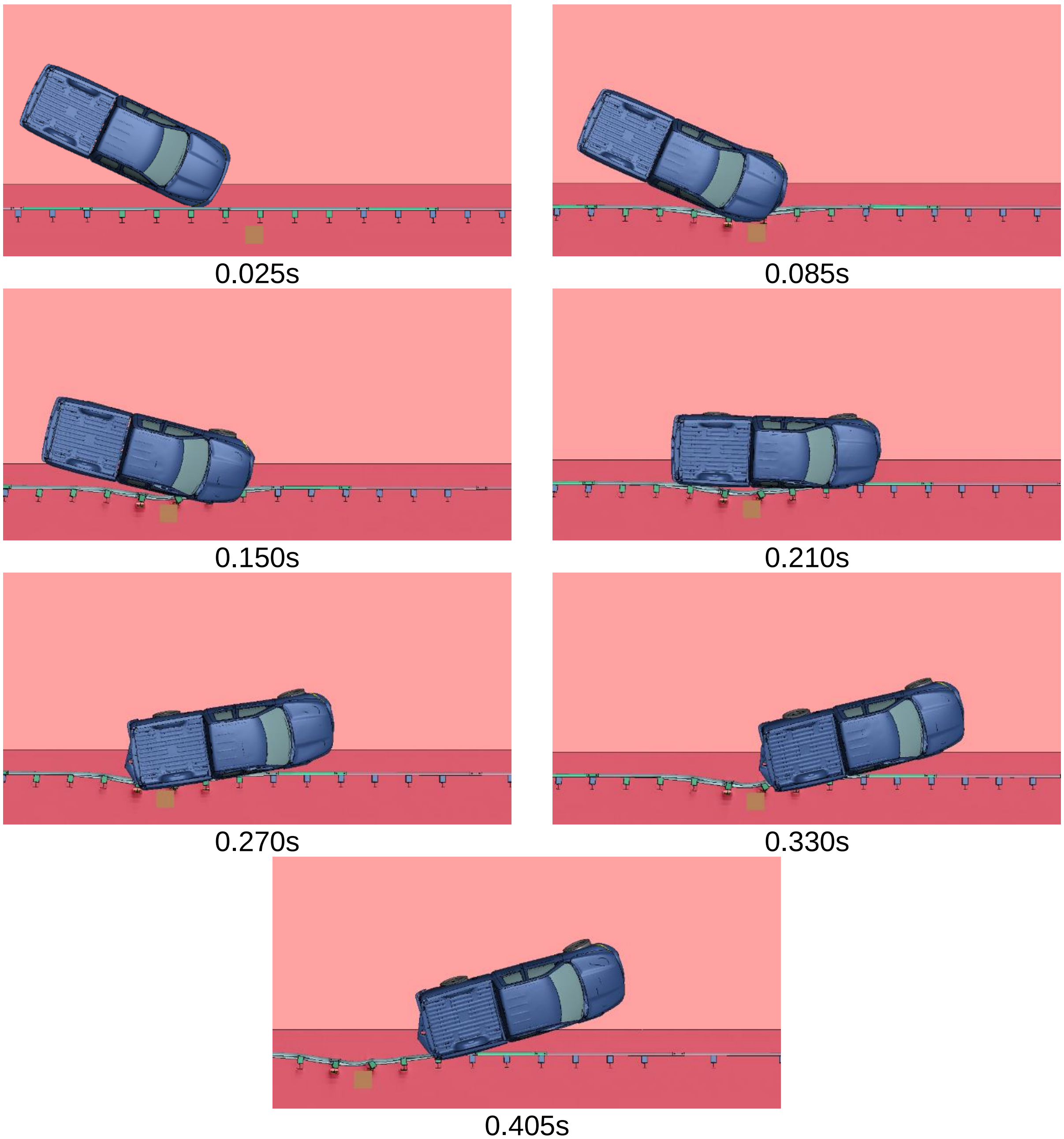


Figure 2.26. *MASH* Test 3-11 Simulation of Half-Post Spacing Thrie-Beam System with Fixed Object 3 inch Offset from Behind Posts – Overhead View

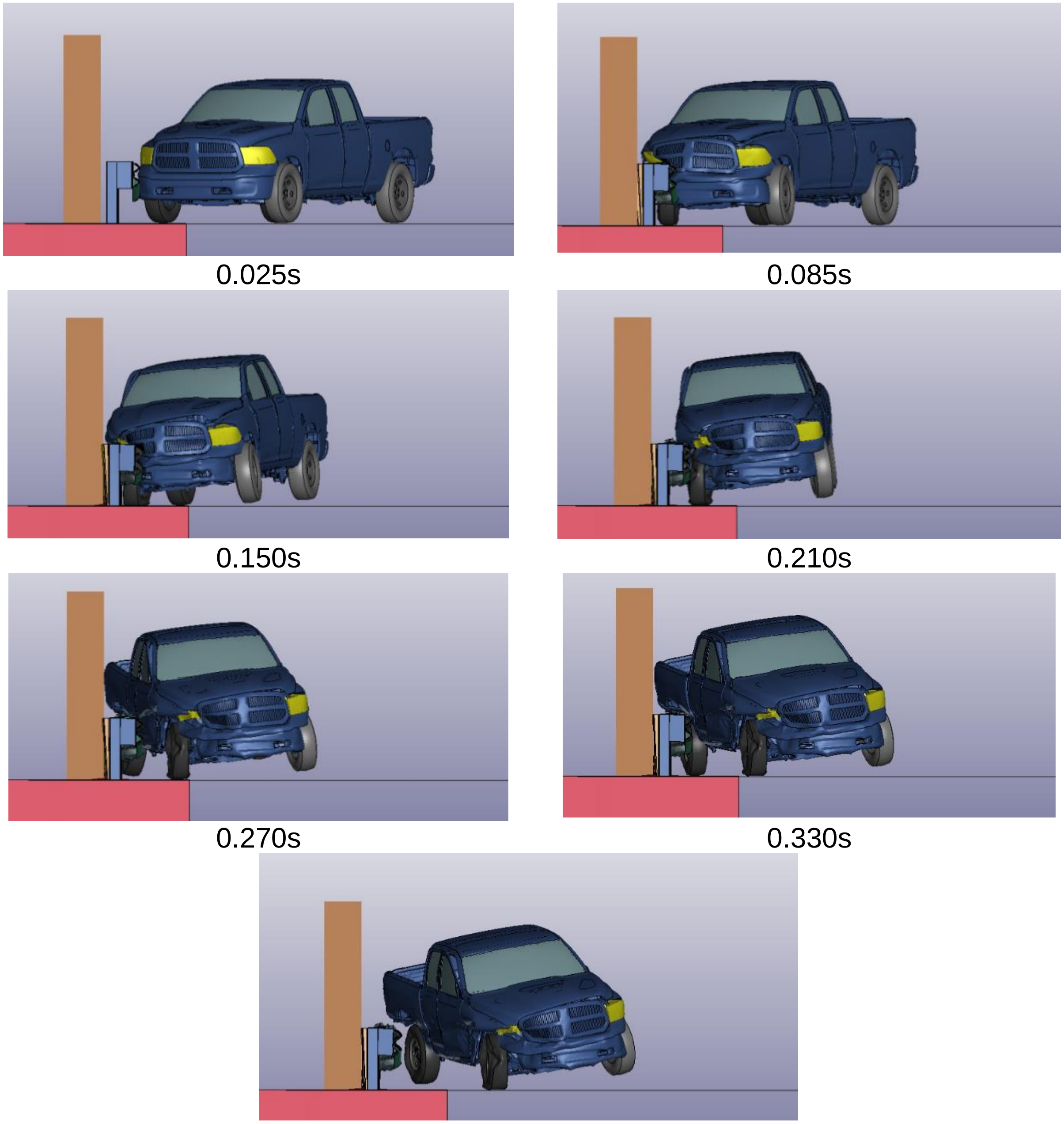


Figure 2.27. *MASH* Test 3-11 Simulation of Half-Post Spacing Thrie-Beam System with Fixed Object 3 inch Offset from Behind Posts – Downstream View

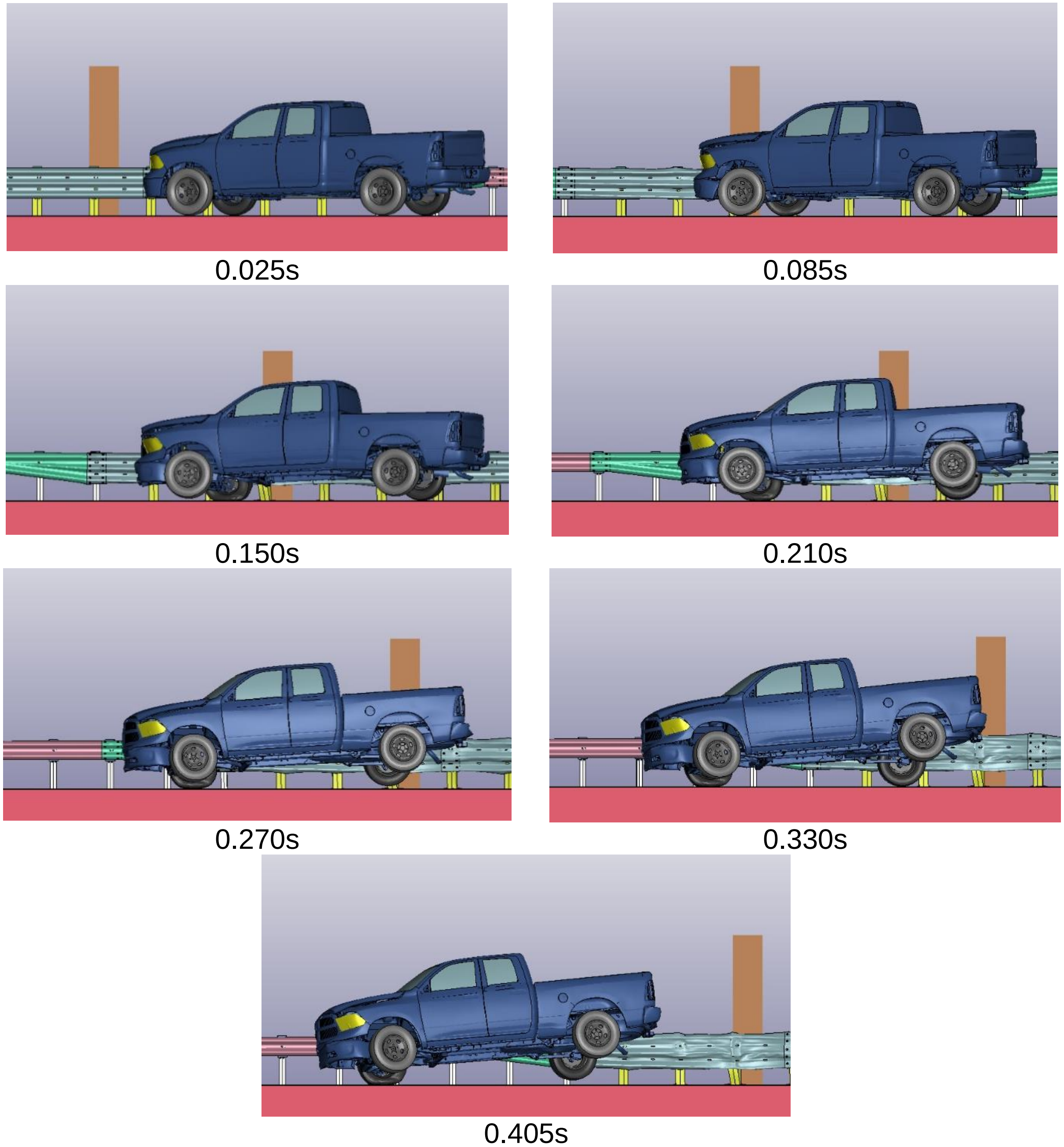


Figure 2.28. *MASH* Test 3-11 Simulation of Half-Post Spacing Thrie-Beam System with Fixed Object 3 inch Offset from Behind Posts – Rear View

2.2.2.5. MASH Test 3-11 Simulation of Half-Post Spacing Thrie-Beam System with Fixed Object 3 inch Offset from Behind Posts & Upstream Relocation

Figure 2.29 through Figure 2.31 show the sequential frames of *MASH* test 3-11 with the fixed object located between the upstream posts and 3 inches away from the back of the posts. This relocation of the fixed object was executed to evaluate the effect of fixed object location on the crashworthiness of the design. The occupant impact velocity was calculated to be 6.9 m/s (preferred limit is 9.1 m/s). The ridedown acceleration was calculated to be 13.6 g's (preferred limit is 15.0 g's). This configuration passed *MASH* test 3-11 by successfully containing and redirecting the vehicle.

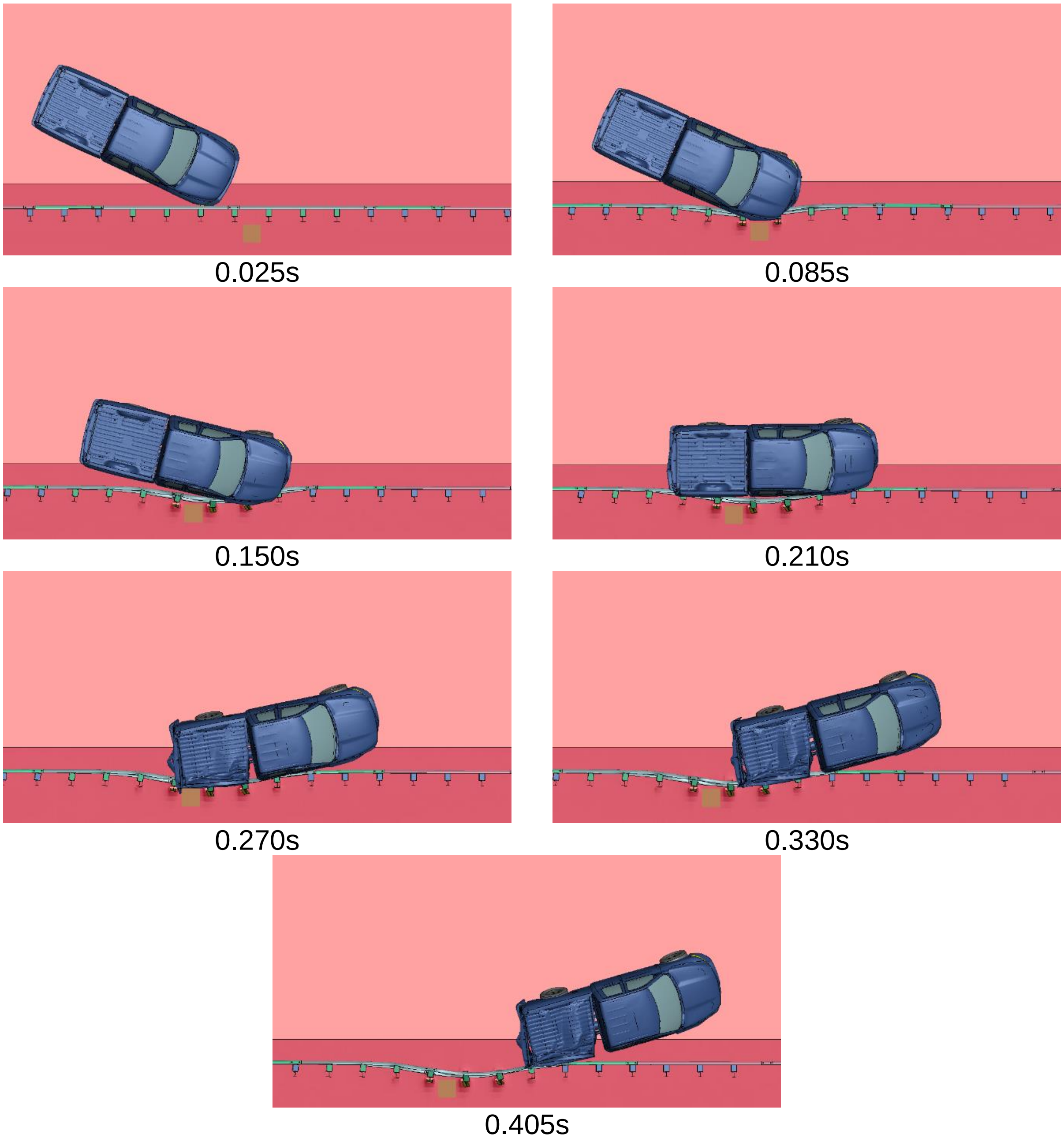
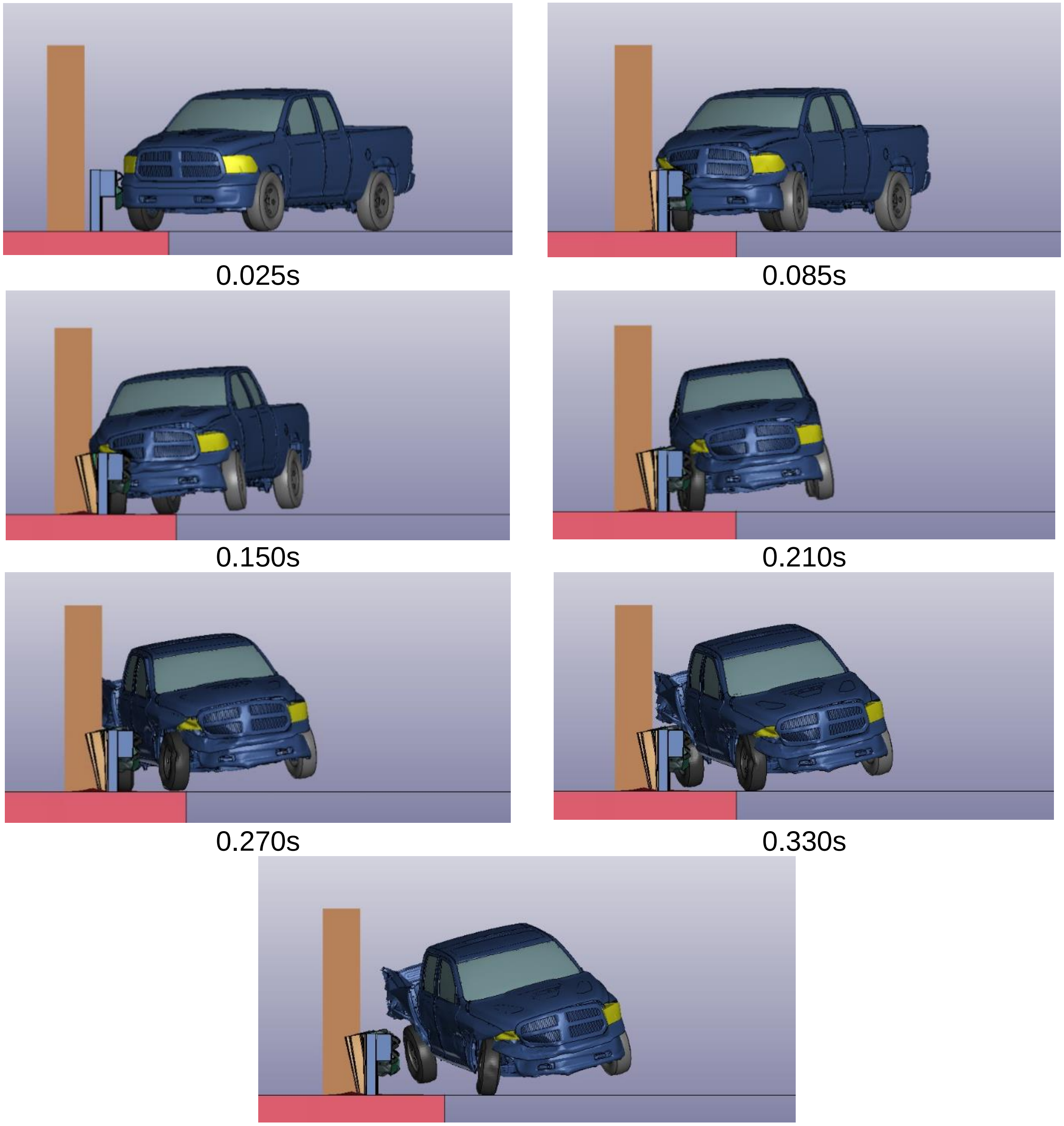


Figure 2.29. *MASH* Test 3-11 Simulation of Half-Post Spacing Thrie-Beam System with Fixed Object 3 inch Offset from Behind Posts & Upstream Relocation – Overhead View



0.405s

Figure 2.30. *MASH* Test 3-11 Simulation of Half-Post Spacing Thrie-Beam System with Fixed Object 3 inch Offset from Behind Posts & Upstream Relocation – Downstream View

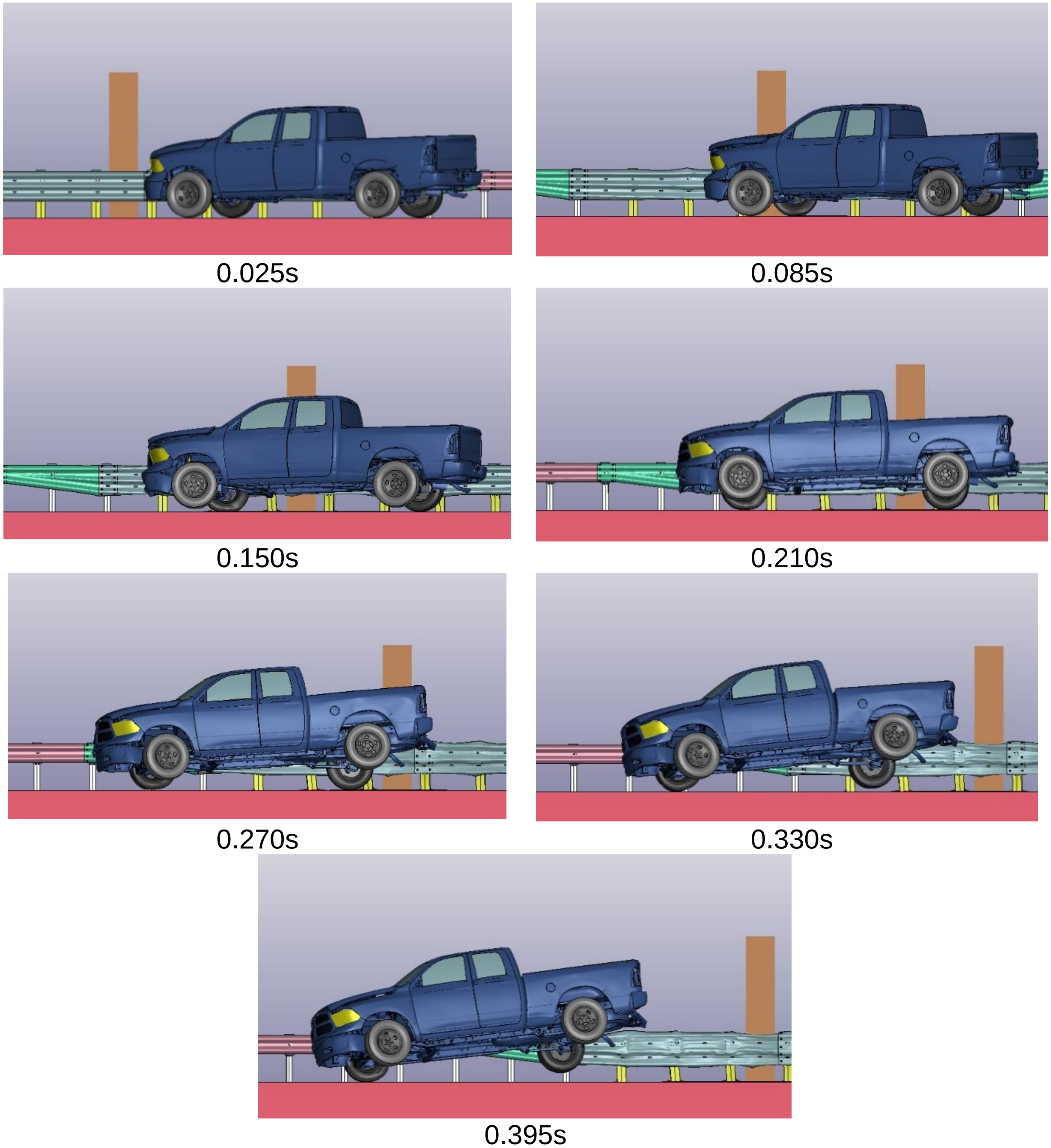


Figure 2.31. *MASH* Test 3-11 Simulation of Half-Post Spacing Thrie-Beam System with Fixed Object 3 inch Offset from Behind Posts & Upstream Relocation – Rear View

2.3. DESIGN OPTIONS WITH ADDITIONAL SPACE BETWEEN POSTS

The following simulations evaluate the crashworthiness of the thrie-beam systems with additional space between posts. This additional distance is intended for installation of larger fixed objects and their appropriate foundations. The size of this gap had two different configurations, 12 ½-ft (large gap) and 6 ¼-ft (small gap). The post spacing in the immediate vicinity around this gap was also varied: half- and quarter-post spacing.

In the following simulations, the research team varied the distance between the back of thrie-beam rail to the front of the rigidized fixed object, herein known as the offset distance. The theoretical fixed object was modeled as a rectangular shape, which represents a worst-case scenario with the discrete corners providing opportunities for vehicle snagging. If excessive interaction with the fixed object was exhibited with the specific configuration, the offset distance was increased. The research team repeated this process until the vehicle did not interact with the fixed object or the interaction was minimal.

2.4. 12 ½-FT GAP BETWEEN POSTS

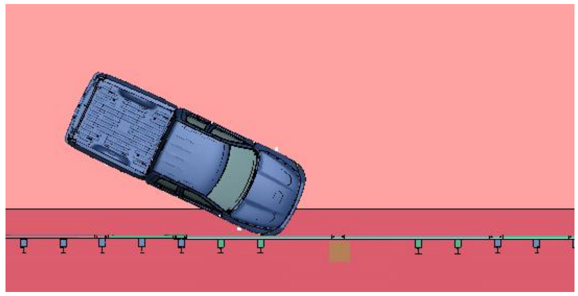
The following simulations evaluated the crashworthiness of the thrie-beam system with a 12 ½-ft gap between posts at the fixed object location.

2.4.1. Half-Post Spacing

The following simulations include offset variations with half-post spacing.

2.4.1.1. MASH Test 3-11 Simulation of Half-Post Spacing Large Gap with Fixed Object – 2 inch Offset

Figure 2.32 through Figure 2.34 show the sequential frames of MASH test 3-11 with half-post spacing, large gap, and a fixed object offset of 2 inches. The pickup truck interacted with the fixed object more than what was allowed within this project scope. Therefore, the offset distance was increased in the next simulation.



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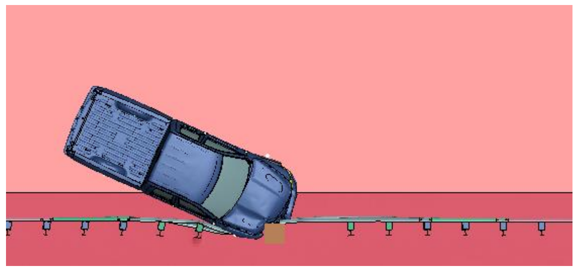

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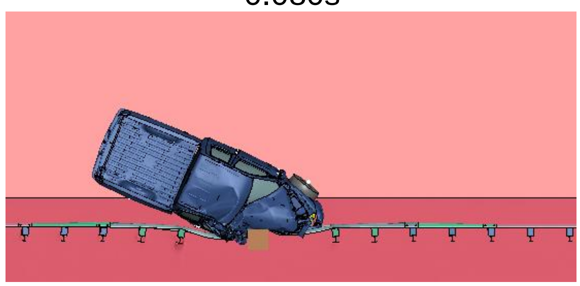

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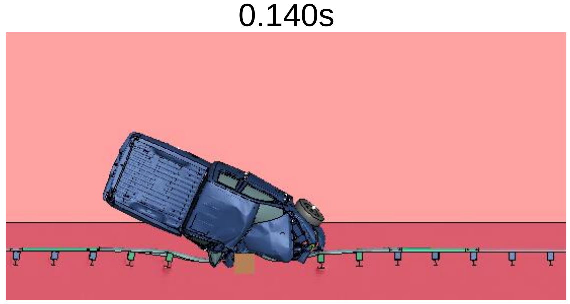
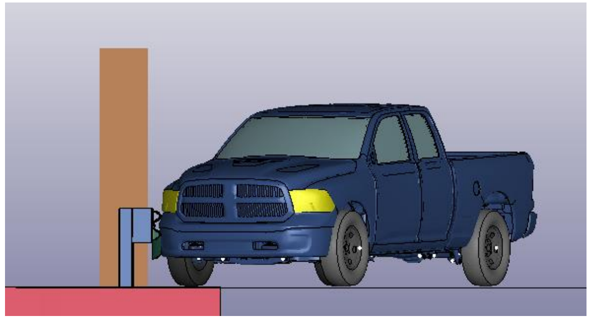


0.195s

Figure 2.32. *MASH* Test 3-11 Simulation of Half-Post Large Gap with Fixed Object 2 inch Offset – Overhead View



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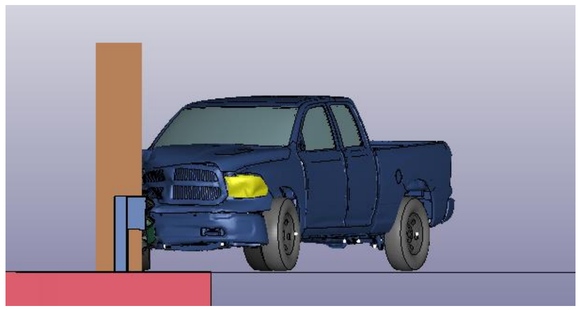

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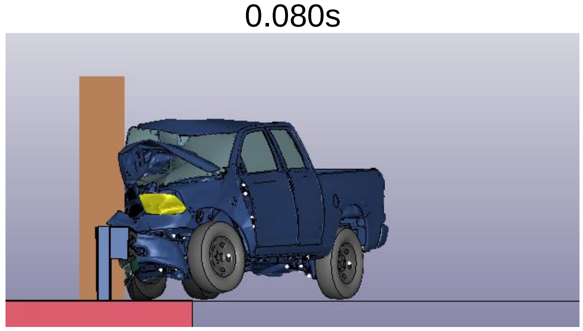

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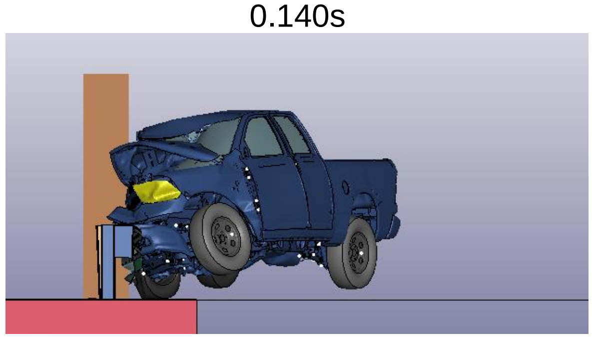

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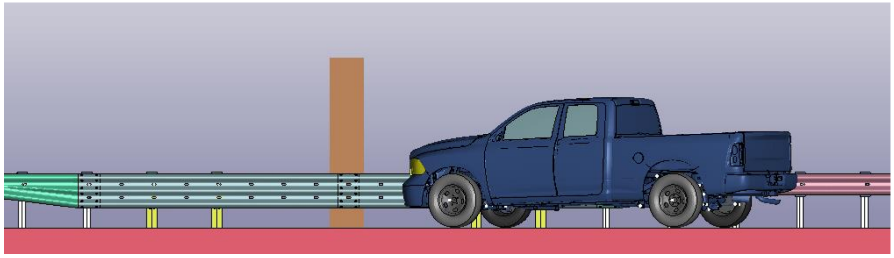
Figure 2.33. *MASH* Test 3-11 Simulation of Half-Post Large Gap with Fixed Object 2 inch Offset – Downstream View



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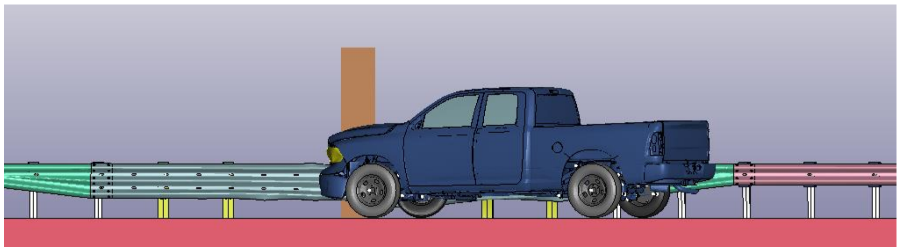

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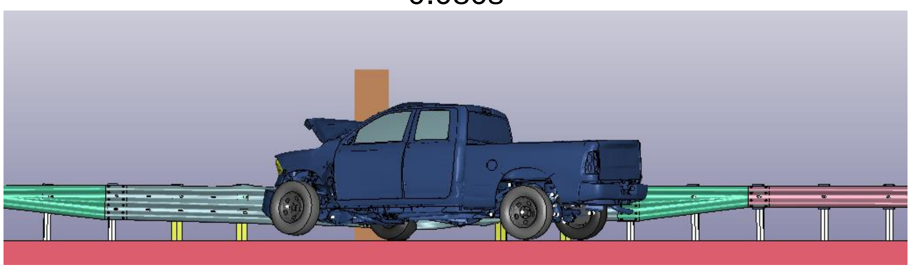

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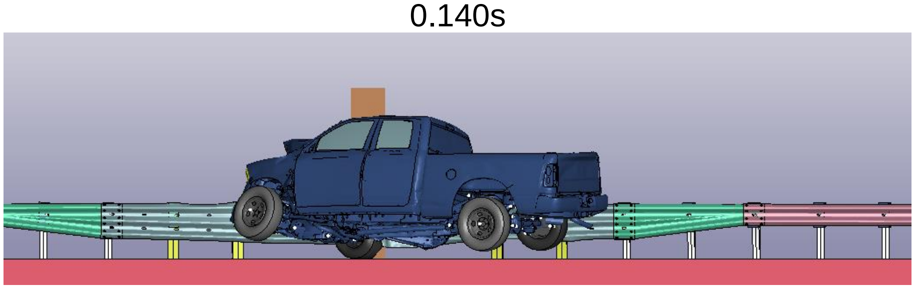
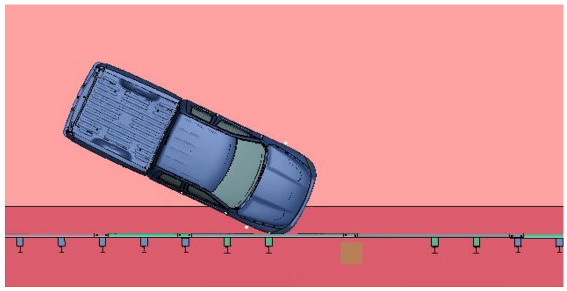


0.195s

Figure 2.34. *MASH* Test 3-11 Simulation of Half-Post Large Gap with Fixed Object 2 inch Offset – Rear View

2.4.1.2. MASH Test 3-11 Simulation of Half-Post Spacing Large Gap with Fixed Object 4 inch Offset

Figure 2.35 through Figure 2.37 show the sequential frames of *MASH* test 3-11 with half-post spacing, large gap, and a fixed object offset of 4 inches. The pickup truck interacted with the fixed object more than what was allowed within this project scope. Therefore, the offset distance was increased in the next simulation.



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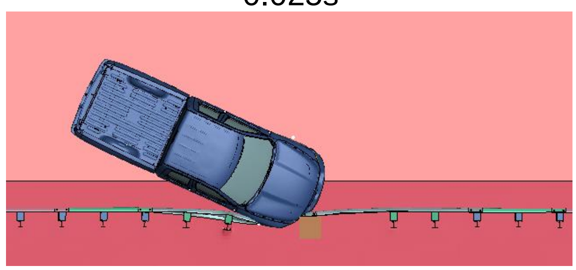

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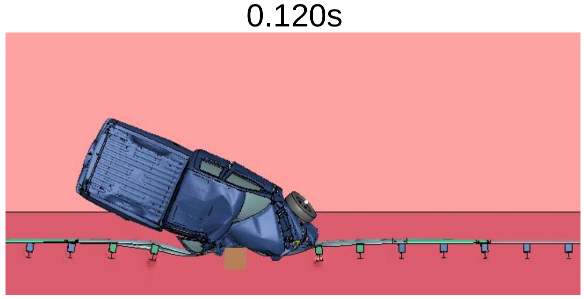
0.120s



0.169s

Figure 2.35. *MASH* Test 3-11 Simulation of Half-Post Large Gap with Fixed Object 4 inch Offset – Overhead View

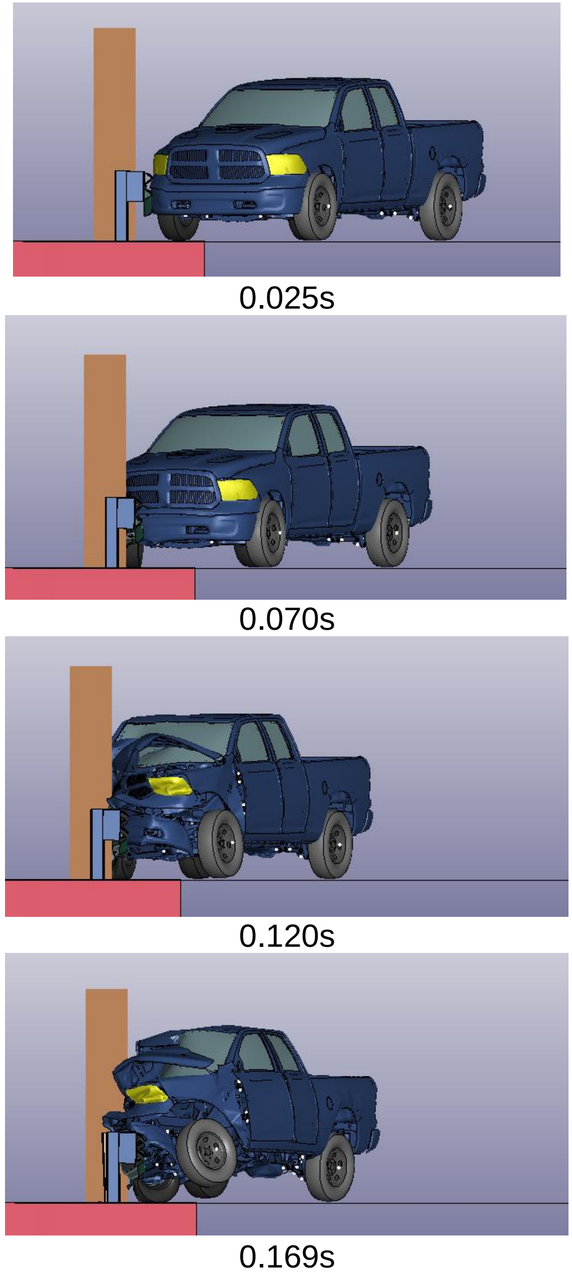
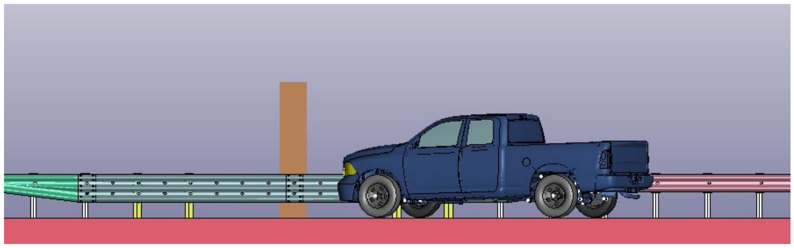


Figure 2.36. *MASH* Test 3-11 Simulation of Half-Post Large Gap with Fixed Object 4 inch Offset – Downstream View



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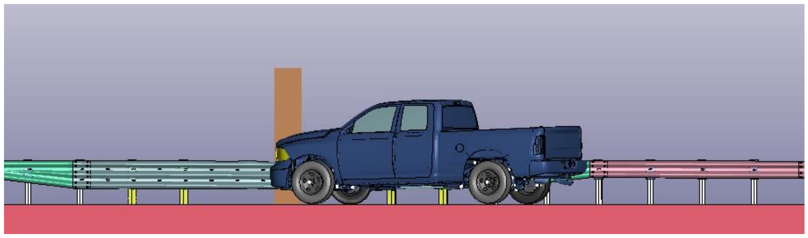

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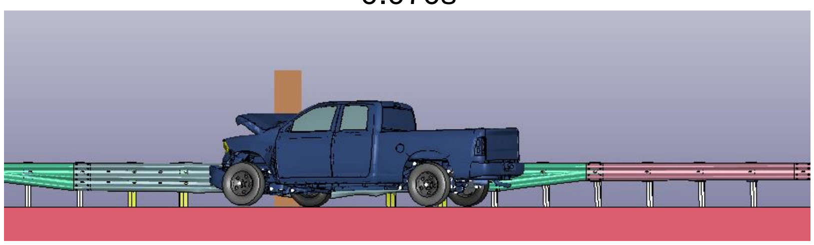

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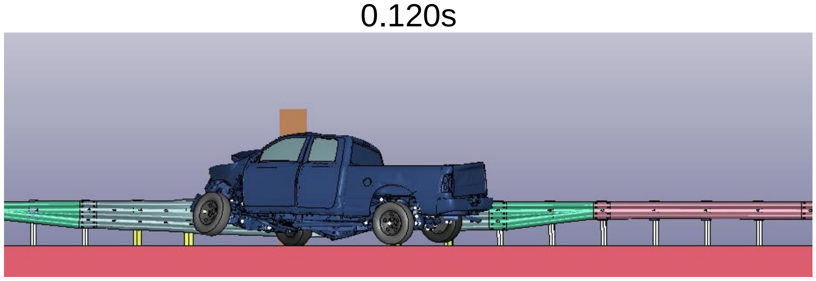
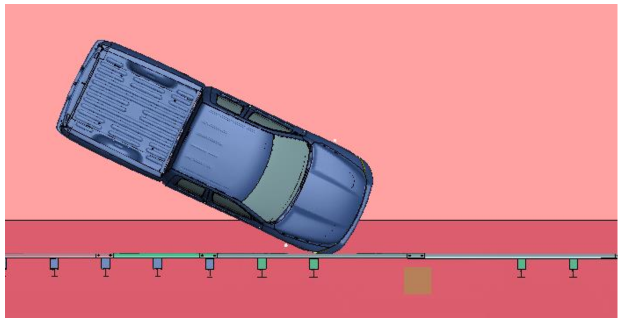


0.169s

Figure 2.37. *MASH* Test 3-11 Simulation of Half-Post Large Gap with Fixed Object 4 inch Offset – Rear View

2.4.1.3. MASH Test 3-11 Simulation of Half-Post Spacing Large Gap with Fixed Object 6 inch Offset

Figure 2.38 through Figure 2.40 show the sequential frames of *MASH* test 3-11 with half-post spacing, large gap, and a fixed object offset of 6 inches. The pickup truck interacted with the fixed object more than what was allowed within this project scope. Therefore, the offset distance was increased in the next simulation.



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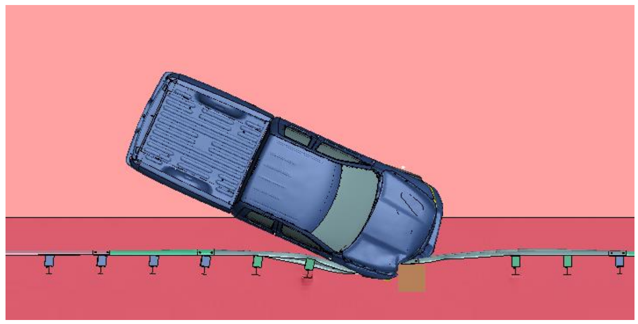

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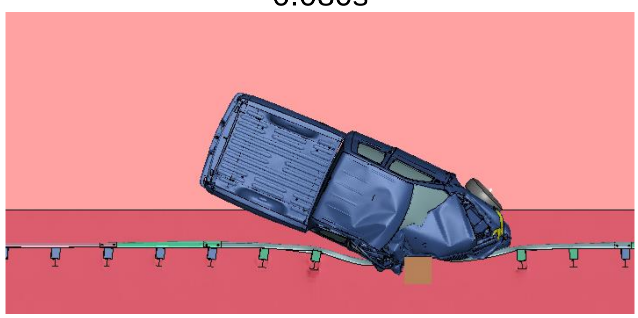

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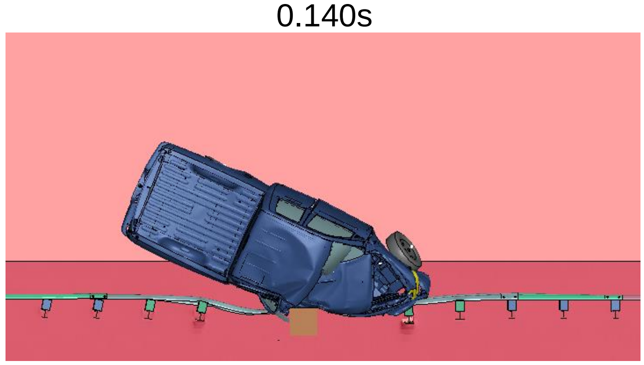
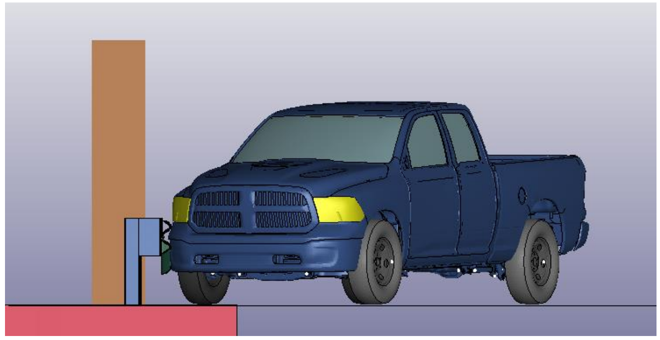


0.195s

Figure 2.38. *MASH* Test 3-11 Simulation of Half-Post Large Gap with Fixed Object 6 inch Offset – Overhead View



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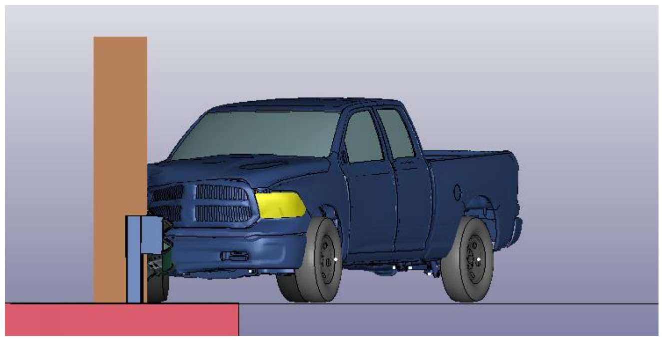

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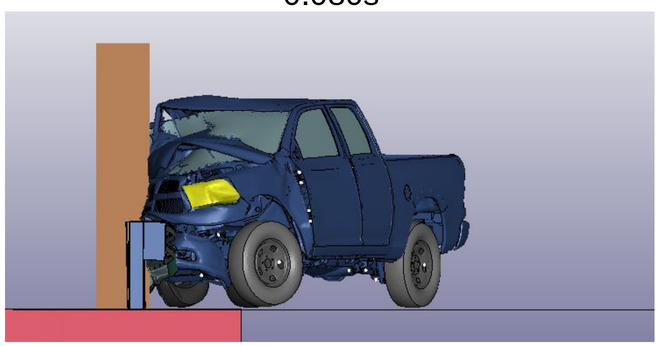

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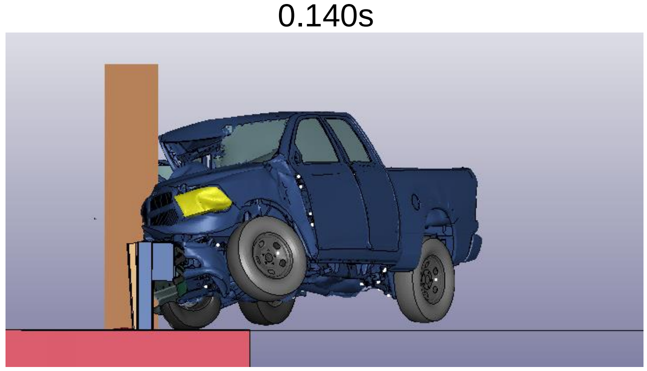

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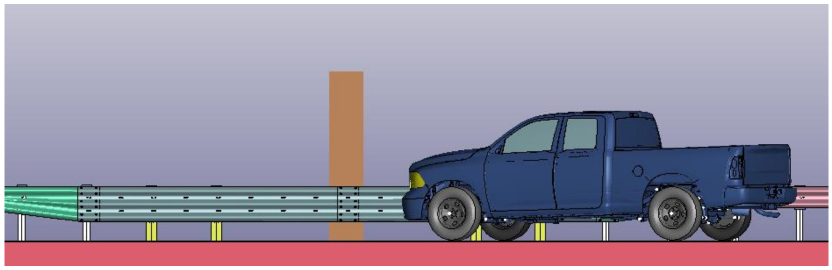
Figure 2.39. *MASH* Test 3-11 Simulation of Half-Post Large Gap with Fixed Object 6 inch Offset – Downstream View



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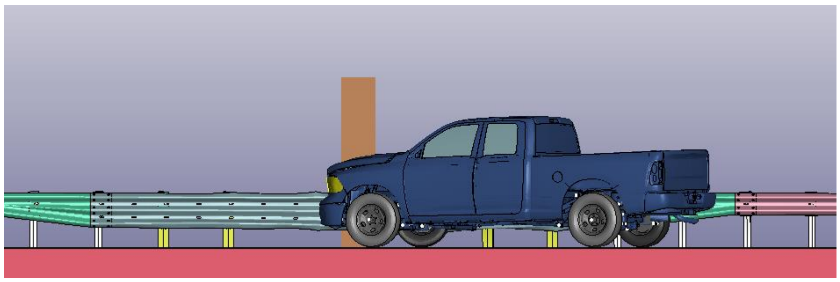

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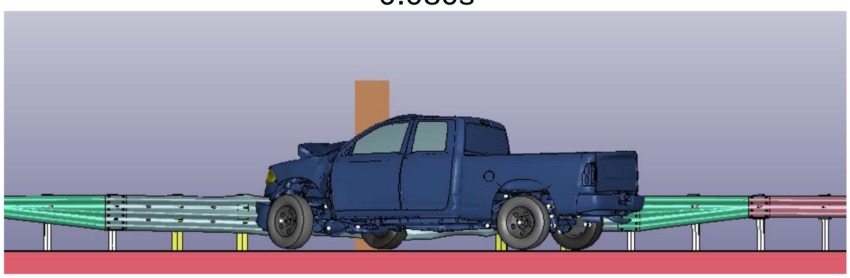

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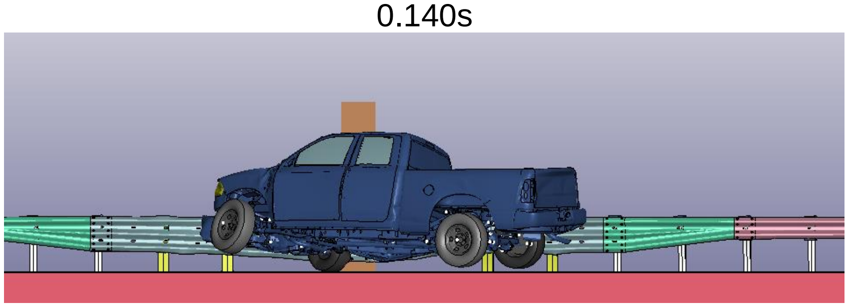
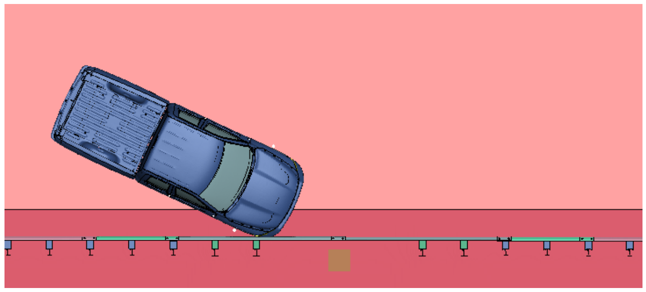


0.195s

Figure 2.40. *MASH* Test 3-11 Simulation of Half-Post Large Gap with Fixed Object 6 inch Offset – Rear View

2.4.1.4. MASH Test 3-11 Simulation of Half-Post Spacing Large Gap with Fixed Object 8 inch Offset

Figure 2.41 through Figure 2.43 show the sequential frames of *MASH* test 3-11 with half-post spacing, large gap, and a fixed object offset of 8 inches. The pickup truck interacted with the fixed object more than what was allowed within this project scope. Therefore, the offset distance was increased in the next simulation.



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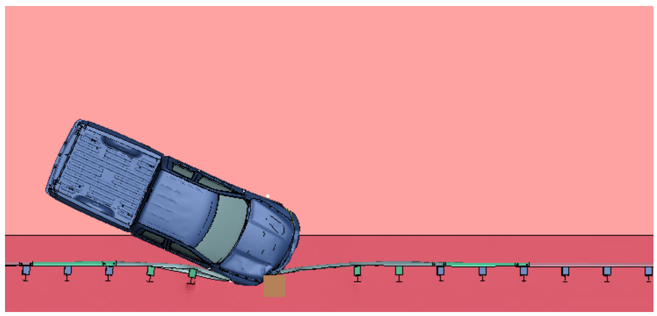

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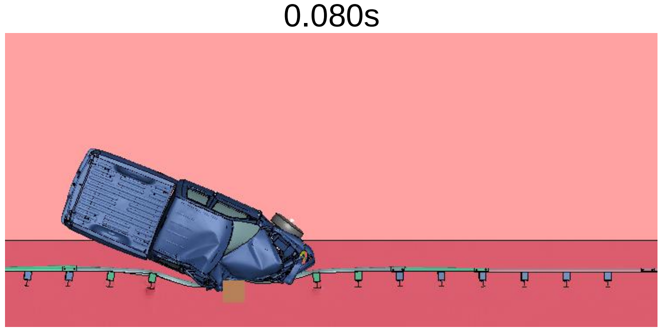

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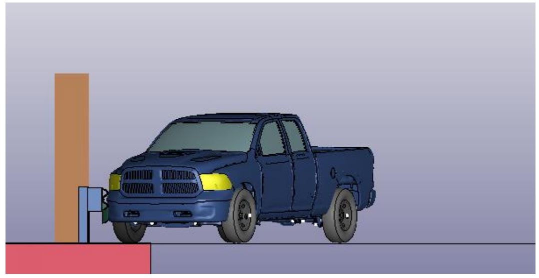
0.195s

Figure 2.41. *MASH* Test 3-11 Simulation of Half-Post Large Gap with Fixed Object 8 inch Offset – Overhead View



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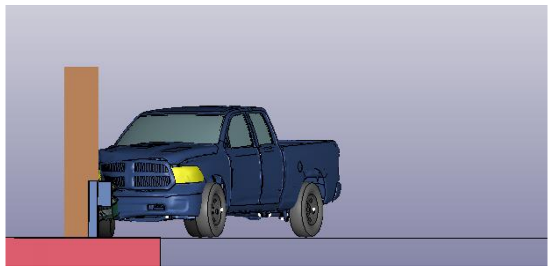

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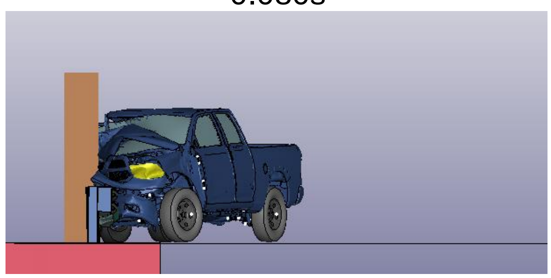

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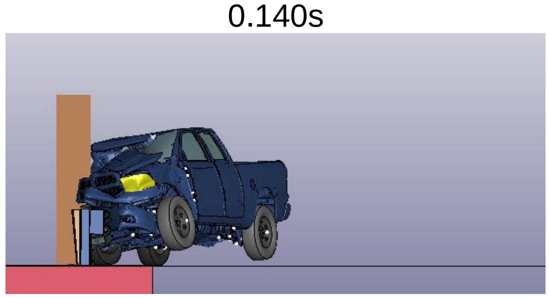
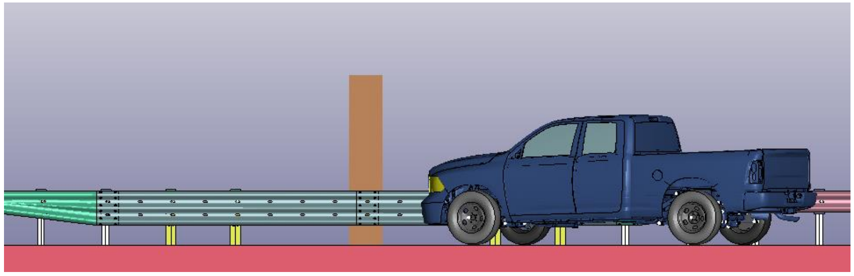


0.195s

Figure 2.42. *MASH* Test 3-11 Simulation of Half-Post Large Gap with Fixed Object 8 inch Offset – Downstream View



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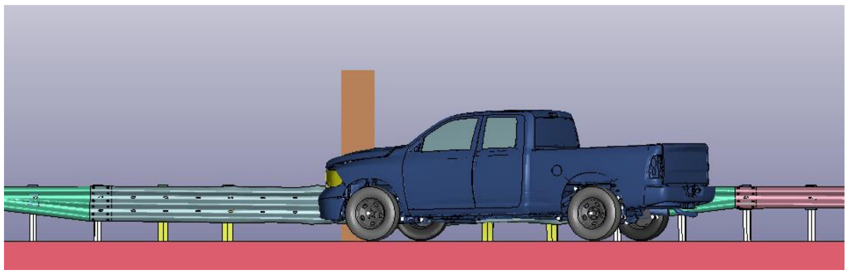

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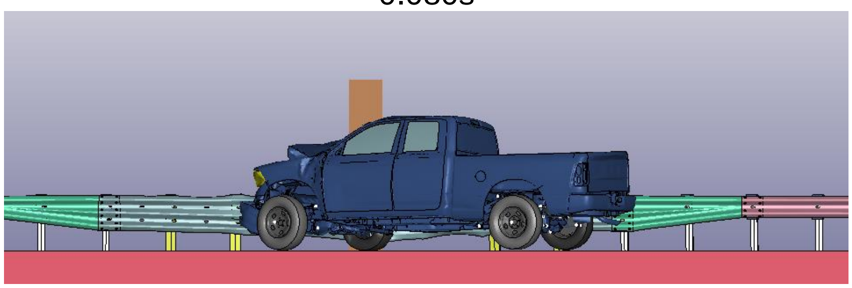

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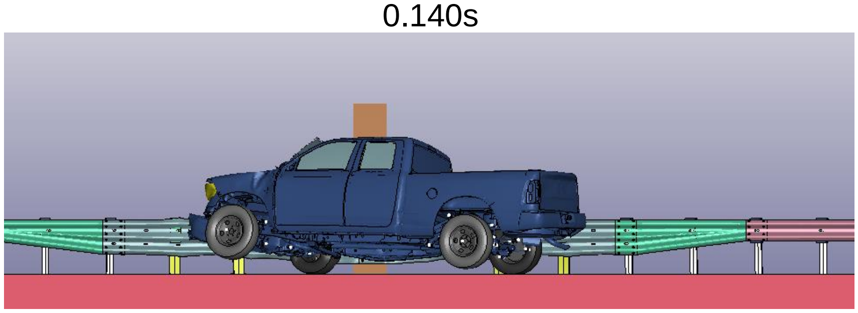


0.195s

Figure 2.43. *MASH* Test 3-11 Simulation of Half-Post Large Gap with Fixed Object 8 inch Offset – Rear View

2.4.1.5. MASH Test 3-11 Simulation of Half-Post Spacing Large Gap with Fixed Object 10 inch Offset

Figure 2.44 through Figure 2.46 show the sequential frames of *MASH* test 3-11 with half-post spacing, large gap, and a fixed object offset of 10 inches. The pickup truck interacted with the fixed object more than what was allowed within this project scope. Therefore, the offset distance was increased in the next simulation.

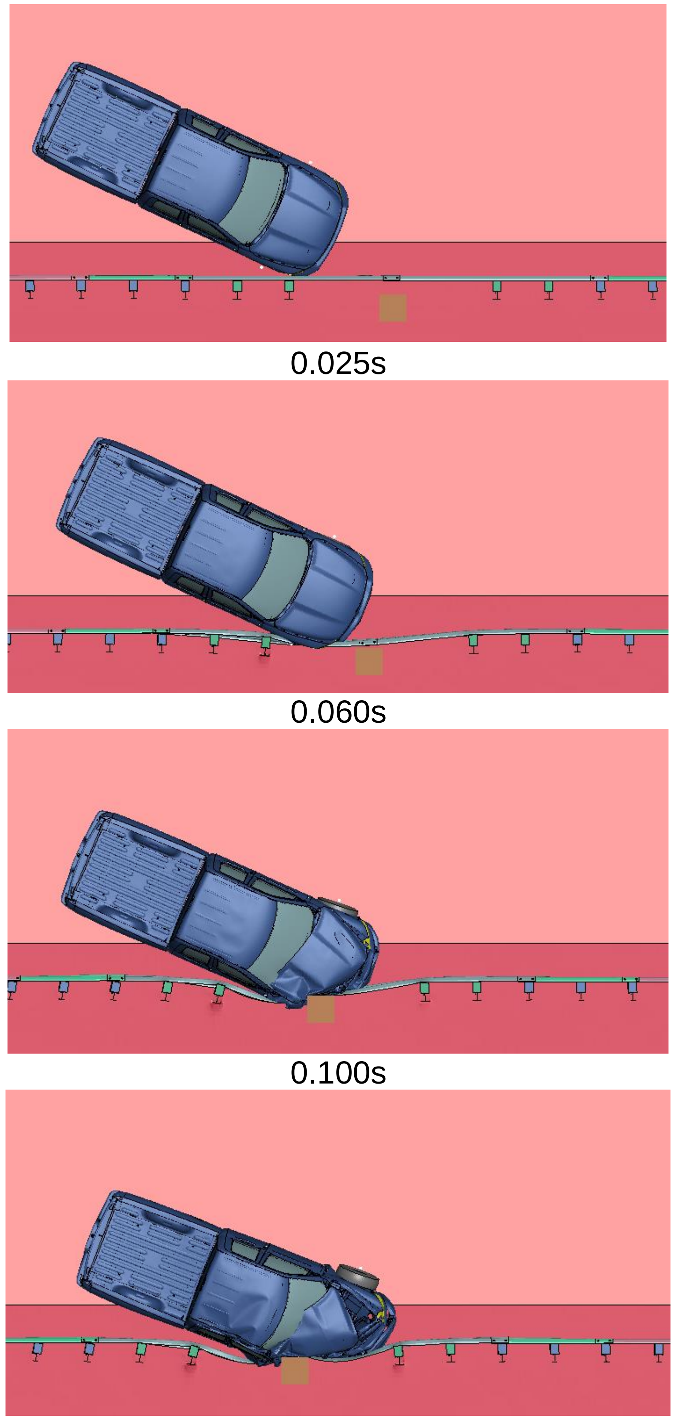
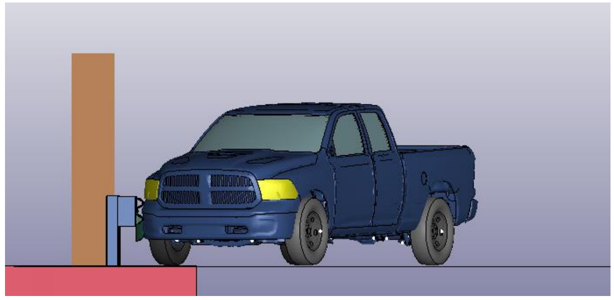


Figure 2.44. *MASH* Test 3-11 Simulation of Half-Post Large Gap with Fixed Object 10 inch Offset – Overhead View



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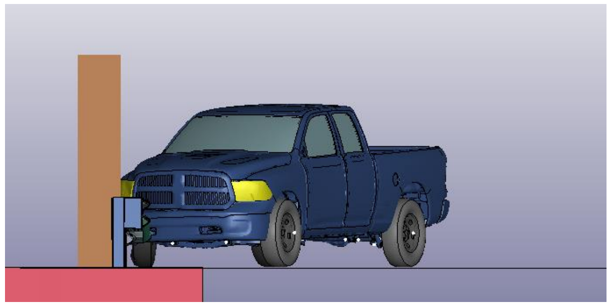

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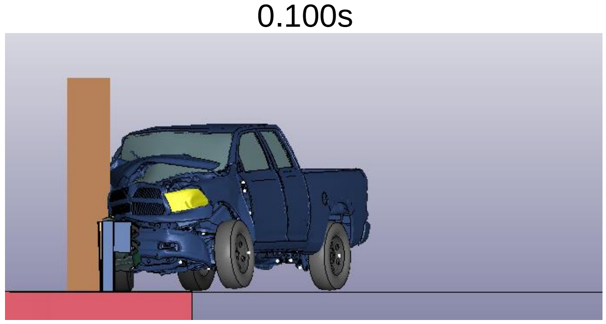
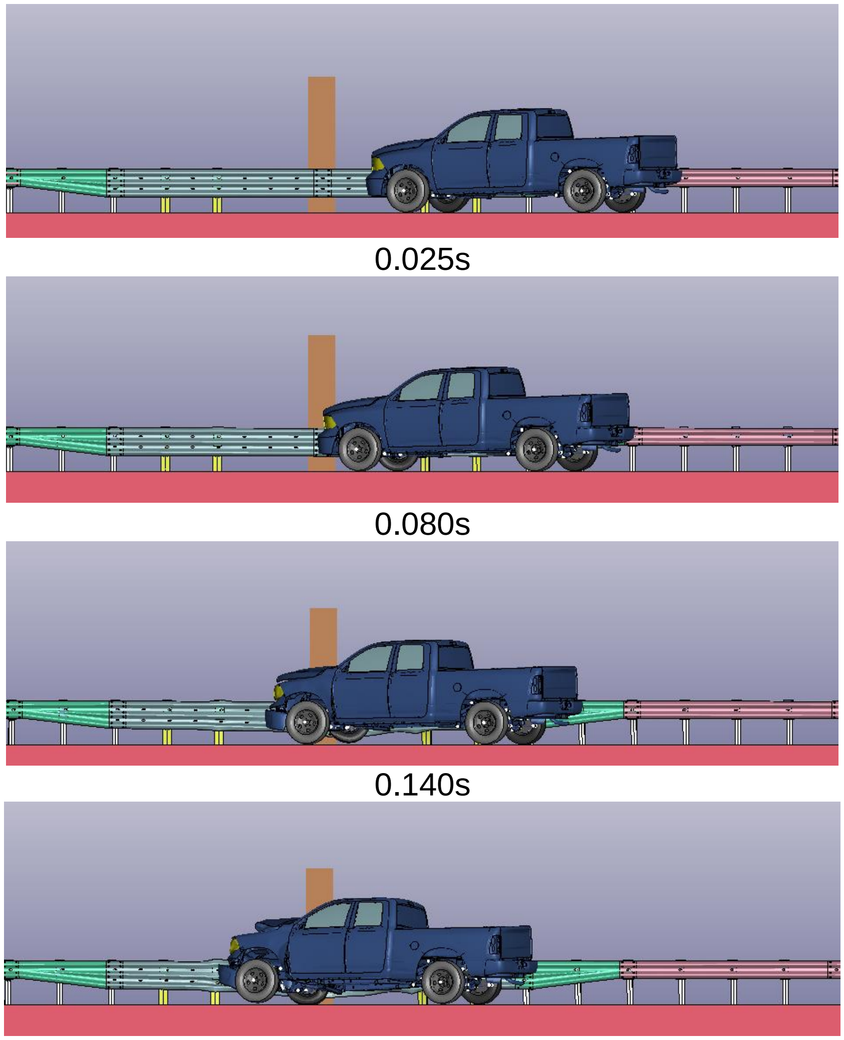
0.100s



0.135s

Figure 2.45. *MASH* Test 3-11 Simulation of Half-Post Large Gap with Fixed Object 10 inch Offset – Downstream View



0.025s

0.080s

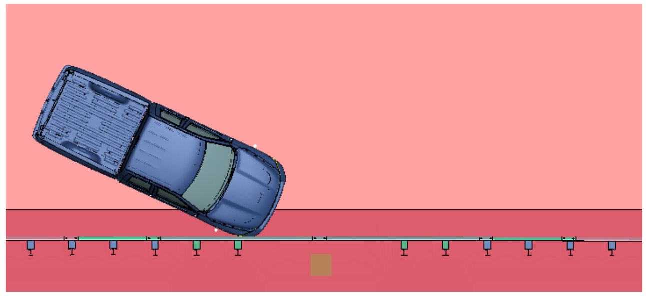
0.140s

0.195s

Figure 2.46. *MASH* Test 3-11 Simulation of Half-Post Large Gap with Fixed Object 10 inch Offset – Rear View

2.4.1.6. MASH Test 3-11 Simulation of Half-Post Spacing Large Gap with Fixed Object 12 inch Offset

Figure 2.47 through Figure 2.49 show the sequential frames of *MASH* test 3-11 with half-post spacing, large gap, and a fixed object offset of 12 inches. The pickup truck interacted with the fixed object more than what was allowed within this project scope. Therefore, the offset distance was increased in the next simulation.



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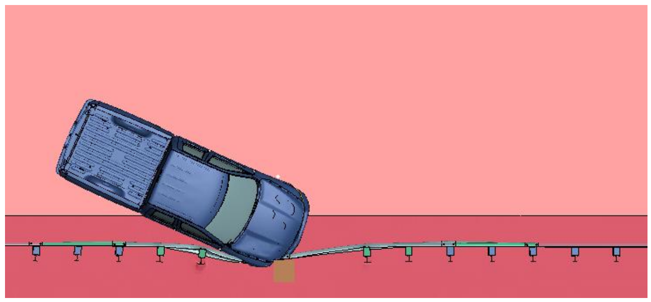

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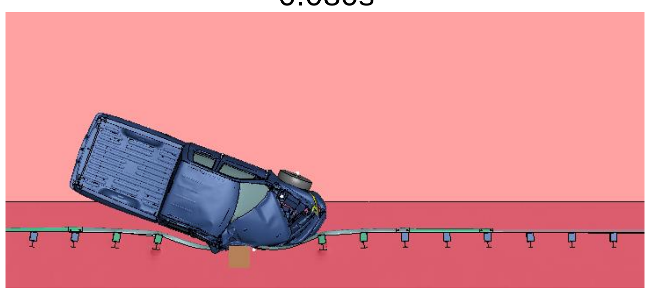

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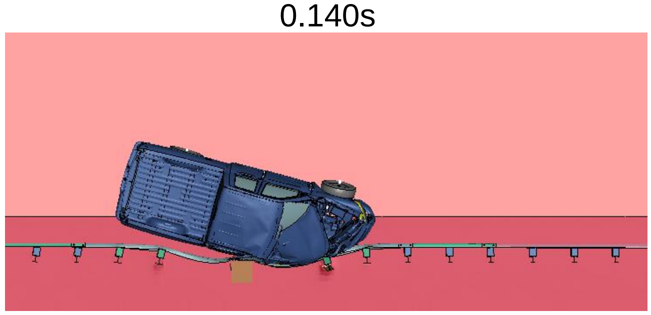

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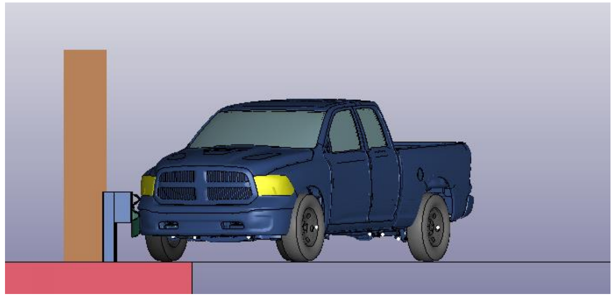
Figure 2.47. *MASH* Test 3-11 Simulation of Half-Post Large Gap with Fixed Object 12 inch Offset – Overhead View



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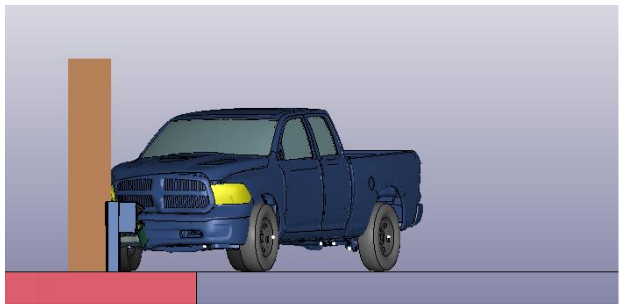

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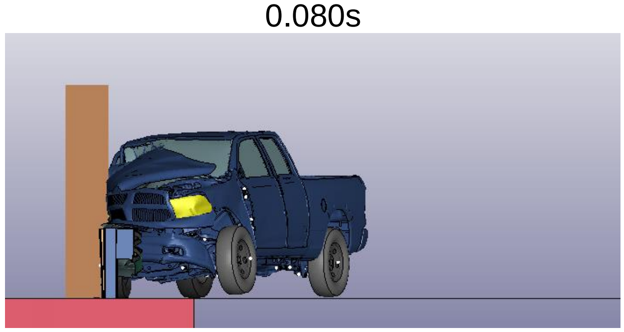

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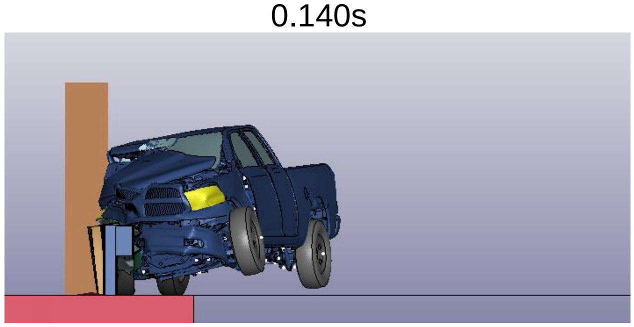

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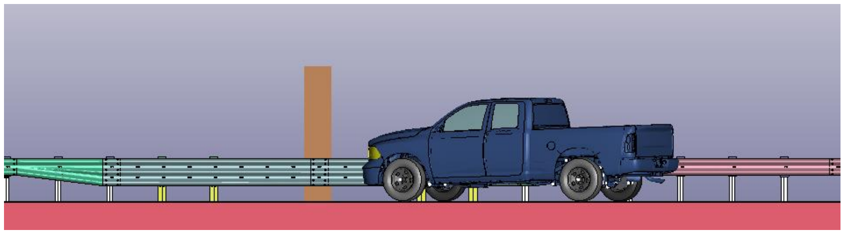
Figure 2.48. *MASH* Test 3-11 Simulation of Half-Post Large Gap with Fixed Object 12 inch Offset – Downstream View



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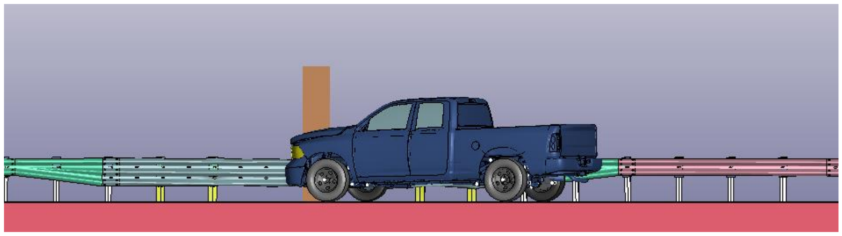

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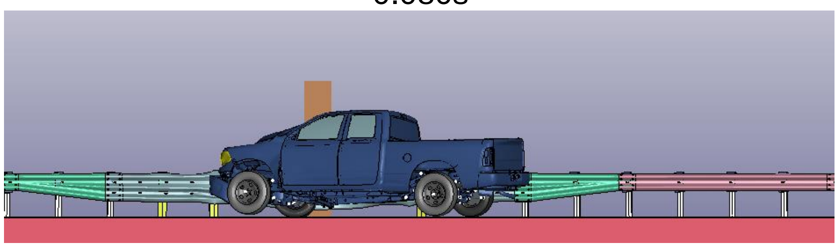

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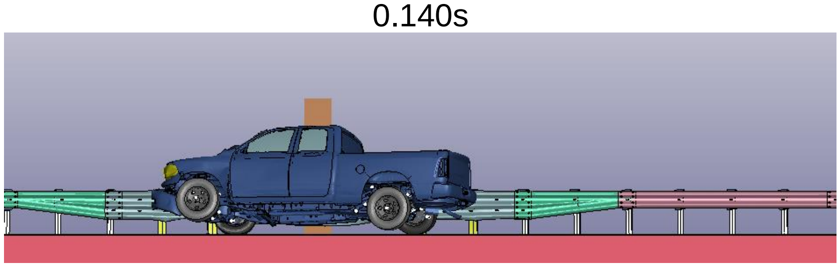

0.195s

Figure 2.49. *MASH* Test 3-11 Simulation of Half-Post Large Gap with Fixed Object 12 inch Offset – Rear View

2.4.1.7. *MASH Test 3-11 Simulation of Half-Post Spacing Large Gap with Fixed Object 16 inch Offset*

Figure 2.50 through Figure 2.52 show the sequential frames of *MASH* test 3-11 with half-post spacing, large gap, and a fixed object offset of 16 inches. The occupant impact velocity was calculated to be 6.8 m/s (preferred limit is 9.1 m/s). The ridedown acceleration was calculated to be 13.9 g's (preferred limit is 15.0 g's). This configuration passed *MASH* test 3-11 by successfully containing and redirecting the vehicle.

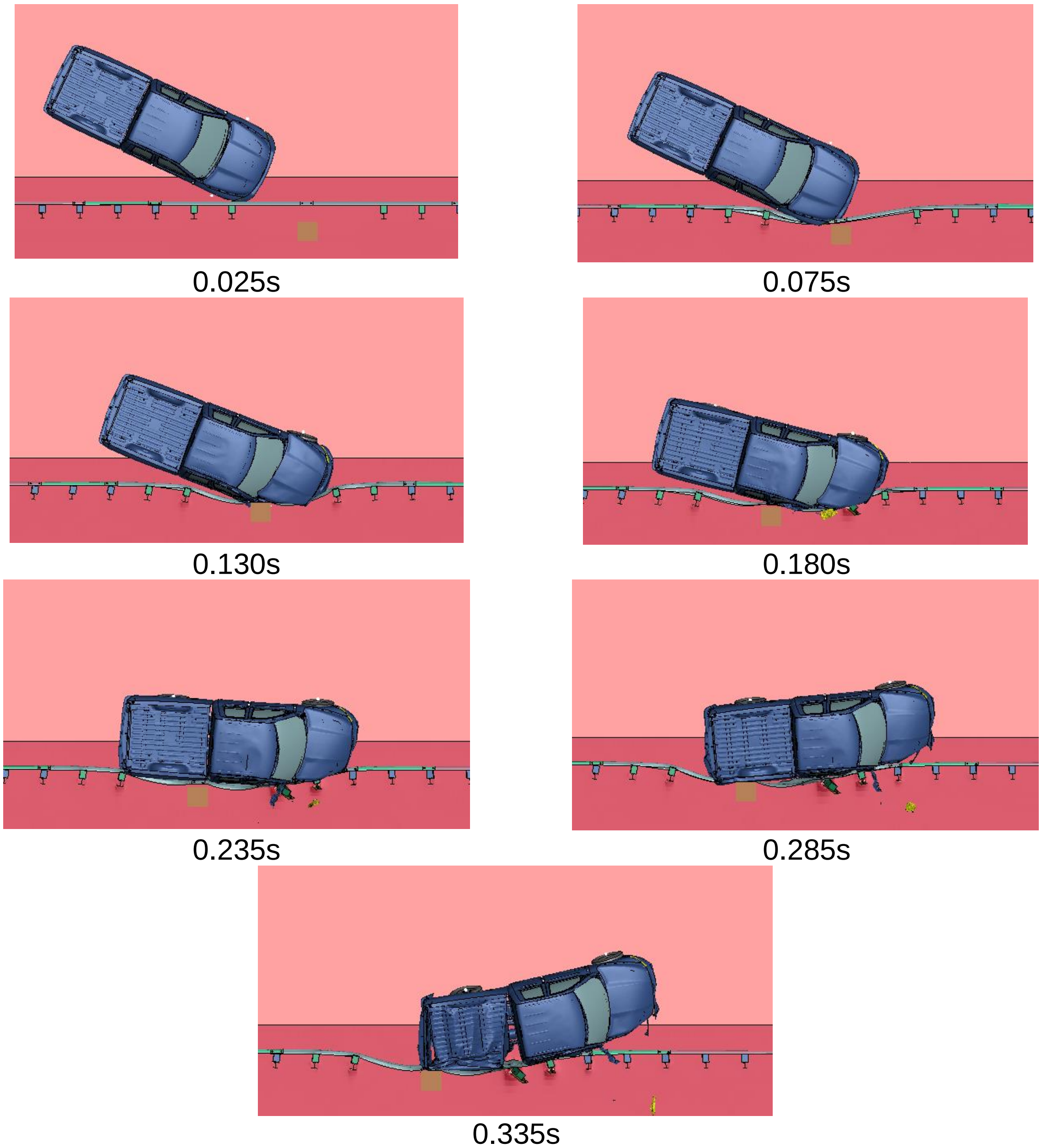

Figure 2.50. *MASH* Test 3-11 Simulation of Half-Post Large Gap with Fixed Object 16 inch Offset – Overhead View

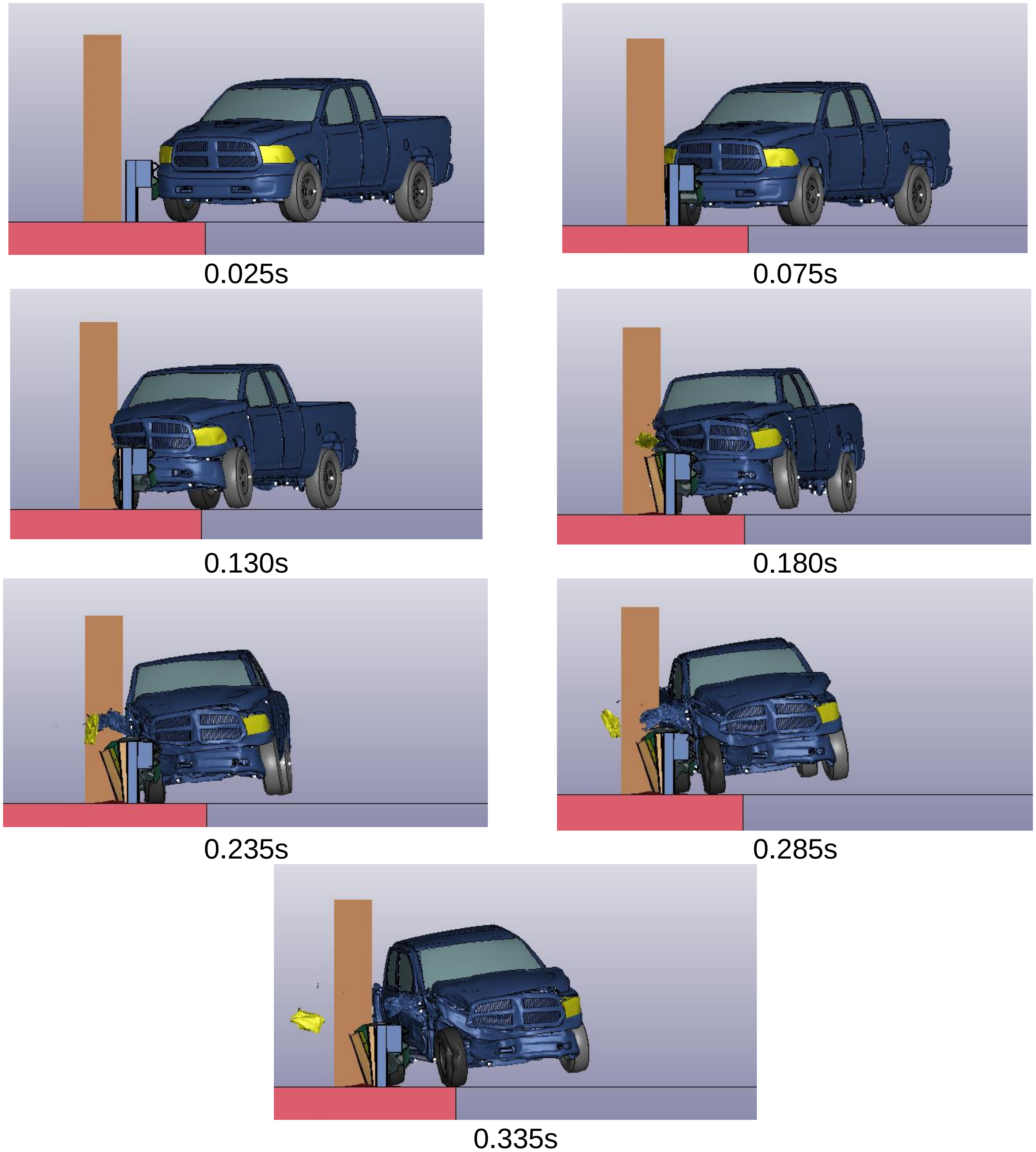

Figure 2.51. *MASH* Test 3-11 Simulation of Half-Post Large Gap with Fixed Object 16 inch Offset – Downstream View

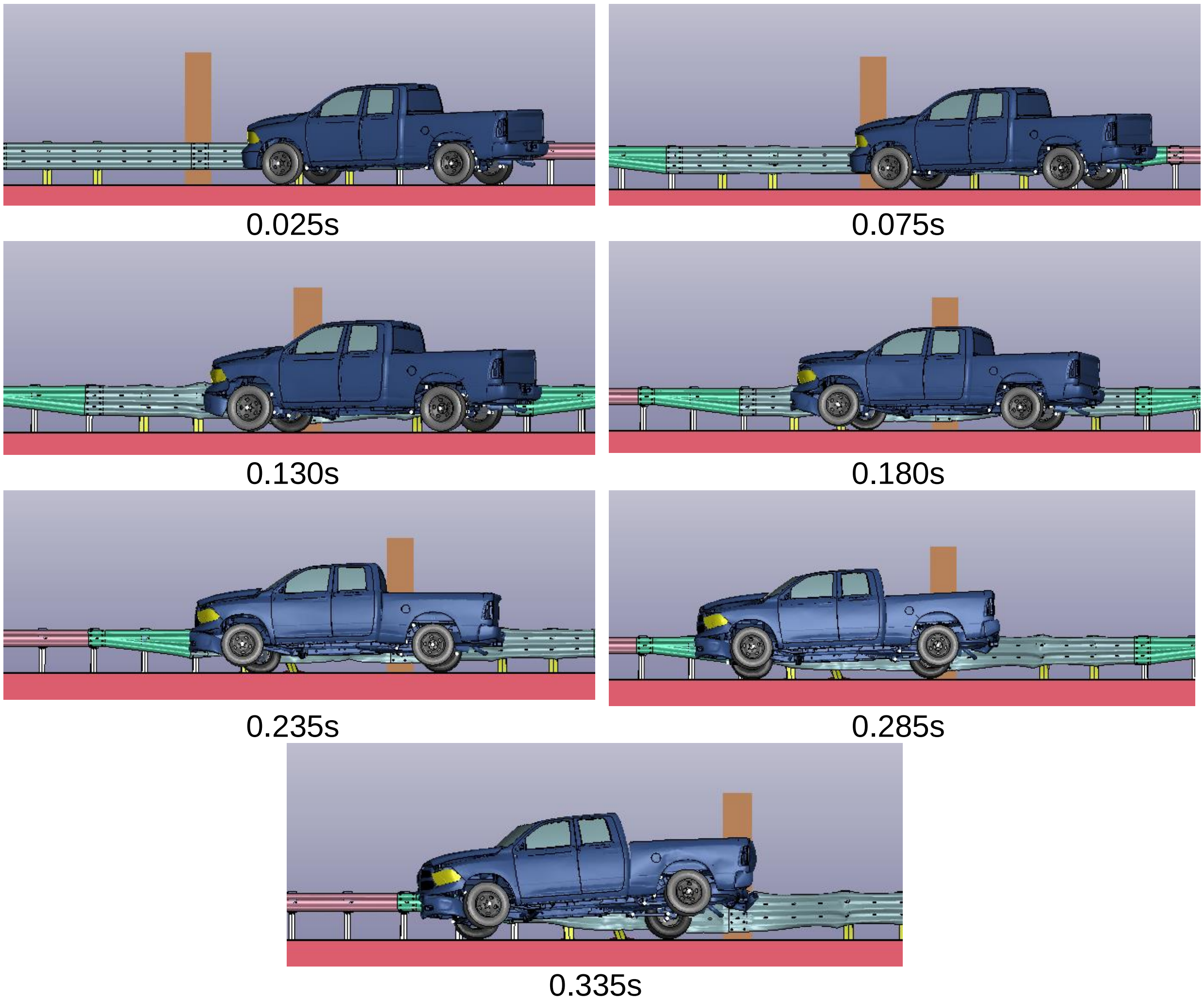

Figure 2.52. *MASH* Test 3-11 Simulation of Half-Post Large Gap with Fixed Object 16 inch Offset – Rear View

2.4.1.8. MASH Test 3-11 Simulation of Half-Post Spacing Large Gap with Fixed Object 24 inch Offset

Figure 2.53 through Figure 2.55 show the sequential frames of *MASH* test 3-11 with half-post spacing, large gap, and a fixed object offset of 24 inches. The occupant impact velocity was calculated to be 5.6 m/s (preferred limit is 9.1 m/s). The ridedown acceleration was calculated to be 20.1 g's (maximum limit is 20.49 g's).

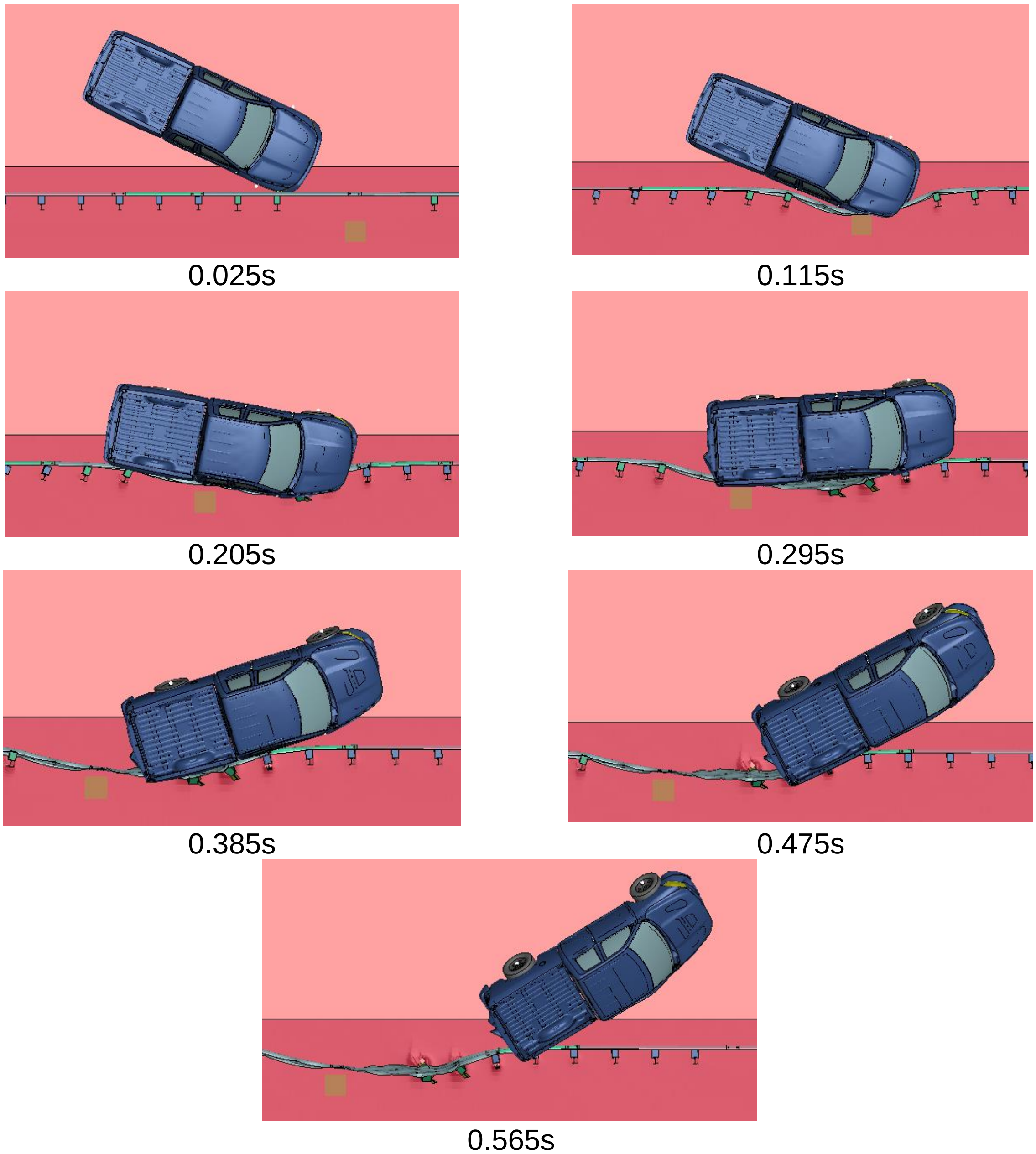

Figure 2.53. *MASH* Test 3-11 Simulation of Half-Post Large Gap with Fixed Object 24 inch Offset– Overhead View

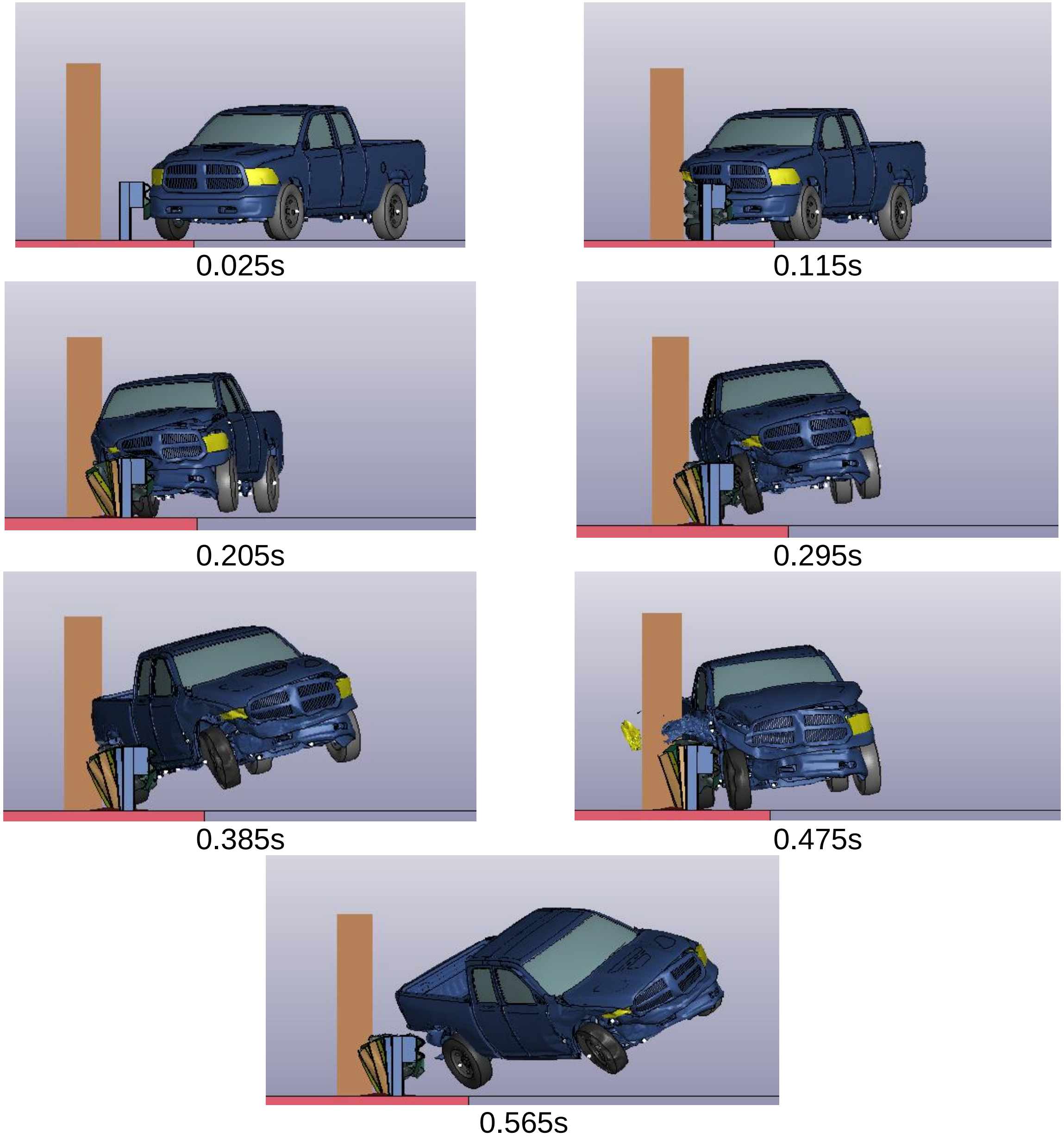

Figure 2.54. *MASH* Test 3-11 Simulation of Half-Post Large Gap with Fixed Object 24 inch Offset – Downstream View

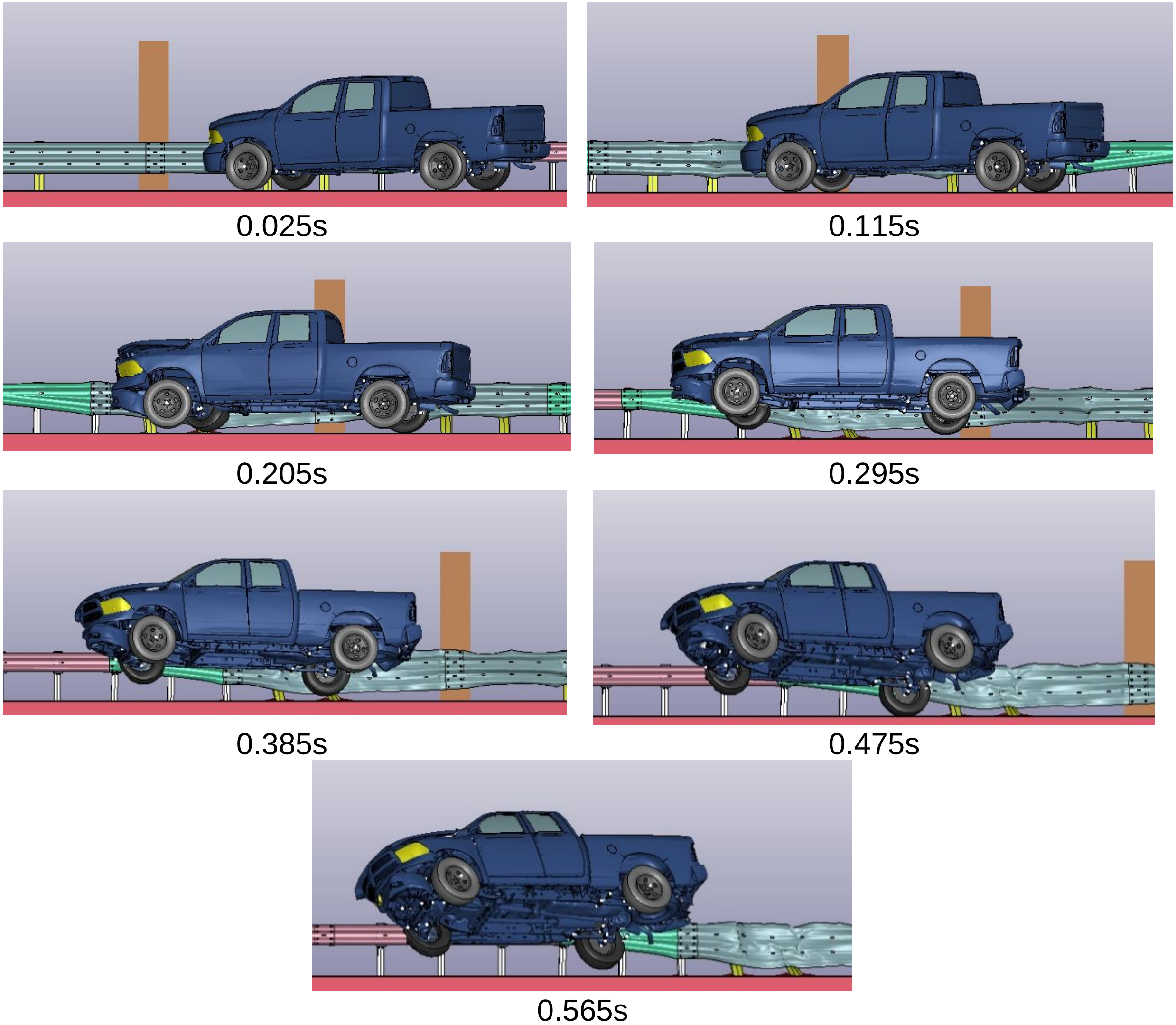

Figure 2.55. *MASH* Test 3-11 Simulation of Half-Post Large Gap with Fixed Object 24 inch Offset – Rear View

2.4.1.9. MASH Test 3-11 Simulation of Half-Post Spacing Large Gap with Fixed Object 30 inch Offset

Figure 2.56 through Figure 2.58 show the sequential frames of *MASH* test 3-11 with half-post spacing, large gap, and a fixed object offset of 30 inches. The occupant impact velocity was calculated to be 5.5m/s (preferred limit is 9.1 m/s). The ridedown acceleration was calculated to be 15.2 g's (maximum limit is 20.49 g's). This configuration passed *MASH* test 3-11 by successfully containing and redirecting the vehicle. Because of the minimal to no interaction exhibited in this simulation, the research team evaluated multiple impact points to determine the most critical. These simulations are included in the sections below.

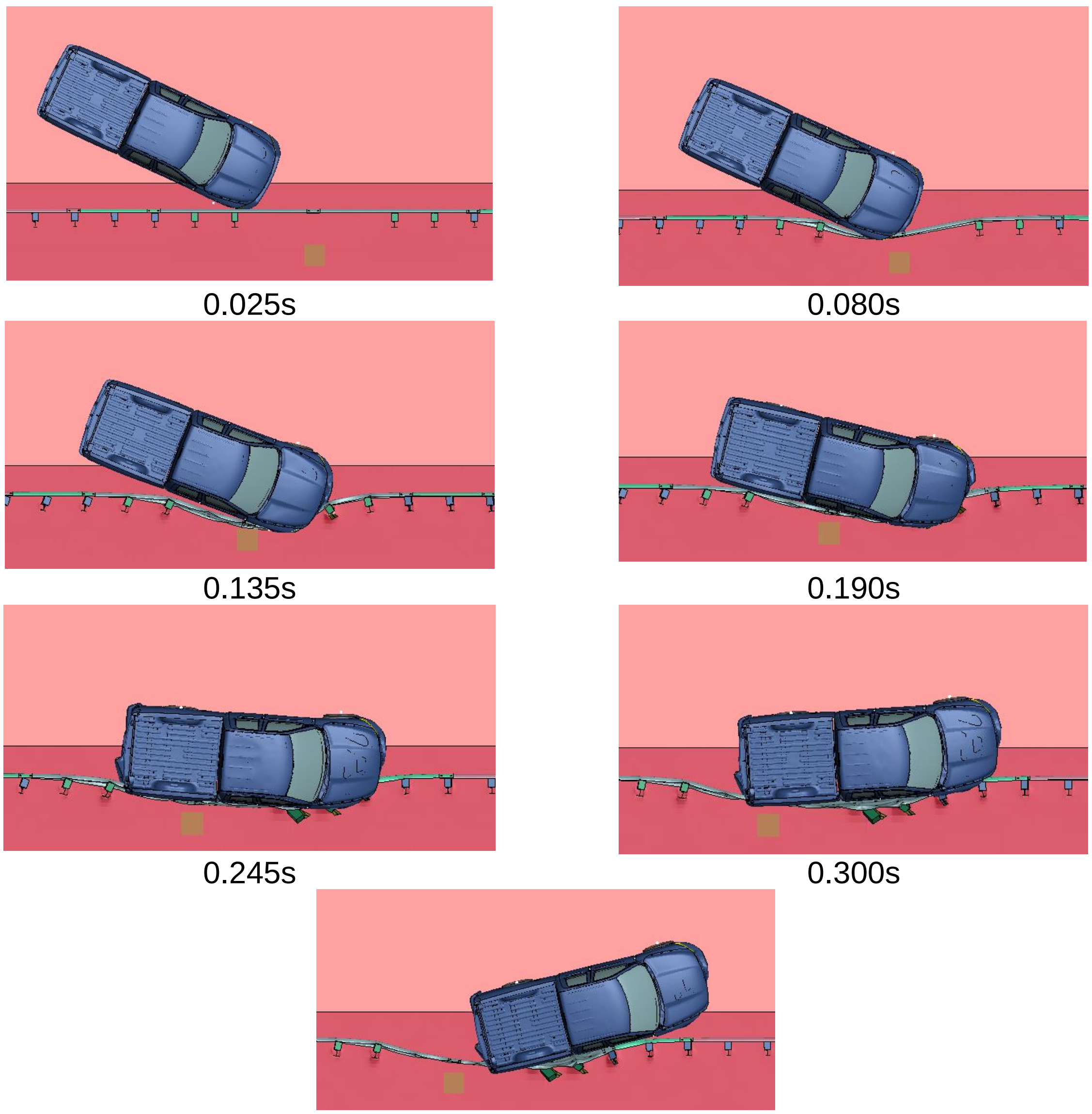

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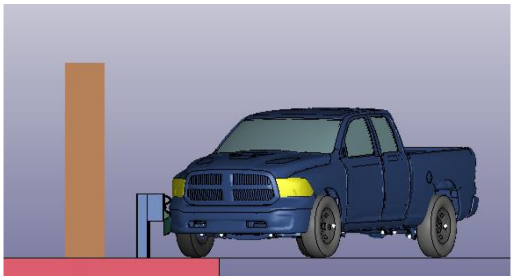
Figure 2.56. *MASH* Test 3-11 Simulation of Half-Post Large Gap with Fixed Object 30 inch Offset – Overhead View



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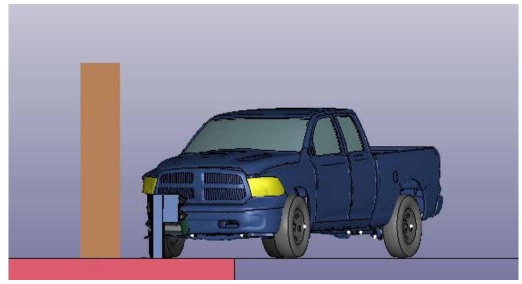

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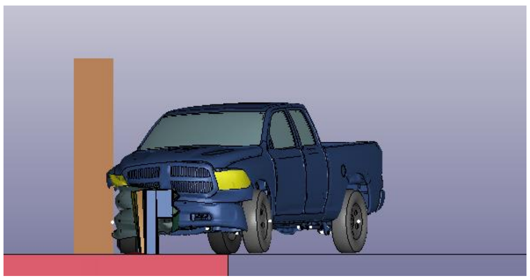

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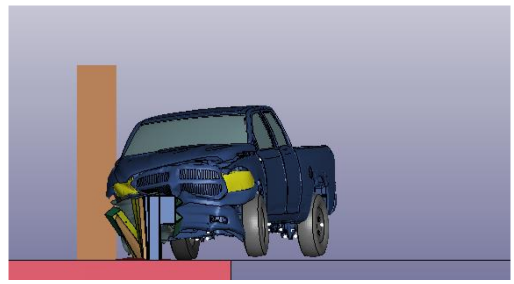

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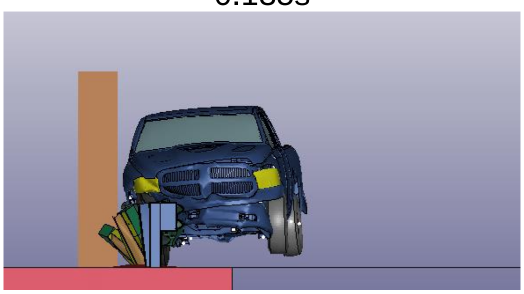

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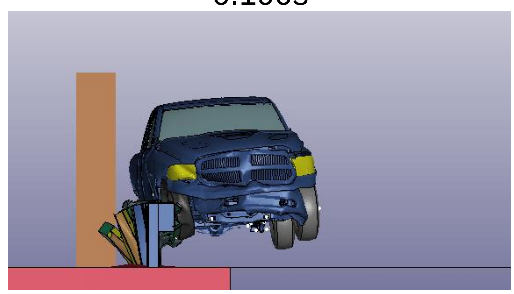

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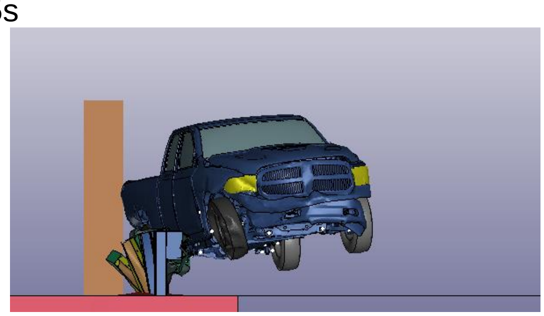


0.370s

Figure 2.57. *MASH* Test 3-11 Simulation of Half-Post Large Gap with Fixed Object 30 inch Offset – Downstream View

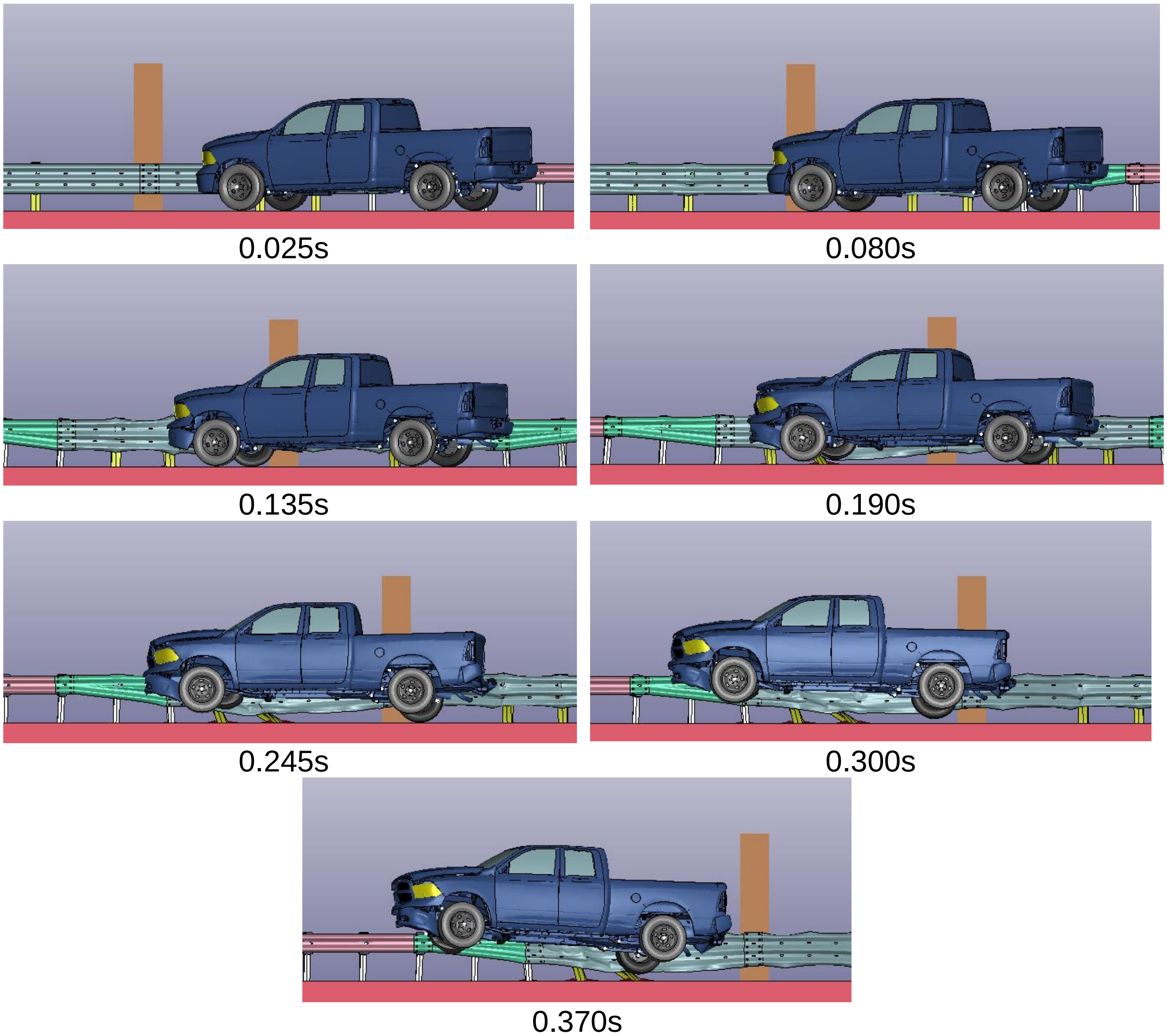


Figure 2.58. *MASH* Test 3-11 Simulation of Half-Post Large Gap with Fixed Object 30 inch Offset – Rear View

2.4.1.10. MASH Test 3-11 Simulation of Half-Post Spacing Large Gap with Fixed Object 30 inch Offset and 1 foot Upstream Impact Variation

Figure 2.59 through Figure 2.61 show the sequential frames of *MASH* test 3-11 with half-post spacing, large gap, a fixed object offset of 30 inches, and an impact variation positioned 1 foot upstream. The occupant impact velocity was calculated to be 4.3 m/s (preferred limit is 9.1 m/s). The ridedown acceleration was calculated to be 20.0 g's (maximum limit is 20.49 g's).

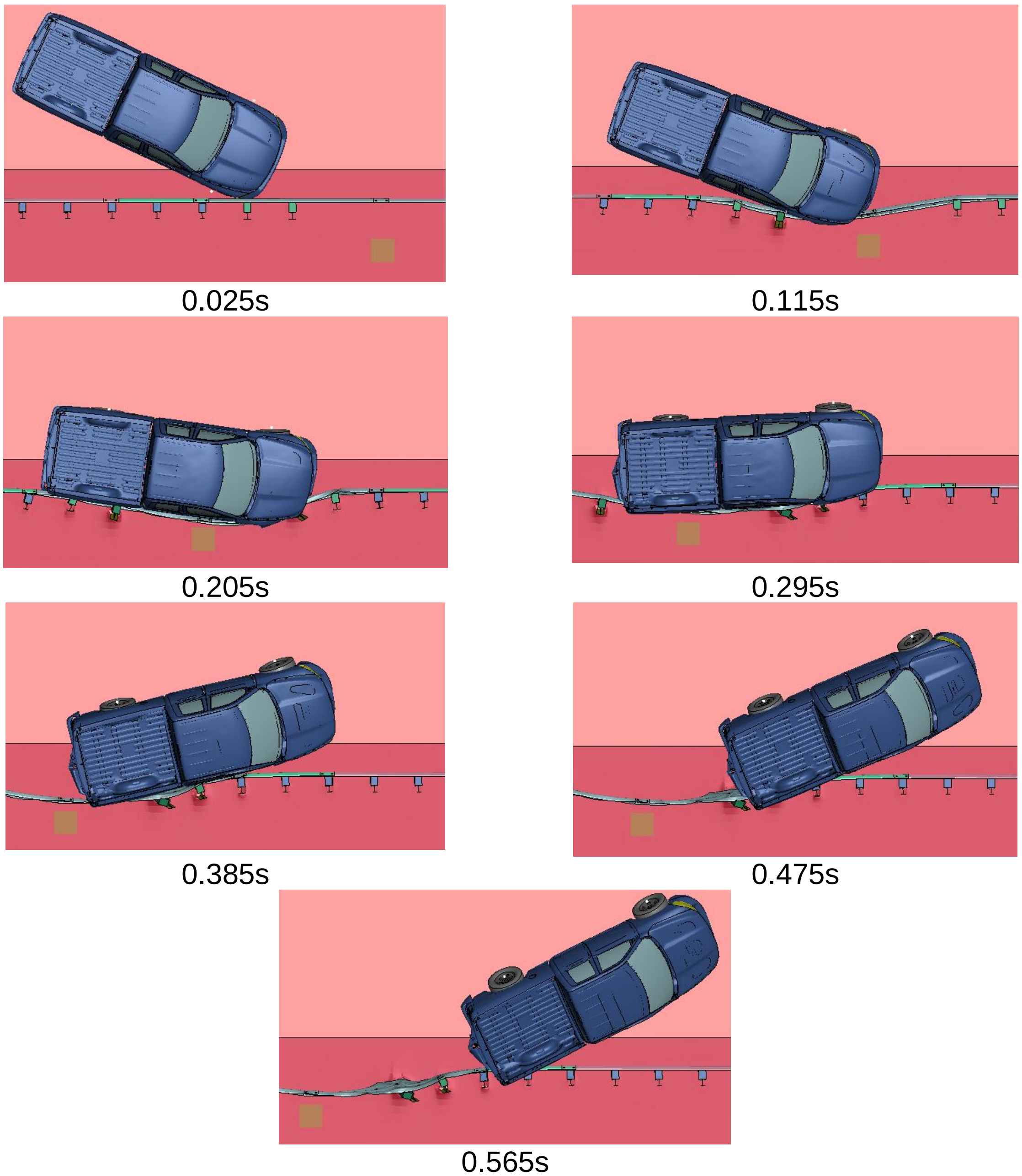


Figure 2.59. *MASH* Test 3-11 Simulation of Half-Post Large Gap with Fixed Object 30 inch Offset 1 foot Upstream Impact Variation – Overhead View

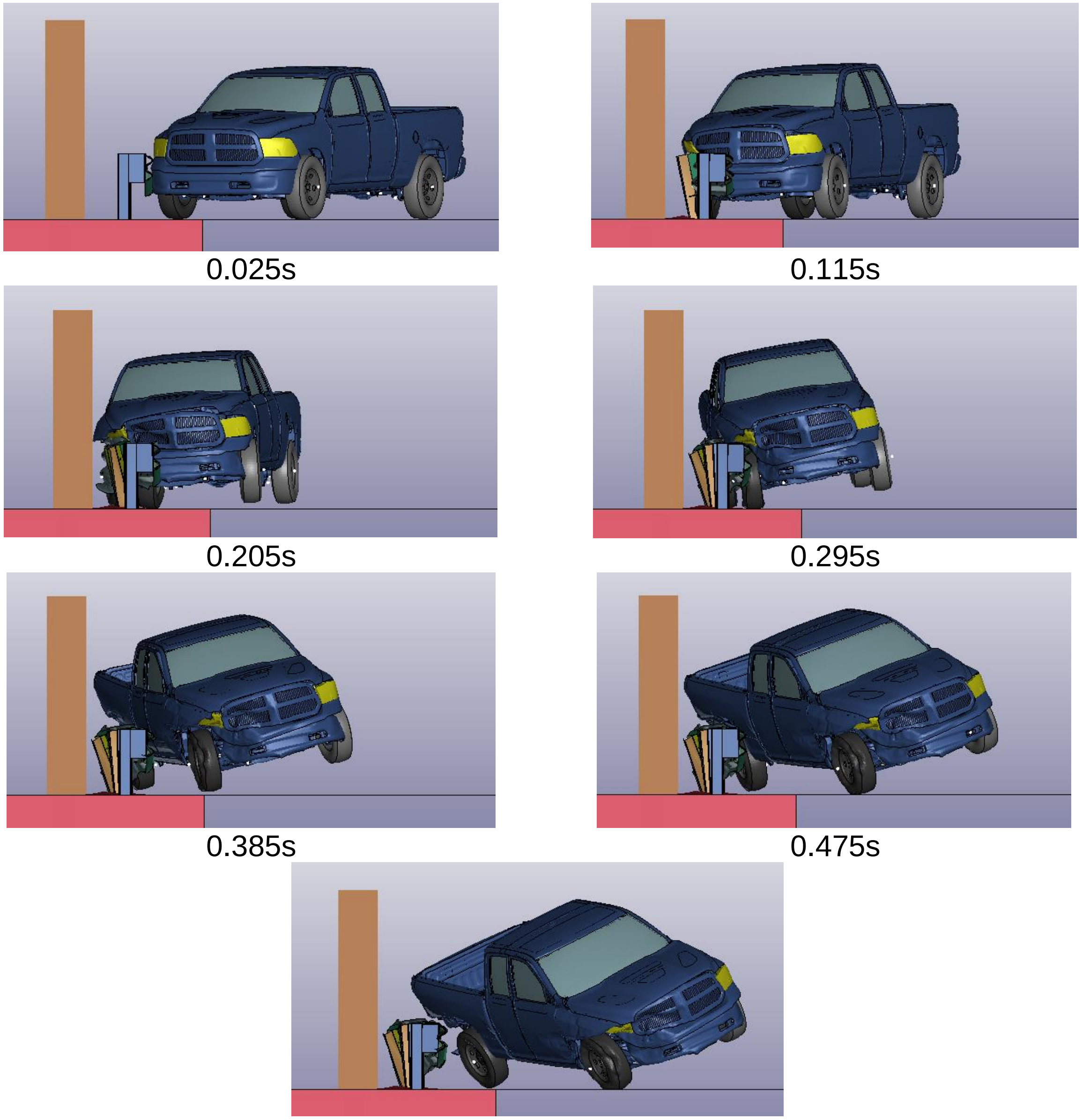


Figure 2.60. *MASH* Test 3-11 Simulation of Half-Post Large Gap with Fixed Object 30 inch Offset 1 foot Upstream Impact Variation– Downstream View

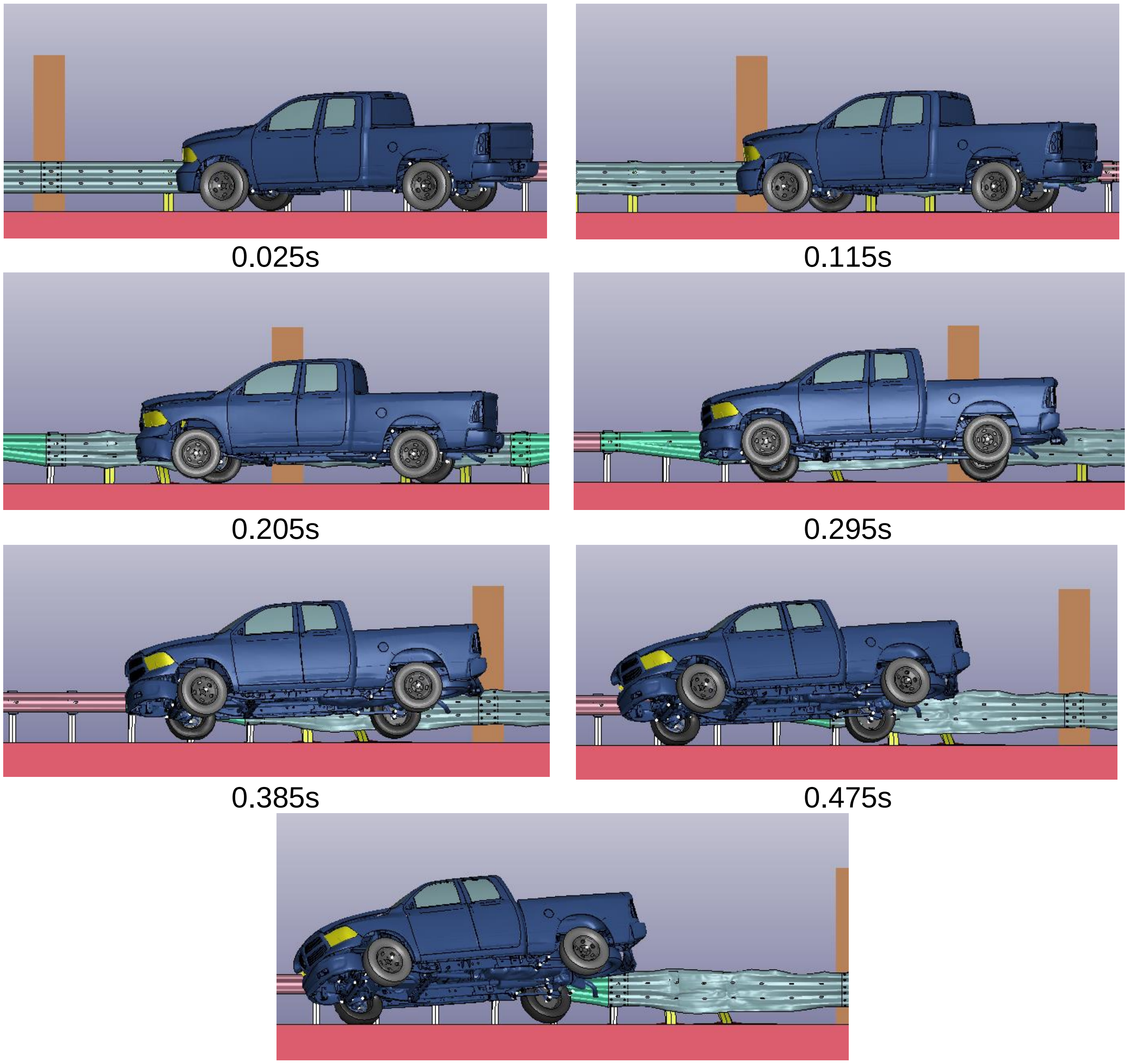
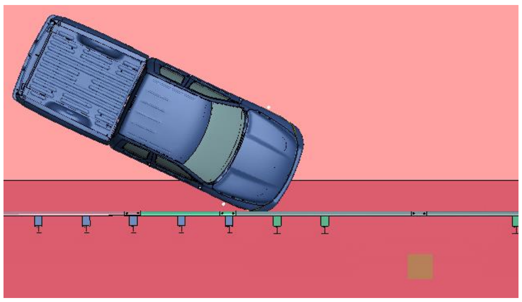


Figure 2.61. *MASH* Test 3-11 Simulation of Half-Post Large Gap with Fixed Object 30 inch Offset 1 foot Upstream Impact Variation– Rear View

2.4.1.11. MASH Test 3-11 Simulation of Half-Post Spacing Large Gap with Fixed Object 30 inch Offset and 2 feet Upstream Impact Variation

Figure 2.62 through Figure 2.64 show the sequential frames of *MASH* test 3-11 with half-post spacing, large gap, a fixed object offset of 30 inches, and an impact variation positioned 2 feet upstream. The occupant impact velocity was calculated to be 5.1m/s (preferred limit is 9.1 m/s). The ridedown acceleration was calculated to be 20.2 g’s (maximum limit is 20.49 g’s). This configuration passed *MASH* test 3-11 by successfully containing and redirecting the vehicle.



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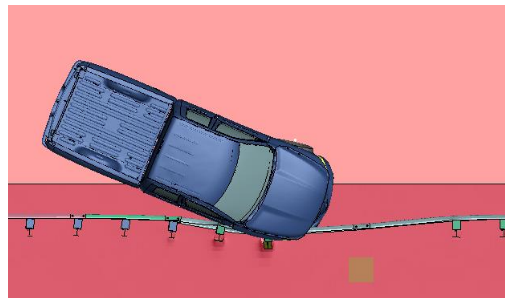

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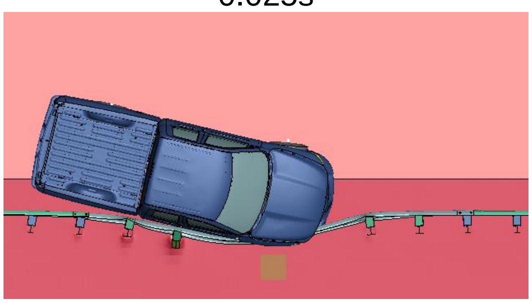

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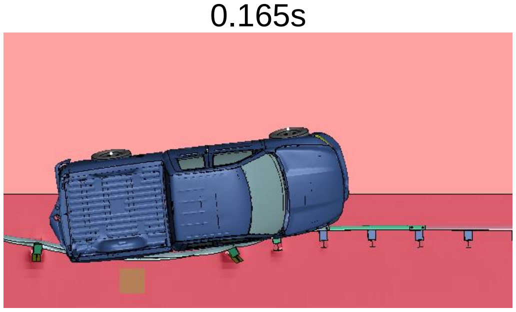
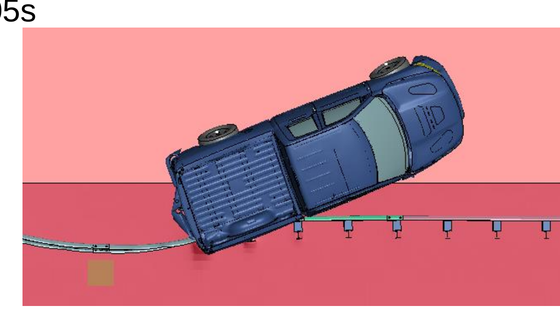
0.235s



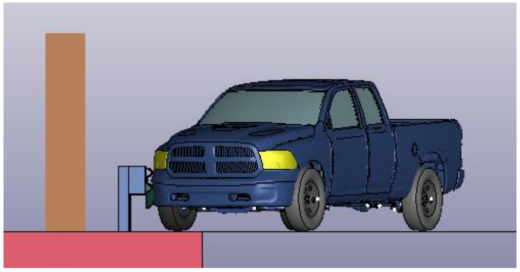
0.305s

0.375s



0.445s

Figure 2.62. *MASH* Test 3-11 Simulation of Half-Post Large Gap with Fixed Object 30 inch Offset 2 feet Upstream Impact Variation– Overhead View



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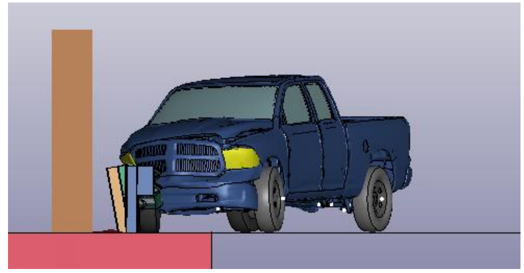

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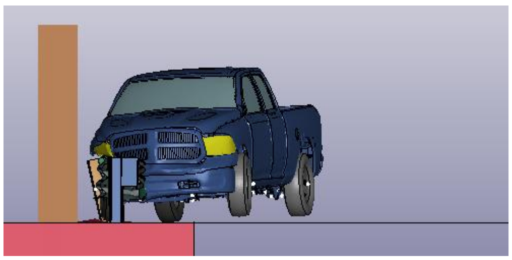

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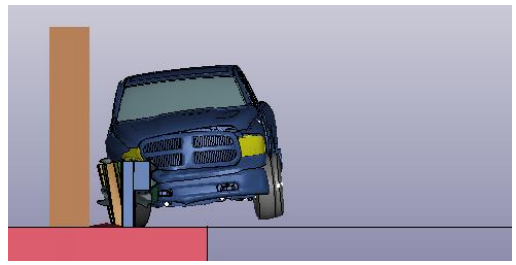

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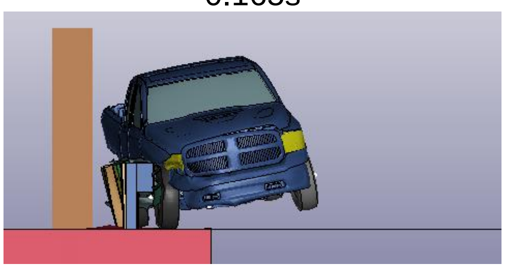

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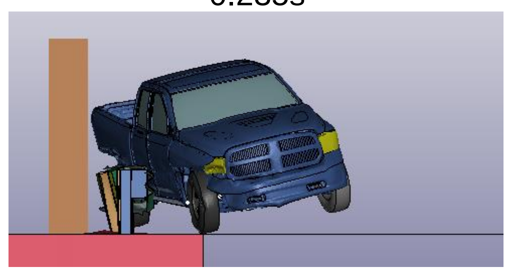

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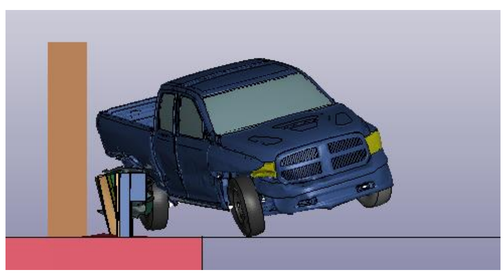
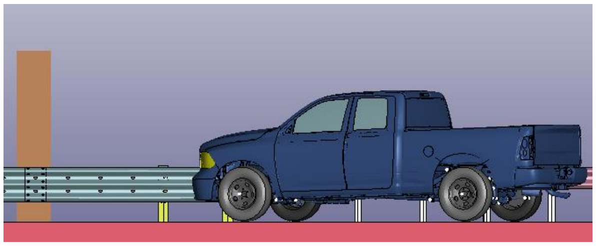


0.445s

Figure 2.63. *MASH* Test 3-11 Simulation of Half-Post Large Gap with Fixed Object 30 inch Offset 2 feet Upstream Impact Variation– Downstream View



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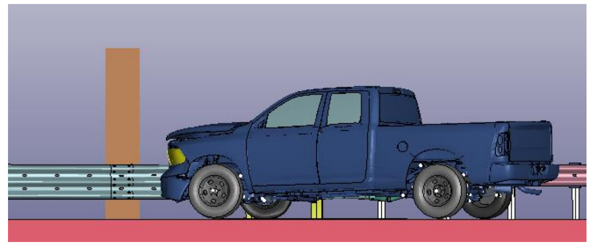

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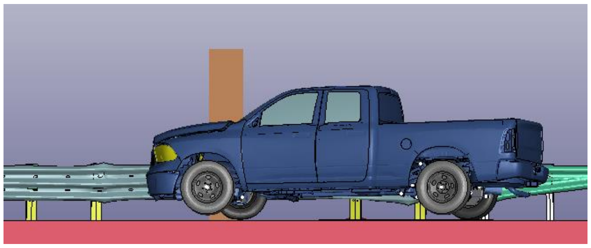

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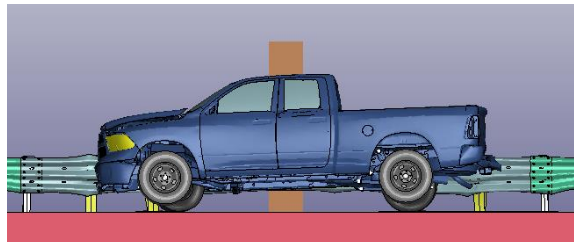

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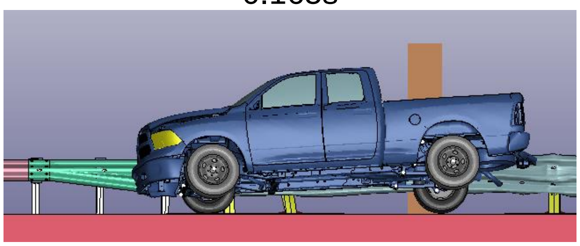

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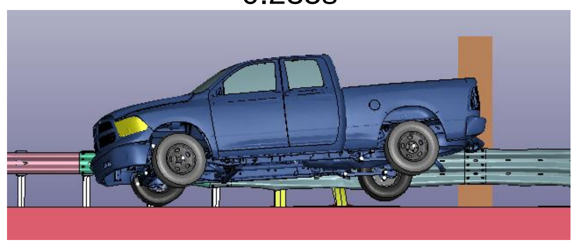

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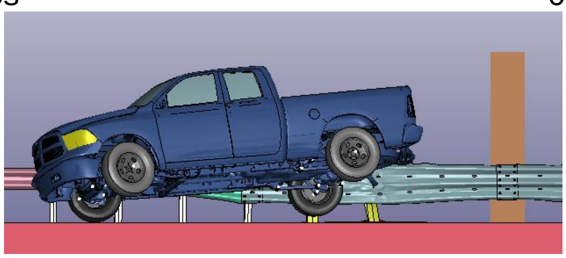


0.370s

Figure 2.64. *MASH* Test 3-11 Simulation of Half-Post Large Gap with Fixed Object 30 inch Offset 2 feet Upstream Impact Variation – Rear View

2.4.1.12. MASH Test 3-11 Simulation of Half-Post Spacing Large Gap with Fixed Object 30 inch Offset and 4 feet Upstream Impact Variation

Figure 2.65 through Figure 2.67 show the sequential frames of *MASH* test 3-11 with half-post spacing, large gap, a fixed object offset of 30 inches, and an impact variation positioned 4 feet upstream. The occupant impact velocity was calculated to be 6.3 m/s (preferred limit is 9.1 m/s). The ridedown acceleration was calculated to be 12.8 g's (preferred limit is 15.0 g's). This configuration passed *MASH* test 3-11 by successfully containing and redirecting the vehicle

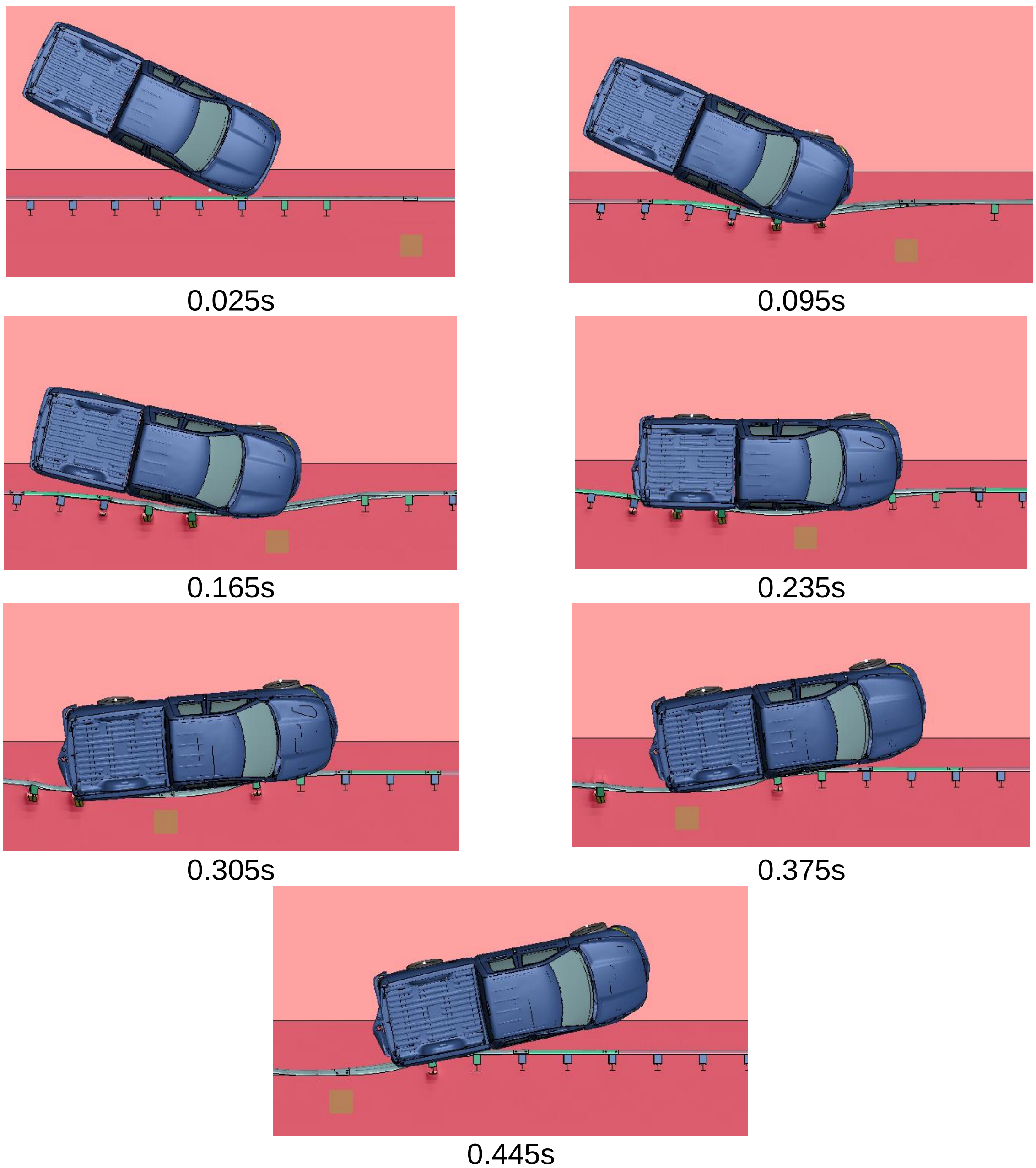
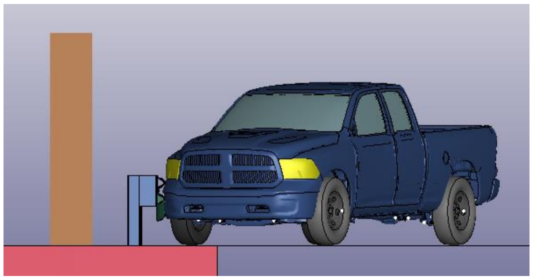
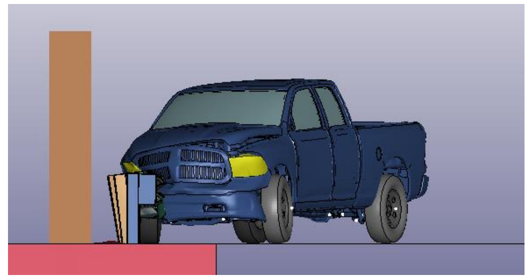
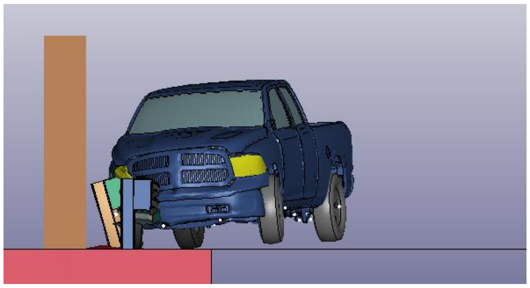


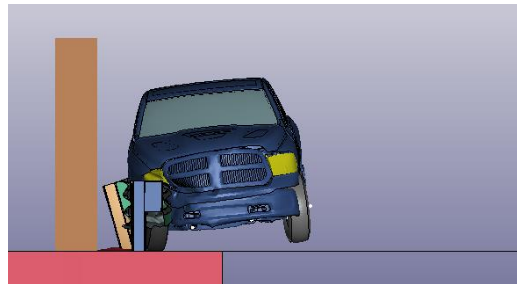
Figure 2.65. *MASH* Test 3-11 Simulation of Half-Post Large Gap with Fixed Object 30 inch Offset 4 feet Upstream Impact Variation – Overhead View



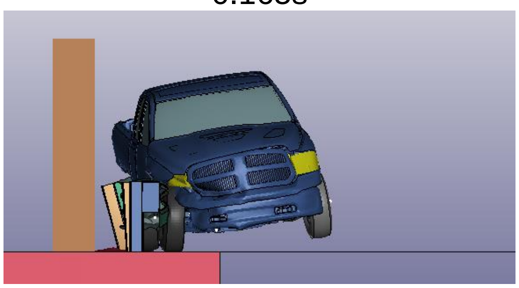


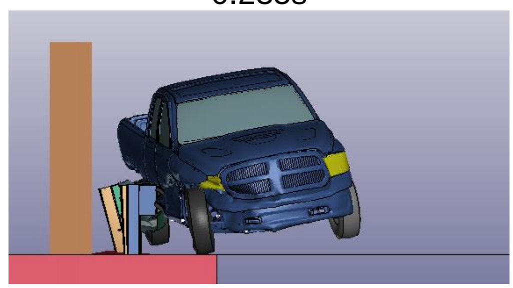
0.025s 0.095s



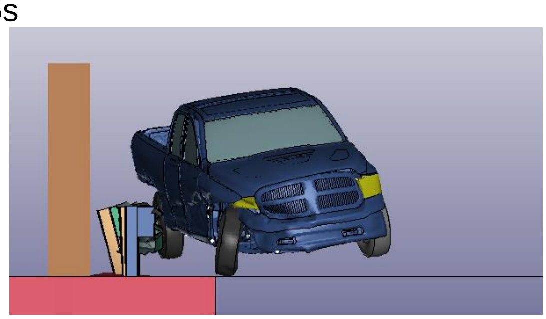


0.165s 0.235s





0.305s 0.375s



0.445s

Figure 2.66. *MASH* Test 3-11 Simulation of Half-Post Large Gap with Fixed Object 30 inch Offset 4 feet Upstream Impact Variation– Downstream View

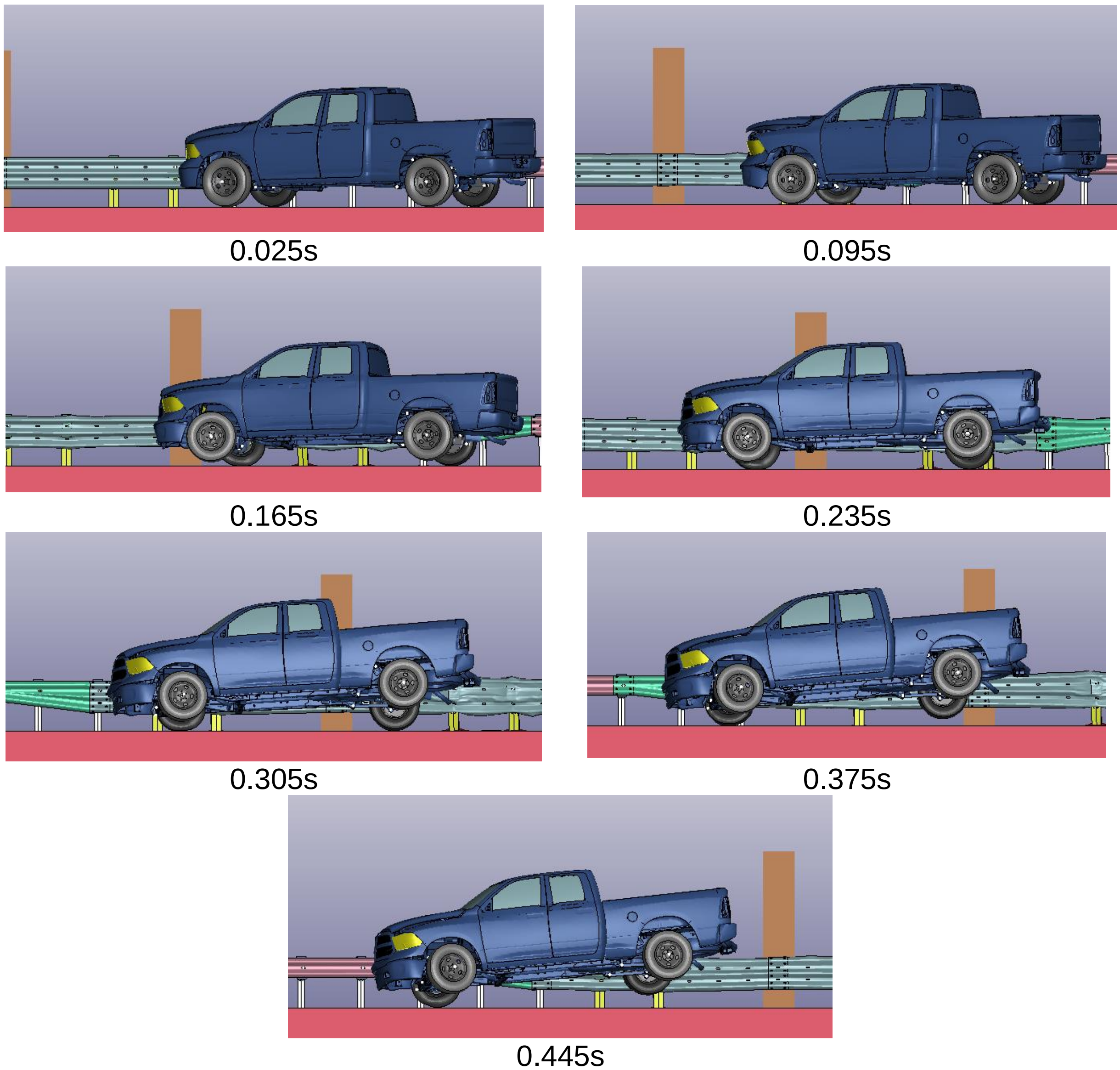


Figure 2.67. *MASH* Test 3-11 Simulation of Half-Post Large Gap with Fixed Object 30 inch Offset 4 feet Upstream Impact Variation – Rear View

2.4.1.13. MASH Test 3-11 Simulation of Half-Post Spacing Large Gap with Fixed Object 30 inch Offset and 6 feet Upstream Impact Variation

Figure 2.68 through Figure 2.70 show the sequential frames of *MASH* test 3-11 with half-post spacing, large gap, a fixed object offset of 30 inches, and an impact variation positioned 6 feet upstream. The occupant impact velocity was calculated to be 6.8 m/s (preferred limit is 9.1 m/s). The ridedown acceleration was calculated to be 10.1 g's (preferred limit is 15.0 g's). This configuration passed *MASH* test 3-11 by successfully containing and redirecting the vehicle

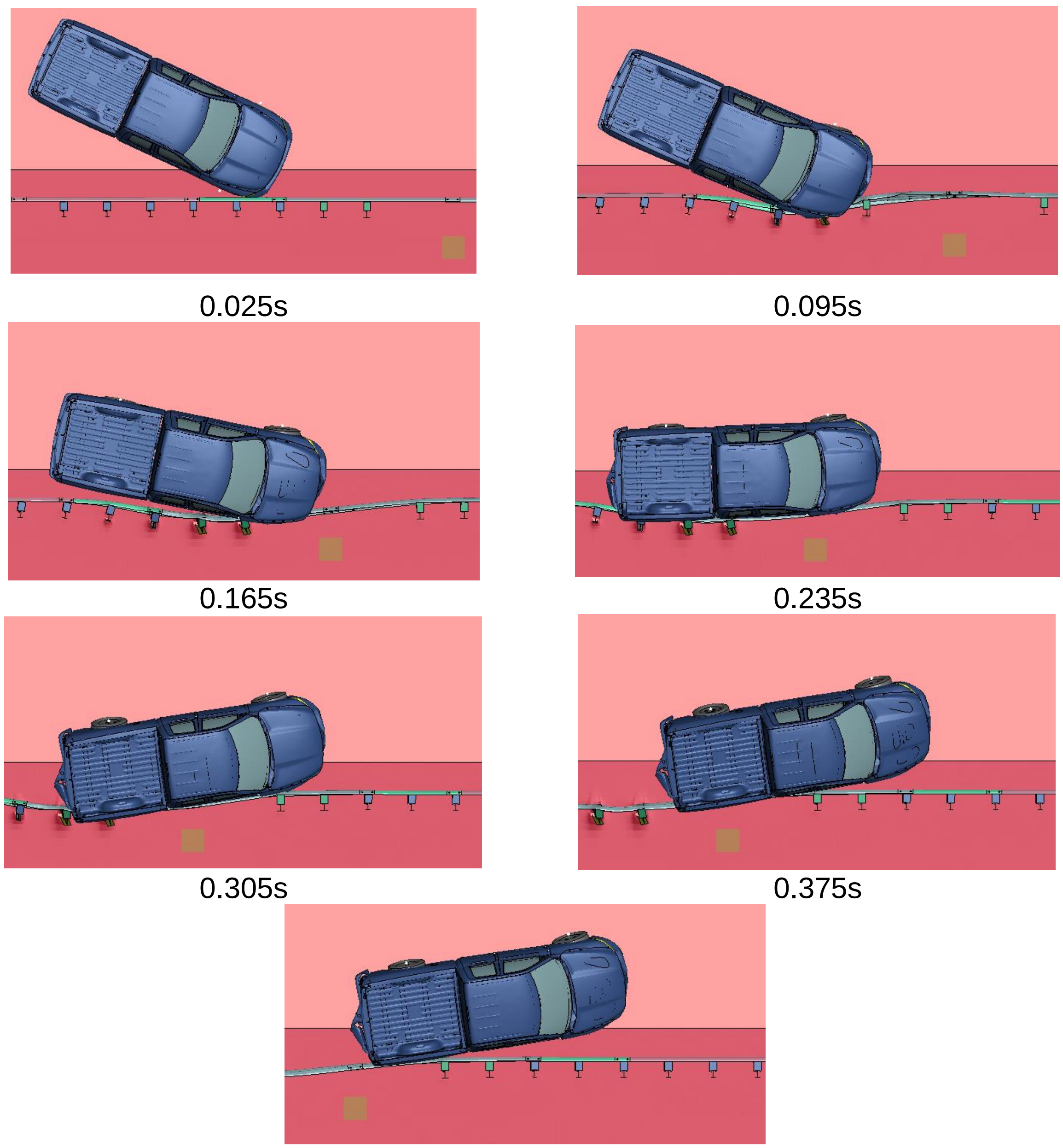


Figure 2.68. *MASH* Test 3-11 Simulation of Half-Post Large Gap with Fixed Object 30 inch Offset 6 feet Upstream Impact Variation – Overhead View

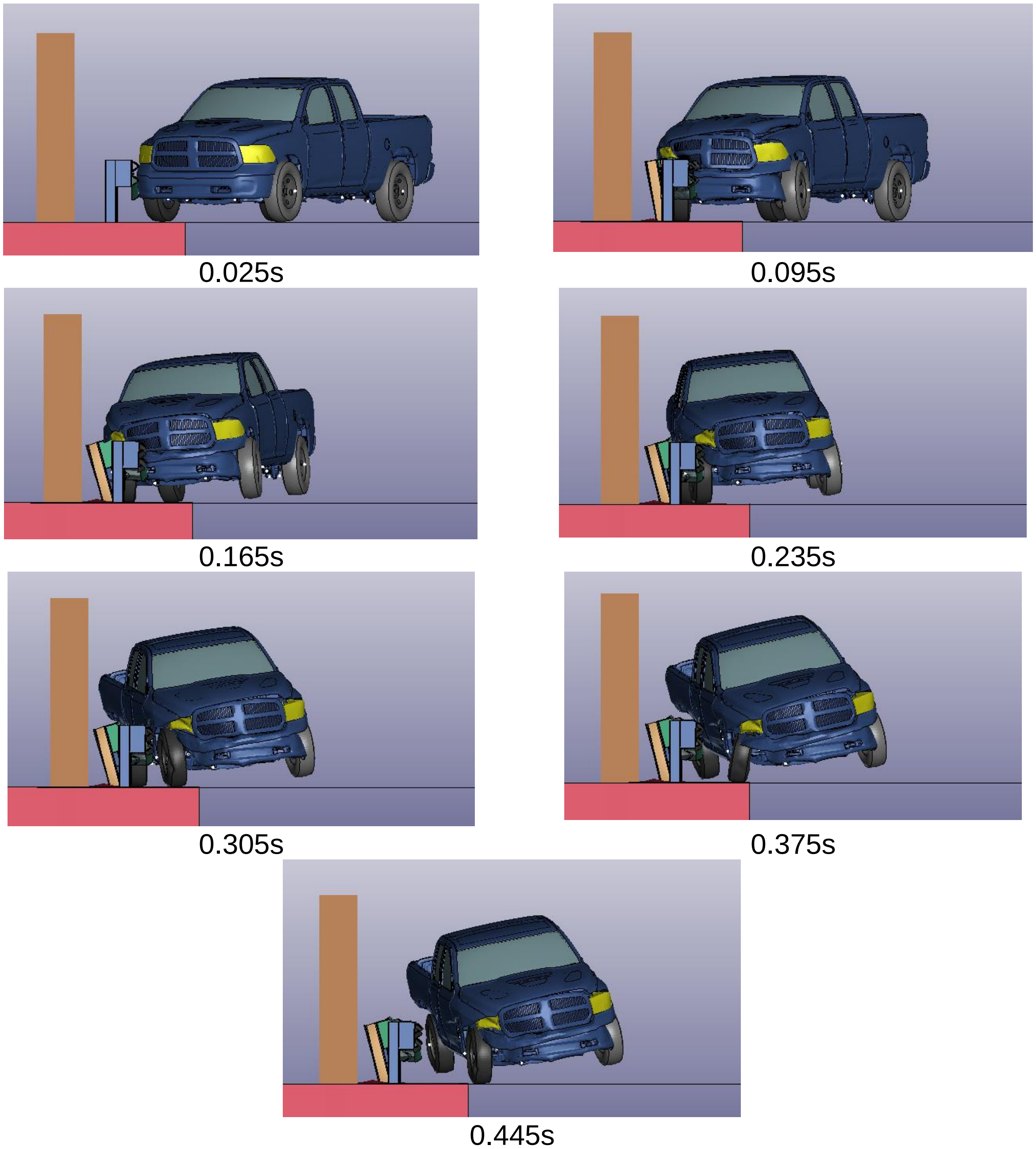
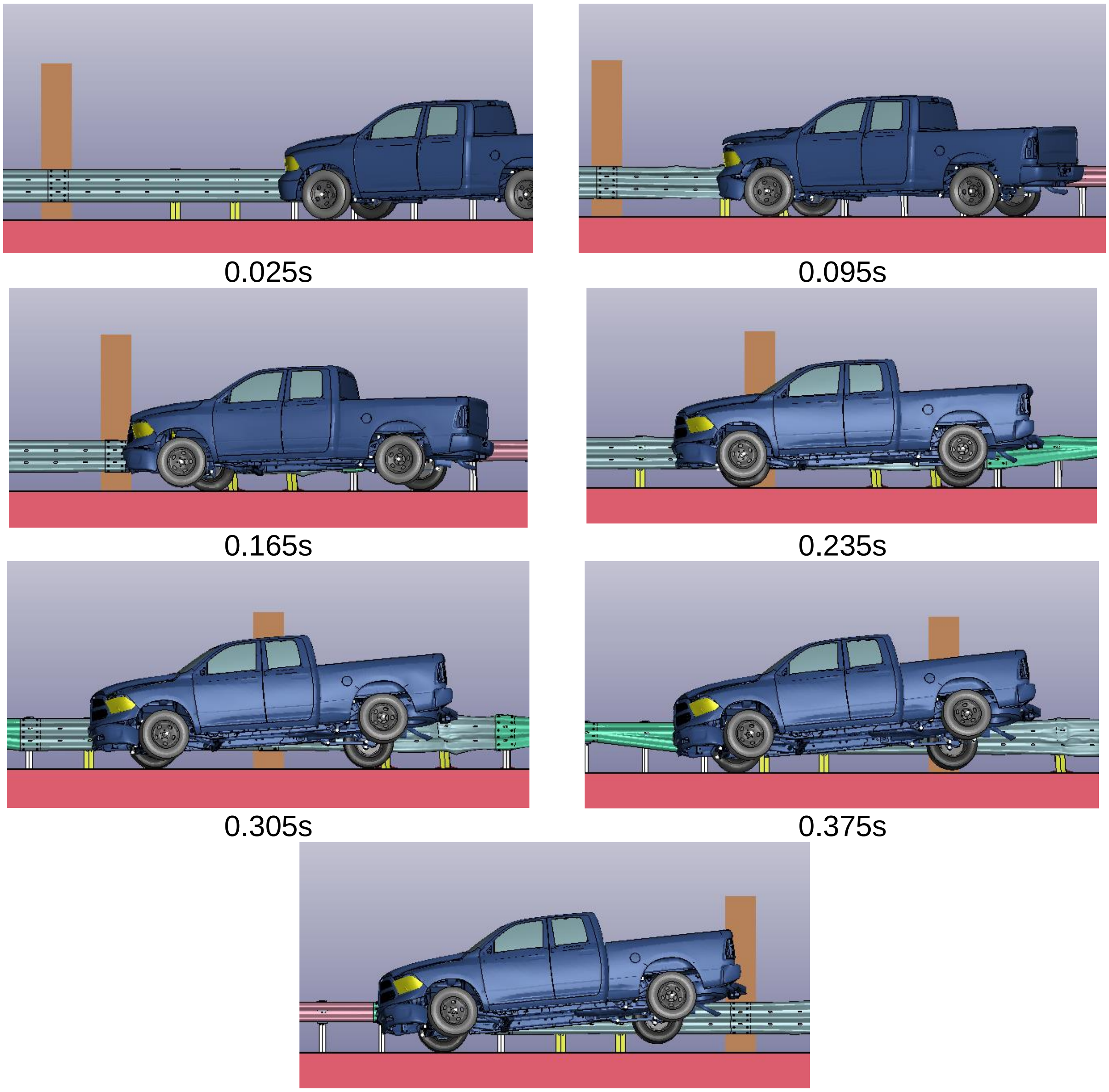


Figure 2.69. *MASH* Test 3-11 Simulation of Half-Post Large Gap with Fixed Object 30 inch Offset 6 feet Upstream Impact Variation– Downstream View

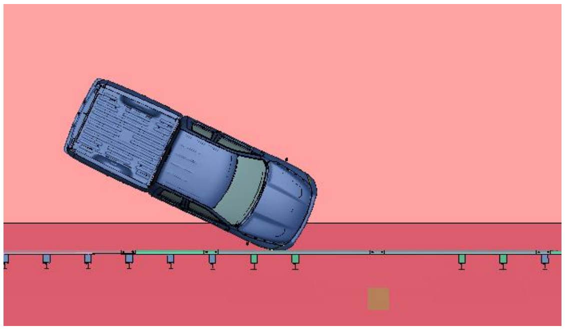


0.025s 0.095s 0.165s 0.235s 0.305s 0.375s 0.445s

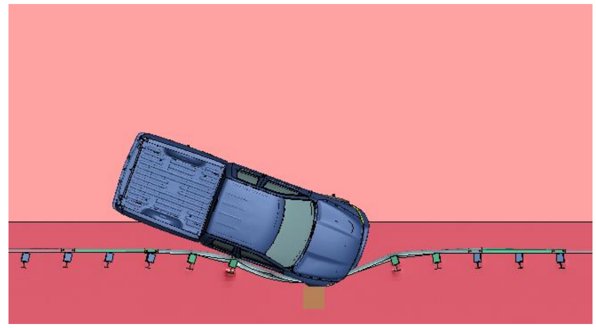
Figure 2.70. *MASH* Test 3-11 Simulation of Half-Post Large Gap with Fixed Object 30 inch Offset 6 feet Upstream Impact Variation– Rear View

2.4.1.14. MASH Test 3-11 Simulation of Half-Post Spacing Large Gap with Fixed Object 30 inch Offset and 1 foot Downstream Impact Variation

Figure 2.71 through Figure 2.73 show the sequential frames of *MASH* test 3-11 with half-post spacing, large gap, a fixed object offset of 30 inches, and an impact variation positioned 1 foot downstream. The pickup truck experienced excessive roll, which was deemed unsatisfactory.



0.025s



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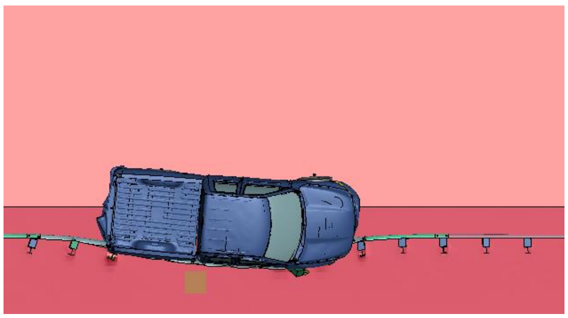

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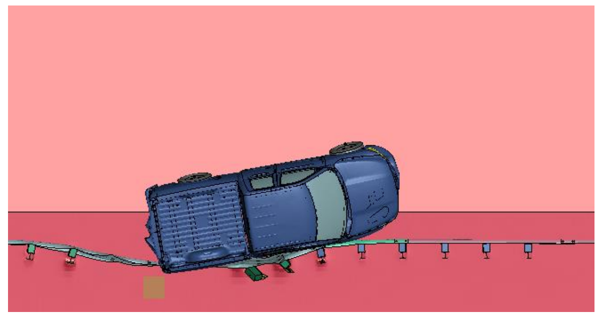

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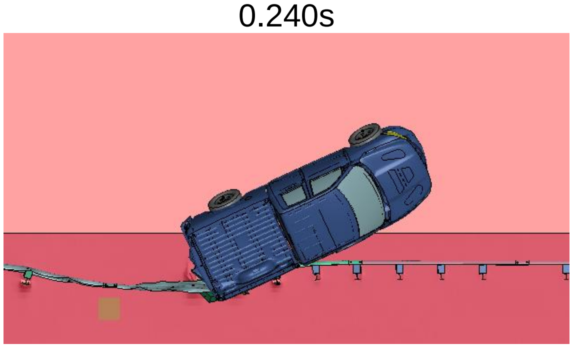
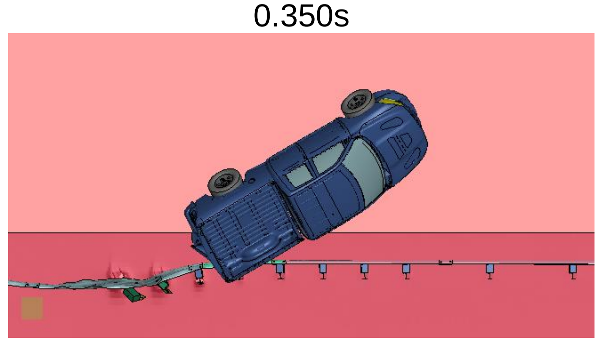


0.455s



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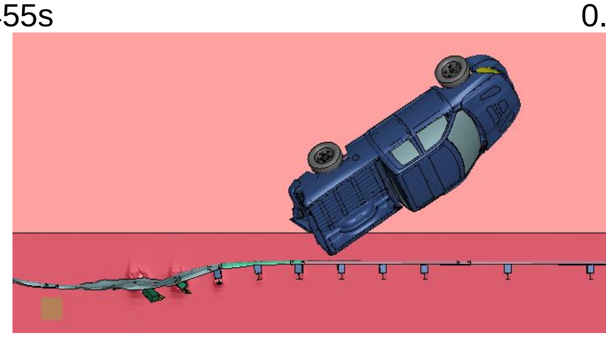


0.670s

Figure 2.71. *MASH* Test 3-11 Simulation of Half-Post Large Gap with Fixed Object 30 inch Offset 1 foot Downstream Impact Variation – Overhead View

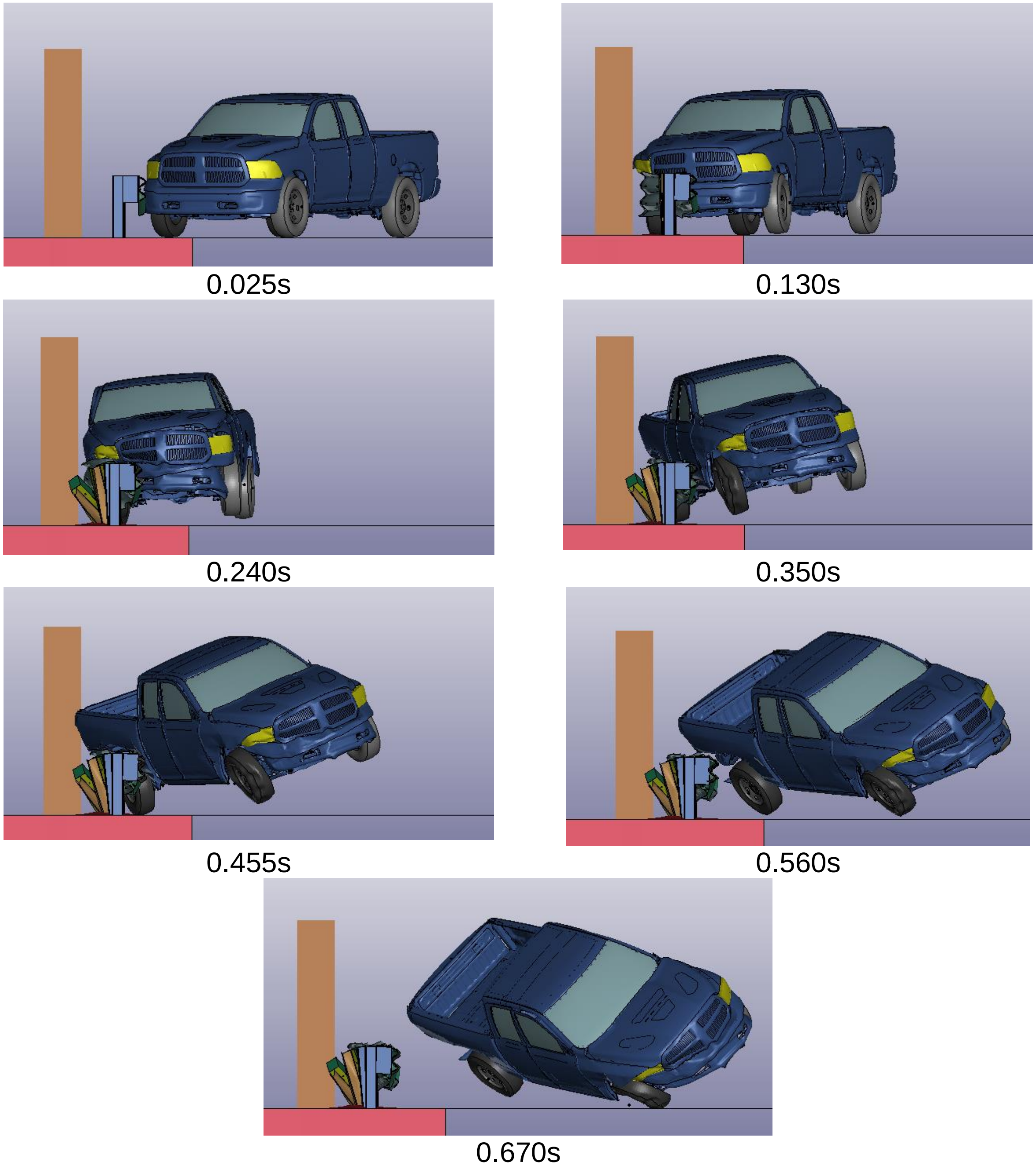


Figure 2.72. *MASH* Test 3-11 Simulation of Half-Post Large Gap with Fixed Object 30 inch Offset 1 foot Downstream Impact Variation– Downstream View

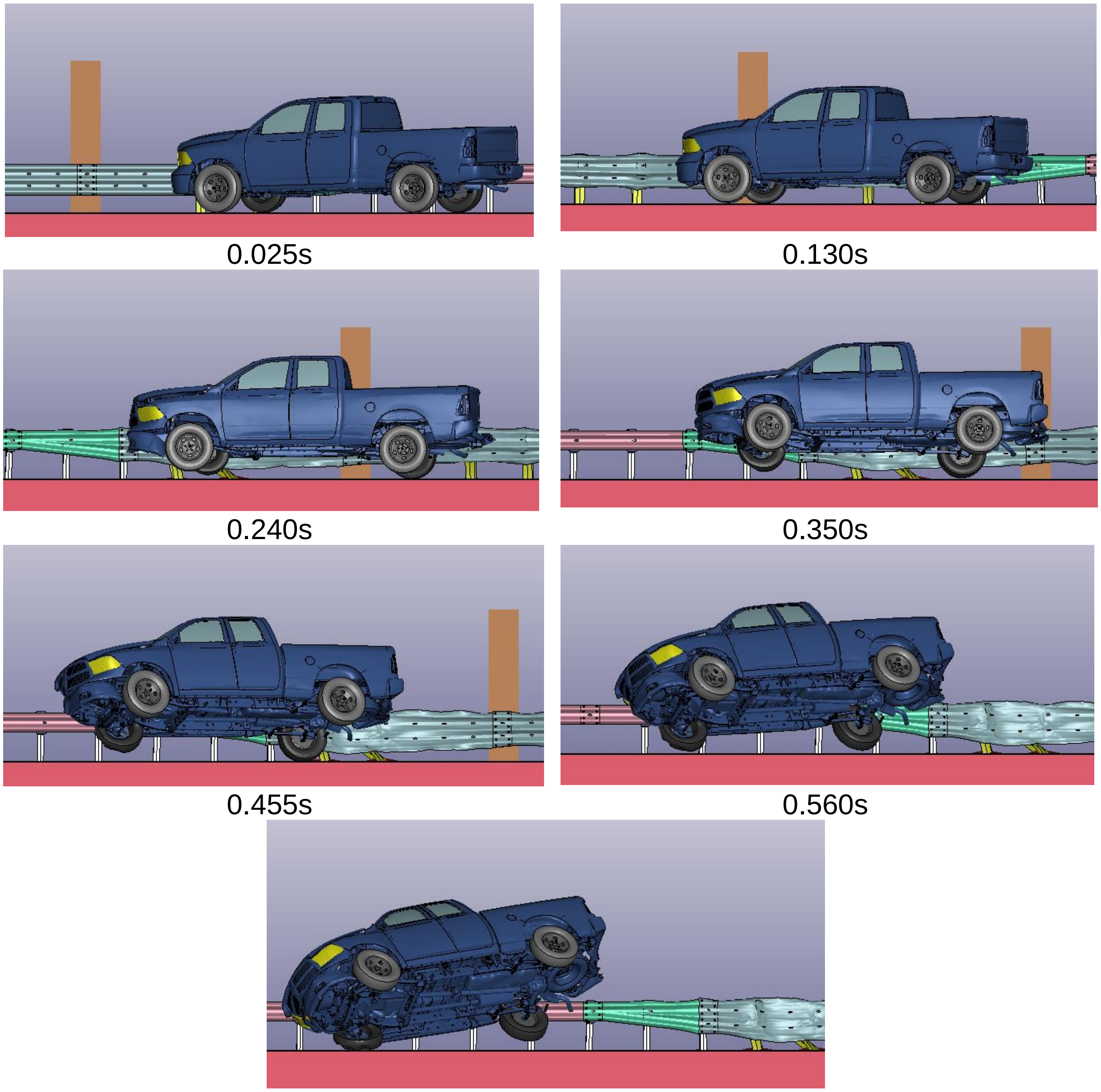
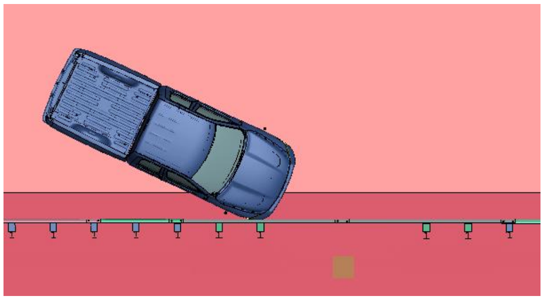


Figure 2.73. *MASH* Test 3-11 Simulation of Half-Post Large Gap with Fixed Object 30 inch Offset 1 foot Downstream Impact Variation– Rear View

2.4.1.15. MASH Test 3-11 Simulation of Half-Post Spacing Large Gap with Fixed Object 30 inch Offset and 2 feet Downstream Impact Variation

Figure 2.74 through Figure 2.76 show the sequential frames of *MASH* test 3-11 with half-post spacing, large gap, a fixed object offset of 30 inches, and an impact variation positioned 2 feet downstream. The pickup truck experienced excessive roll, which was deemed unsatisfactory.



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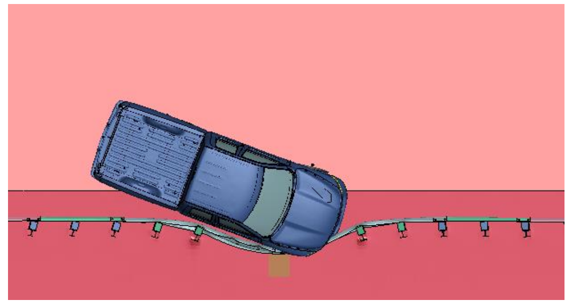

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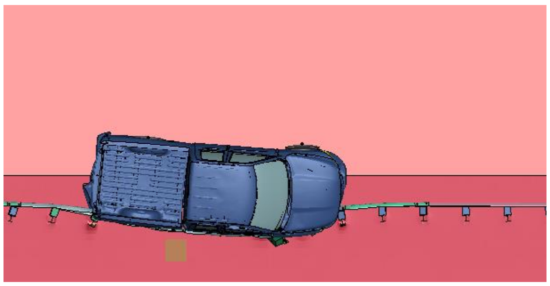
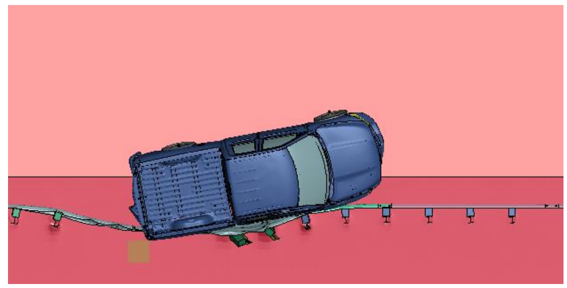


0.235s



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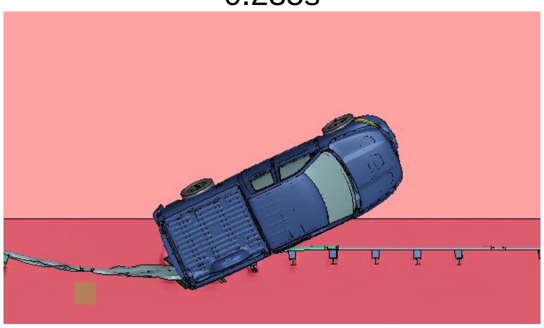

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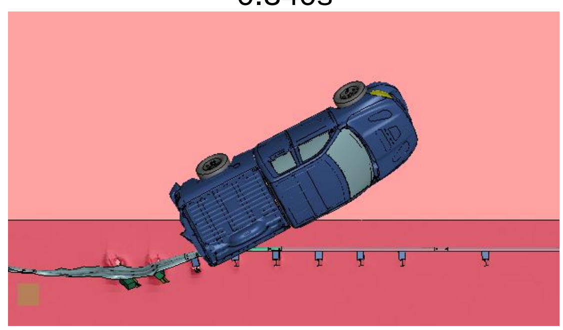

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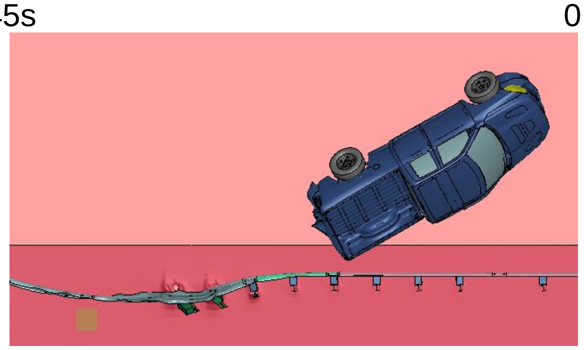
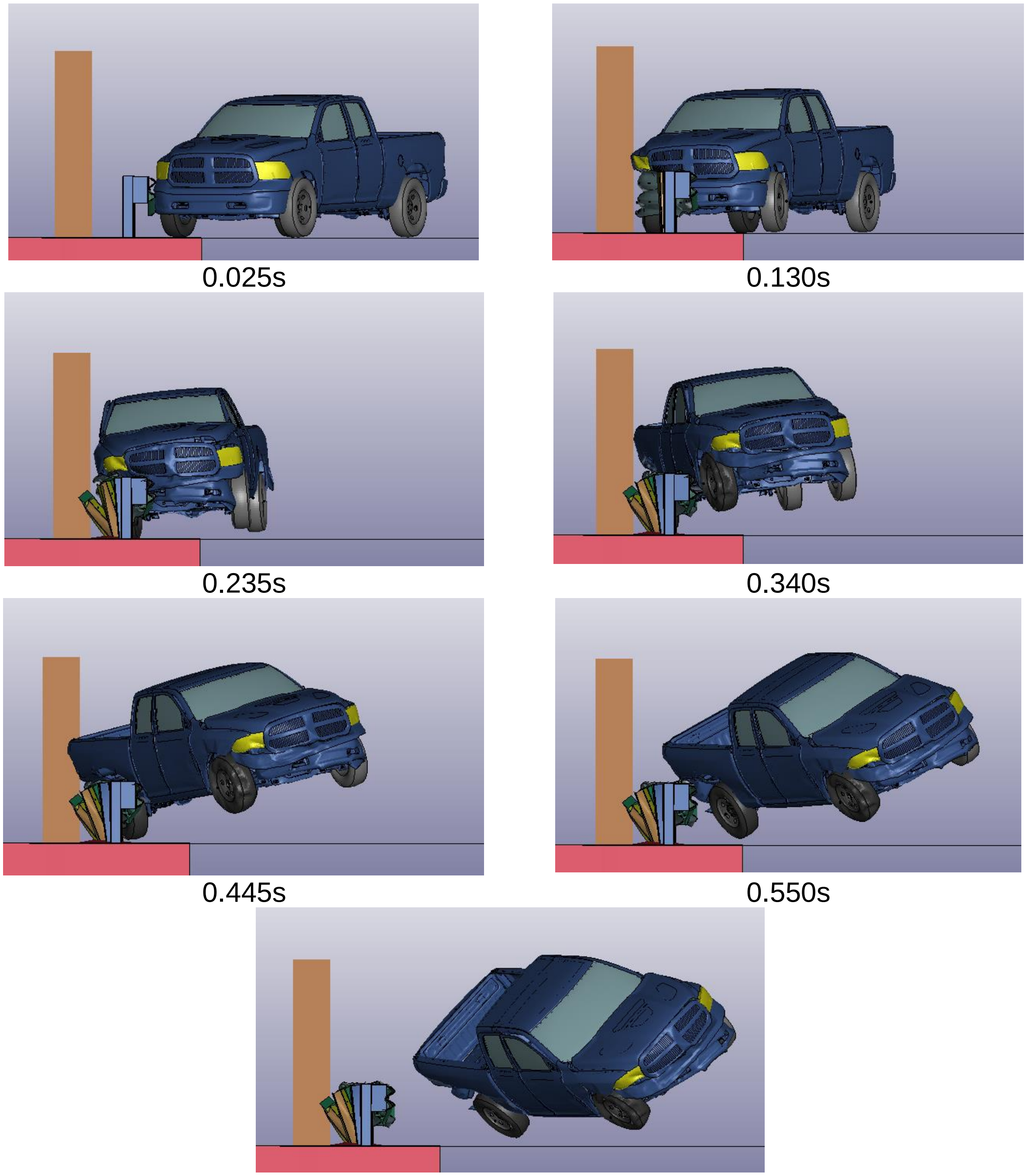


0.660s

Figure 2.74. *MASH* Test 3-11 Simulation of Half-Post Large Gap with Fixed Object 30 inch Offset 2 feet Downstream Impact Variation – Overhead View



0.025s 0.130s 0.235s 0.340s 0.445s 0.550s 0.660s

Figure 2.75. *MASH* Test 3-11 Simulation of Half-Post Large Gap with Fixed Object 30 inch Offset 2 feet Downstream Impact Variation– Downstream View

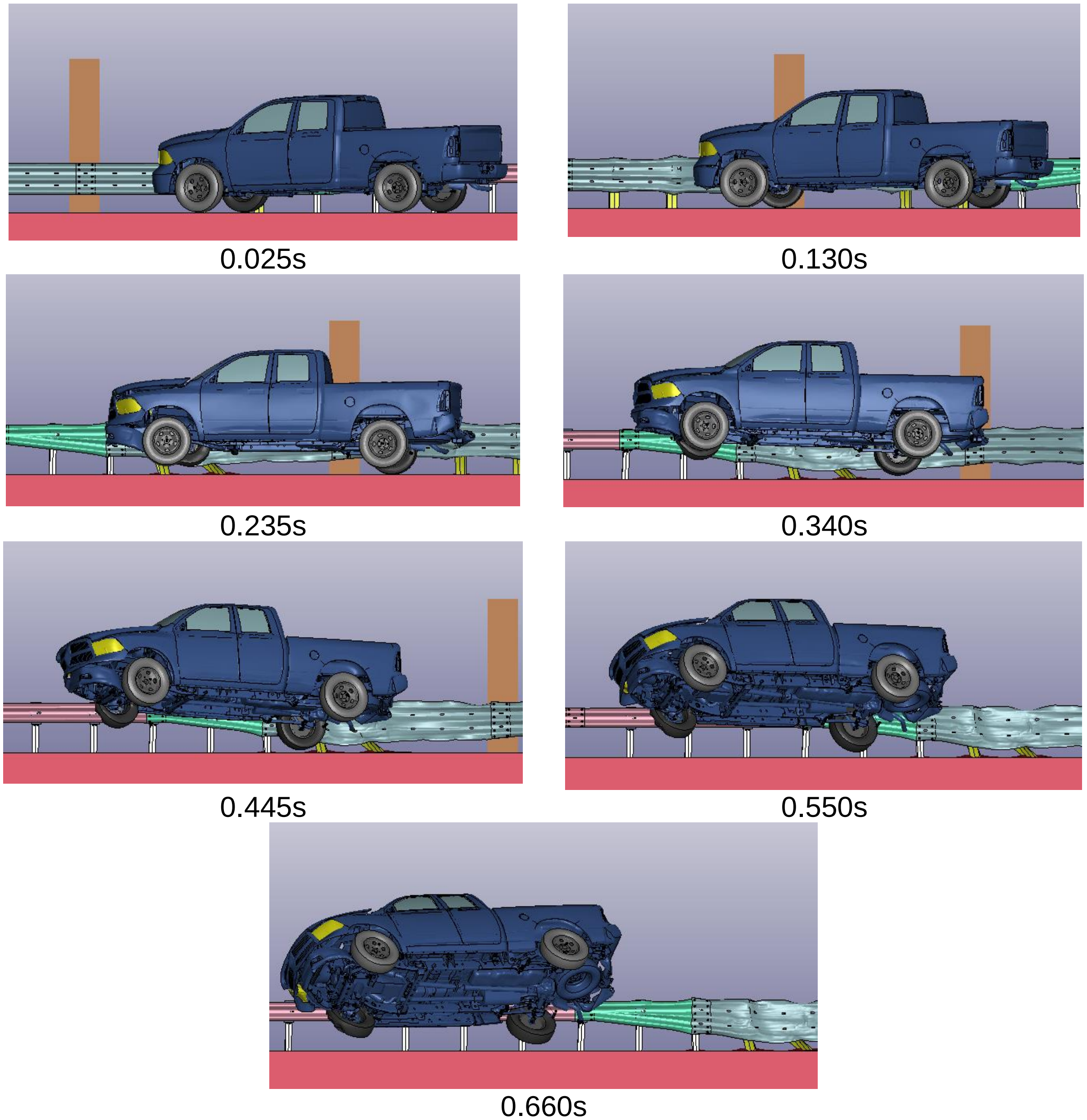


Figure 2.76. *MASH* Test 3-11 Simulation of Half-Post Large Gap with Fixed Object 30 inch Offset 2 feet Downstream Impact Variation– Rear View

2.4.1.16. MASH Test 3-11 Simulation of Half-Post Spacing Large Gap with Fixed Object 30 inch Offset and 4 feet Downstream Impact Variation

Figure 2.77 through Figure 2.79 show the sequential frames of *MASH* test 3-11 with half-post spacing, large gap, a fixed object offset of 30 inches, and an impact variation positioned 4 feet downstream. The pickup truck experienced excessive vehicle climb, which was deemed unsatisfactory.

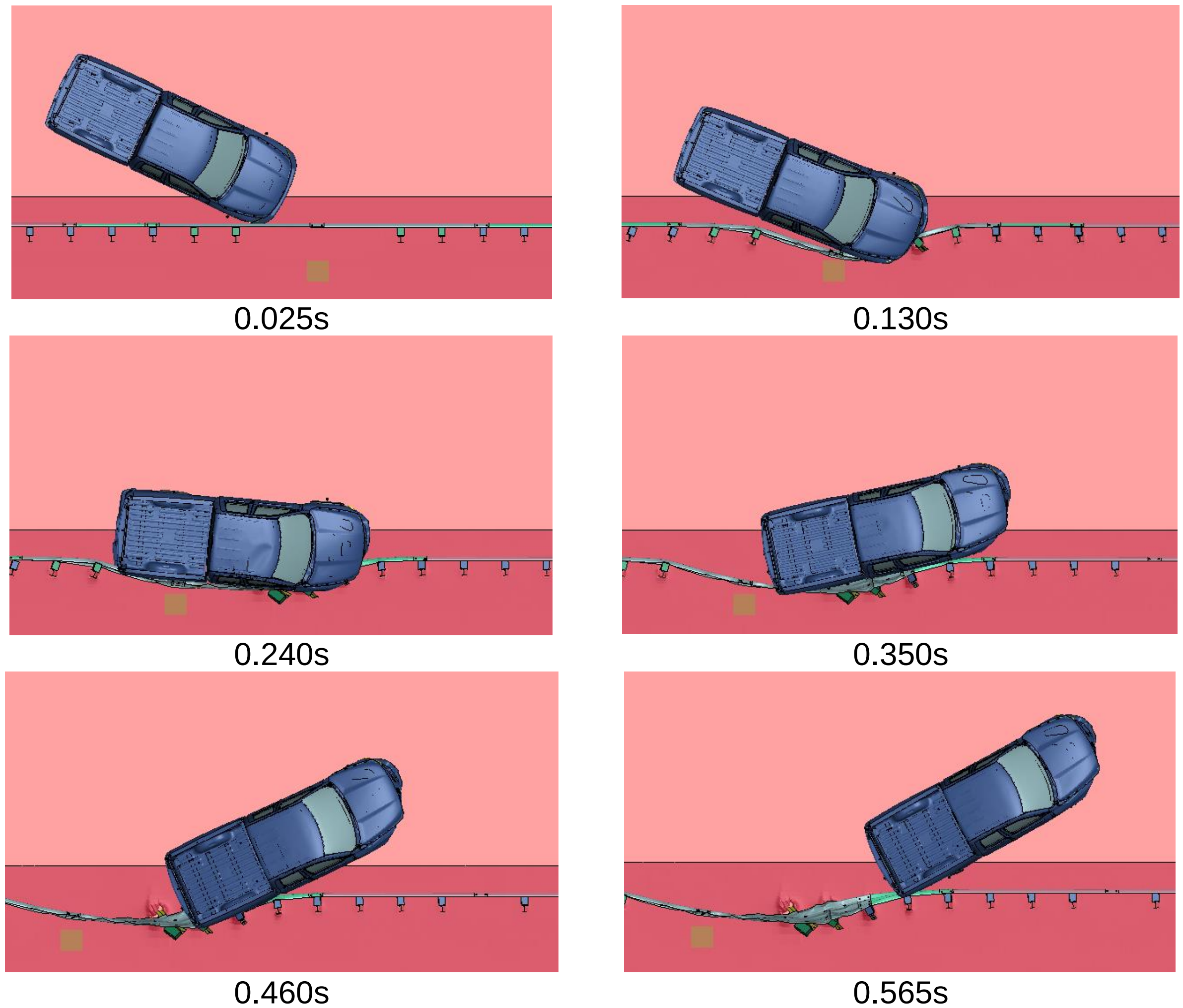


Figure 2.77. *MASH* Test 3-11 Simulation of Half-Post Large Gap with Fixed Object 30 inch Offset 4 feet Downstream Impact Variation – Overhead View

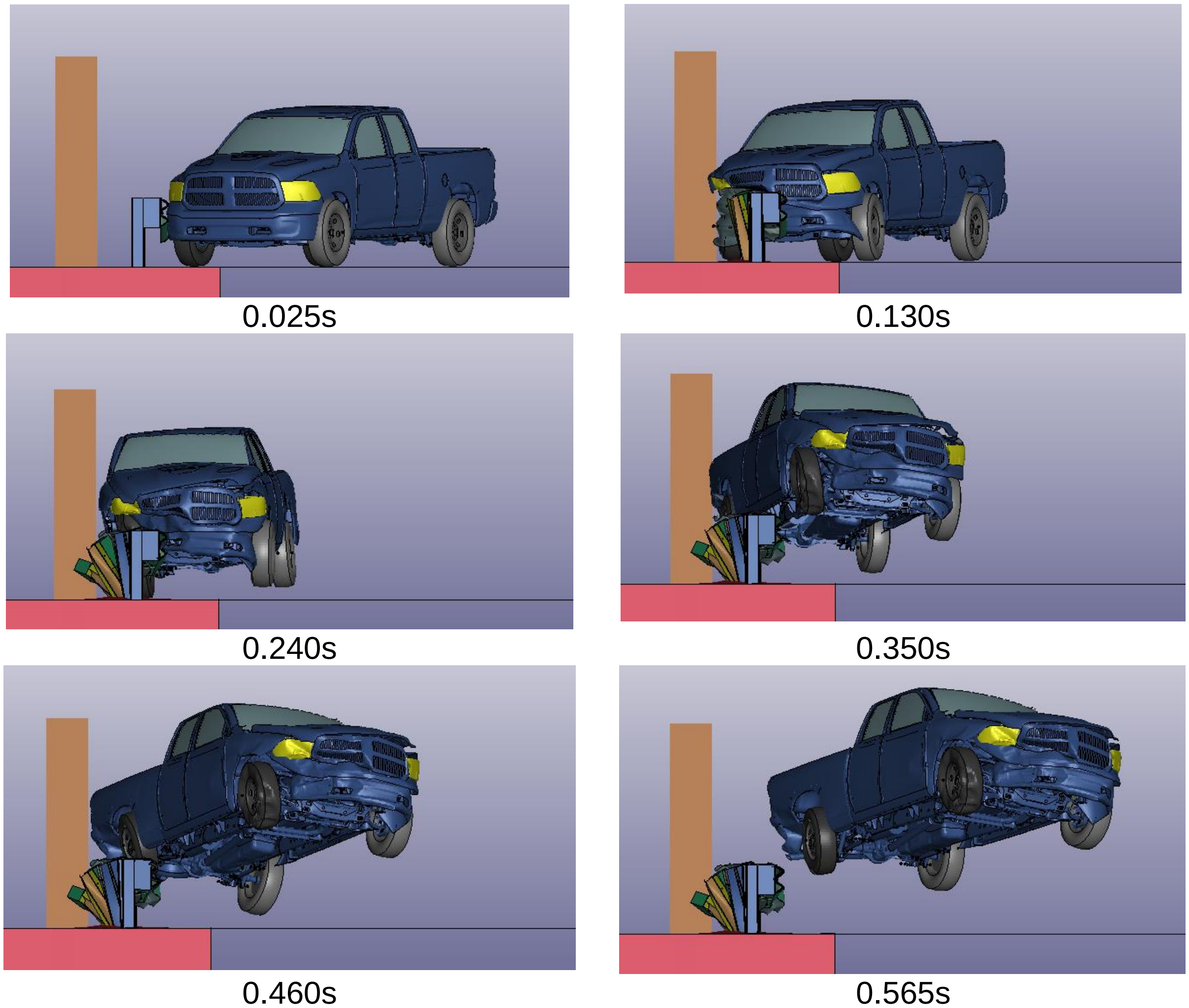


Figure 2.78. *MASH* Test 3-11 Simulation of Half-Post Large Gap with Fixed Object 30 inch Offset 4 feet Downstream Impact Variation– Downstream View

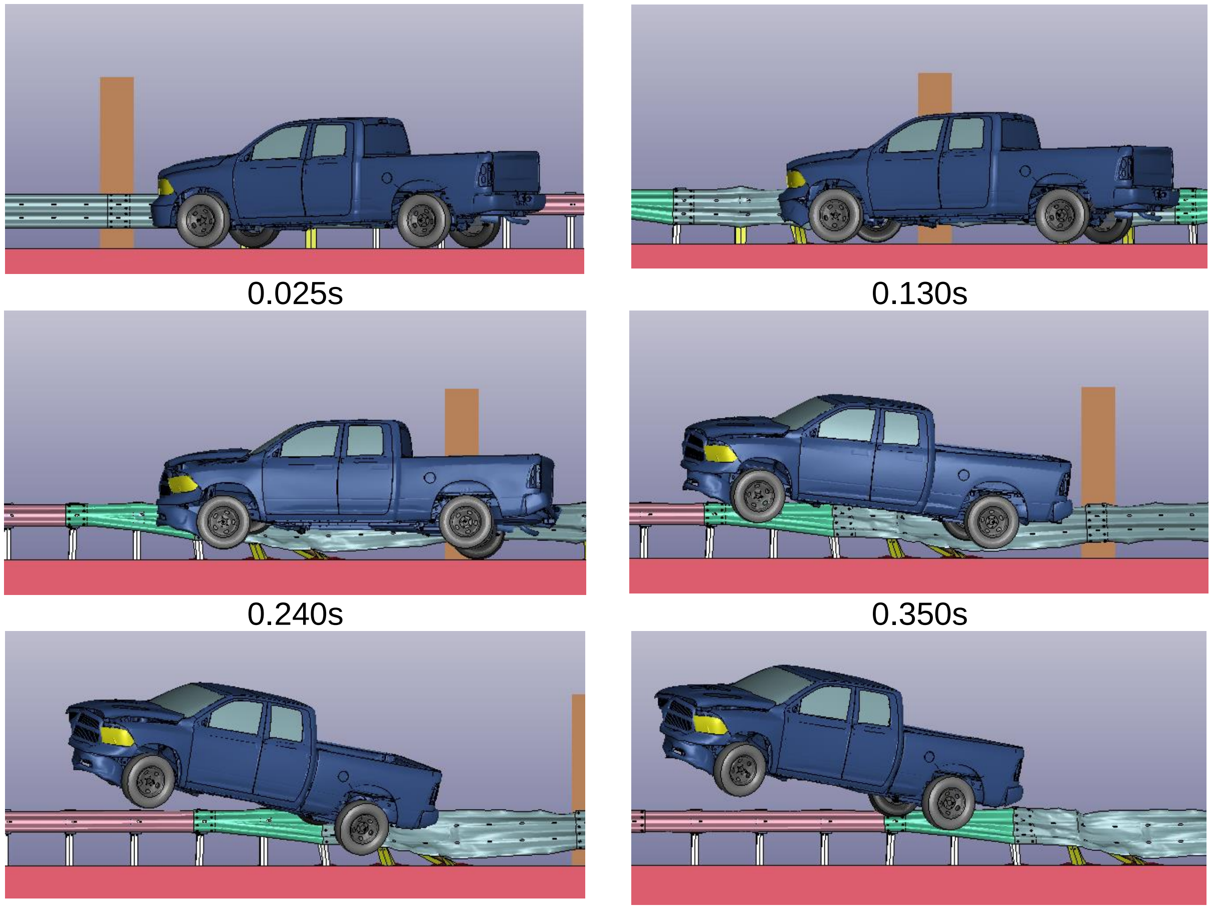


Figure 2.79. *MASH* Test 3-11 Simulation of Half-Post Large Gap with Fixed Object 30 inch Offset 4 feet Downstream Impact Variation– Rear View

2.4.1.17. MASH Test 3-11 Simulation of Half-Post Spacing Large Gap with Fixed Object 30 inch Offset and 6 feet Downstream Impact Variation

Figure 2.80 through Figure 2.82 show the sequential frames of *MASH* test 3-11 with half-post spacing, large gap, a fixed object offset of 30 inches, and an impact variation positioned 6 feet downstream. The pickup truck experienced excessive roll, which was deemed unsatisfactory.

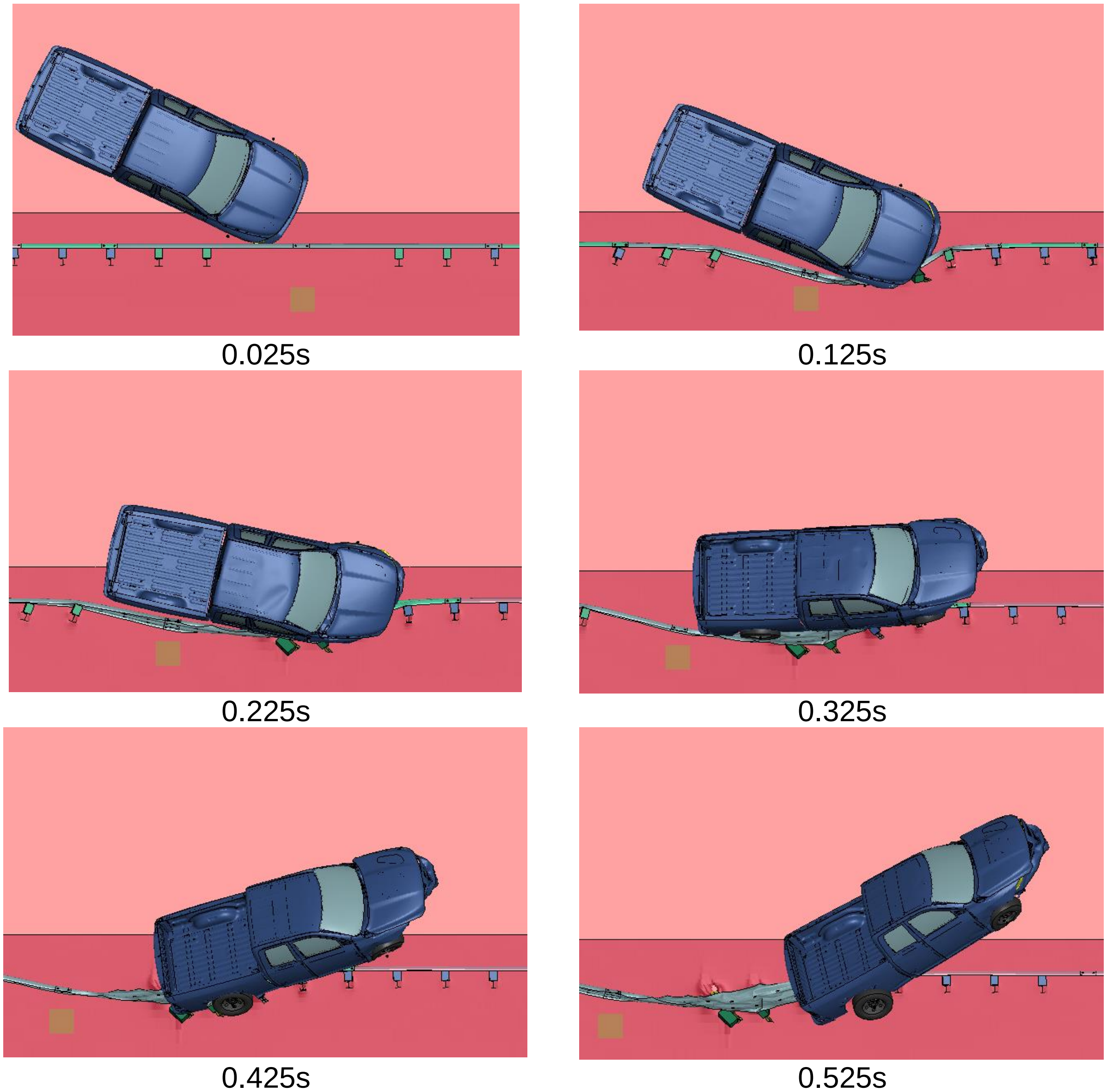


Figure 2.80. *MASH* Test 3-11 Simulation of Half-Post Large Gap with Fixed Object 30 inch Offset 6 feet Downstream Impact Variation – Overhead View

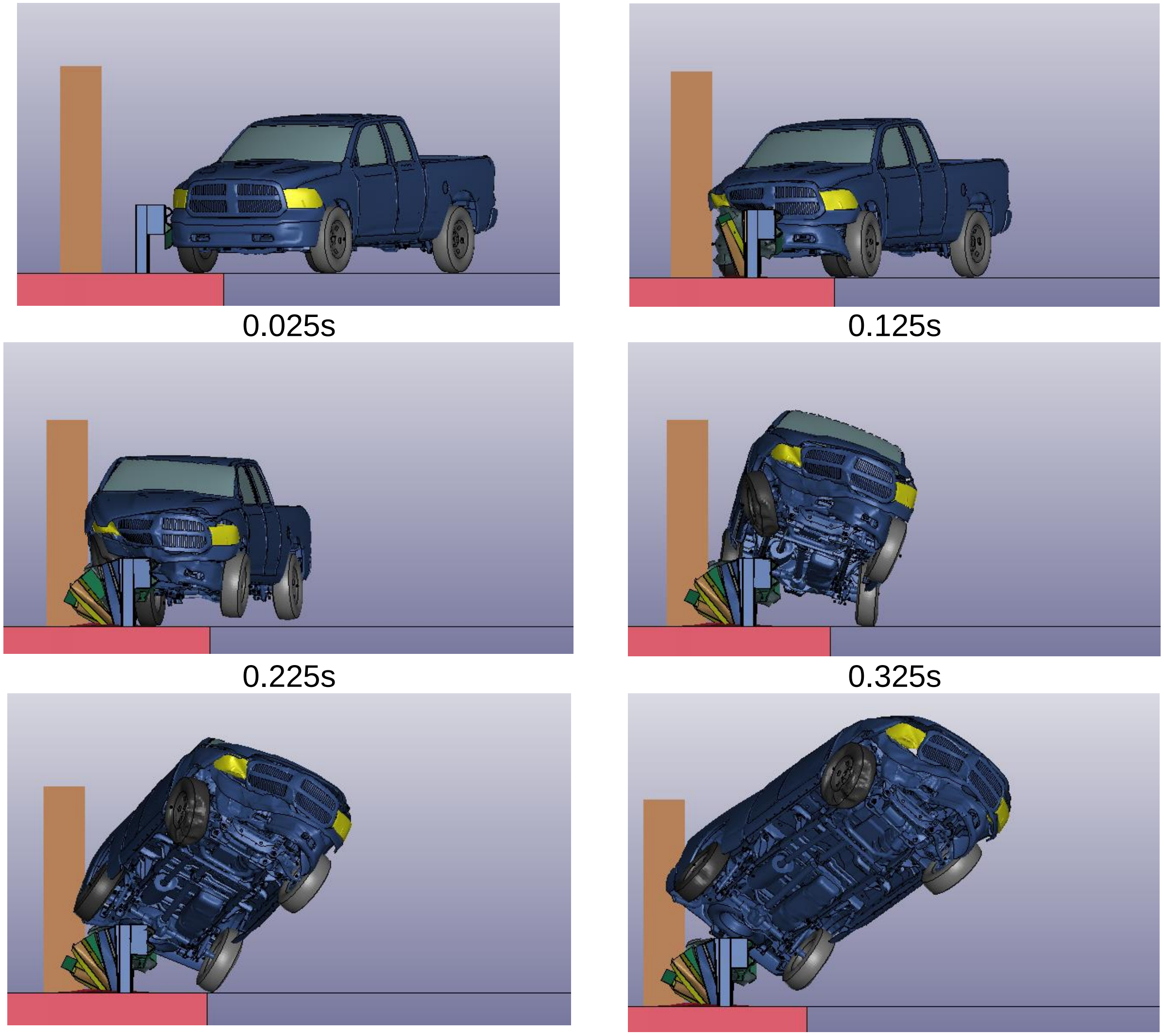


Figure 2.81. *MASH* Test 3-11 Simulation of Half-Post Large Gap with Fixed Object 30 inch Offset 6 feet Downstream Impact Variation– Downstream View

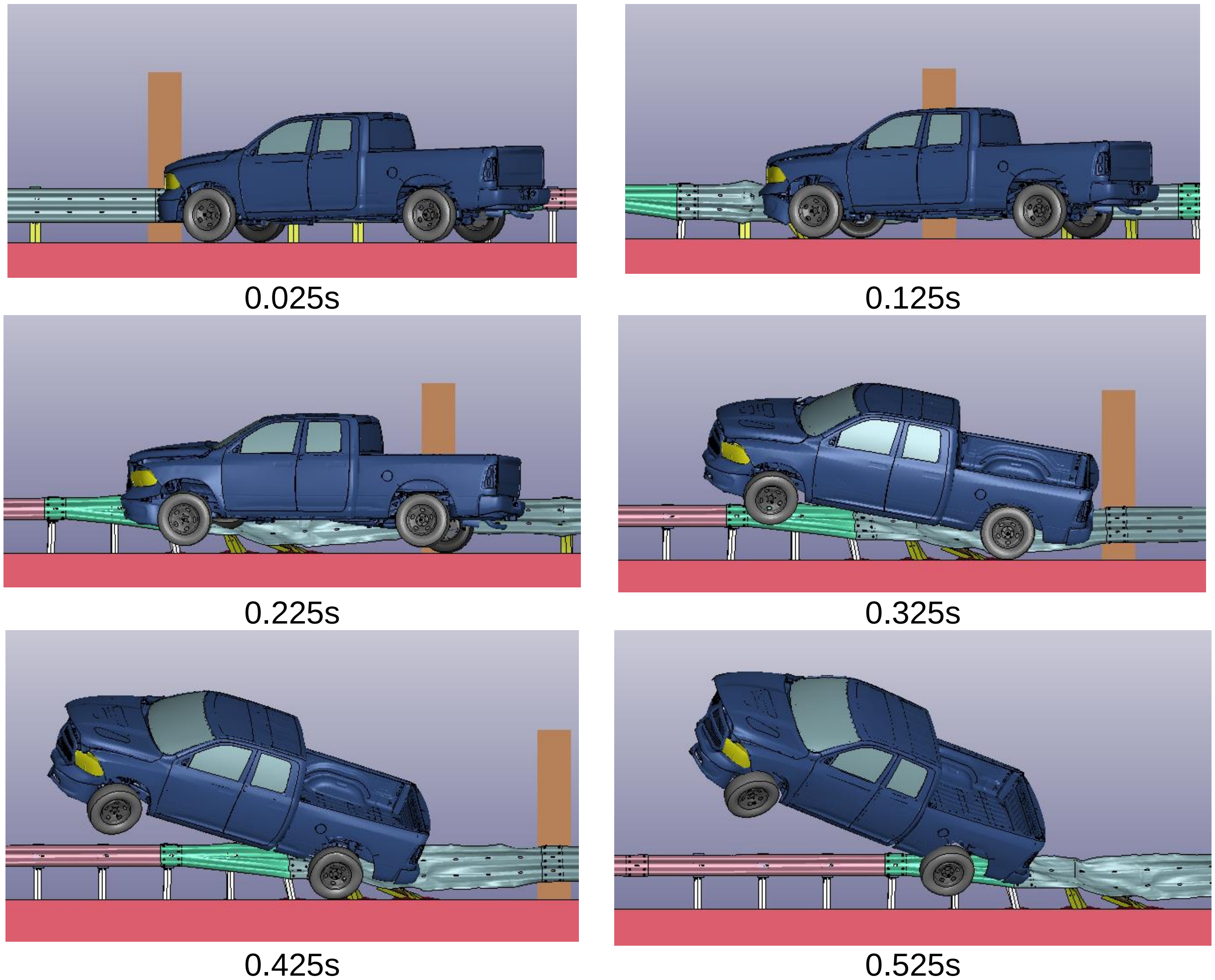
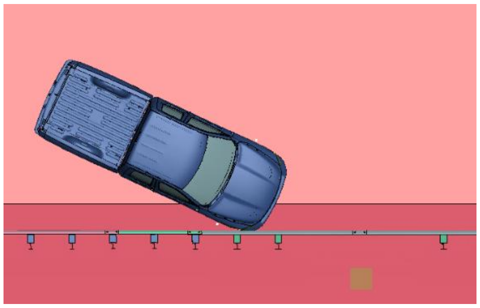


Figure 2.82. *MASH* Test 3-11 Simulation of Half-Post Large Gap with Fixed Object 30 inch Offset 6 feet Downstream Impact Variation– Rear View

2.4.1.18. MASH Test 3-11 Simulation of Half-Post Spacing Large Gap with Fixed Object 30 inch Offset with Upstream Varied Impact Point

Figure 2.83 through Figure 2.85 show the sequential frames of *MASH* test 3-11 with half-post spacing, large gap, a fixed object offset of 30 inches, and impact point moved one post upstream. The occupant impact velocity was calculated to be 4.7 m/s (preferred limit is 9.1 m/s). The ridedown acceleration was calculated to be 17.5 g's (maximum limit is 20.49 g's). This configuration passed *MASH* test 3-11 by successfully containing and redirecting the vehicle.



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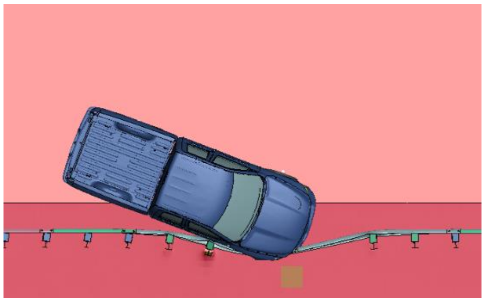

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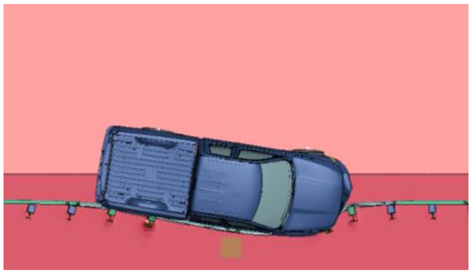

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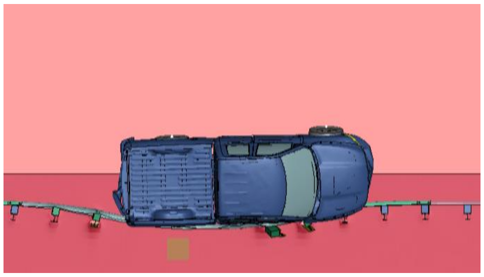

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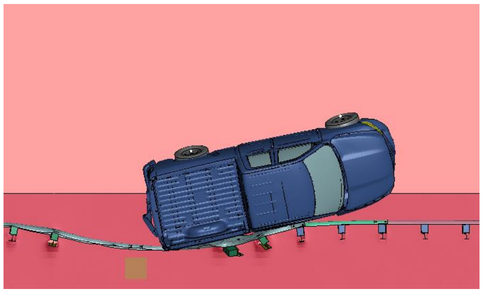

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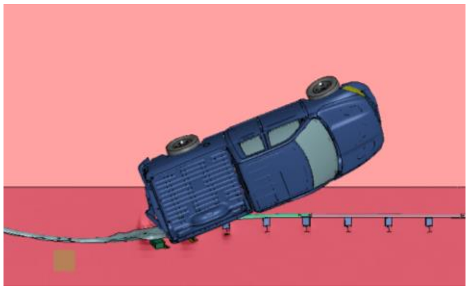

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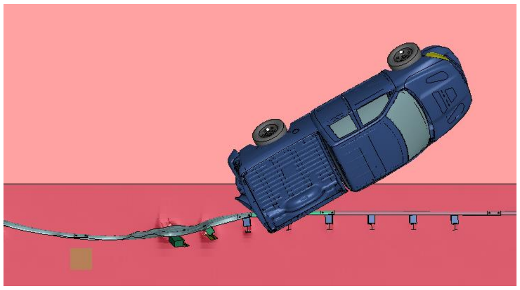

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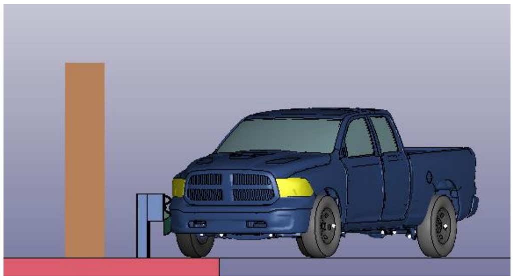
Figure 2.83. *MASH* Test 3-11 Simulation of Half-Post Large Gap with Fixed Object 30 inch Offset with Upstream Varied Impact Point – Overhead View



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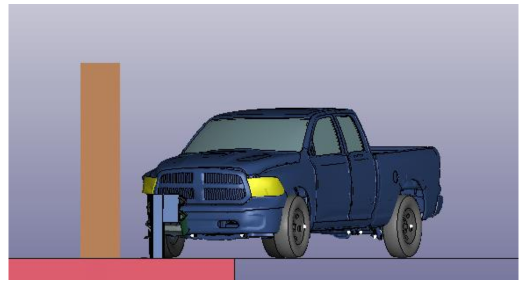

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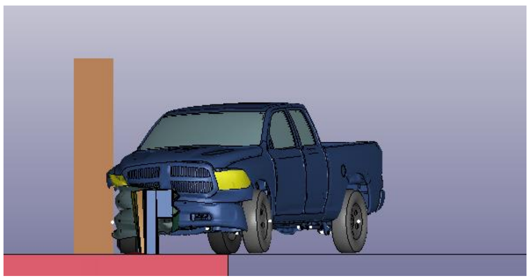

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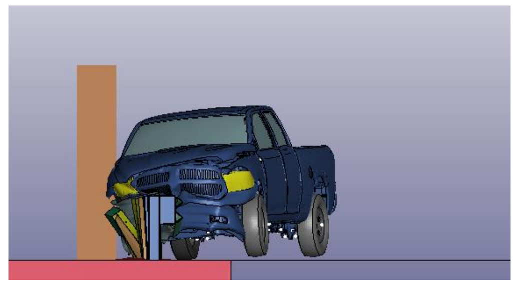

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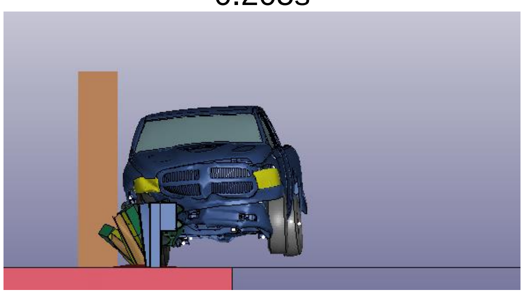

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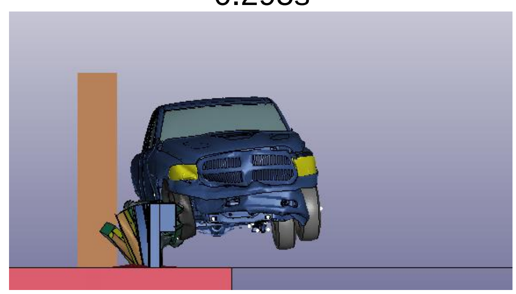

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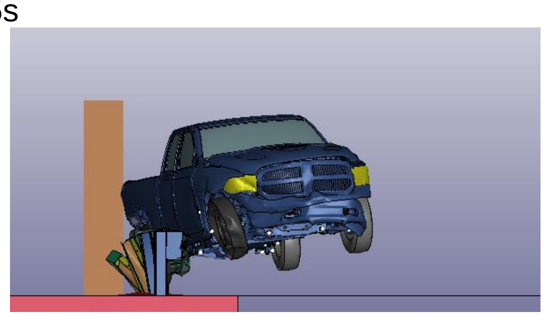


0.565s

Figure 2.84. *MASH* Test 3-11 Simulation of Half-Post Large Gap with Fixed Object 30 inch Offset with Upstream Varied Impact Point – Downstream View

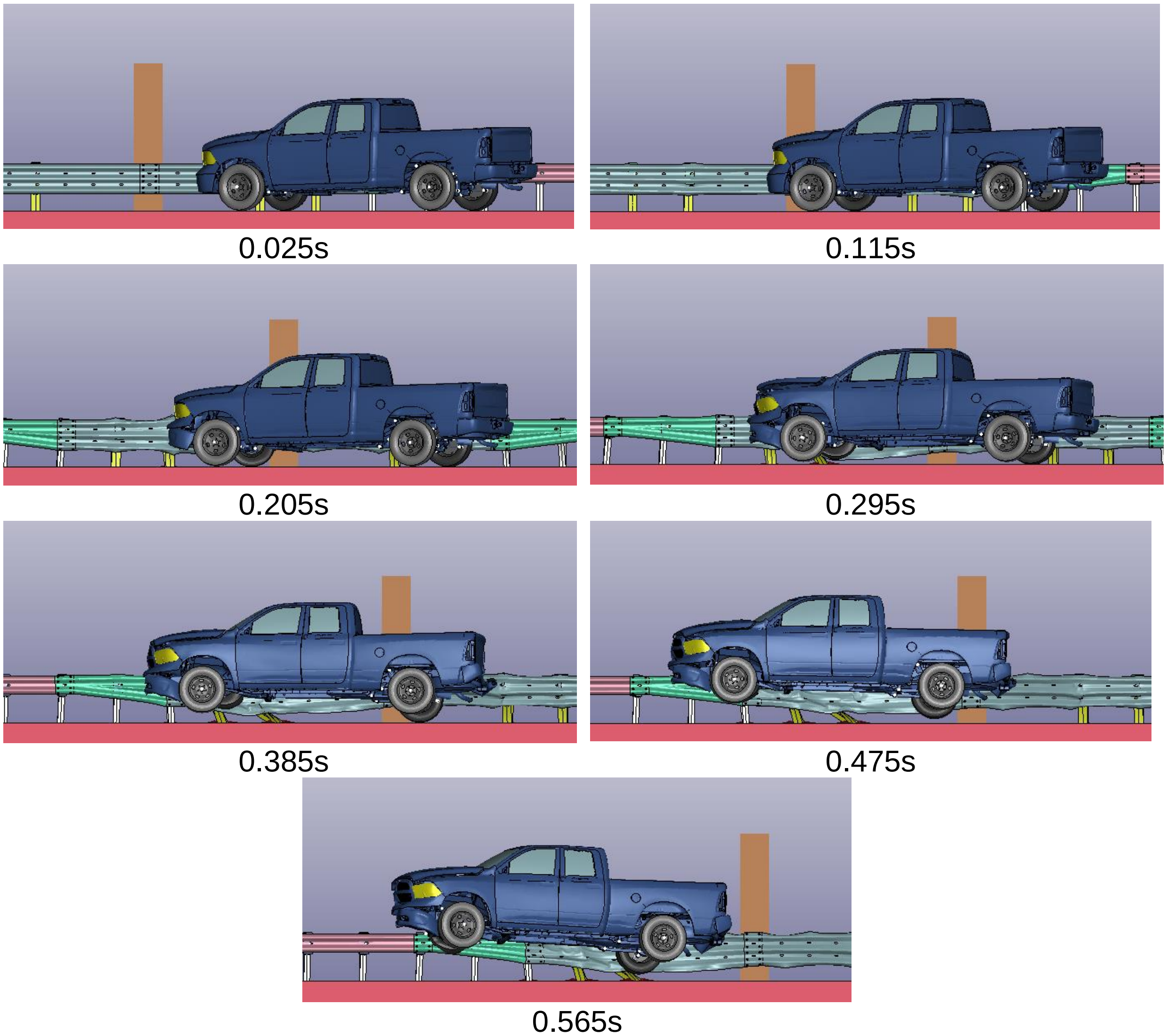


Figure 2.85. *MASH* Test 3-11 Simulation of Half-Post Large Gap with Fixed Object 30 inch Offset with Upstream Varied Impact Point – Rear View

2.4.1.19. MASH Test 3-10 Simulation of Half-Post Spacing Large Gap with Fixed Object 30 inch Offset

Figure 2.86 through Figure 2.88 show the sequential frames of MASH test 3-10 with half-post spacing, large gap, and a fixed object offset of 30 inches. The OIV was calculated to be 7.0 m/s (preferred limit is 9.1 m/s). The RDA was calculated to be 32.0 g’s (maximum limit is 20.49 g’s). This configuration failed *MASH* test 3-10 by excessive ridedown acceleration.

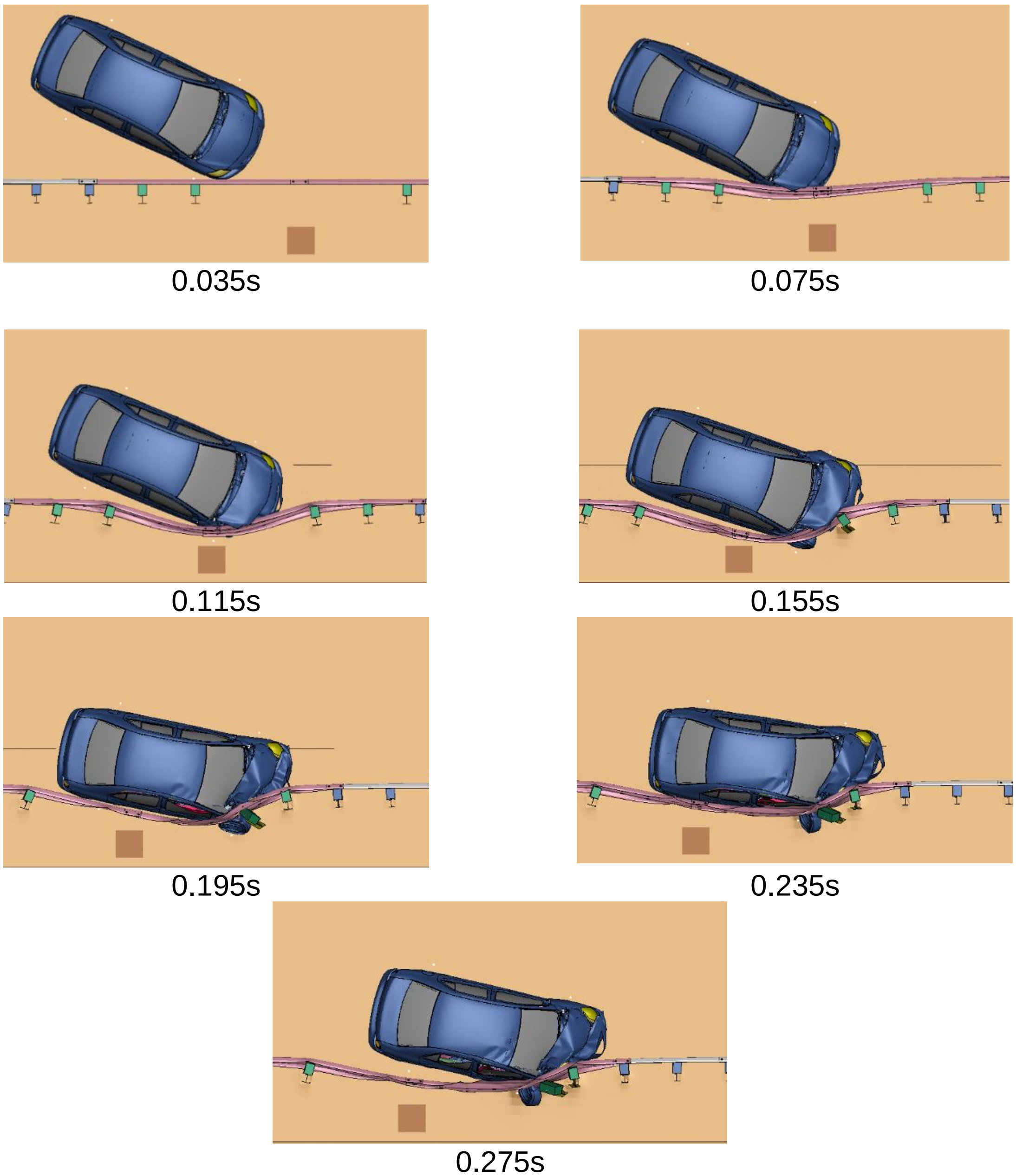


Figure 2.86. *MASH* Test 3-10 Simulation of Half-Post Large Gap with Fixed Object 30 inch Offset – Overhead View

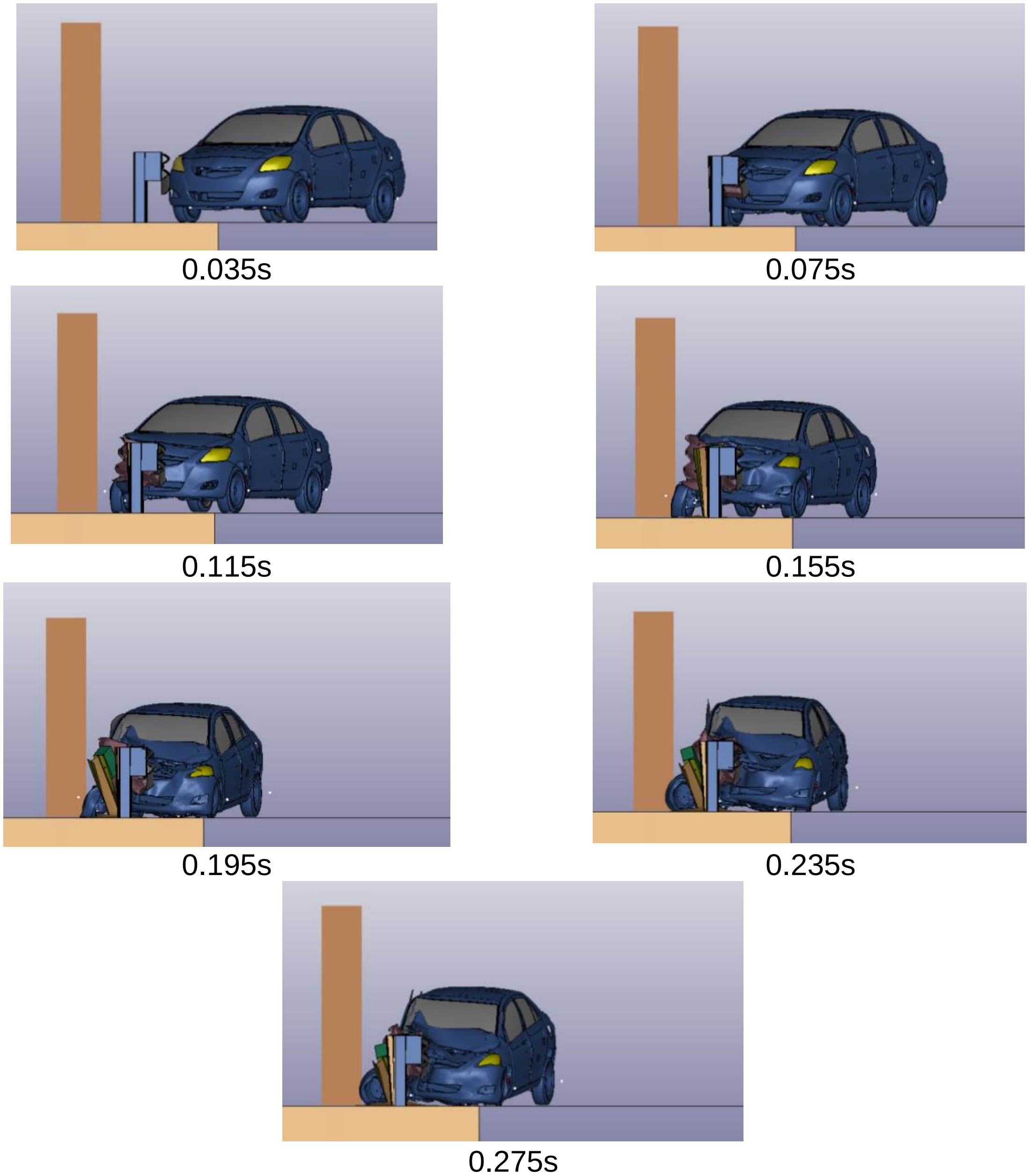
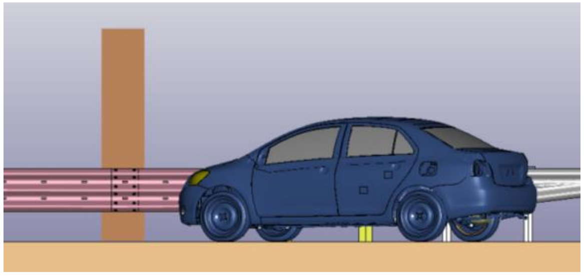


Figure 2.87. *MASH* Test 3-10 Simulation of Half-Post Large Gap with Fixed Object 30 inch Offset – Downstream View



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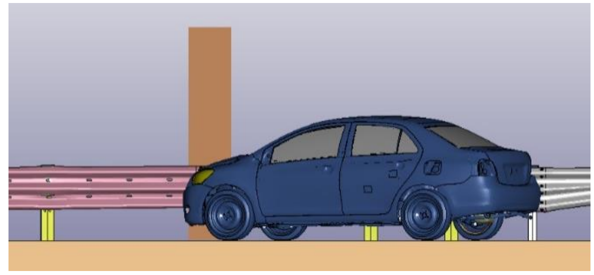

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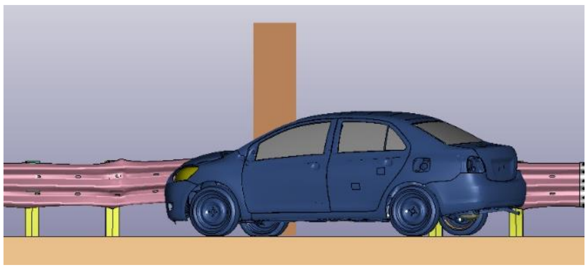

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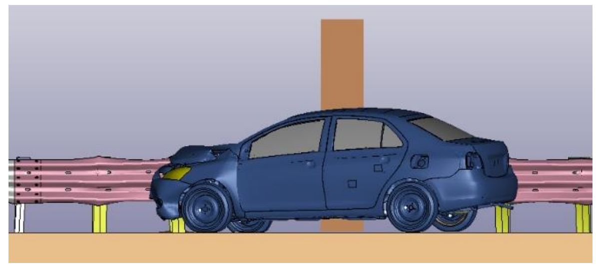
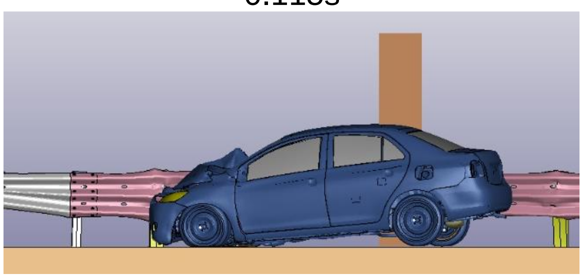
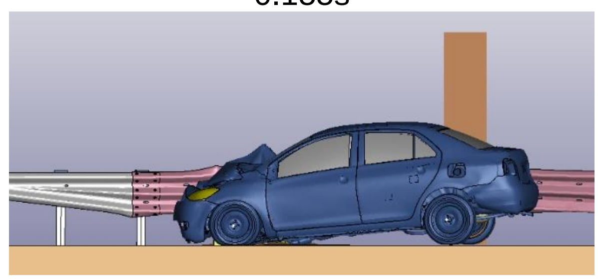


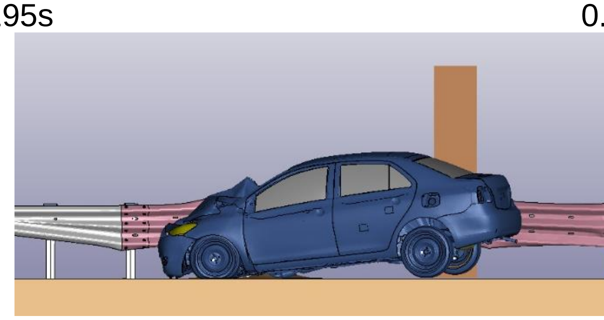
0.155s



0.195s



0.235s



0.395s

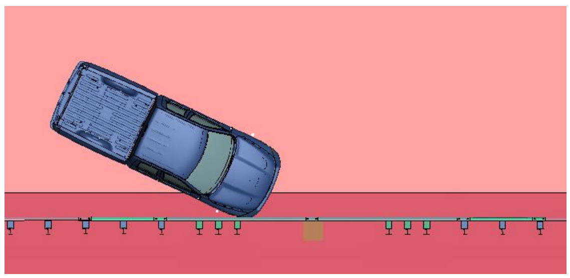
Figure 2.88. *MASH* Test 3-10 Simulation of Half-Post Large Gap with Fixed Object 30 inch Offset – Rear View

2.4.2. Quarter-Post Spacing

The following simulations include offset variations with quarter-post spacing.

2.4.2.1. MASH Test 3-11 Simulation of Quarter-Post Spacing Large Gap with Fixed Object 0 inch Offset

Figure 2.89 through Figure 2.91 show the sequential frames of *MASH* test 3-11 with quarter-post spacing, large gap, and a fixed object offset of 0 inches. The pickup truck interacted with the fixed object more than what was allowed within this project scope. Therefore, the offset distance was increased in the next simulation.



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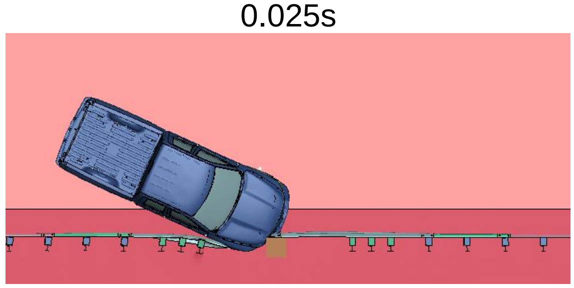

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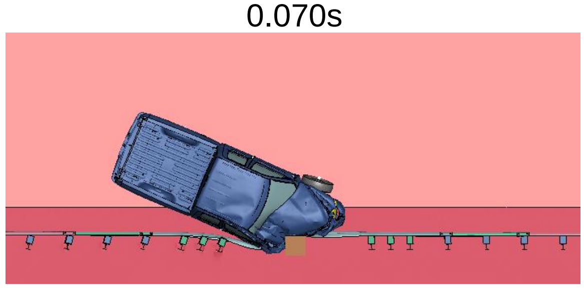
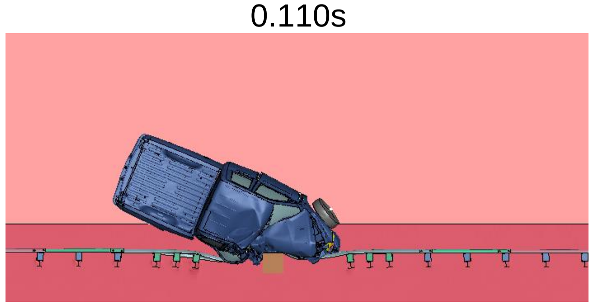


0.110s



0.155s

Figure 2.89. *MASH* Test 3-11 Simulation of Quarter-Post Large Gap with Fixed Object 0 inch Offset – Overhead View

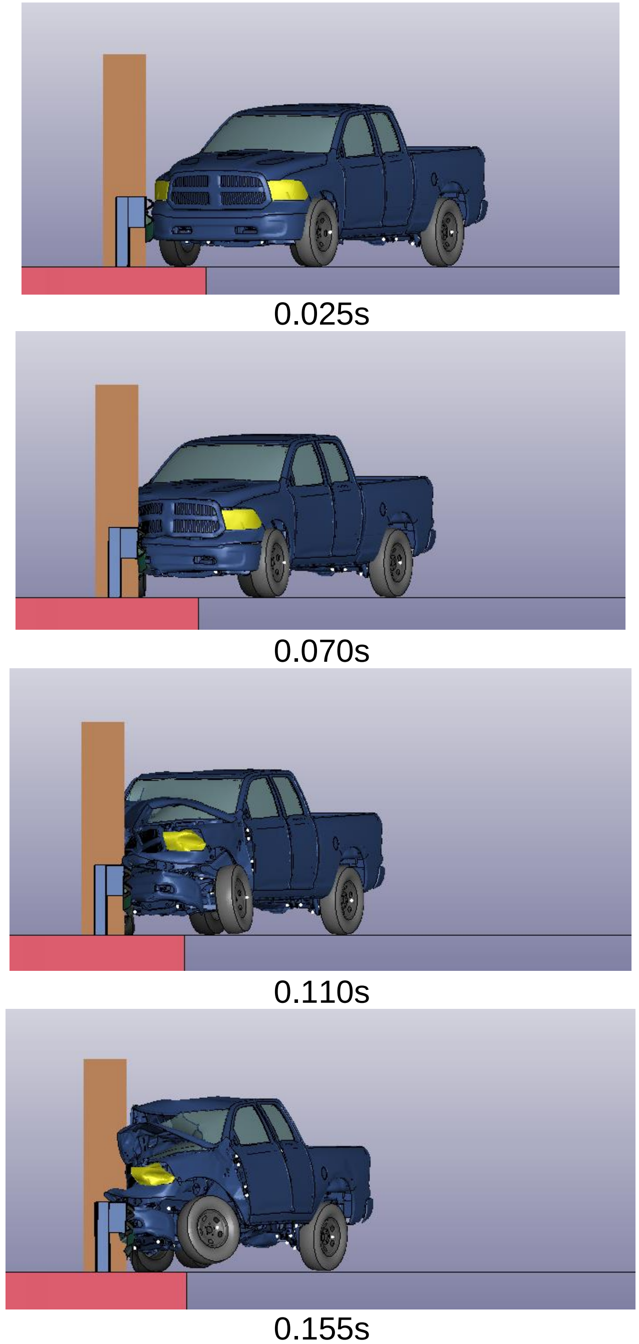
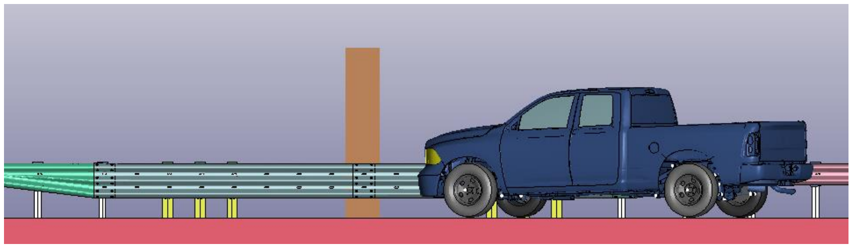
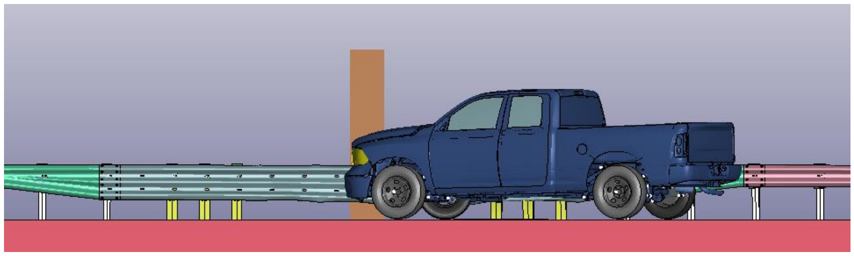


Figure 2.90. *MASH* Test 3-11 Simulation of Quarter-Post Large Gap with Fixed Object 0 inch Offset – Downstream View



0.025s



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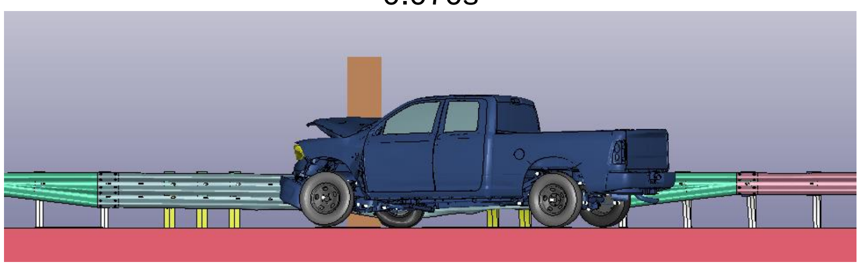

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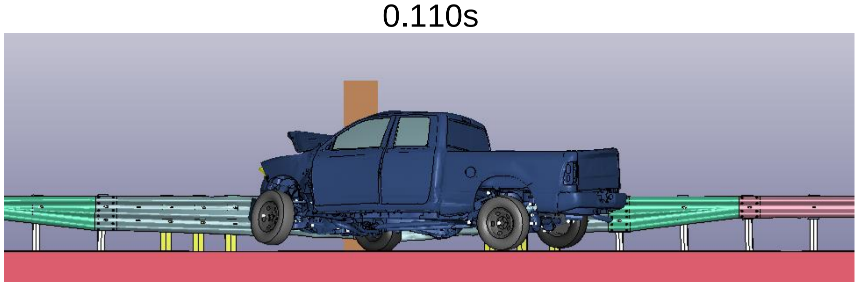
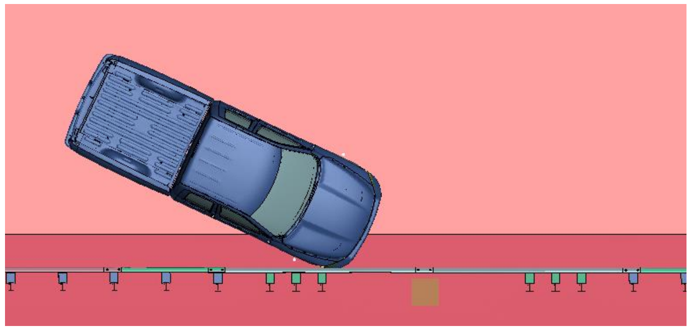


0.155s

Figure 2.91. *MASH* Test 3-11 Simulation of Quarter-Post Large Gap with Fixed Object 0 inch Offset – Rear View

2.4.2.2. MASH Test 3-11 Simulation of Quarter-Post Spacing Large Gap with Fixed Object 4 inch Offset

Figure 2.92 through Figure 2.94 show the sequential frames of *MASH* test 3-11 with quarter-post spacing, large gap, and a fixed object offset of 4 inches. The pickup truck interacted with the fixed object more than what was allowed within this project scope. Therefore, the offset distance was increased in the next simulation.



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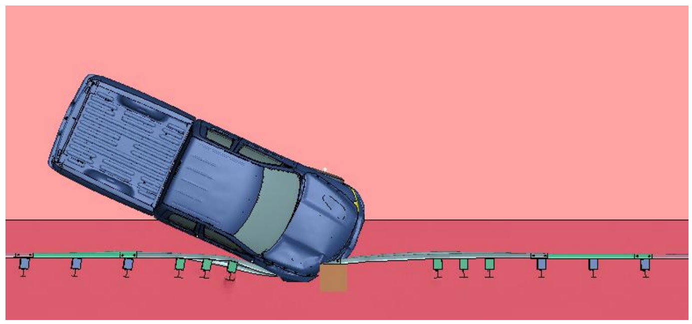

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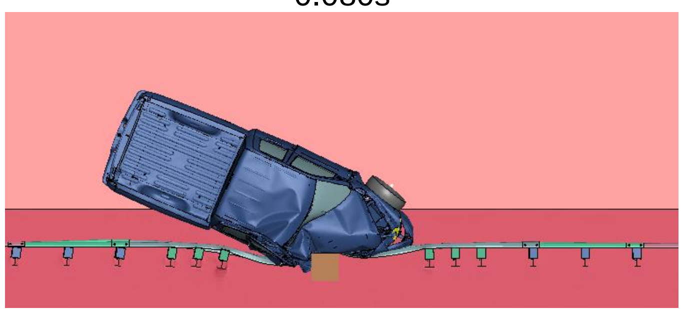

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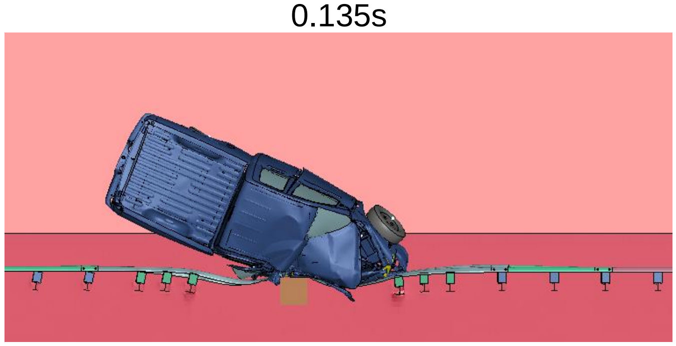
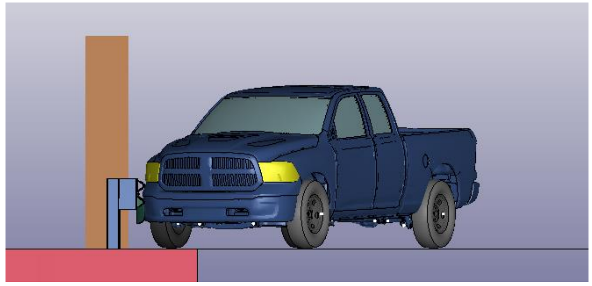
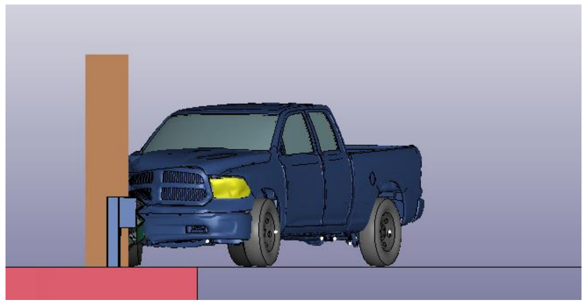


0.190s

Figure 2.92. *MASH* Test 3-11 Simulation of Quarter-Post Large Gap with Fixed Object 4 inch Offset – Overhead View



0.025s



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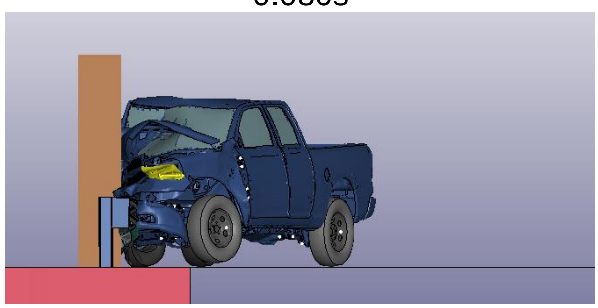

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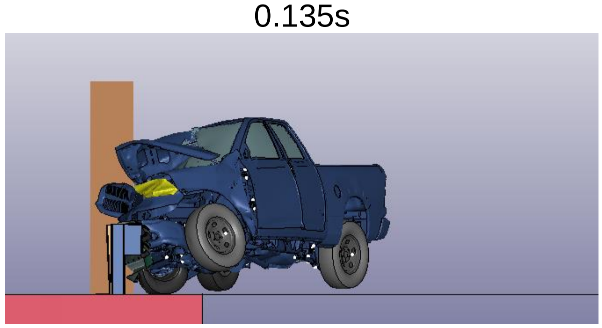
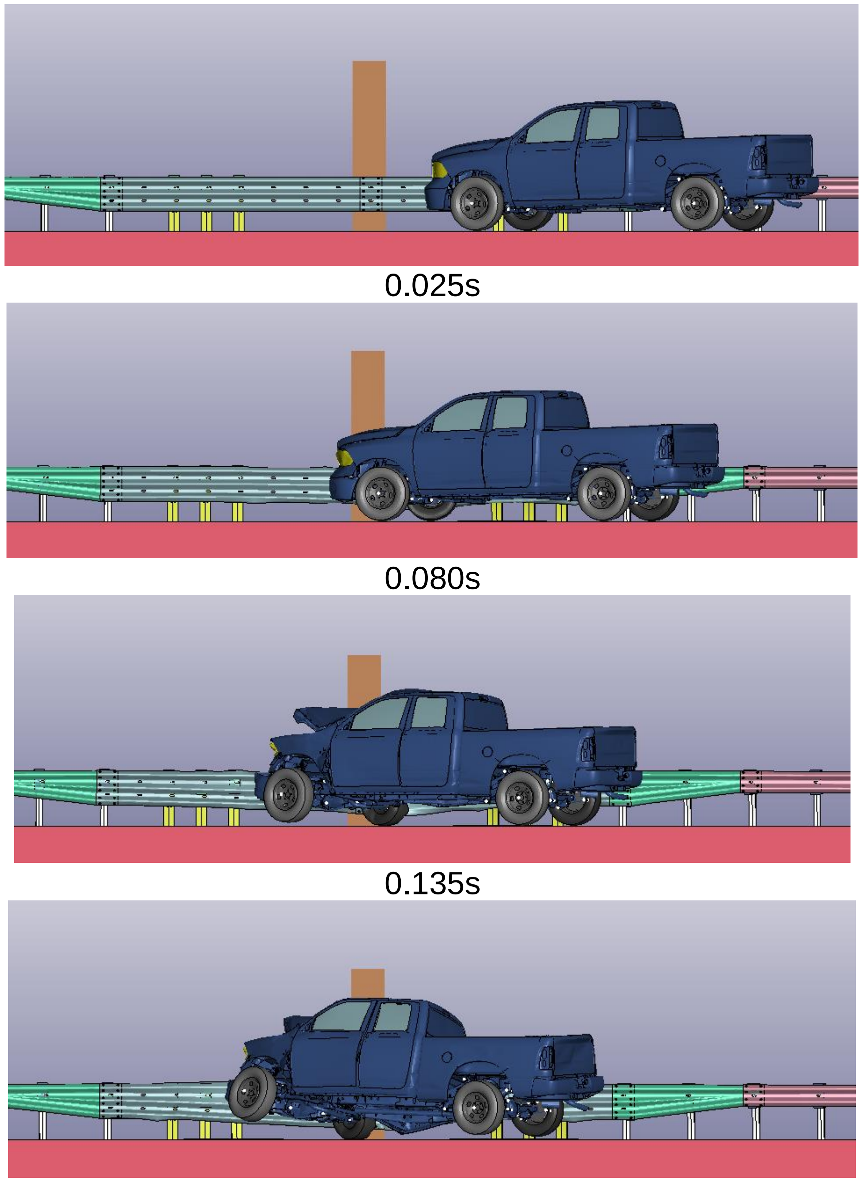


0.190s

Figure 2.93. *MASH* Test 3-11 Simulation of Quarter-Post Large Gap with Fixed Object 4 inch Offset – Downstream View



0.025s

0.080s

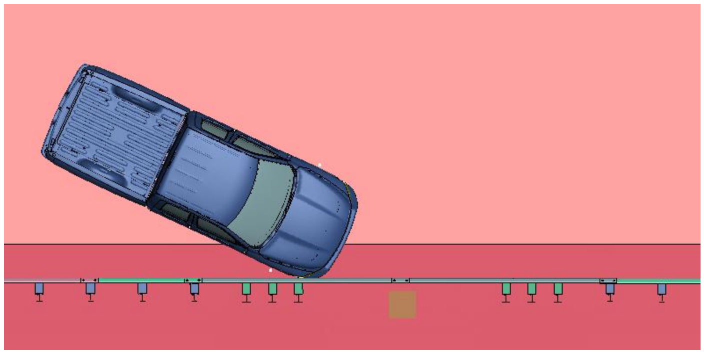
0.135s

0.190s

Figure 2.94. *MASH* Test 3-11 Simulation of Quarter-Post Large Gap with Fixed Object 4 inch Offset – Rear View

2.4.2.3. MASH Test 3-11 Simulation of Quarter-Post Spacing Large Gap with Fixed Object 6 inch Offset

Figure 2.95 through Figure 2.97 show the sequential frames of *MASH* test 3-11 with quarter-post spacing, large gap, and a fixed object offset of 6 inches. The pickup truck interacted with the fixed object more than what was allowed within this project scope. Therefore, the offset distance was increased in the next simulation.



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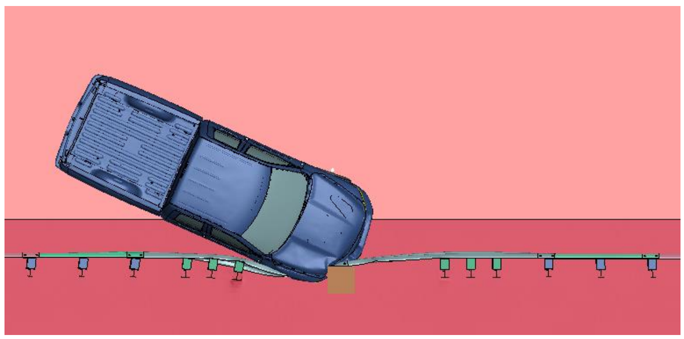

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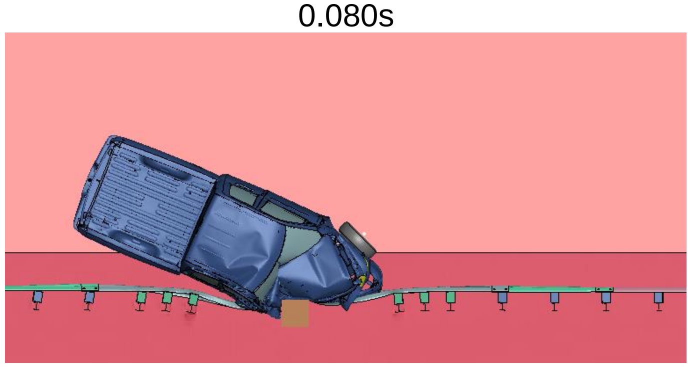

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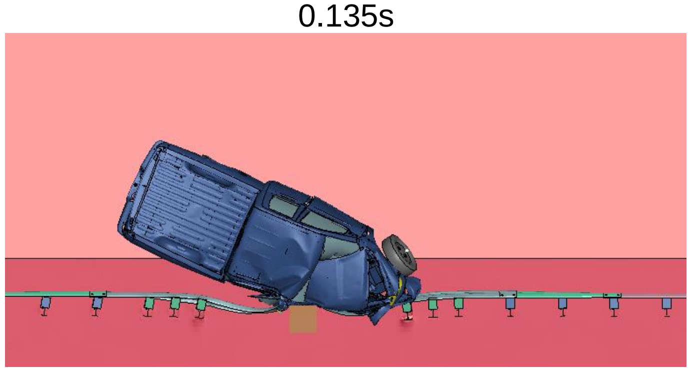


0.190s

Figure 2.95. *MASH* Test 3-11 Simulation of Quarter-Post Large Gap with Fixed Object 6 inch Offset – Overhead View

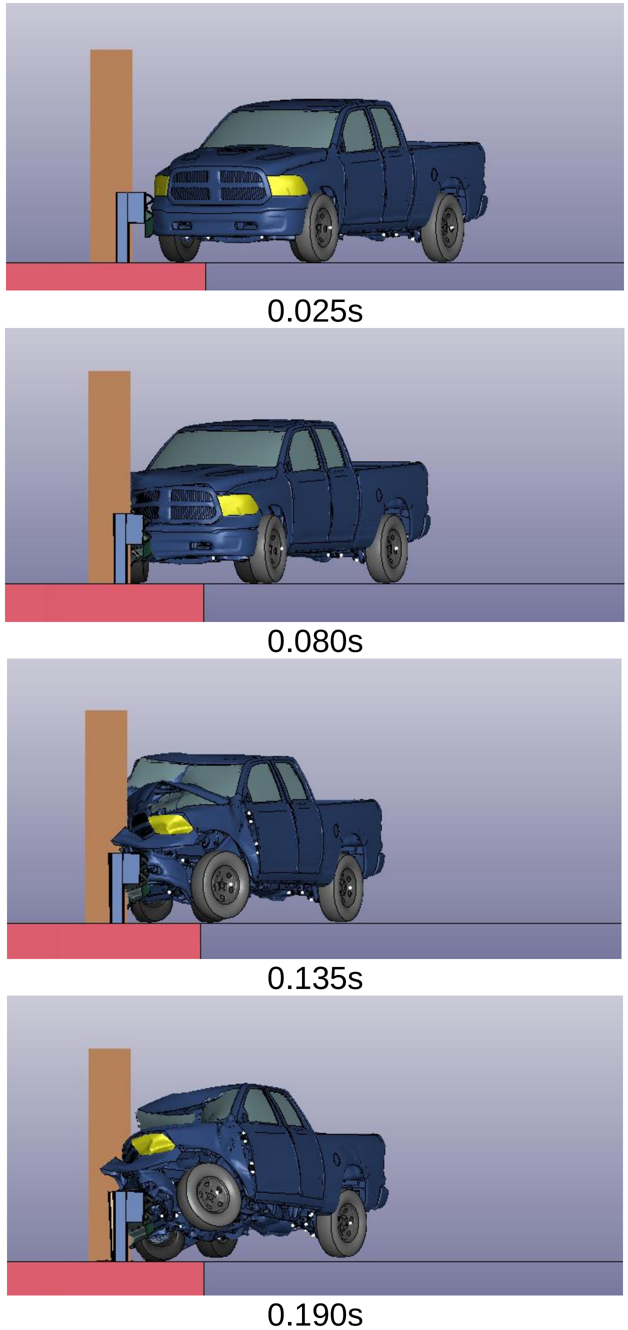


Figure 2.96. *MASH* Test 3-11 Simulation of Quarter-Post Large Gap with Fixed Object 6 inch Offset – Downstream View

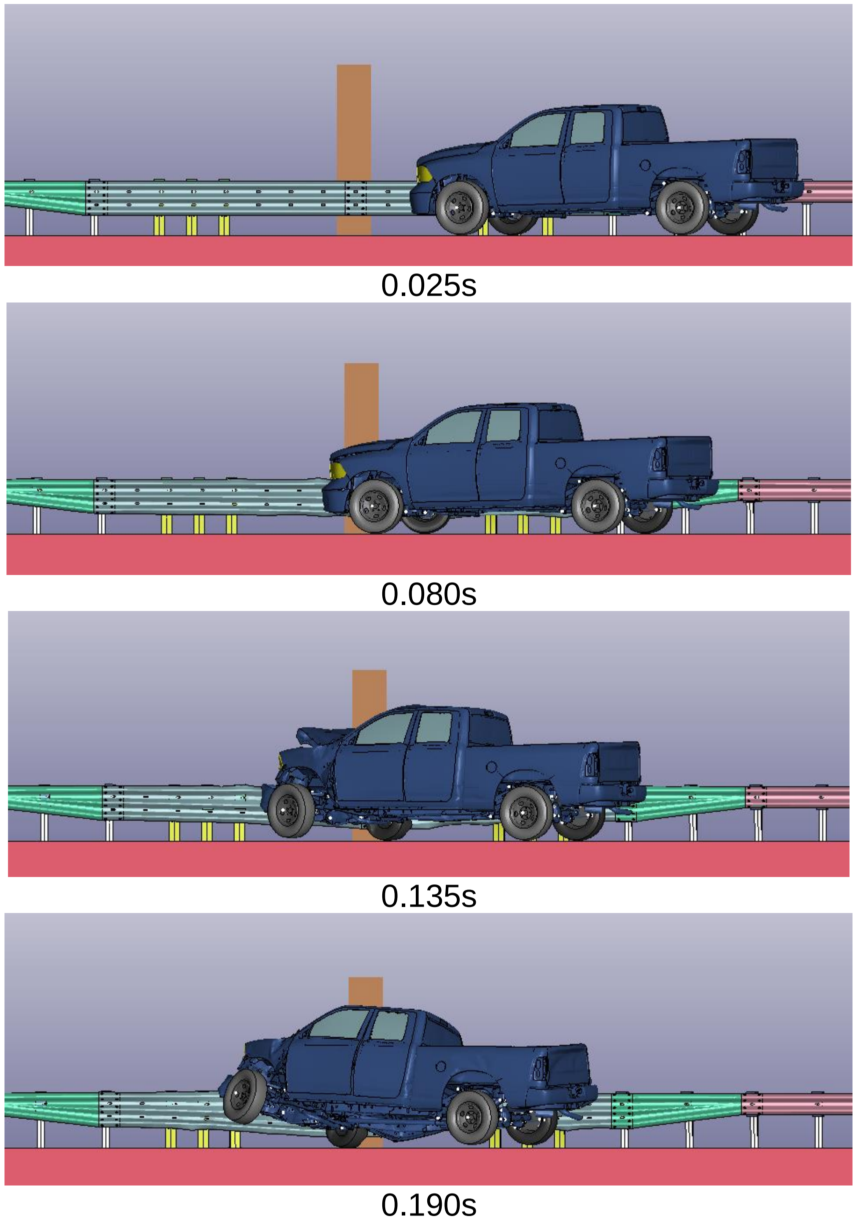
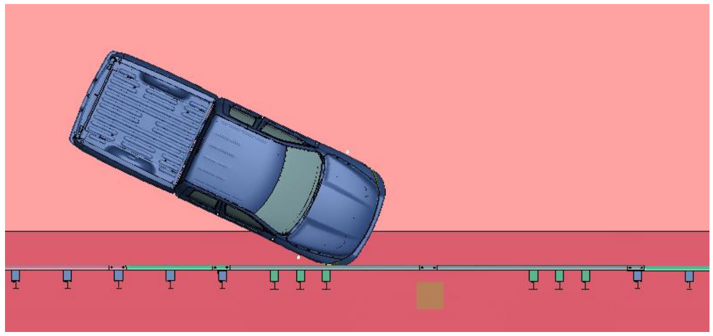


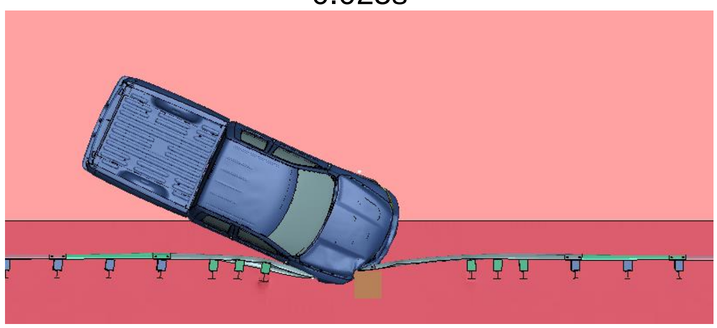
Figure 2.97. *MASH* Test 3-11 Simulation of Quarter-Post Large Gap with Fixed Object 6 inch Offset – Rear View

2.4.2.4. MASH Test 3-11 Simulation of Quarter-Post Spacing Large Gap with Fixed Object 8 inch Offset

Figure 2.98 through Figure 2.100 show the sequential frames of *MASH* test 3-11 with quarter-post spacing, large gap, and a fixed object offset of 8 inches. The pickup truck interacted with the fixed object more than what was allowed within this project scope. Therefore, the offset distance was increased in the next simulation.



0.025s



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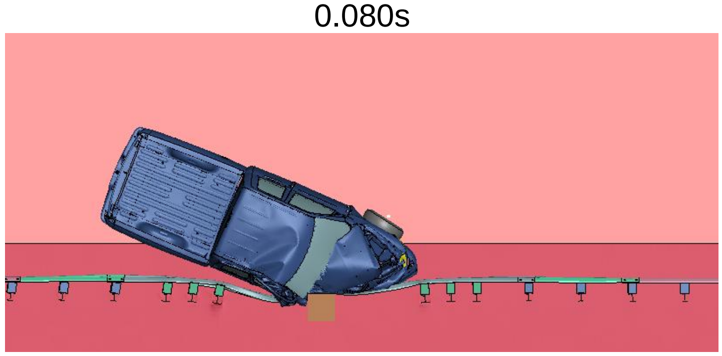
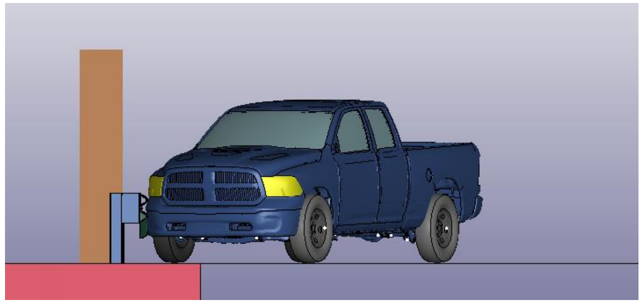


0.135s

0.190s

Figure 2.98. *MASH* Test 3-11 Simulation of Quarter-Post Large Gap with Fixed Object 8 inch Offset – Overhead View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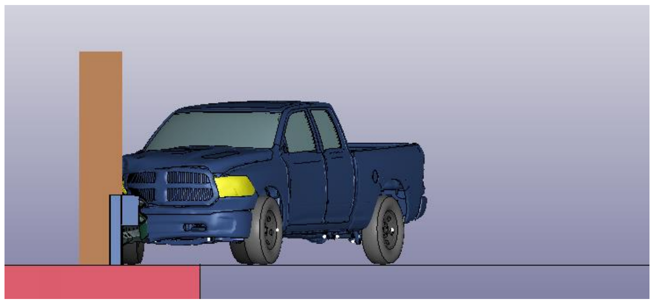
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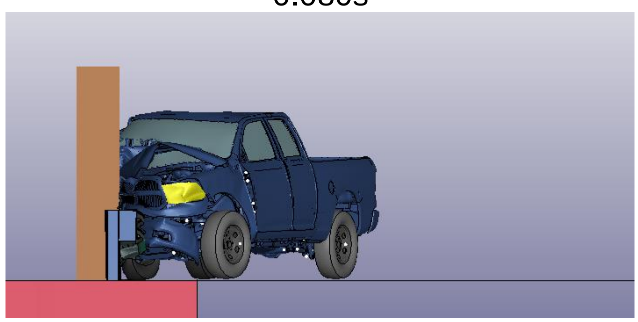
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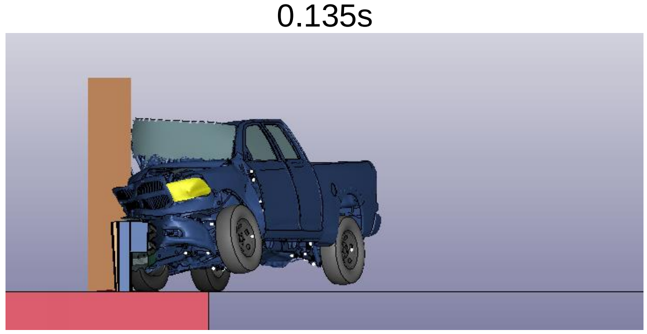
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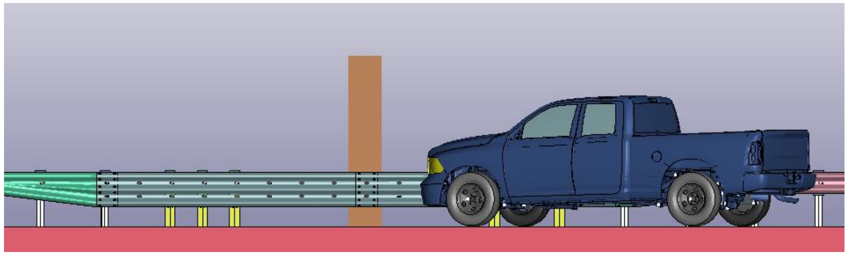
Figure 2.99. *MASH* Test 3-11 Simulation of Quarter-Post Large Gap with Fixed Object 8 inch Offset – Downstream View



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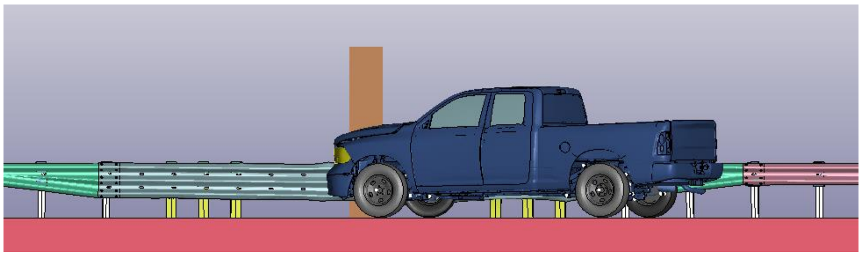

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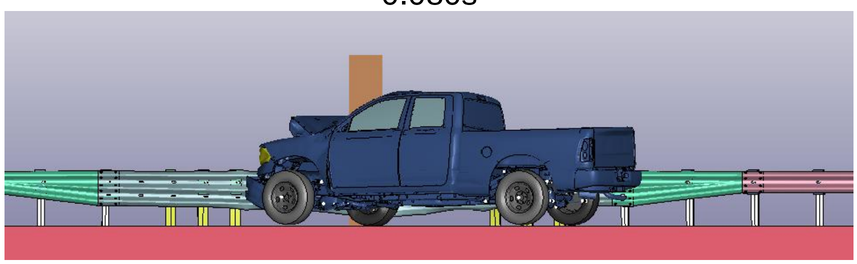

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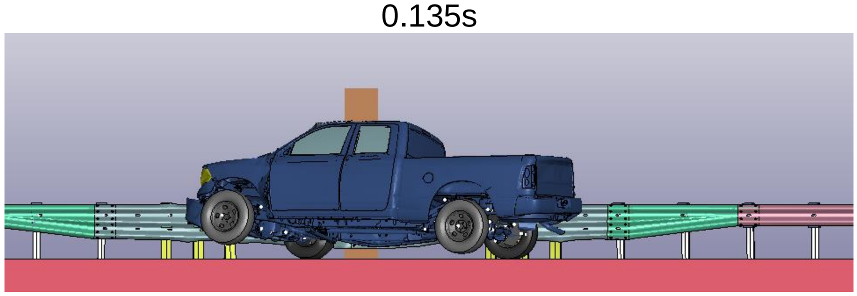
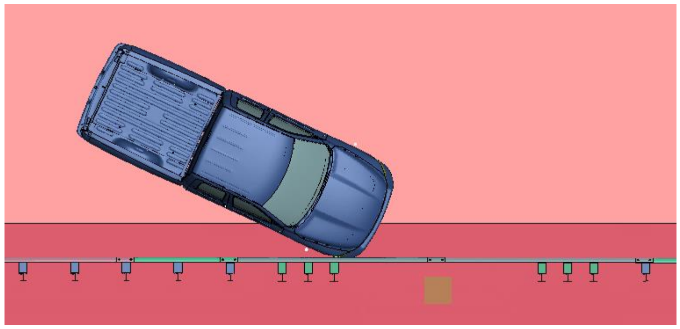


0.190s

Figure 2.100. *MASH* Test 3-11 Simulation of Quarter-Post Large Gap with Fixed Object 8 inch Offset – Rear View

2.4.2.5. MASH Test 3-11 Simulation of Quarter-Post Spacing Large Gap with Fixed Object 10 inch Offset

Figure 2.101 through Figure 2.103 show the sequential frames of *MASH* test 3-11 with quarter-post spacing, large gap, and a fixed object offset of 10 inches. The pickup truck interacted with the fixed object more than what was allowed within this project scope. Therefore, the offset distance was increased in the next simulation.



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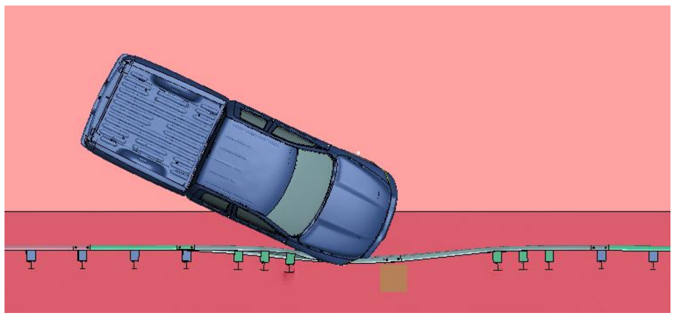

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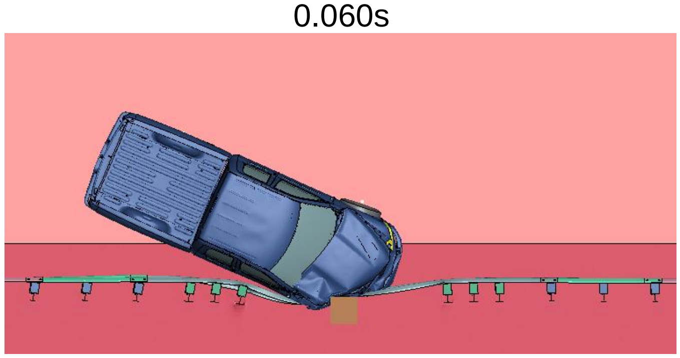

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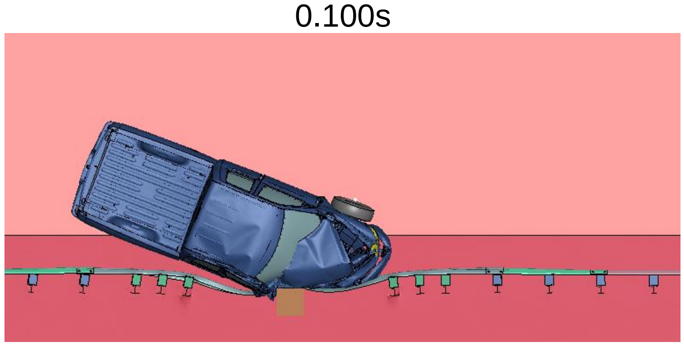
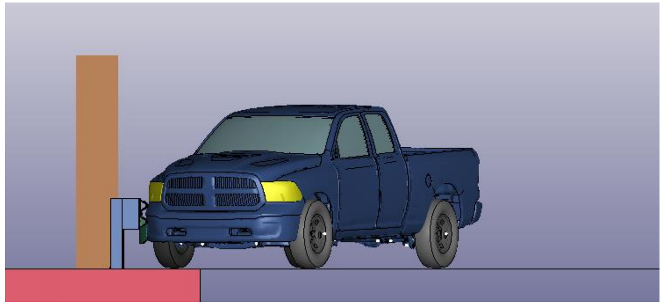


0.135s

Figure 2.101. *MASH* Test 3-11 Simulation of Quarter-Post Large Gap with Fixed Object 10 inch Offset – Overhead View



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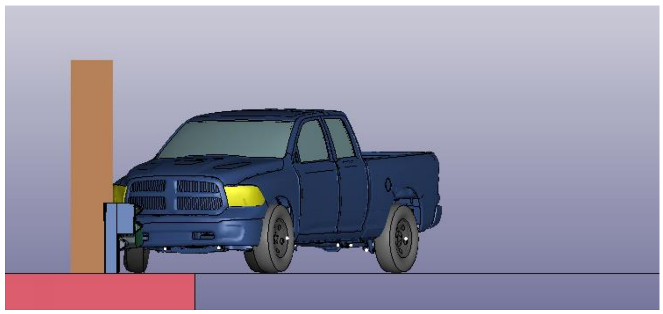

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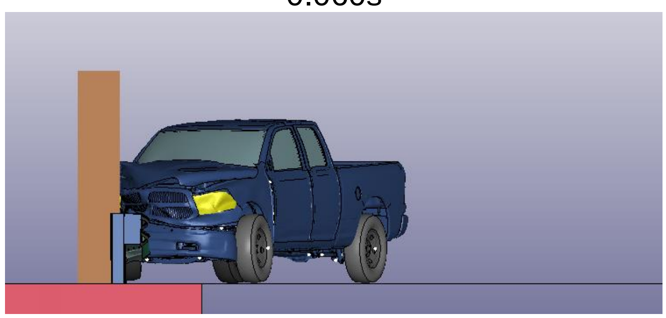
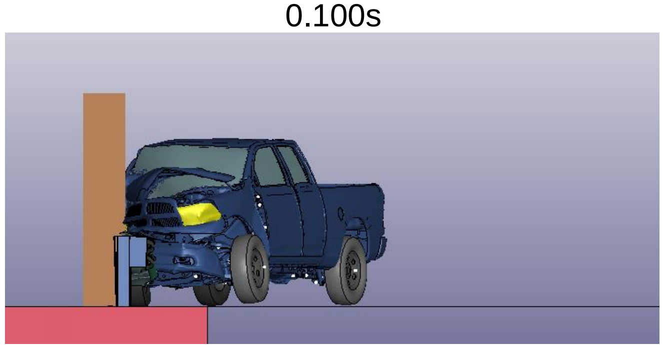


0.100s



0.135s

Figure 2.102. *MASH* Test 3-11 Simulation of Quarter-Post Large Gap with Fixed Object 10 inch Offset – Downstream View

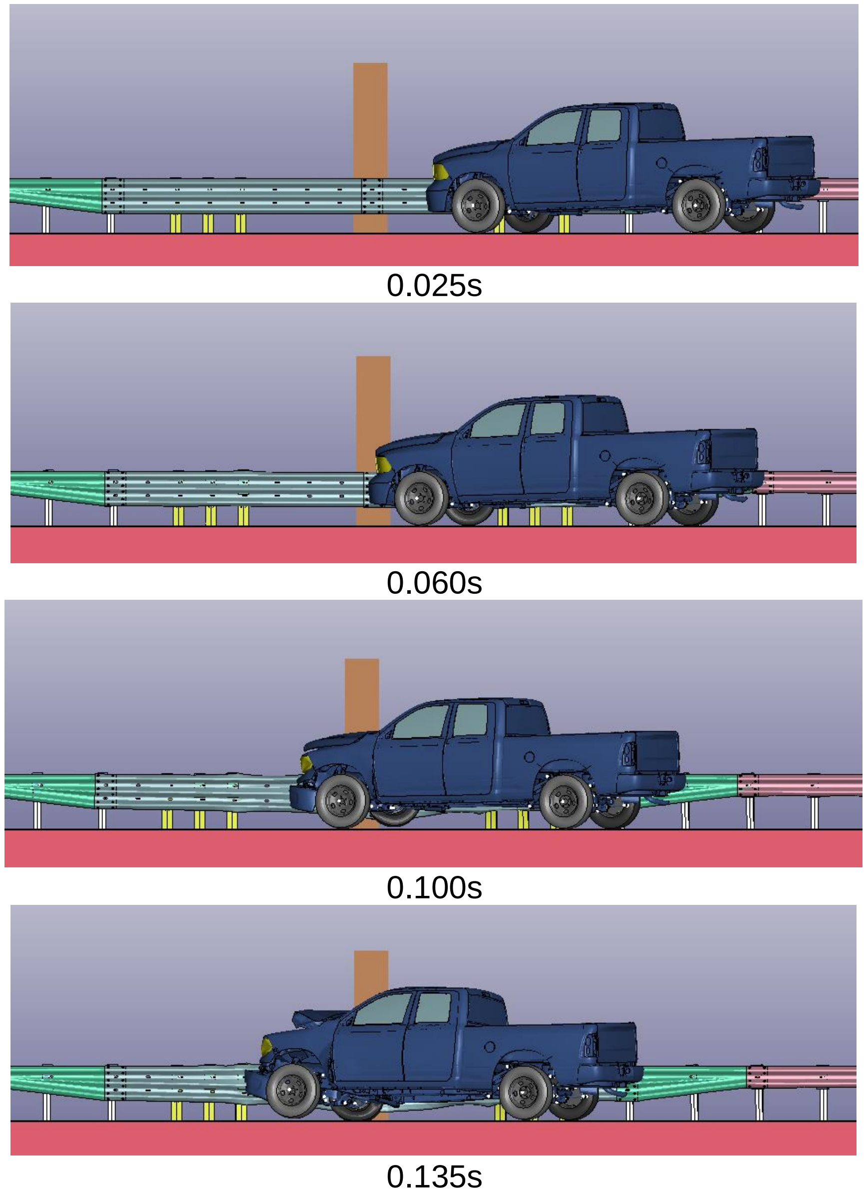
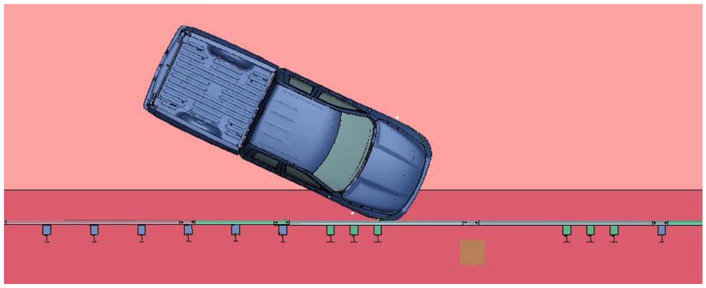


Figure 2.103. *MASH* Test 3-11 Simulation of Quarter-Post Large Gap with Fixed Object 10 inch Offset – Rear View

2.4.2.6. MASH Test 3-11 Simulation of Quarter-Post Spacing Large Gap with Fixed Object 12 inch Offset

Figure 2.104 through Figure 2.106 show the sequential frames of *MASH* test 3-11 with quarter-post spacing, large gap, and a fixed object offset of 12 inches. The pickup truck interacted with the fixed object more than what was allowed within this project scope. Therefore, the offset distance was increased in the next simulation.



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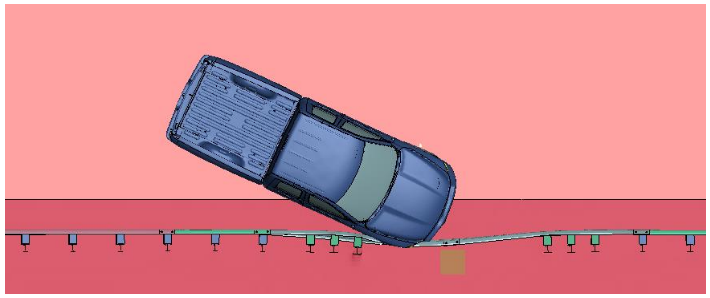

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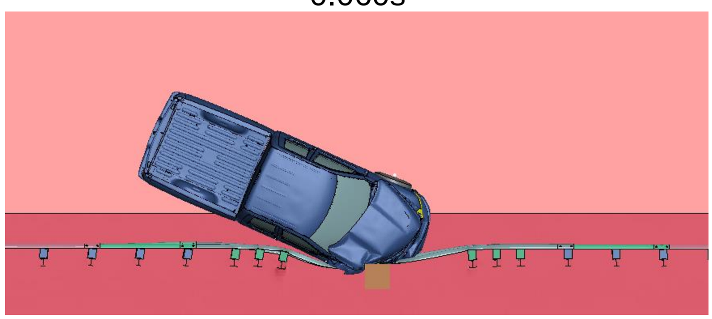

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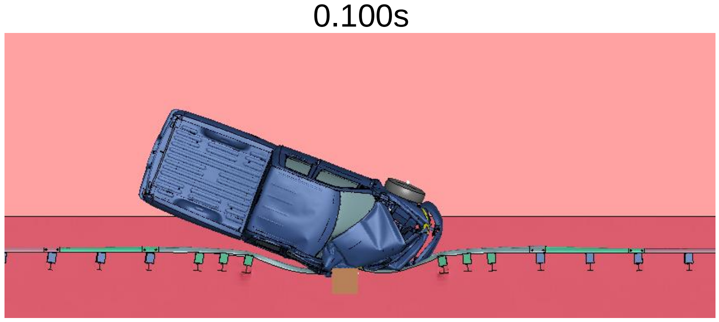
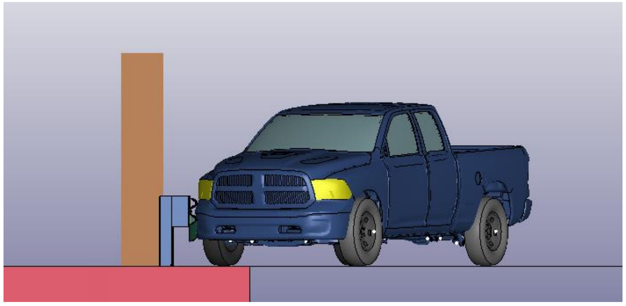
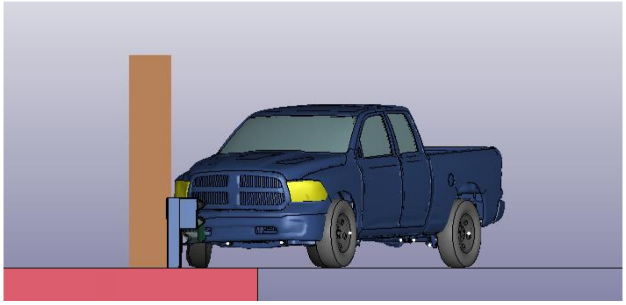


0.135s

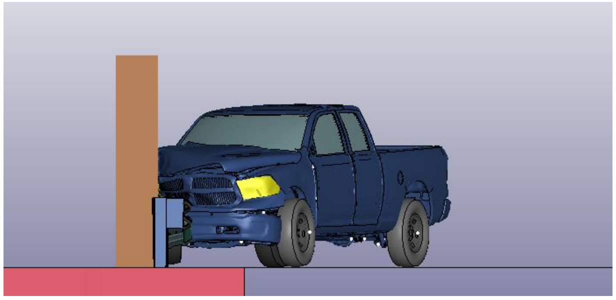
Figure 2.104. *MASH* Test 3-11 Simulation of Quarter-Post Large Gap with Fixed Object 12 inch Offset – Overhead View



0.025s



0.060s



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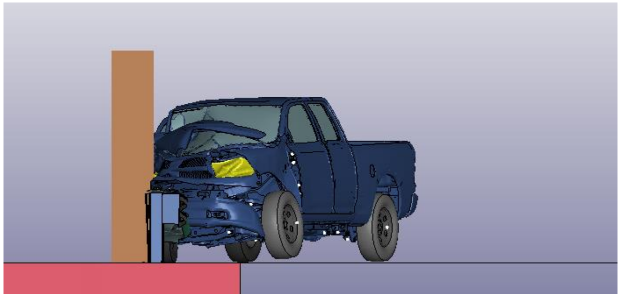
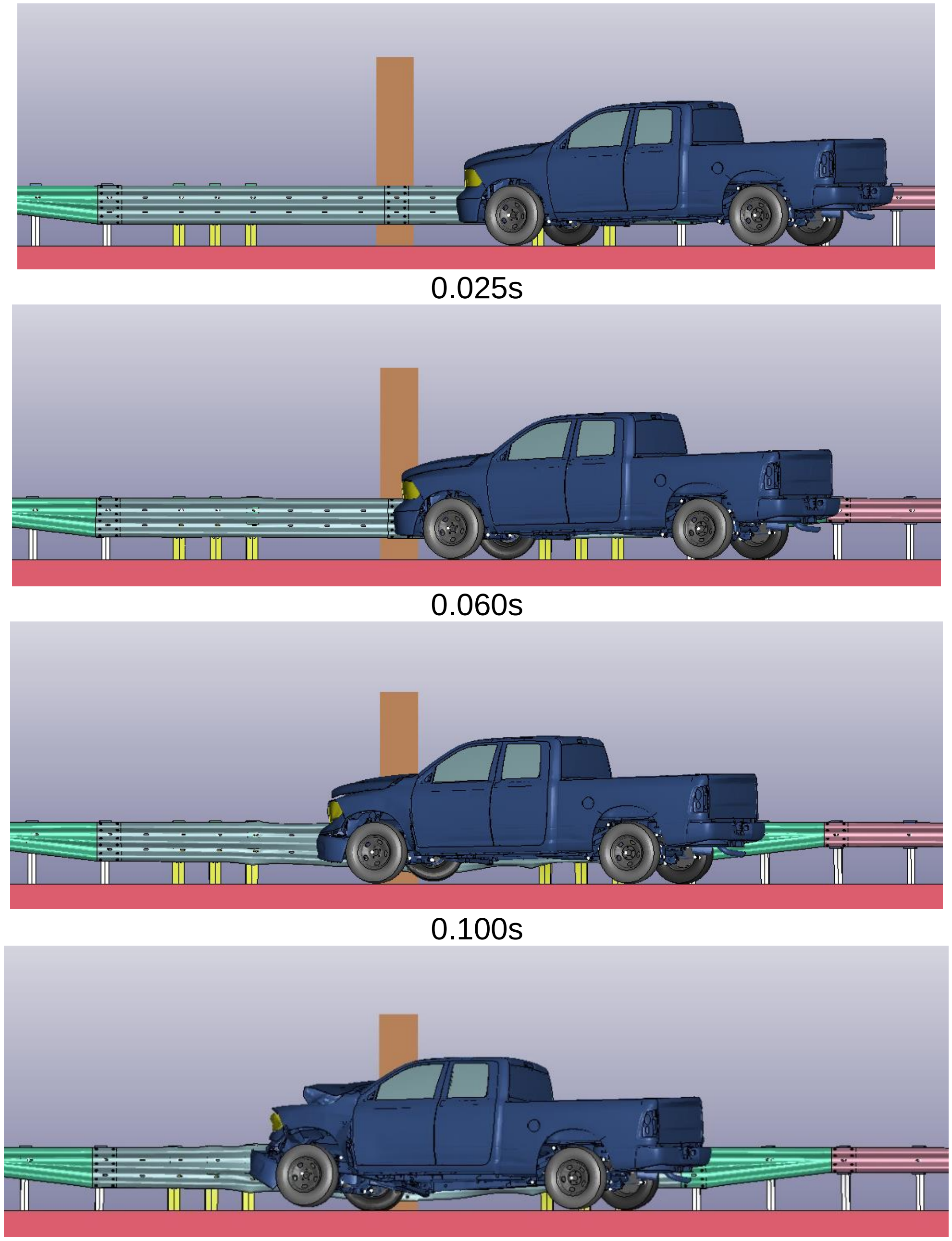


0.135s

Figure 2.105. *MASH* Test 3-11 Simulation of Quarter-Post Large Gap with Fixed Object 12 inch Offset – Downstream View



0.025s

0.060s

0.100s

0.135s

Figure 2.106. ***MASH*** **Test 3-11 Simulation of Quarter-Post Large Gap with Fixed Object 12 inch Offset – Rear View**

2.4.2.7. MASH Test 3-11 Simulation of Quarter-Post Spacing Large Gap with Fixed Object 16 inch Offset

Figure 2.107 through Figure 2.109 show the sequential frames of *MASH* test 3-11 with quarter-post spacing, large gap, and a fixed object offset of 16 inches. The occupant impact velocity was calculated to be 6.7 m/s (preferred limit is 9.1 m/s). The ridedown acceleration was calculated to be 15.5 g's (maximum limit is 20.49 g's). This configuration passed *MASH* test 3-11 by successfully containing and redirecting the vehicle.

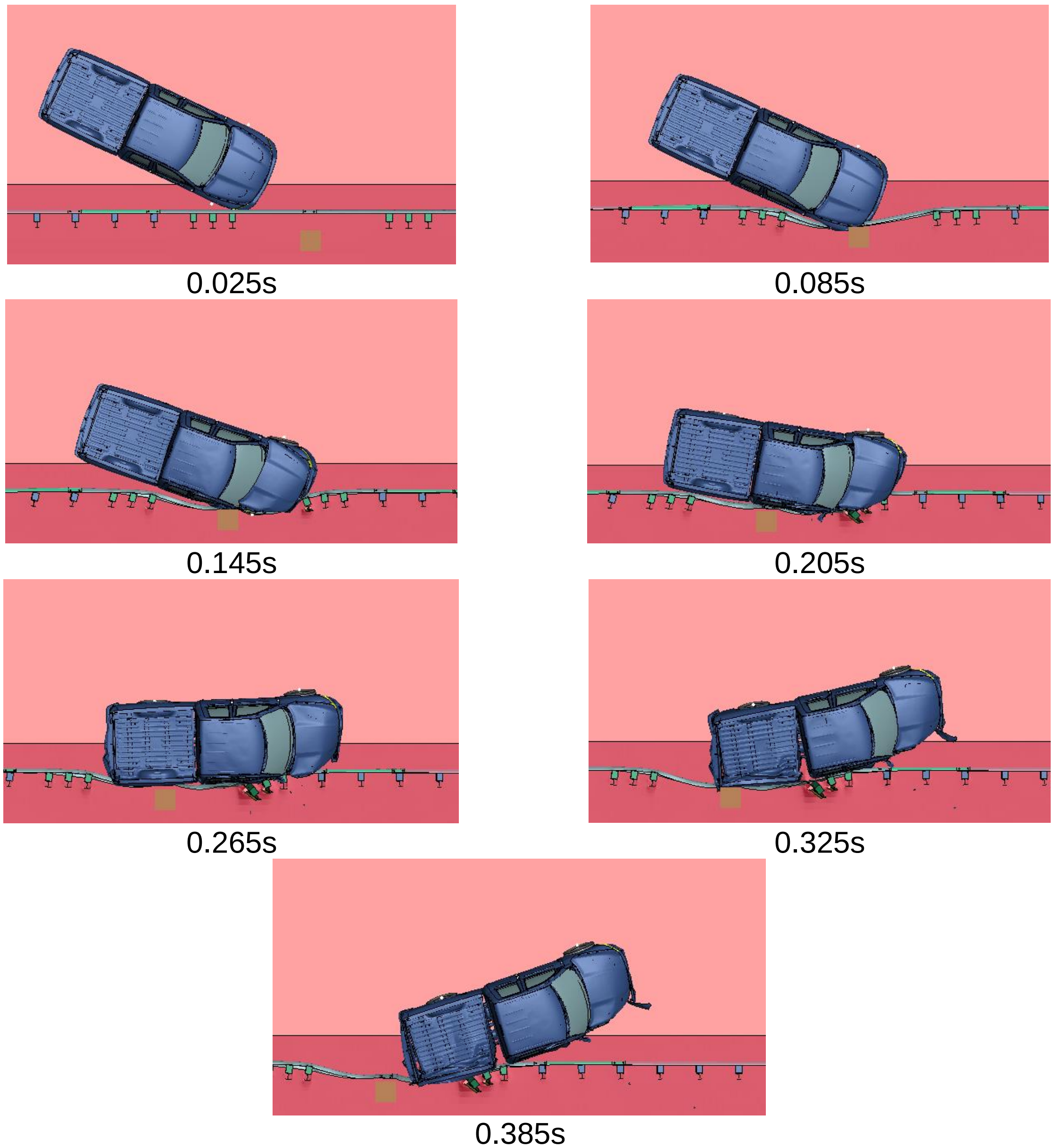


Figure 2.107. *MASH* Test 3-11 Simulation of Quarter-Post Large Gap with Fixed Object 16 inch Offset – Overhead View

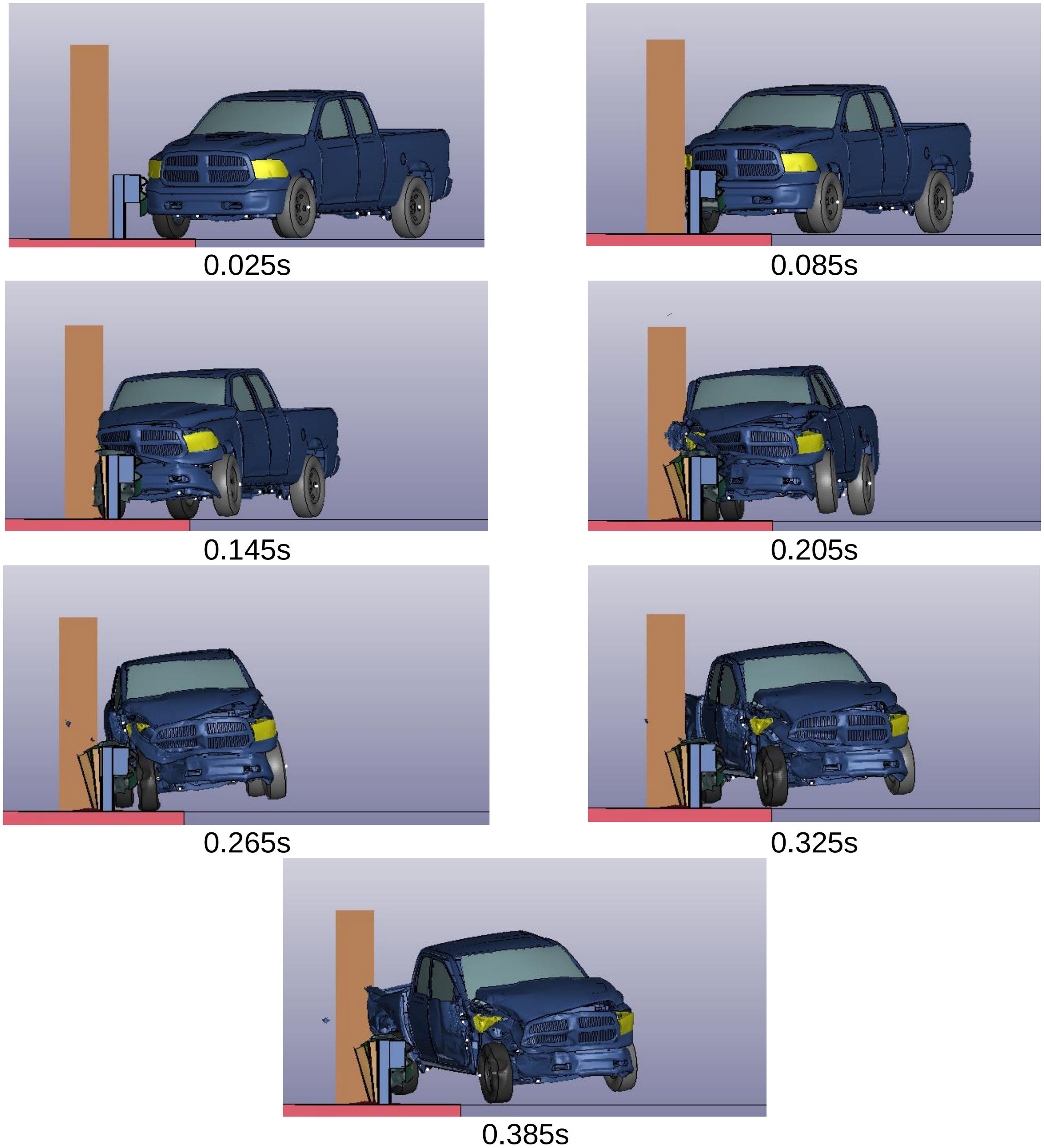


Figure 2.108. ***MASH*** **Test 3-11 Simulation of Quarter-Post Large Gap with Fixed Object 16 inch Offset – Downstream View**

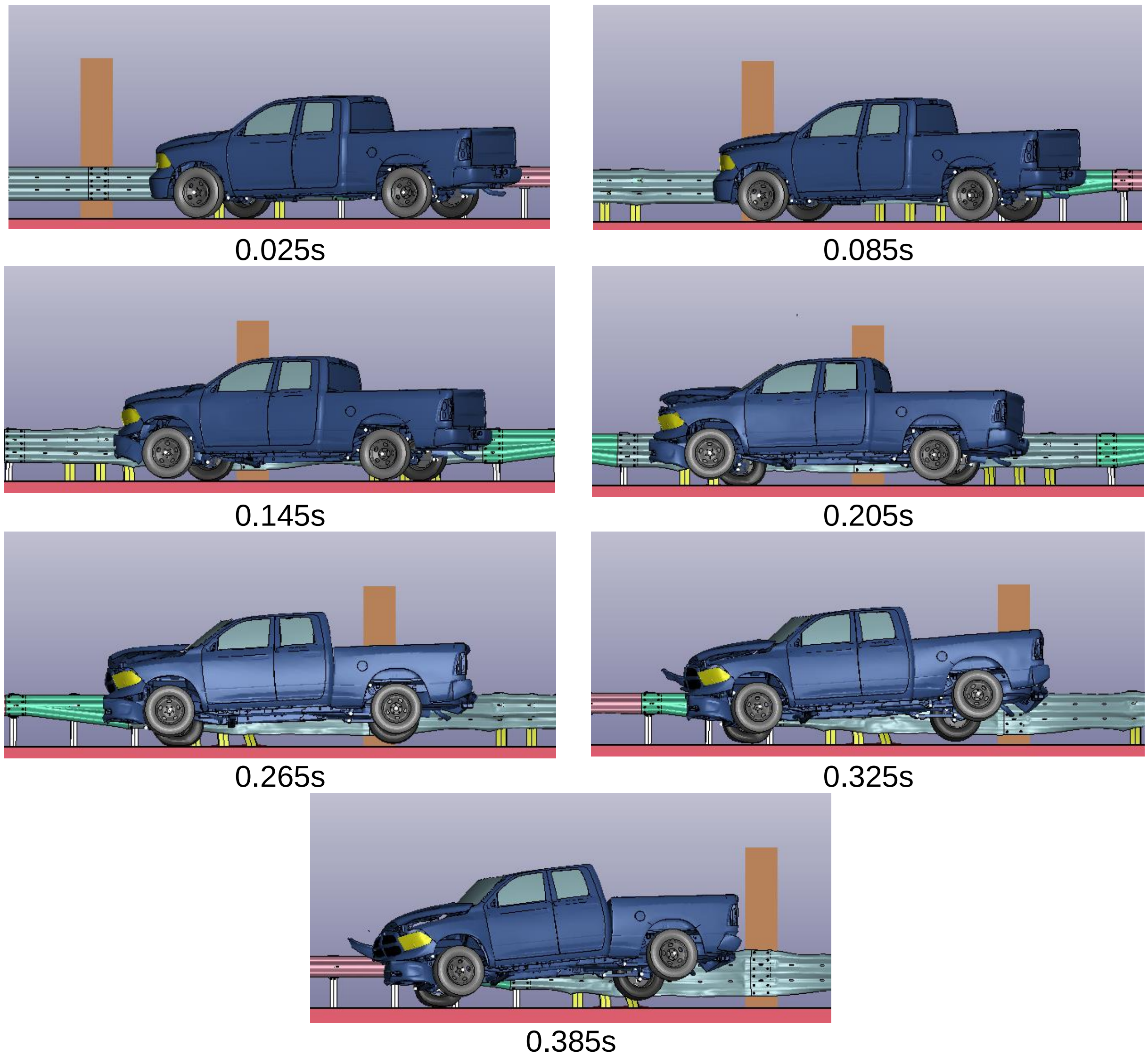


Figure 2.109. *MASH* Test 3-11 Simulation of Quarter-Post Large Gap with Fixed Object 16 inch Offset – Rear View

2.4.2.8. MASH Test 3-11 Simulation of Quarter-Post Spacing Large Gap with Fixed Object 20 inch Offset

Figure 2.110 through Figure 2.112 show the sequential frames of *MASH* test 3-11 with quarter-post spacing, large gap, and a fixed object offset of 20 inches. The occupant impact velocity was calculated to be 5.8 m/s (preferred limit is 9.1 m/s). The ridedown acceleration was calculated to be 13.5 g's (preferred limit is 15.0 g's).

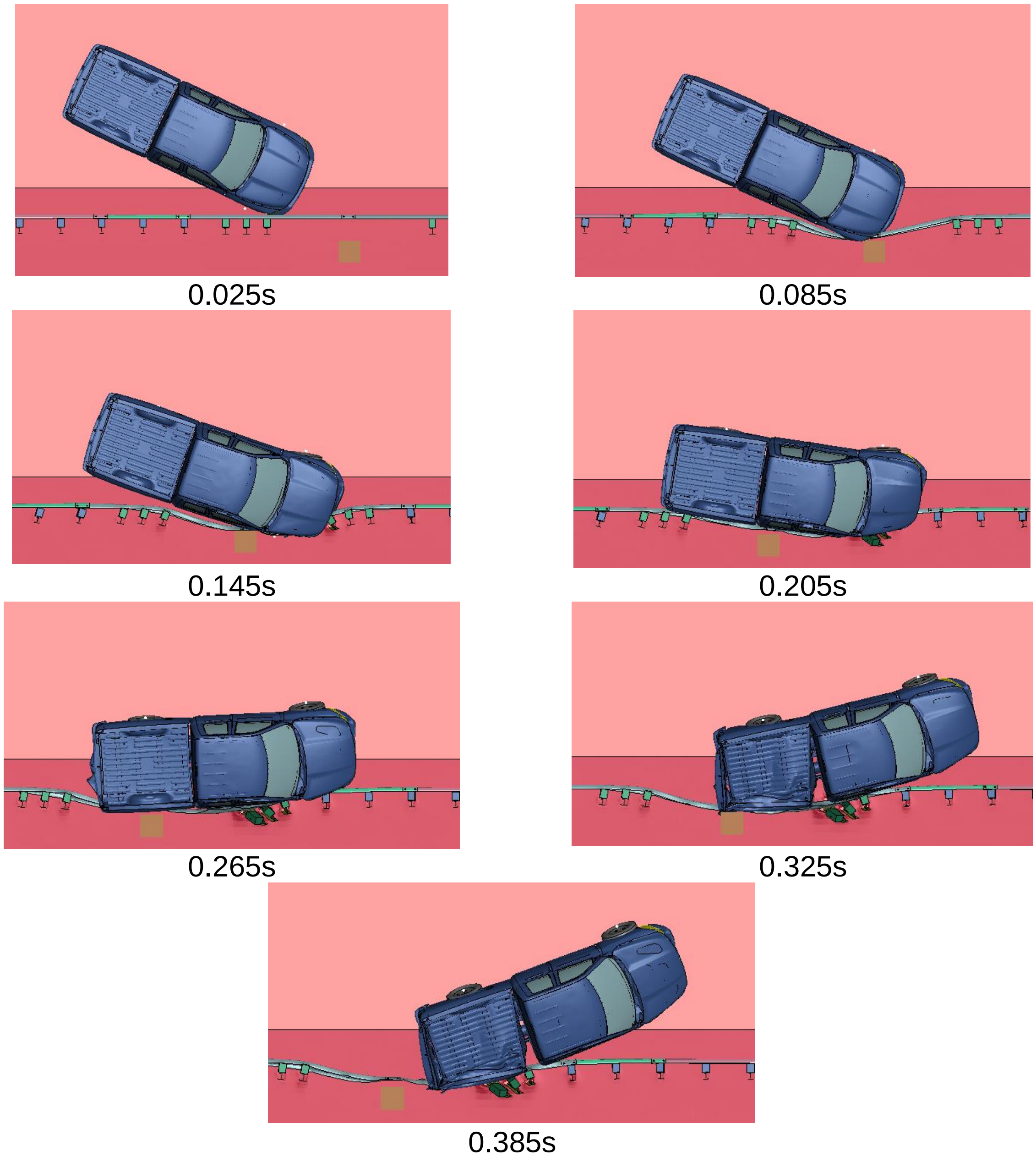


Figure 2.110. *MASH* Test 3-11 Simulation of Quarter-Post Large Gap with Fixed Object 20 inch Offset – Overhead View

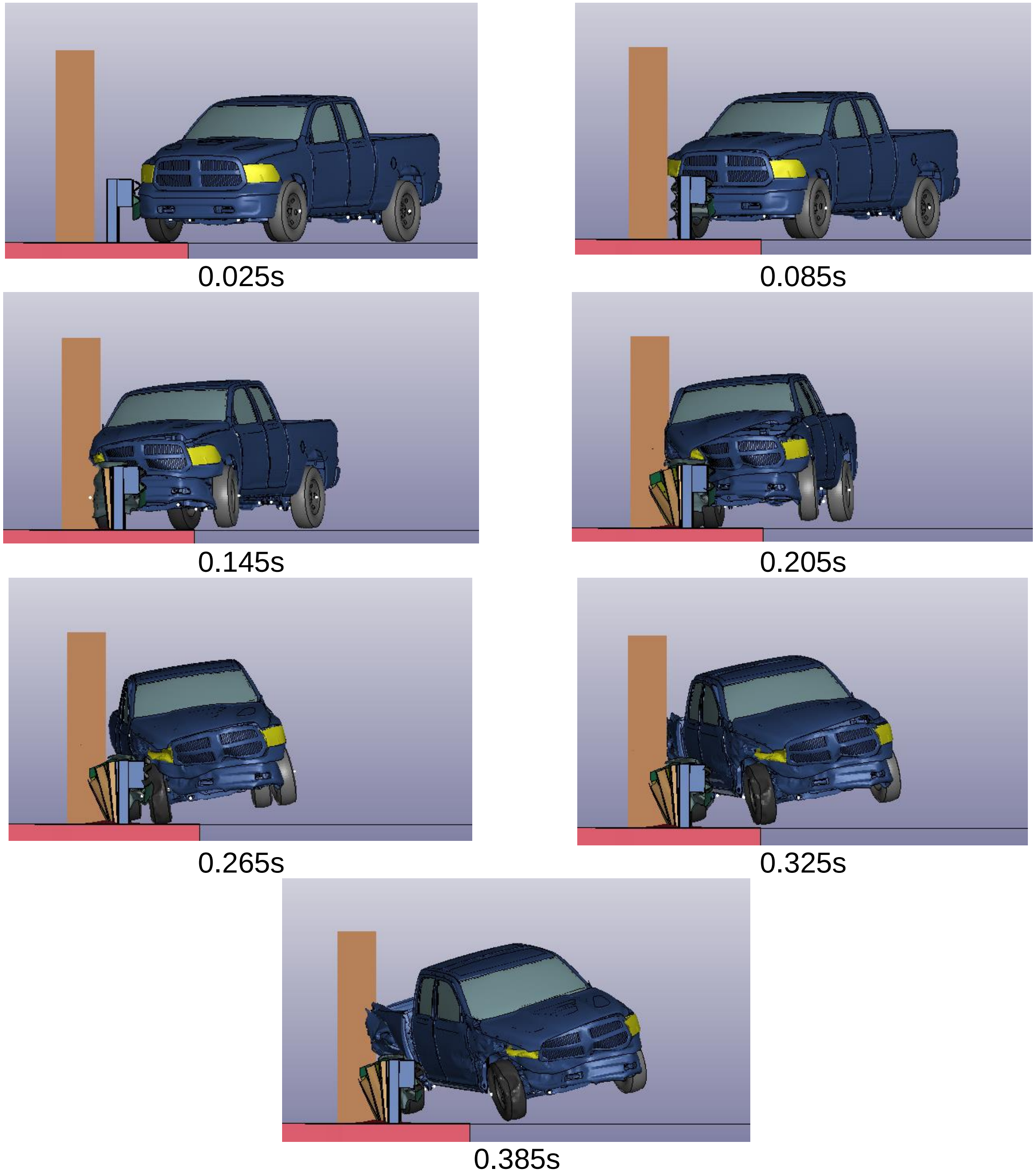


Figure 2.111. *MASH* Test 3-11 Simulation of Quarter-Post Large Gap with Fixed Object 20 inch Offset – Downstream View

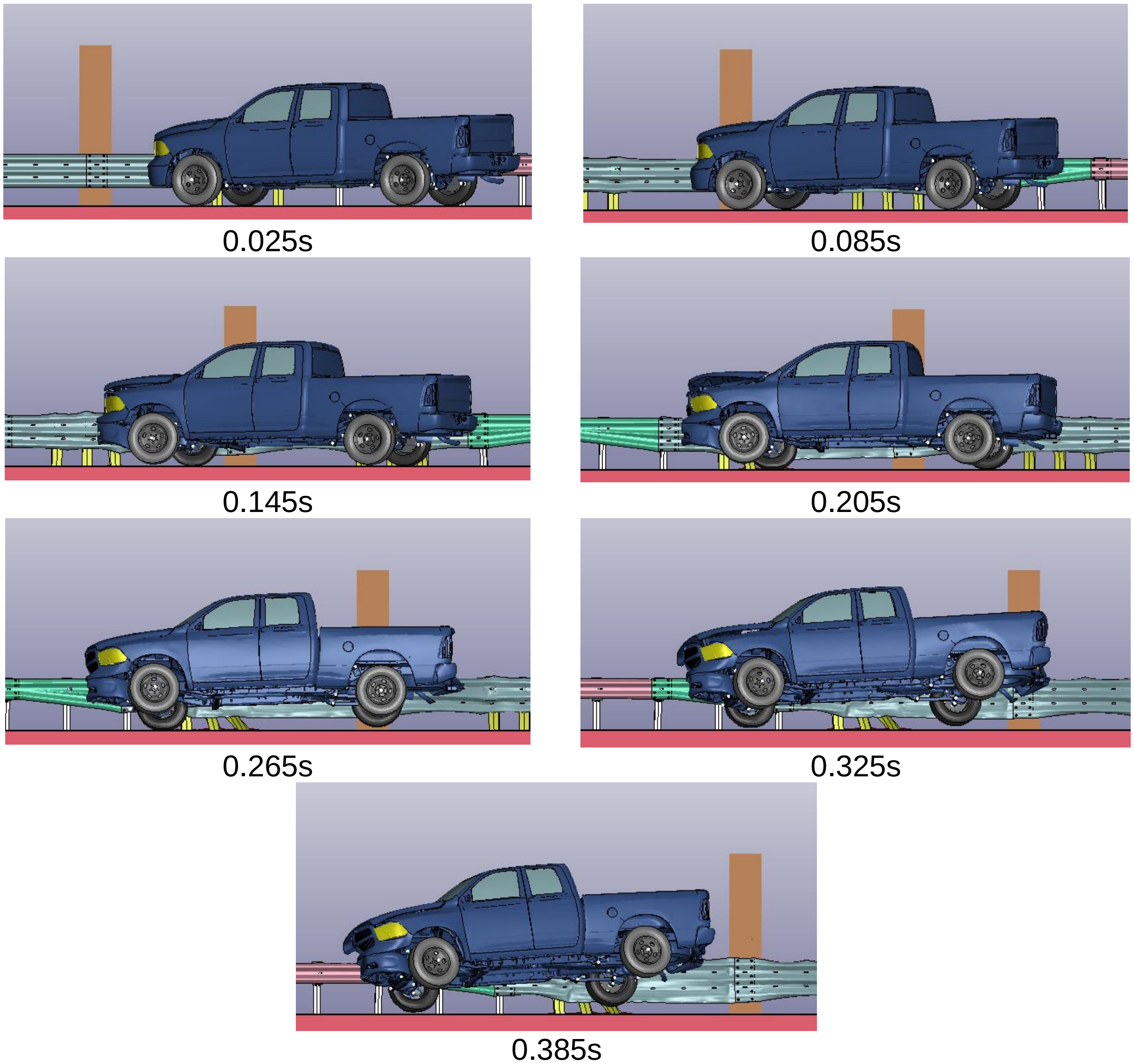


Figure 2.112. *MASH* Test 3-11 Simulation of Quarter-Post Large Gap with Fixed Object 20 inch Offset – Rear View

2.4.2.9. MASH Test 3-11 Simulation of Quarter-Post Spacing Large Gap with Fixed Object 24 inch Offset

Figure 2.113 through Figure 2.115 show the sequential frames of *MASH* test 3-11 with quarter-post spacing, large gap, and a fixed object offset of 24 inches. The occupant impact velocity was calculated to be 5.6 m/s (preferred limit is 9.1 m/s). The ridedown acceleration was calculated to be 15.5 g's (maximum limit is 20.49 g's).

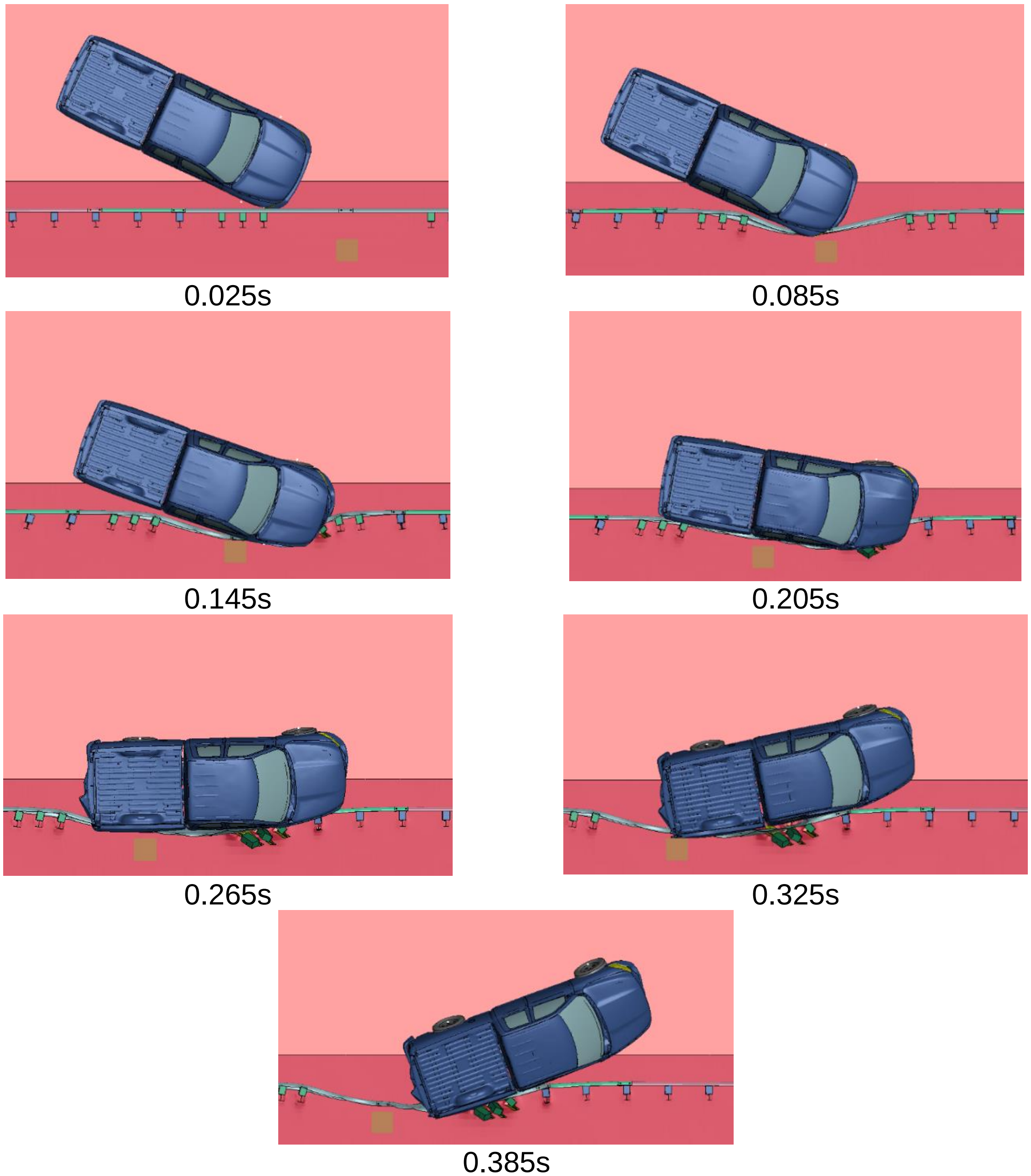
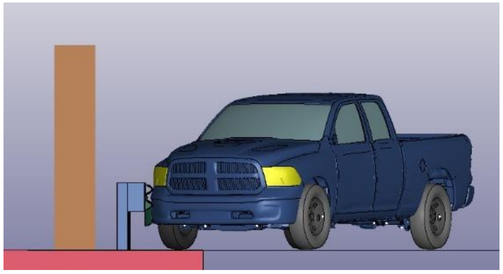


Figure 2.113. *MASH* Test 3-11 Simulation of Quarter-Post Large Gap with Fixed Object 24 inch Offset – Overhead View



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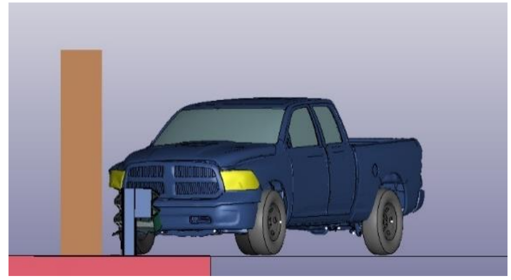

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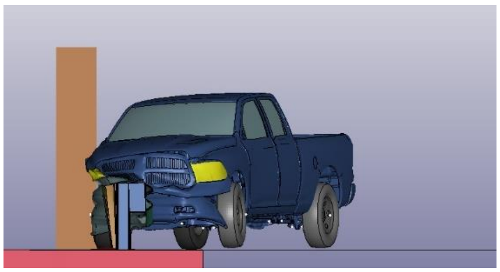

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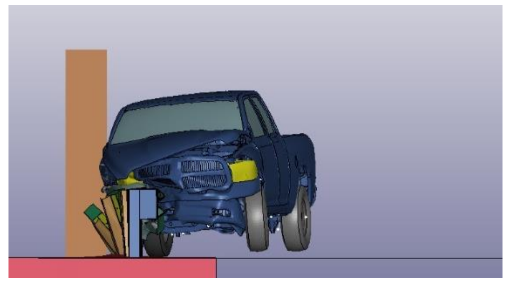

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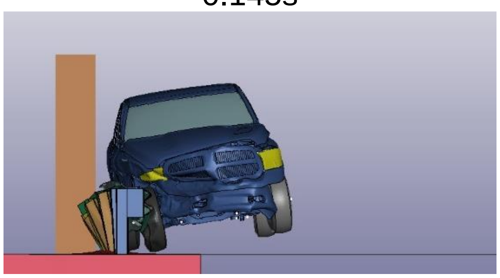

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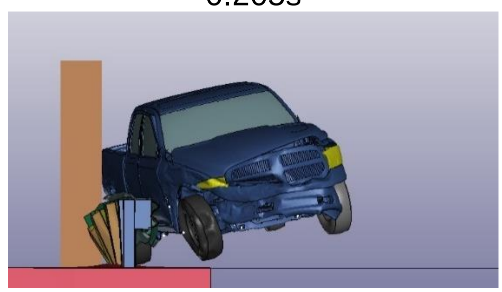


0.325s

0.385s

Figure 2.114. *MASH* Test 3-11 Simulation of Quarter-Post Large Gap with Fixed Object 24 inch Offset – Downstream View

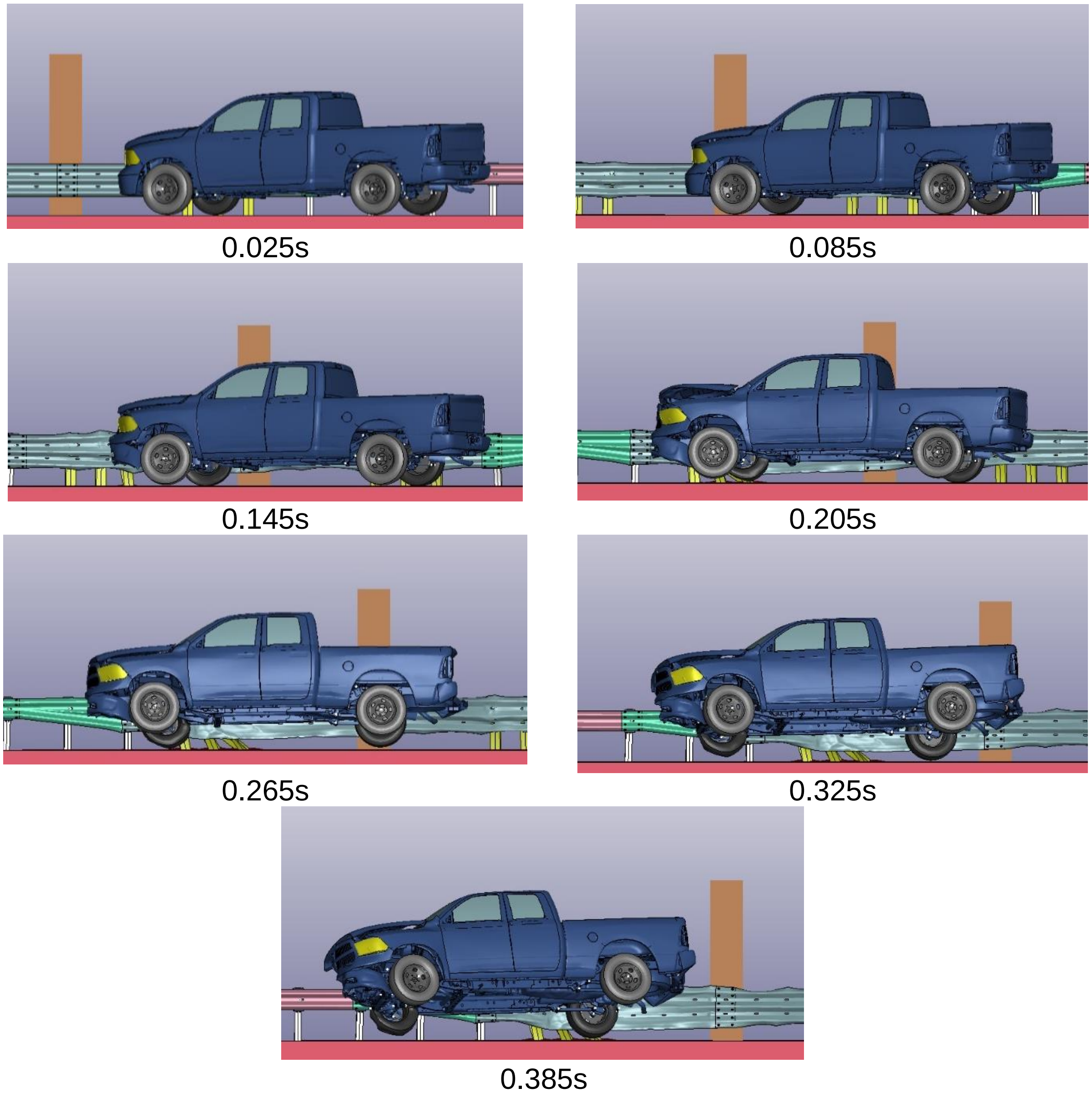


Figure 2.115. *MASH* Test 3-11 Simulation of Quarter-Post Large Gap with Fixed Object 24 inch Offset – Rear View

2.4.2.10. MASH Test 3-11 Simulation of Quarter-Post Spacing Large Gap with Fixed Object 30 inch Offset

Figure 2.116 through Figure 2.118 show the sequential frames of *MASH* test 3-11 with quarter-post spacing, large gap, and a fixed object offset of 30 inches. The occupant impact velocity was calculated to be 5.7 m/s (preferred limit is 9.1 m/s). The ridedown acceleration was calculated to be 18.3 g's (maximum limit is 20.49 g's). This configuration passed *MASH* test 3-11 by successfully containing and redirecting the vehicle. Because of the minimal to no interaction exhibited in this simulation, the research team evaluated multiple impact points to determine the most critical. These simulations are included in the sections below.

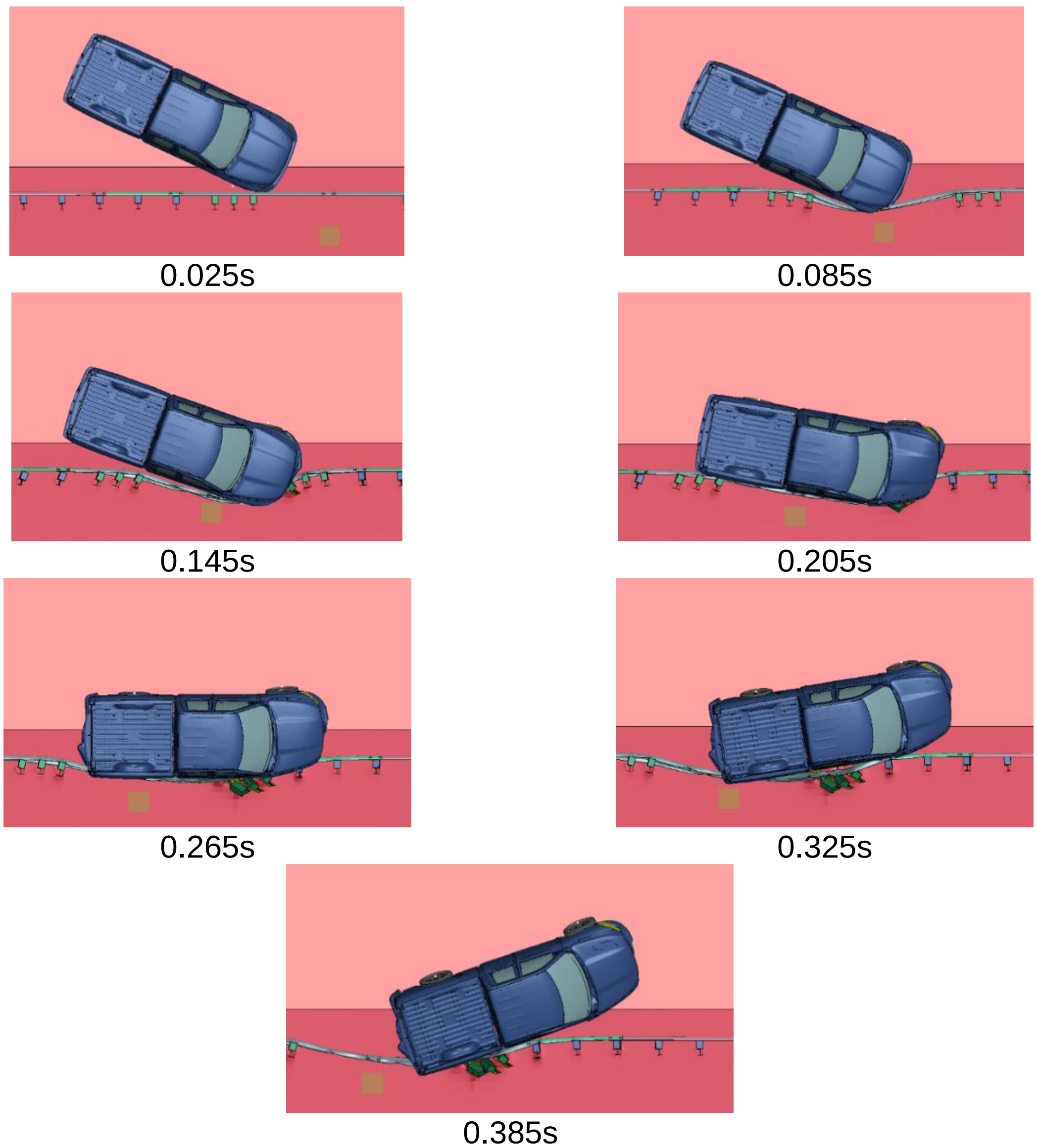


Figure 2.116. *MASH* Test 3-11 Simulation of Quarter-Post Large Gap with Fixed Object 30 inch Offset – Overhead View

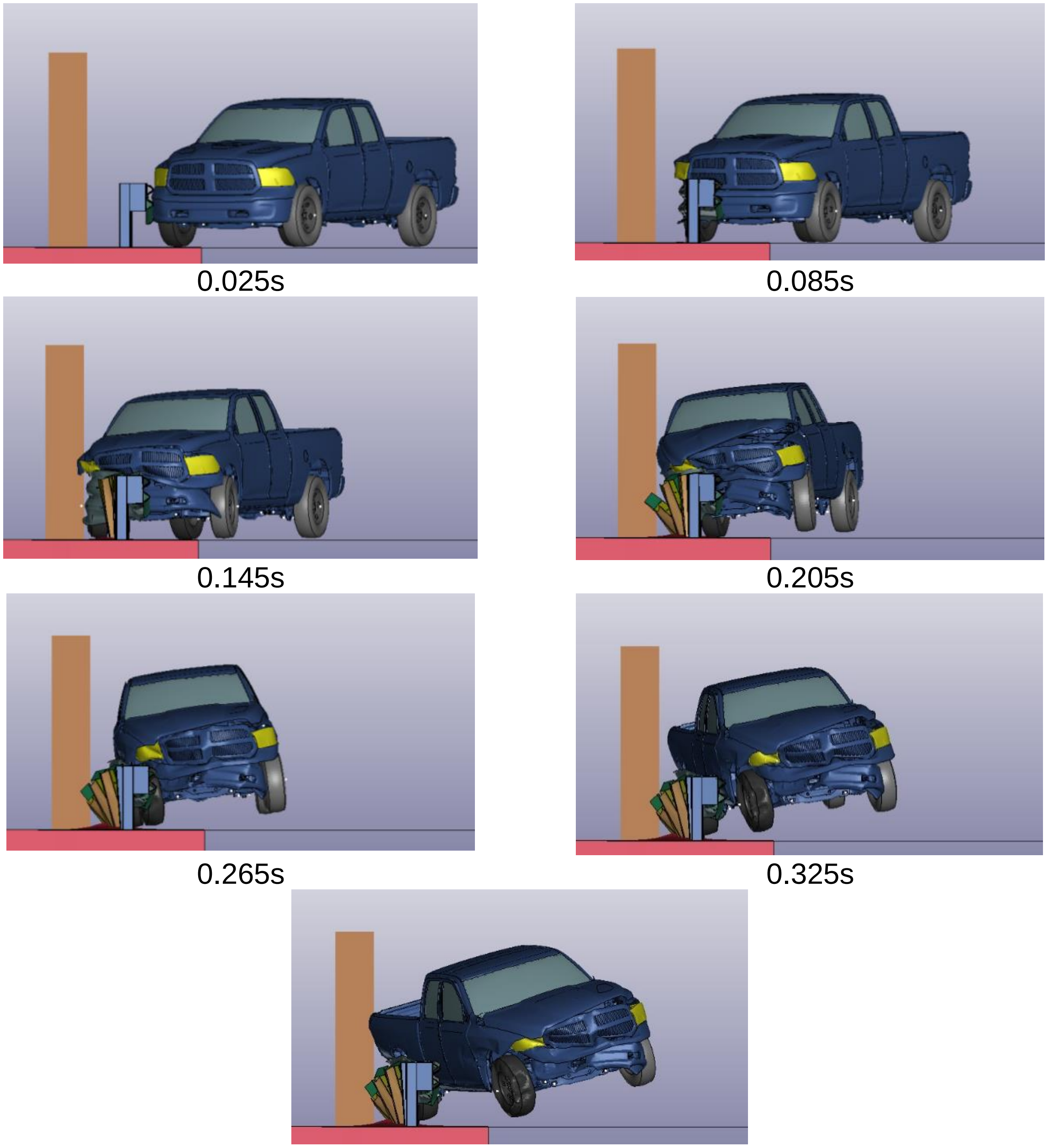
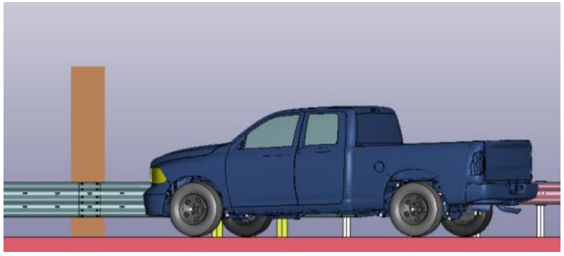


Figure 2.117. *MASH* Test 3-11 Simulation of Quarter-Post Large Gap with Fixed Object 30 inch Offset – Downstream View



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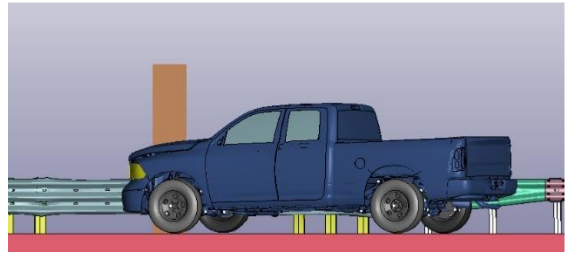

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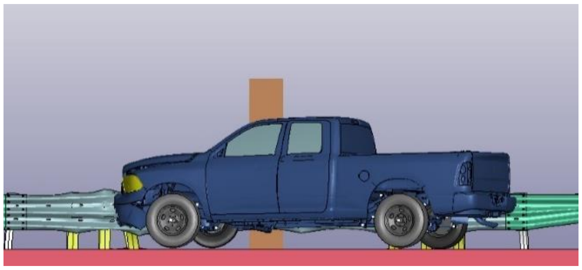

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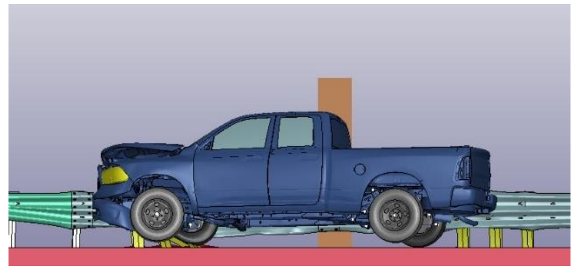

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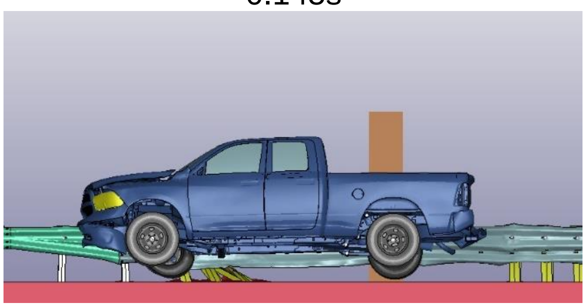

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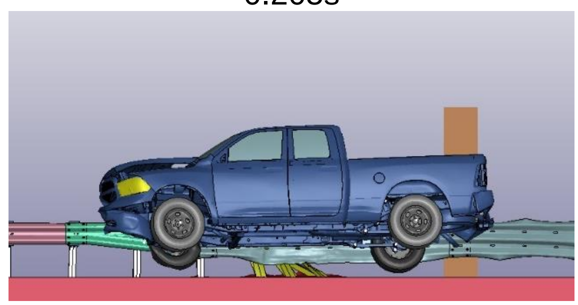
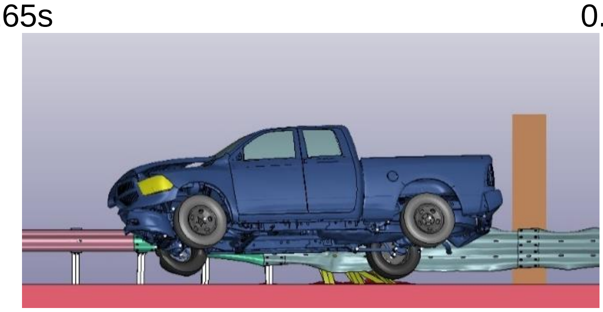


0.325s



0.385s

Figure 2.118. *MASH* Test 3-11 Simulation of Quarter-Post Large Gap with Fixed Object 30 inch Offset – Rear View

2.4.2.11. MASH Test 3-11 Simulation of Quarter-Post Spacing Large Gap with Fixed Object 30 inch Offset and 1 foot Upstream Impact Variation

Figure 2.119 through Figure 2.121 show the sequential frames of *MASH* test 3-11 with quarter-post spacing, large gap, a fixed object offset of 30 inches, and an impact variation positioned 1 foot upstream. The pickup truck experienced excessive roll, which was deemed unsatisfactory.

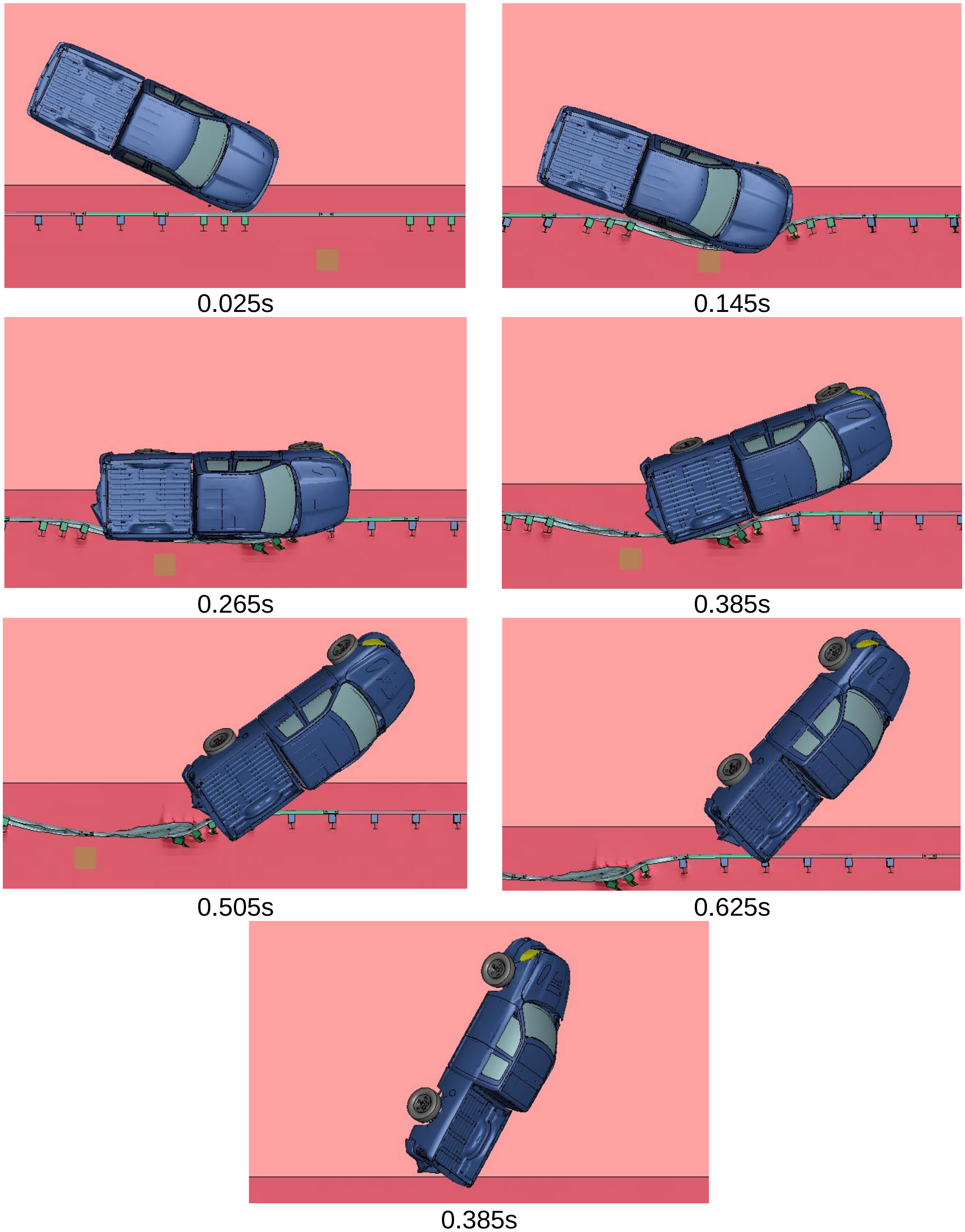


Figure 2.119. *MASH* Test 3-11 Simulation of Quarter-Post Large Gap with Fixed Object 30 inch Offset 1 foot Upstream Impact Variation – Overhead View

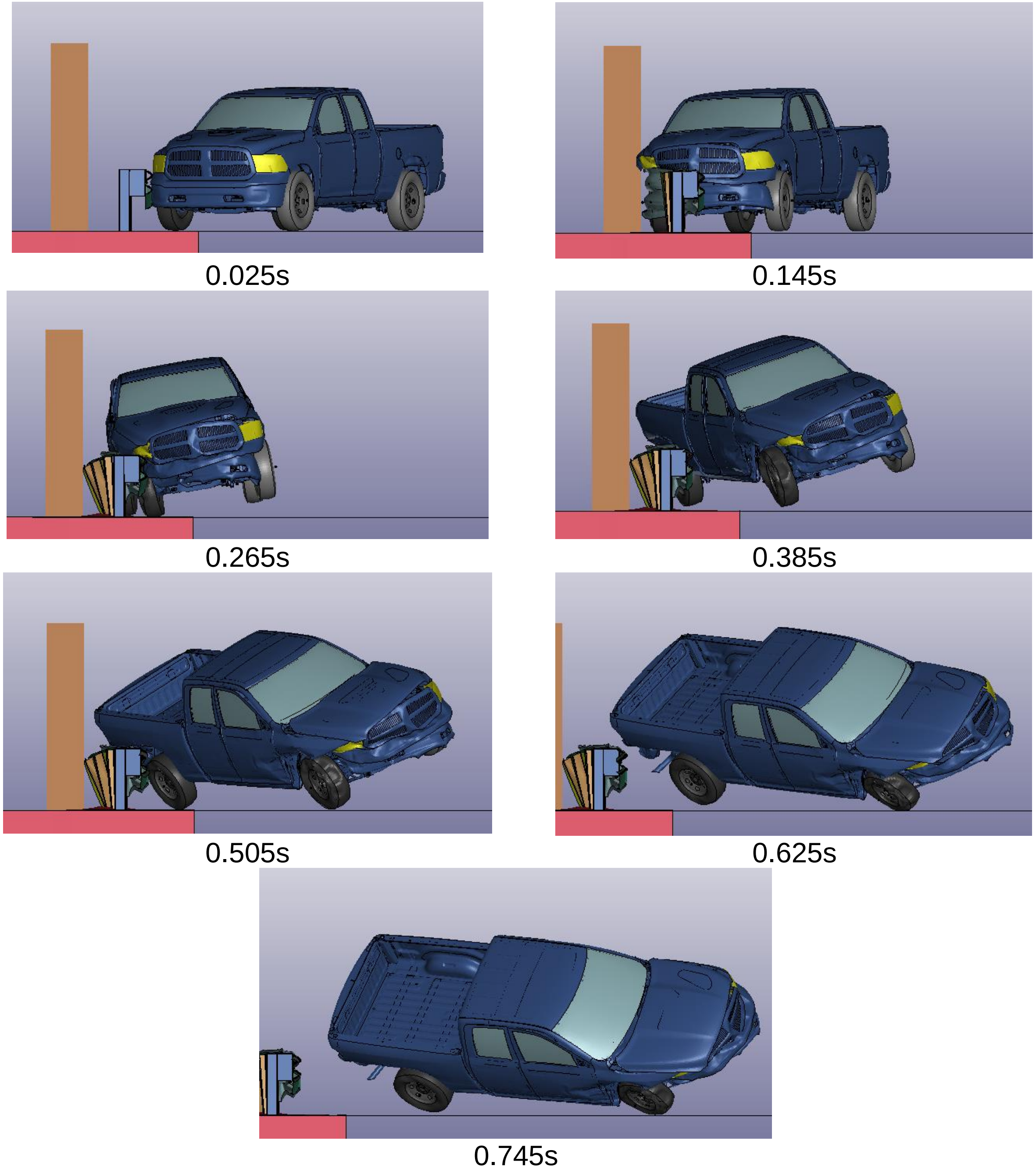
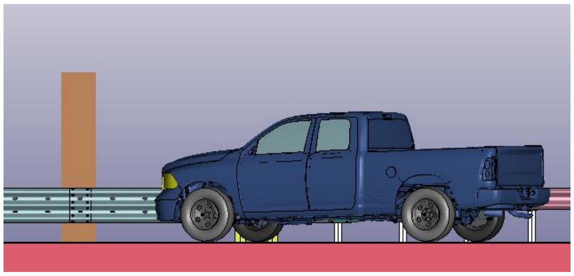


Figure 2.120. ***MASH*** **Test 3-11 Simulation of Quarter-Post Large Gap with Fixed Object 30 inch Offset 1 foot Upstream Impact Variation – Downstream View**



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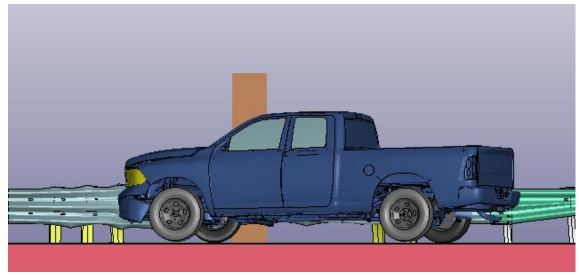

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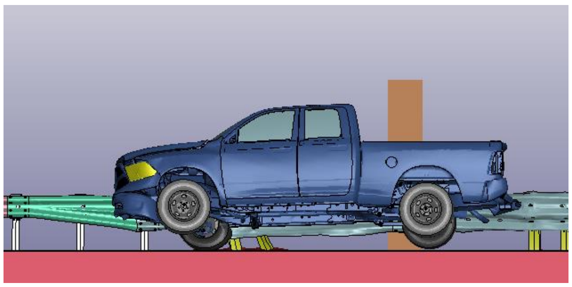

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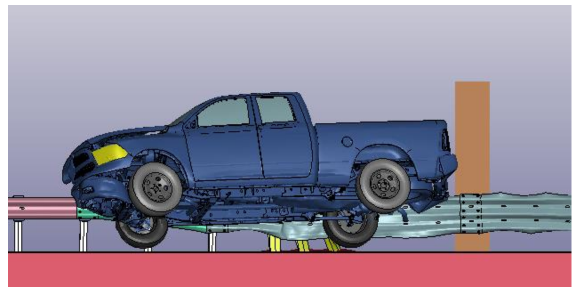

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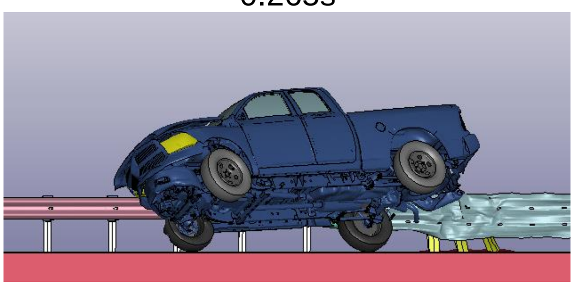

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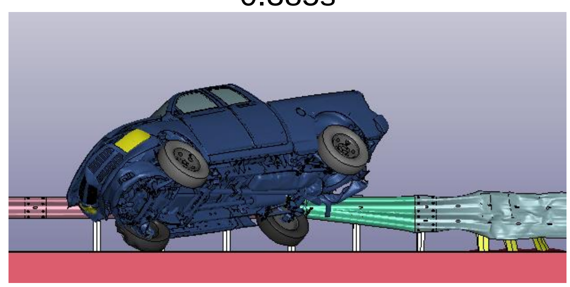

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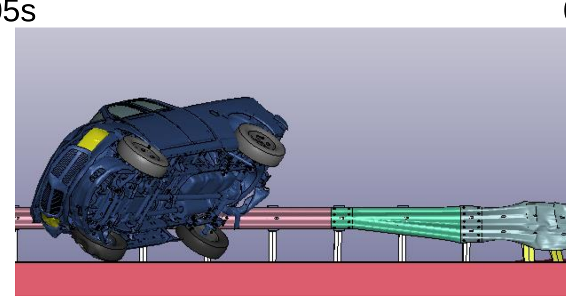


0.745s

Figure 2.121. *MASH* Test 3-11 Simulation of Quarter-Post Large Gap with Fixed Object 30 inch Offset 1 foot Upstream Impact Variation – Rear View

2.4.2.12. MASH Test 3-11 Simulation of Quarter-Post Spacing Large Gap with Fixed Object 30 inch Offset and 2 feet Upstream Impact Variation

Figure 2.122 through Figure 2.124 show the sequential frames of *MASH* test 3-11 with quarter-post spacing, large gap, a fixed object offset of 30 inches, and an impact variation positioned 2 feet upstream. The pickup truck experienced excessive roll.

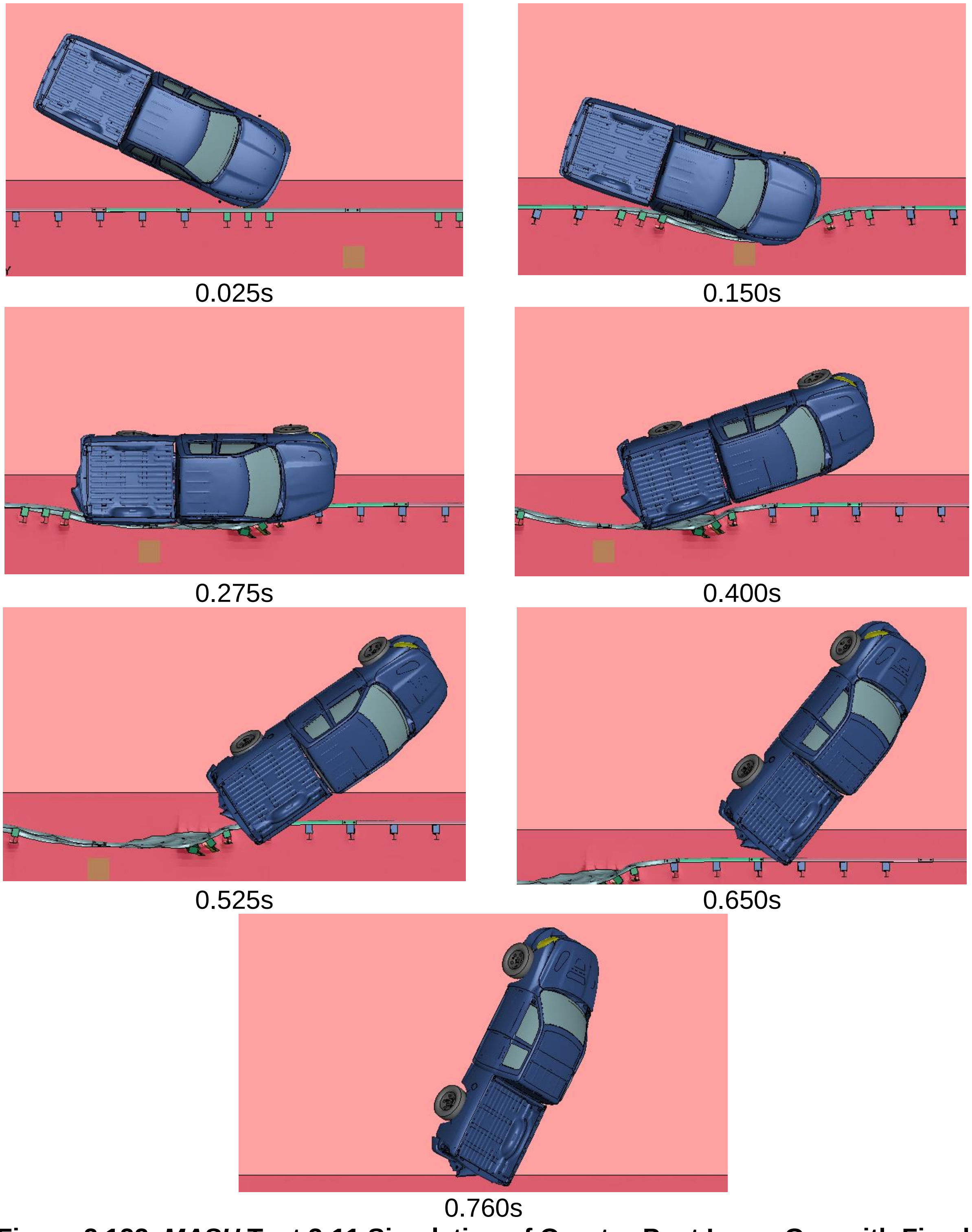


Figure 2.122. *MASH* Test 3-11 Simulation of Quarter-Post Large Gap with Fixed Object 30 inch Offset 2 feet Upstream Impact Variation – Overhead View

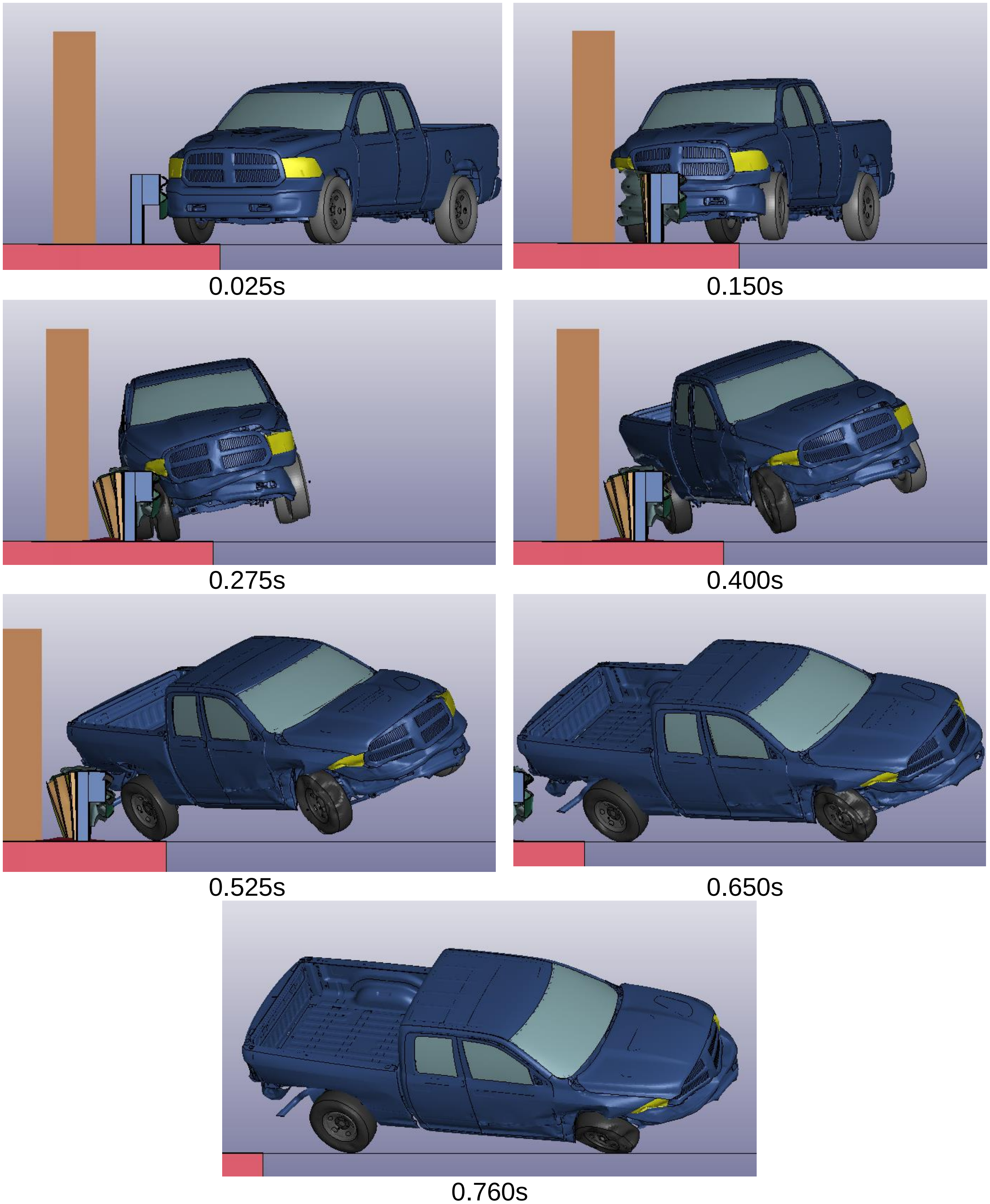


Figure 2.123. *MASH* Test 3-11 Simulation of Quarter-Post Large Gap with Fixed Object 30 inch Offset 2 feet Upstream Impact Variation – Downstream View

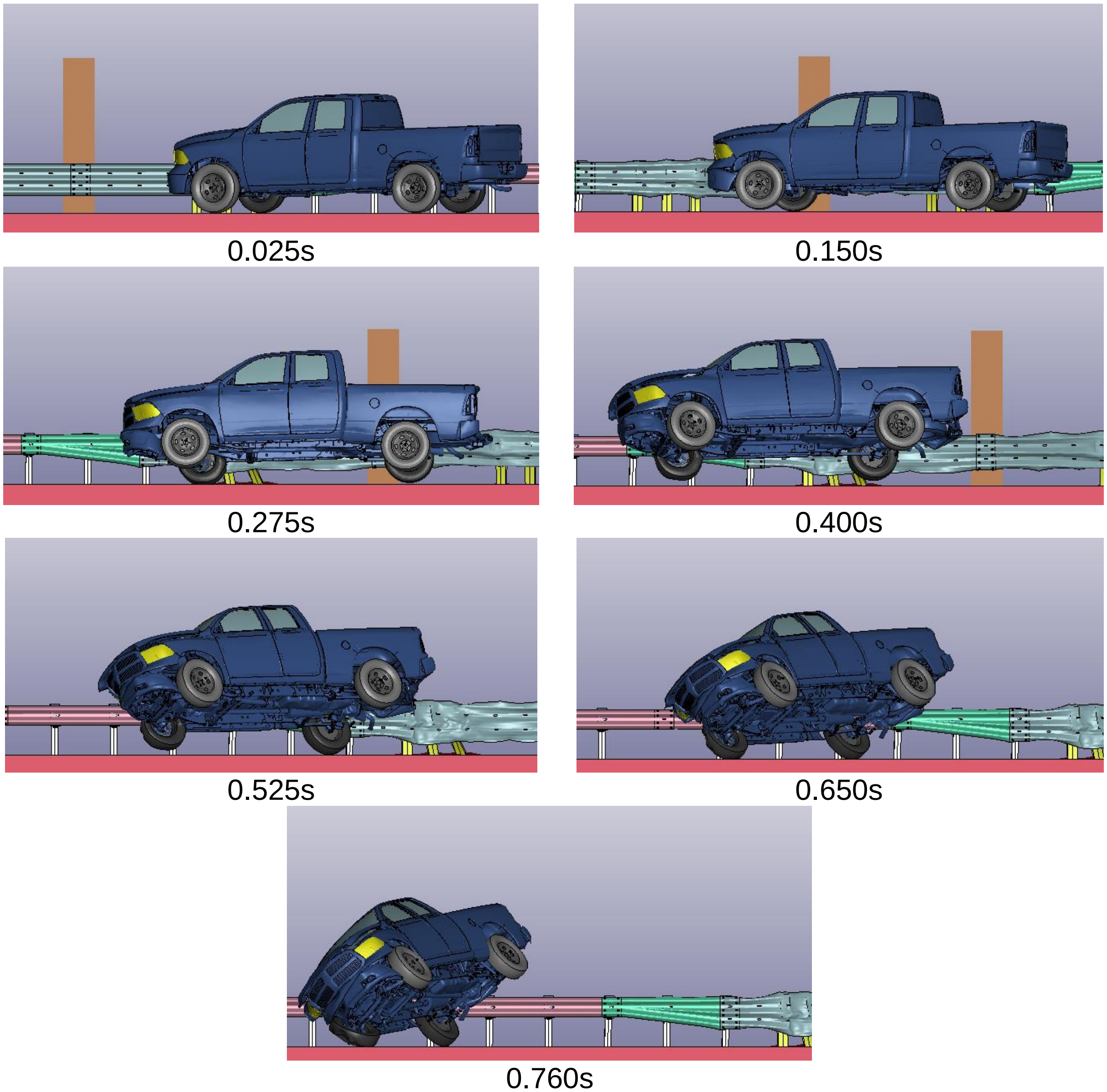


Figure 2.124. *MASH* Test 3-11 Simulation of Quarter-Post Large Gap with Fixed Object 30 inch Offset 2 feet Upstream Impact Variation – Rear View

2.4.2.13. MASH Test 3-11 Simulation of Quarter-Post Spacing Large Gap with Fixed Object 30 inch Offset and 4 feet Upstream Impact Variation

Figure 2.125 through Figure 2.127 show the sequential frames of *MASH* test 3-11 with quarter-post spacing, large gap, a fixed object offset of 30 inches, and an impact variation positioned 4 feet upstream. The occupant impact velocity was calculated to be 4.6 m/s (preferred limit is 9.1 m/s). The ridedown acceleration was calculated to be 23.0 g’s (maximum limit is 20.49 g’s). This configuration failed *MASH* test 3-11 by exceeding the allowable ridedown acceleration limit.

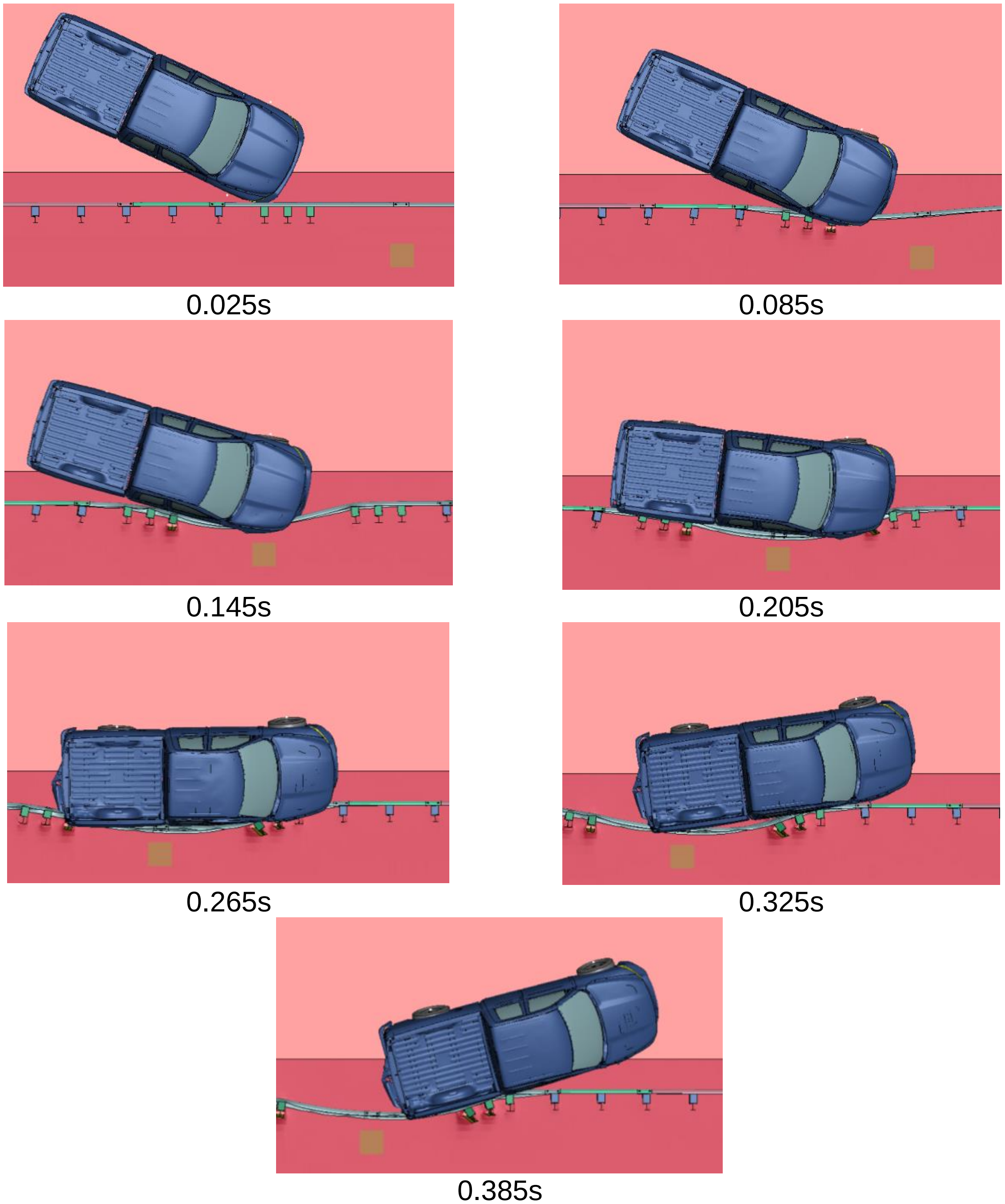


Figure 2.125. *MASH* Test 3-11 Simulation of Quarter-Post Large Gap with Fixed Object 30 inch Offset 4 feet Upstream Impact Variation – Overhead View

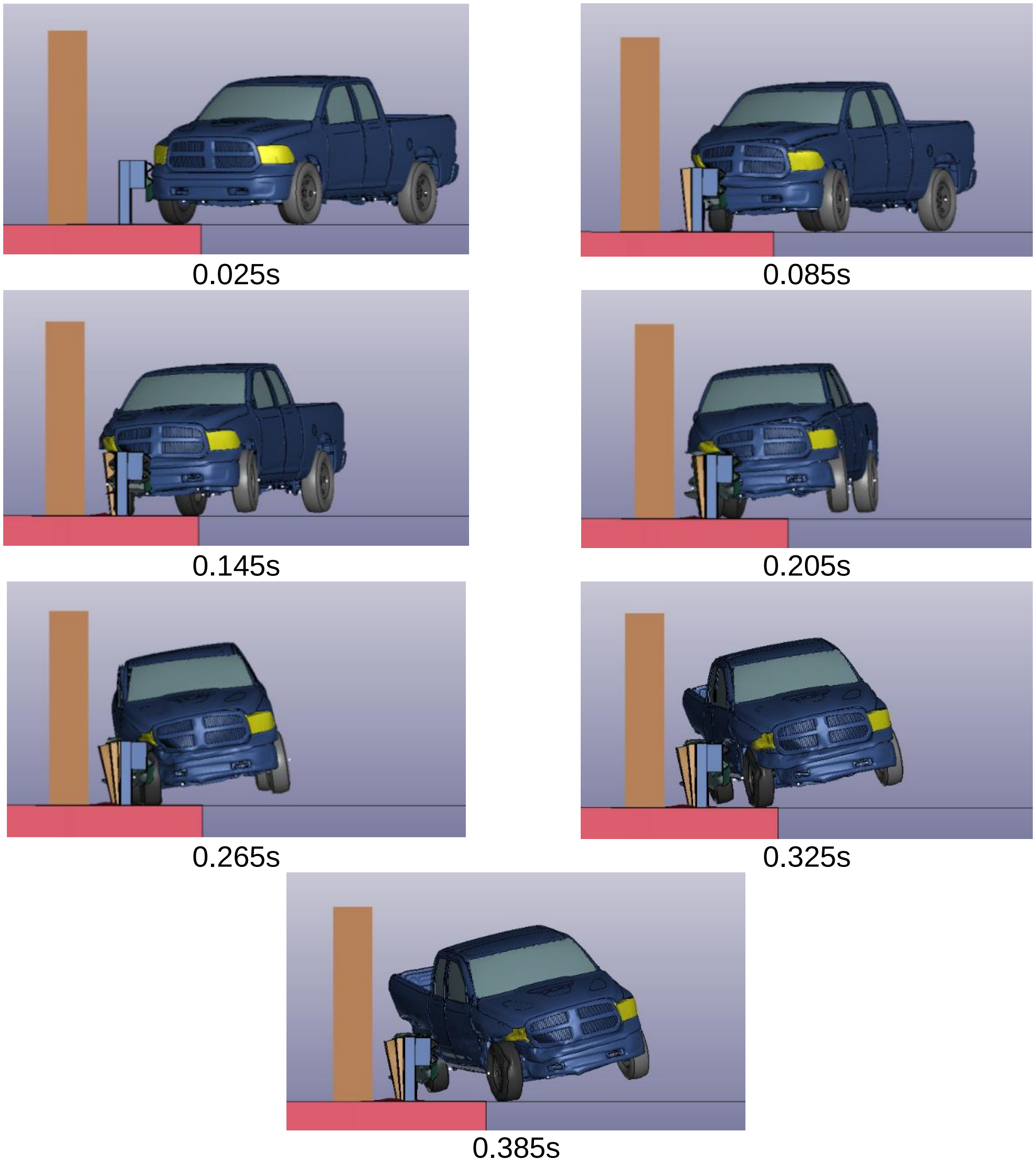
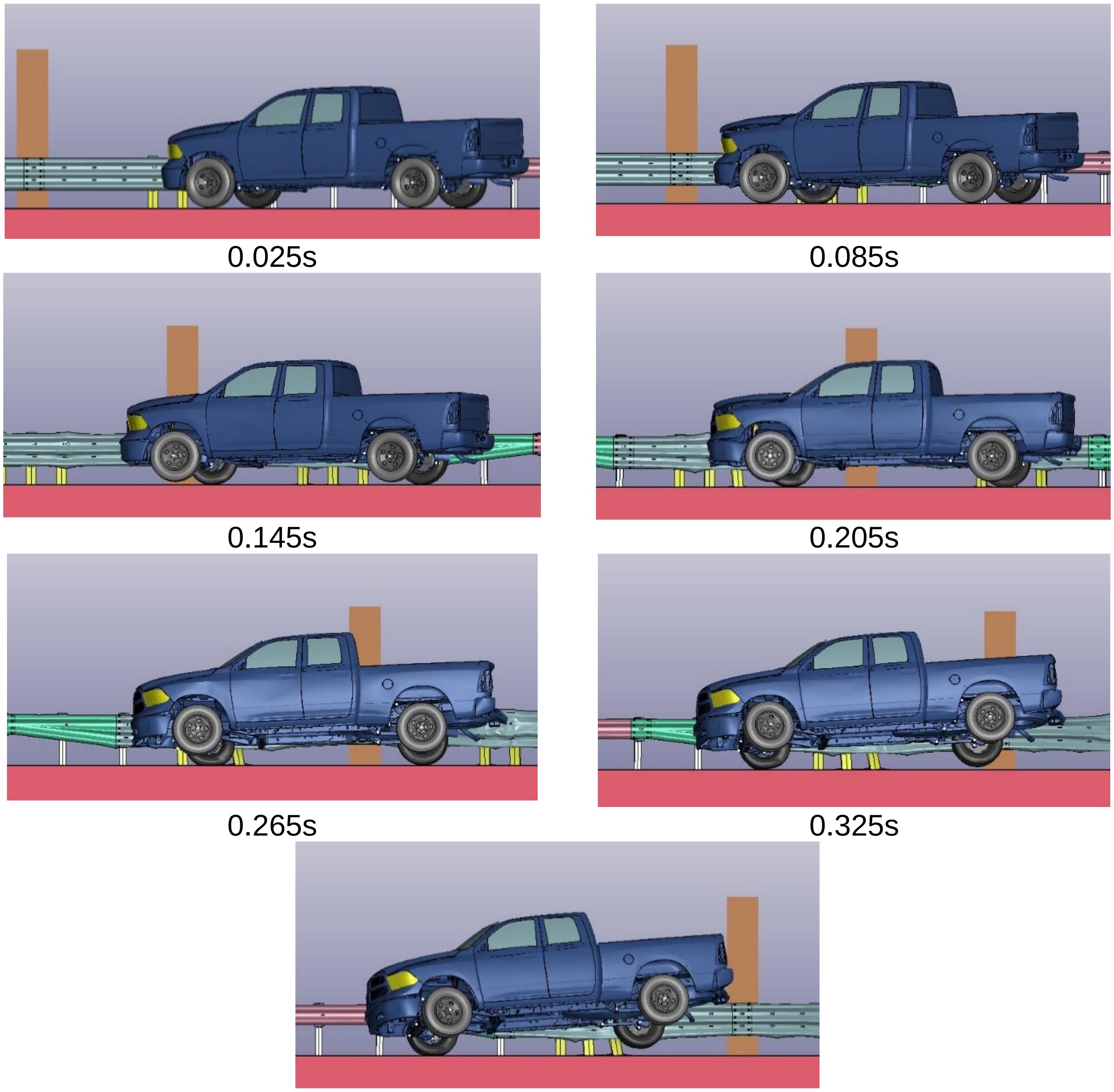


Figure 2.126. *MASH* Test 3-11 Simulation of Quarter-Post Large Gap with Fixed Object 30 inch Offset 4 feet Upstream Impact Variation – Downstream View



0.025s 0.085s 0.145s 0.205s 0.265s 0.325s 0.385s

Figure 2.127. *MASH* Test 3-11 Simulation of Quarter-Post Large Gap with Fixed Object 30 inch Offset 4 feet Upstream Impact Variation – Rear View

2.4.2.14. MASH Test 3-11 Simulation of Quarter-Post Spacing Large Gap with Fixed Object 30 inch Offset and 6 feet Upstream Impact Variation

Figure 2.128 through Figure 2.130 show the sequential frames of *MASH* test 3-11 with quarter-post spacing, large gap, a fixed object offset of 30 inches, and an impact variation positioned 6 feet upstream. The occupant impact velocity was calculated to be 6.6 m/s (preferred limit is 9.1 m/s). The ridedown acceleration was calculated to be 12.2 g's (preferred limit is 15.0 g's). This configuration passed *MASH* test 3-11 by successfully containing and redirecting the vehicle.

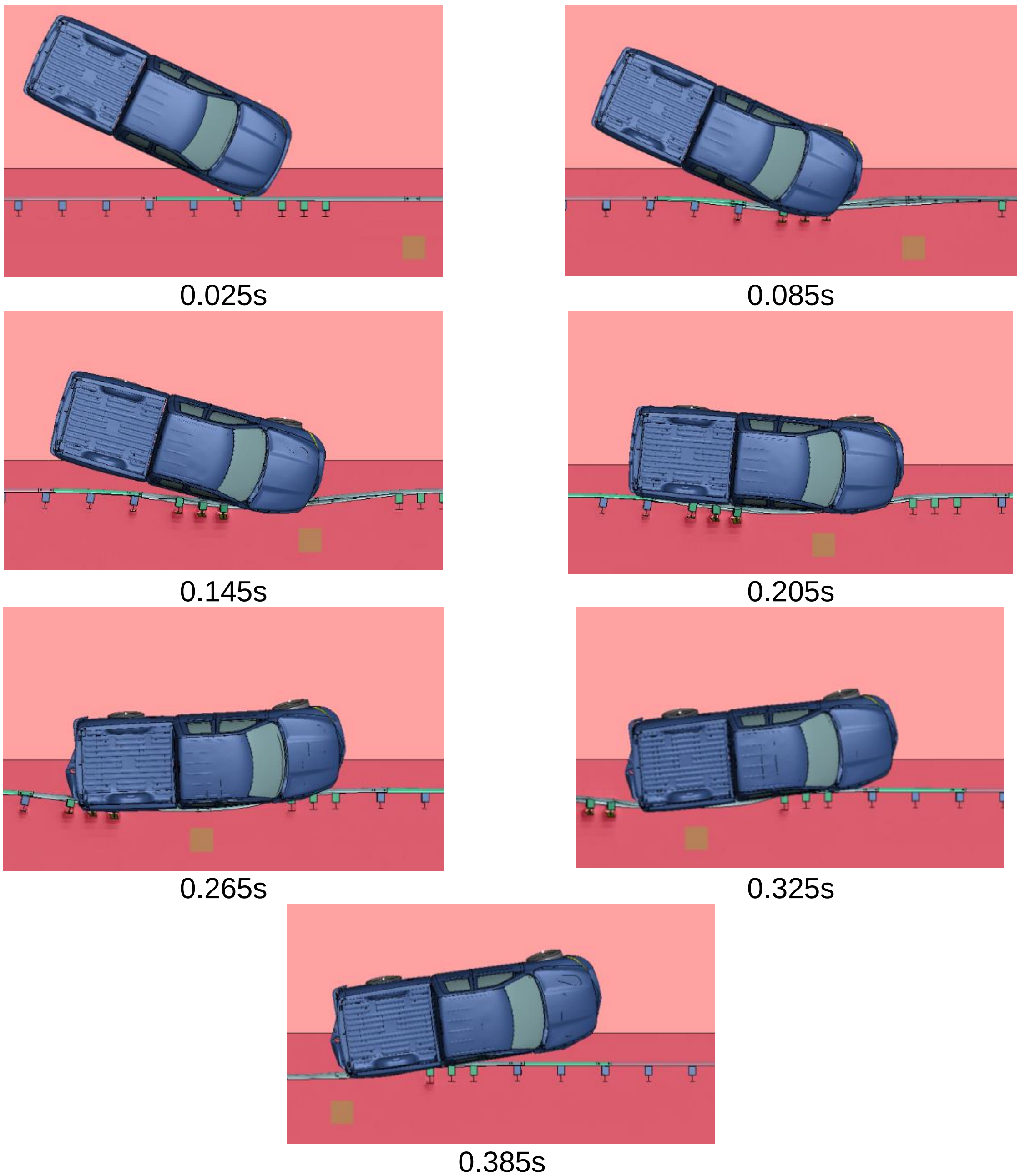


Figure 2.128. *MASH* Test 3-11 Simulation of Quarter-Post Large Gap with Fixed Object 30 inch Offset 6 feet Upstream Impact Variation – Overhead View

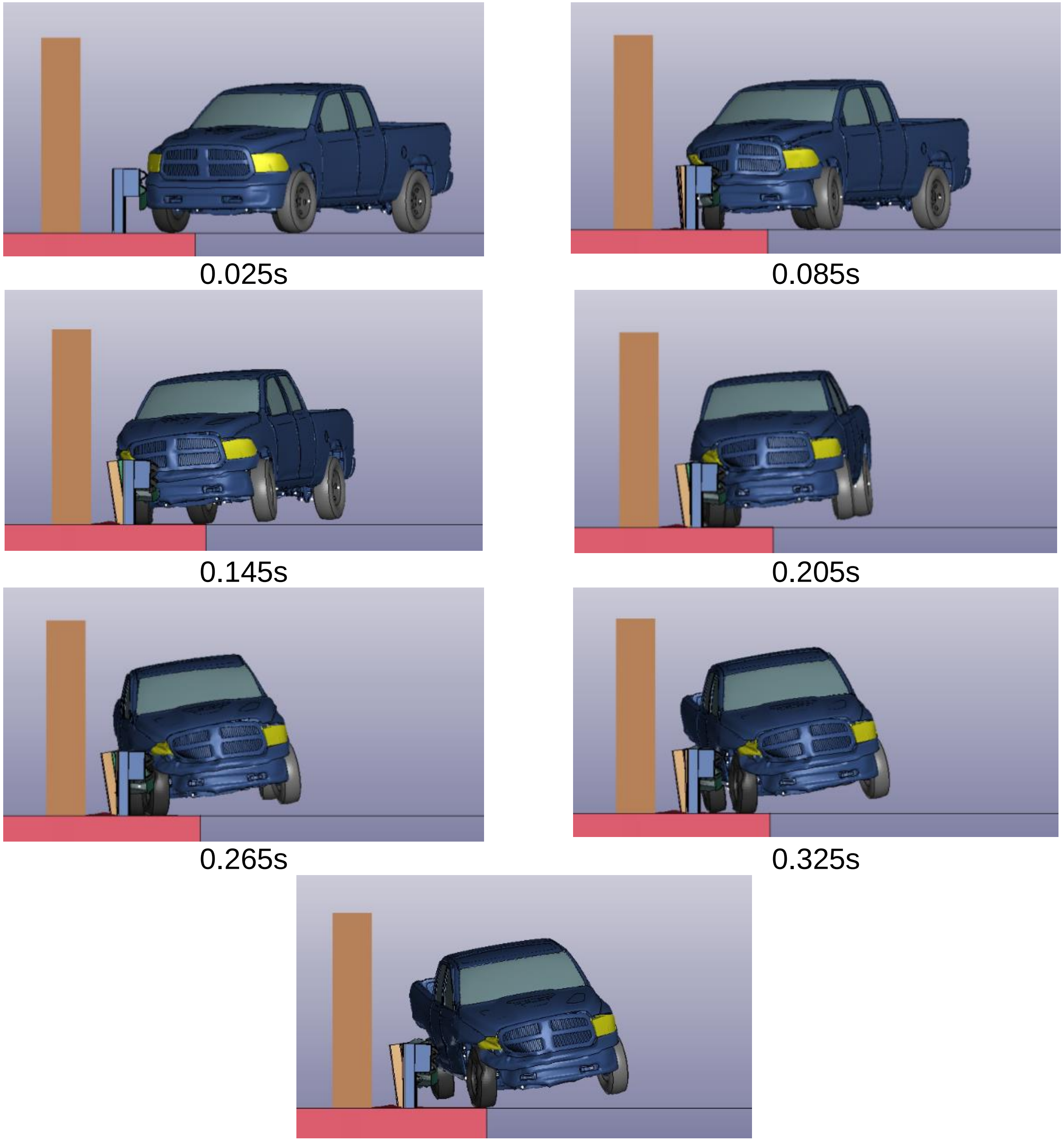
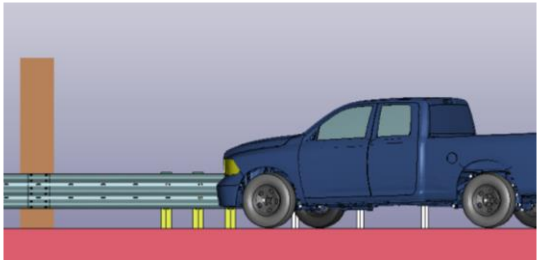


Figure 2.129. *MASH* Test 3-11 Simulation of Quarter-Post Large Gap with Fixed Object 30 inch Offset 6 feet Upstream Impact Variation – Downstream View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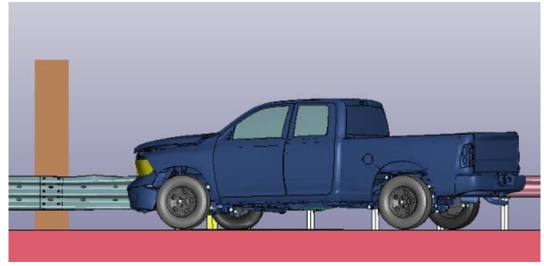
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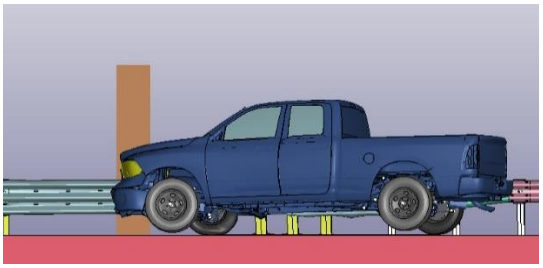
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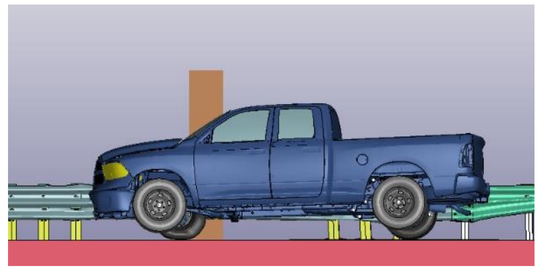
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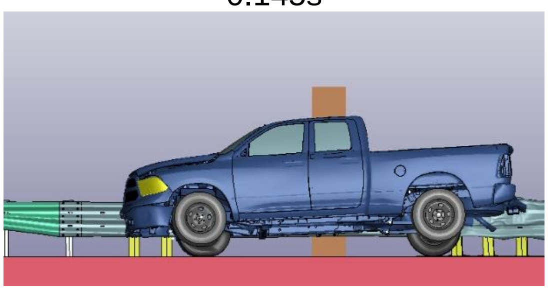
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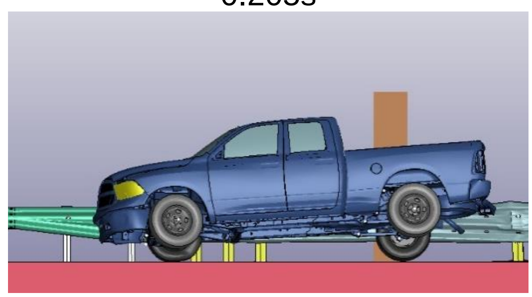
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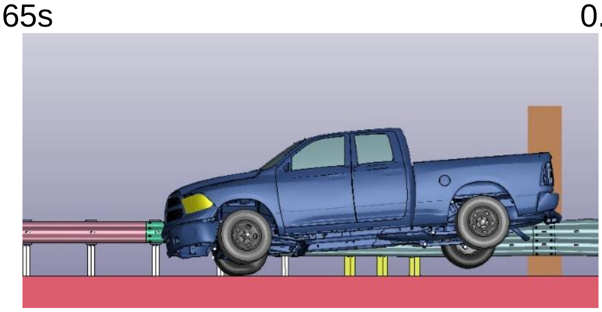
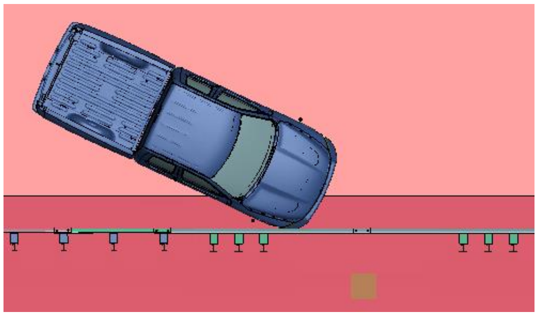

0.385s

Figure 2.130. *MASH* Test 3-11 Simulation of Quarter-Post Large Gap with Fixed Object 30 inch Offset 6 feet Upstream Impact Variation – Rear View

2.4.2.15. MASH Test 3-11 Simulation of Quarter-Post Spacing Large Gap with Fixed Object 30 inch Offset and 1 foot Downstream Impact Variation

Figure 2.131 through Figure 2.133 show the sequential frames of *MASH* test 3-11 with quarter-post spacing, large gap, a fixed object offset of 30 inches, and an impact variation positioned 1 foot downstream. The pickup truck experienced excessive roll, which was deemed unsatisfactory.



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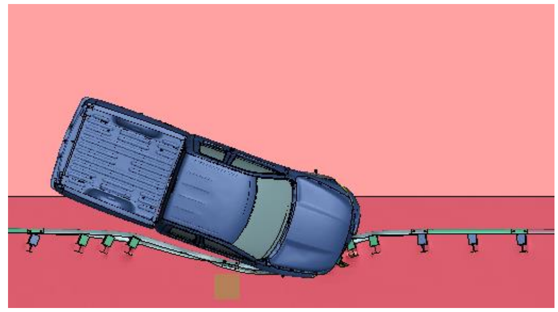

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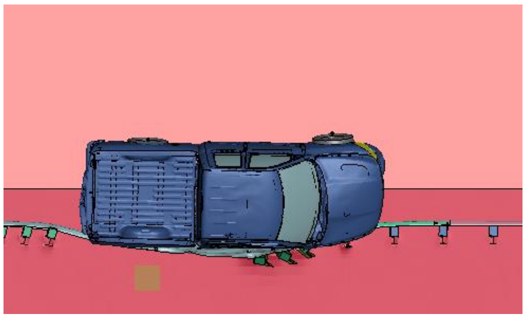

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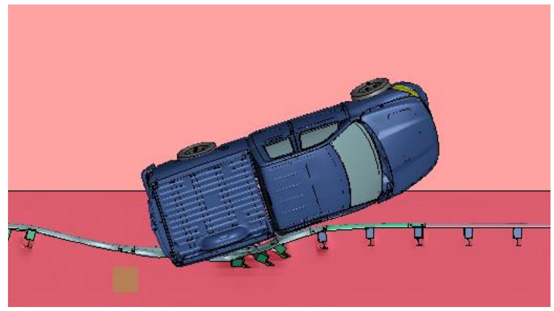
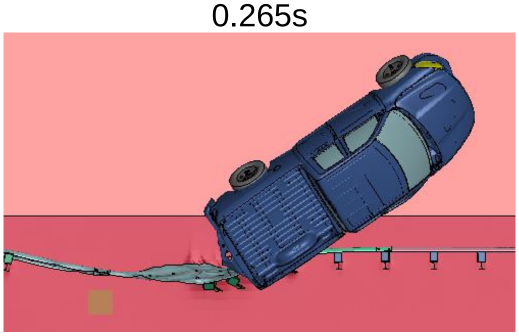
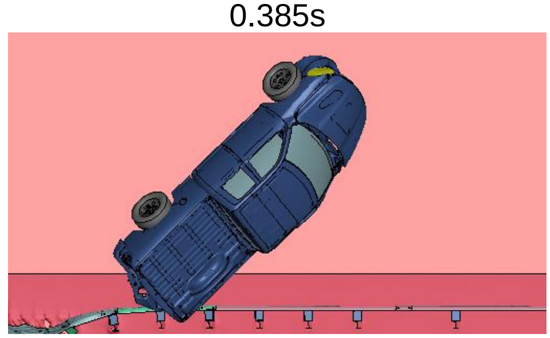


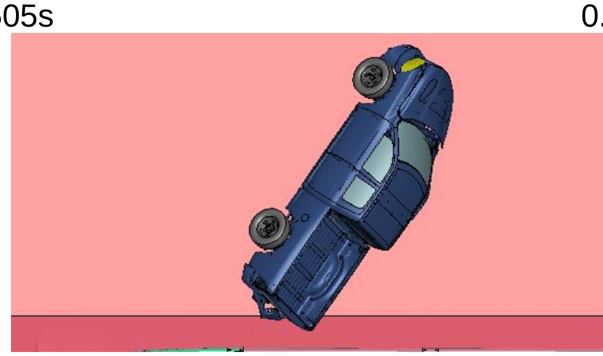
0.385s



0.505s



0.625s



0.750s

Figure 2.131. *MASH* Test 3-11 Simulation of Quarter-Post Large Gap with Fixed Object 30 inch Offset 1 foot Downstream Impact Variation – Overhead View

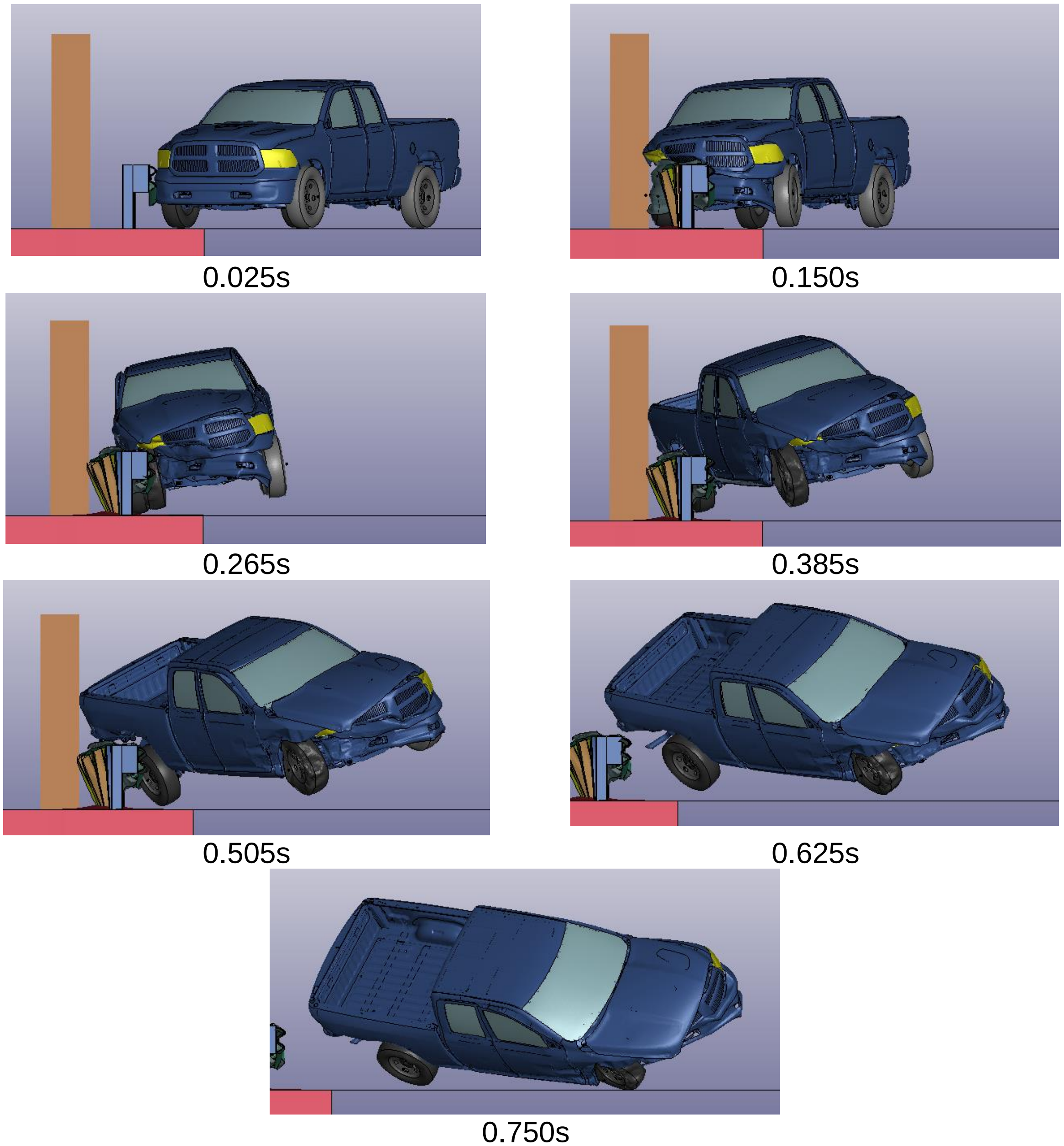


Figure 2.132. *MASH* Test 3-11 Simulation of Quarter-Post Large Gap with Fixed Object 30 inch Offset 1 foot Downstream Impact Variation – Downstream View

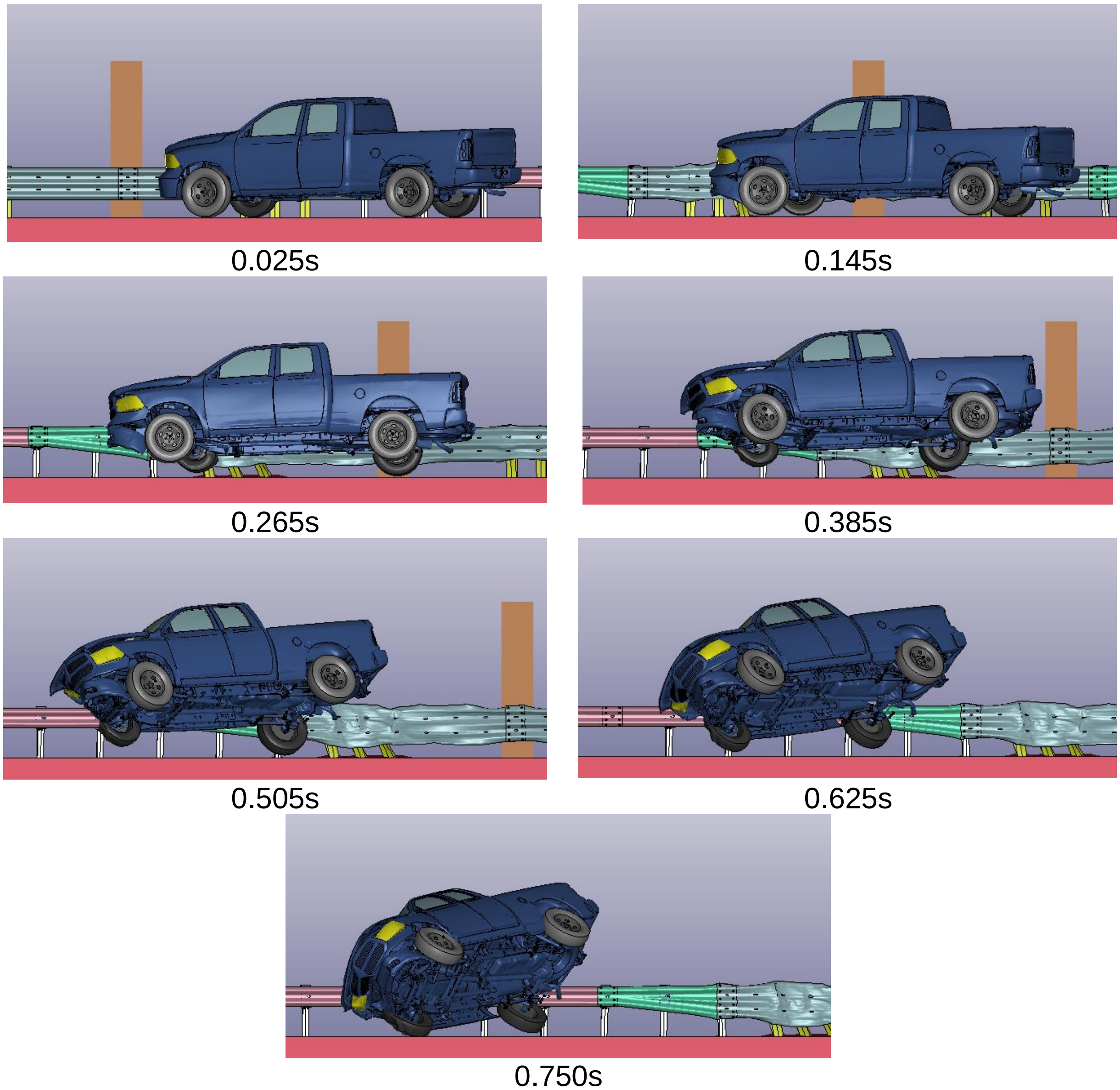


Figure 2.133. *MASH* Test 3-11 Simulation of Quarter-Post Large Gap with Fixed Object 30 inch Offset 1 foot Downstream Impact Variation – Rear View

2.4.2.16. MASH Test 3-11 Simulation of Quarter-Post Spacing Large Gap with Fixed Object 30 inch Offset and 2 feet Downstream Impact Variation

Figure 2.134 through Figure 2.136 show the sequential frames of *MASH* test 3-11 with quarter-post spacing, large gap, a fixed object offset of 30 inches, and an impact variation positioned 2 feet downstream. The pickup truck experienced excessive roll, which was deemed unsatisfactory.

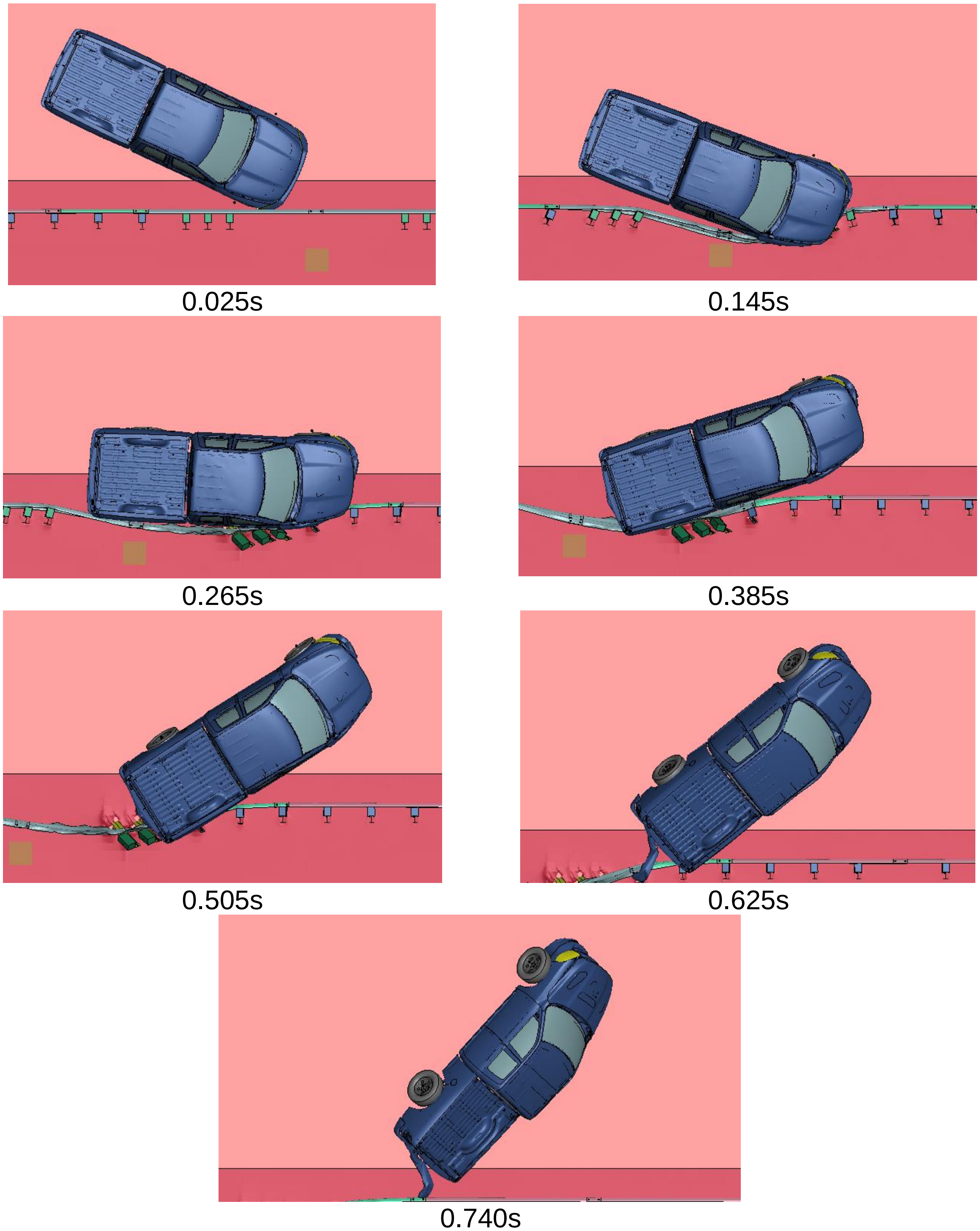


Figure 2.134. ***MASH*** **Test 3-11 Simulation of Quarter-Post Large Gap with Fixed Object 30 inch Offset 2 feet Downstream Impact Variation – Overhead View**

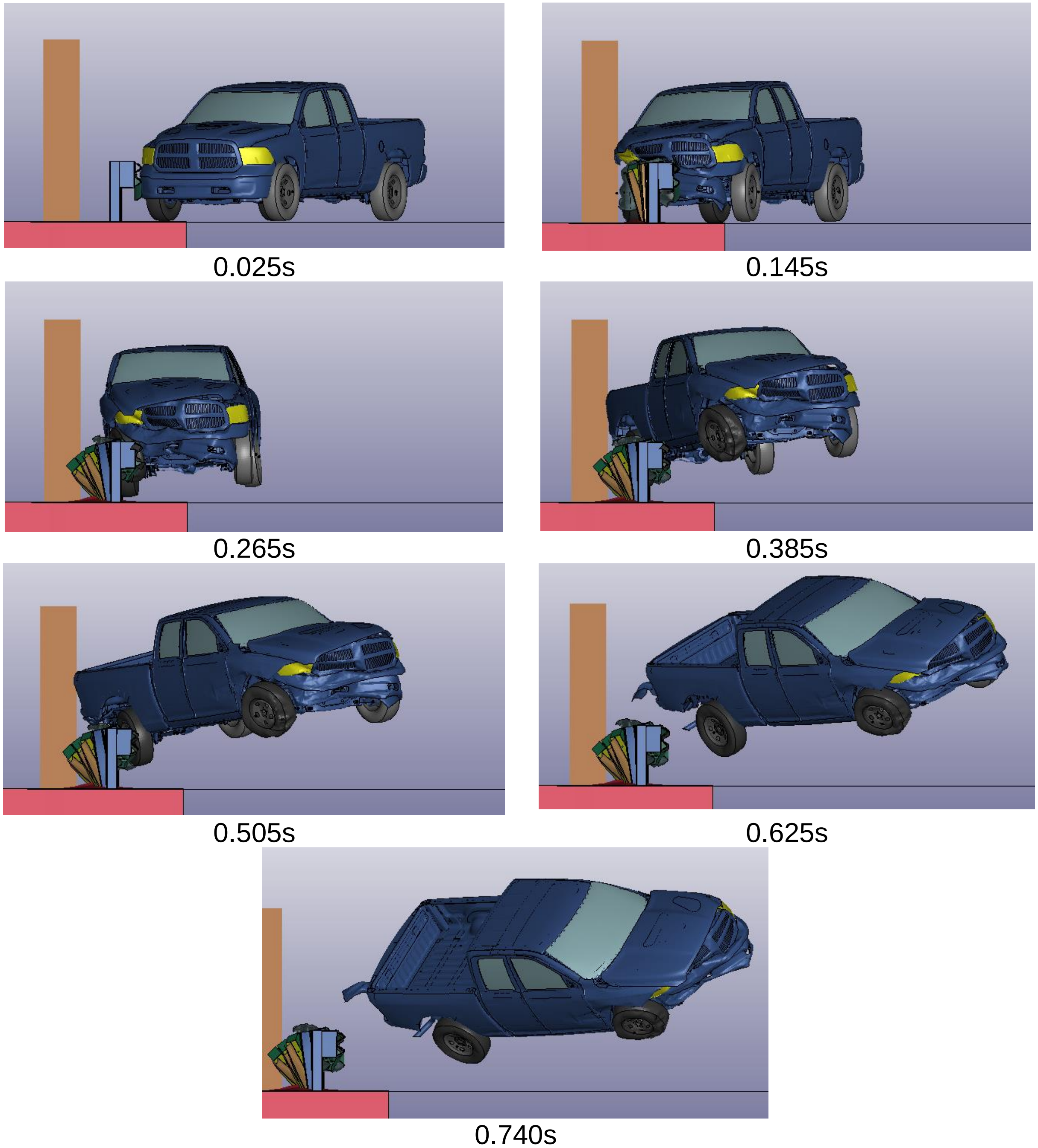


Figure 2.135. *MASH* Test 3-11 Simulation of Quarter-Post Large Gap with Fixed Object 30 inch Offset 2 feet Downstream Impact Variation – Downstream View

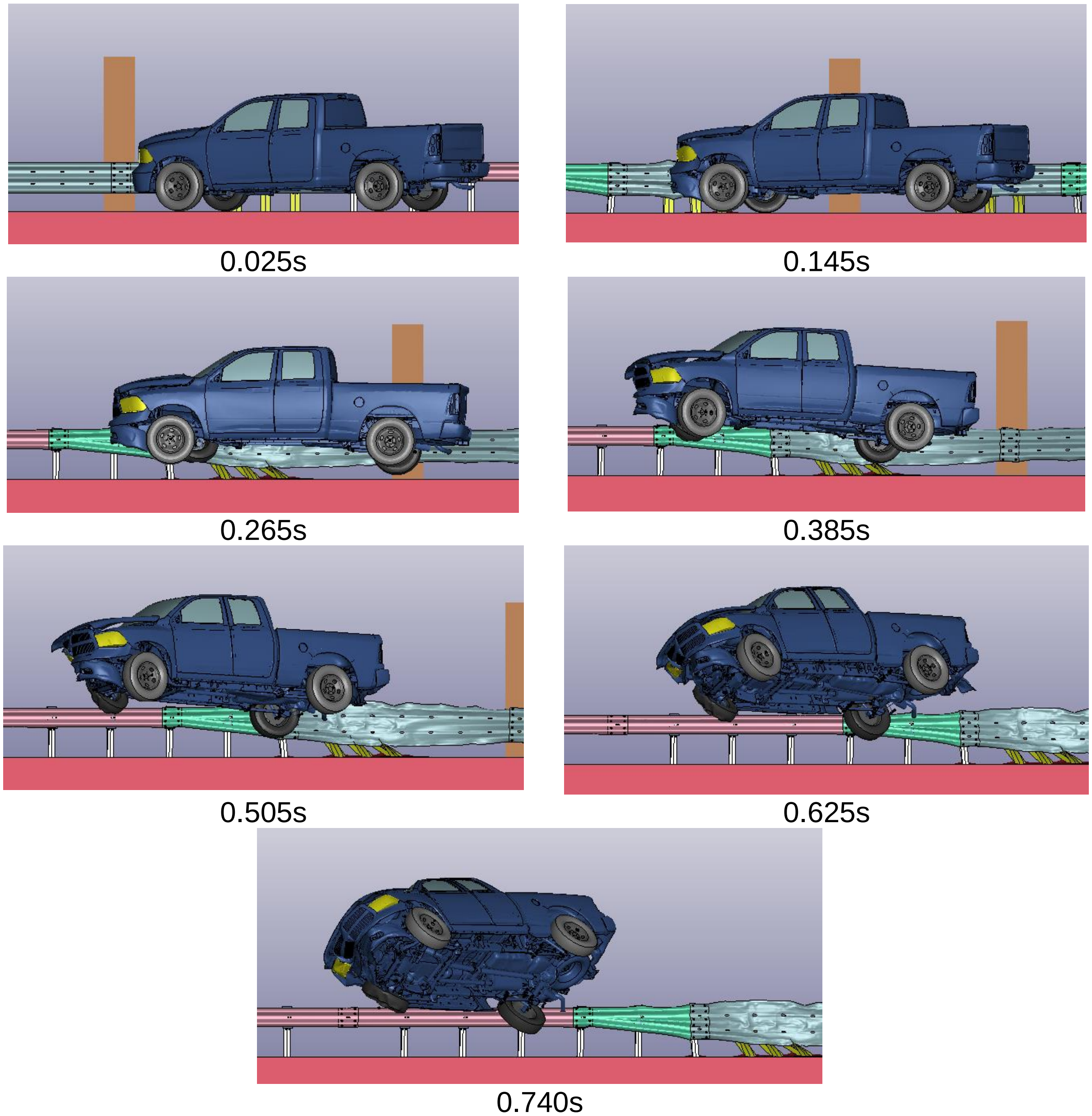


Figure 2.136. *MASH* Test 3-11 Simulation of Quarter-Post Large Gap with Fixed Object 30 inch Offset 2 feet Downstream Impact Variation – Rear View

2.4.2.17. MASH Test 3-11 Simulation of Quarter-Post Spacing Large Gap with Fixed Object 30 inch Offset and 4 feet Downstream Impact Variation

Figure 2.137 through Figure 2.139 show the sequential frames of *MASH* test 3-11 with quarter-post spacing, large gap, a fixed object offset of 30 inches, and an impact variation positioned 4 feet downstream. The pickup truck experienced excessive roll, which was deemed unsatisfactory.

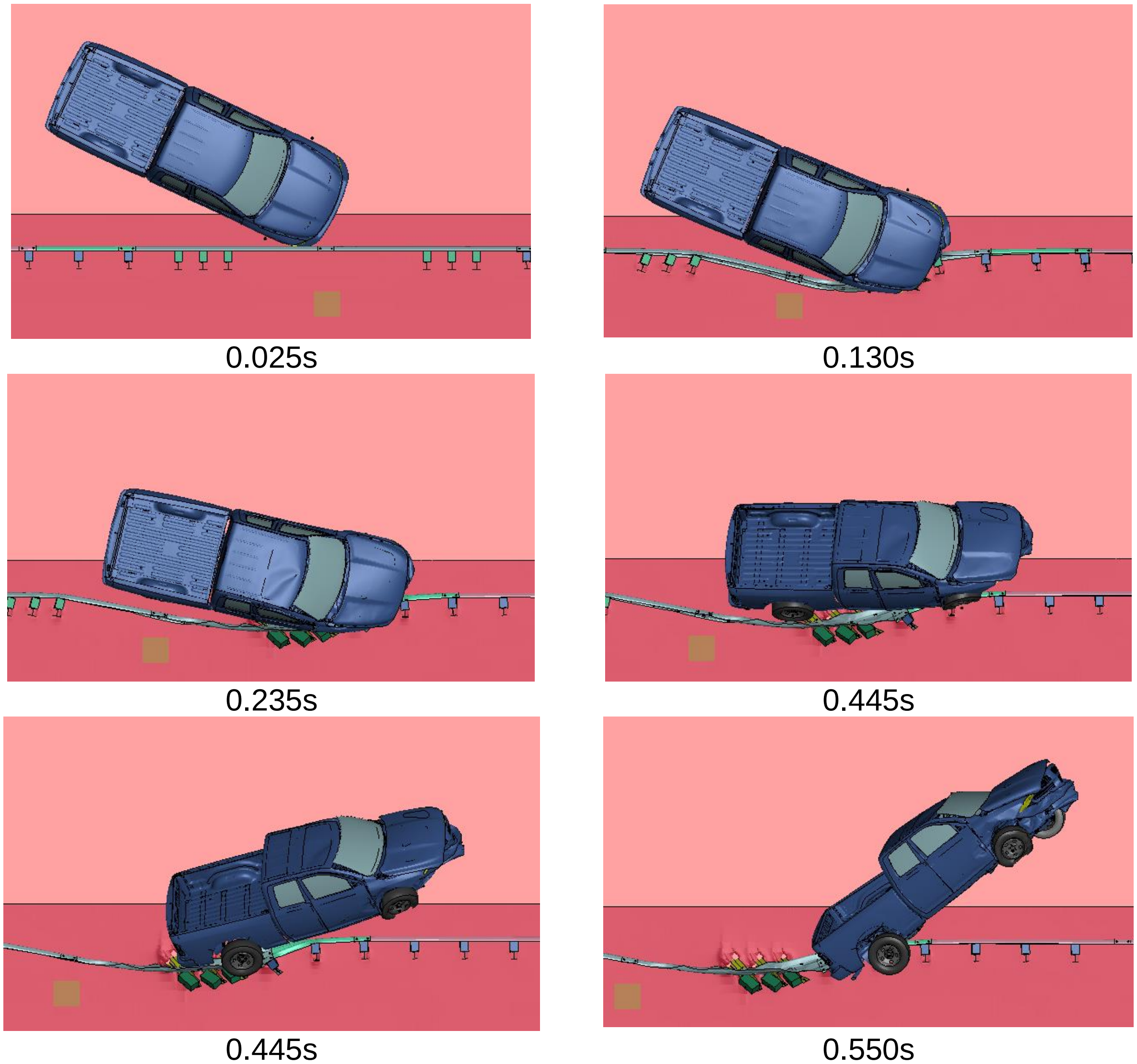


Figure 2.137. *MASH* Test 3-11 Simulation of Quarter-Post Large Gap with Fixed Object 30 inch Offset 4 feet Downstream Impact Variation – Overhead View

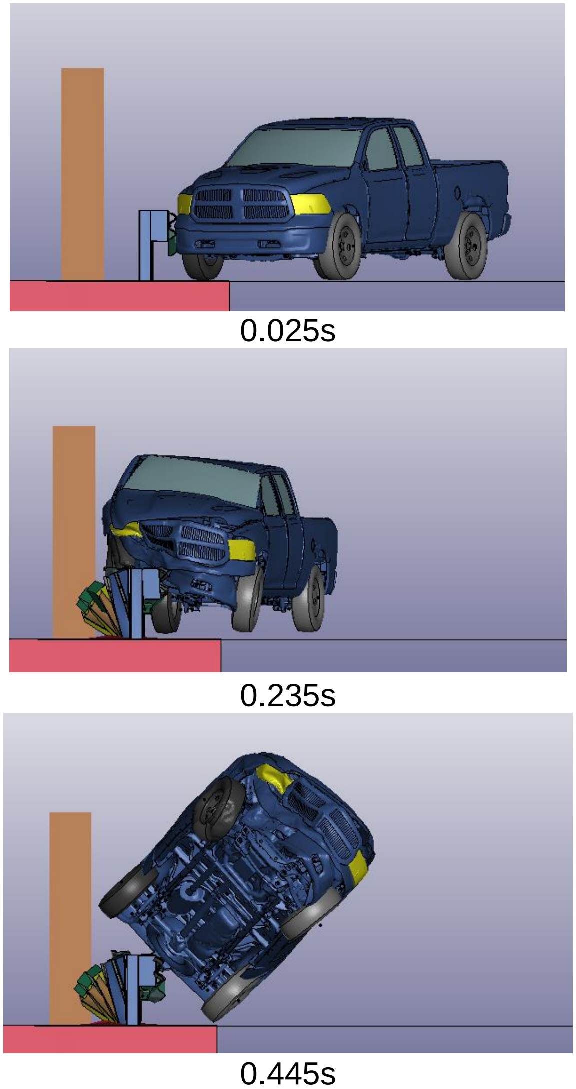
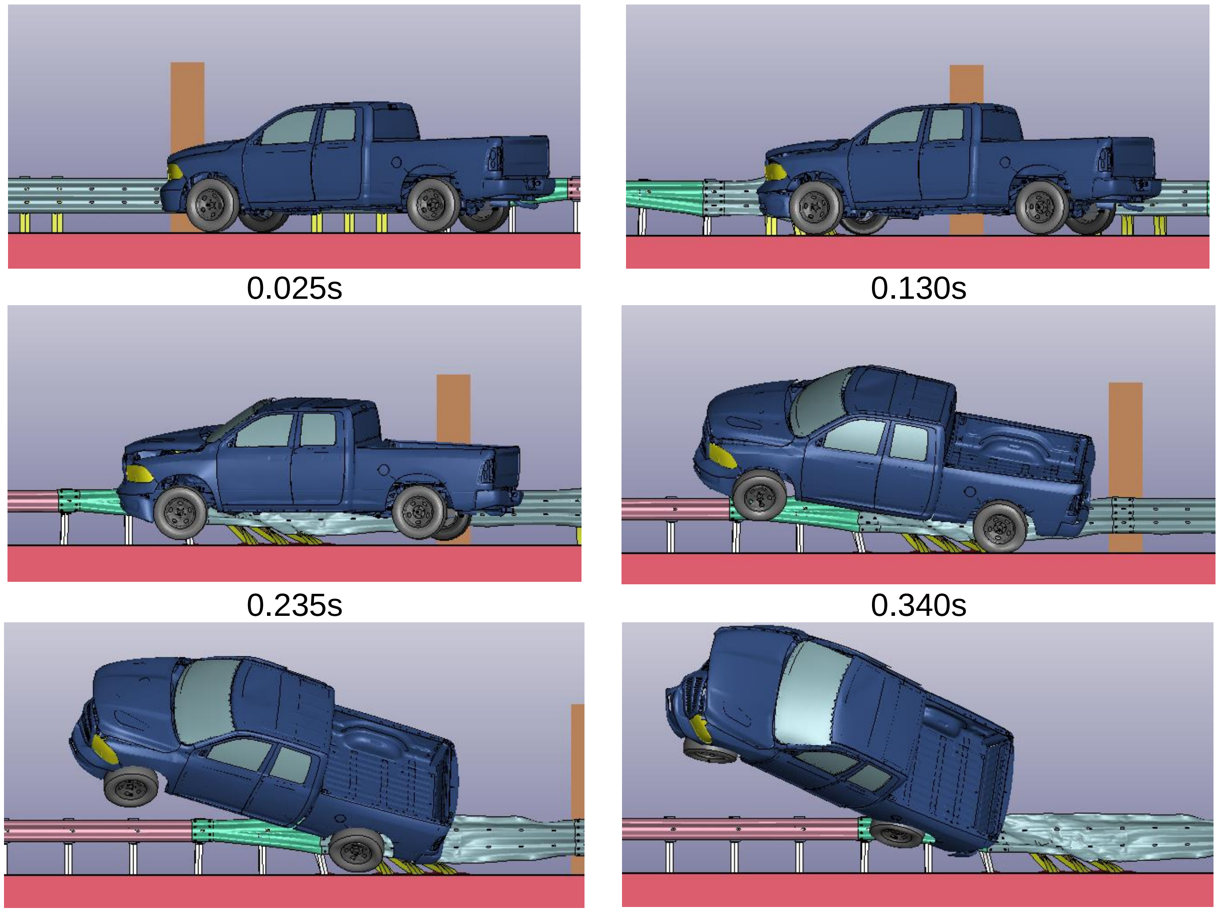


Figure 2.138. *MASH* Test 3-11 Simulation of Quarter-Post Large Gap with Fixed Object 30 inch Offset 4 feet Downstream Impact Variation – Downstream View

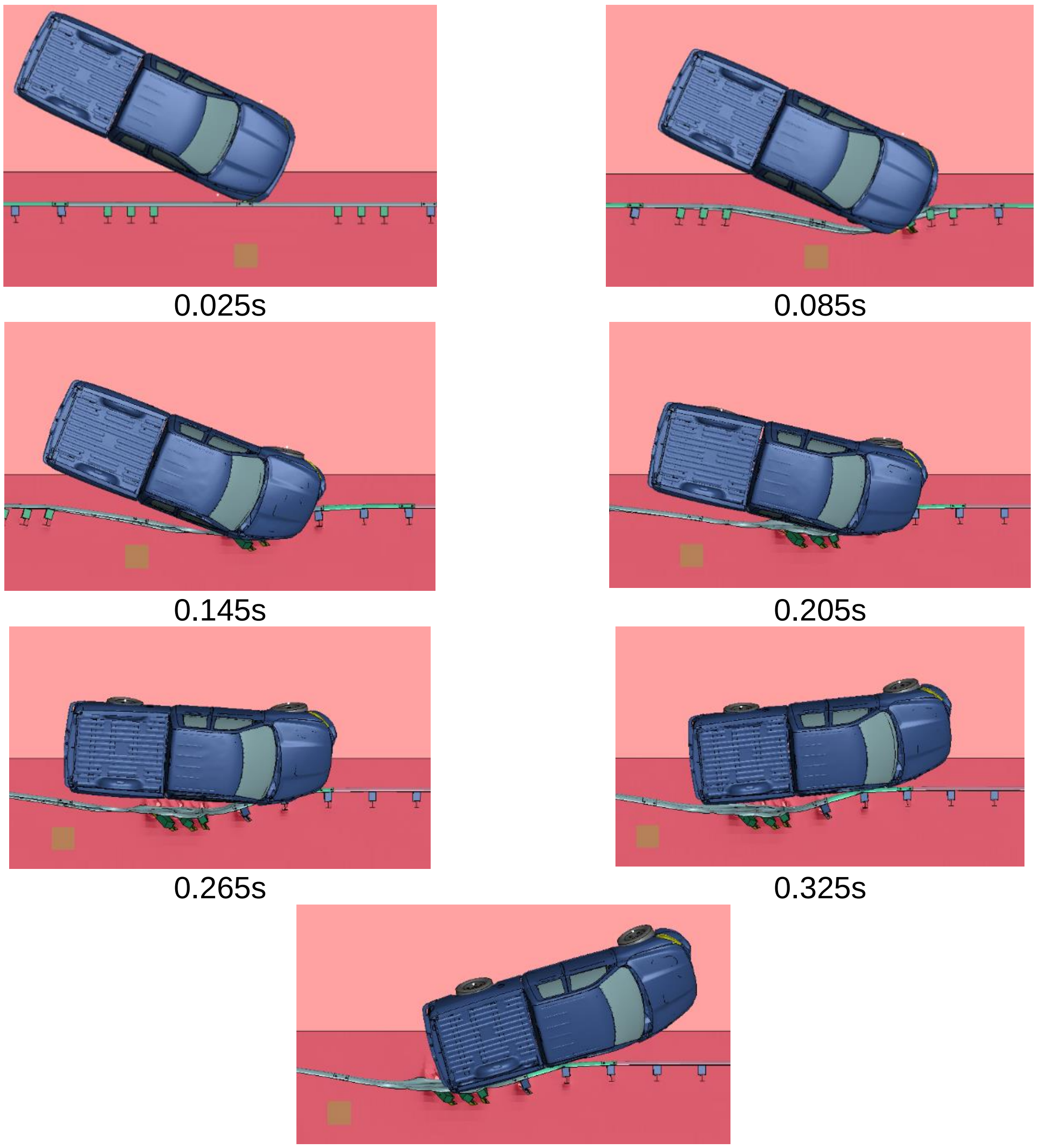


0.025s 0.130s 0.235s 0.340s 0.445s 0.550s

Figure 2.139. *MASH* Test 3-11 Simulation of Quarter-Post Large Gap with Fixed Object 30 inch Offset 4 feet Downstream Impact Variation – Rear View

2.4.2.18. MASH Test 3-11 Simulation of Quarter-Post Spacing Large Gap with Fixed Object 30 inch Offset and 6 feet Downstream Impact Variation

Figure 2.140 through Figure 2.142 show the sequential frames of *MASH* test 3-11 with quarter-post spacing, large gap, a fixed object offset of 30 inches, and an impact variation positioned 6 feet downstream. The occupant impact velocity was calculated to be 10.2 m/s (maximum limit is 12.2 m/s). The ridedown acceleration was calculated to be 16.5 g’s (maximum limit is 20.49 g’s). This configuration passed *MASH* test 3-11 by successfully containing and redirecting the vehicle.



0.025s 0.085s

0.145s 0.205s

0.265s 0.325s

0.385s

Figure 2.140. *MASH* Test 3-11 Simulation of Quarter-Post Large Gap with Fixed Object 30 inch Offset 6 feet Downstream Impact Variation – Overhead View

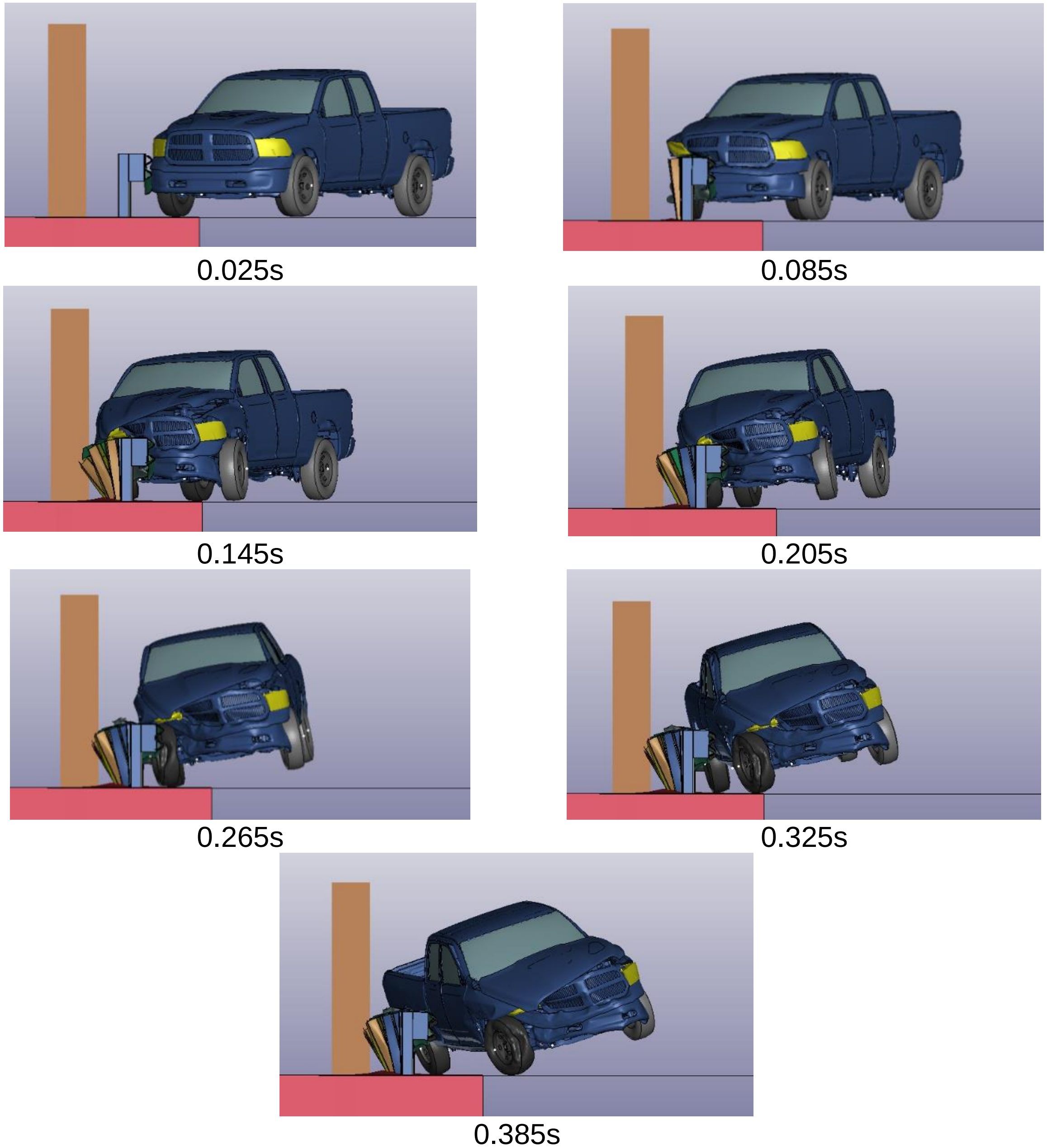


Figure 2.141. *MASH* Test 3-11 Simulation of Quarter-Post Large Gap with Fixed Object 30 inch Offset 6 feet Downstream Impact Variation – Downstream View

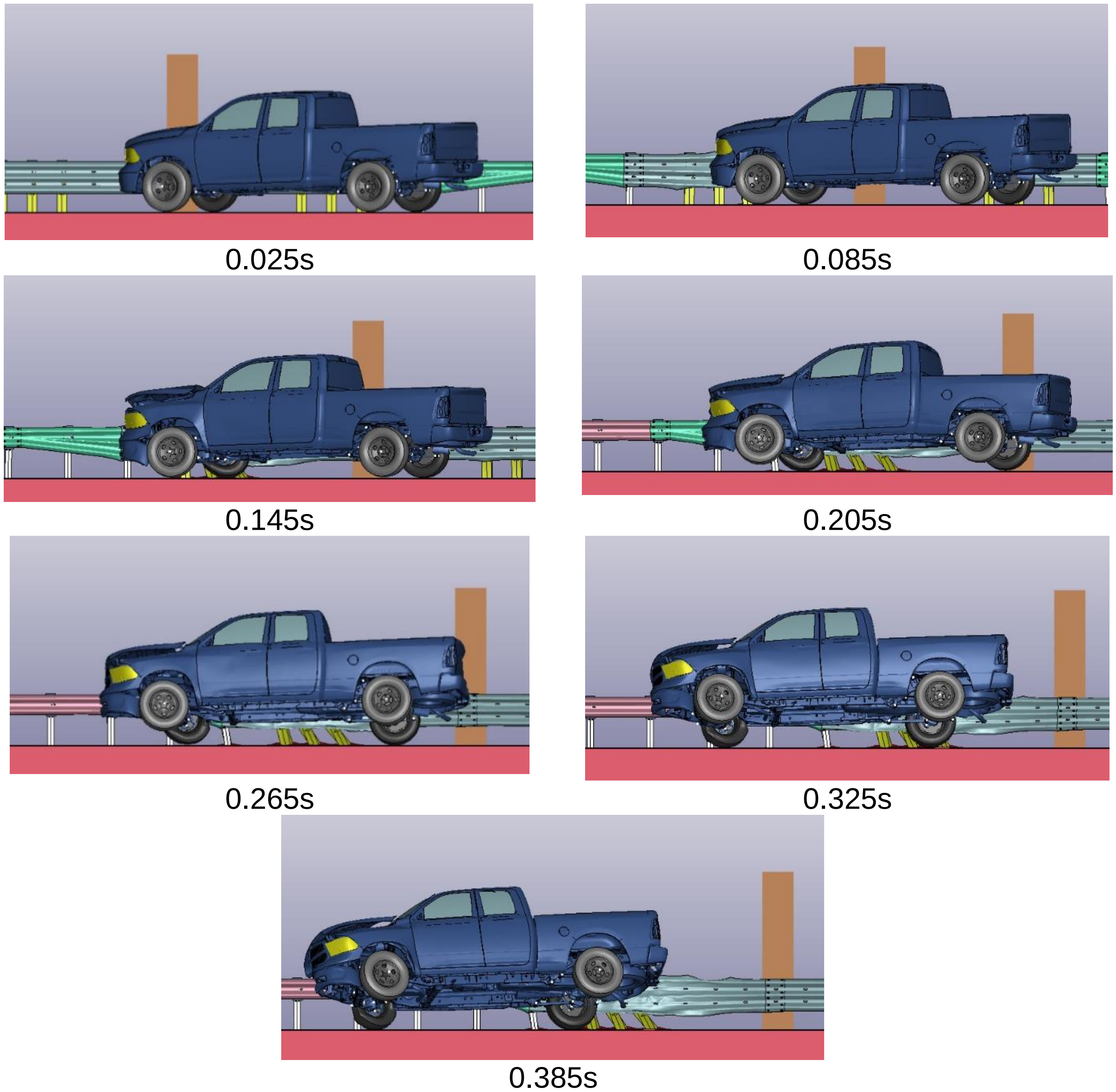


Figure 2.142. *MASH* Test 3-11 Simulation of Quarter-Post Large Gap with Fixed Object 30 inch Offset 6 feet Downstream Impact Variation – Rear View

2.4.2.19. MASH Test 3-10 Simulation of Quarter-Post Spacing Large Gap with Fixed Object 30 inch Offset

Figure 2.143 through Figure 2.145 show the sequential frames of MASH test 3-10 with quarter-post spacing, large gap, and a fixed object offset of 30 inches. The OIV was calculated to be 7.1 m/s (preferred limit is 9.1 m/s). The RDA was calculated to be 33.3 g's (maximum limit is 20.49 g's). This configuration failed *MASH* test 3-10 by exceeding the allowable ridedown acceleration limit.

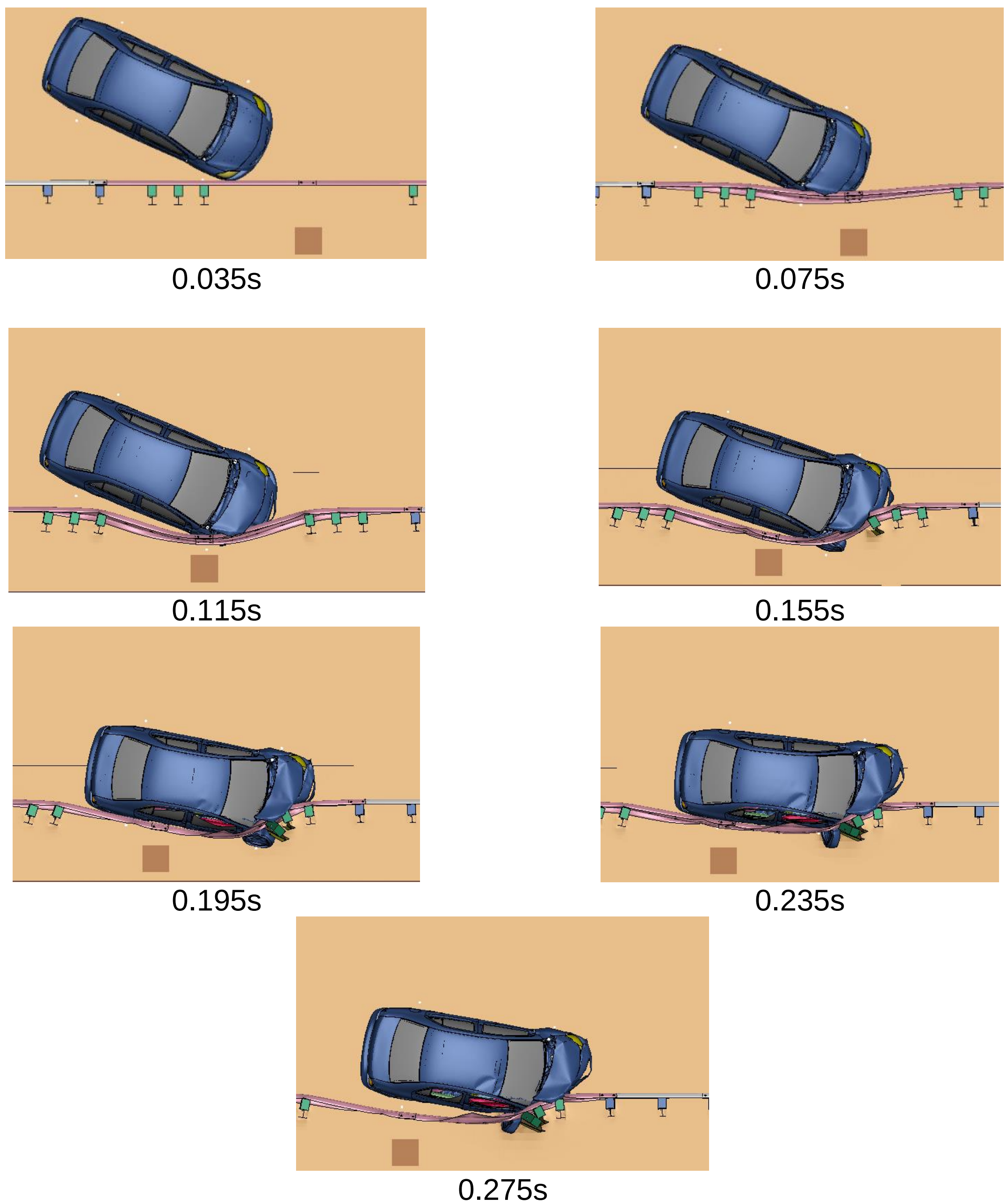


Figure 2.143. *MASH* Test 3-10 Simulation of Quarter-Post Large Gap with Fixed Object 30 inch Offset – Overhead View

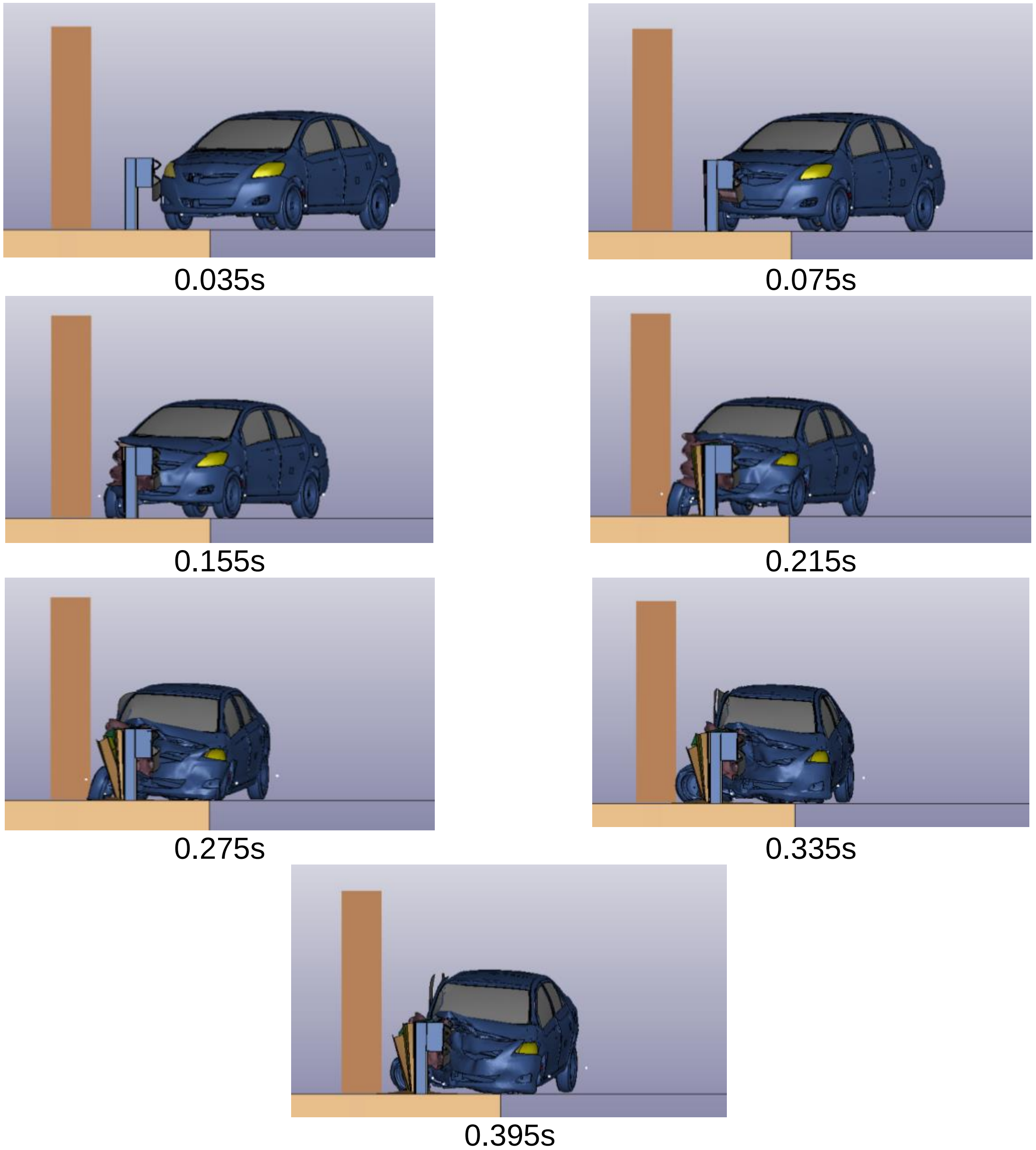
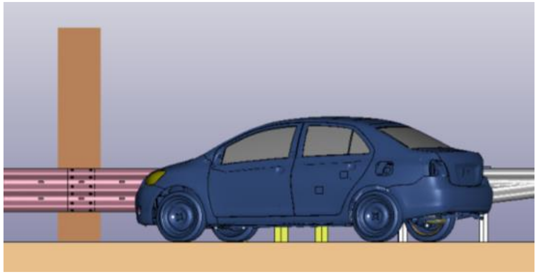
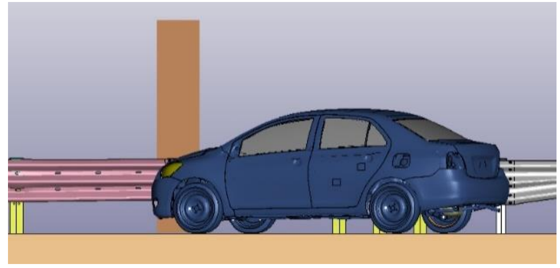


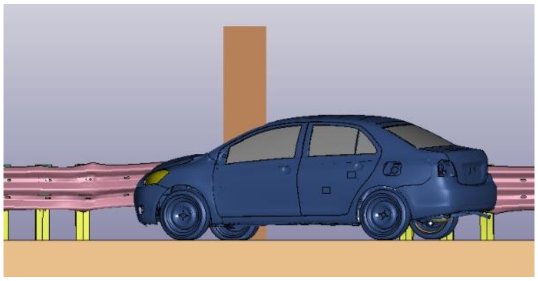
Figure 2.144. *MASH* Test 3-10 Simulation of Quarter-Post Large Gap with Fixed Object 30 inch Offset – Downstream View



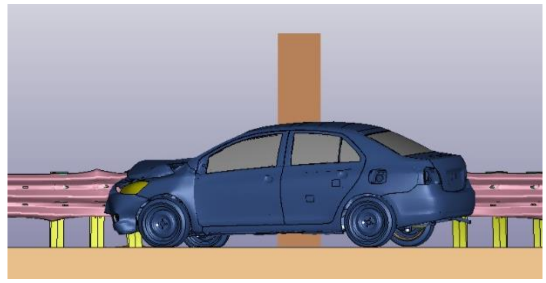
0.035s



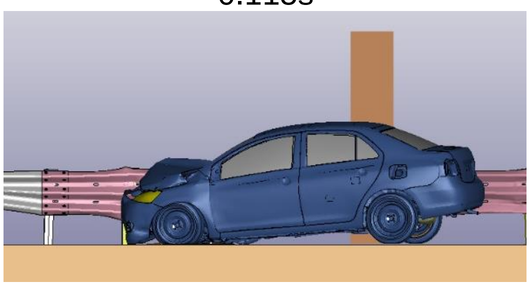
0.075s



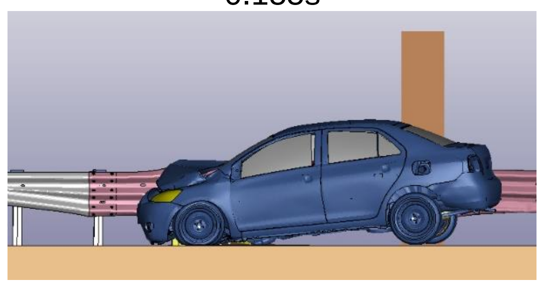
0.115s



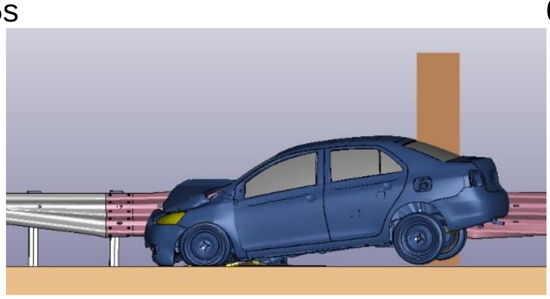
0.155s



0.195s



0.235s



0.275s

Figure 2.145. *MASH* Test 3-10 Simulation of Quarter-Post Large Gap with Fixed Object 30 inch Offset – Rear View

2.5. 6 ¼- FT GAP BETWEEN POSTS

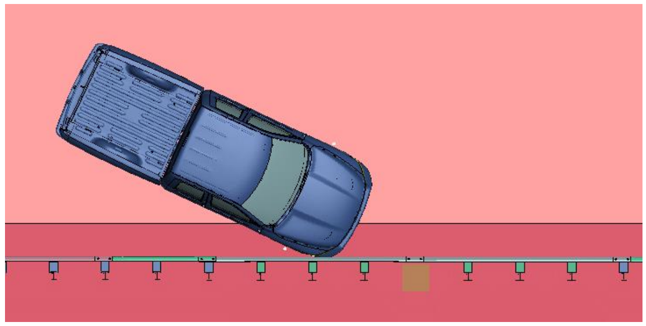
The following simulations evaluate the crashworthiness of the thrie-beam system with a 6 ¼-ft gap between posts at the fixed object location.

2.5.1. Half-Post Spacing

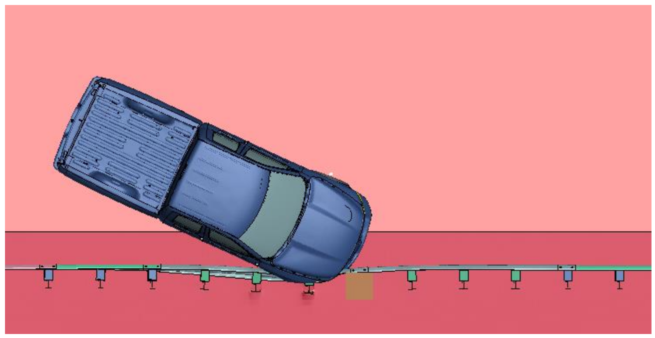
The following simulations include offset variations with half-post spacing.

2.5.1.1. MASH Test 3-11 Simulation of Half-Post Spacing Small Gap with Fixed Object 2 inch Offset

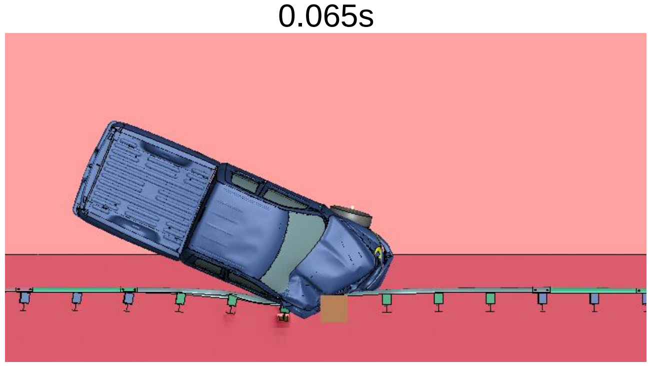
Figure 2.146 through Figure 2.148 show the sequential frames of *MASH* test 3-11 with half-post spacing, small gap, and a fixed object offset of 2 inches. The pickup truck interacted with the fixed object more than what was allowed within this project scope. Therefore, the offset distance was increased in the next simulation.



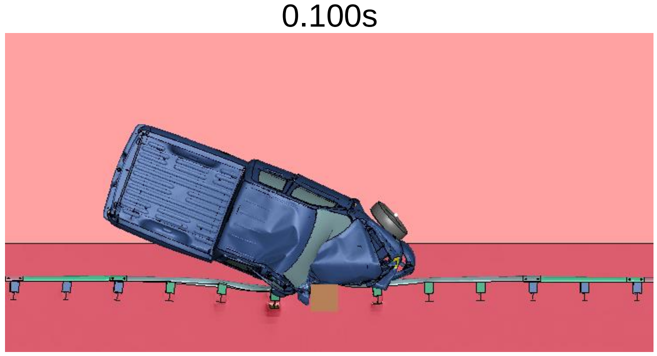
0.025s



0.065s

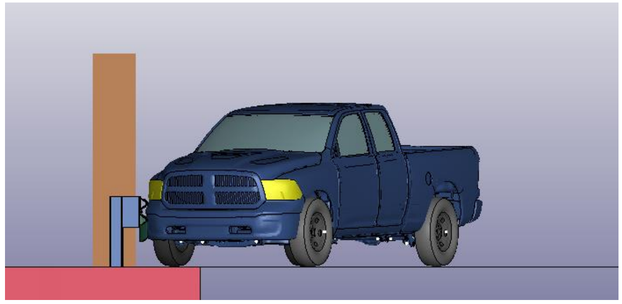


0.100s



0.140s

Figure 2.146. *MASH* Test 3-11 Simulation of Half-Post Small Gap with Fixed Object 2 inch Offset – Overhead View



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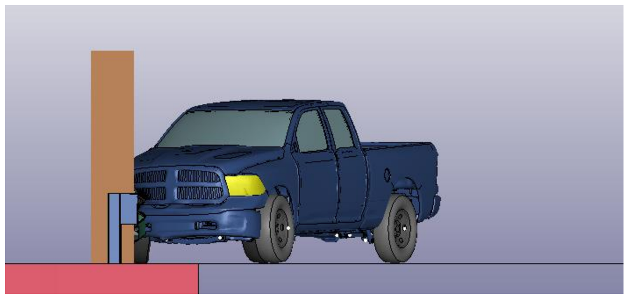

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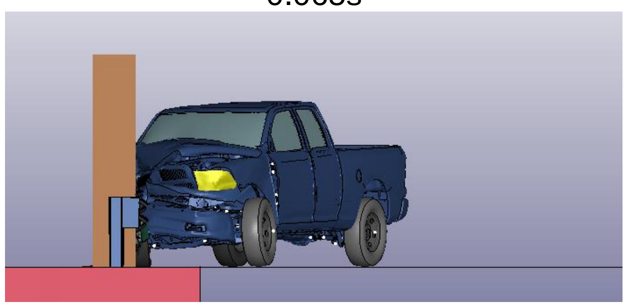
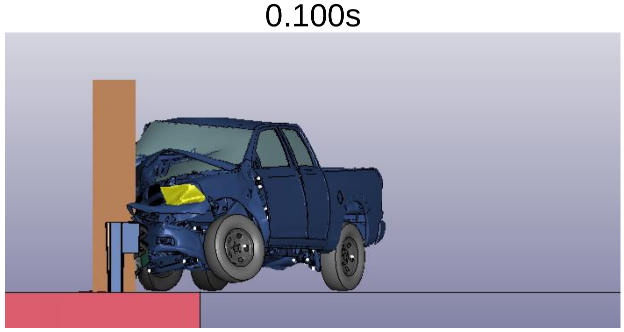
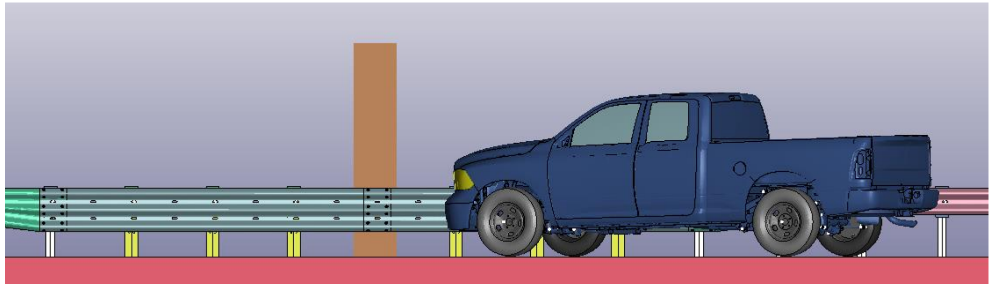


0.100s



0.140s

Figure 2.147. *MASH* Test 3-11 Simulation of Half-Post Small Gap with Fixed Object 2 inch Offset – Downstream View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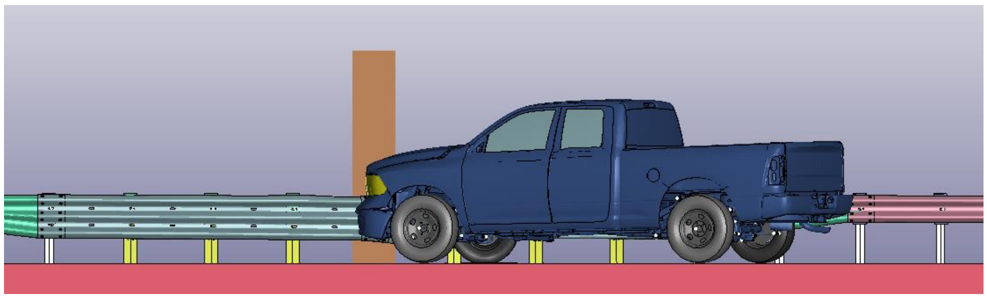
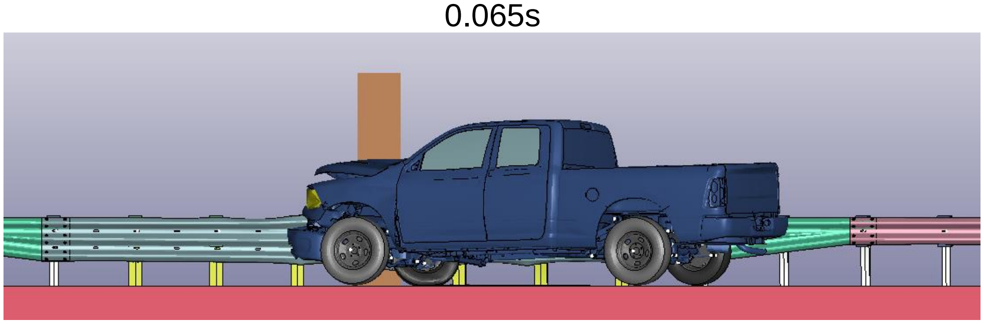

0.065s

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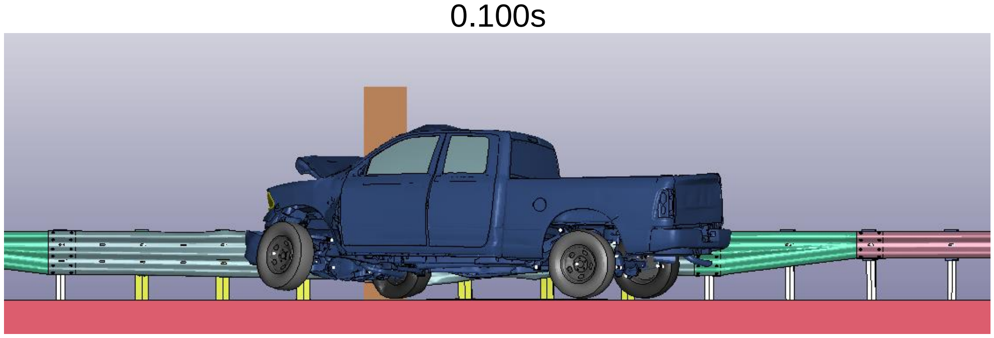
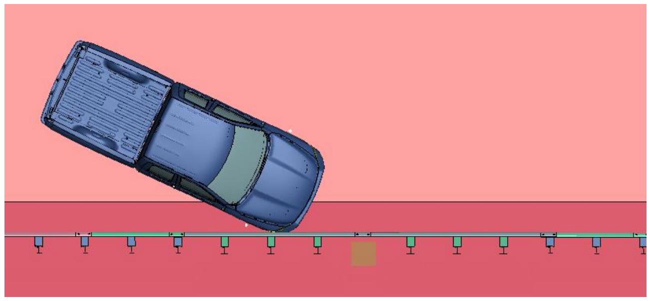

0.140s

Figure 2.148. *MASH* Test 3-11 Simulation of Half-Post Small Gap with Fixed Object 2 inch Offset – Rear View

2.5.1.2. MASH Test 3-11 Simulation of Half-Post Spacing Small Gap with Fixed Object 4 inch Offset

Figure 2.149 through Figure 2.151 show the sequential frames of *MASH* test 3-11 with half-post spacing, small gap, and a fixed object offset of 4 inches. The pickup truck interacted with the fixed object more than what was allowed within this project scope. Therefore, the offset distance was increased in the next simulation.



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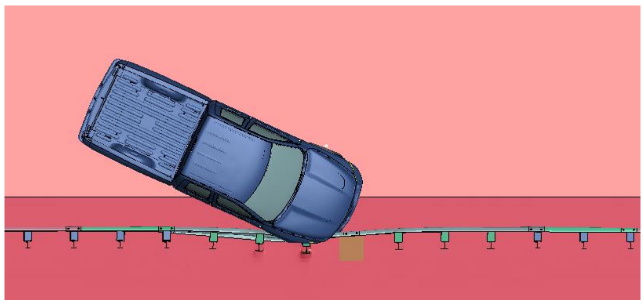
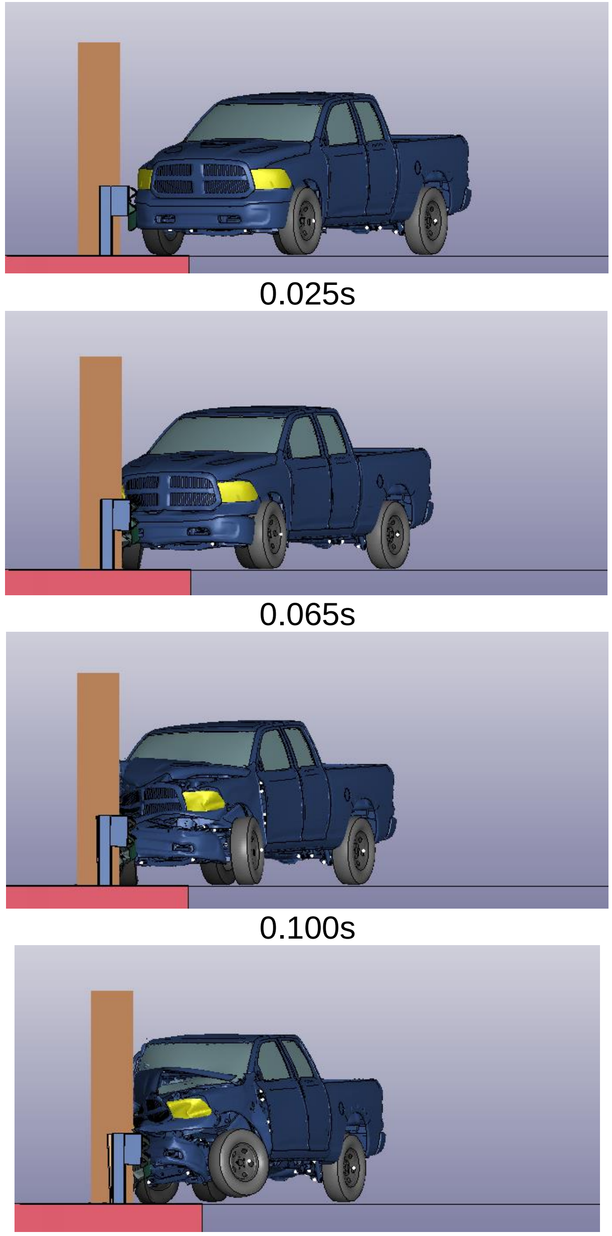


0.065s

0.100s

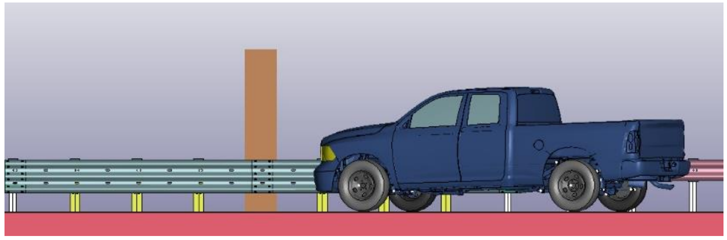
0.140s

Figure 2.149. *MASH* Test 3-11 Simulation of Half-Post Small Gap with Fixed Object 4 inch Offset – Overhead View



0.140s

Figure 2.150. *MASH* Test 3-11 Simulation of Half-Post Small Gap with Fixed Object 4 inch Offset – Downstream View



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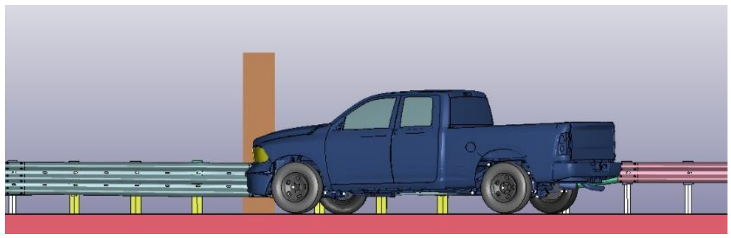

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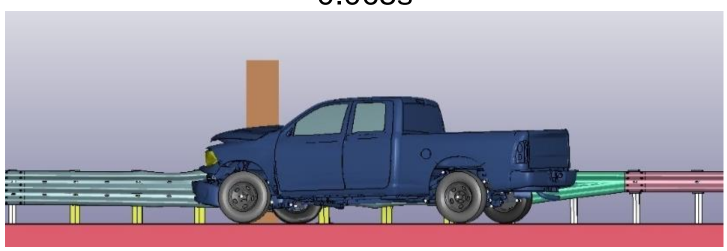

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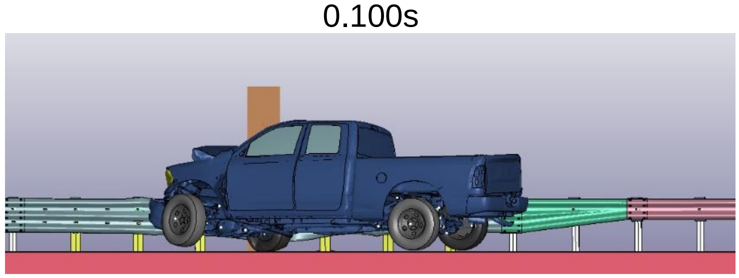
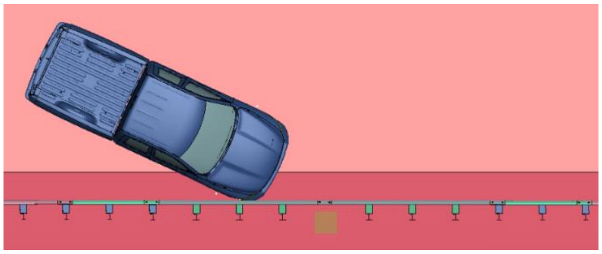


0.140s

Figure 2.151. *MASH* Test 3-11 Simulation of Half-Post Small Gap with Fixed Object 4 inch Offset – Rear View

2.5.1.3. MASH Test 3-11 Simulation of Half-Post Spacing Small Gap with Fixed Object 6 inch Offset

Figure 2.152 through Figure 2.154 show the sequential frames of *MASH* test 3-11 with half-post spacing, small gap, and a fixed object offset of 6 inches. The pickup truck interacted with the fixed object more than what was allowed within this project scope. Therefore, the offset distance was increased in the next simulation.



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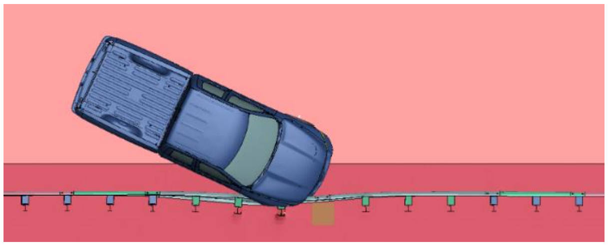

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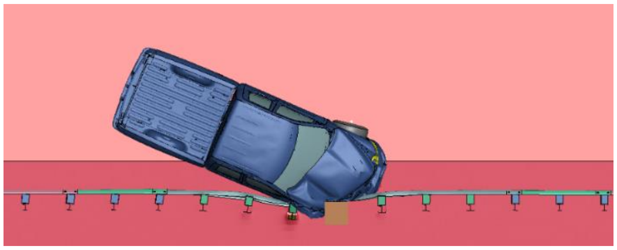

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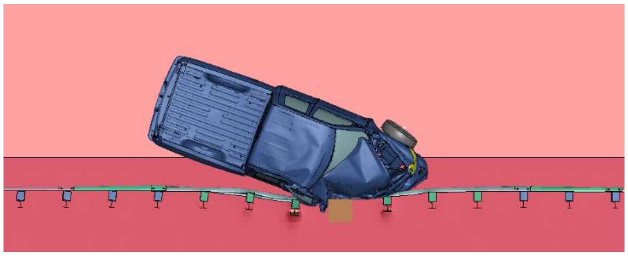
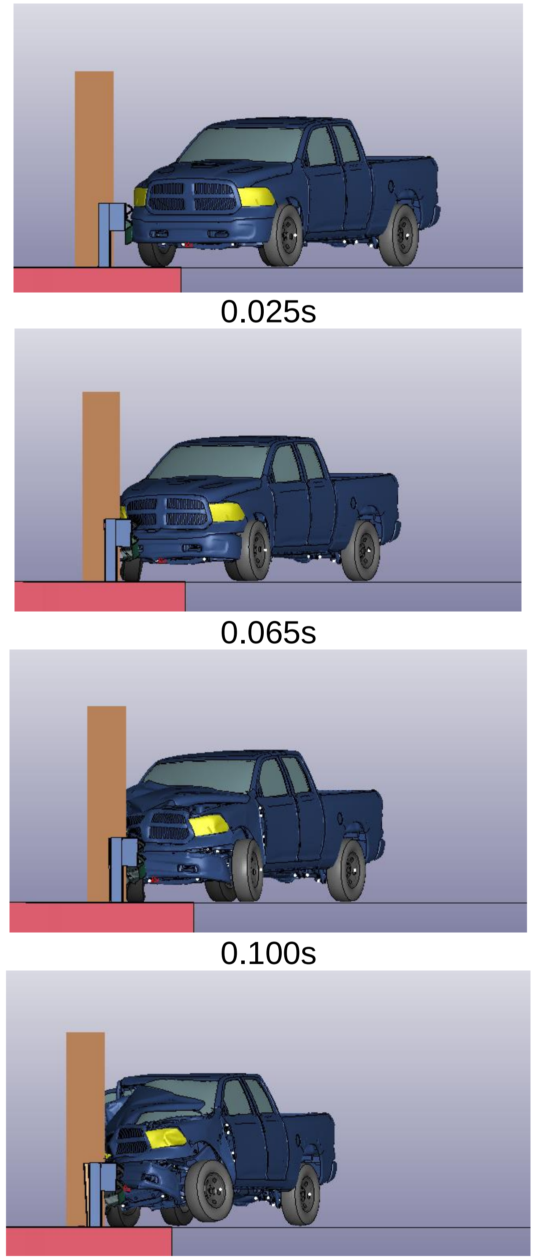


0.140s

Figure 2.152. *MASH* Test 3-11 Simulation of Half-Post Small Gap with Fixed Object 6 inch Offset – Overhead View



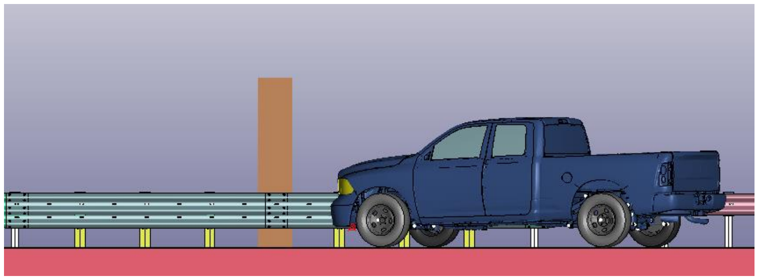
0.025s

0.065s

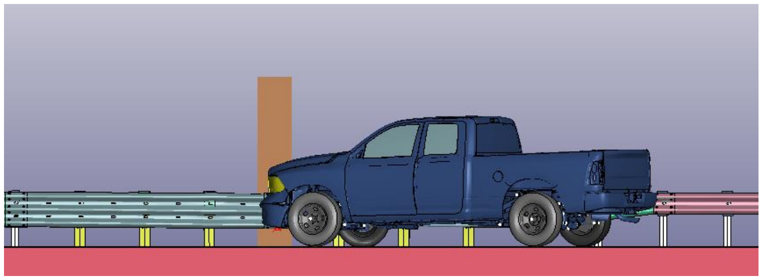
0.100s

0.140s

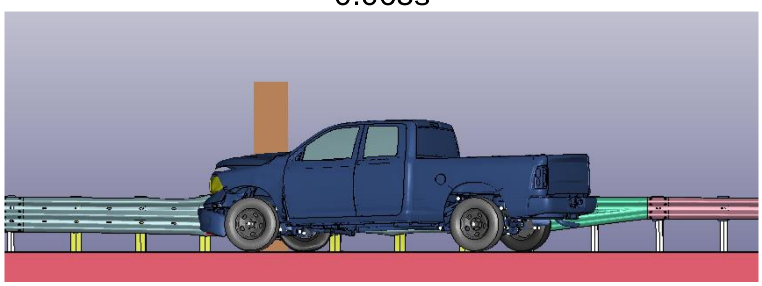
Figure 2.153. *MASH* Test 3-11 Simulation of Half-Post Small Gap with Fixed Object 6 inch Offset – Downstream View



0.025s



0.065s



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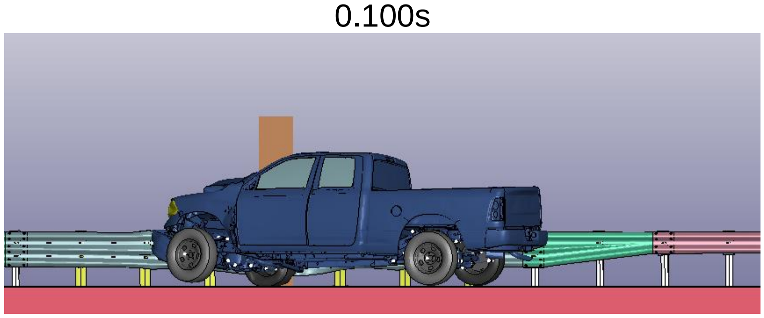
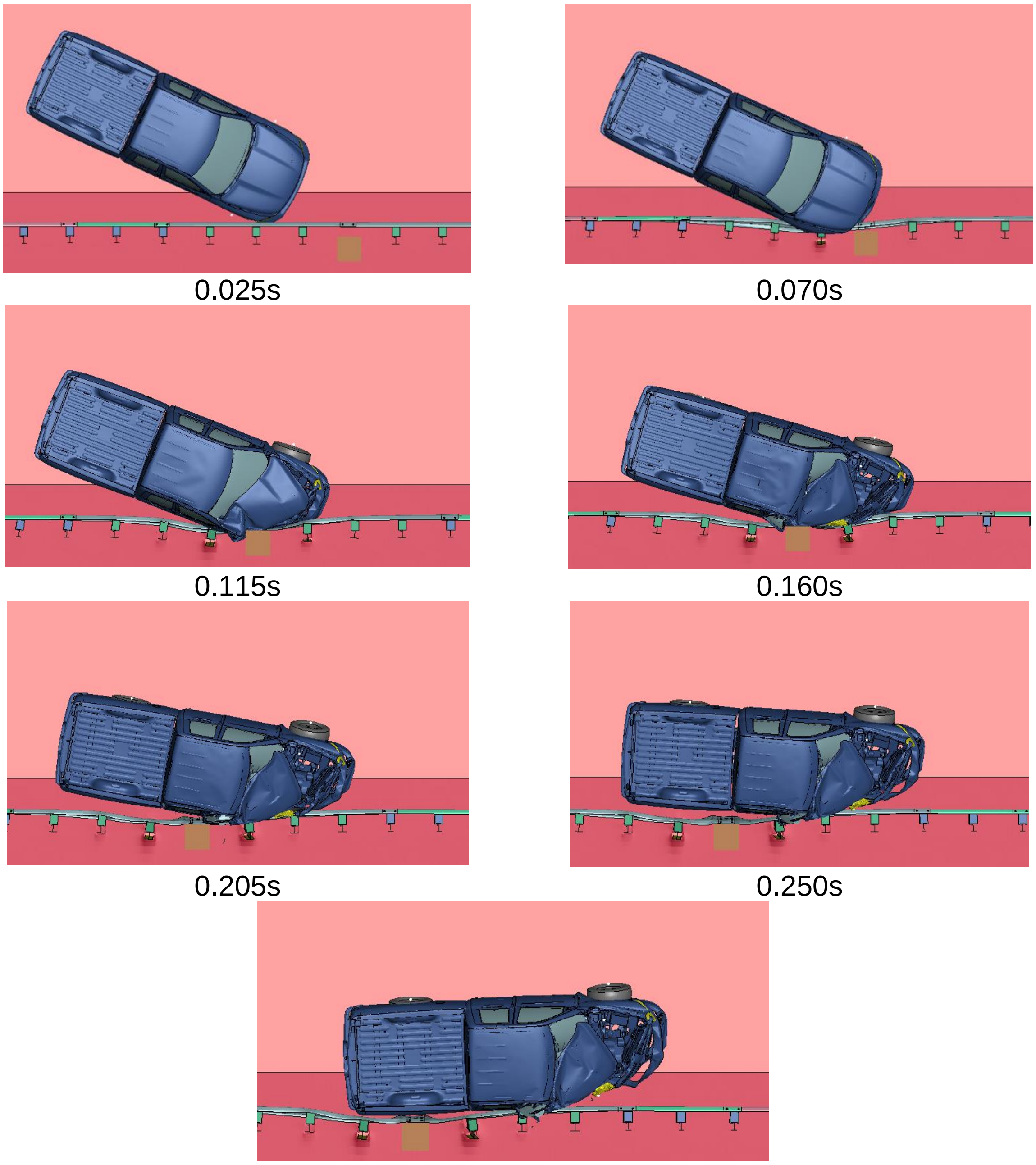


0.140s

Figure 2.154. *MASH* Test 3-11 Simulation of Half-Post Small Gap with Fixed Object 6 inch Offset – Rear View

2.5.1.4. MASH Test 3-11 Simulation of Half-Post Spacing Small Gap with Fixed Object 8 inch Offset

Figure 2.155 through Figure 2.157 show the sequential frames of *MASH* test 3-11 with half-post spacing, small gap, and a fixed object offset of 8 inches. The pickup truck interacted with the fixed object more than what was allowed within this project scope. Therefore, the offset distance was increased in the next simulation.



0.025s
0.070s
0.115s
0.160s
0.205s
0.250s
0.295s

Figure 2.155. *MASH* Test 3-11 Simulation of Half-Post Small Gap with Fixed Object 8 inch Offset – Overhead View

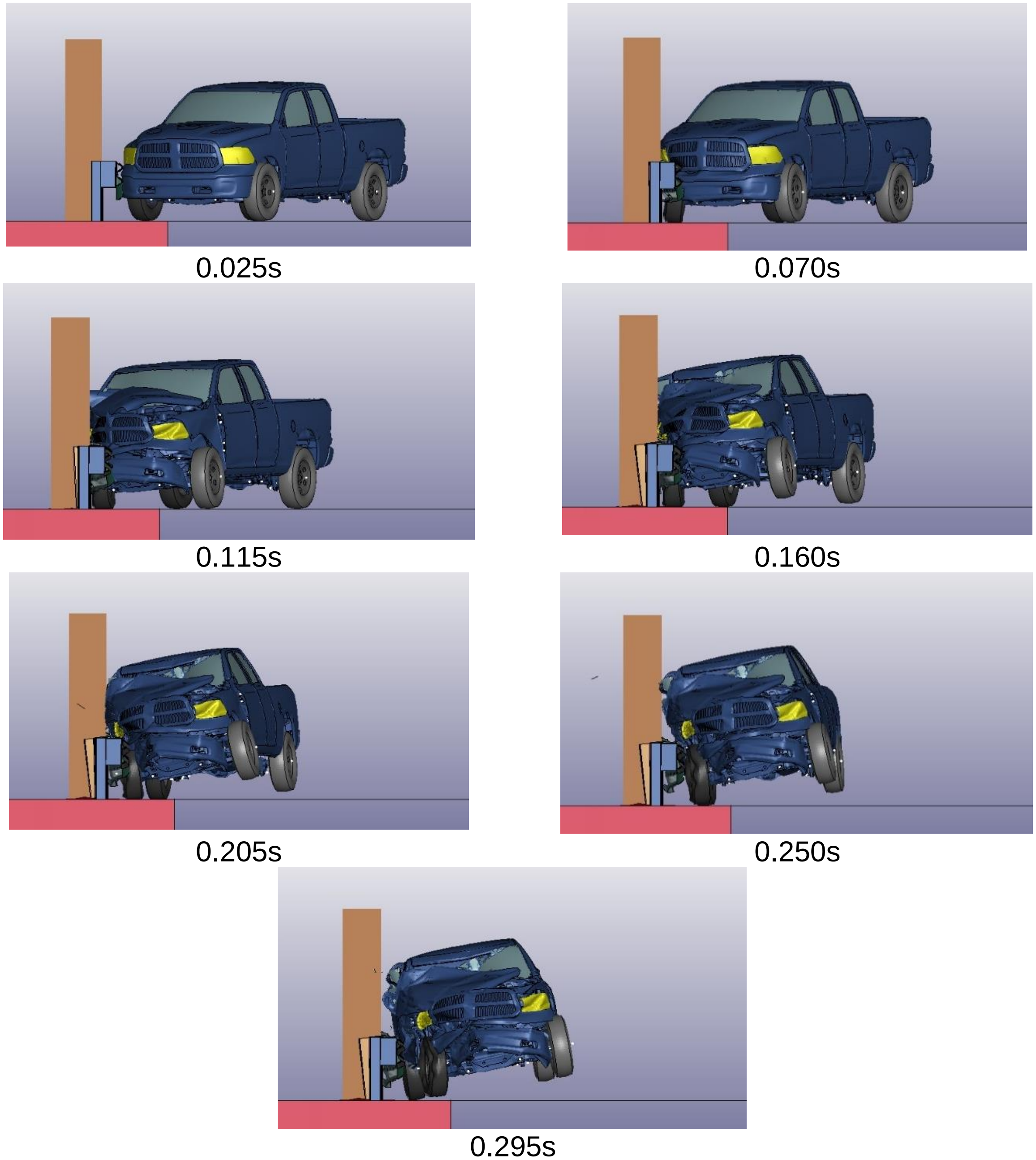


Figure 2.156. *MASH* Test 3-11 Simulation of Half-Post Small Gap with Fixed Object 8 inch Offset – Downstream View

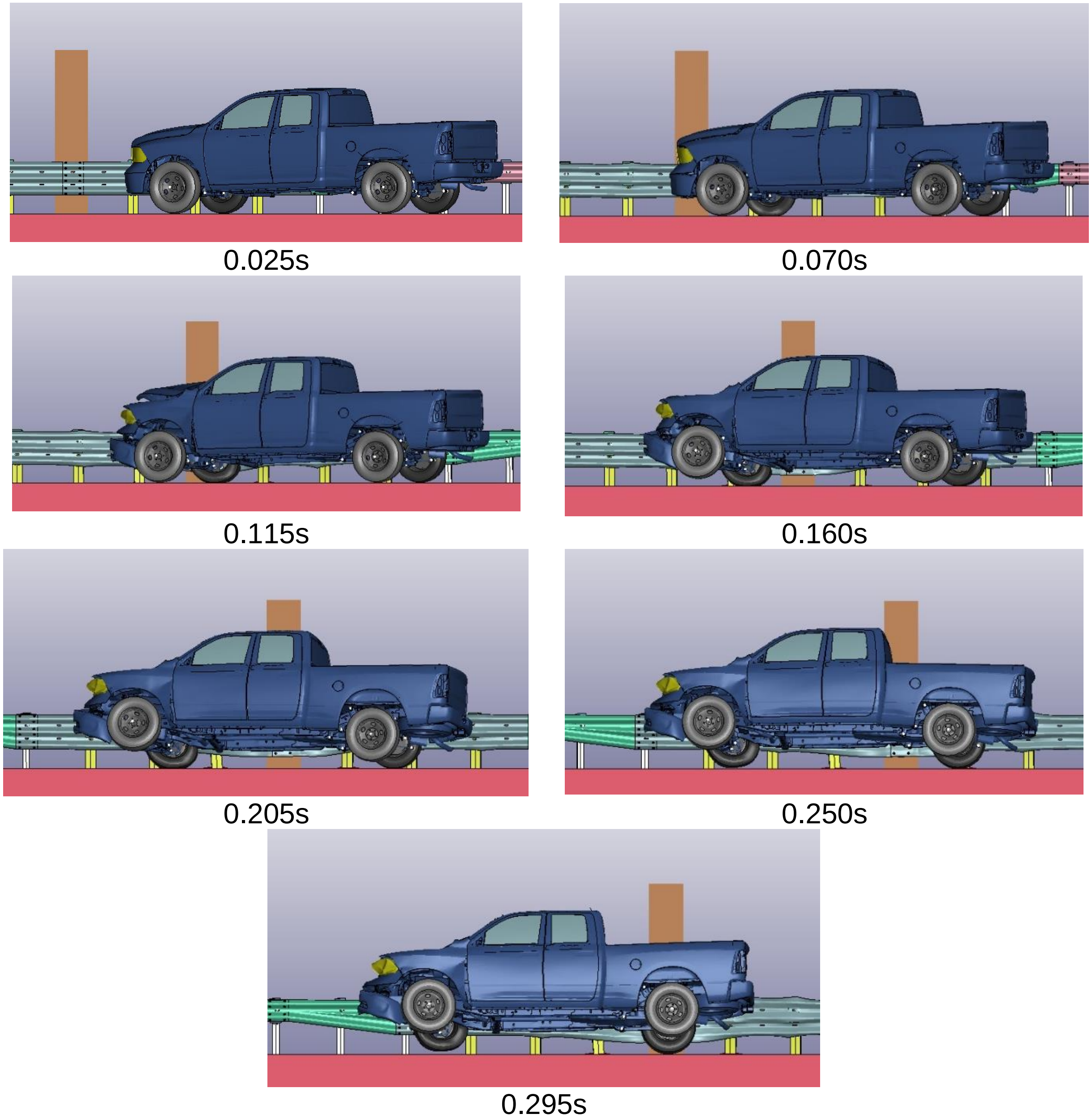


Figure 2.157. *MASH* Test 3-11 Simulation of Half-Post Small Gap with Fixed Object 8 inch Offset– Rear View

2.5.1.5. MASH Test 3-11 Simulation of Half-Post Spacing Small Gap with Fixed Object 10 inch Offset

Figure 2.158 through Figure 2.160 show the sequential frames of *MASH* test 3-11 with half-post spacing, small gap, and a fixed object offset of 10 inches. The pickup truck interacted with the fixed object more than what was allowed within this project scope. Therefore, the offset distance was increased in the next simulation.

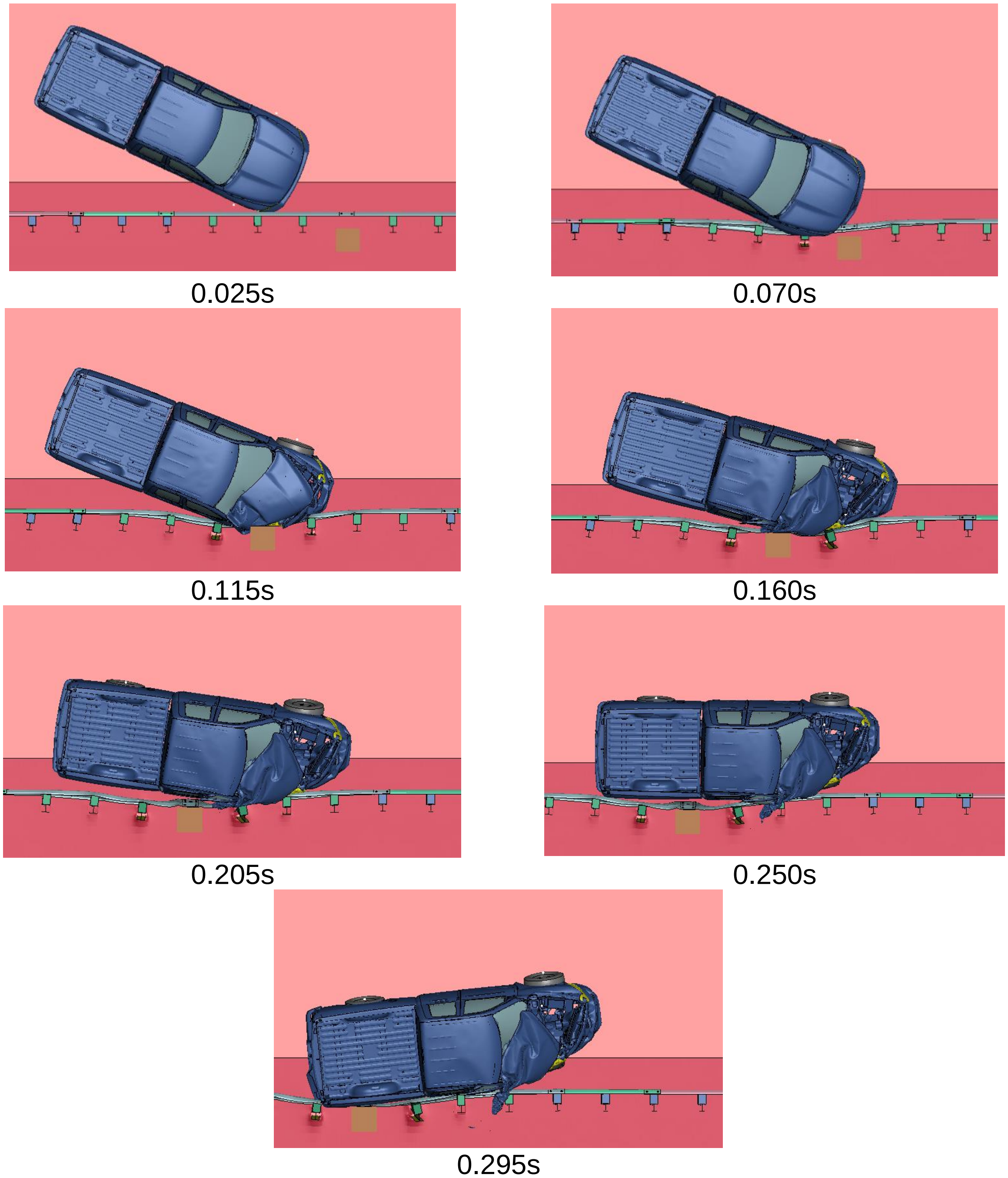


Figure 2.158. ***MASH*** **Test 3-11 Simulation of Half-Post Small Gap with Fixed Object 10 inch Offset – Overhead View**

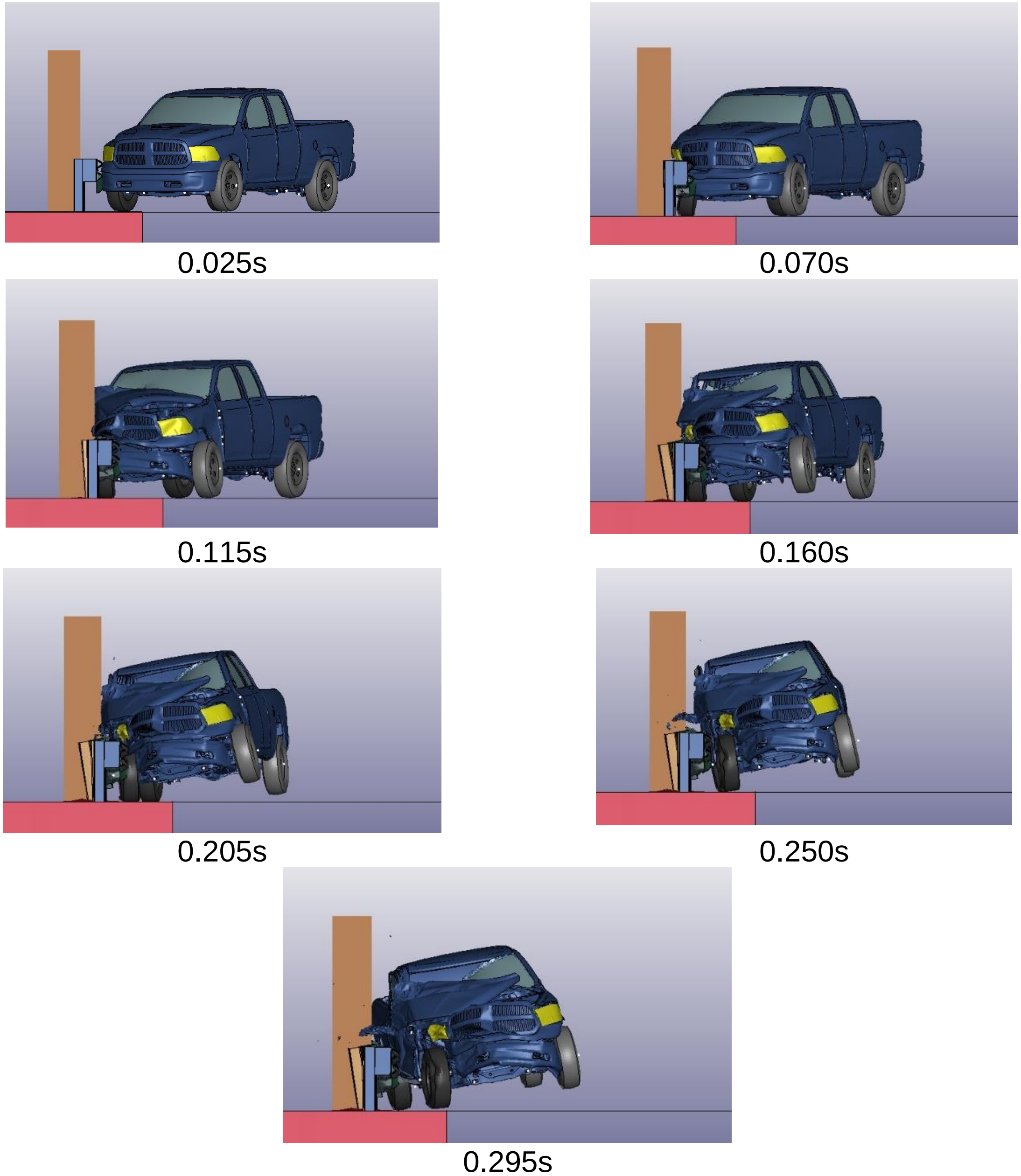


Figure 2.159. *MASH* Test 3-11 Simulation of Half-Post Small Gap with Fixed Object 10 inch Offset – Downstream View

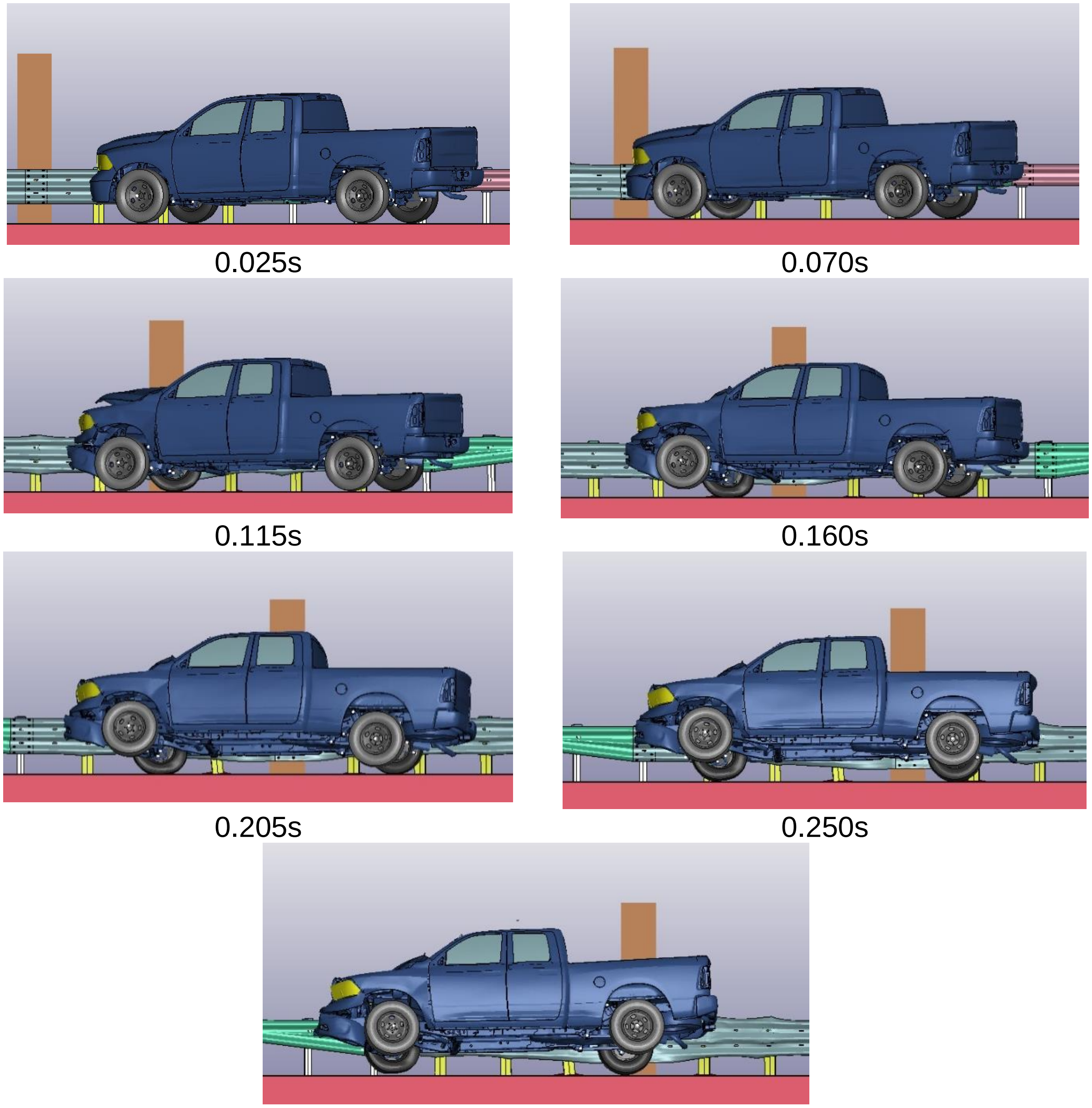
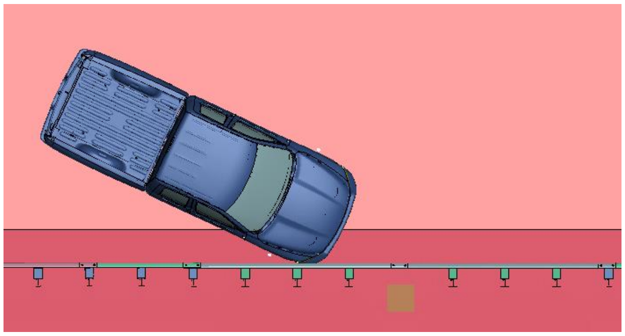


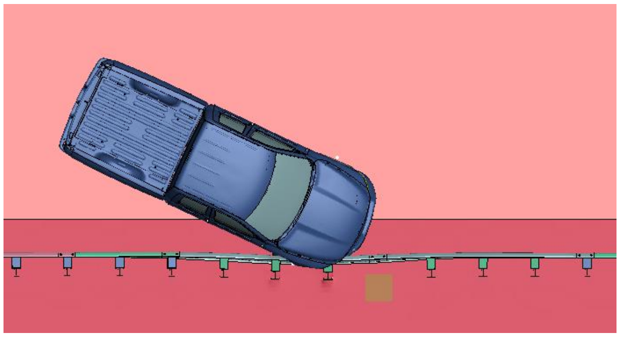
Figure 2.160. ***MASH*** **Test 3-11 Simulation of Half-Post Small Gap with Fixed Object 10 inch Offset– Rear View**

2.5.1.6. MASH Test 3-11 Simulation of Half-Post Spacing Small Gap with Fixed Object 12 inch Offset

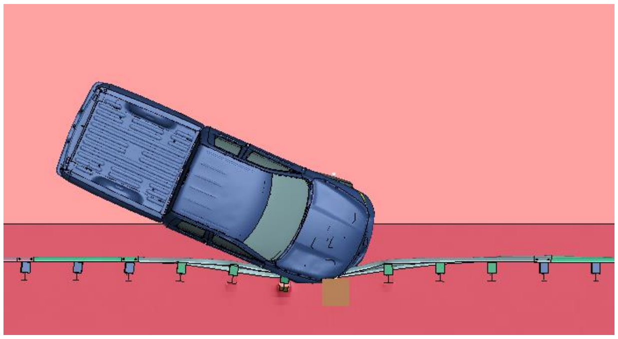
Figure 2.161 through Figure 2.163 show the sequential frames of *MASH* test 3-11 with half-post spacing, small gap, and a fixed object offset of 12 inches. The pickup truck interacted with the fixed object more than what was allowed within this project scope. Therefore, the offset distance was increased in the next simulation.



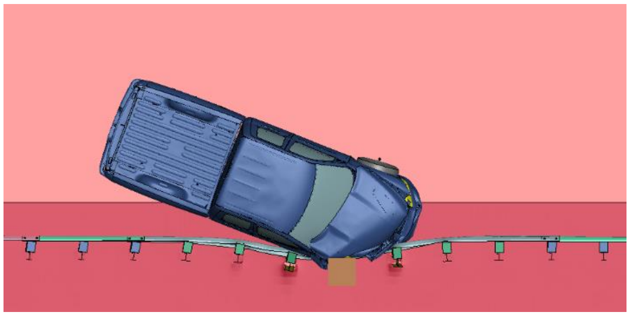
0.025s



0.055s

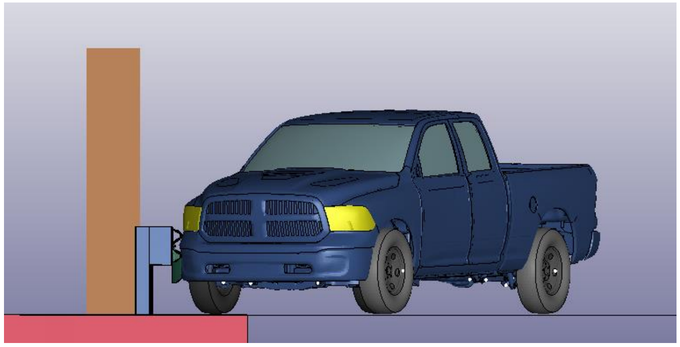


0.085s

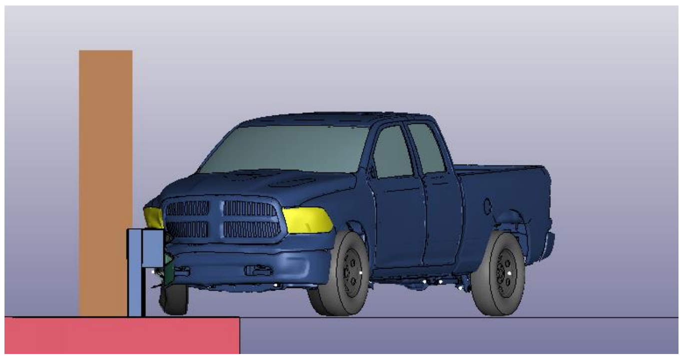


0.115s

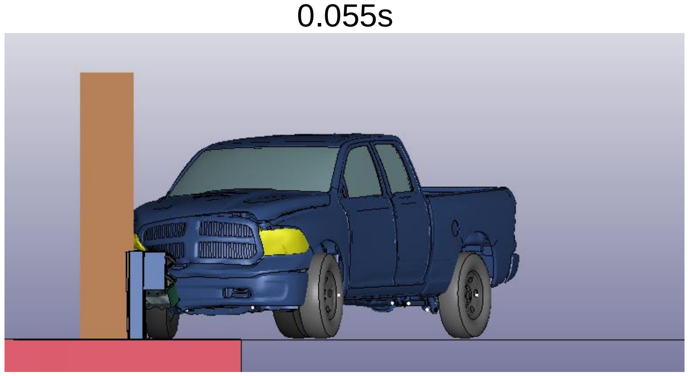
Figure 2.161. *MASH* Test 3-11 Simulation of Half-Post Small Gap with Fixed Object 12 inch Offset – Overhead View



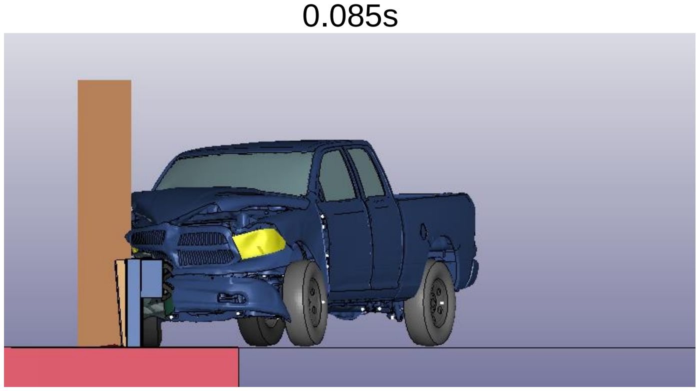
0.025s



0.055s

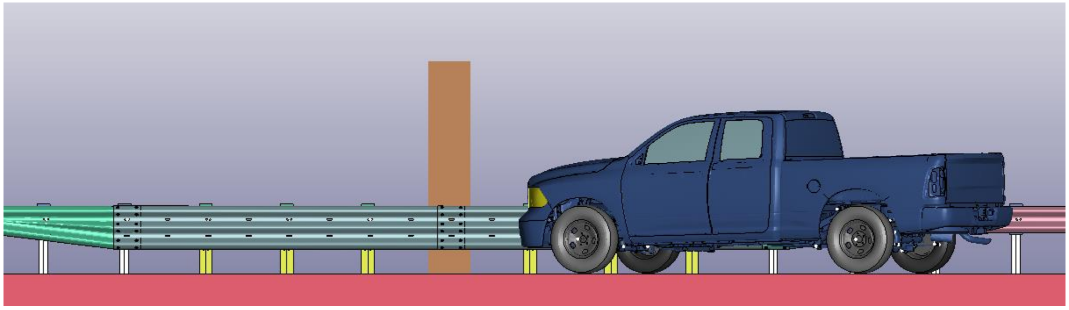


0.085s

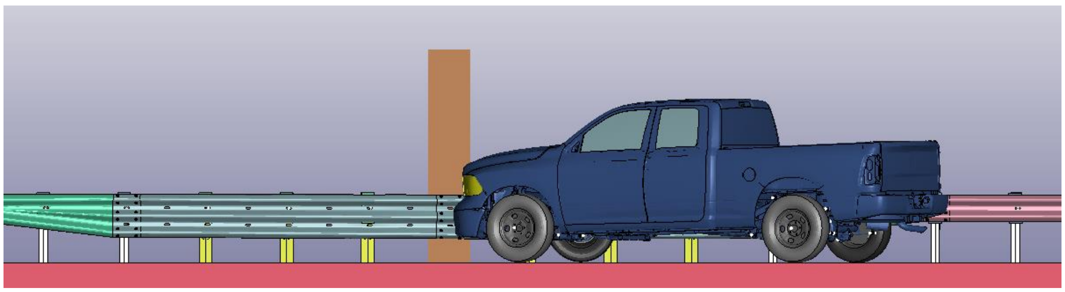


0.115s

Figure 2.162. *MASH* Test 3-11 Simulation of Half-Post Small Gap with Fixed Object 12 inch Offset – Downstream View



0.025s



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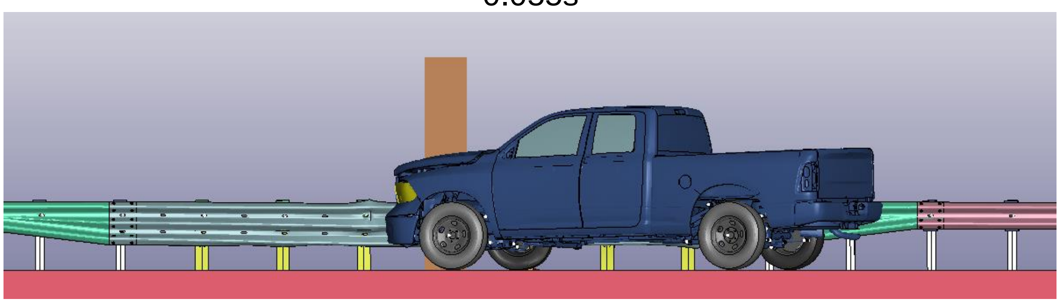
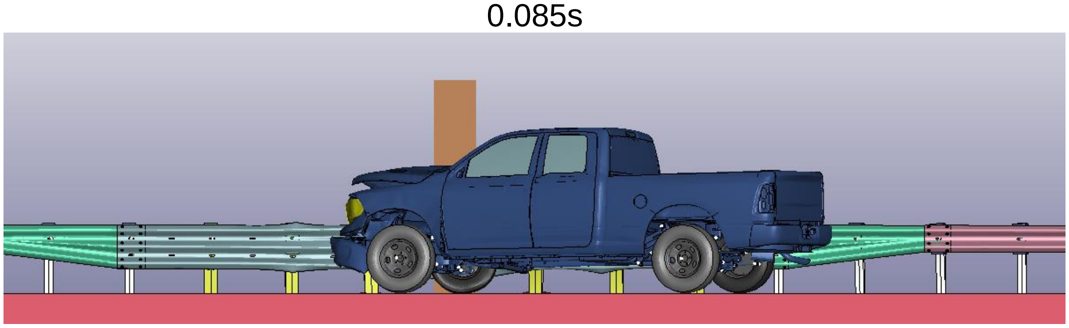


0.085s

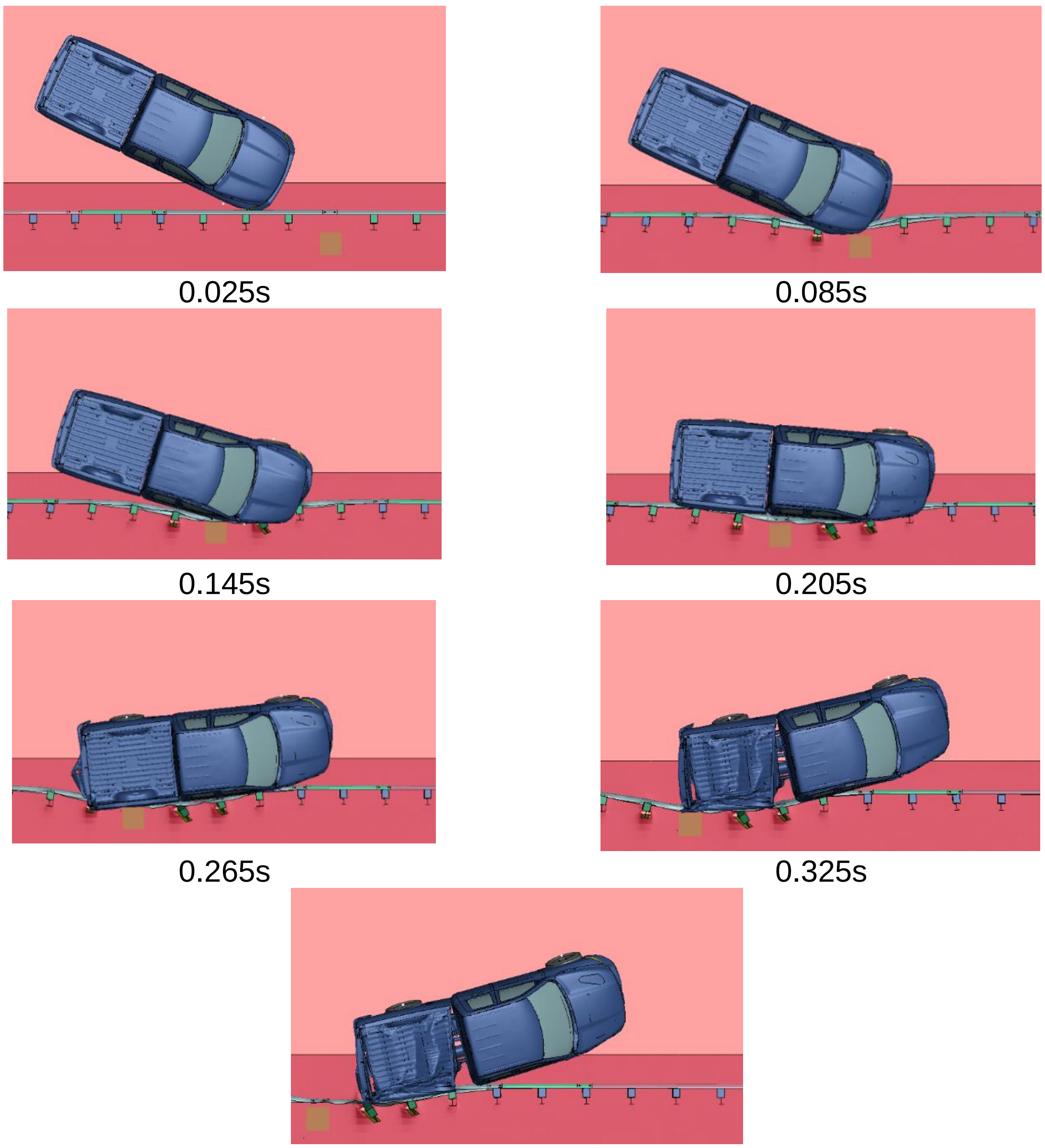


0.115s

Figure 2.163. ***MASH*** **Test 3-11 Simulation of Half-Post Small Gap with Fixed Object 12 inch Offset – Rear View**

2.5.1.7. MASH Test 3-11 Simulation of Half-Post Spacing Small Gap with Fixed Object 16 inch Offset

Figure 2.164 through Figure 2.166 show the sequential frames of *MASH* test 3-11 with half-post spacing, small gap, and a fixed object offset of 16 inches. The occupant impact velocity was calculated to be 6.1 m/s (preferred limit is 9.1 m/s). The ridedown acceleration was calculated to be 12.8 g's (preferred limit is 15.0 g's). This configuration passed *MASH* test 3-11 by successfully containing and redirecting the vehicle.



0.025s 0.085s

0.145s 0.205s

0.265s 0.325s

0.385s

Figure 2.164. *MASH* Test 3-11 Simulation of Half-Post Small Gap with Fixed Object 16 inch Offset– Overhead View

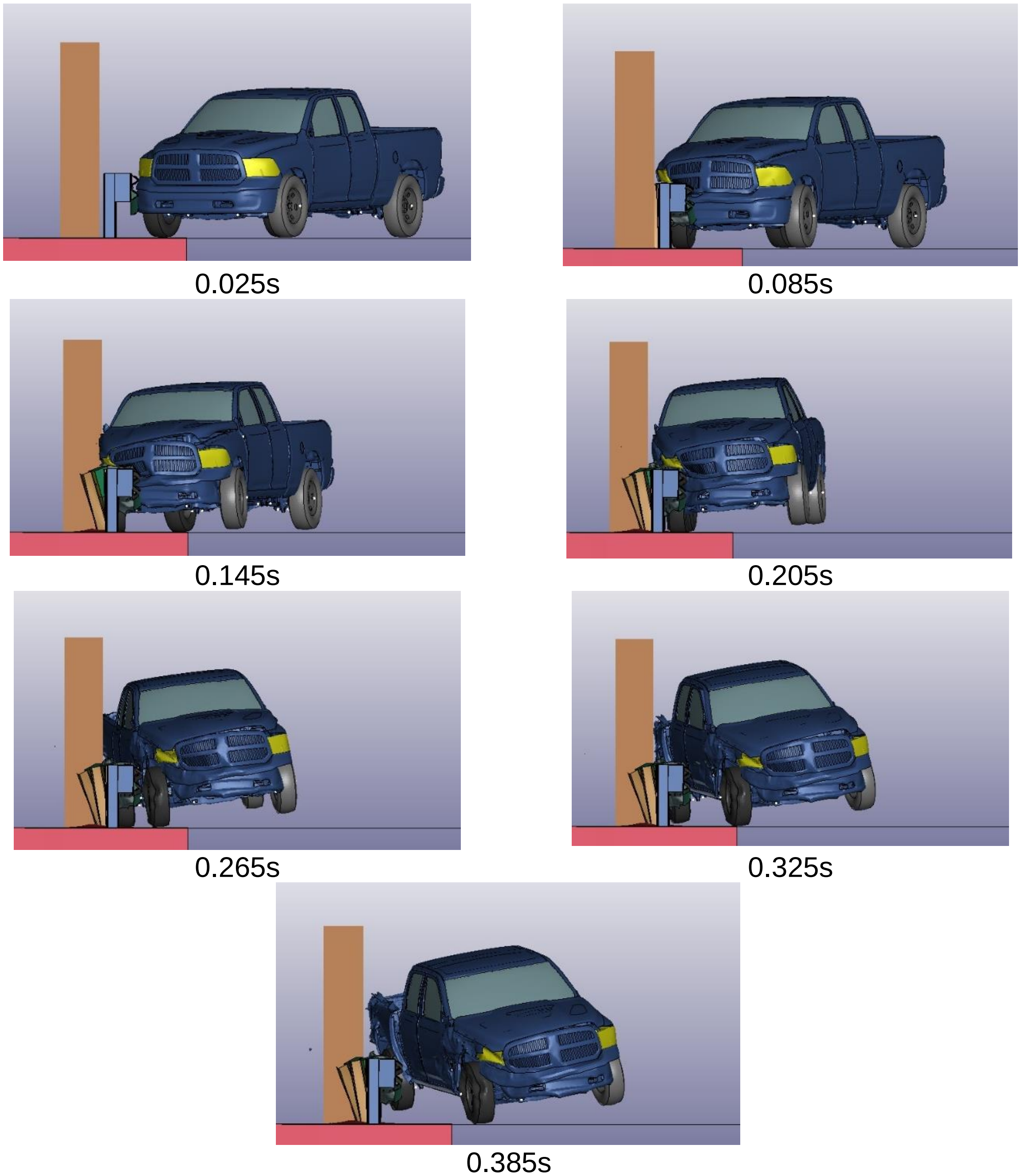


Figure 2.165. *MASH* Test 3-11 Simulation of Half-Post Small Gap with Fixed Object 16 inch Offset– Downstream View

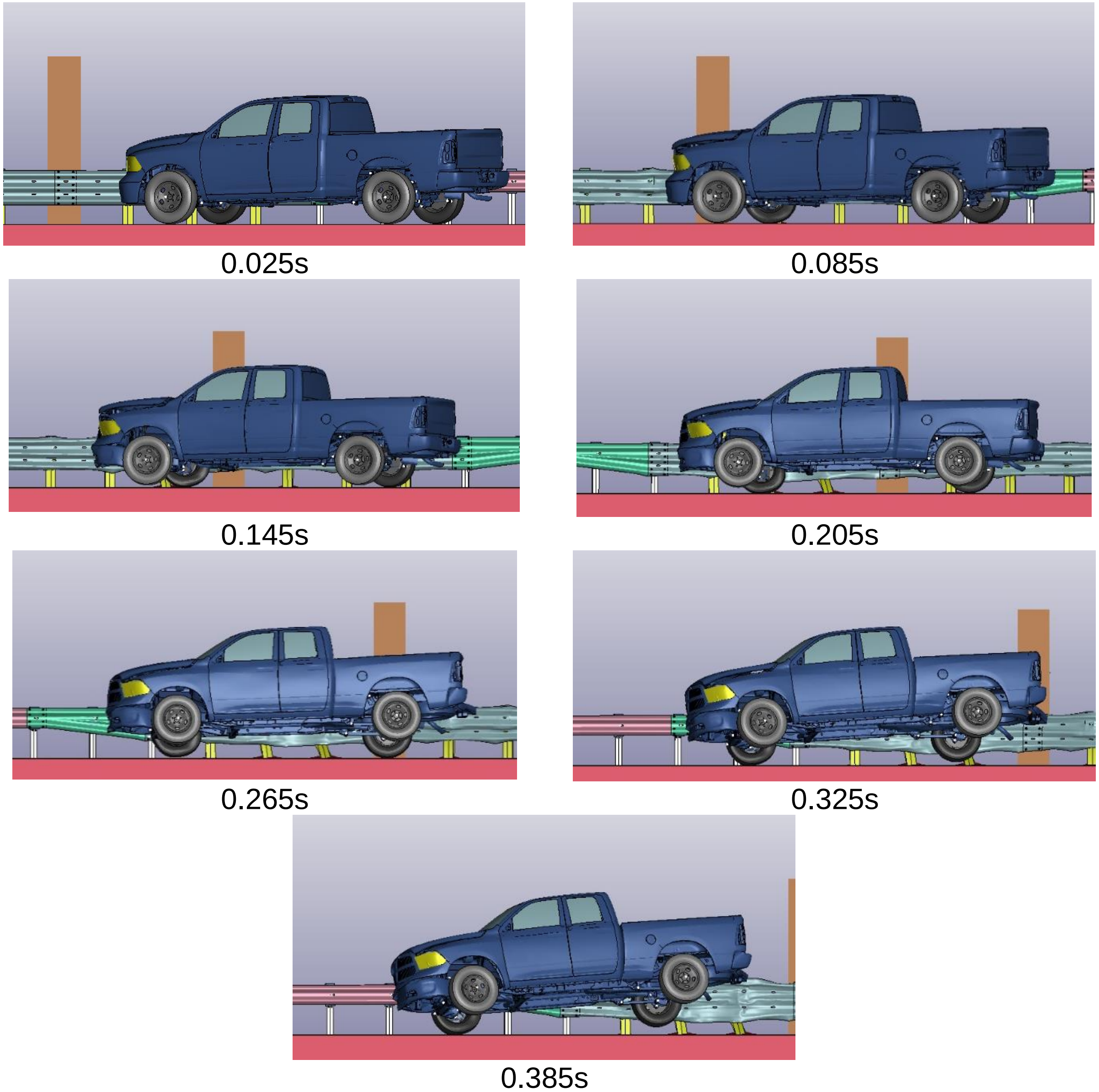


Figure 2.166. *MASH* Test 3-11 Simulation of Half-Post Small Gap with Fixed Object 16 inch Offset– Rear View

2.5.1.8. MASH Test 3-11 Simulation of Half-Post Spacing Small Gap with Fixed Object 20 inch Offset

Figure 2.167 through Figure 2.169 show the sequential frames of *MASH* test 3-11 with half-post spacing, small gap, and a fixed object offset of 20 inches. The occupant impact velocity was calculated to be 5.5 m/s (preferred limit is 9.1 m/s). The ridedown acceleration was calculated to be 14.4 g's (preferred limit is 15.0 g's). This configuration passed *MASH* test 3-11 by successfully containing and redirecting the vehicle.

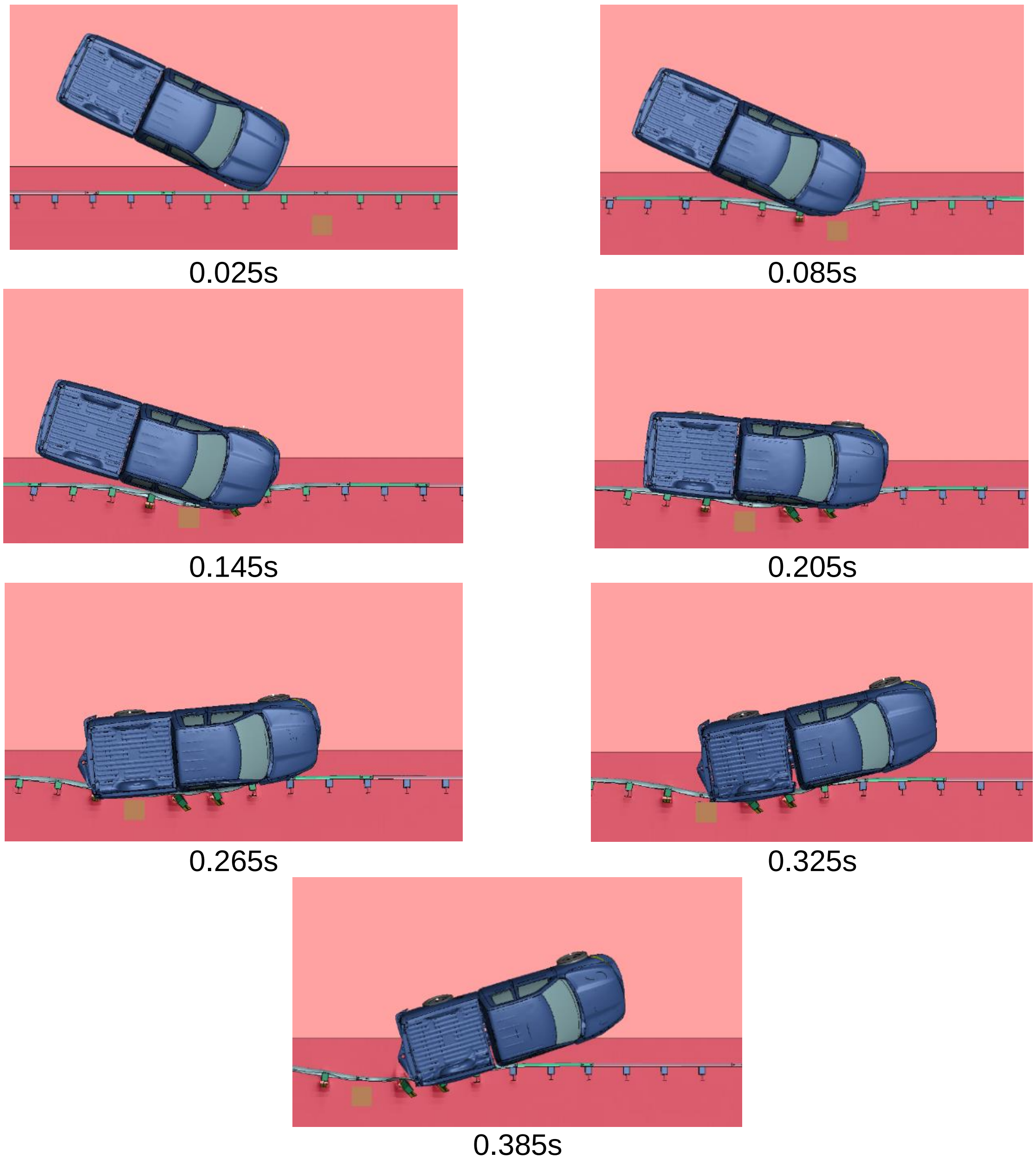


Figure 2.167. *MASH* Test 3-11 Simulation of Half-Post Small Gap with Fixed Object 20 inch Offset – Overhead View

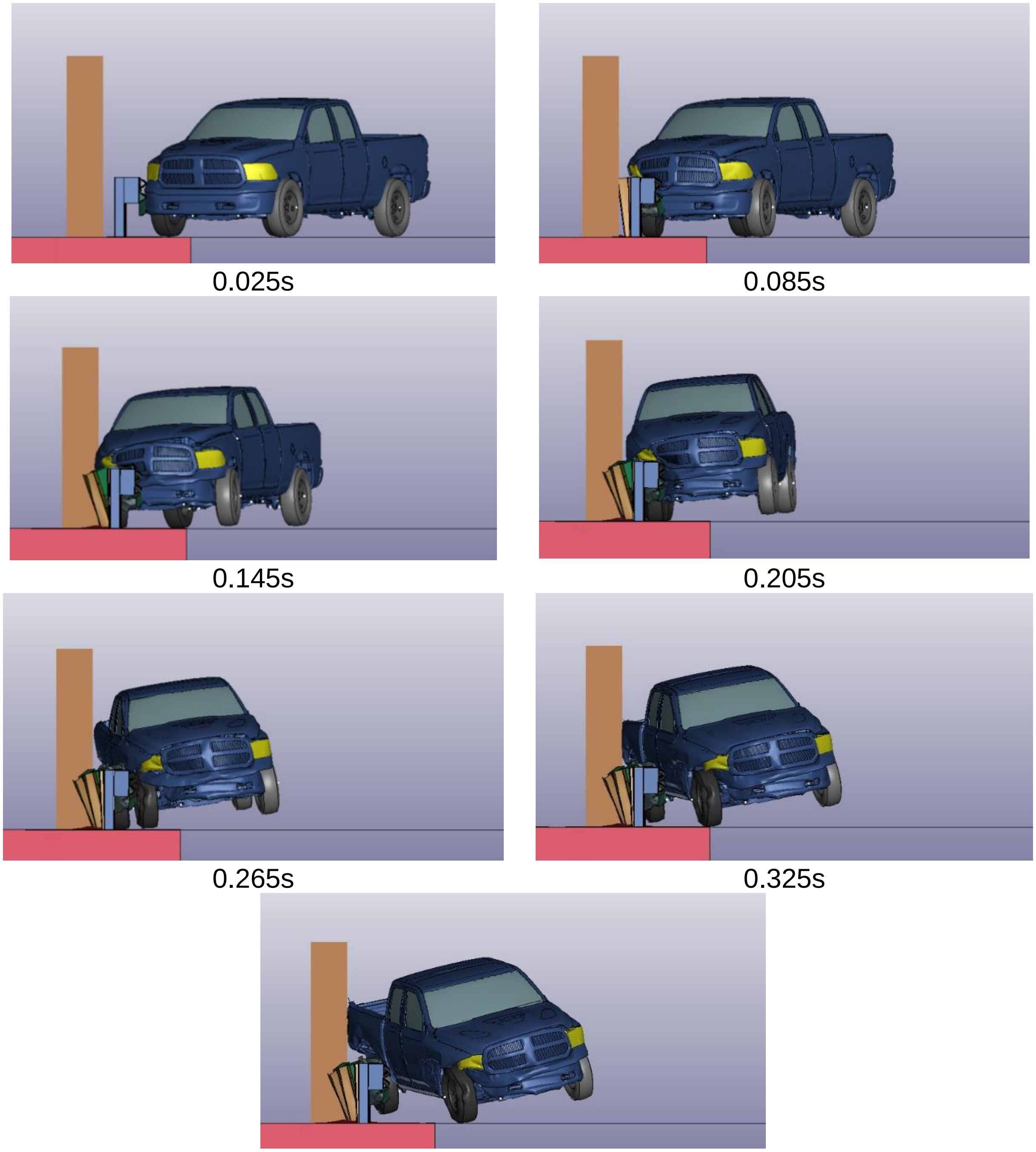


Figure 2.168. *MASH* Test 3-11 Simulation of Half-Post Small Gap with Fixed Object 20 inch Offset – Downstream View

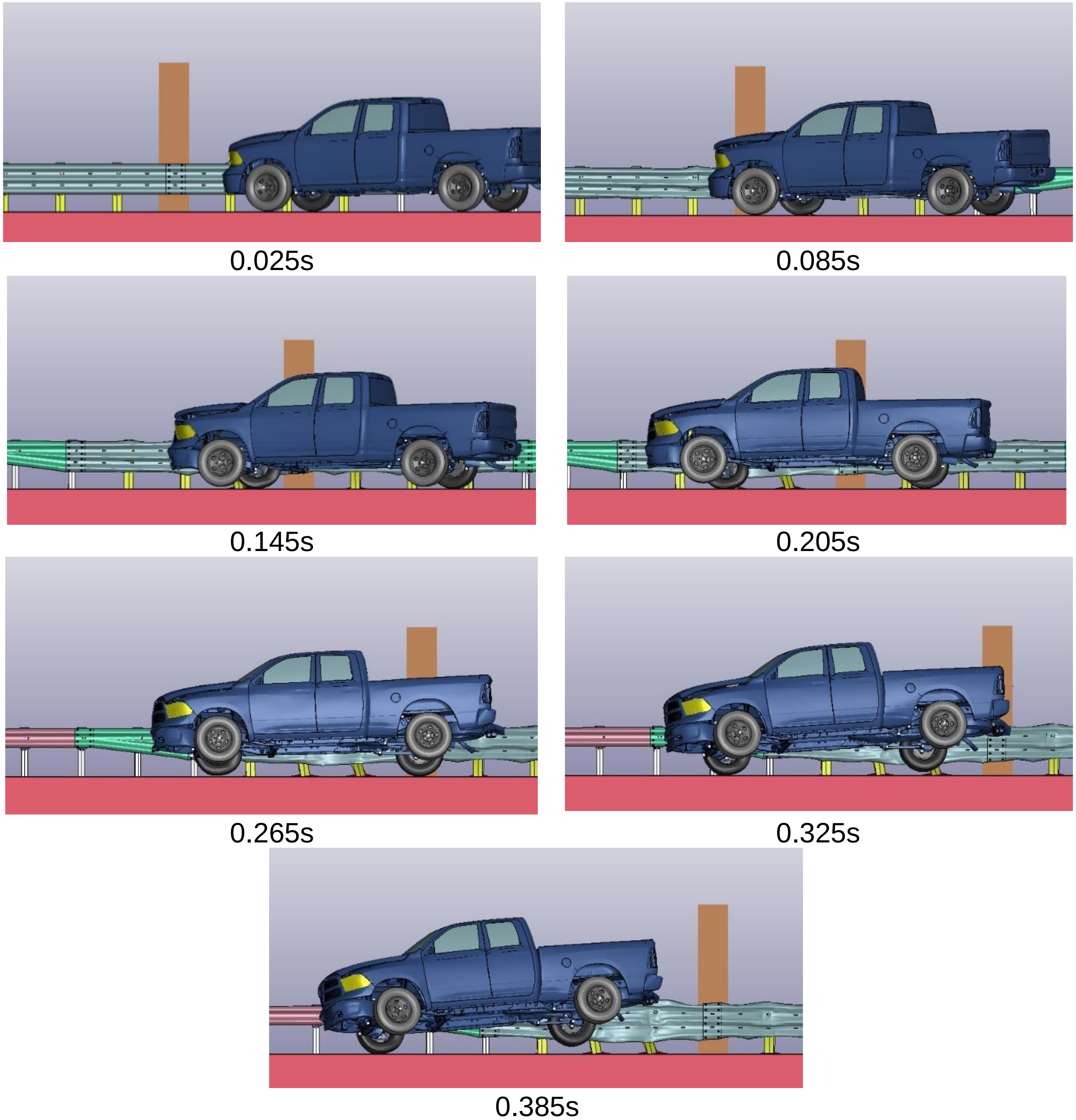


Figure 2.169. *MASH* Test 3-11 Simulation of Half-Post Small Gap with Fixed Object 20 inch Offset – Rear View

2.5.1.9. MASH Test 3-11 Simulation of Half-Post Spacing Small Gap with Fixed Object 24 inch Offset

Figure 2.170 through Figure 2.172 show the sequential frames of *MASH* test 3-11 with half-post spacing, small gap, and a fixed object offset of 24 inches. The occupant impact velocity was calculated to be 5.5 m/s (preferred limit is 9.1 m/s). The ridedown acceleration was calculated to be 15.0 g's (maximum limit is 20.49 g's). This configuration passed *MASH* test 3-11 by successfully containing and redirecting the vehicle. Because of the minimal to no interaction exhibited in this simulation, the research team evaluated multiple impact points to determine the most critical. These simulations are included in the sections below.

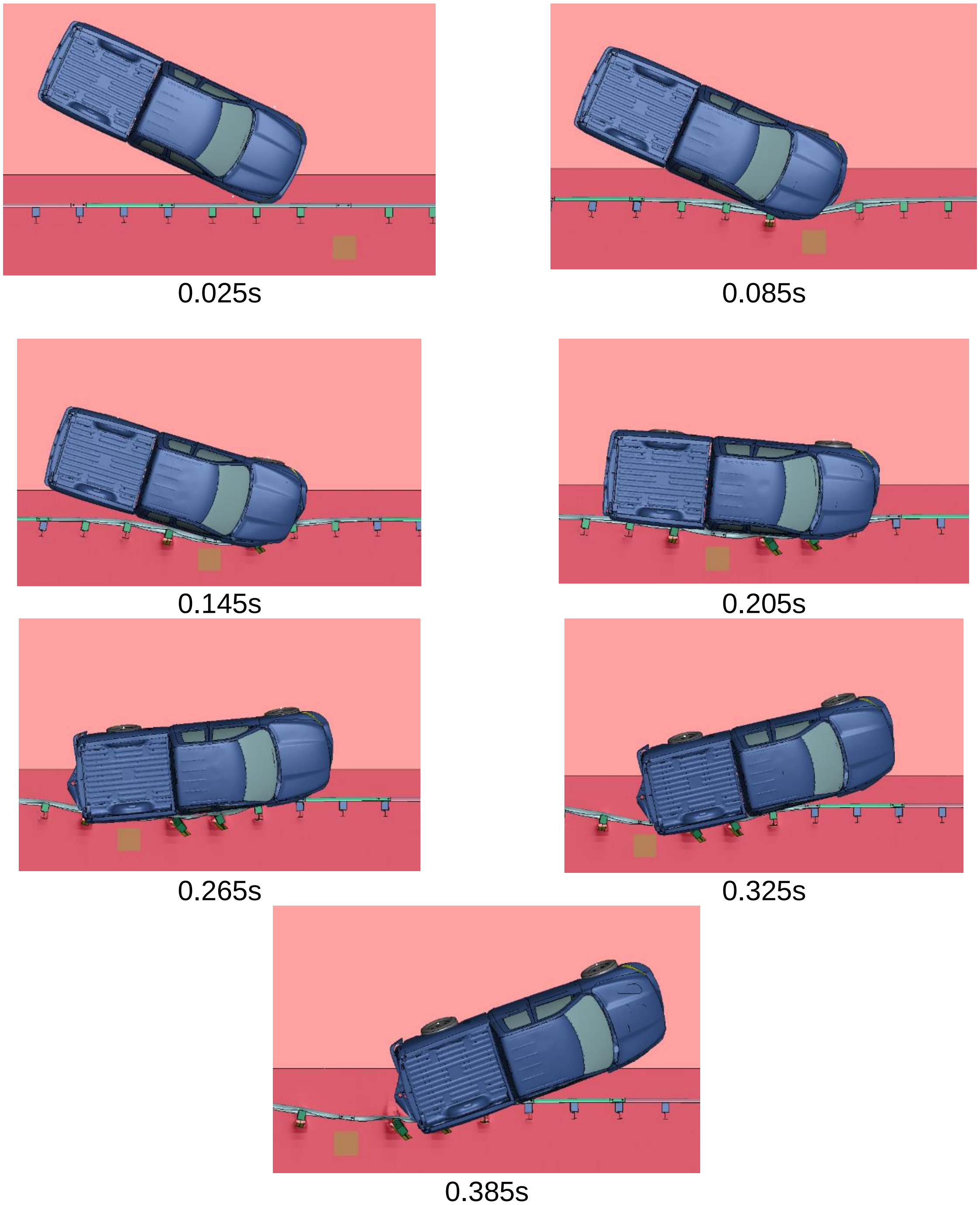


Figure 2.170. *MASH* Test 3-11 Simulation of Half-Post Small Gap with Fixed Object 24 inch Offset – Overhead View

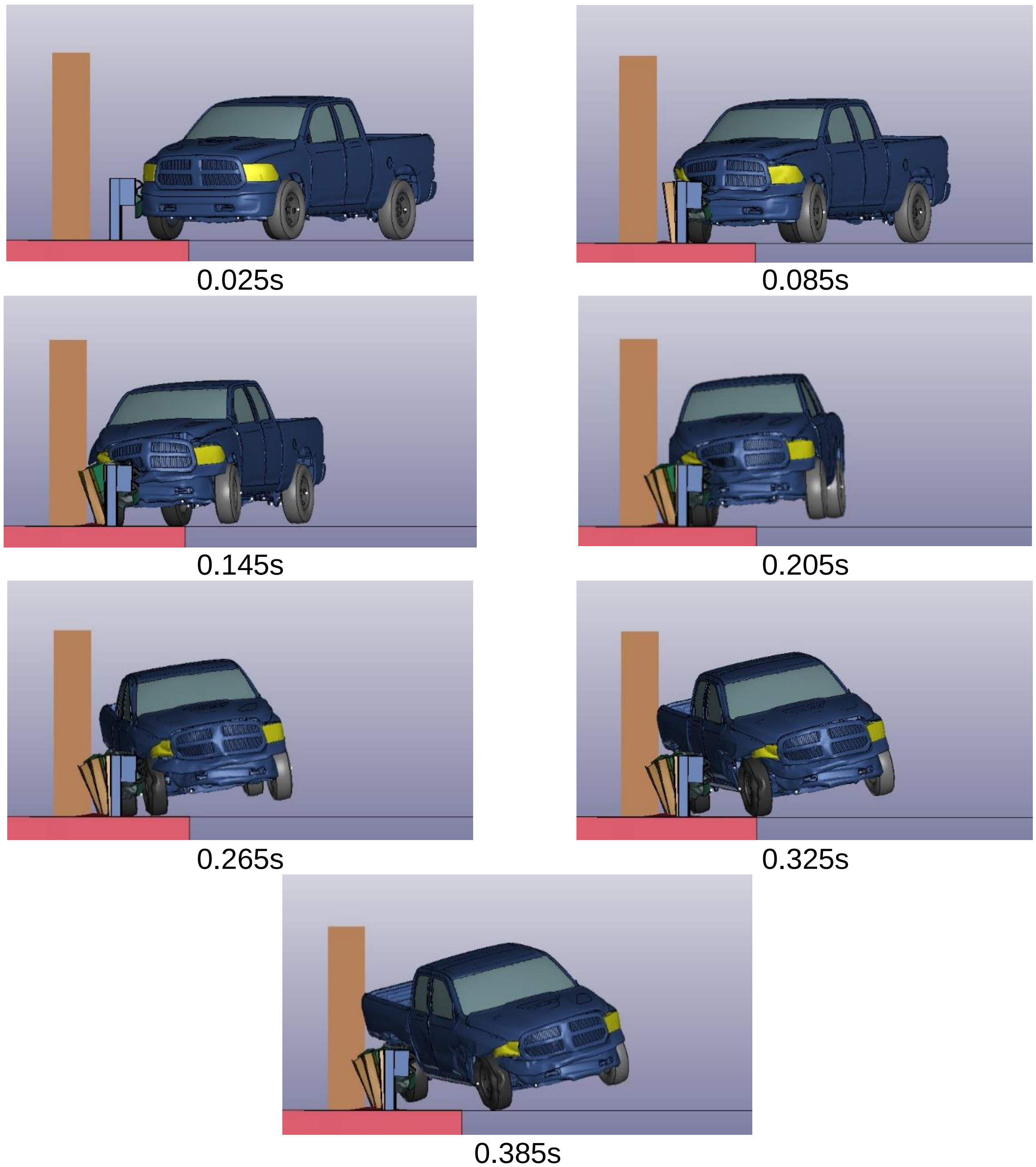
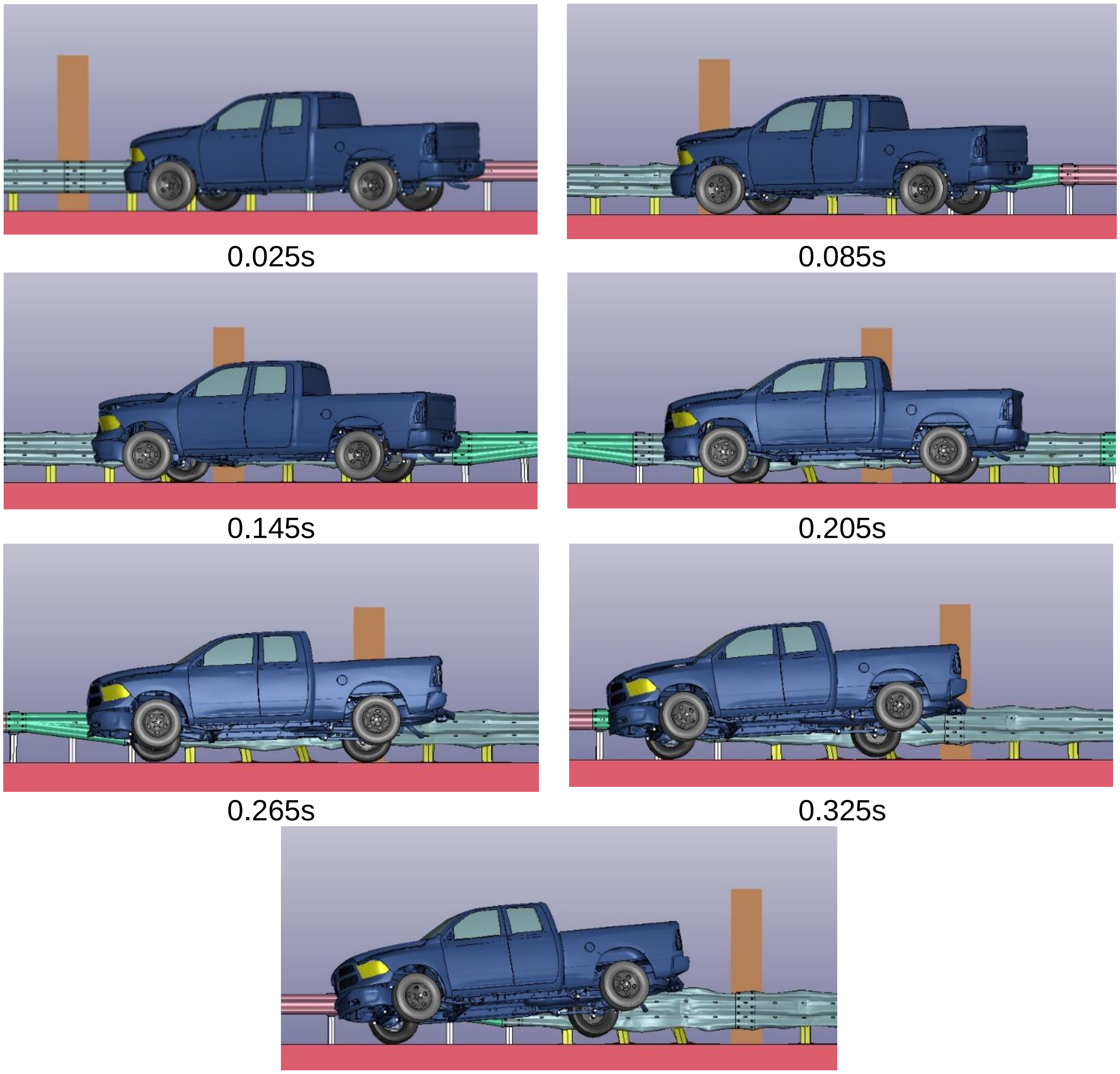


Figure 2.171. ***MASH*** **Test 3-11 Simulation of Half-Post Small Gap with Fixed Object 24 inch Offset – Downstream View**

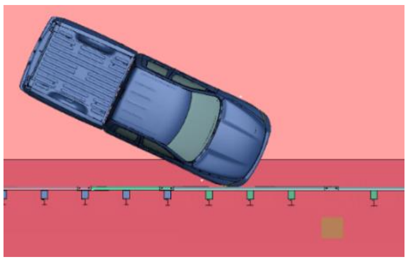


0.025s 0.085s 0.145s 0.205s 0.265s 0.325s 0.385s

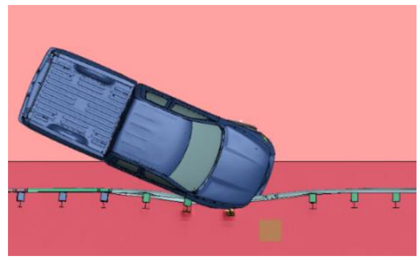
Figure 2.172. *MASH* Test 3-11 Simulation of Half-Post Small Gap with Fixed Object 24 inch Offset – Rear View

2.5.1.10. MASH Test 3-11 Simulation of Half-Post Spacing Small Gap with Fixed Object 24 inch Offset and 2 feet Upstream Impact Variation

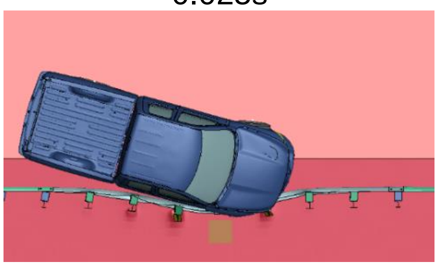
Figure 2.173 through Figure 2.175 show the sequential frames of *MASH* test 3-11 with half-post spacing, small gap, a fixed object offset of 24 inches, and an impact variation positioned 2 feet upstream. The occupant impact velocity was calculated to be 5.6 m/s (preferred limit is 9.1 m/s). The ridedown acceleration was calculated to be 12.9 g's (preferred limit is 15.0 g's). This configuration passed *MASH* test 3-11 by successfully containing and redirecting the vehicle.



0.025s

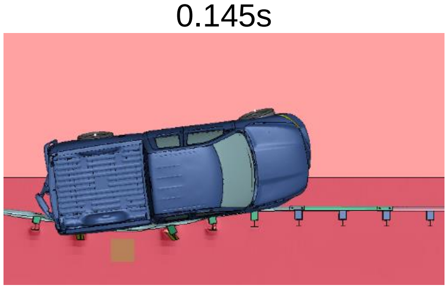


0.085s

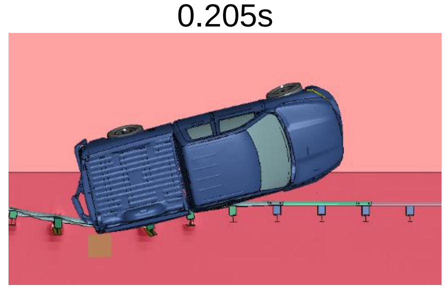


0.145s

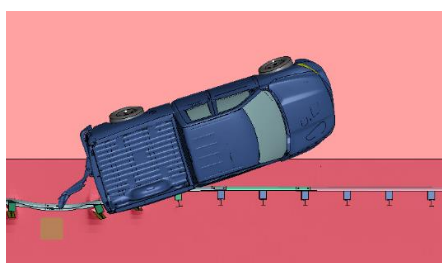
0.205s



0.265s



0.325s



0.385s

Figure 2.173. *MASH* Test 3-11 Simulation of Half-Post Small Gap with Fixed Object 24 inch Offset 2 feet Upstream Impact Variation – Overhead View

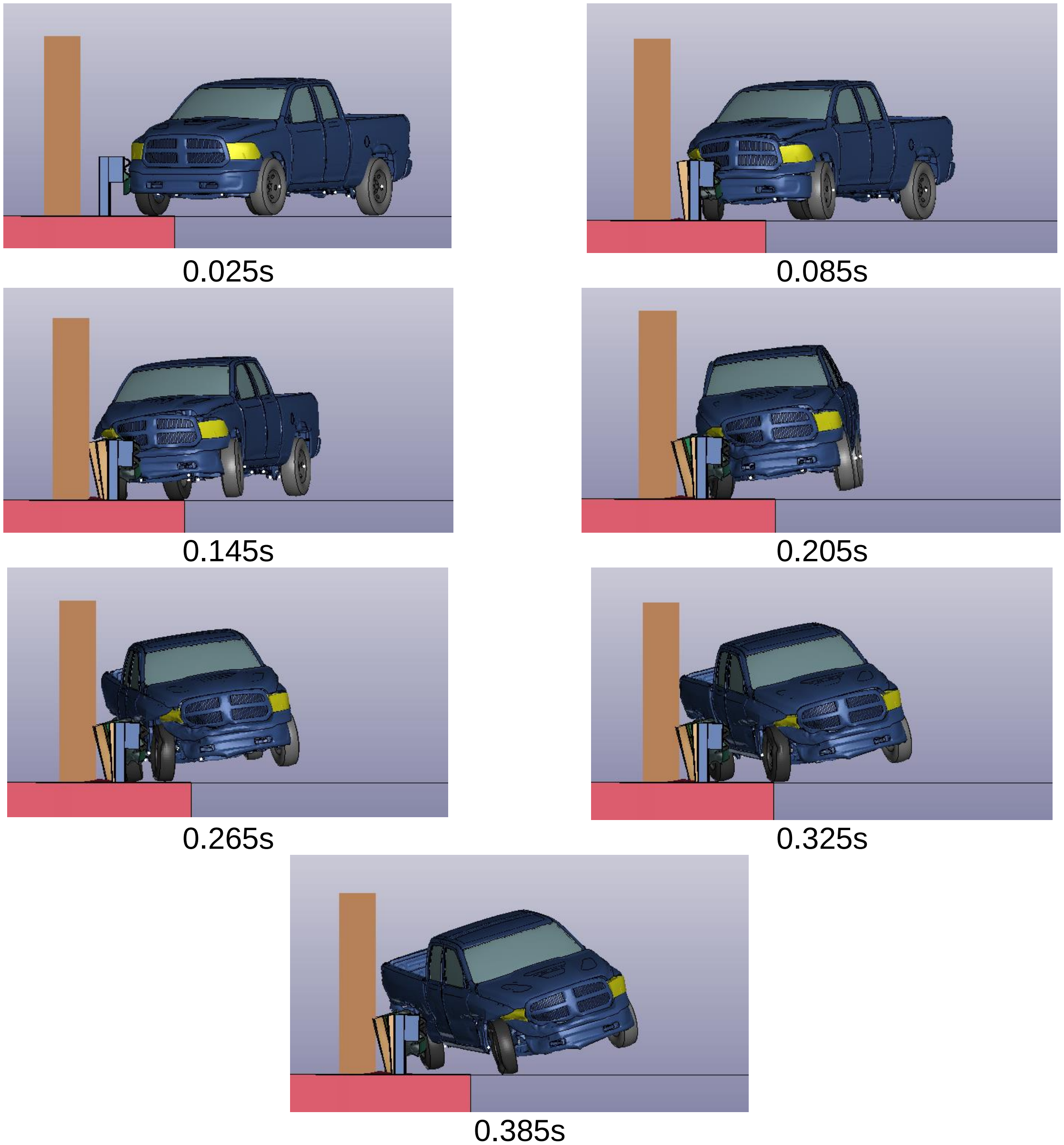


Figure 2.174. *MASH* Test 3-11 Simulation of Half-Post Small Gap with Fixed Object 24 inch Offset 2 feet Upstream Impact Variation – Downstream View

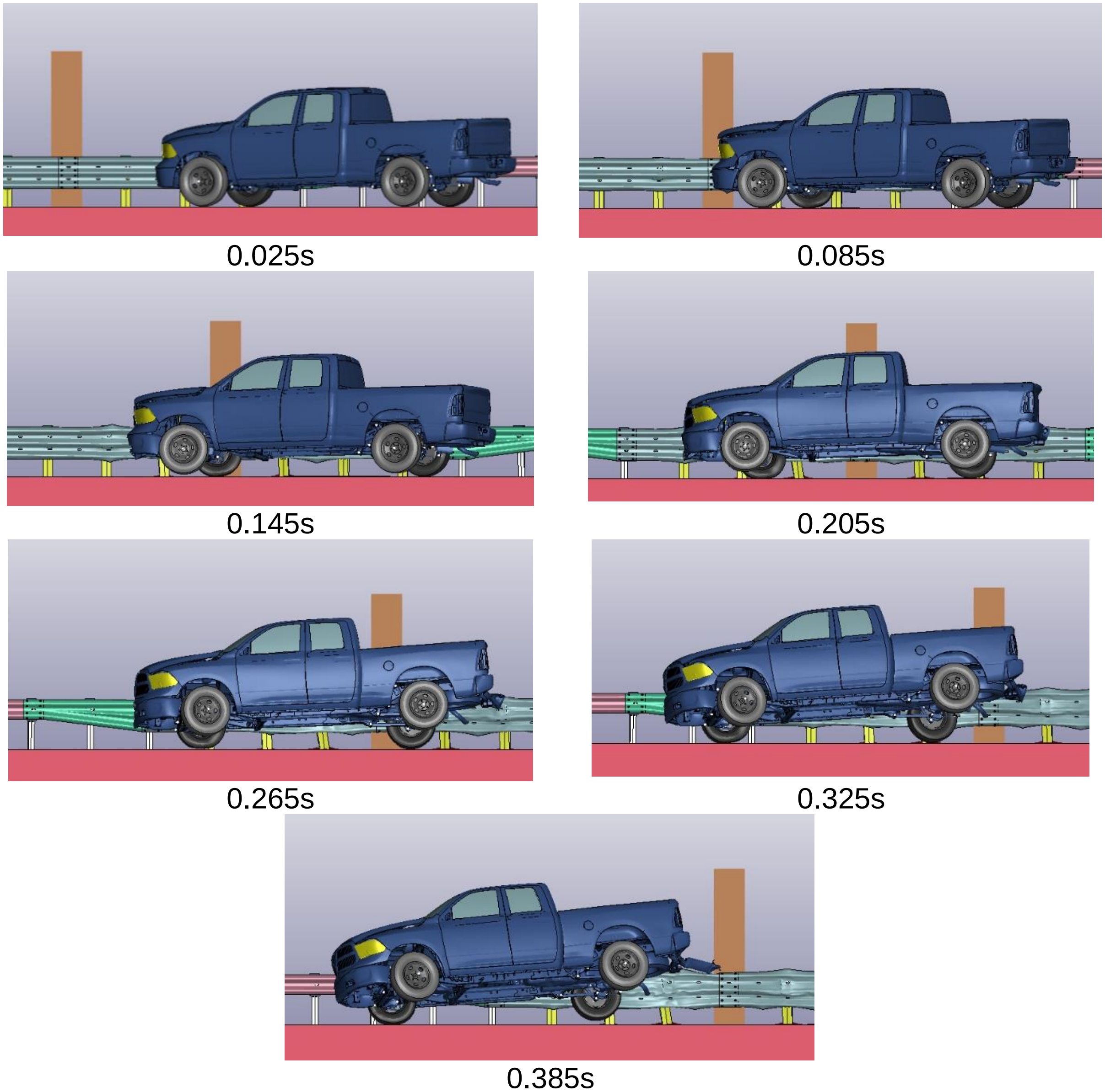


Figure 2.175. *MASH* Test 3-11 Simulation of Half-Post Small Gap with Fixed Object 24 inch Offset 2 feet Upstream Impact Variation – Rear View

2.5.1.11. MASH Test 3-11 Simulation of Half-Post Spacing Small Gap with Fixed Object 24 inch Offset and 4 feet Upstream Impact Variation

Figure 2.176 through Figure 2.178 show the sequential frames of *MASH* test 3-11 with half-post spacing, small gap, a fixed object offset of 24 inches, and an impact variation positioned 4 feet upstream. The occupant impact velocity was calculated to be 6.7 m/s (preferred limit is 9.1 m/s). The ridedown acceleration was calculated to be 10.0 g’s (preferred limit is 15.0 g’s). This configuration passed *MASH* test 3-11 by successfully containing and redirecting the vehicle.

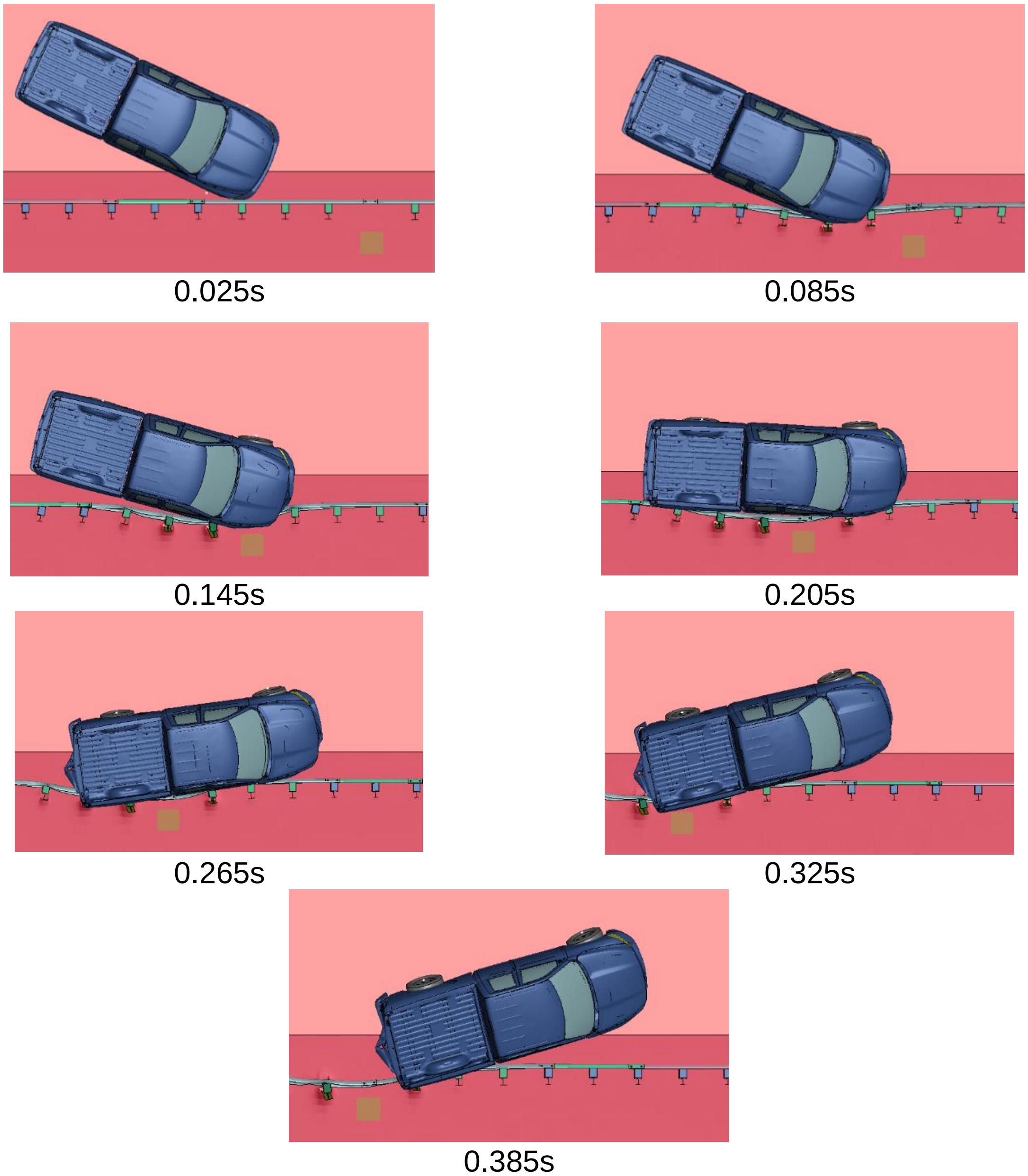


Figure 2.176. *MASH* Test 3-11 Simulation of Half-Post Small Gap with Fixed Object 24 inch Offset 4 feet Upstream Impact Variation – Overhead View

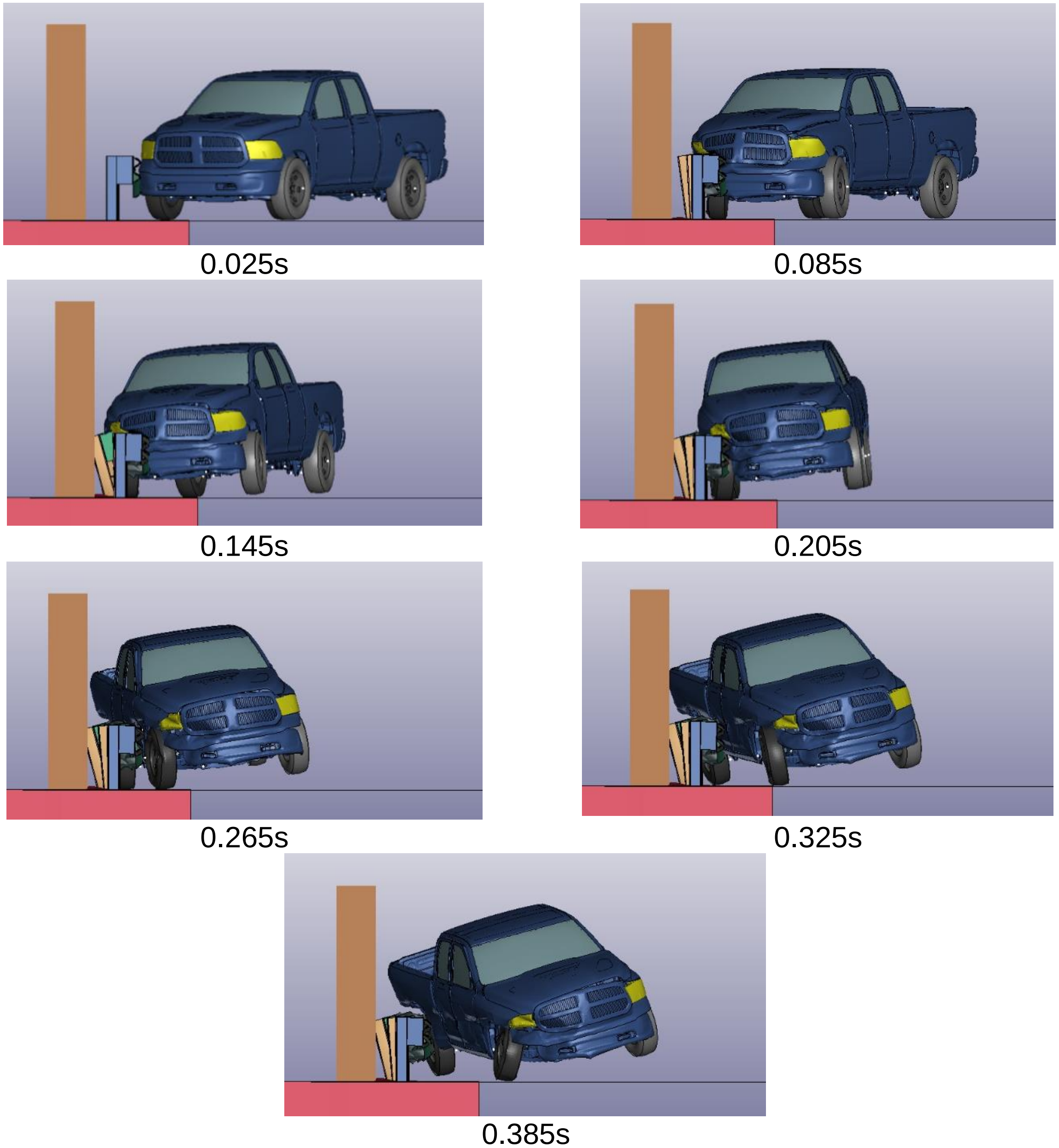


Figure 2.177. *MASH* Test 3-11 Simulation of Half-Post Small Gap with Fixed Object 24 inch Offset 4 feet Upstream Impact Variation – Downstream View

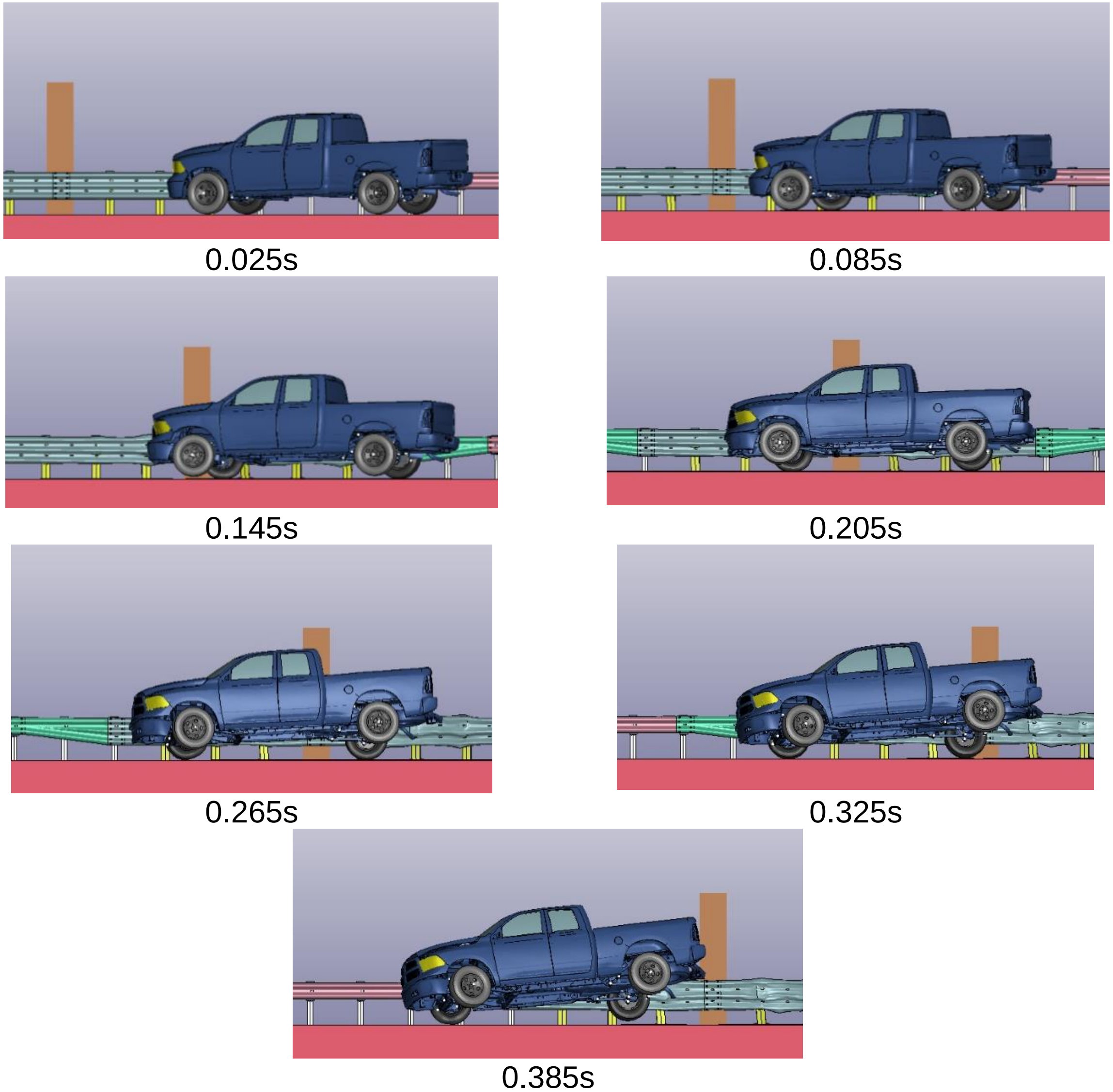
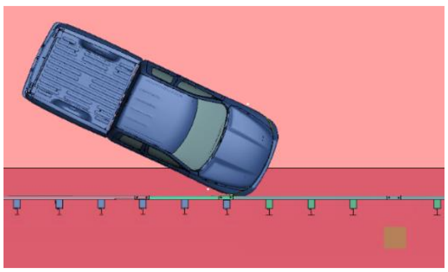


Figure 2.178. ***MASH*** **Test 3-11 Simulation of Half-Post Small Gap with Fixed Object 24 inch Offset 4 feet Upstream Impact Variation – Rear View**

2.5.1.12. MASH Test 3-11 Simulation of Half-Post Spacing Small Gap with Fixed Object 24 inch Offset and 6 feet Upstream Impact Variation

Figure 2.179 through Figure 2.181 show the sequential frames of *MASH* test 3-11 with half-post spacing, small gap, a fixed object offset of 24 inches, and an impact variation positioned 6 feet upstream. The occupant impact velocity was calculated to be 6.8 m/s (preferred limit is 9.1 m/s). The ridedown acceleration was calculated to be 11.3 g’s (preferred limit is 15.0 g’s). This configuration passed *MASH* test 3-11 by successfully containing and redirecting the vehicle.



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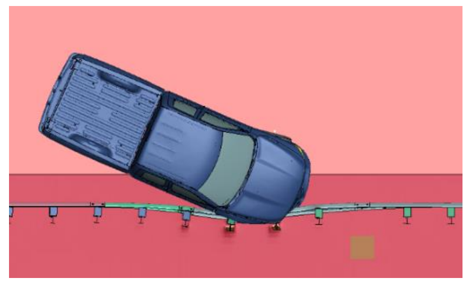

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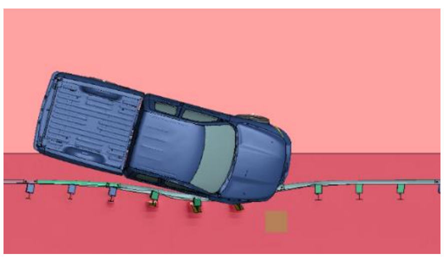
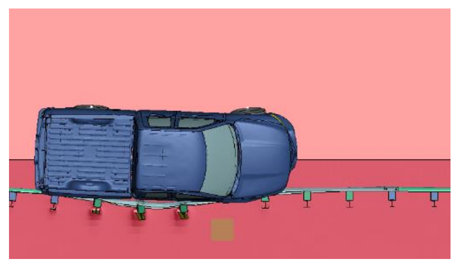


0.145s



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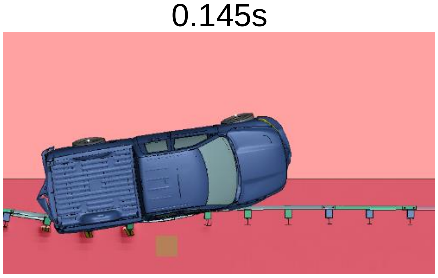
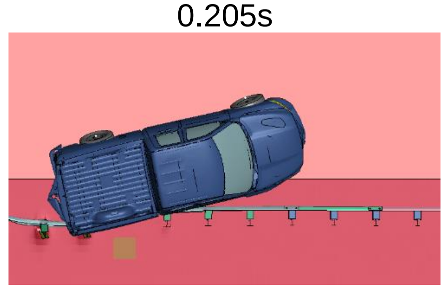
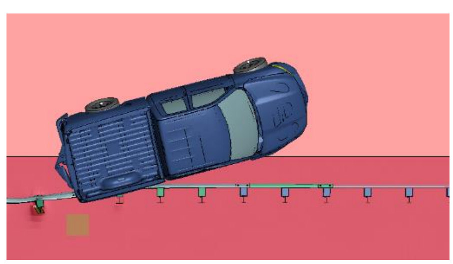


0.265s



0.325s



0.385s

Figure 2.179. *MASH* Test 3-11 Simulation of Half-Post Small Gap with Fixed Object 24 inch Offset 6 feet Upstream Impact Variation – Overhead View

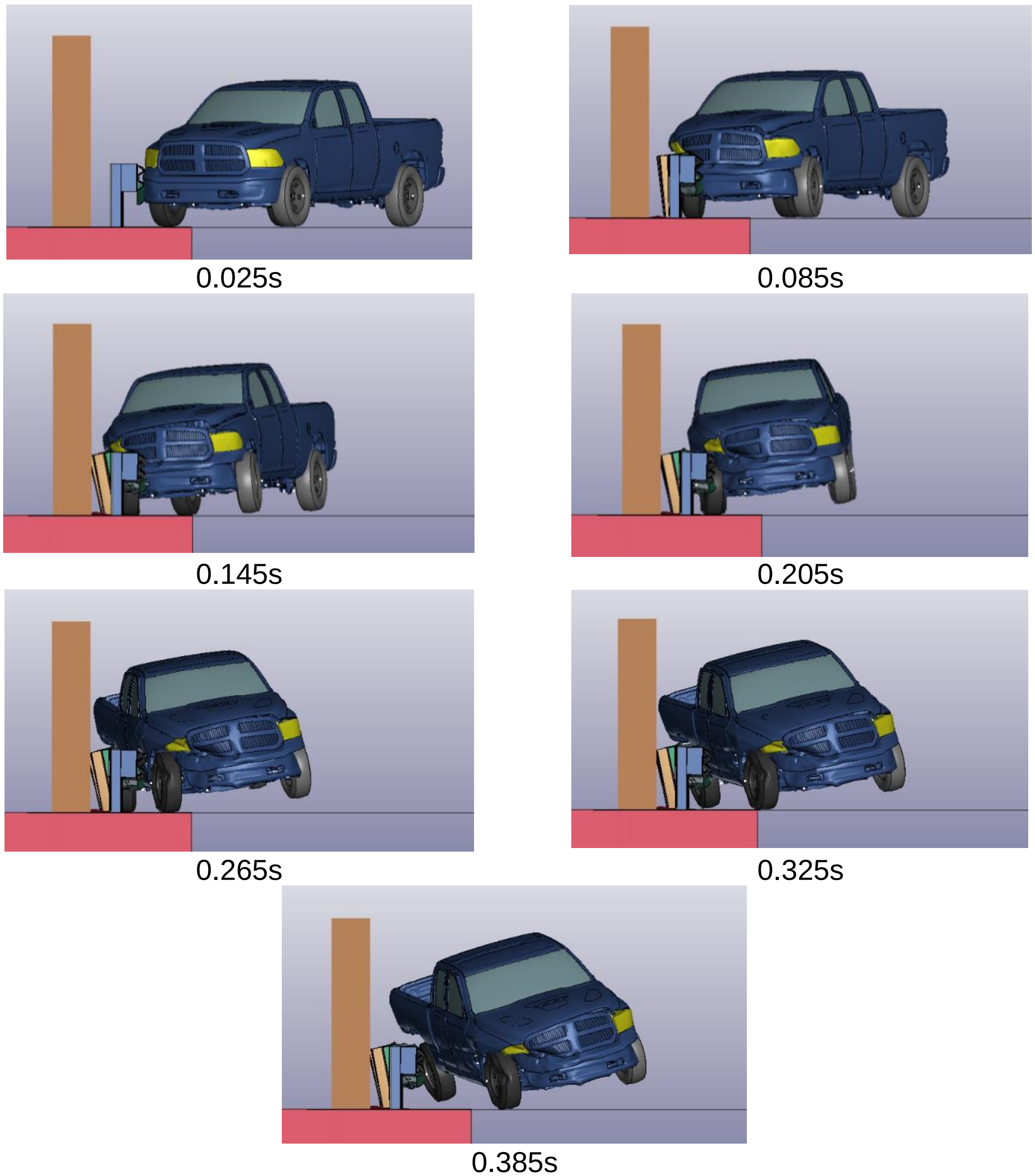
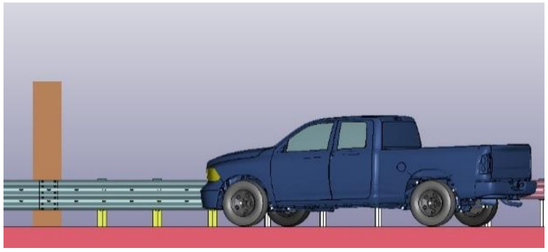


Figure 2.180. *MASH* Test 3-11 Simulation of Half-Post Small Gap with Fixed Object 24 inch Offset 6 feet Upstream Impact Variation – Downstream View



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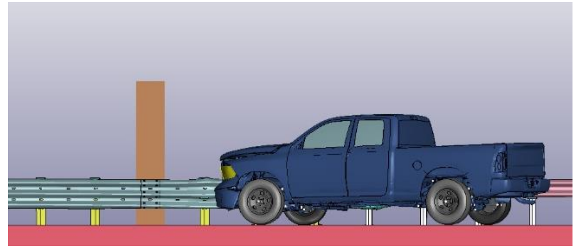

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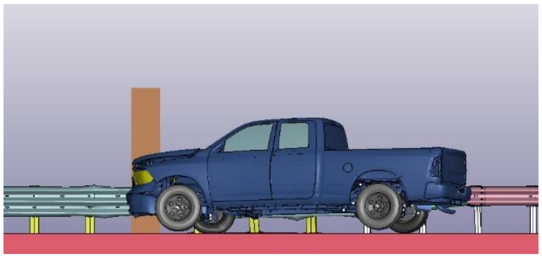

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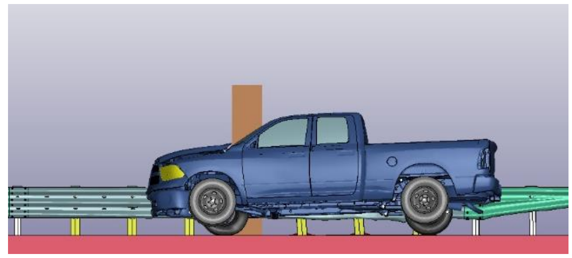

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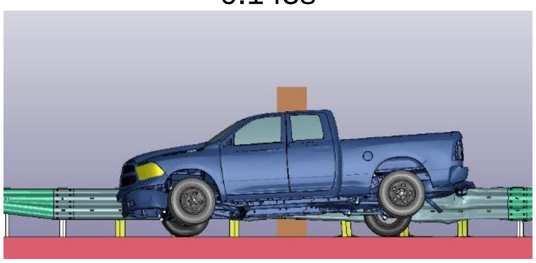

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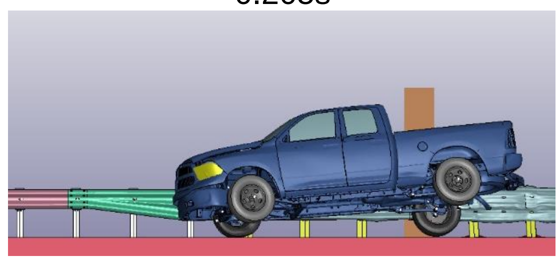

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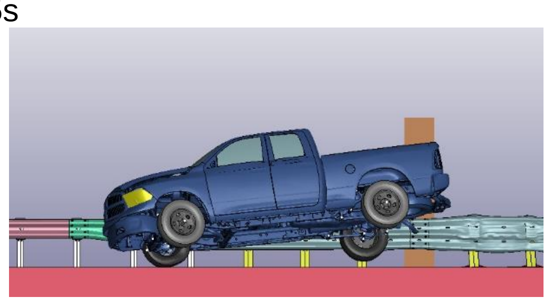
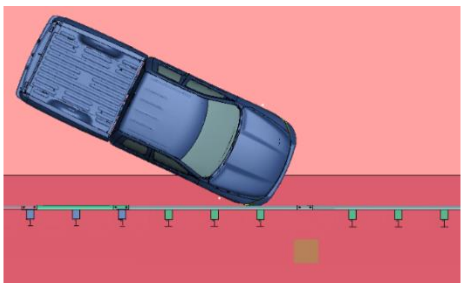


0.385s

Figure 2.181. *MASH* Test 3-11 Simulation of Half-Post Small Gap with Fixed Object 24 inch Offset 6 feet Upstream Impact Variation – Rear View

2.5.1.13. MASH Test 3-11 Simulation of Half-Post Spacing Small Gap with Fixed Object 24 inch Offset and 2 feet Downstream Impact Variation

Figure 2.182 through Figure 2.184 show the sequential frames of *MASH* test 3-11 with half-post spacing, small gap, a fixed object offset of 24 inches, and an impact variation positioned 2 feet downstream. The occupant impact velocity was calculated to be 5.5 m/s (preferred limit is 9.1 m/s). The ridedown acceleration was calculated to be 15.0 g's (maximum limit is 20.49 g's). This configuration passed *MASH* test 3-11 by successfully containing and redirecting the vehicle.



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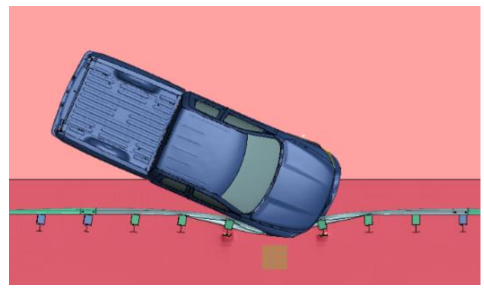

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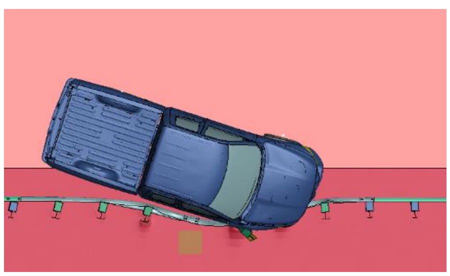
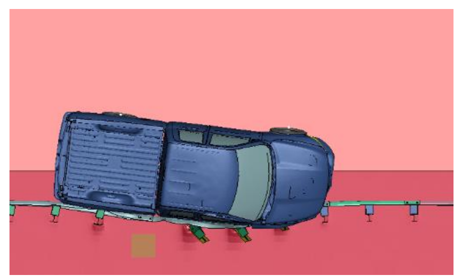
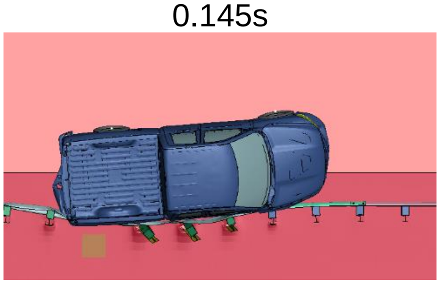


0.145s

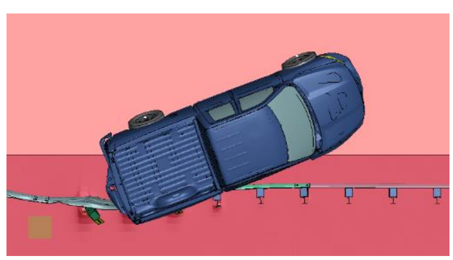


0.205s



0.265s

0.325s



0.385s

Figure 2.182. *MASH* Test 3-11 Simulation of Half-Post Small Gap with Fixed Object 24 inch Offset 2 feet Downstream Impact Variation – Overhead View

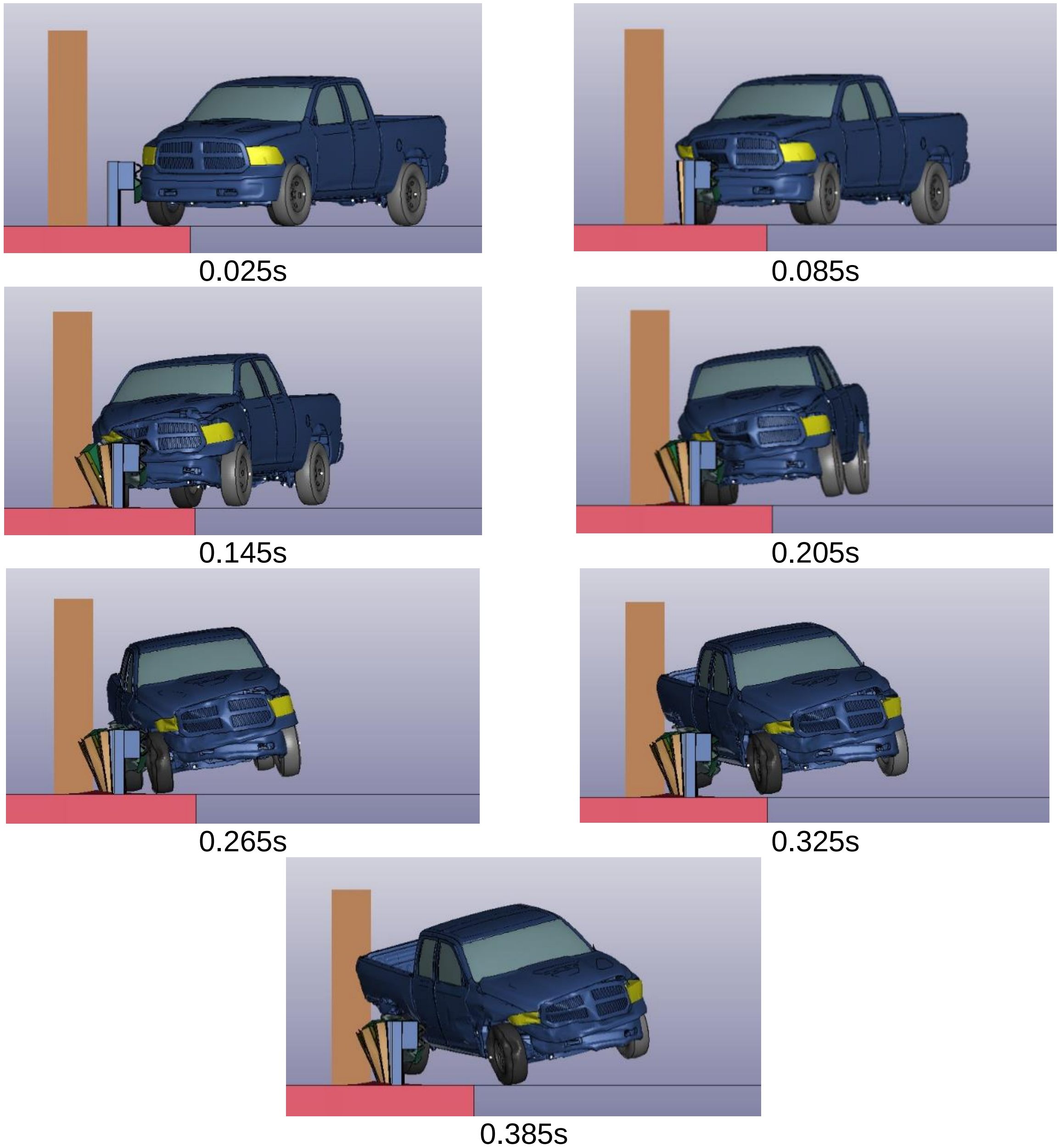


Figure 2.183. *MASH* Test 3-11 Simulation of Half-Post Small Gap with Fixed Object 24 inch Offset 2 feet Downstream Impact Variation – Downstream View

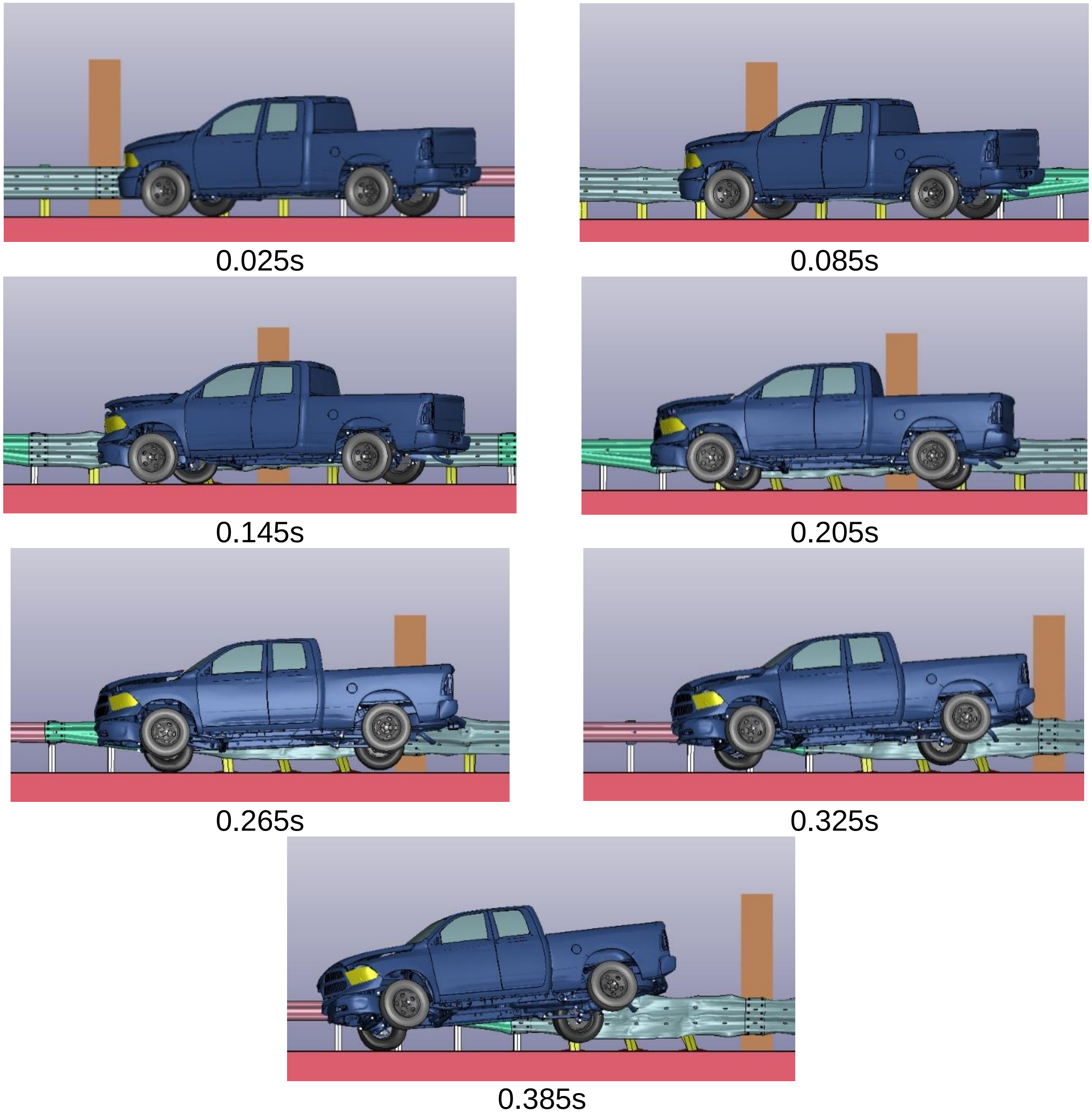


Figure 2.184. *MASH* Test 3-11 Simulation of Half-Post Small Gap with Fixed Object 24 inch Offset 2 feet Downstream Impact Variation – Rear View

2.5.1.14. MASH Test 3-11 Simulation of Half-Post Spacing Small Gap with Fixed Object 24 inch Offset and 4 feet Downstream Impact Variation

Figure 2.185 through Figure 2.187 show the sequential frames of *MASH* test 3-11 with half-post spacing, small gap, a fixed object offset of 24 inches, and an impact variation positioned 4 feet downstream. The occupant impact velocity was calculated to be 6.8 m/s (preferred limit is 9.1 m/s). The ridedown acceleration was calculated to be 14.9 g's (preferred limit is 15.0 g's). This configuration passed *MASH* test 3-11 by successfully containing and redirecting the vehicle.

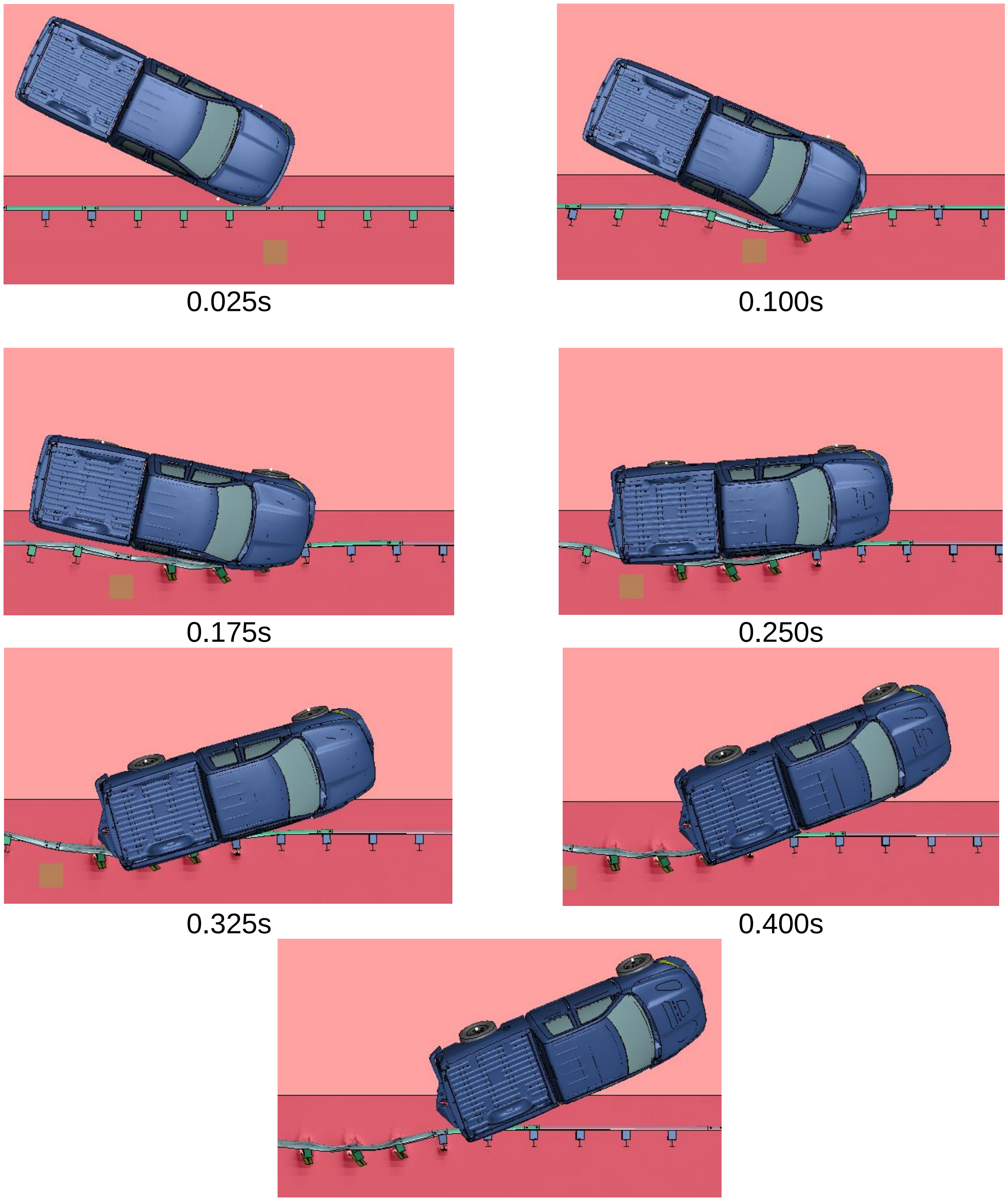


Figure 2.185. *MASH* Test 3-11 Simulation of Half-Post Small Gap with Fixed Object 24 inch Offset 4 feet Downstream Impact Variation – Overhead View

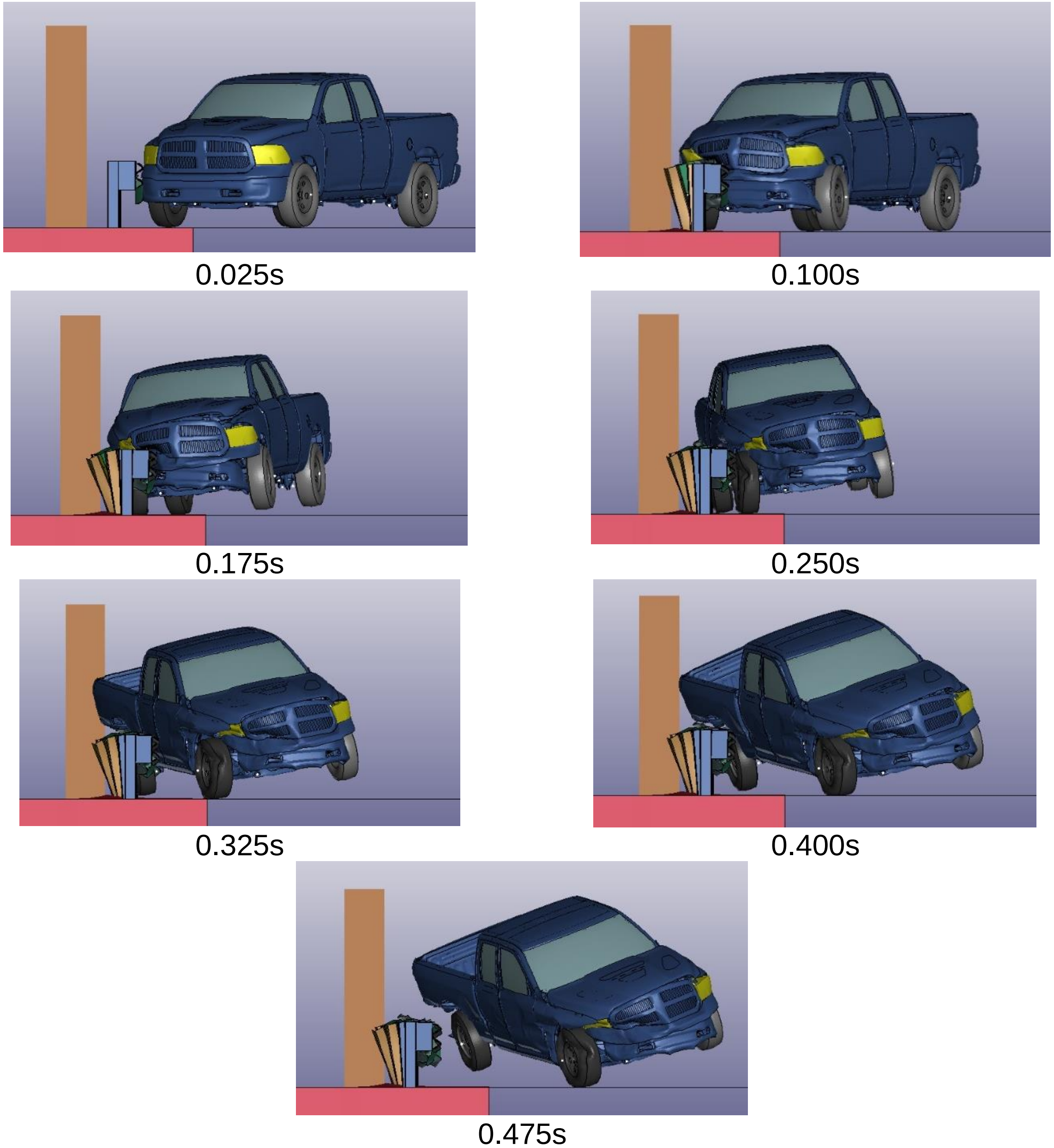


Figure 2.186. *MASH* Test 3-11 Simulation of Half-Post Small Gap with Fixed Object 24 inch Offset 4 feet Downstream Impact Variation – Downstream View

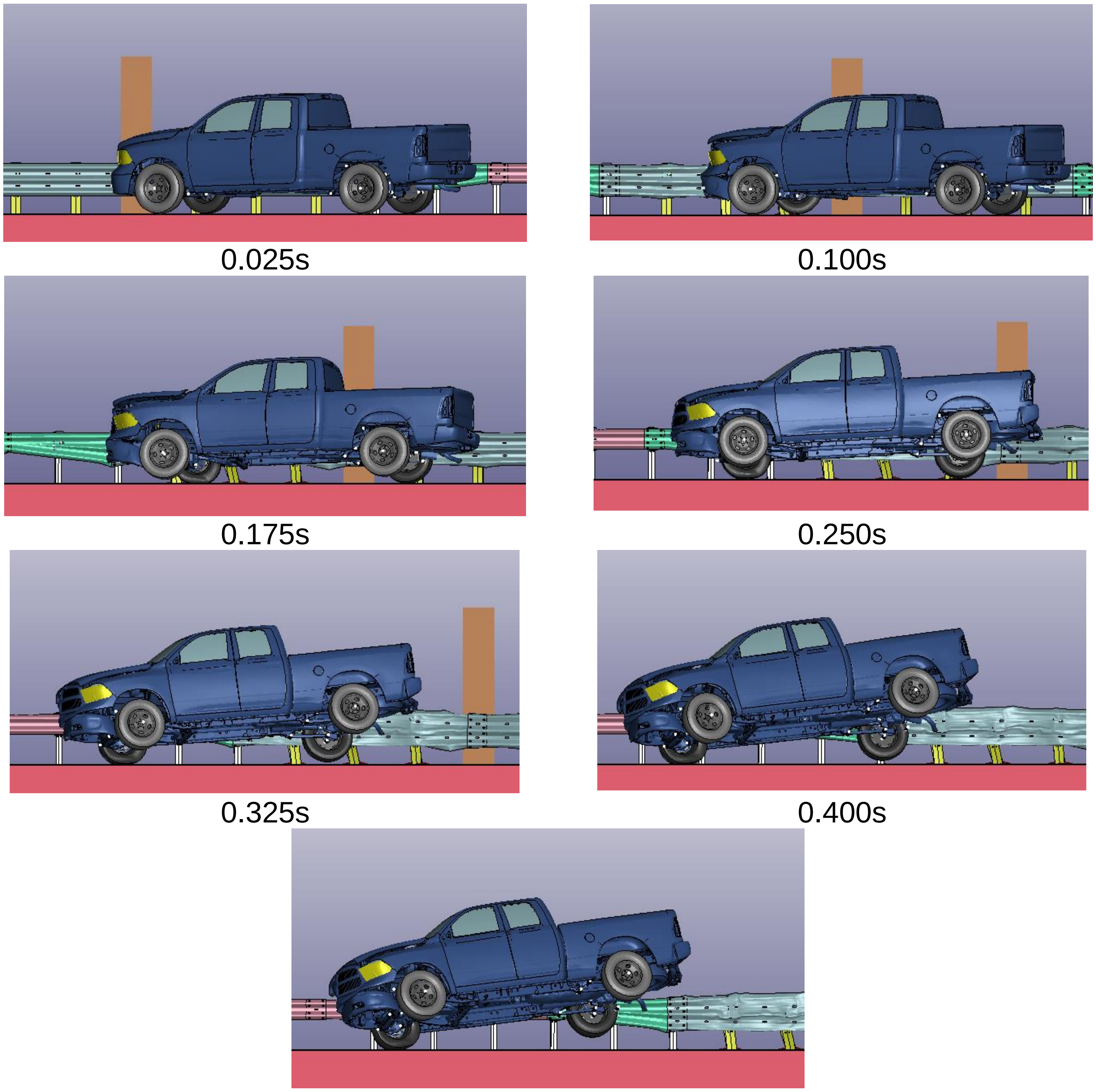
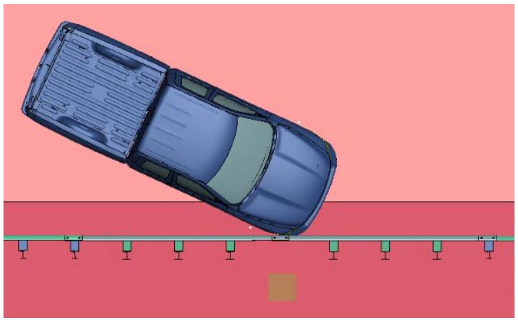


Figure 2.187. *MASH* Test 3-11 Simulation of Half-Post Small Gap with Fixed Object 24 inch Offset 4 feet Downstream Impact Variation – Rear View

2.5.1.15. MASH Test 3-11 Simulation of Half-Post Spacing Small Gap with Fixed Object 24 inch Offset and 6 feet Downstream Impact Variation

Figure 2.188 through Figure 2.190 show the sequential frames of *MASH* test 3-11 with half-post spacing, small gap, a fixed object offset of 24 inches, and an impact variation positioned 6 feet downstream. The occupant impact velocity was calculated to be 6.5 m/s (preferred limit is 9.1 m/s). The ridedown acceleration was calculated to be 9.6 g's (preferred limit is 15.0 g's). This configuration passed *MASH* test 3-11 by successfully containing and redirecting the vehicle.



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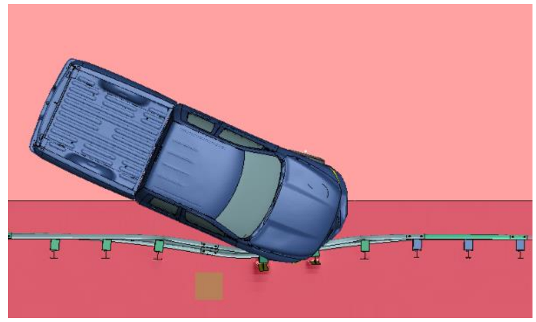

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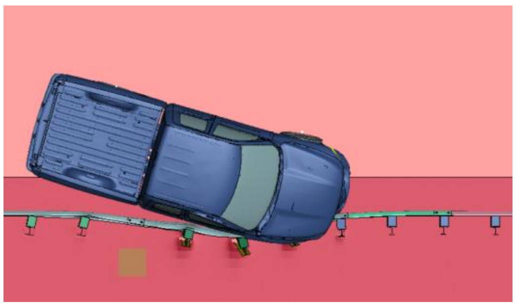
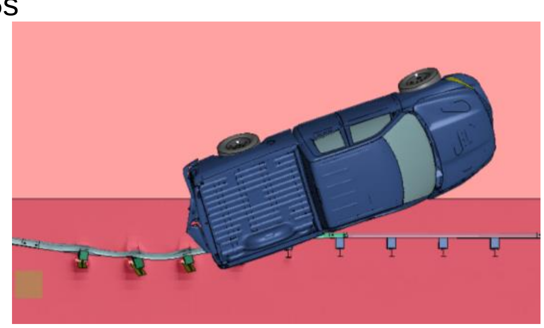


0.145s

0.205s

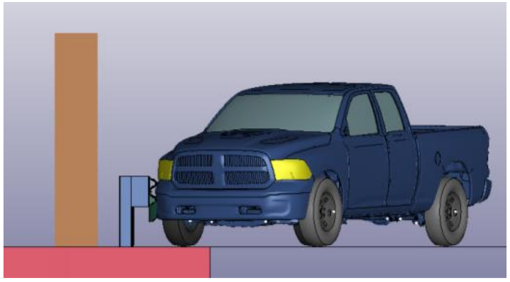
0.265s

0.325s



0.385s

Figure 2.188. *MASH* Test 3-11 Simulation of Half-Post Small Gap with Fixed Object 24 inch Offset 6 feet Downstream Impact Variation – Overhead View



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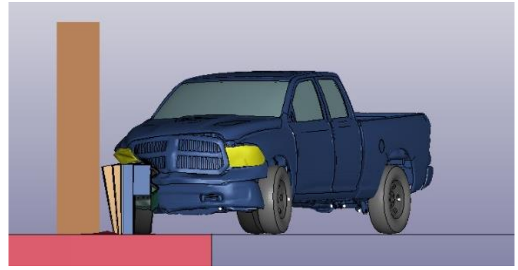

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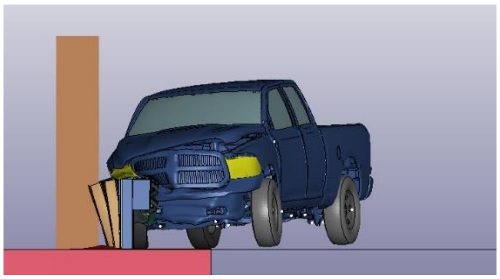

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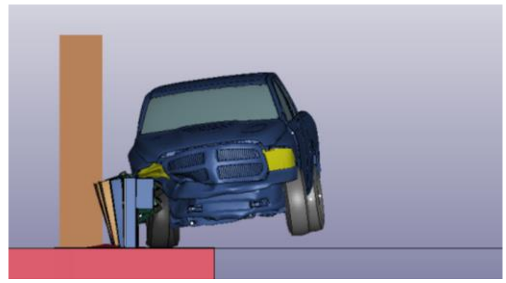

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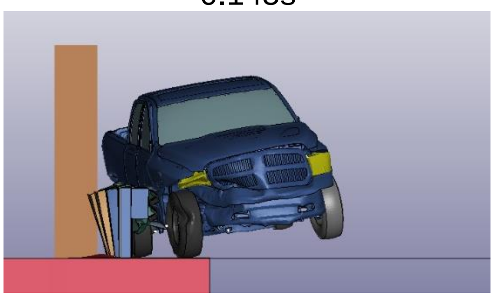

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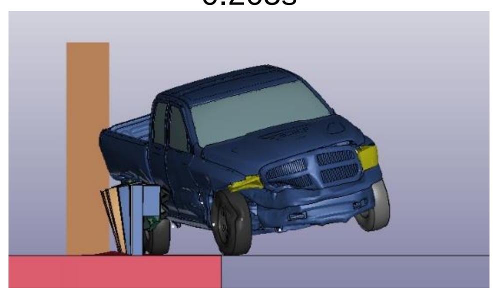

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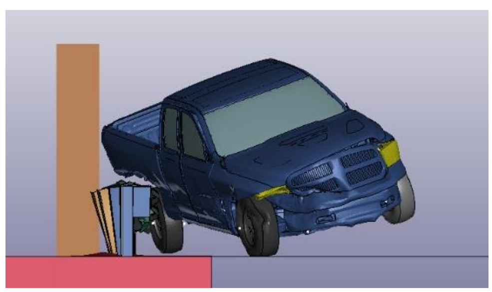


0.385s

Figure 2.189. *MASH* Test 3-11 Simulation of Half-Post Small Gap with Fixed Object 24 inch Offset 6 feet Downstream Impact Variation – Downstream View

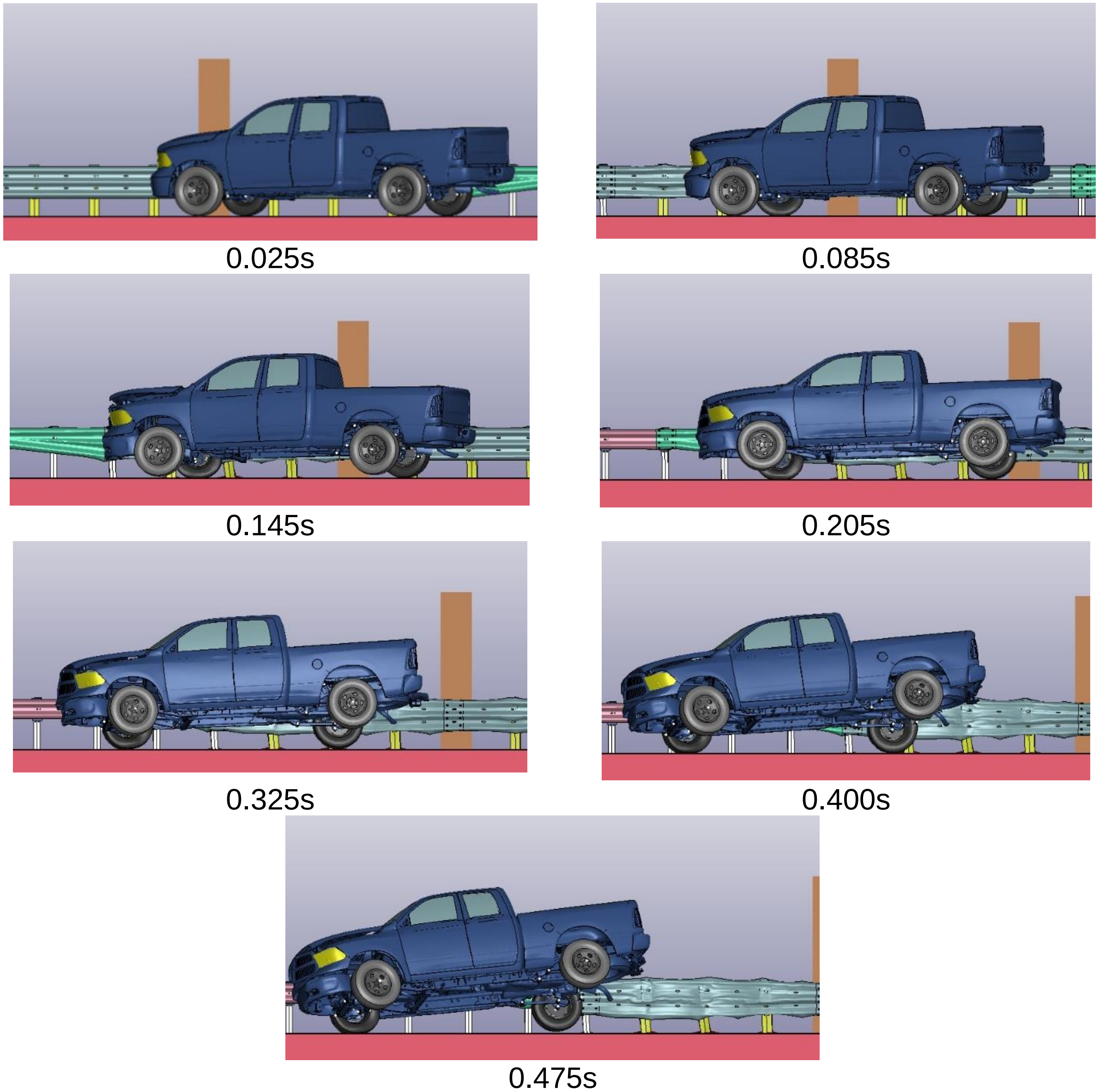


Figure 2.190. *MASH* Test 3-11 Simulation of Half-Post Small Gap with Fixed Object 24 inch Offset 6 feet Downstream Impact Variation – Rear View

2.5.1.16. MASH Test 3-10 Simulation of Half-Post Spacing Small Gap with Fixed Object 24 inch Offset

Figure 2.191 through Figure 2.193 show the sequential frames of MASH test 3-10 with half-post spacing, small gap, and a fixed object offset of 24 inches. The OIV was calculated to be 7.2 m/s (preferred limit is 9.1 m/s). The RDA was calculated to be 18.4 g's (maximum limit is 20.49 g's). This configuration passed *MASH* test 3-10 by successfully containing and redirecting the vehicle.

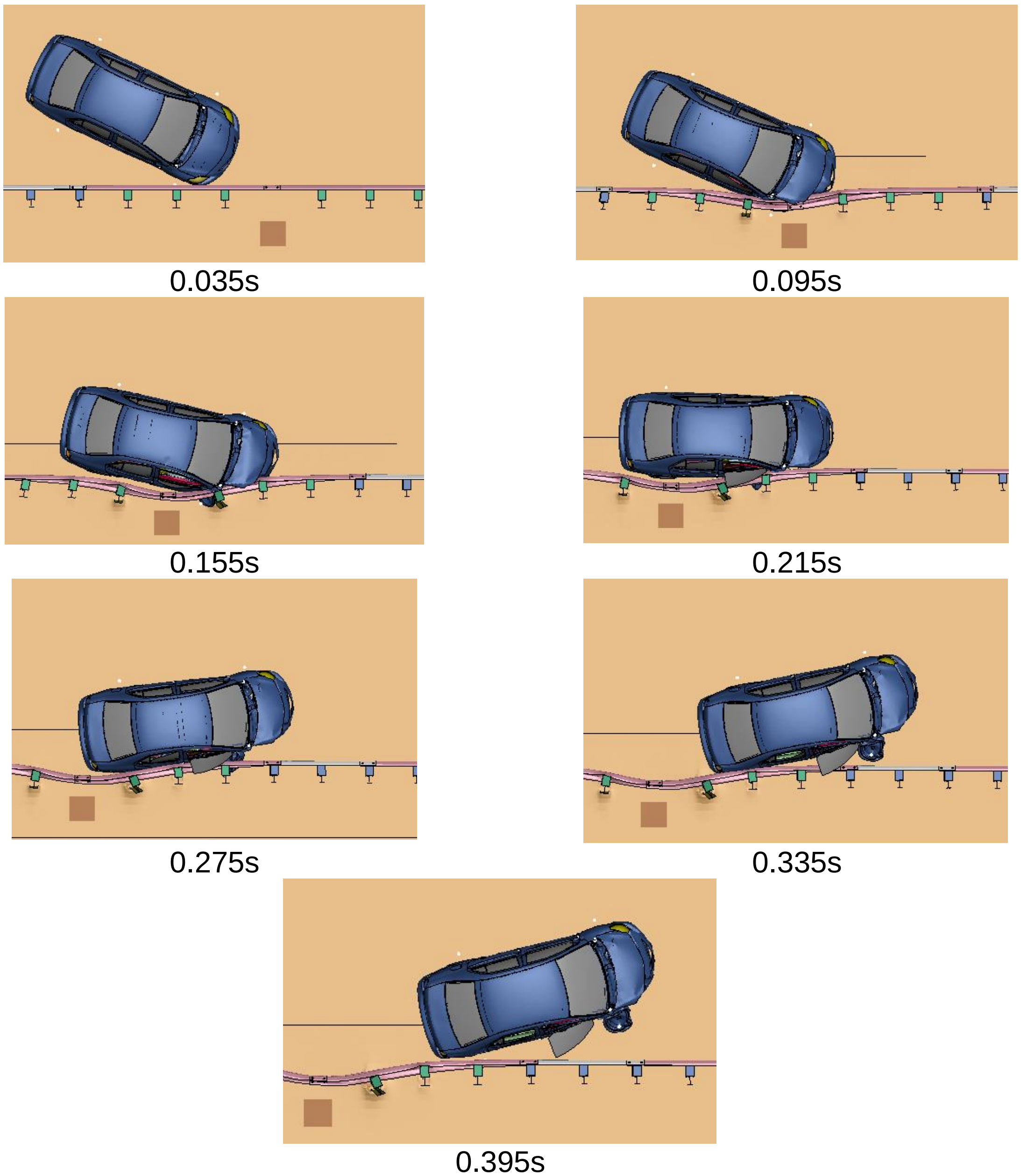
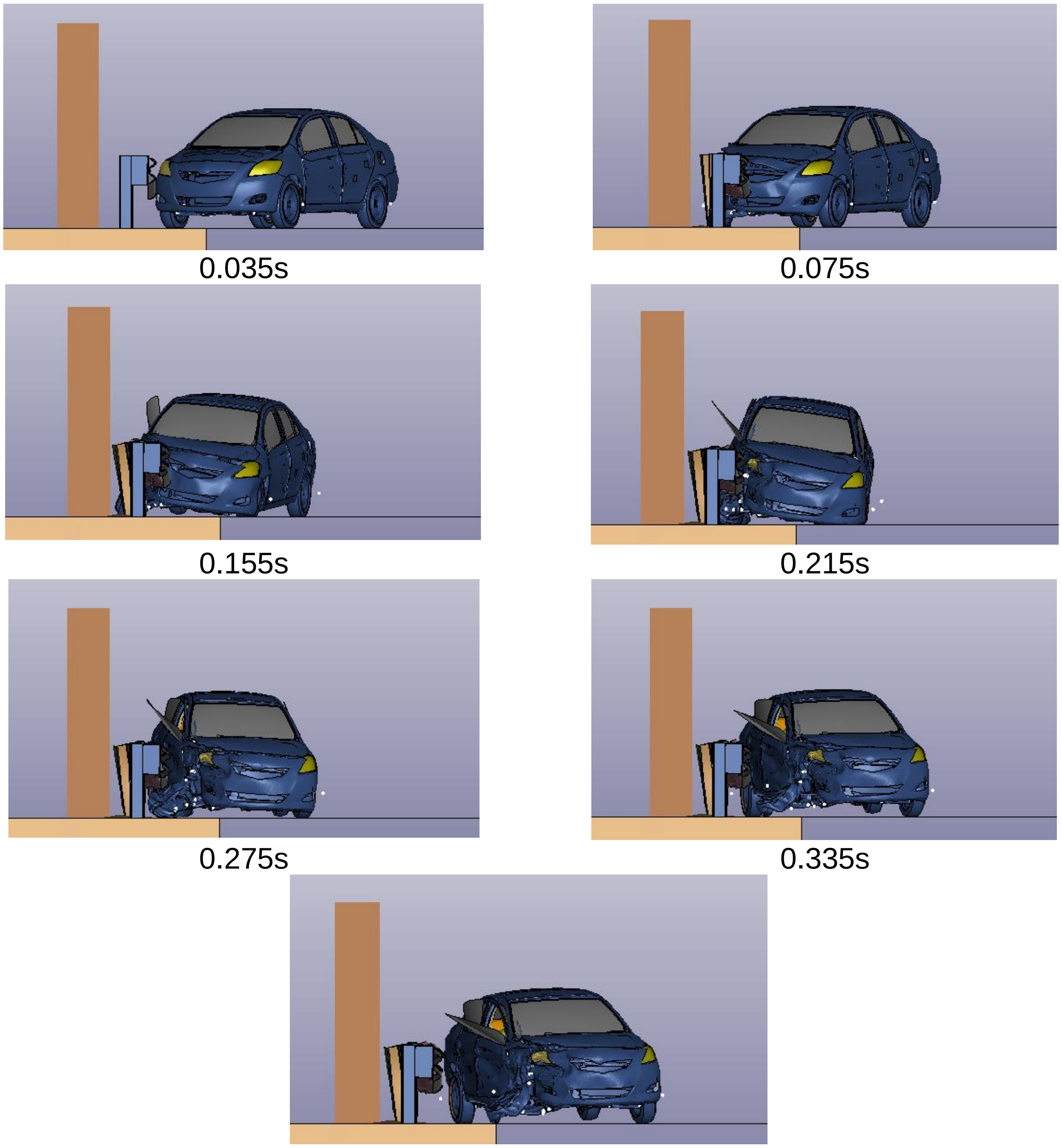


Figure 2.191. *MASH* Test 3-10 Simulation of Half-Post Small Gap with Fixed Object 24 inch Offset – Overhead View



0.035s 0.075s

0.155s 0.215s

0.275s 0.335s

0.395s

Figure 2.192. ***MASH*** **Test 3-10 Simulation of Half-Post Small Gap with Fixed Object 24 inch Offset – Downstream View**

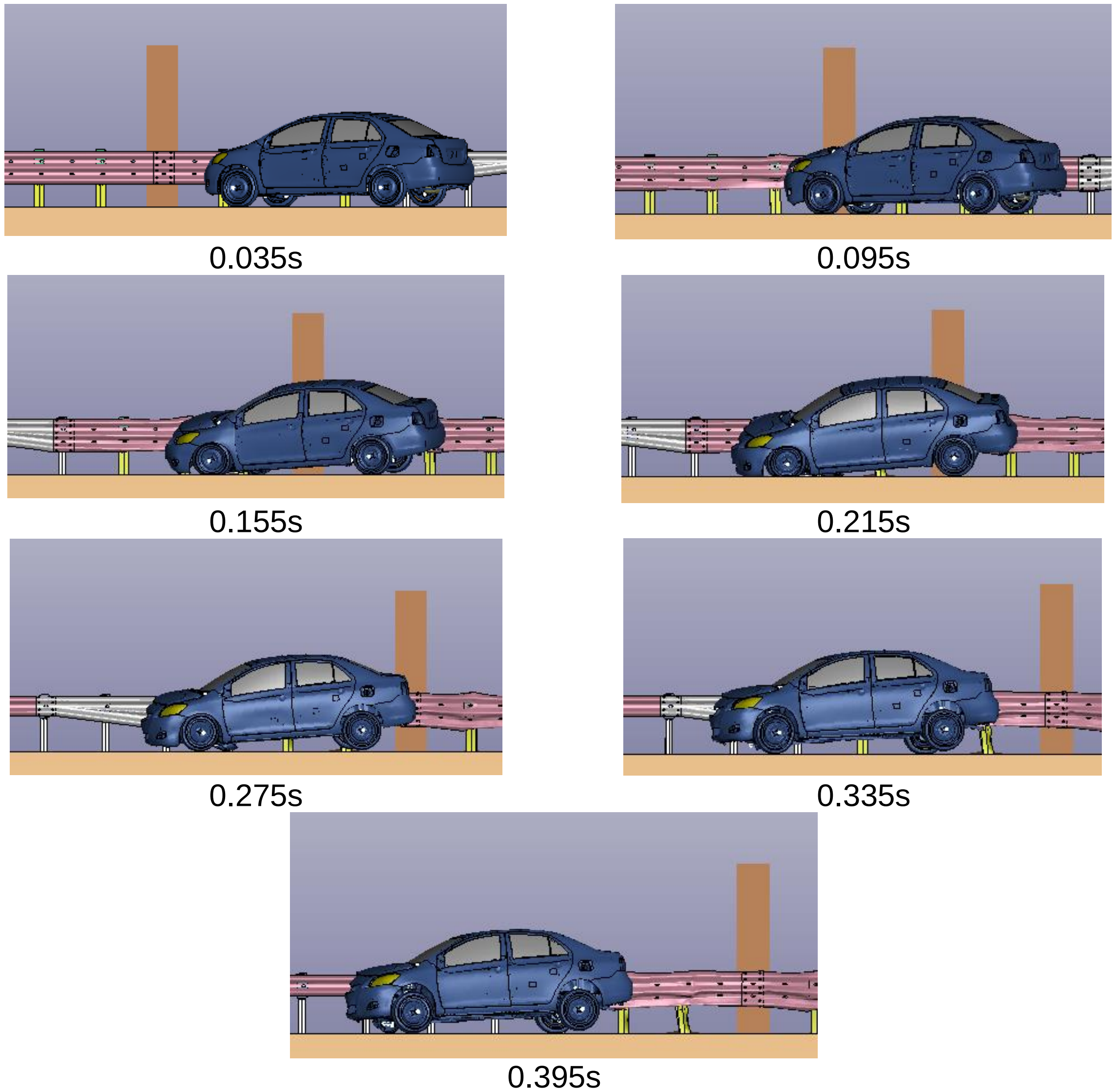


Figure 2.193. *MASH* Test 3-10 Simulation of Half-Post Small Gap with Fixed Object 24 inch Offset – Rear View

2.5.1.17. MASH Test 3-10 Simulation of Half-Post Spacing Small Gap with Fixed Object 24 inch Offset and 2 feet Upstream Impact Variation

Figure 2.194 through Figure 2.196 show the sequential frames of MASH test 3-10 with half-post spacing, small gap, a fixed object offset of 24 inches, and an impact variation positioned 2 feet upstream. The OIV was calculated to be 7.1 m/s (preferred limit is 9.1 m/s). The RDA was calculated to be 11.9 g’s (maximum limit is 20.49 g’s). This configuration passed *MASH* test 3-10 by successfully containing and redirecting the vehicle.

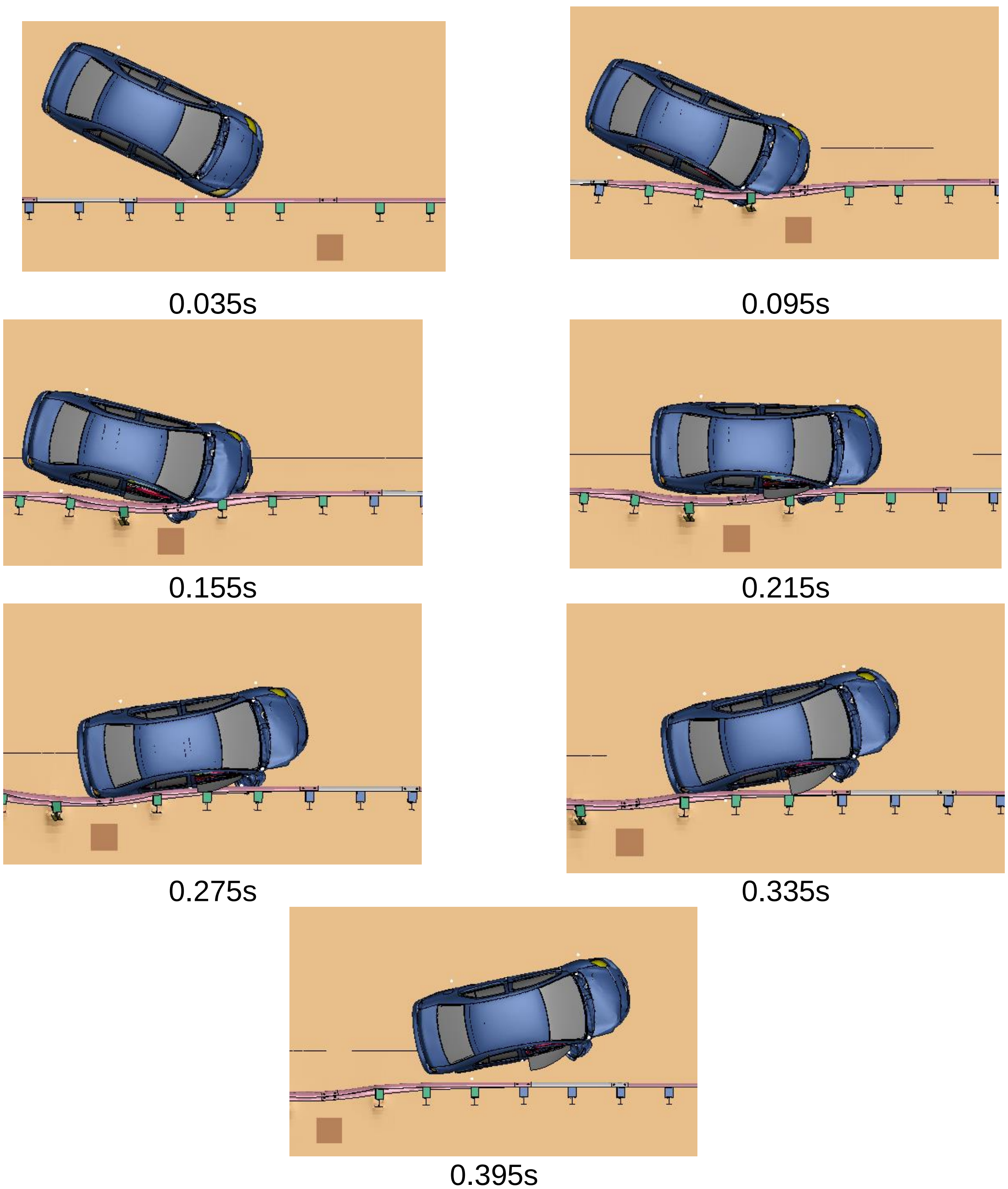


Figure 2.194. *MASH* Test 3-10 Simulation of Half-Post Small Gap with Fixed Object 24 inch Offset 2 feet Upstream Impact Variation – Overhead View

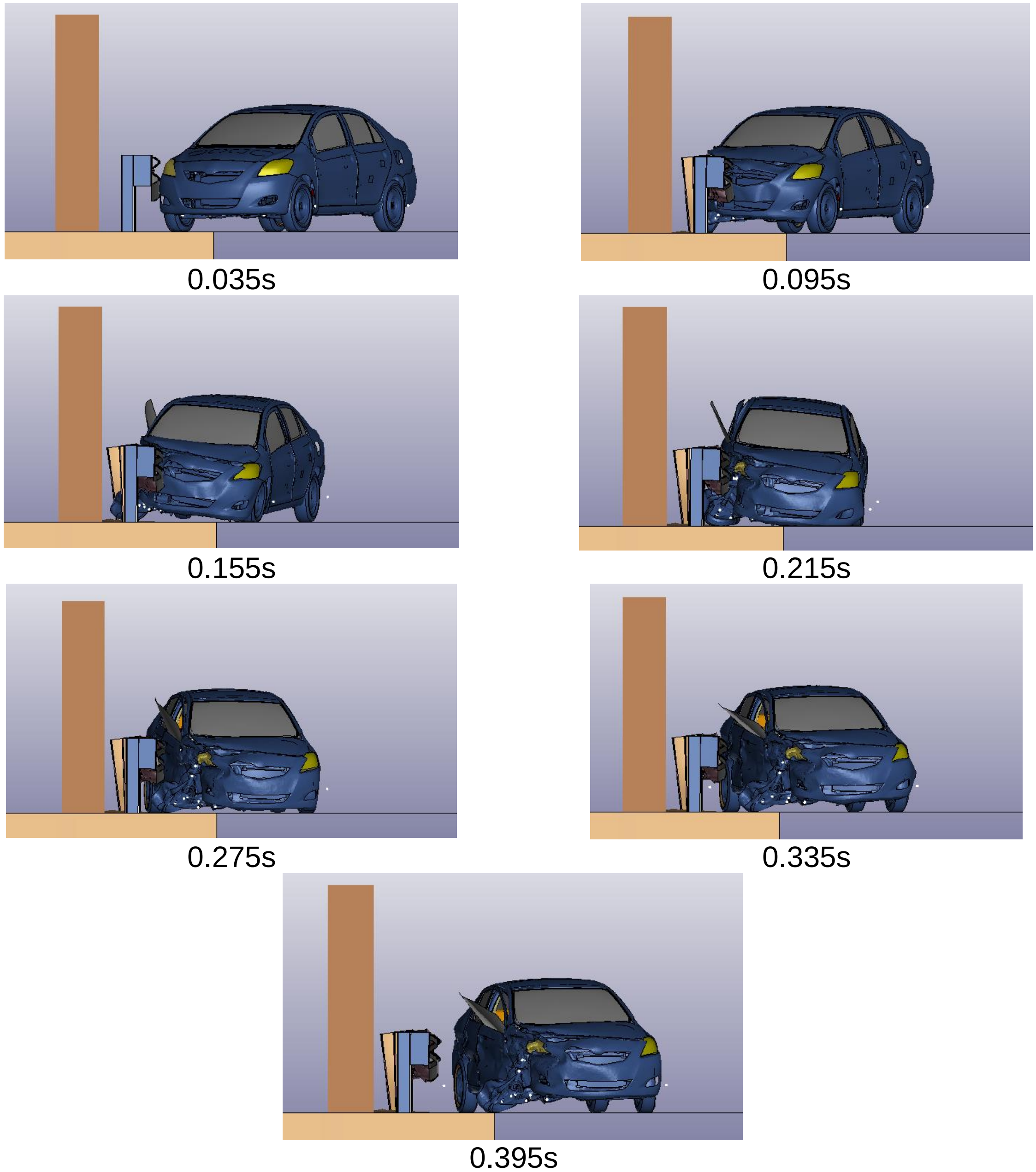


Figure 2.195. *MASH* Test 3-10 Simulation of Half-Post Small Gap with Fixed Object 24 inch Offset 2 feet Upstream Impact Variation– Downstream View

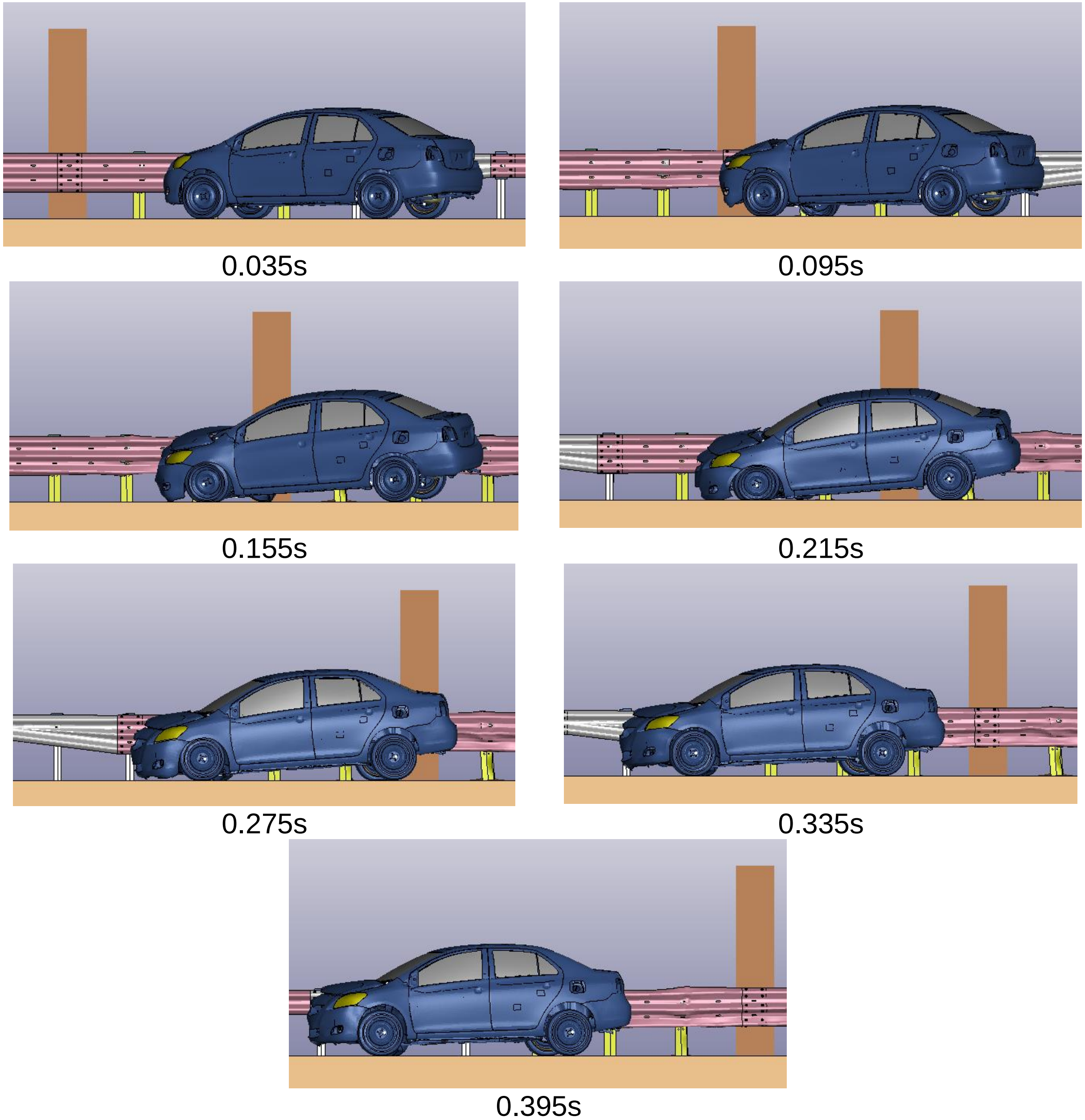
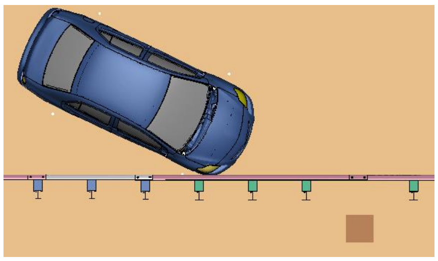


Figure 2.196. *MASH* Test 3-10 Simulation of Half-Post Small Gap with Fixed Object 24 inch Offset 2 feet Upstream Impact Variation– Rear View

2.5.1.18. MASH Test 3-10 Simulation of Half-Post Spacing Small Gap with Fixed Object 24 inch Offset and 4 feet Upstream Impact Variation

Figure 2.197 through Figure 2.199 show the sequential frames of MASH test 3-10 with half-post spacing, small gap, a fixed object offset of 24 inches, and an impact variation positioned 4 feet upstream. The OIV was calculated to be 7.7 m/s (preferred limit is 9.1 m/s). The RDA was calculated to be 11.7 g’s (maximum limit is 20.49 g’s). This configuration passed *MASH* test 3-10 by successfully containing and redirecting the vehicle.



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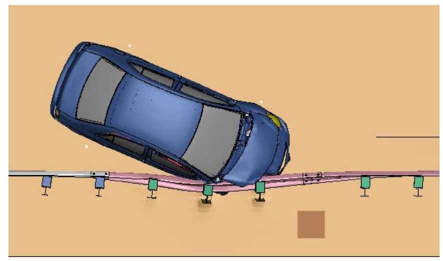

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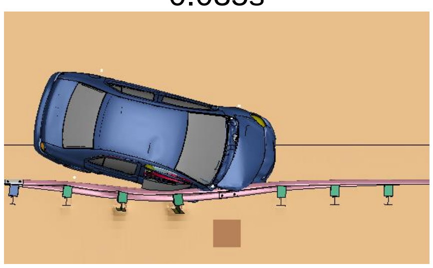

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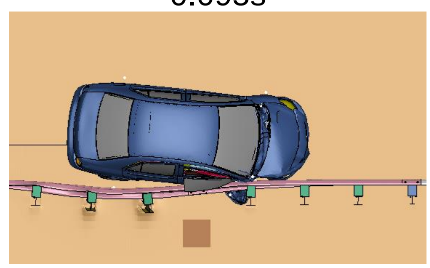

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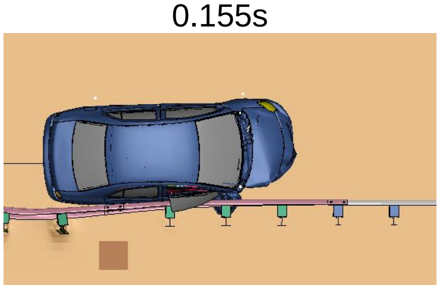

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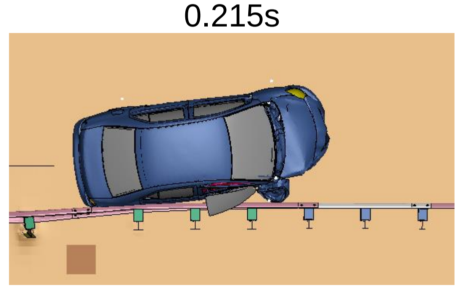

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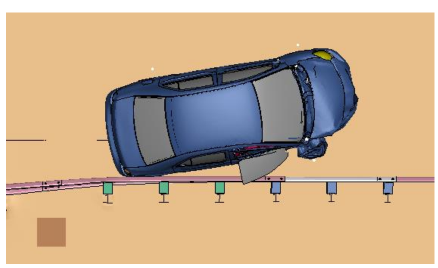

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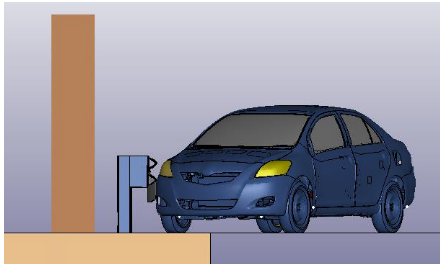
Figure 2.197. *MASH* Test 3-10 Simulation of Half-Post Small Gap with Fixed Object 24 inch Offset 4 feet Upstream Impact Variation – Overhead View



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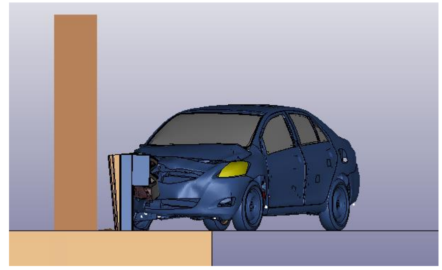

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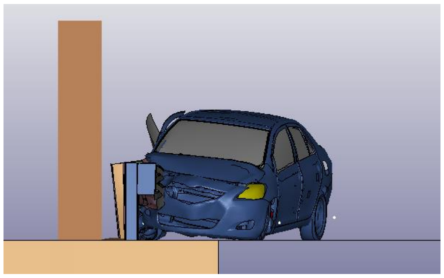

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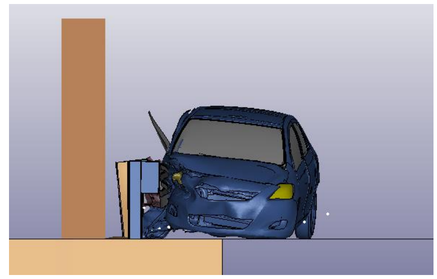

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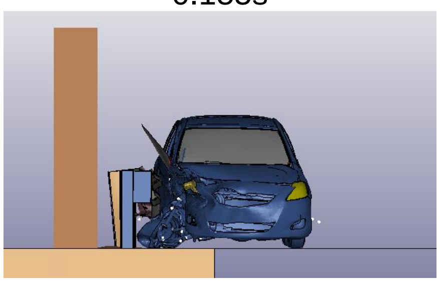

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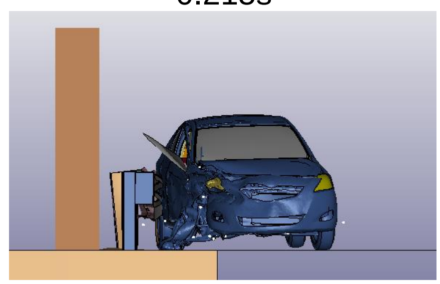

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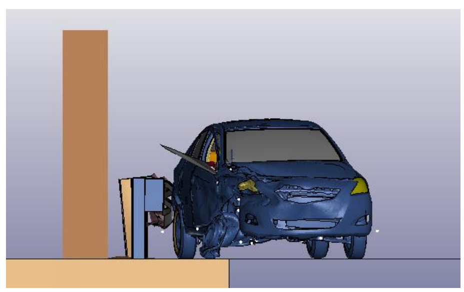


0.395s

Figure 2.198. *MASH* Test 3-10 Simulation of Half-Post Small Gap with Fixed Object 24 inch Offset 4 feet Upstream Impact Variation – Downstream View

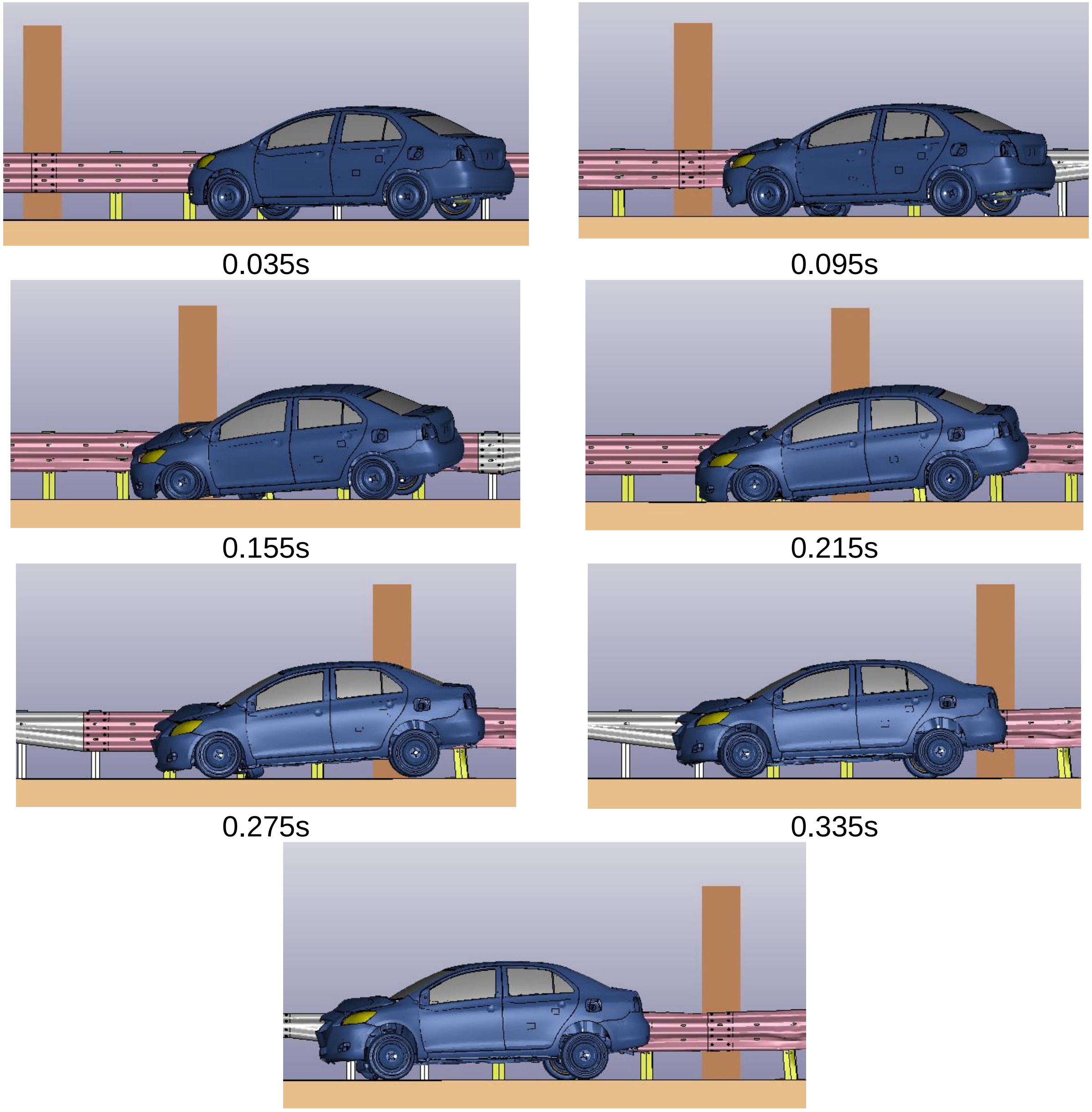


Figure 2.199. *MASH* Test 3-10 Simulation of Half-Post Small Gap with Fixed Object 24 inch Offset 4 feet Upstream Impact Variation– Rear View

2.5.1.19. MASH Test 3-10 Simulation of Half-Post Spacing Small Gap with Fixed Object 24 inch Offset and 6 feet Upstream Impact Variation

Figure 2.200 through Figure 2.202 show the sequential frames of *MASH* test 3-10 with half-post spacing, small gap, a fixed object offset of 24 inches, and an impact variation positioned 6 feet upstream. The OIV was calculated to be 8.0 m/s (preferred limit is 9.1 m/s). The RDA was calculated to be 14.1 g's (preferred limit is 15.0 g's). This configuration passed *MASH* test 3-10 by successfully containing and redirecting the vehicle.

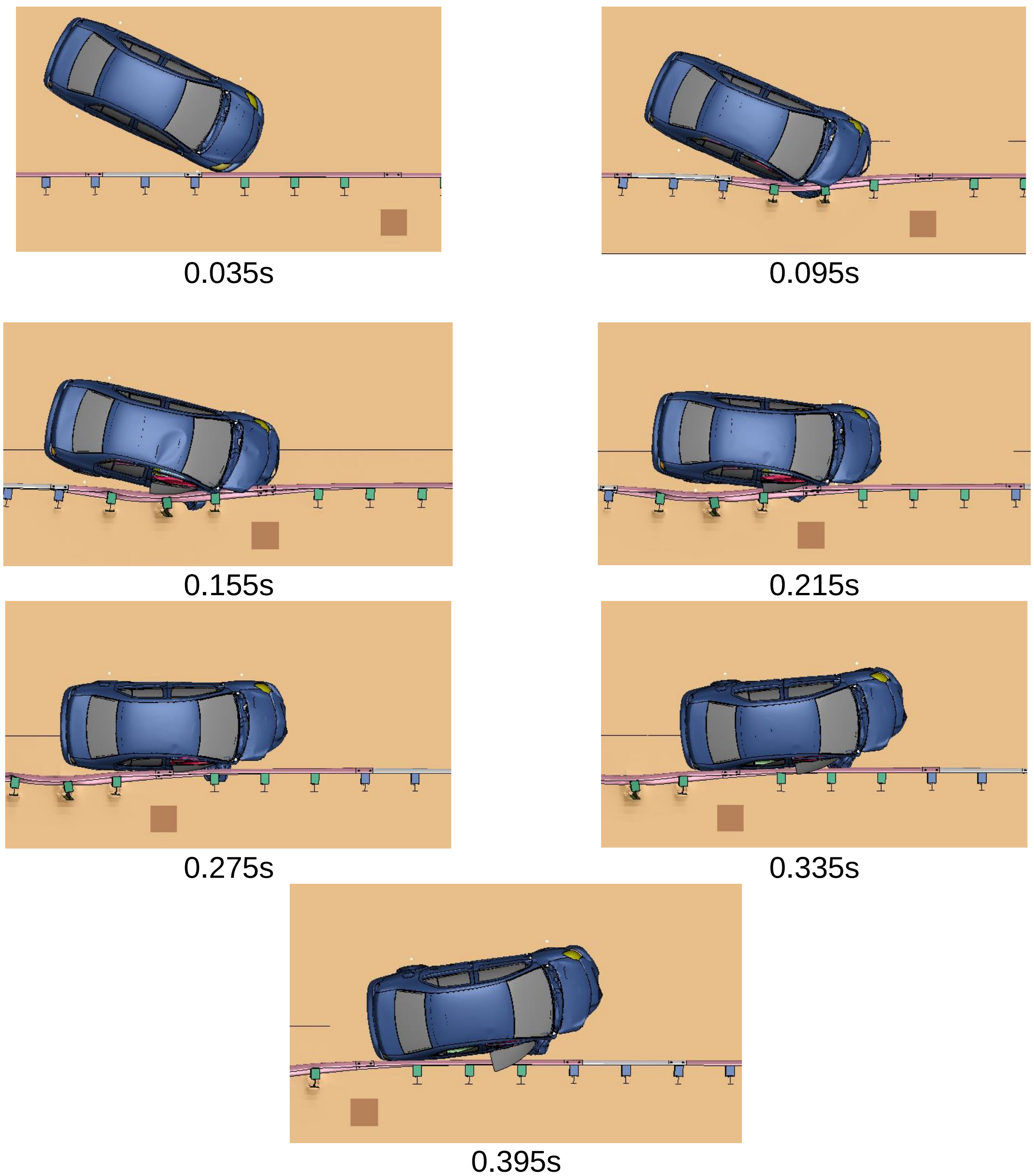


Figure 2.200. *MASH* Test 3-10 Simulation of Half-Post Small Gap with Fixed Object 24 inch Offset 6 feet Upstream Impact Variation – Overhead View

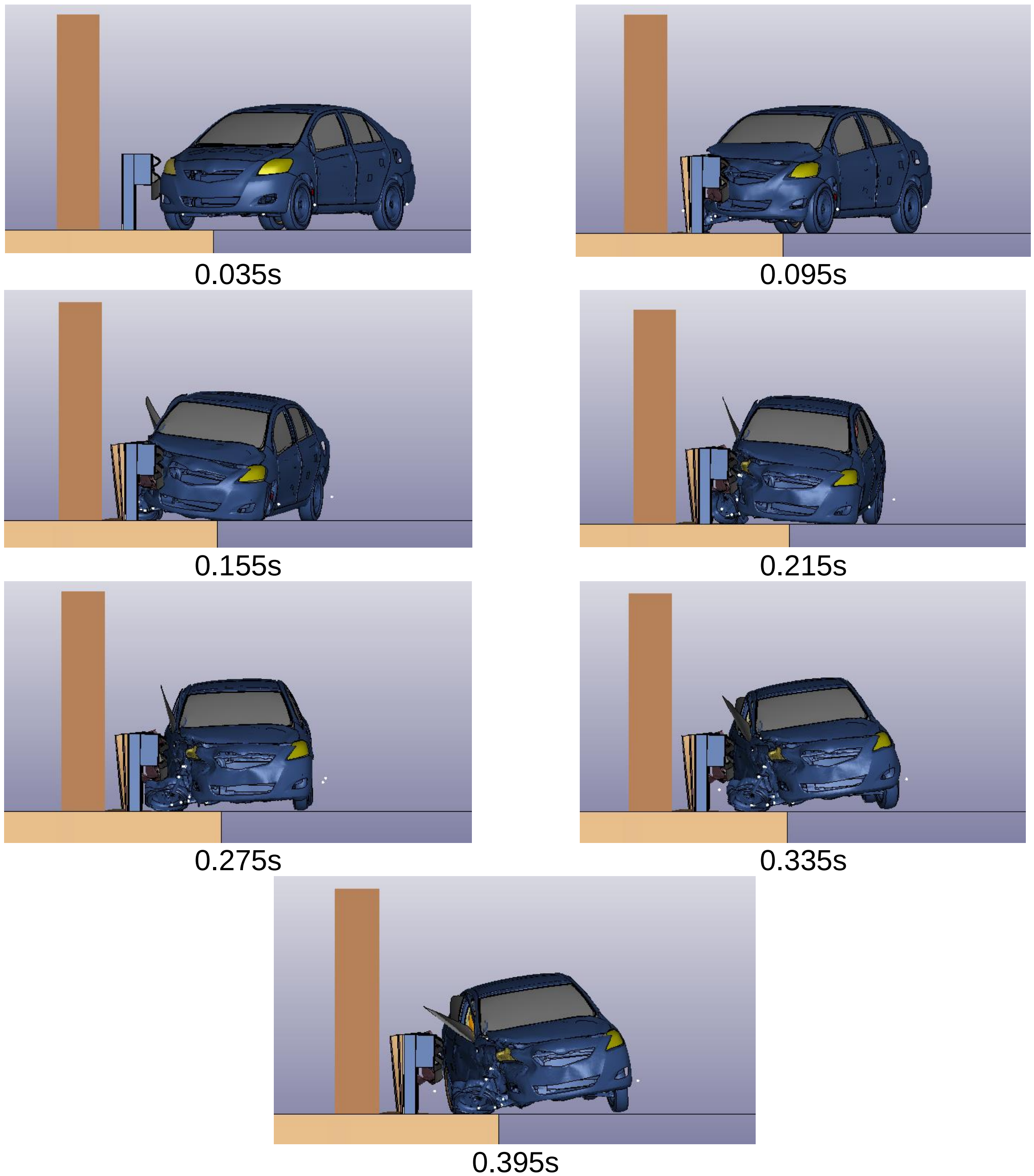


Figure 2.201. *MASH* Test 3-10 Simulation of Half-Post Small Gap with Fixed Object 24 inch Offset 6 feet Upstream Impact Variation – Downstream View

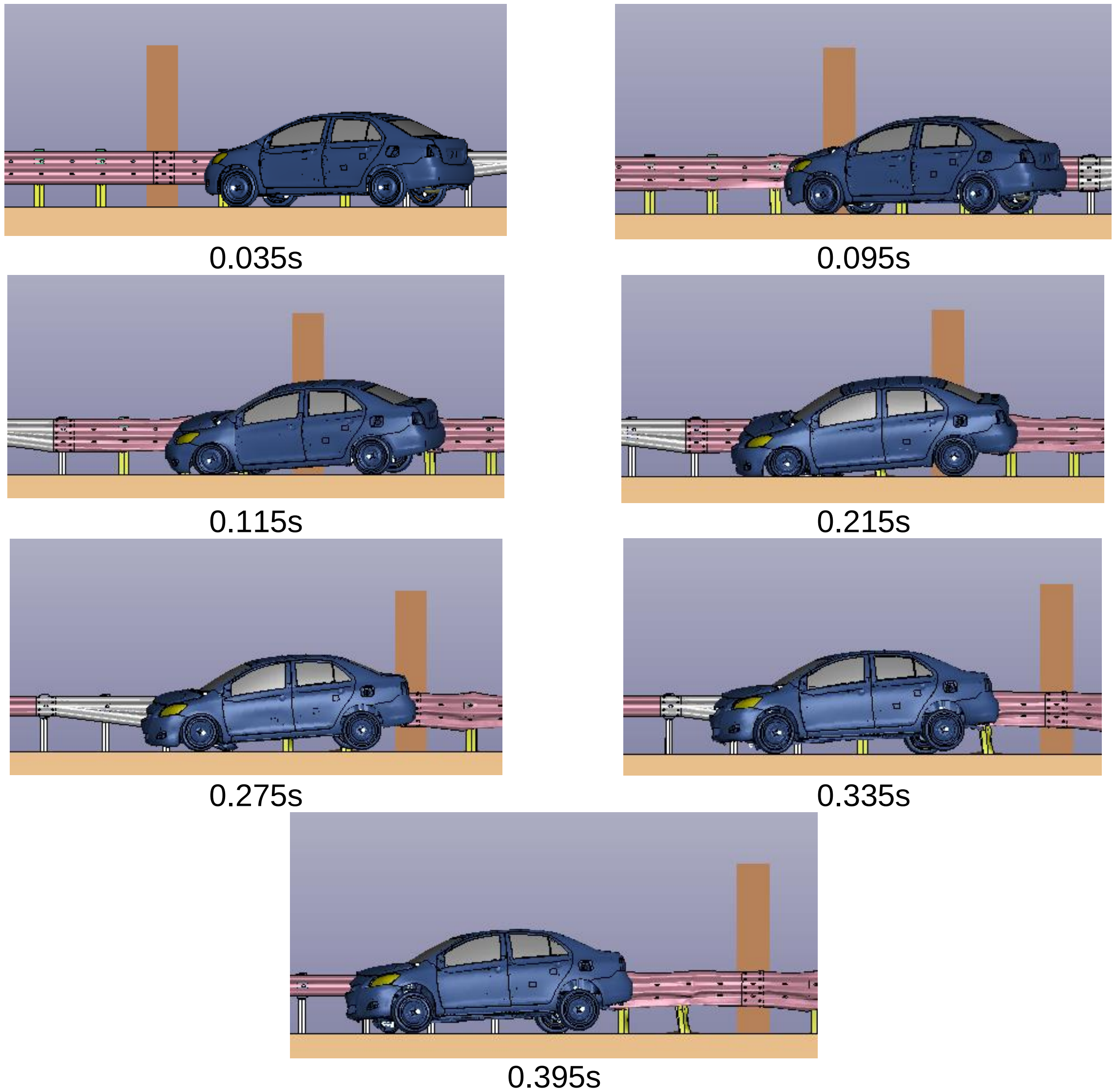


Figure 2.202. *MASH* Test 3-10 Simulation of Half-Post Small Gap with Fixed Object 24 inch Offset 6 feet Upstream Impact Variation – Rear View

2.5.1.20. MASH Test 3-10 Simulation of Half-Post Spacing Small Gap with Fixed Object 24” Offset and 2’ Downstream Impact Variation

Figure 2.203 through Figure 2.205 show the sequential frames of MASH test 3-10 with half-post spacing, small gap, a fixed object offset of 24 inches, and an impact variation positioned 2 feet downstream. The OIV was calculated to be 8.6 m/s (preferred limit is 9.1 m/s). The RDA was calculated to be 15.9 g’s (maximum limit is 20.49 g’s). This configuration passed *MASH* test 3-10 by successfully containing and redirecting the vehicle.

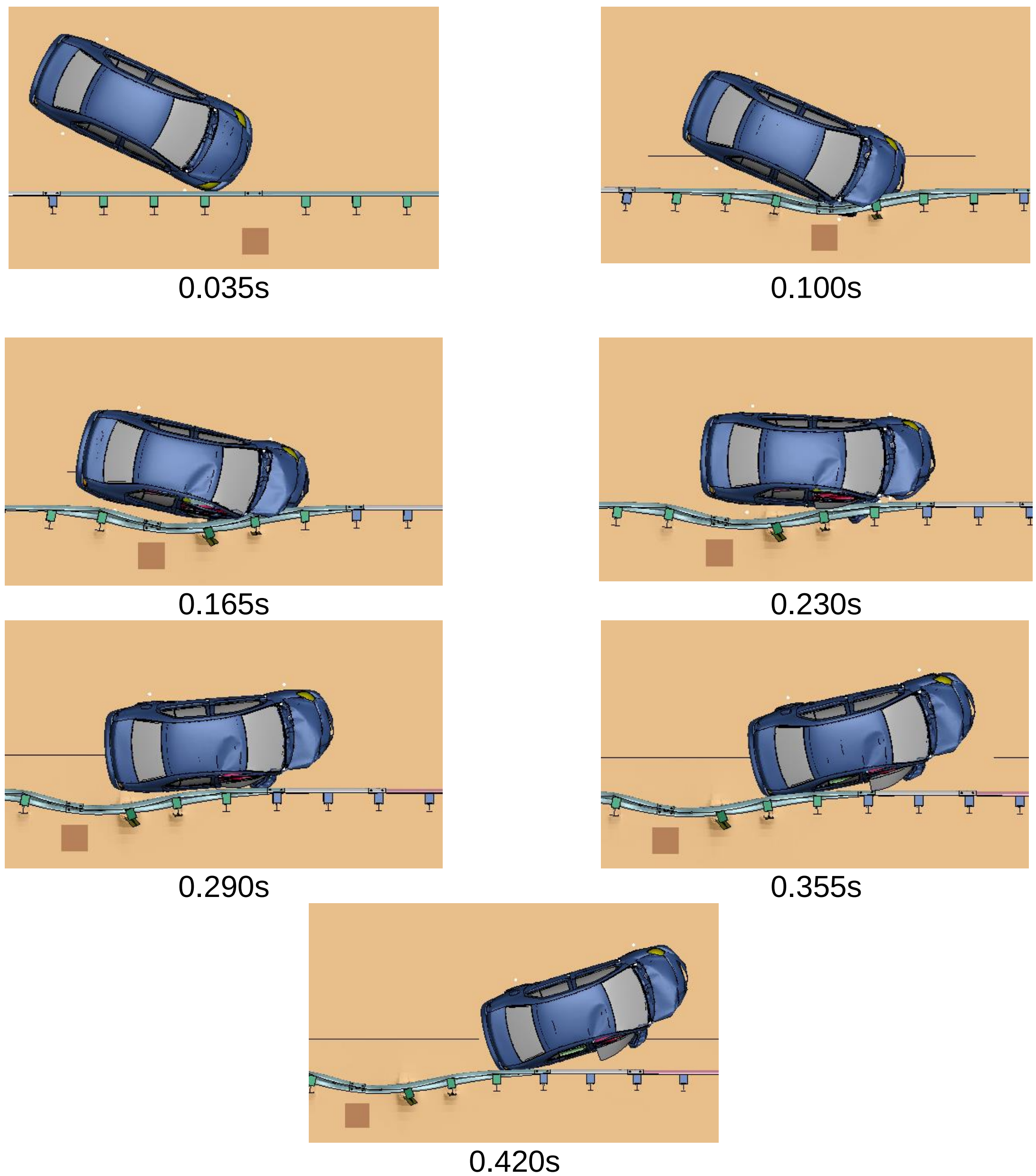


Figure 2.203. *MASH* Test 3-10 Simulation of Half-Post Small Gap with Fixed Object 24 inch Offset 2 feet Downstream Impact Variation– Overhead View

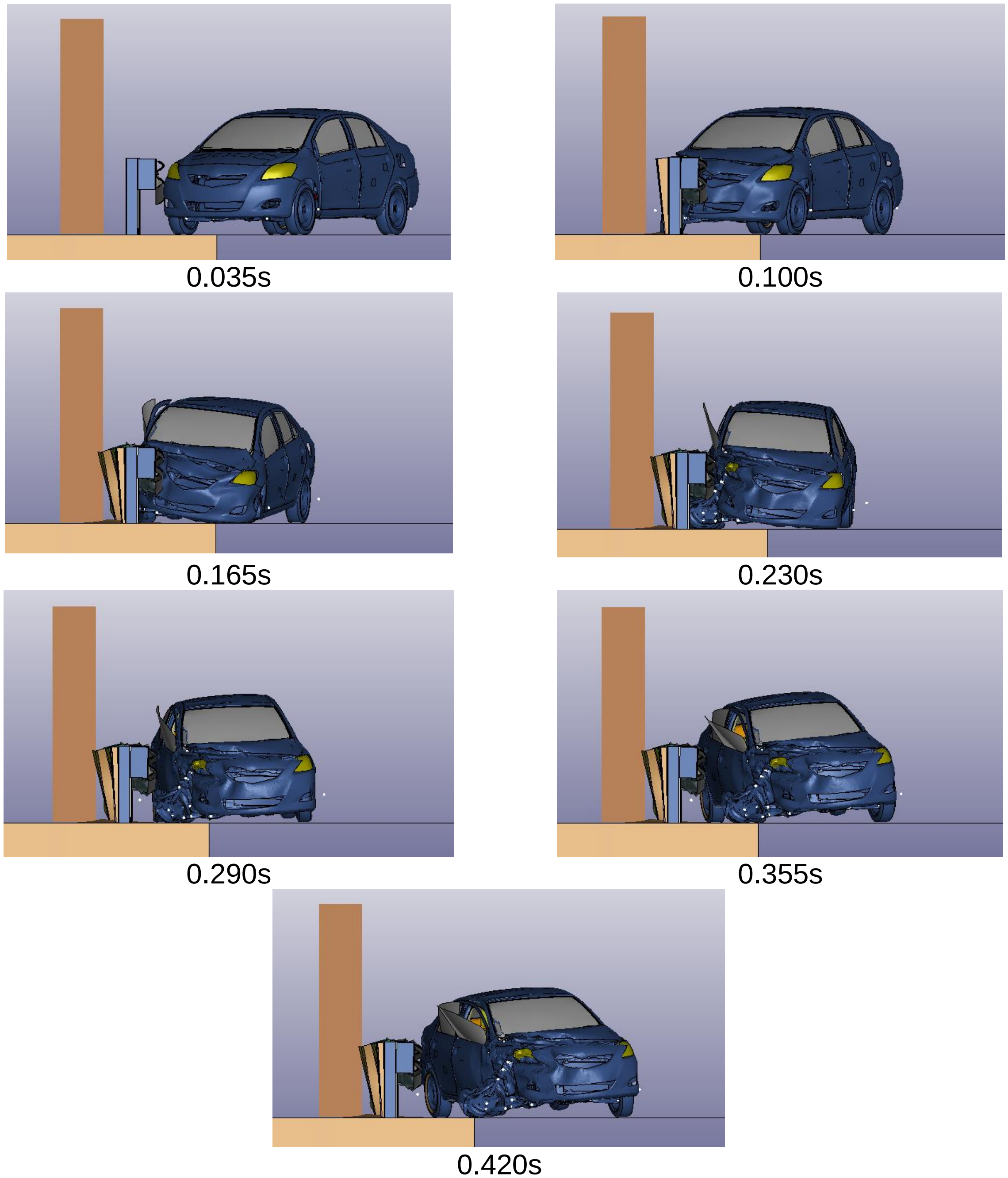


Figure 2.204. *MASH* Test 3-10 Simulation of Half-Post Small Gap with Fixed Object 24 inch Offset 2 feet Downstream Impact Variation – Downstream View

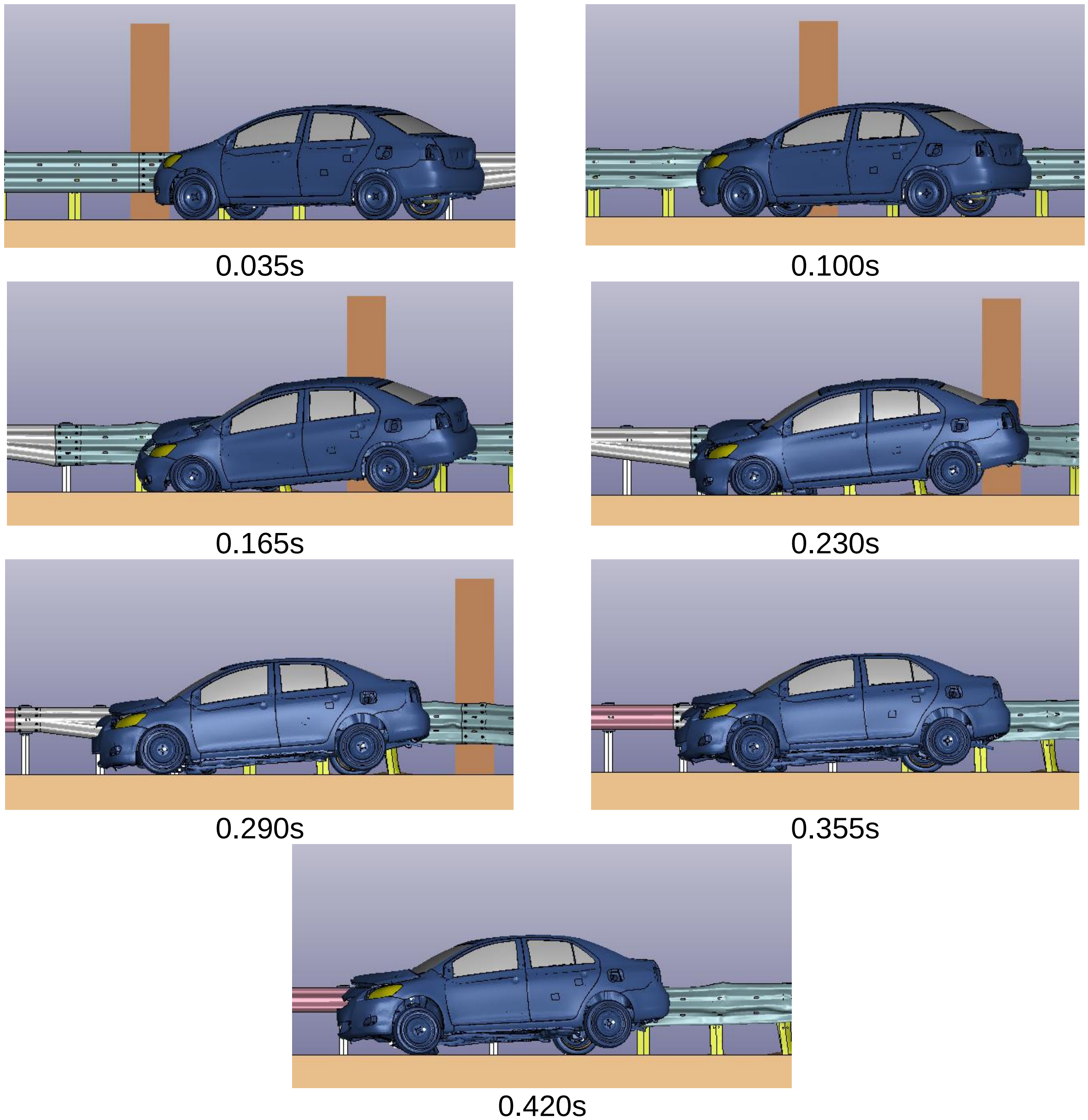


Figure 2.205. *MASH* Test 3-10 Simulation of Half-Post Small Gap with Fixed Object 24 inch Offset 2 feet Downstream Impact Variation – Rear View

2.5.1.21. MASH Test 3-10 Simulation of Half-Post Spacing Small Gap with Fixed Object 24 inch Offset and 4 feet Downstream Impact Variation

Figure 2.206 through Figure 2.208 show the sequential frames of MASH test 3-10 with half-post spacing, small gap, a fixed object offset of 24 inches, and an impact variation positioned 4 feet downstream. The OIV was calculated to be 9.0 m/s (preferred limit is 9.1 m/s). The RDA was calculated to be 14.5 g's (preferred limit is 15.0 g's). This configuration passed *MASH* test 3-10 by successfully containing and redirecting the vehicle.

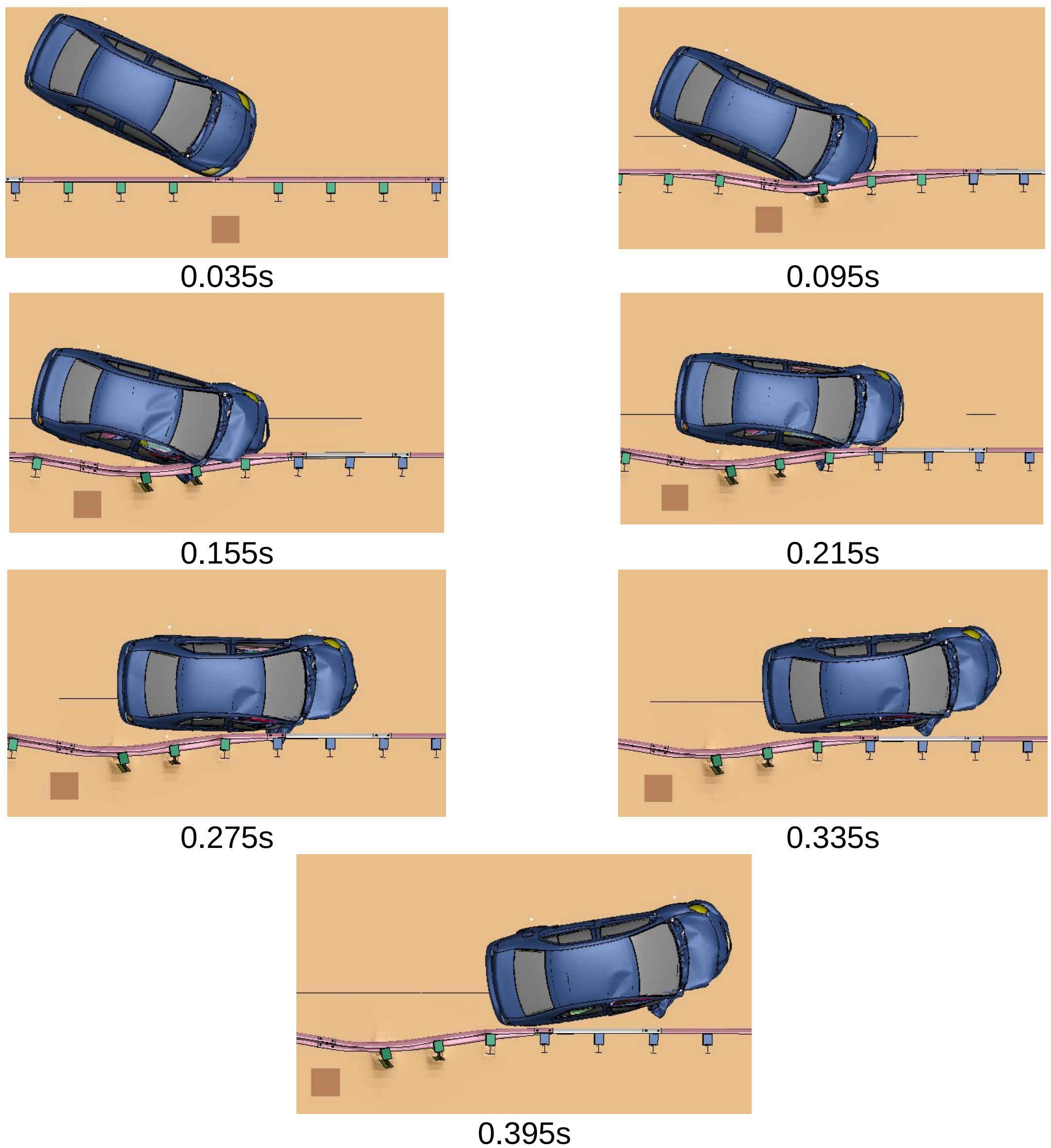
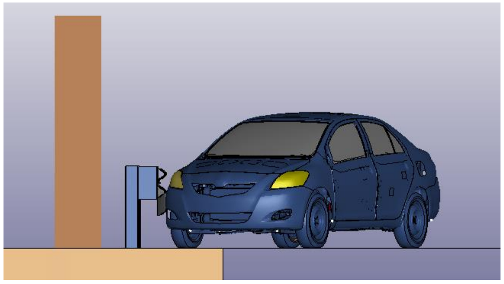


Figure 2.206. *MASH* Test 3-10 Simulation of Half-Post Small Gap with Fixed Object 24 inch Offset 4 feet Downstream Impact Variation – Overhead View



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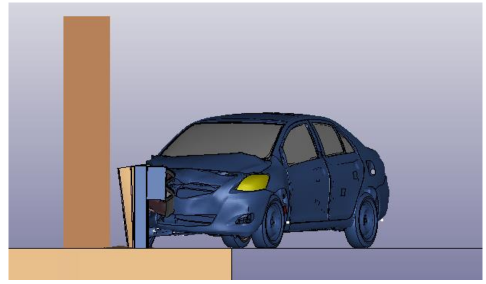

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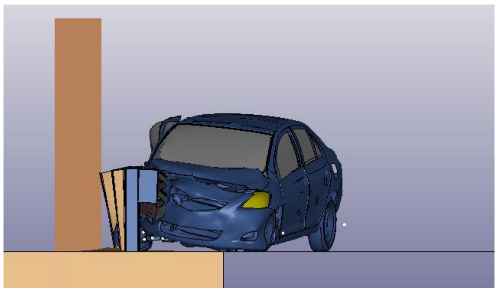

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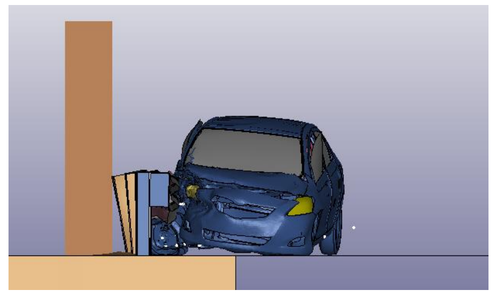

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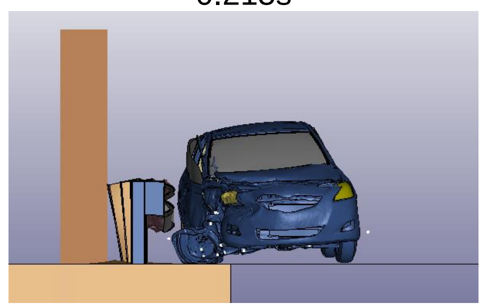

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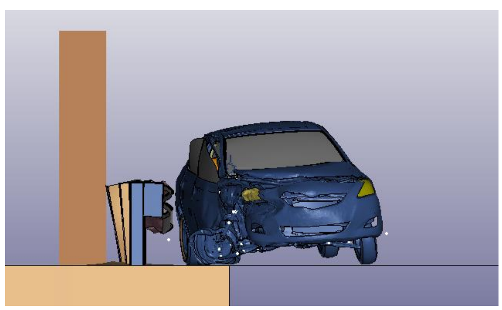
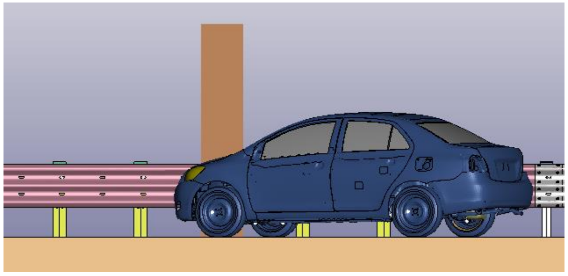
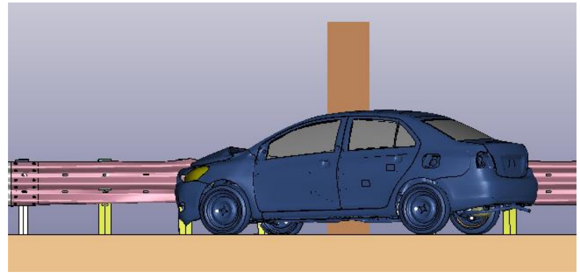


0.395s

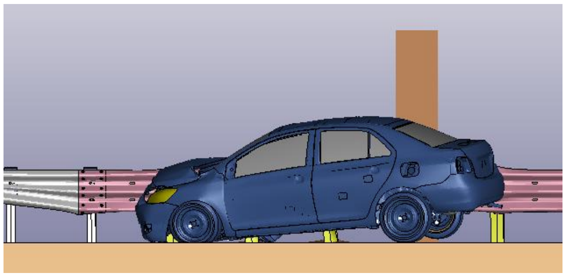
Figure 2.207. *MASH* Test 3-10 Simulation of Half-Post Small Gap with Fixed Object 24 inch Offset 4 feet Downstream Impact Variation – Downstream View



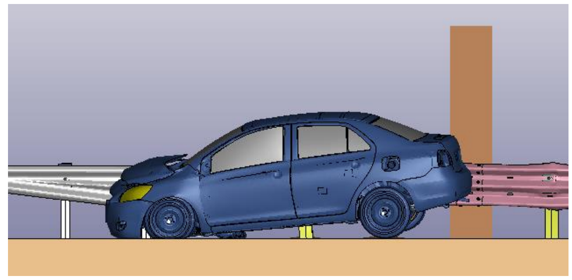
0.035s



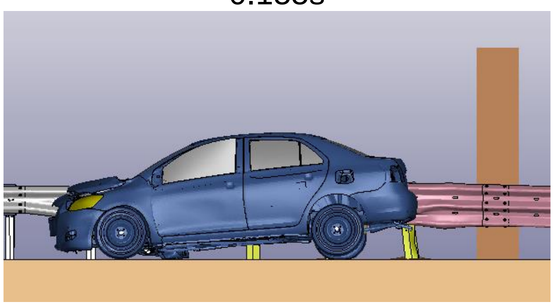
0.095s



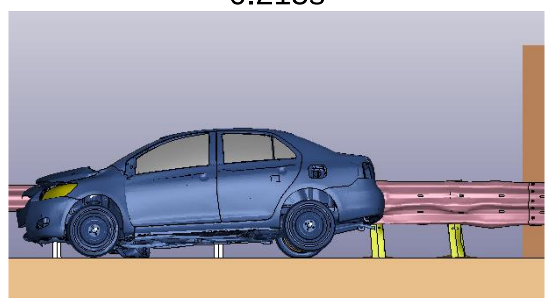
0.155s



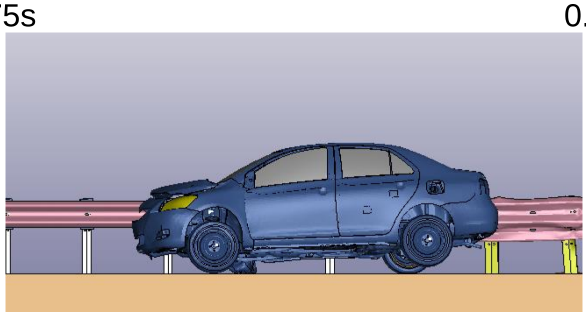
0.215s



0.275s



0.335s



0.395s

Figure 2.208. *MASH* Test 3-10 Simulation of Half-Post Small Gap with Fixed Object 24 inch Offset 4 feet Downstream Impact Variation – Rear View

2.5.1.22. MASH Test 3-10 Simulation of Half-Post Spacing Small Gap with Fixed Object 24 inch Offset and 6 feet Downstream Impact Variation

Figure 2.209 through Figure 2.211 show the sequential frames of MASH test 3-10 with half-post spacing, small gap, a fixed object offset of 24 inches, and an impact variation positioned 6 feet downstream. The OIV was calculated to be 8.1 m/s (preferred limit is 9.1 m/s). The RDA was calculated to be 12.7 g's (maximum limit is 20.49 g's). This configuration passed *MASH* test 3-10 by successfully containing and redirecting the vehicle.

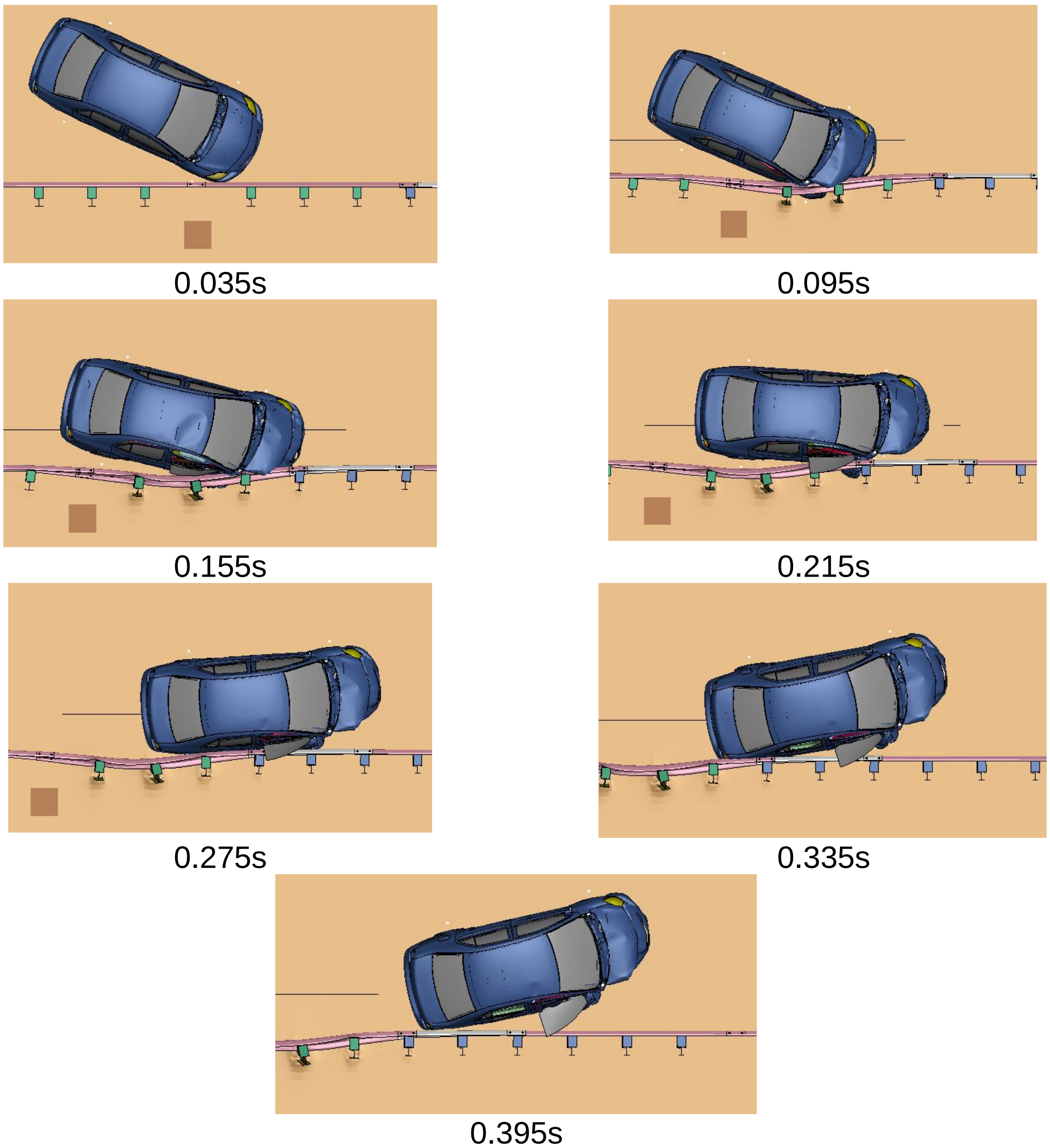


Figure 2.209. *MASH* Test 3-10 Simulation of Half-Post Small Gap with Fixed Object 24 inch Offset 6 feet Downstream Impact Variation– Overhead View

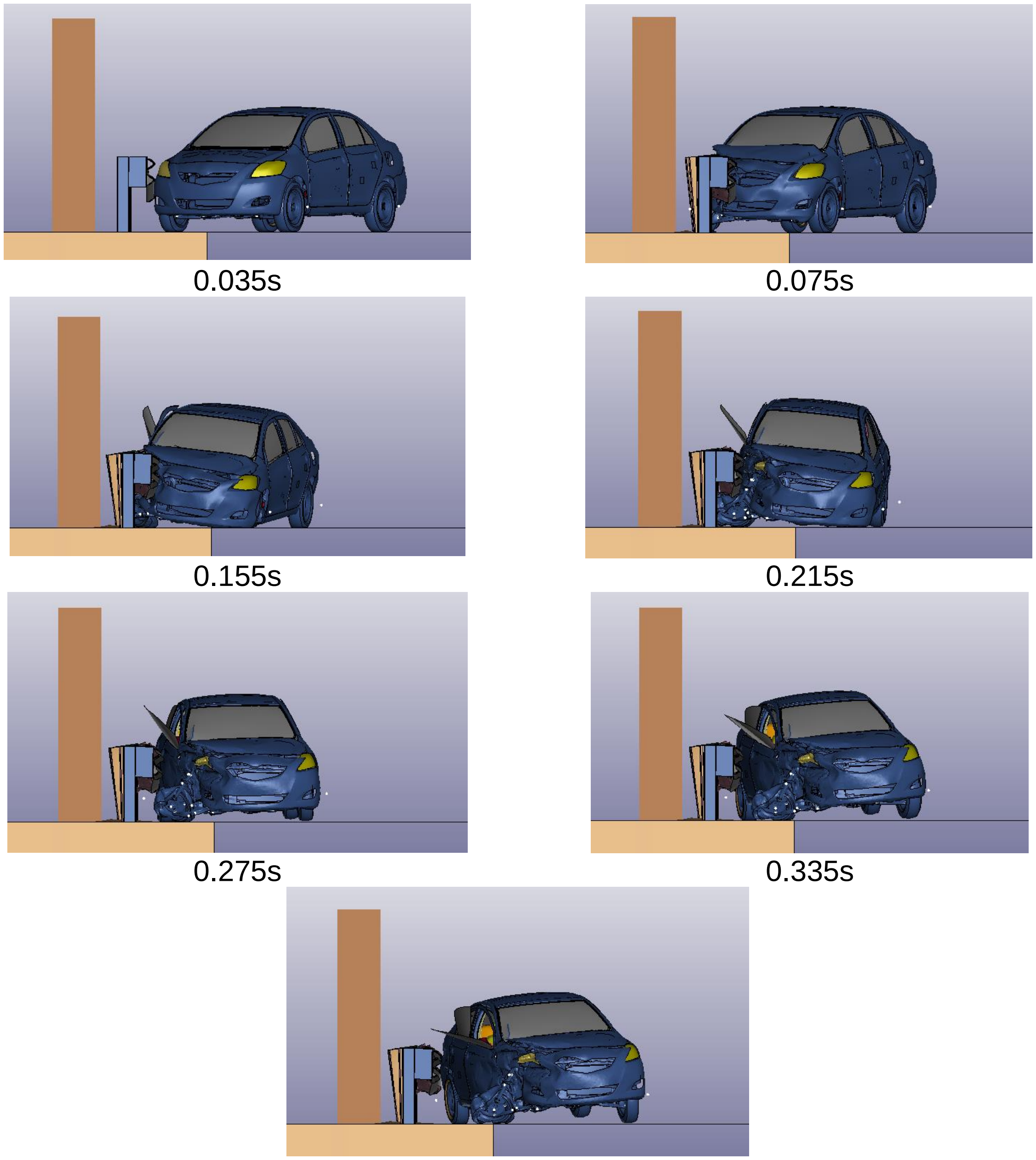

0.035s 0.075s 0.155s 0.215s 0.275s 0.335s 0.395s

Figure 2.210. *MASH* Test 3-10 Simulation of Half-Post Small Gap with Fixed Object 24 inch Offset 6 feet Downstream Impact Variation – Downstream View

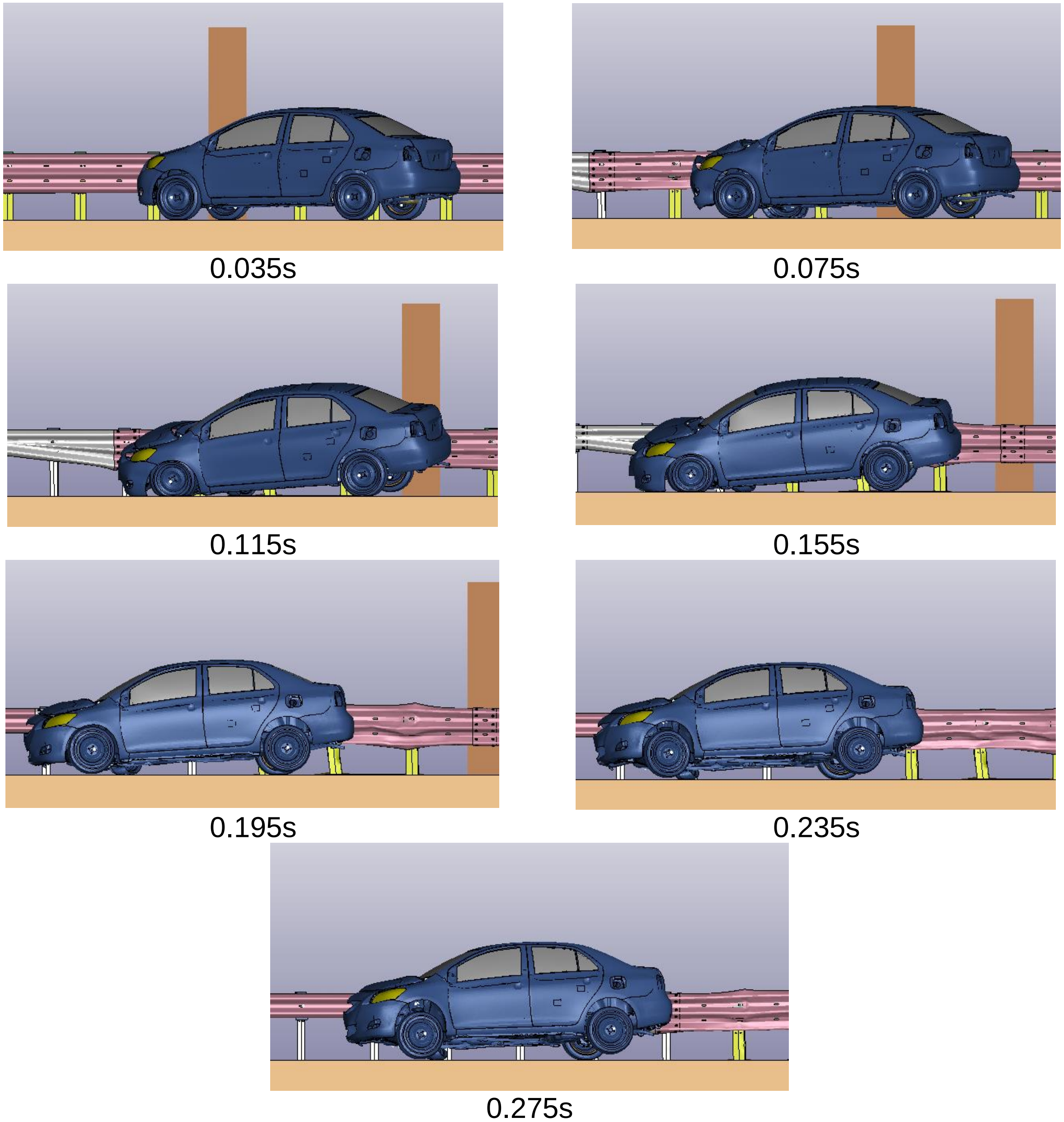


Figure 2.211. ***MASH*** **Test 3-10 Simulation of Half-Post Small Gap with Fixed Object 24 inch Offset 6 feet Downstream Impact Variation – Rear View**

2.5.2. Quarter-Post Spacing

The following simulations include offset variations with quarter-post spacing.

2.5.2.1. MASH Test 3-11 Simulation of Quarter-Post Spacing Small Gap with Fixed Object 0 inch Offset

Figure 2.212 through Figure 2.214 show the sequential frames of *MASH* test 3-11 with quarter-post spacing, small gap, and a fixed object offset of 0 inches. The pickup truck interacted with the fixed object more than what was allowed within this project scope. Therefore, the offset distance was increased in the next simulation.

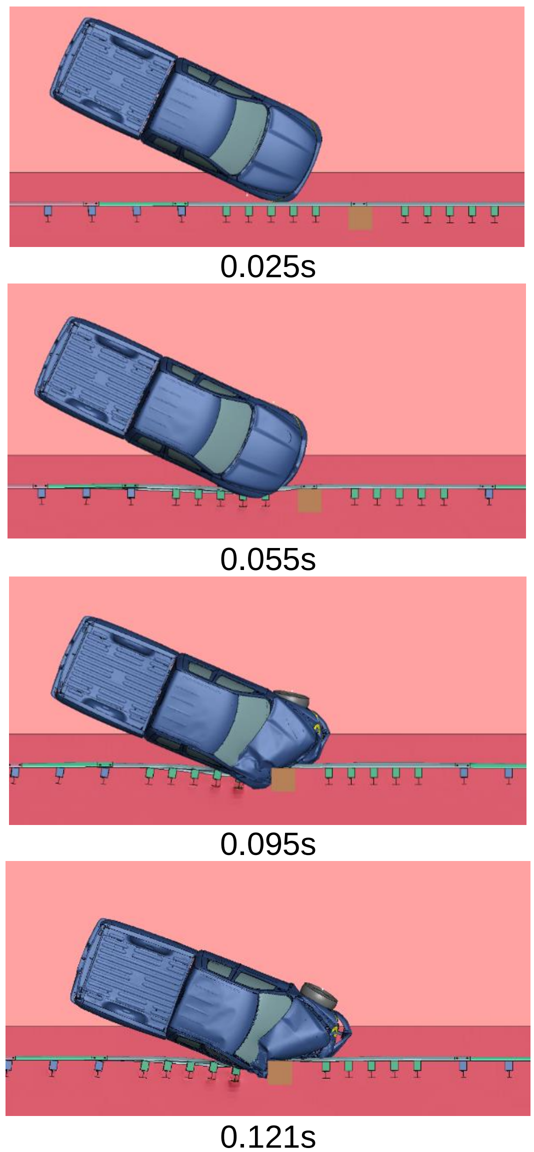
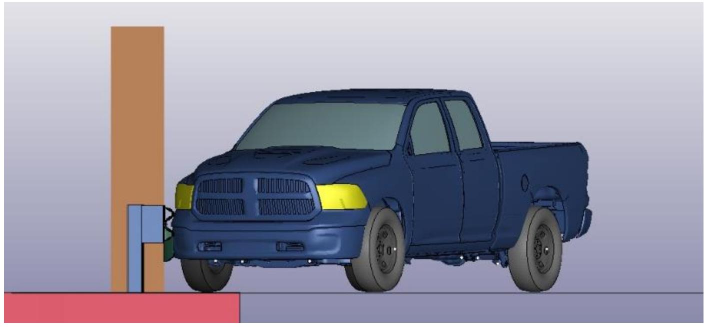
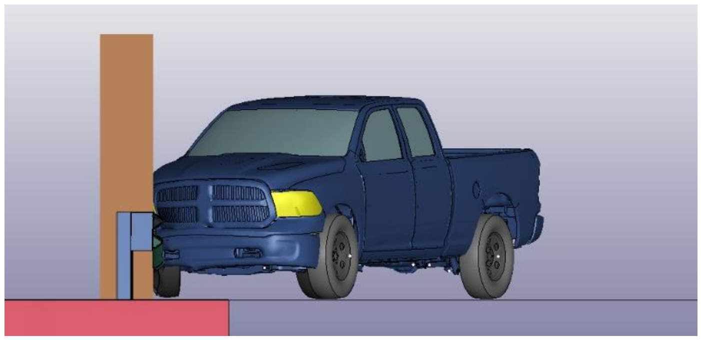


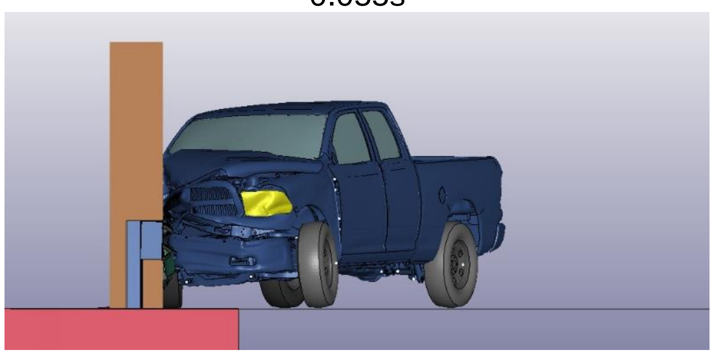
Figure 2.212. *MASH* Test 3-11 Simulation of Quarter-Post Small Gap with Fixed Object 0 inch Offset – Overhead View MASH Test 3-11



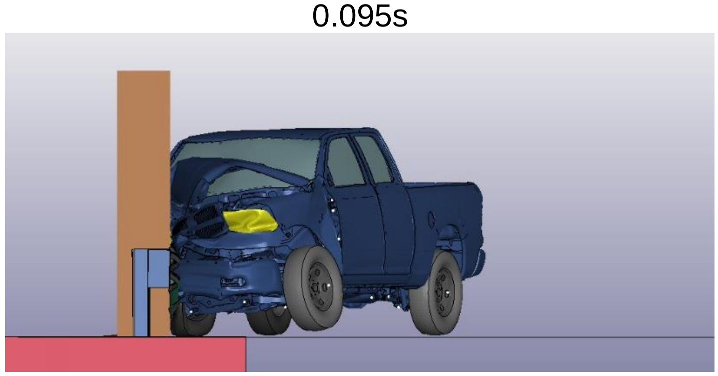
0.025s



0.055s

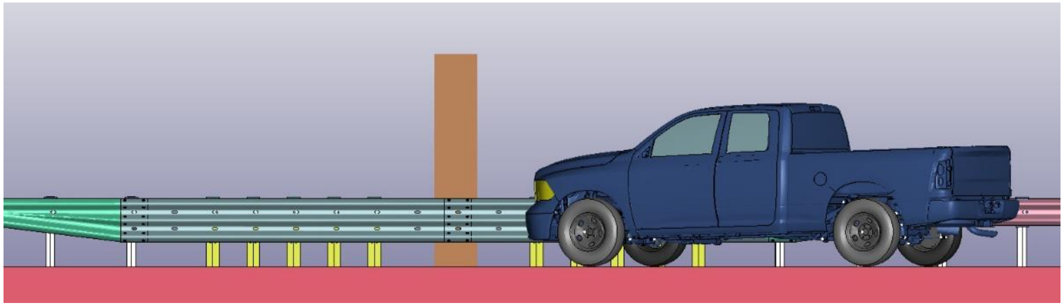


0.095s

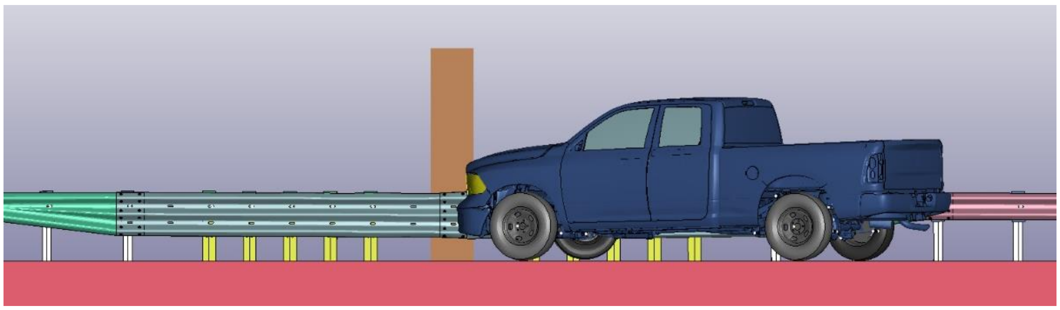


0.121s

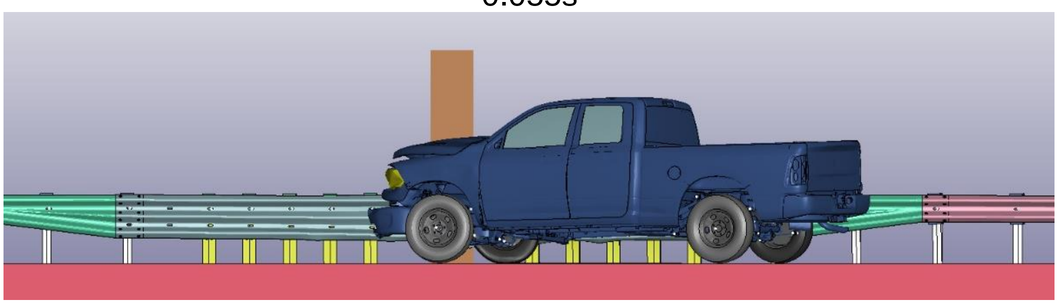
Figure 2.213. *MASH* Test 3-11 Simulation of Quarter-Post Small Gap with Fixed Object 0 inch Offset – Downstream View



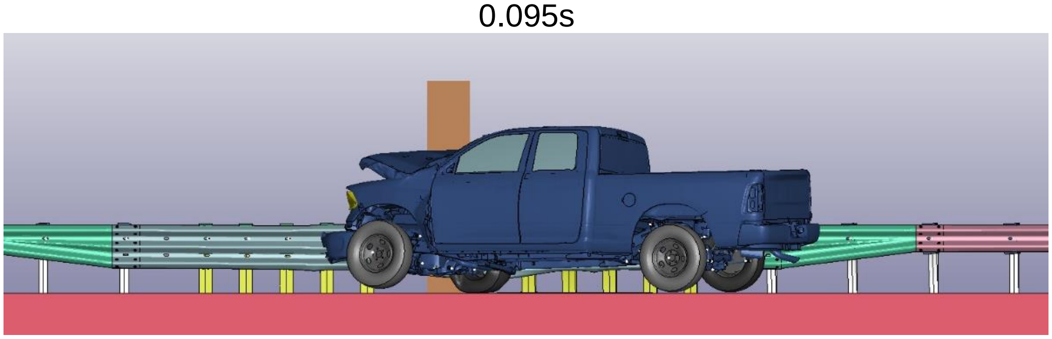
0.025s



0.055s



0.095s

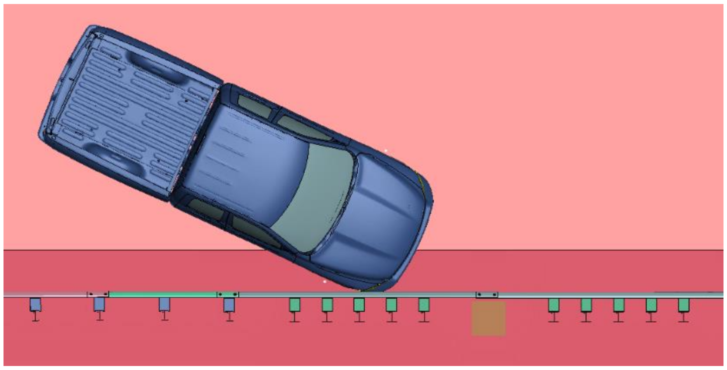


0.121s

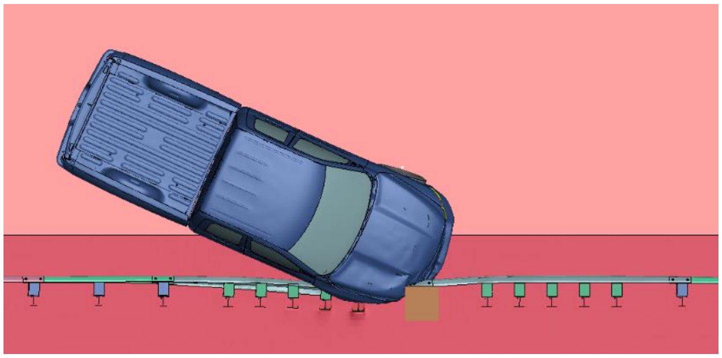
Figure 2.214. *MASH* Test 3-11 Simulation of Quarter-Post Small Gap with Fixed Object 0 inch Offset – Rear View

2.5.2.2. MASH Test 3-11 Simulation of Quarter-Post Spacing Small Gap with Fixed Object 2 inch Offset

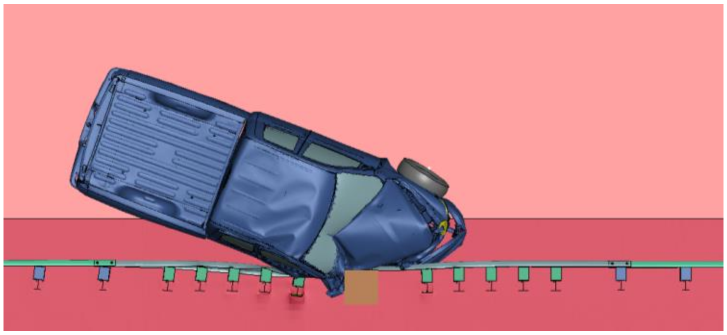
Figure 2.215 through Figure 2.217 show the sequential frames of *MASH* test 3-11 with quarter-post spacing, small gap, and a fixed object offset of 2 inches. The pickup truck interacted with the fixed object more than what was allowed within this project scope. Therefore, the offset distance was increased in the next simulation.



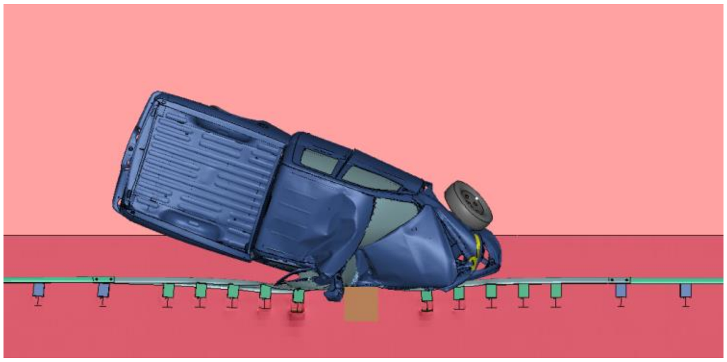
0.025s



0.075s



0.125s



0.170s

Figure 2.215. *MASH* Test 3-11 Simulation of Quarter-Post Small Gap with Fixed Object 2 inch Offset – Overhead View

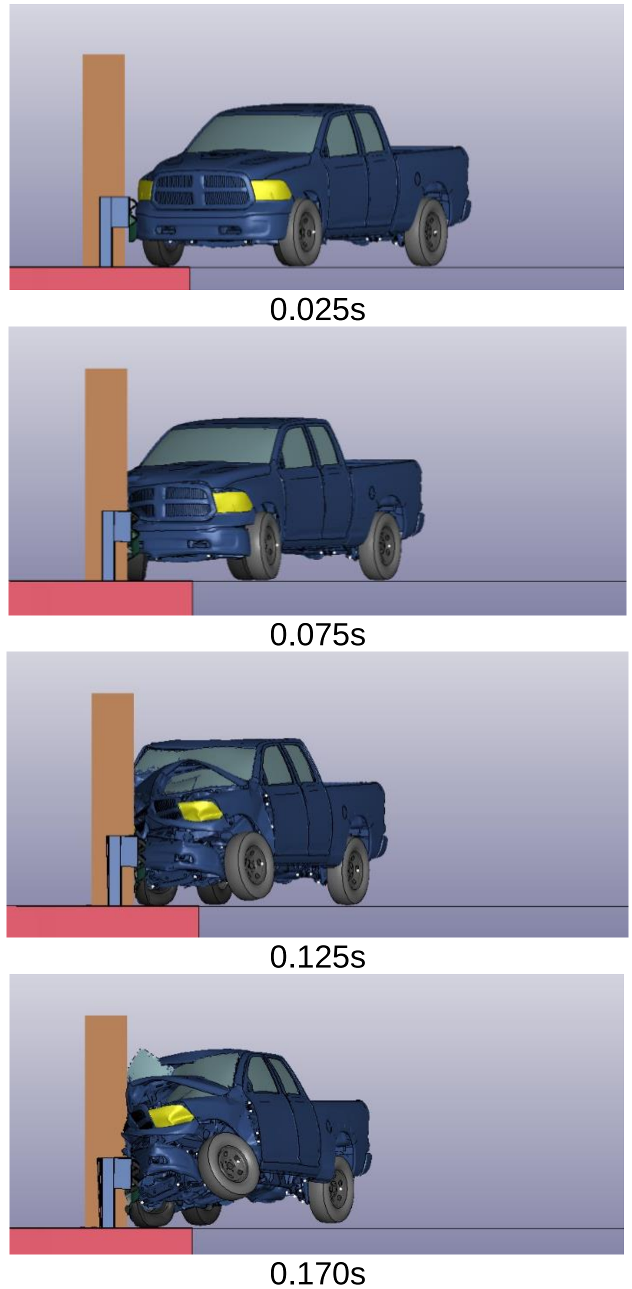
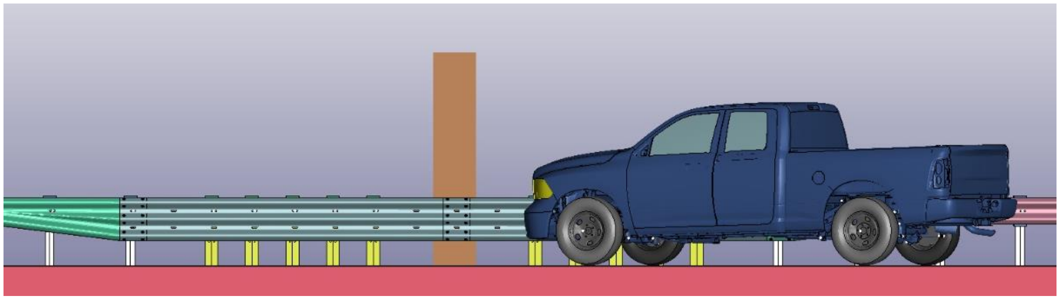
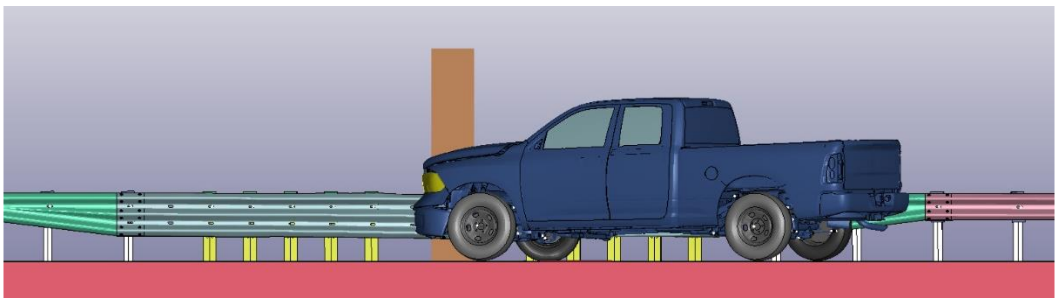


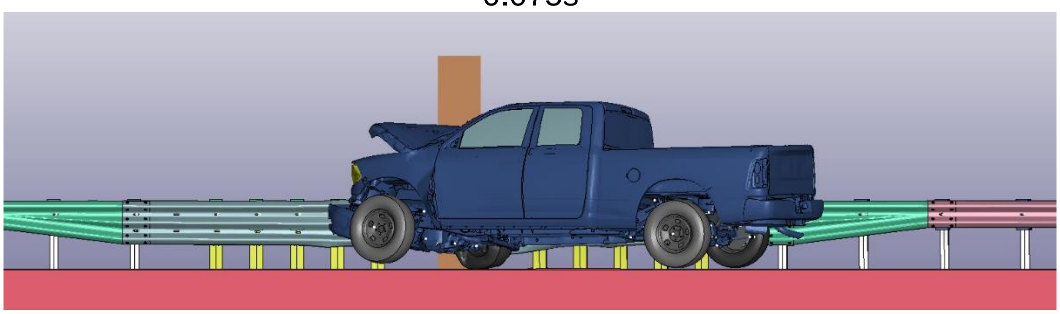
Figure 2.216. ***MASH*** **Test 3-11 Simulation of Quarter-Post Small Gap with Fixed Object 2 inch Offset – Downstream View**



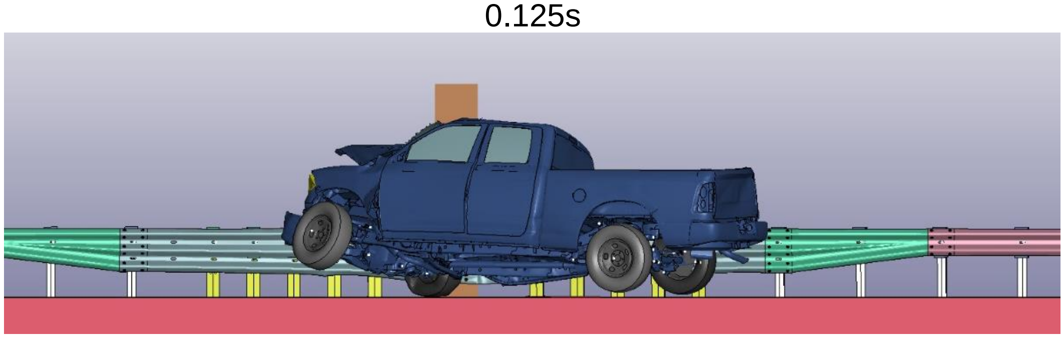
0.025s



0.075s



0.125s

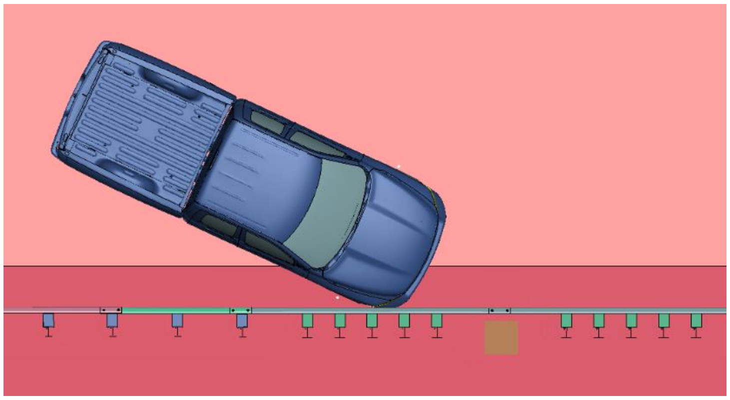


0.170s

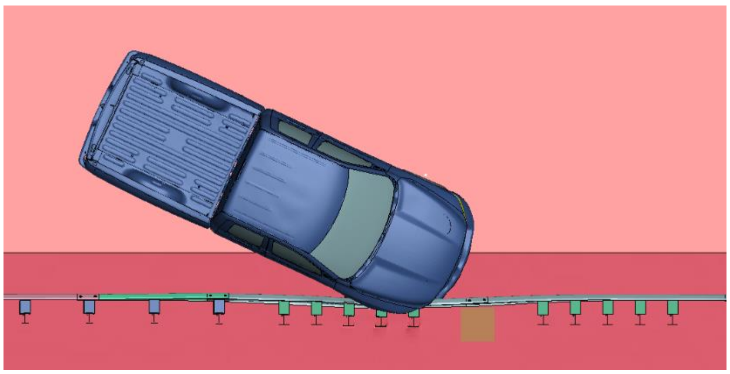
Figure 2.217. *MASH* Test 3-11 Simulation of Quarter-Post Small Gap with Fixed Object 2 inch Offset – Rear View

2.5.2.3. MASH Test 3-11 Simulation of Quarter-Post Spacing Small Gap with Fixed Object 4 inch Offset

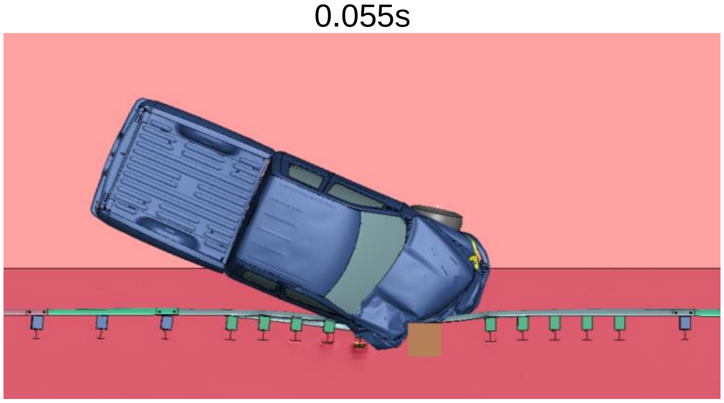
Figure 2.218 through Figure 2.220 show the sequential frames of *MASH* test 3-11 with quarter-post spacing, small gap, and a fixed object offset of 4 inches. The pickup truck interacted with the fixed object more than what was allowed within this project scope. Therefore, the offset distance was increased in the next simulation.



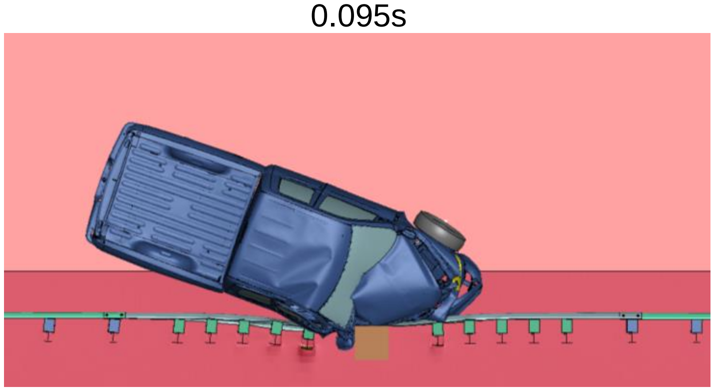
0.025s



0.055s

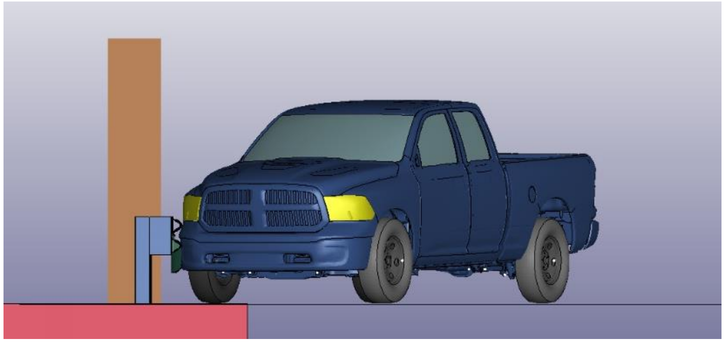


0.095s

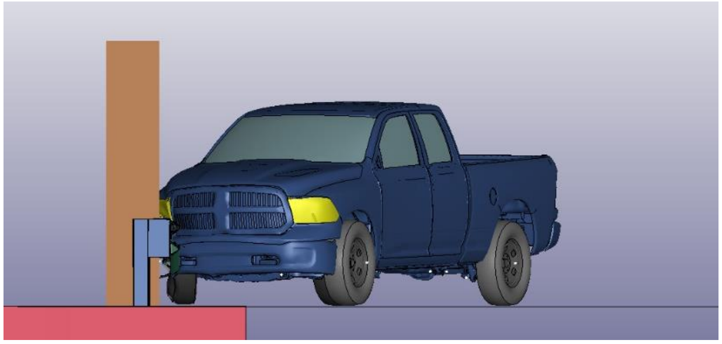


0.129s

Figure 2.218. *MASH* Test 3-11 Simulation of Quarter-Post Small Gap with Fixed Object 4 inch Offset – Overhead View



0.025s



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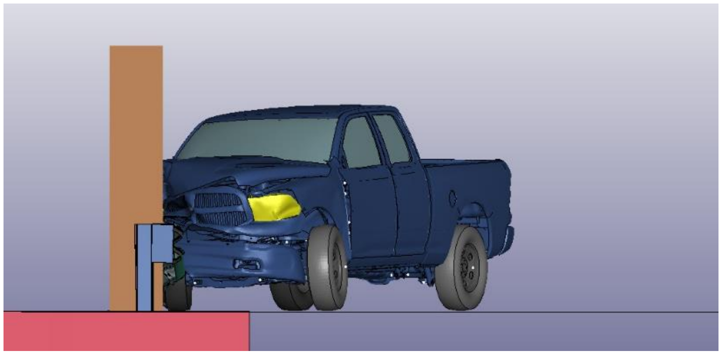

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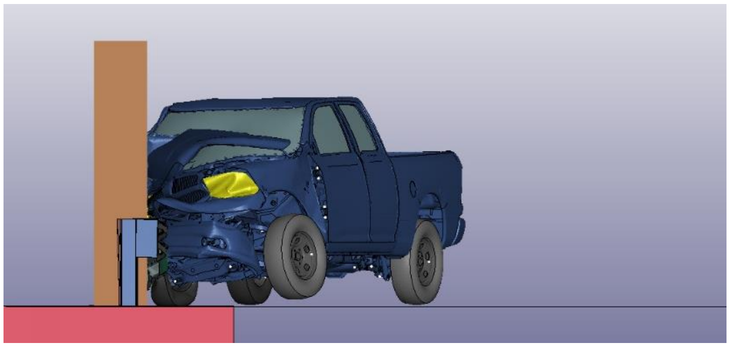


0.129s

Figure 2.219. ***MASH*** **Test 3-11 Simulation of Quarter-Post Small Gap with Fixed Object 4 inch Offset – Downstream View**

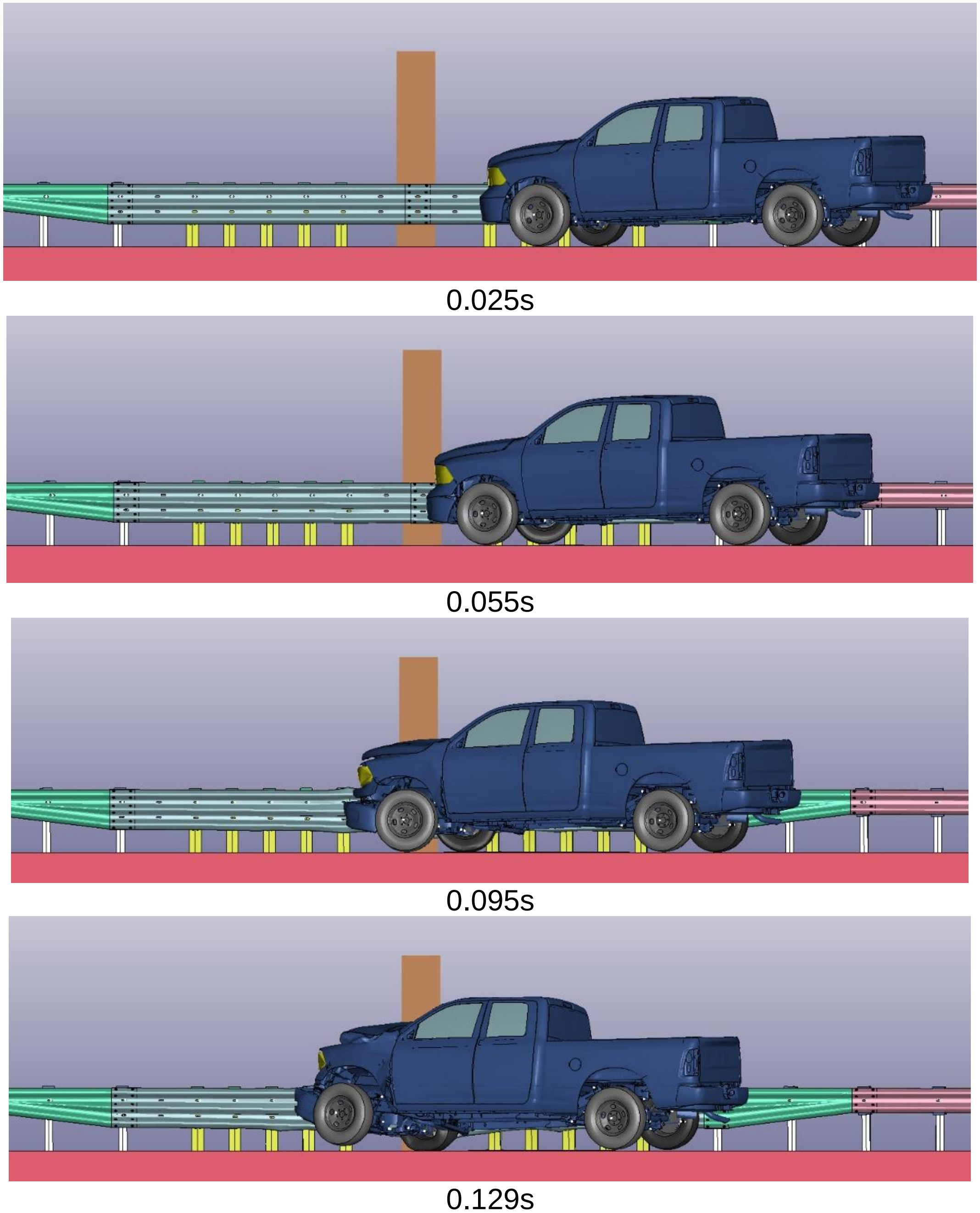
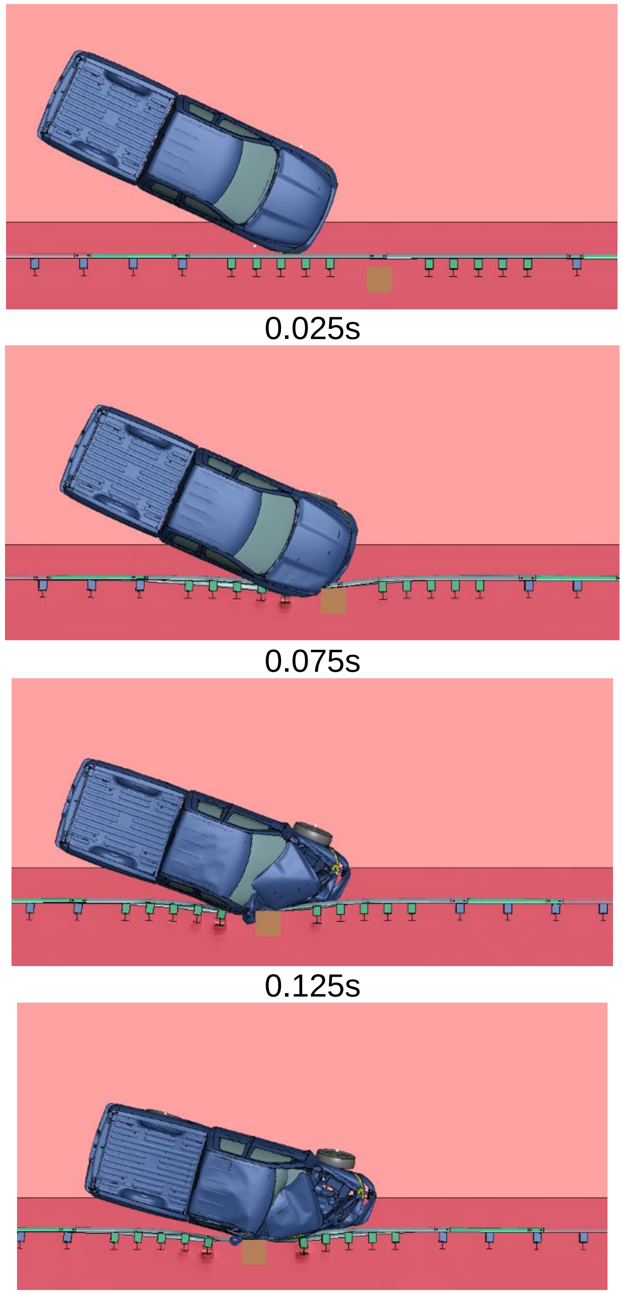


Figure 2.220. *MASH* Test 3-11 Simulation of Quarter-Post Small Gap with Fixed Object 4 inch Offset – Rear View

2.5.2.4. MASH Test 3-11 Simulation of Quarter-Post Spacing Small Gap with Fixed Object 6 inch Offset

Figure 2.221 through Figure 2.223 show the sequential frames of *MASH* test 3-11 with quarter-post spacing, small gap, and a fixed object offset of 6 inches. The pickup truck interacted with the fixed object more than what was allowed within this project scope. Therefore, the offset distance was increased in the next simulation.



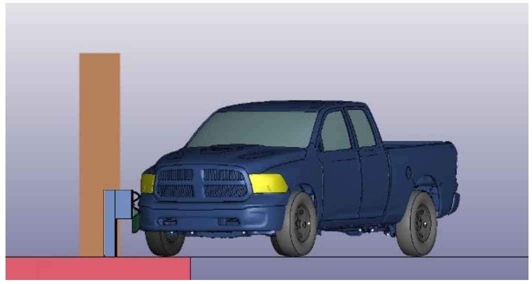
0.025s

0.075s

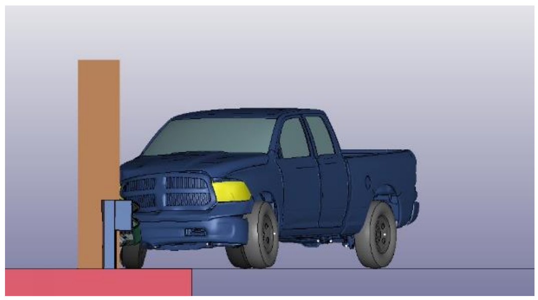
0.125s

0.170s

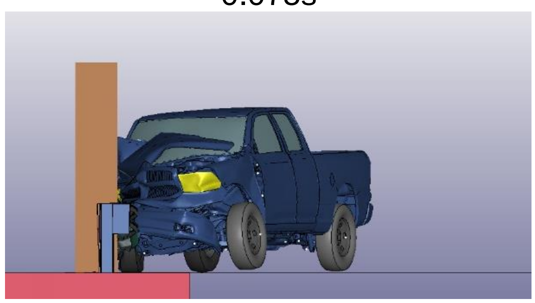
Figure 2.221. ***MASH*** **Test 3-11 Simulation of Quarter-Post Small Gap with Fixed Object 6 inch Offset – Overhead View**



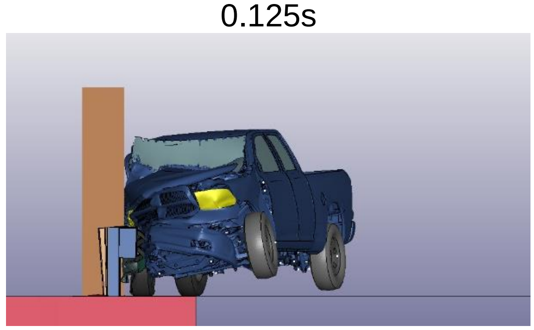
0.025s



0.075s

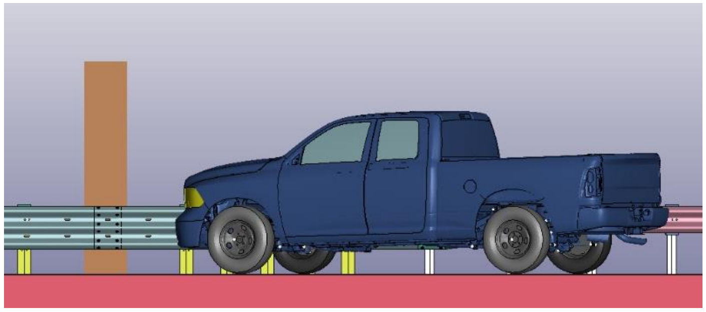


0.125s

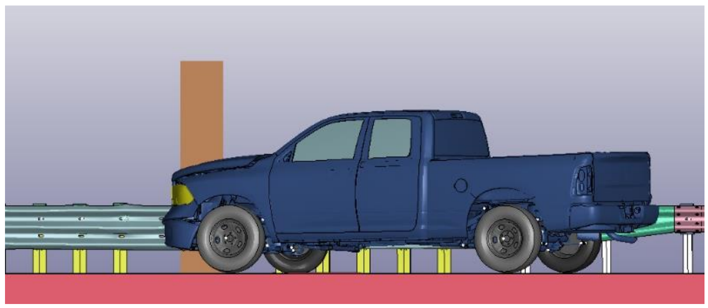


0.170s

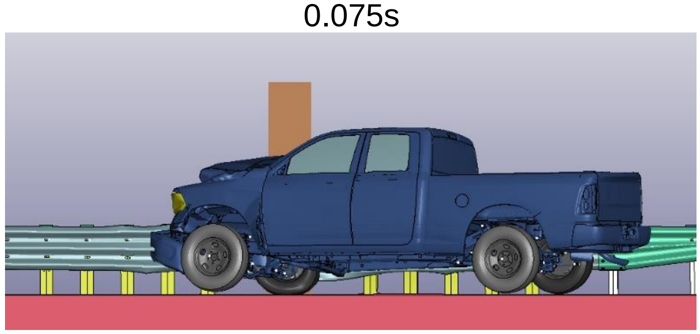
Figure 2.222. *MASH* Test 3-11 Simulation of Quarter-Post Small Gap with Fixed Object 6 inch Offset – Downstream View



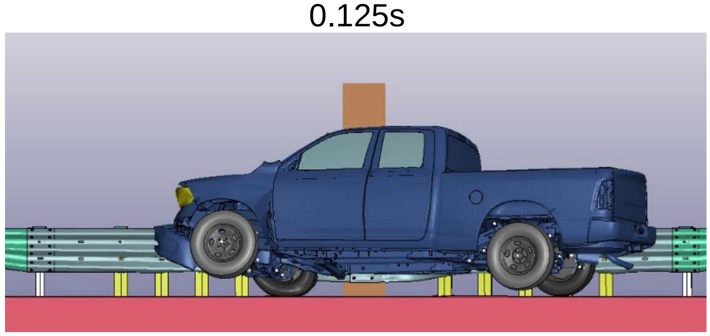
0.025s



0.075s



0.125s



0.170s

Figure 2.223. *MASH* Test 3-11 Simulation of Quarter-Post Small Gap with Fixed Object 6 inch Offset – Rear View

2.5.2.5. MASH Test 3-11 Simulation of Quarter-Post Spacing Small Gap with Fixed Object 8 inch Offset

Figure 2.224 through Figure 2.226 show the sequential frames of *MASH* test 3-11 with quarter-post spacing, small gap, and a fixed object offset of 8 inches. The pickup truck interacted with the fixed object more than what was allowed within this project scope. Therefore, the offset distance was increased in the next simulation.

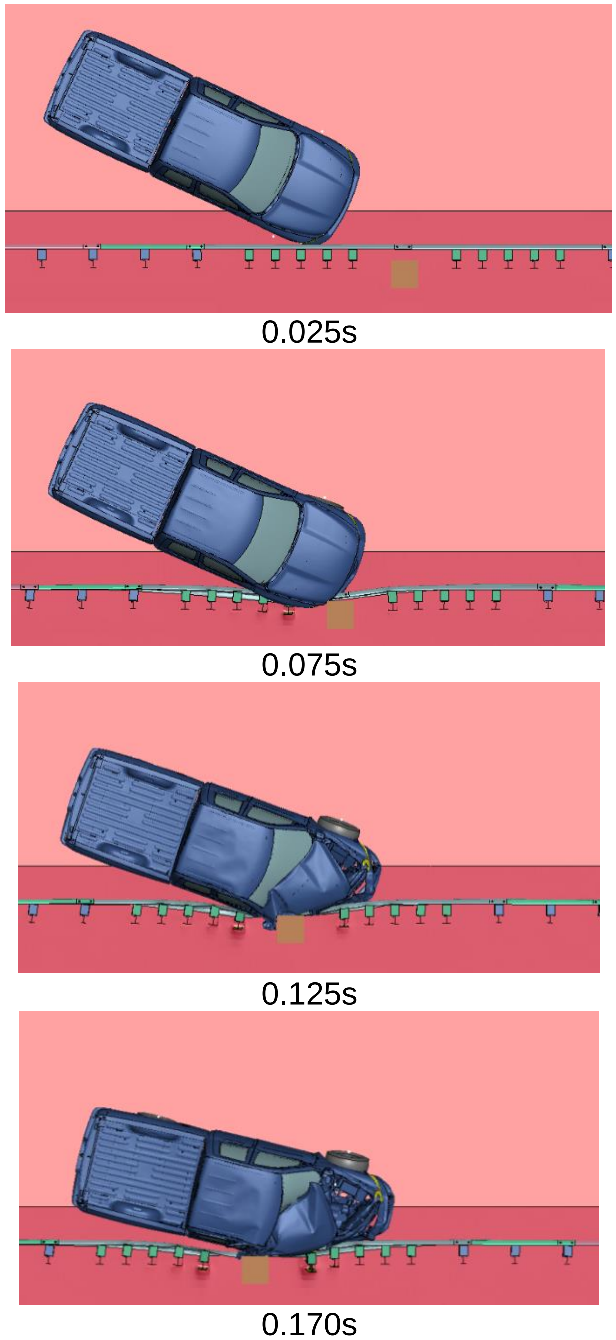
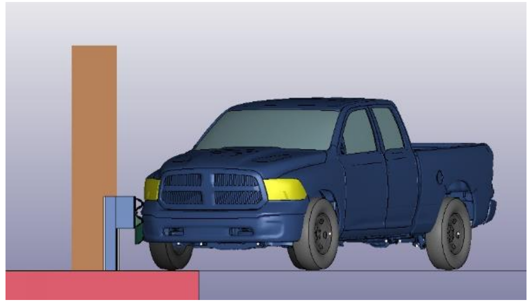
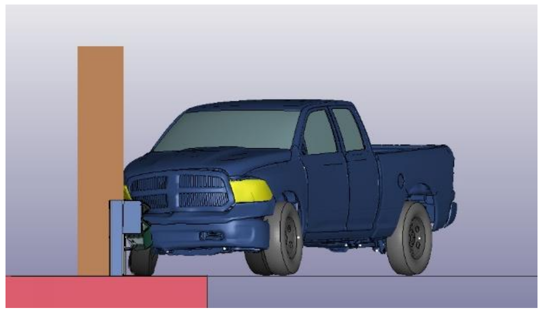


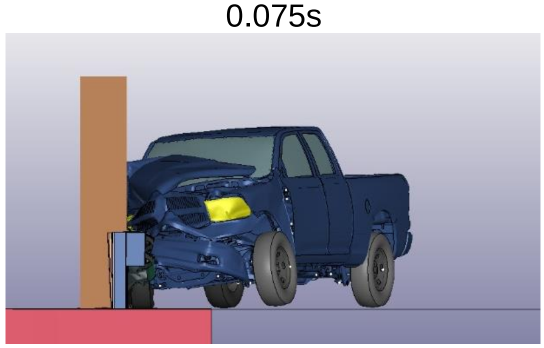
Figure 2.224. *MASH* Test 3-11 Simulation of Quarter-Post Small Gap with Fixed Object 8 inch Offset – Overhead View



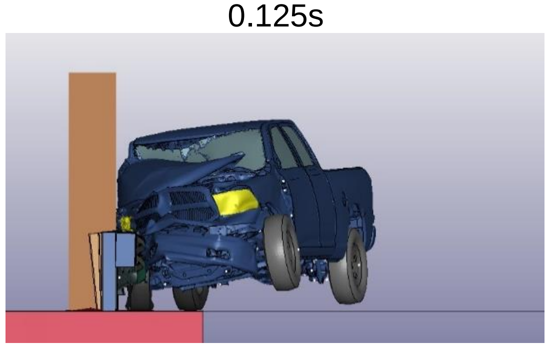
0.025s



0.075s

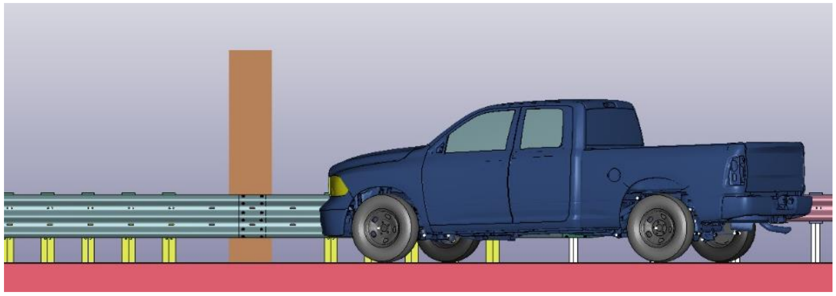


0.125s

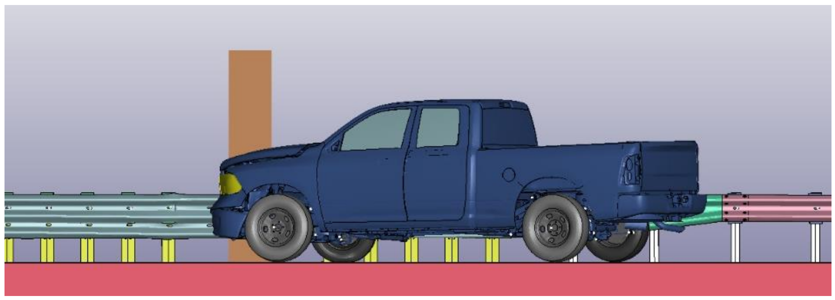


0.170s

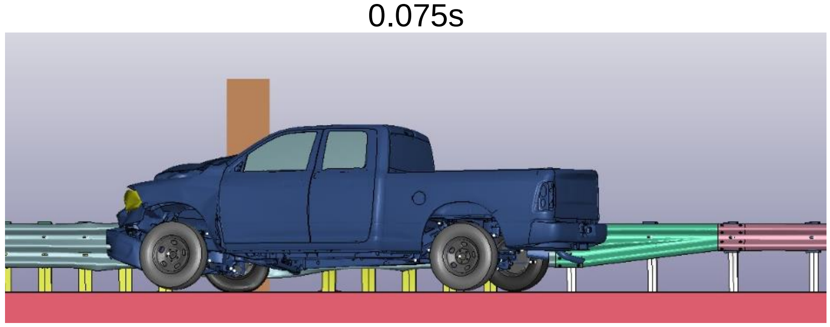
Figure 2.225. *MASH* Test 3-11 Simulation of Quarter-Post Small Gap with Fixed Object 8 inch Offset – Downstream View



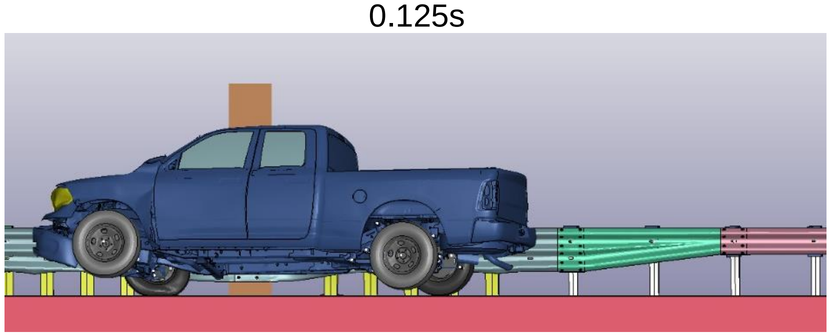
0.025s



0.075s



0.125s

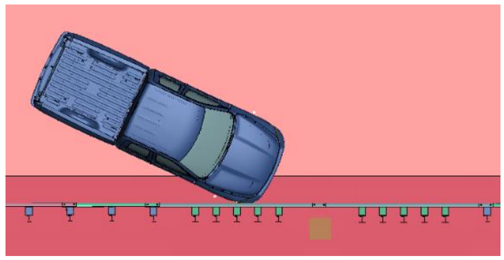


0.170s

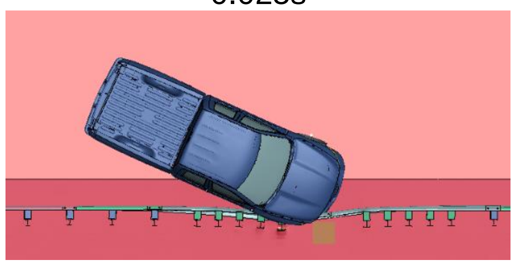
Figure 2.226. ***MASH*** **Test 3-11 Simulation of Quarter-Post Small Gap with Fixed Object 8 inch Offset – Rear View**

2.5.2.6. MASH Test 3-11 Simulation of Quarter-Post Spacing Small Gap with Fixed Object 10 inch Offset

Figure 2.227 through Figure 2.229 show the sequential frames of *MASH* test 3-11 with quarter-post spacing, small gap, and a fixed object offset of 10 inches. The pickup truck interacted with the fixed object more than what was allowed within this project scope. Therefore, the offset distance was increased in the next simulation.



0.025s

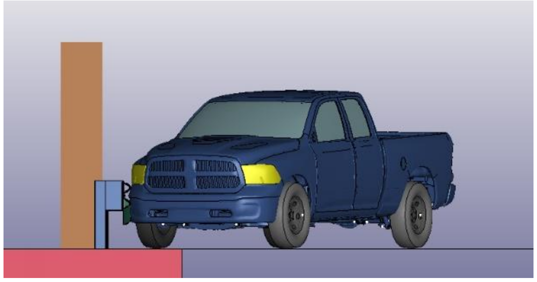


0.075s

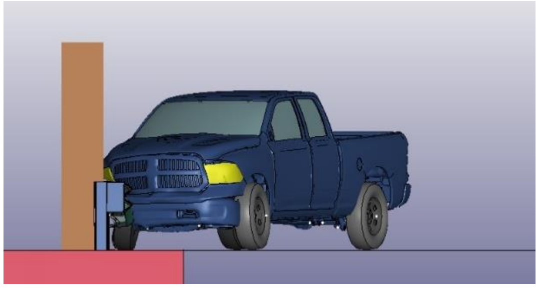
0.125s

0.170s

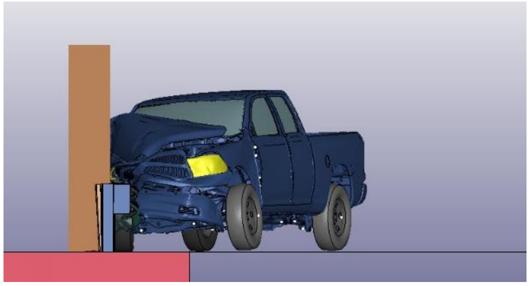
Figure 2.227. *MASH* Test 3-11 Simulation of Quarter-Post Small Gap with Fixed Object 10 inch Offset – Overhead View



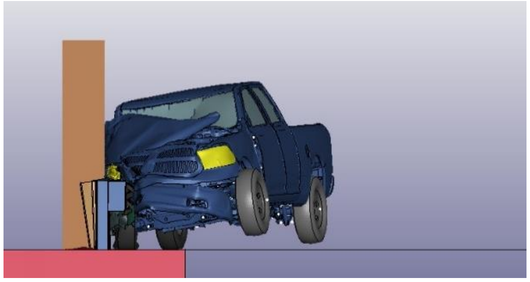
0.025s



0.075s



0.125s



0.170s

Figure 2.228. ***MASH*** **Test 3-11 Simulation of Quarter-Post Small Gap with Fixed Object 10 inch Offset – Downstream View**

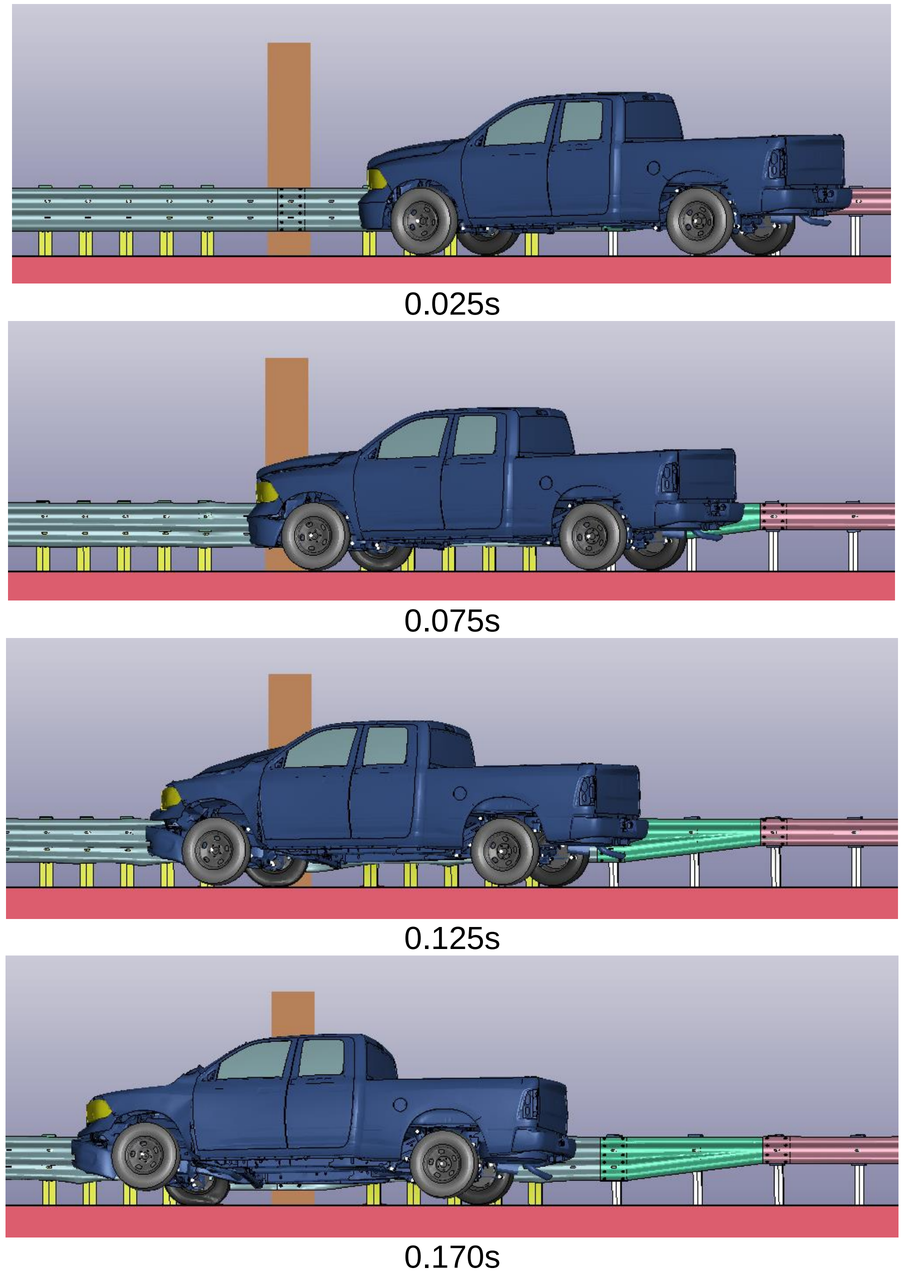


Figure 2.229. ***MASH*** **Test 3-11 Simulation of Quarter-Post Small Gap with Fixed Object 10 inch Offset – Rear View**

2.5.2.7. MASH Test 3-11 Simulation of Quarter-Post Spacing Small Gap with Fixed Object 12 inch Offset

Figure 2.230 through Figure 2.232 show the sequential frames of *MASH* test 3-11 with quarter-post spacing, small gap, and a fixed object offset of 12 inches. The occupant impact velocity was calculated to be 6.7 m/s (preferred limit is 9.1 m/s). The ridedown acceleration was calculated to be 13.1 g's (preferred limit is 15.0 g's). This configuration passed *MASH* test 3-11 by successfully containing and redirecting the vehicle.

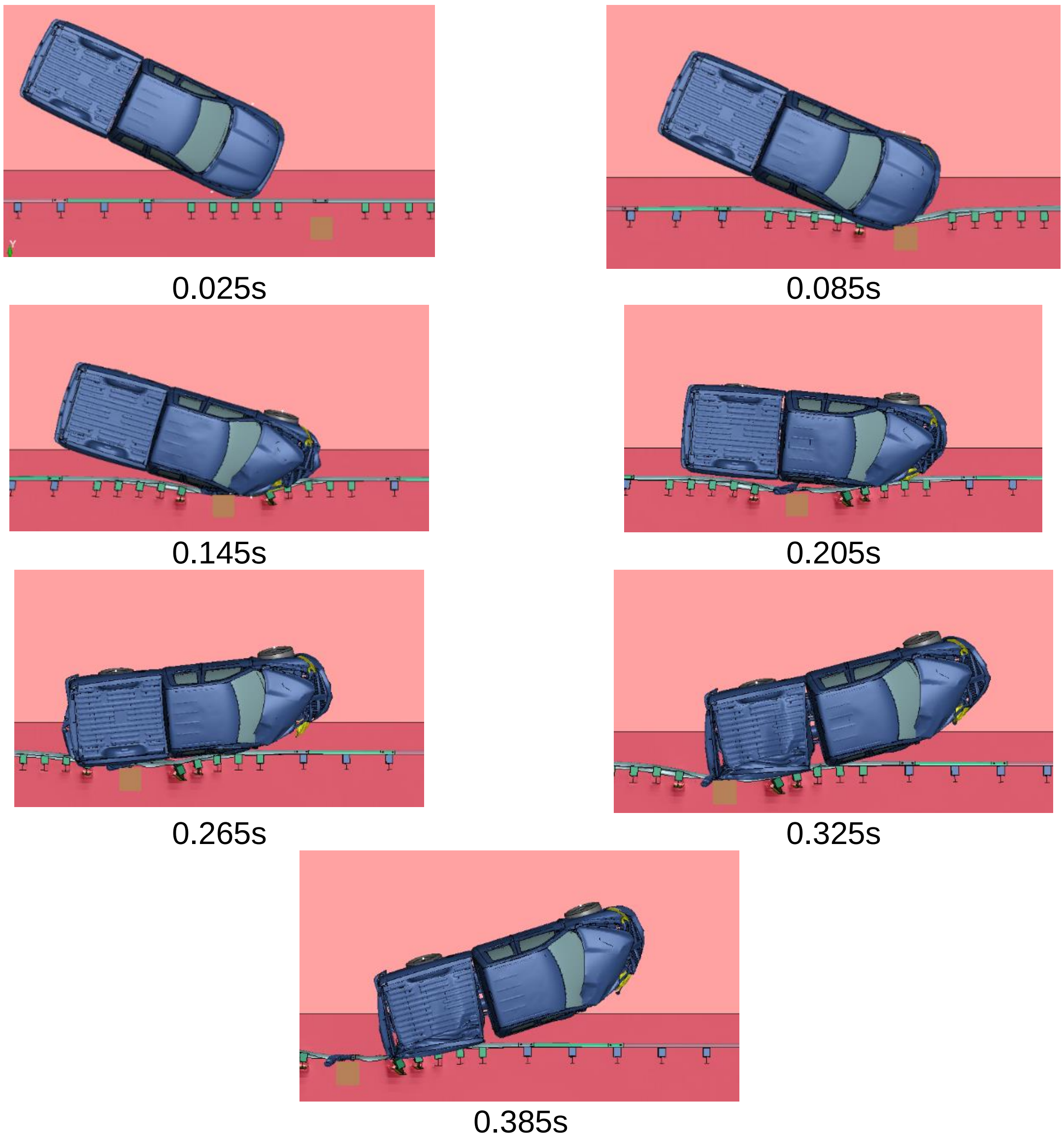
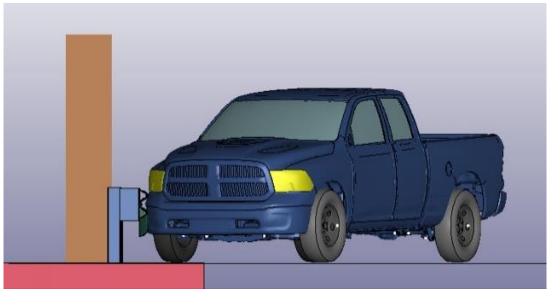


Figure 2.230. *MASH* Test 3-11 Simulation of Quarter-Post Small Gap with Fixed Object 12 inch Offset – Overhead View



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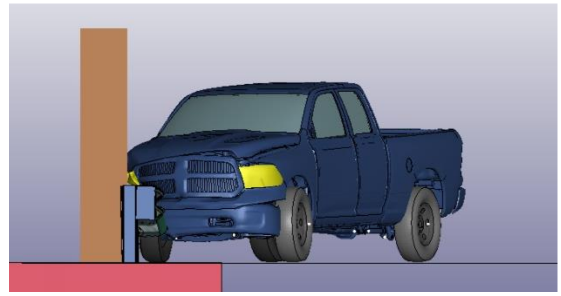

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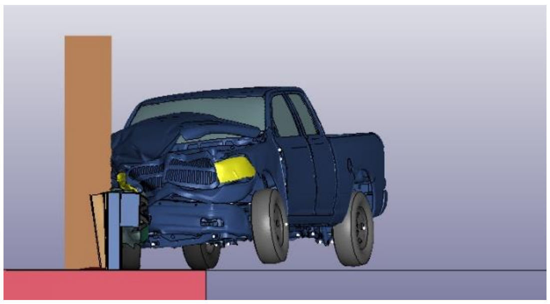

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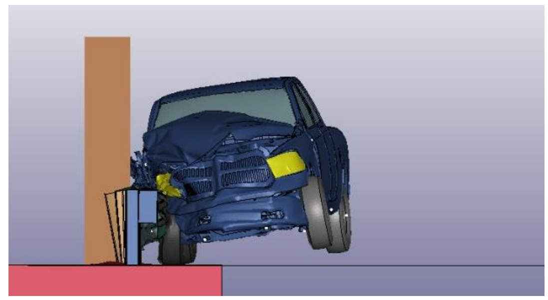

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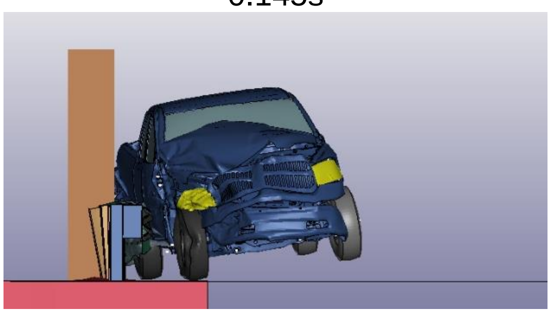

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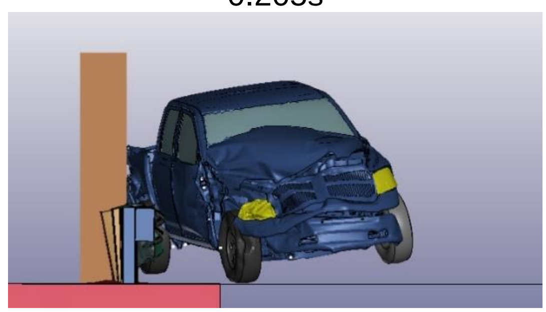

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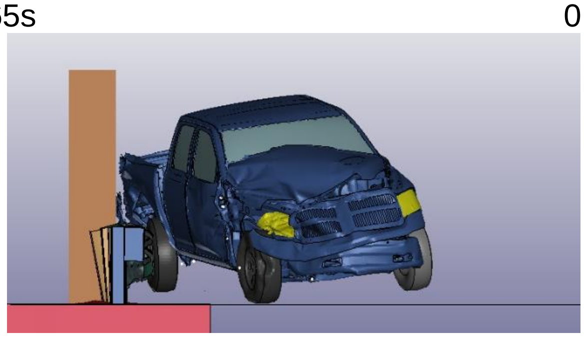


0.385s

Figure 2.231. *MASH* Test 3-11 Simulation of Quarter-Post Small Gap with Fixed Object 12 inch Offset – Downstream View

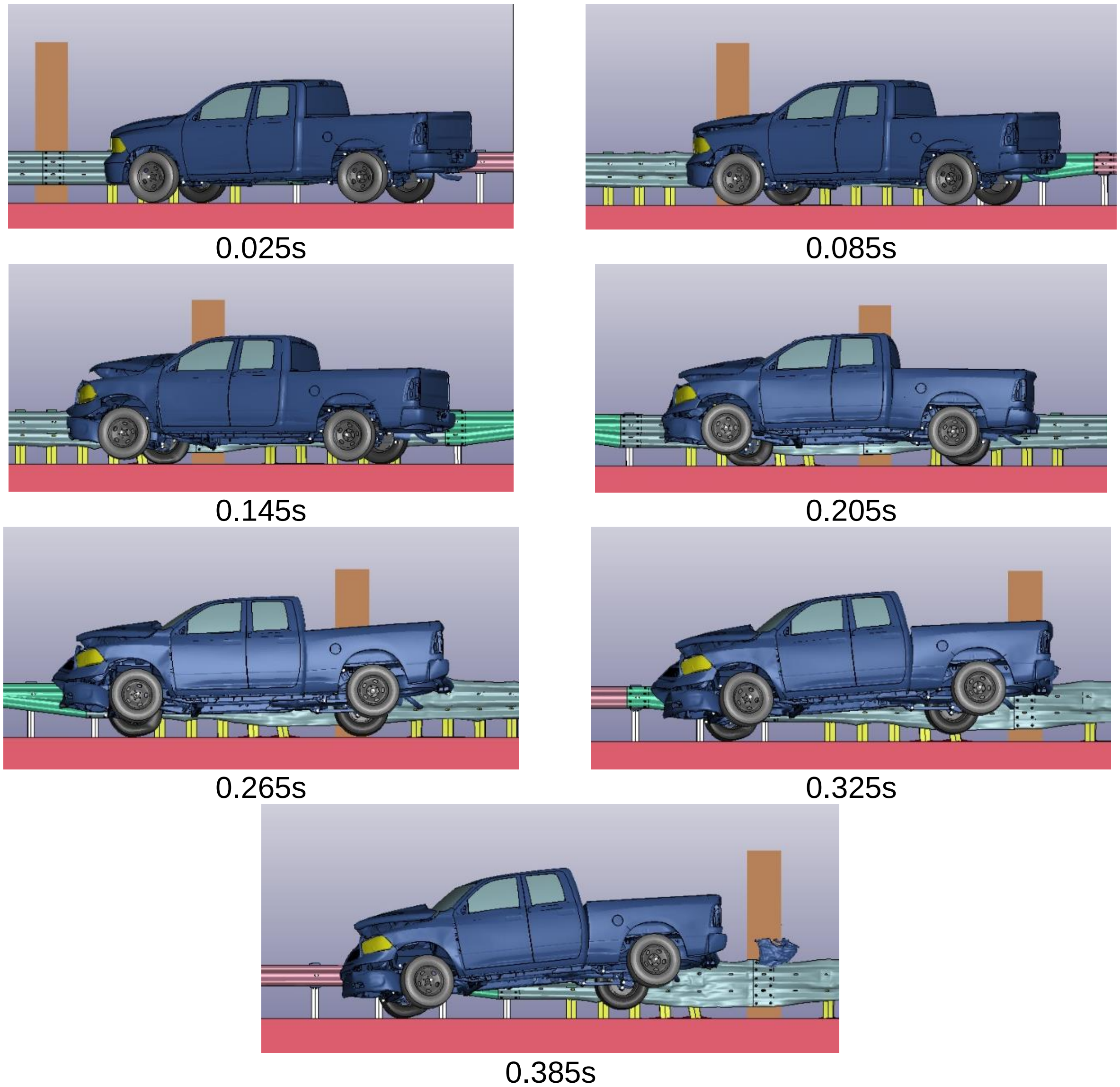


Figure 2.232. *MASH* Test 3-11 Simulation of Quarter-Post Small Gap with Fixed Object 12 inch Offset – Rear View

2.5.2.8. *MASH Test 3-11 Simulation of Quarter-Post Spacing Small Gap with Fixed Object 16 inch Offset*

Figure 2.233 through Figure 2.235 show the sequential frames of *MASH* test 3-11 with quarter-post spacing, small gap, and a fixed object offset of 16 inches. The occupant impact velocity was calculated to be 5.5 m/s (preferred limit is 9.1 m/s). The ridedown acceleration was calculated to be 17.9 g's (maximum limit is 20.49 g's). This configuration passed *MASH* test 3-11 by successfully containing and redirecting the vehicle.

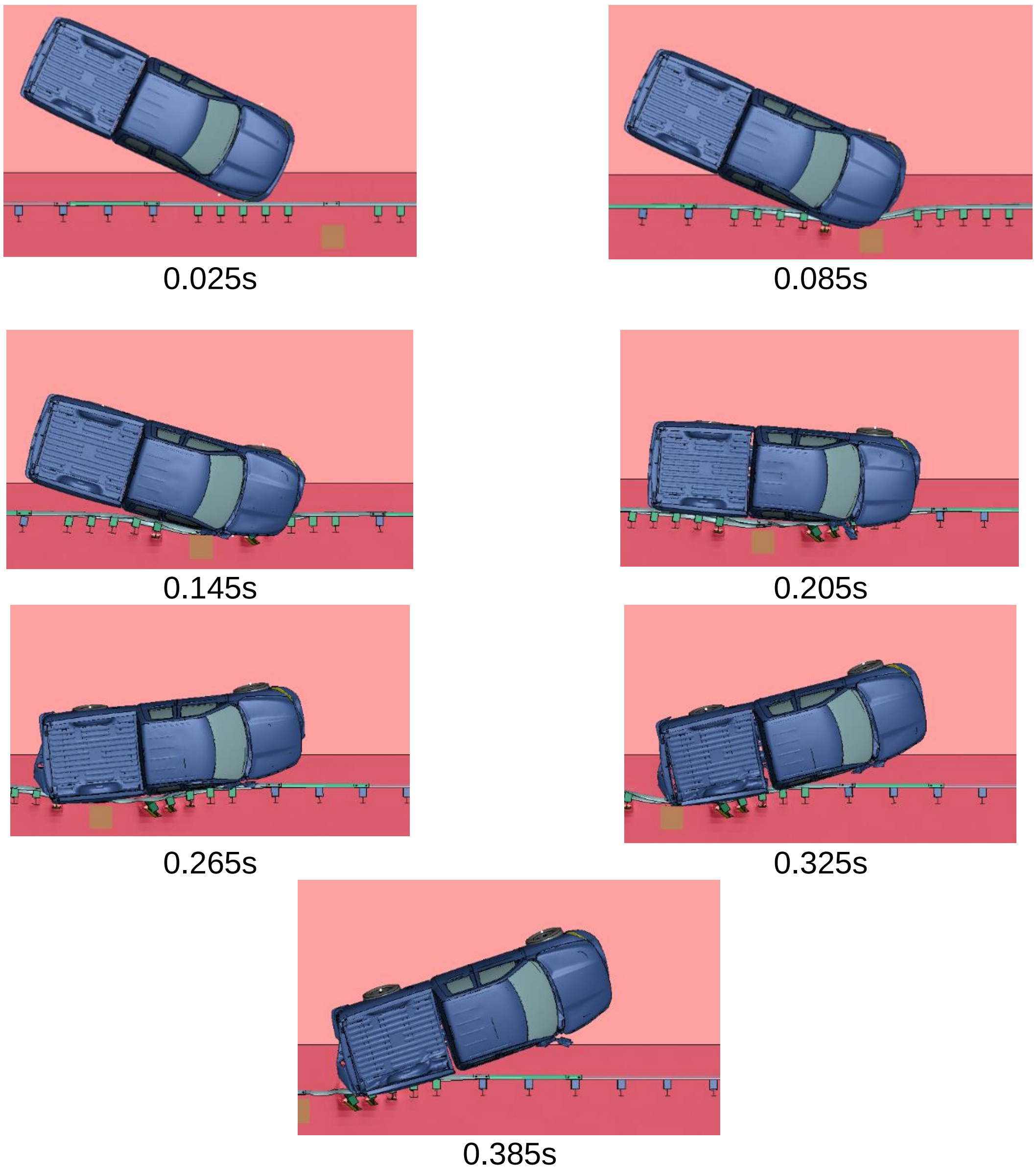


Figure 2.233. *MASH* Test 3-11 Simulation of Quarter-Post Small Gap with Fixed Object 16 inch Offset – Overhead View

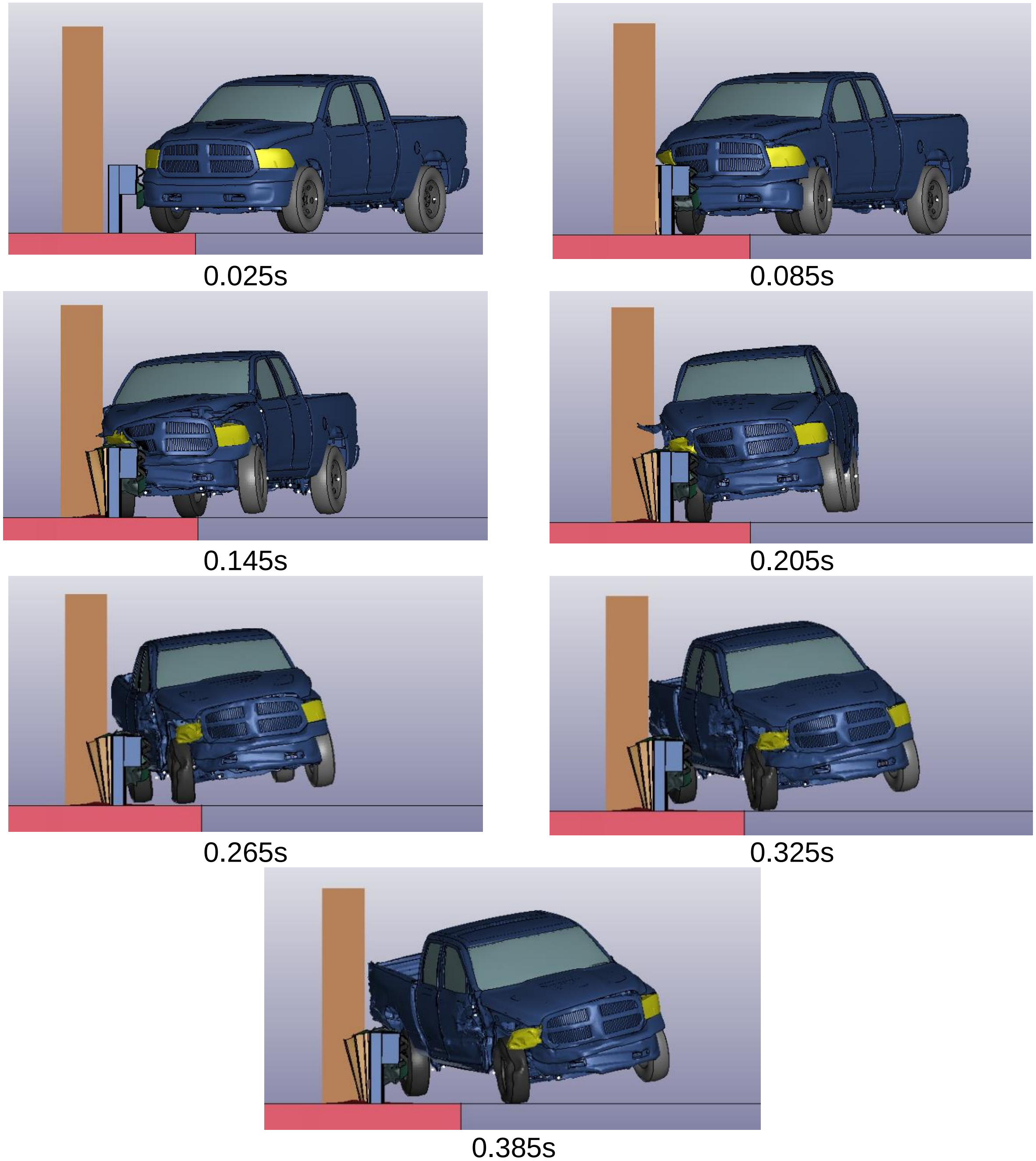


Figure 2.234. ***MASH*** **Test 3-11 Simulation of Quarter-Post Small Gap with Fixed Object 16 inch Offset – Downstream View**

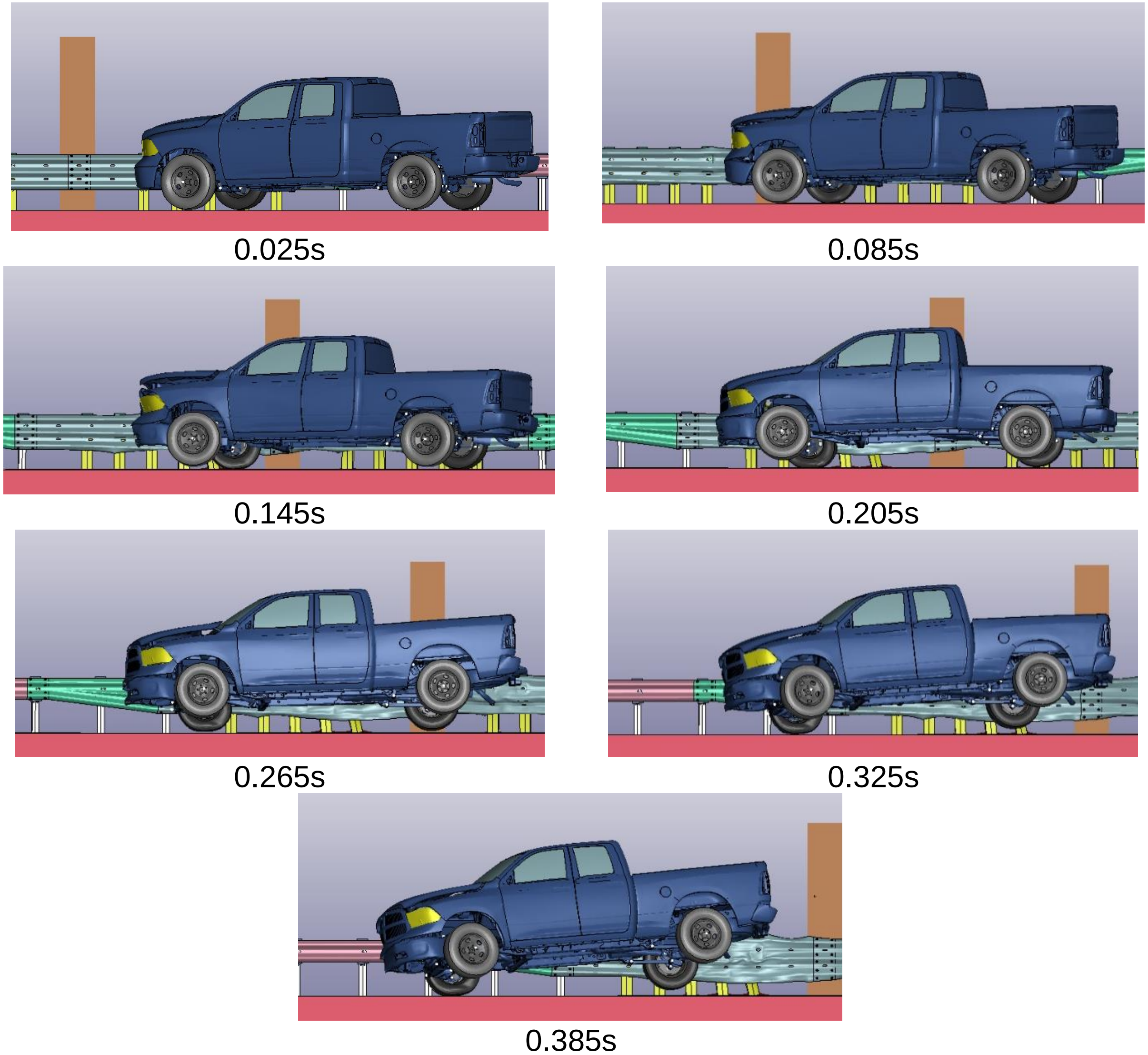


Figure 2.235. *MASH* Test 3-11 Simulation of Quarter-Post Small Gap with Fixed Object 16 inch Offset – Rear View

2.5.2.9. MASH Test 3-10 Simulation of Quarter-Post Spacing Small Gap with Fixed Object 16 inch Offset

Figure 2.236 through Figure 2.238 show the sequential frames of MASH test 3-10 with quarter-post spacing, small gap, and a fixed object offset of 16 inches. The OIV was calculated to be 7.5 m/s (preferred limit is 9.1 m/s). The RDA was calculated to be 17.7 g’s (maximum limit is 20.49 g’s). This configuration passed *MASH* test 3-10 by successfully containing and redirecting the vehicle.

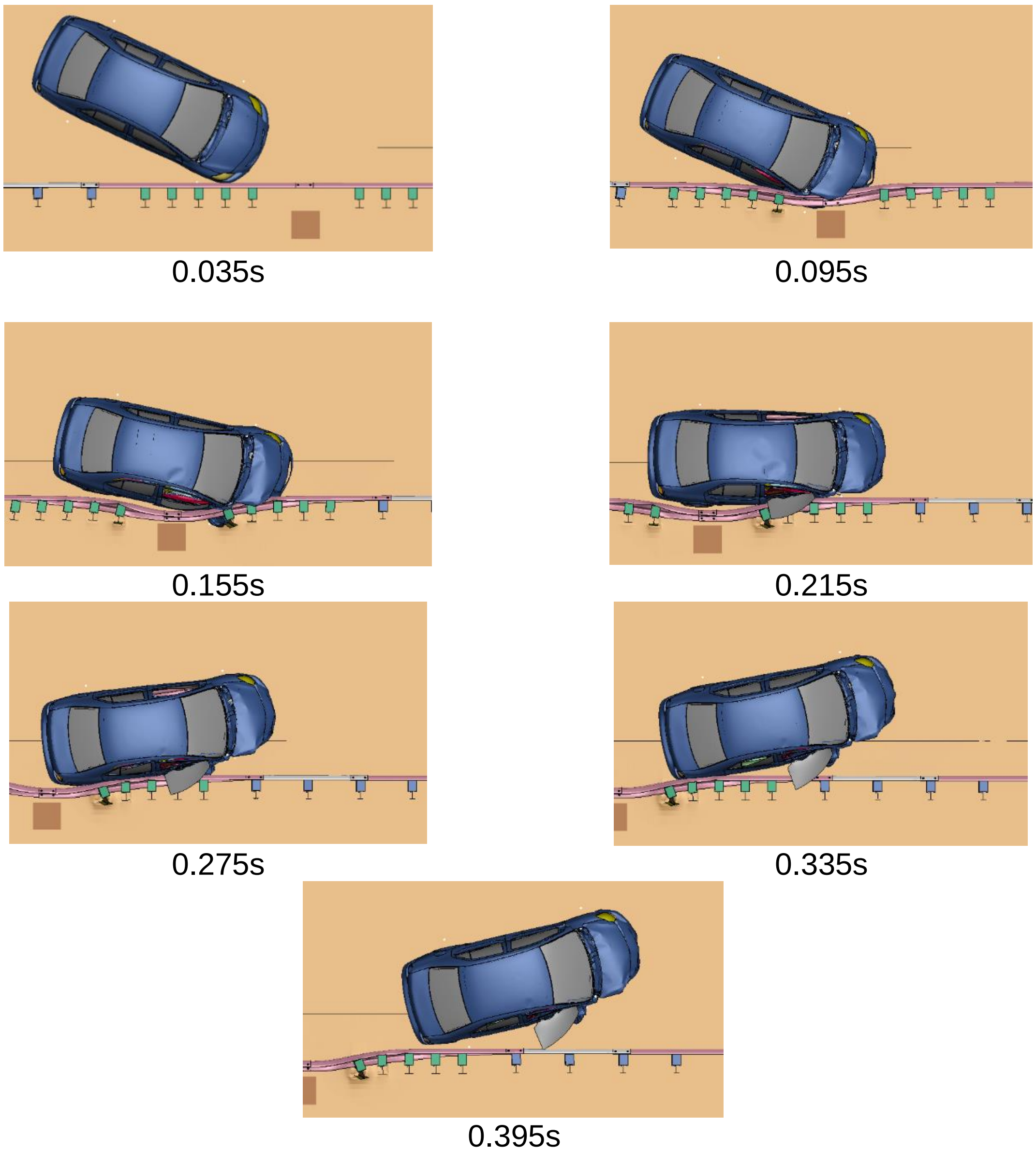


Figure 2.236. *MASH* Test 3-10 Simulation of Quarter-Post Small Gap with Fixed Object 16 inch Offset – Overhead View

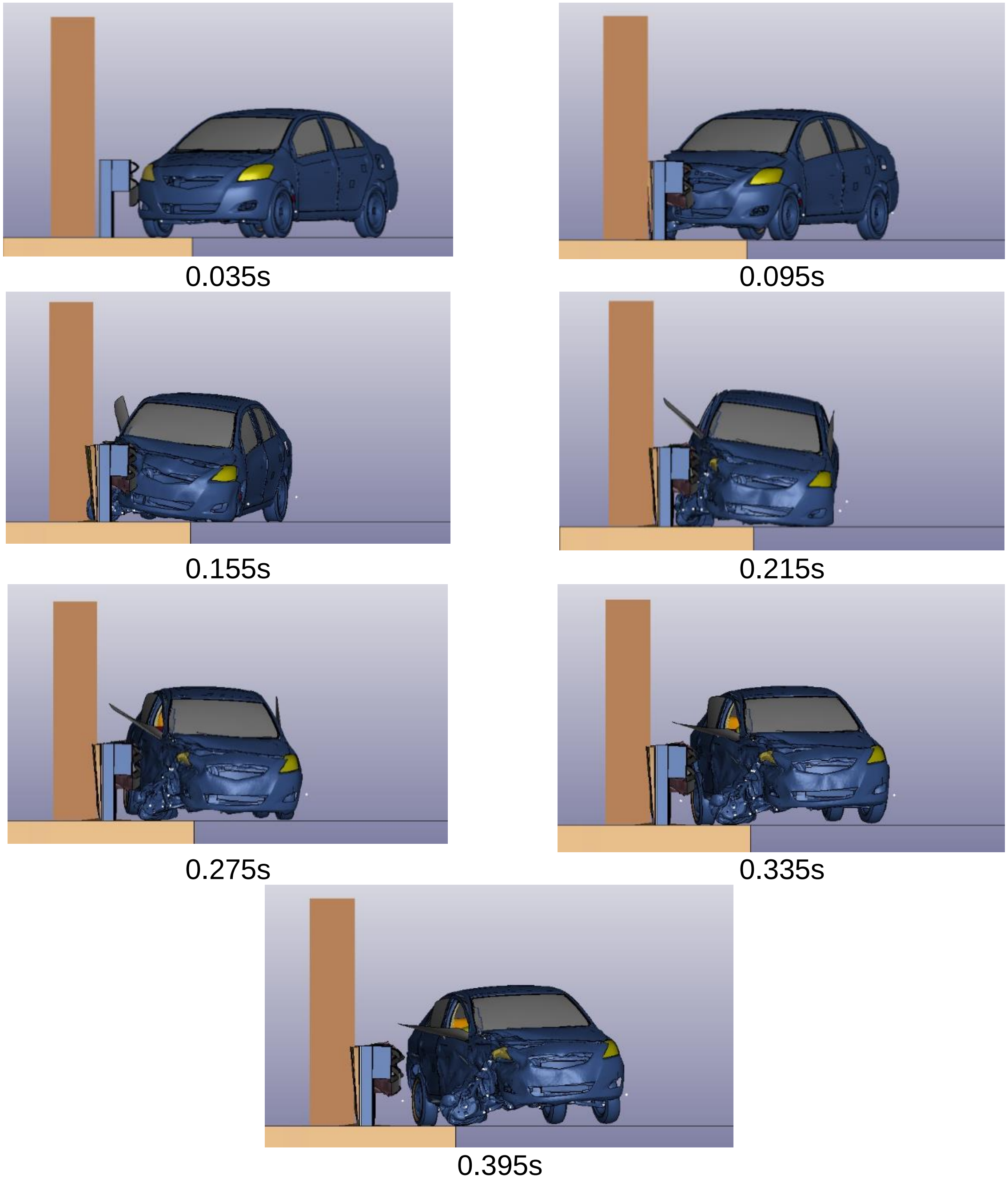


Figure 2.237. ***MASH*** **Test 3-10 Simulation of Quarter-Post Small Gap with Fixed Object 16 inch Offset – Downstream View**

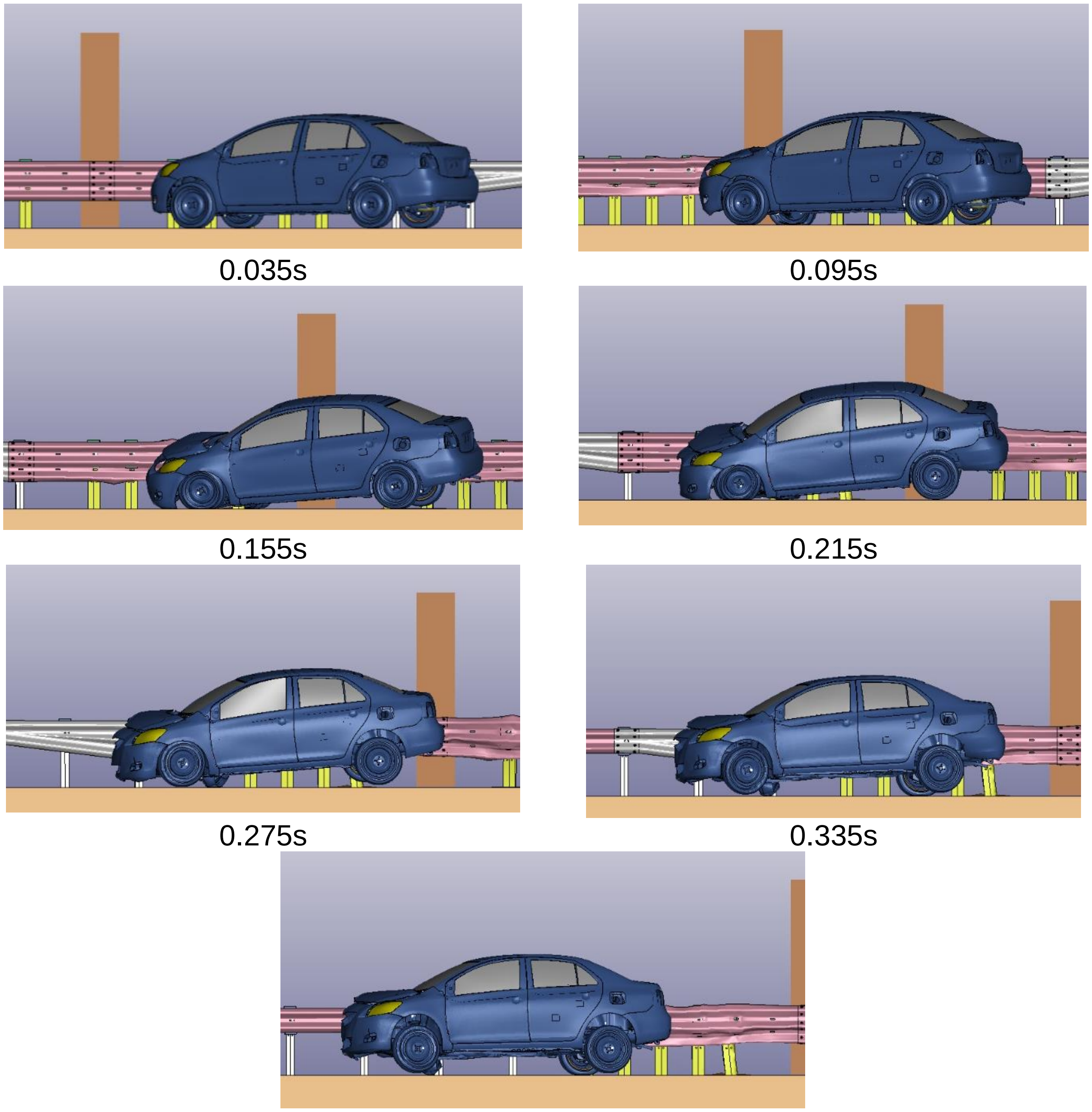


Figure 2.238. *MASH* Test 3-10 Simulation of Quarter-Post Small Gap with Fixed Object 16 inch Offset – Rear View

2.5.2.10. MASH Test 3-11 Simulation of Quarter-Post Spacing Small Gap with Fixed Object 20 inch Offset

Figure 2.239 through Figure 2.241 show the sequential frames of *MASH* test 3-11 with quarter-post spacing, small gap, and a fixed object offset of 20 inches. The occupant impact velocity was calculated to be 5.5 m/s (preferred limit is 9.1 m/s). The ridedown acceleration was calculated to be 18.0 g's (maximum limit is 20.49 g's). This configuration passed *MASH* test 3-11 by successfully containing and redirecting the vehicle. Because of the minimal to no interaction exhibited in this simulation, the research team evaluated multiple impact points to determine the most critical. These simulations are included in the following sections.

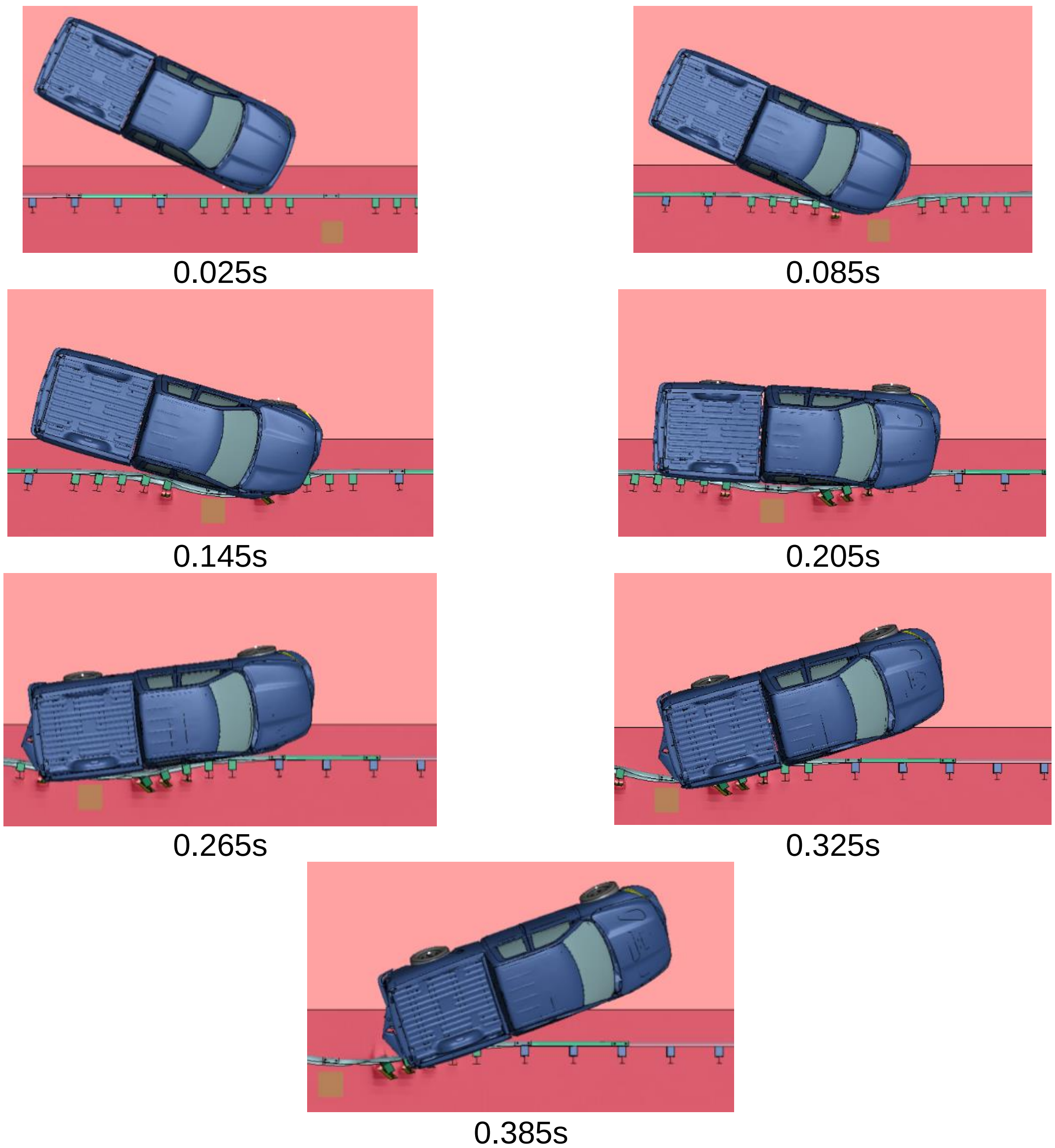


Figure 2.239. *MASH* Test 3-11 Simulation of Quarter-Post Small Gap with Fixed Object 20 inch Offset – Overhead View

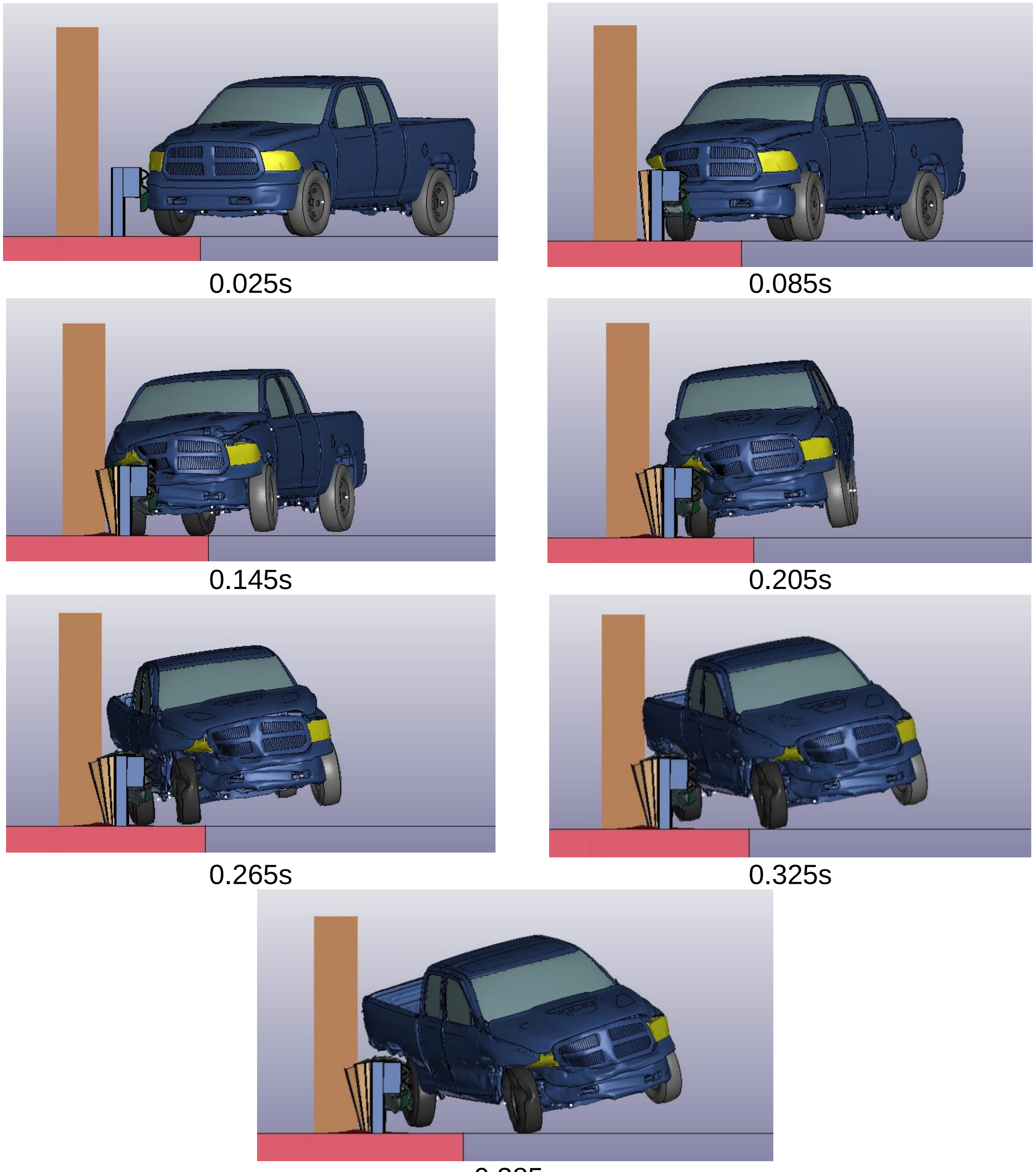


Figure 2.240. *MASH* Test 3-11 Simulation of Quarter-Post Small Gap with Fixed Object 20 inch Offset – Downstream View

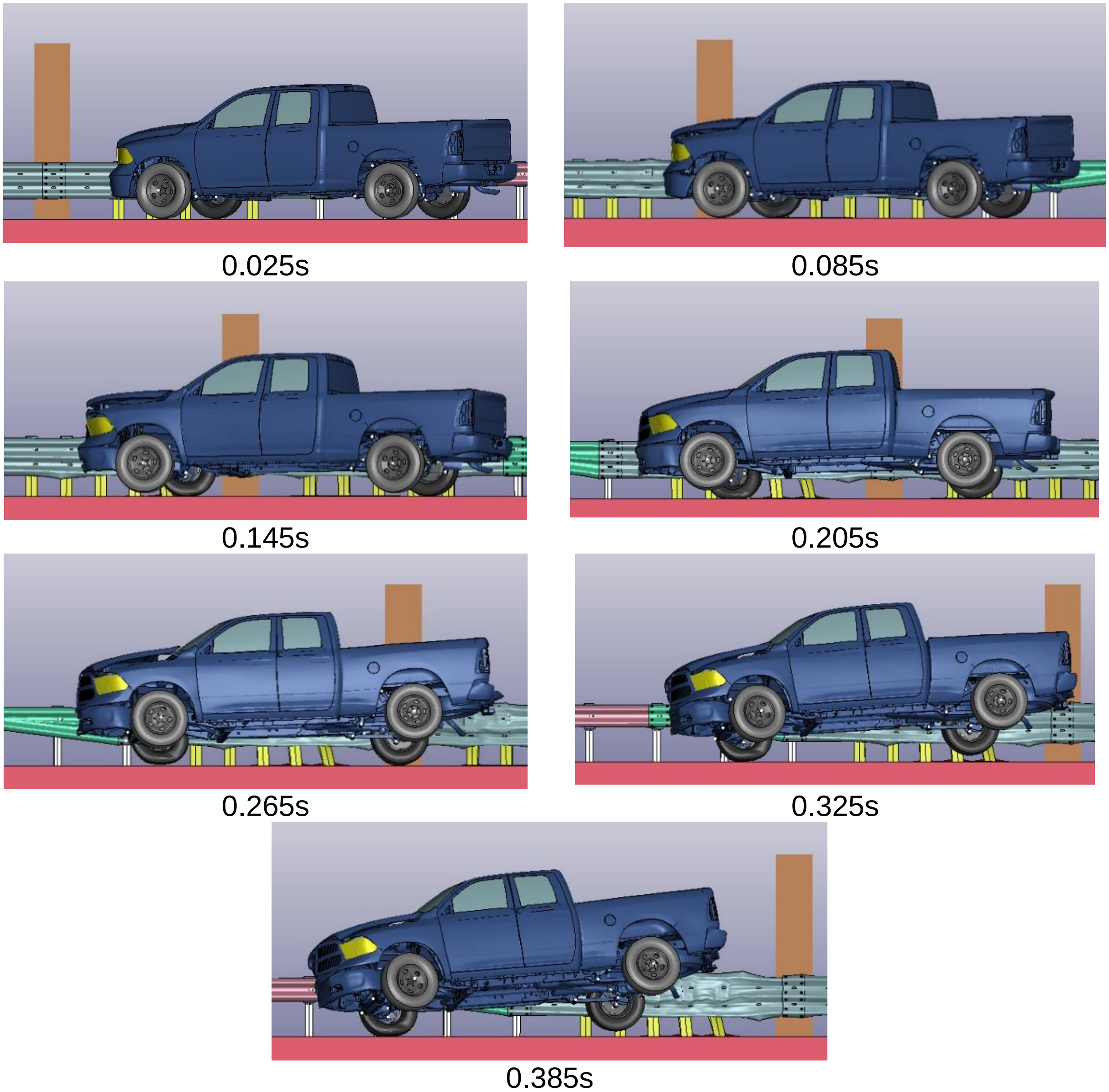


Figure 2.241. *MASH* Test 3-11 Simulation of Quarter-Post Small Gap with Fixed Object 20 inch Offset – Rear View

2.5.2.11. MASH Test 3-11 Simulation of Quarter-Post Spacing Small Gap with Fixed Object 20 inch Offset and 2 feet Upstream Impact Variation

Figure 2.242 through Figure 2.244 show the sequential frames of *MASH* test 3-11 with quarter-post spacing, small gap, a fixed object offset of 20 inches, and an impact variation positioned 2 feet upstream. The occupant impact velocity was calculated to be 6.1 m/s (preferred limit is 9.1 m/s). The ridedown acceleration was calculated to be 12.7 g's (preferred limit is 15.0 g's). This configuration passed *MASH* test 3-11 by successfully containing and redirecting the vehicle.

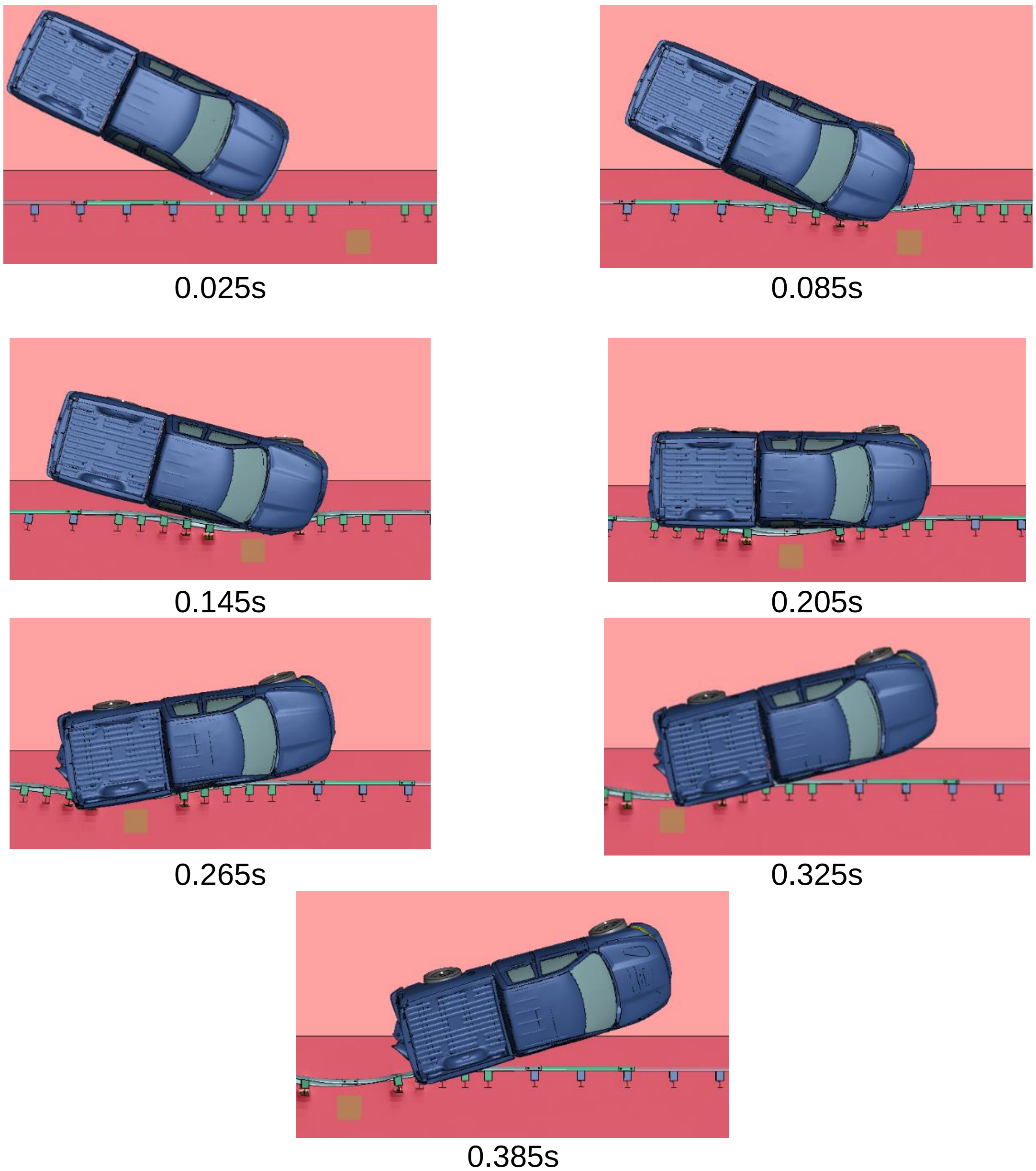
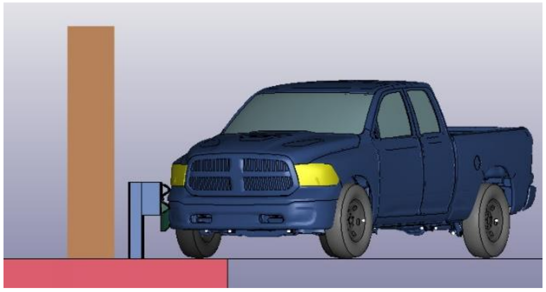


Figure 2.242. *MASH* Test 3-11 Simulation of Quarter-Post Small Gap with Fixed Object 20 inch Offset 2 feet Upstream Impact Variation – Overhead View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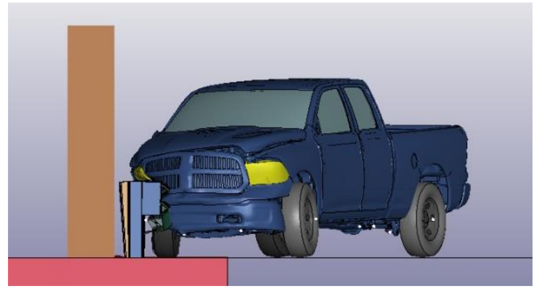
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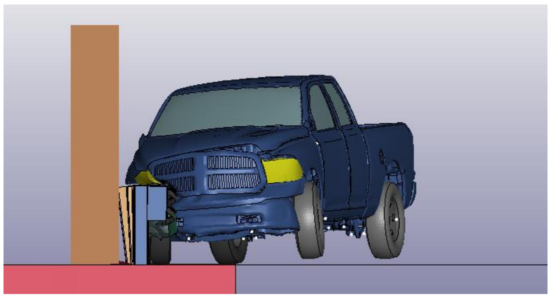
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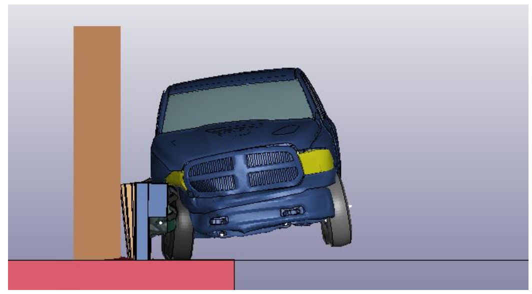
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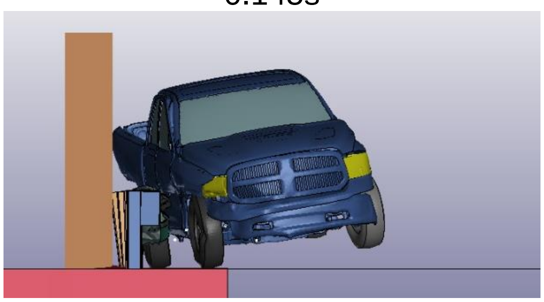
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0.325s

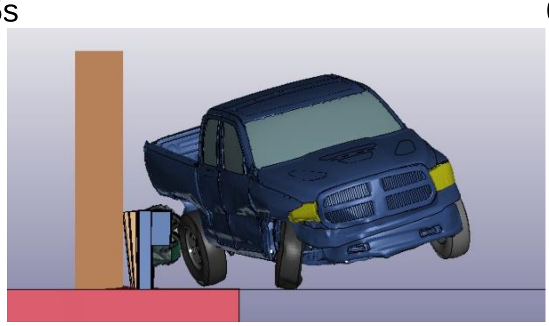
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Figure 2.243. *MASH* Test 3-11 Simulation of Quarter-Post Small Gap with Fixed Object 20 inch Offset 2 feet Upstream Impact Variation– Downstream View

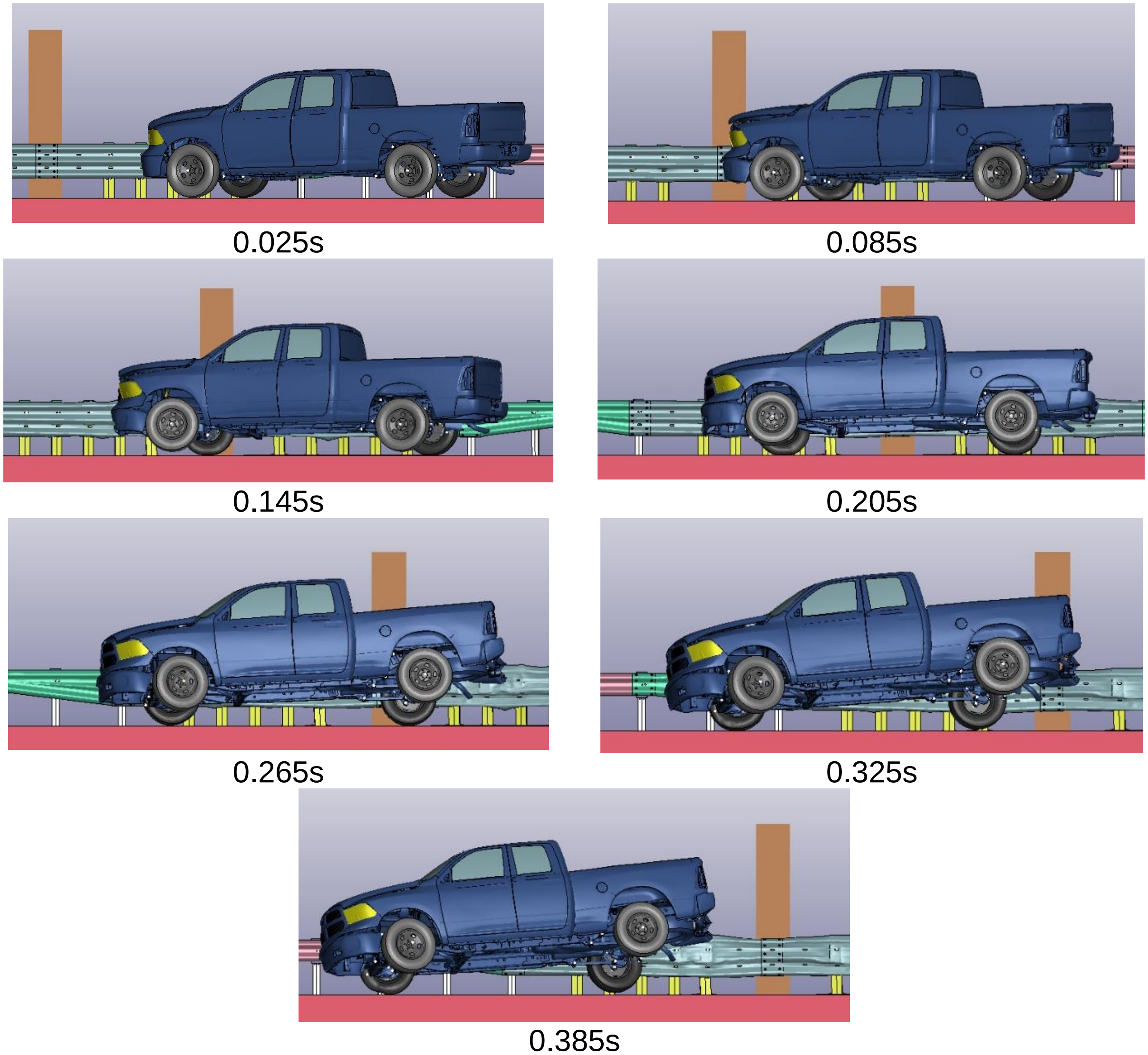
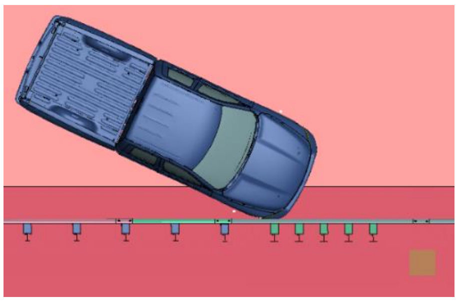


Figure 2.244. *MASH* Test 3-11 Simulation of Quarter-Post Small Gap with Fixed Object 20 inch Offset 2 feet Upstream Impact Variation– Rear View

2.5.2.12. MASH Test 3-11 Simulation of Quarter-Post Spacing Small Gap with Fixed Object 20 inch Offset and 4 feet Upstream Impact Variation

Figure 2.245 through Figure 2.247 show the sequential frames of *MASH* test 3-11 with quarter-post spacing, small gap, a fixed object offset of 20 inches, and an impact variation positioned 4 feet upstream. The occupant impact velocity was calculated to be 7.5 m/s (preferred limit is 9.1 m/s). The ridedown acceleration was calculated to be 9.5 g's (preferred limit is 15.0 g's). This configuration passed *MASH* test 3-11 by successfully containing and redirecting the vehicle.



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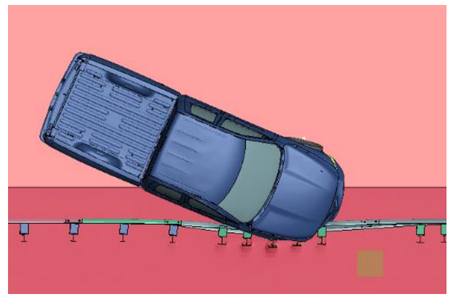

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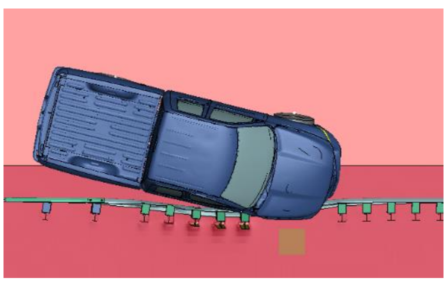

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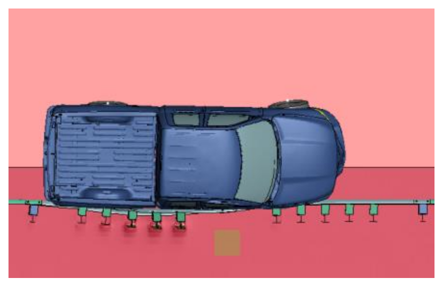

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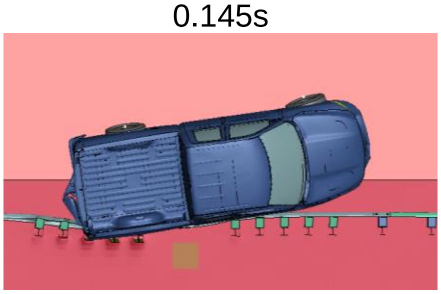

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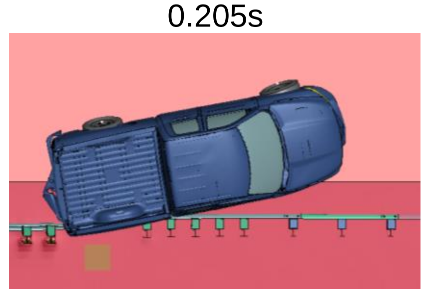

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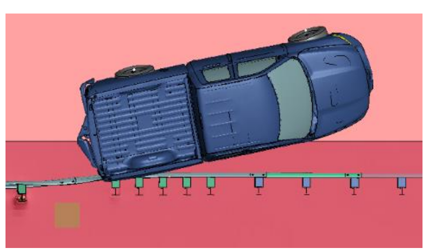

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Figure 2.245. *MASH* Test 3-11 Simulation of Quarter-Post Small Gap with Fixed Object 20 inch Offset 4 feet Upstream Impact Variation – Overhead View

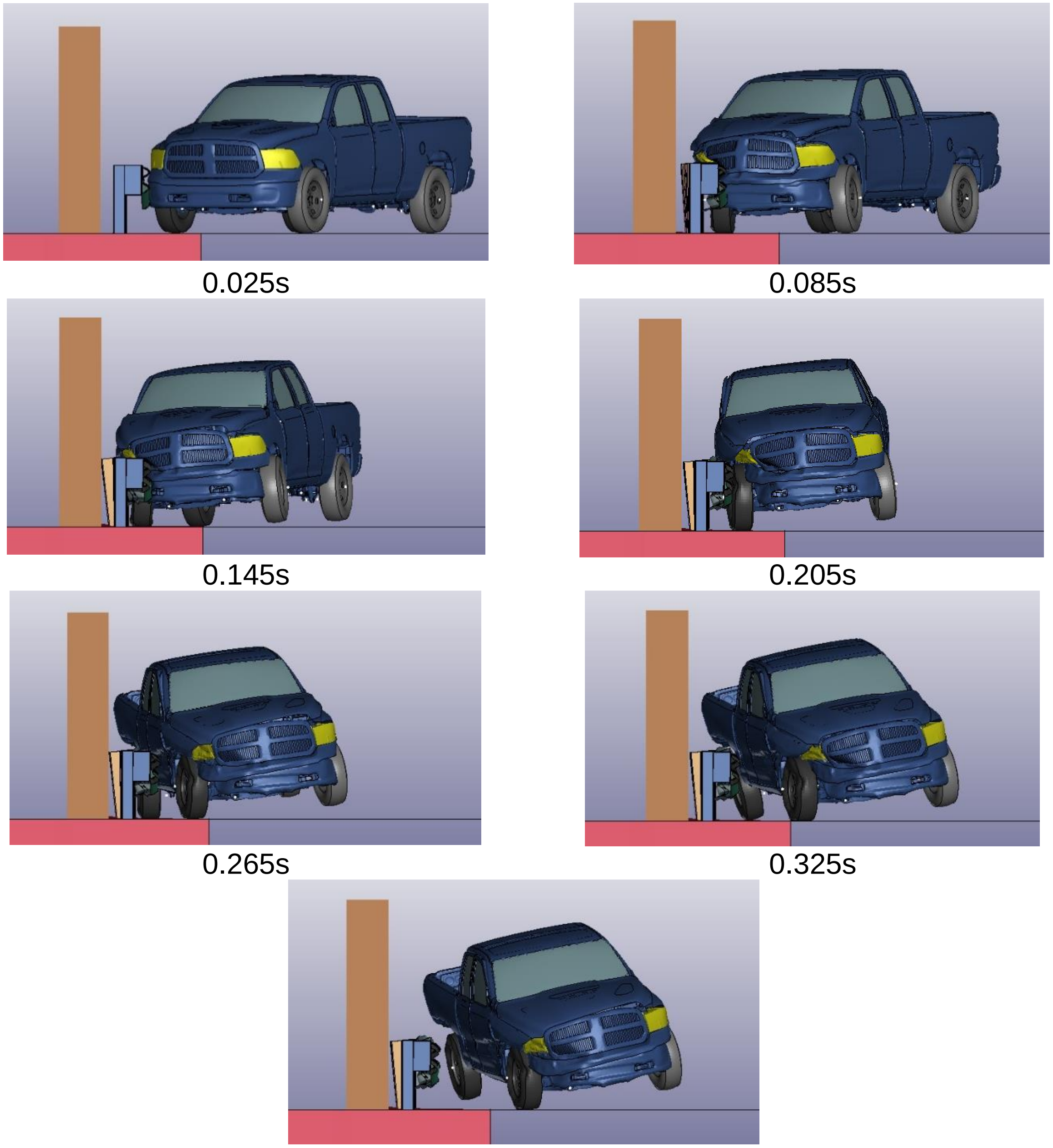
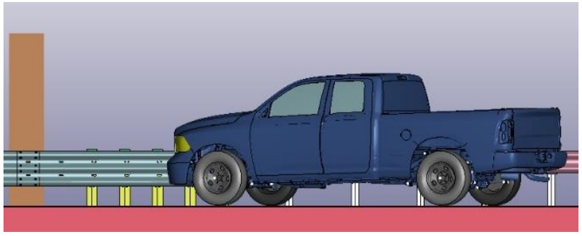


Figure 2.246. *MASH* Test 3-11 Simulation of Quarter-Post Small Gap with Fixed Object 20 inch Offset 4 feet Upstream Impact Variation– Downstream View



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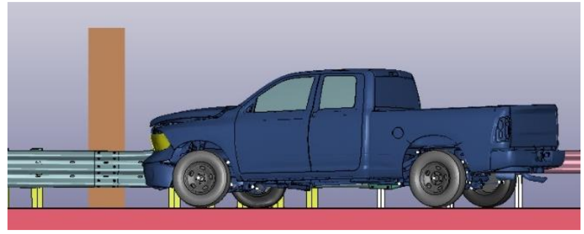

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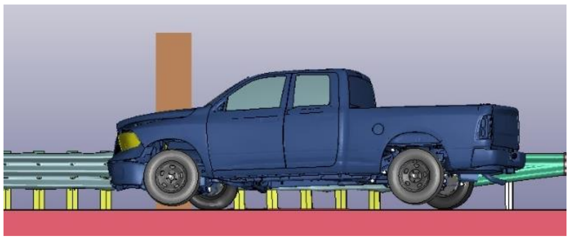

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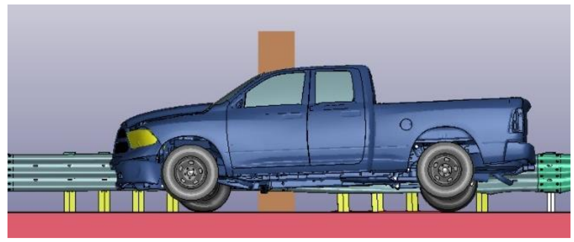

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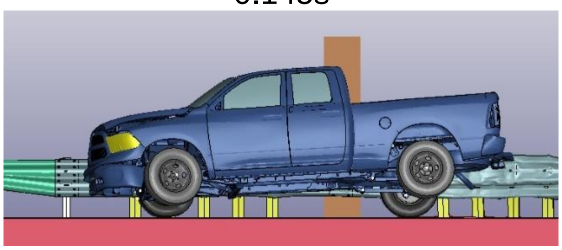

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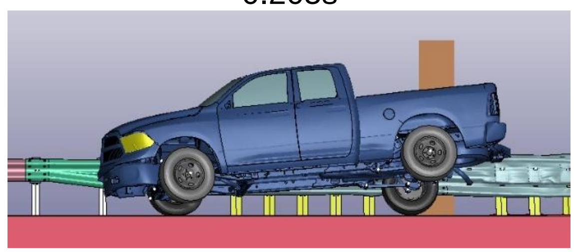

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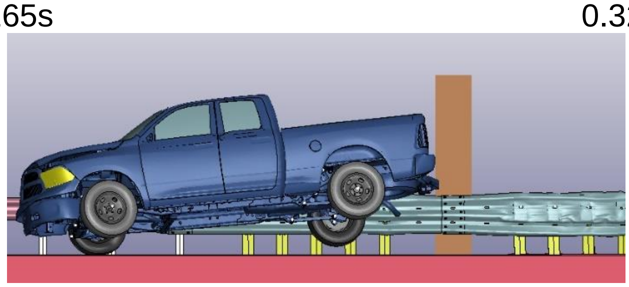


0.385s

Figure 2.247. *MASH* Test 3-11 Simulation of Quarter-Post Small Gap with Fixed Object 20 inch Offset 4 feet Upstream Impact Variation– Rear View

2.5.2.13. MASH Test 3-11 Simulation of Quarter-Post Spacing Small Gap with Fixed Object 20 inch Offset and 6 feet Upstream Impact Variation

Figure 2.248 through Figure 2.250 show the sequential frames of *MASH* test 3-11 with quarter-post spacing, small gap, a fixed object offset of 20 inches, and an impact variation positioned 6 feet upstream. The occupant impact velocity was calculated to be 7.8 m/s (preferred limit is 9.1 m/s). The ridedown acceleration was calculated to be 9.8 g's (preferred limit is 15.0 g's). This configuration passed *MASH* test 3-11 by successfully containing and redirecting the vehicle.

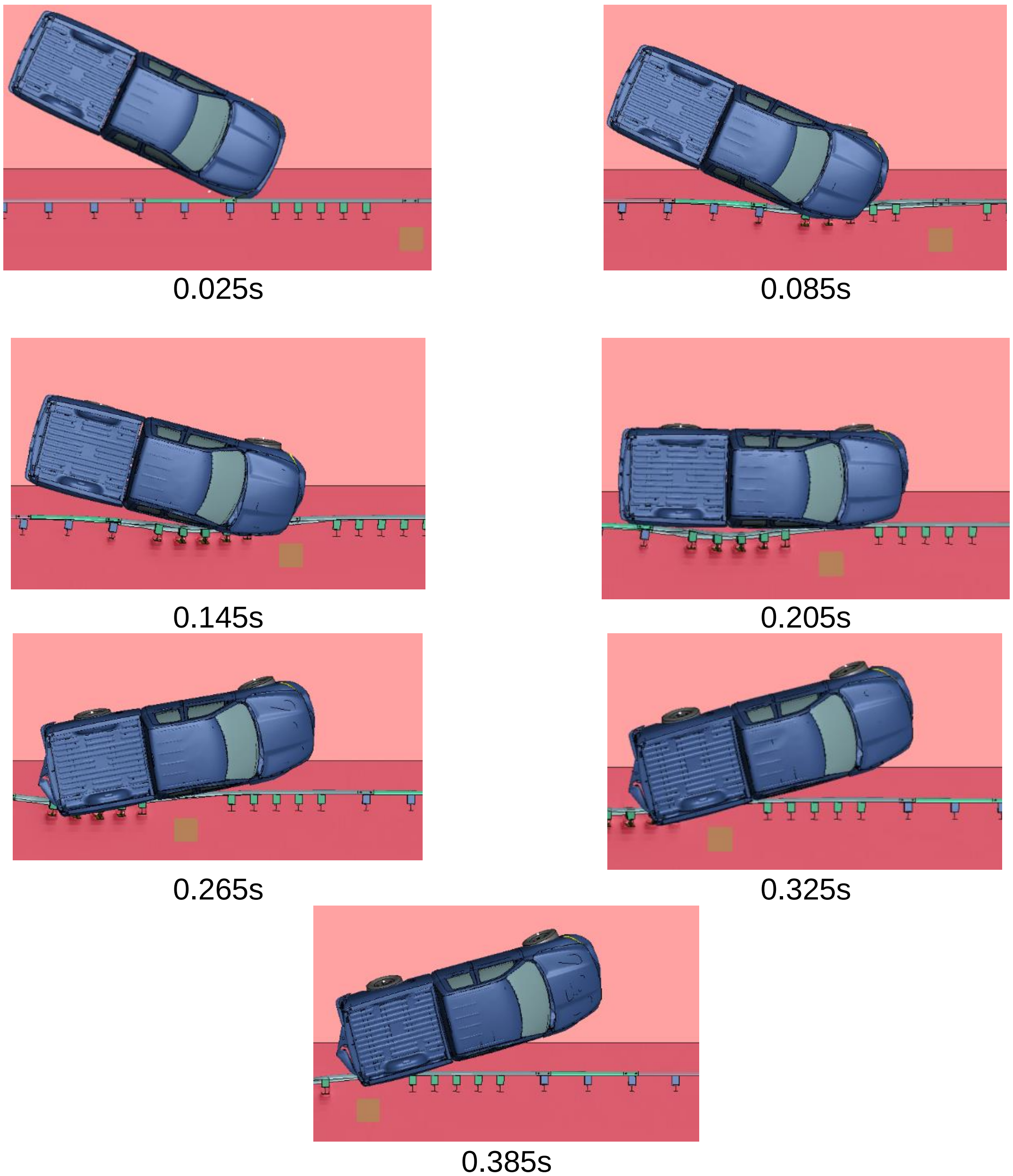
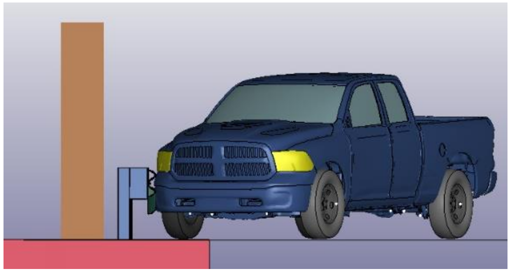


Figure 2.248. *MASH* Test 3-11 Simulation of Quarter-Post Small Gap with Fixed Object 20 inch Offset 6 feet Upstream Impact Variation – Overhead View



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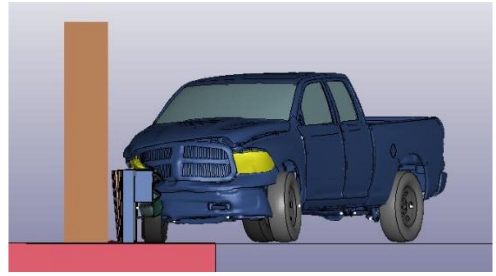

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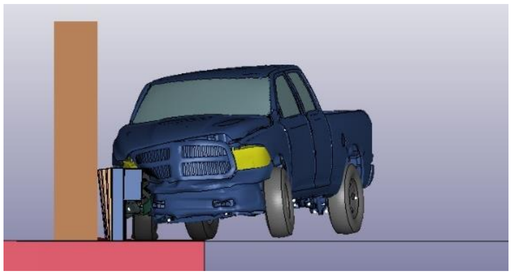

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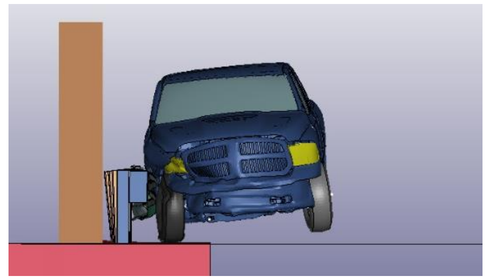

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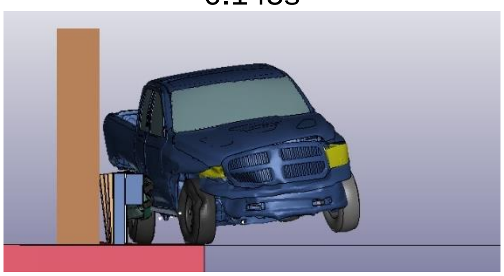

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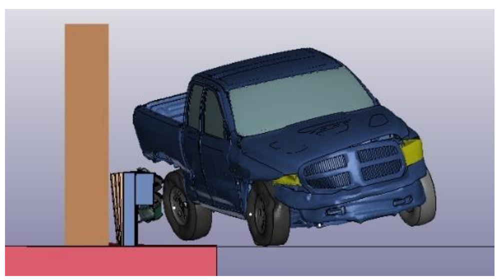


0.385s

Figure 2.249. *MASH* Test 3-11 Simulation of Quarter-Post Small Gap with Fixed Object 20 inch Offset 6 feet Upstream Impact Variation– Downstream View

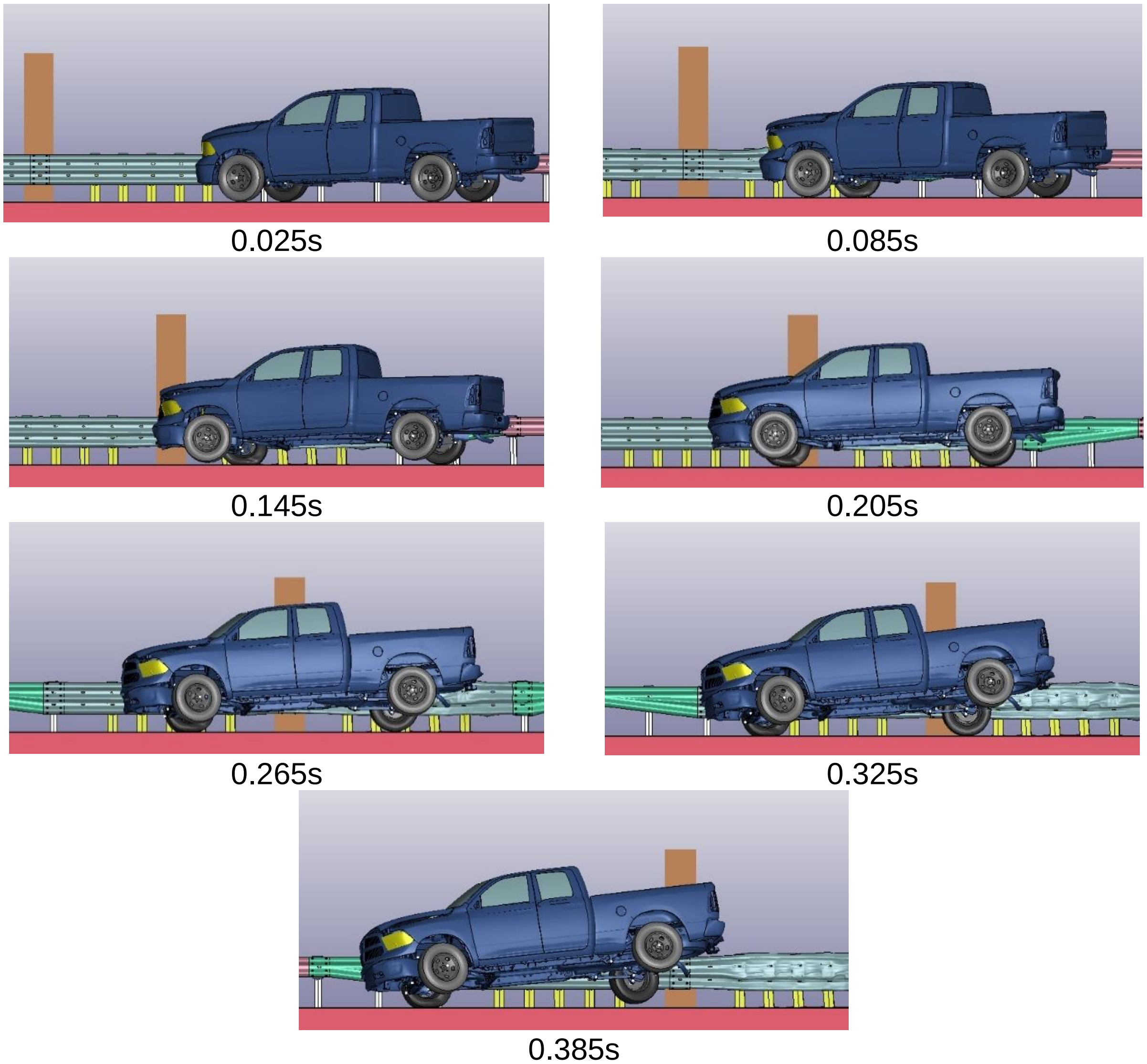


Figure 2.250. *MASH* Test 3-11 Simulation of Quarter-Post Small Gap with Fixed Object 20 inch Offset 6 feet Upstream Impact Variation– Rear View

2.5.2.14. MASH Test 3-11 Simulation of Quarter-Post Spacing Small Gap with Fixed Object 20 inch Offset and 2 feet Downstream Impact Variation

Figure 2.251 through Figure 2.253 show the sequential frames of *MASH* test 3-11 with quarter-post spacing, small gap, a fixed object offset of 20 inches, and an impact variation positioned 2 feet downstream. The occupant impact velocity was calculated to be 7.5 m/s (preferred limit is 9.1 m/s). The ridedown acceleration was calculated to be 18.2 g’s (preferred limit is 15.0 g’s). This configuration passed *MASH* test 3-11 by successfully containing and redirecting the vehicle.

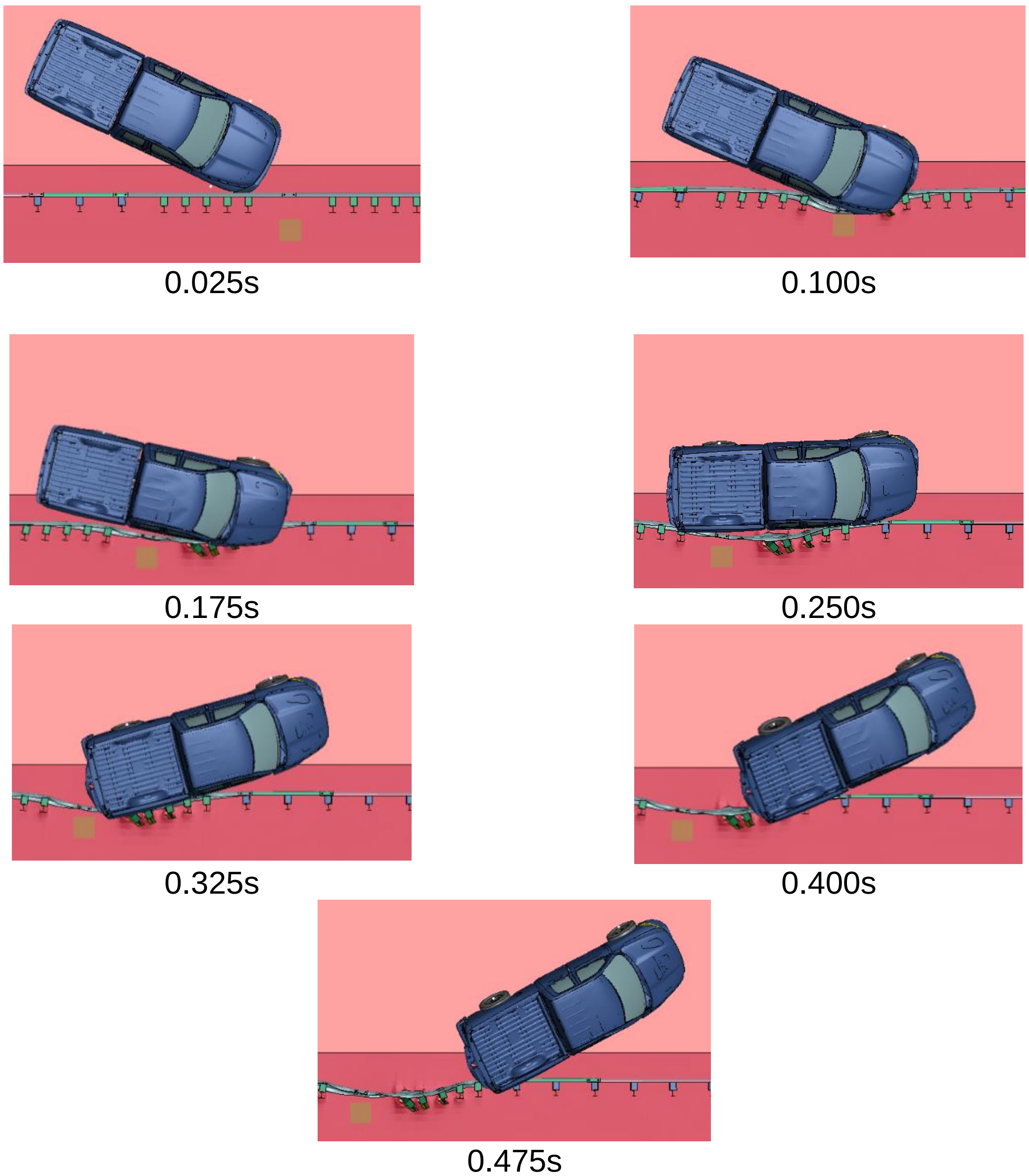


Figure 2.251. *MASH* Test 3-11 Simulation of Quarter-Post Small Gap with Fixed Object 20 inch Offset 2 feet Downstream Impact Variation – Overhead View

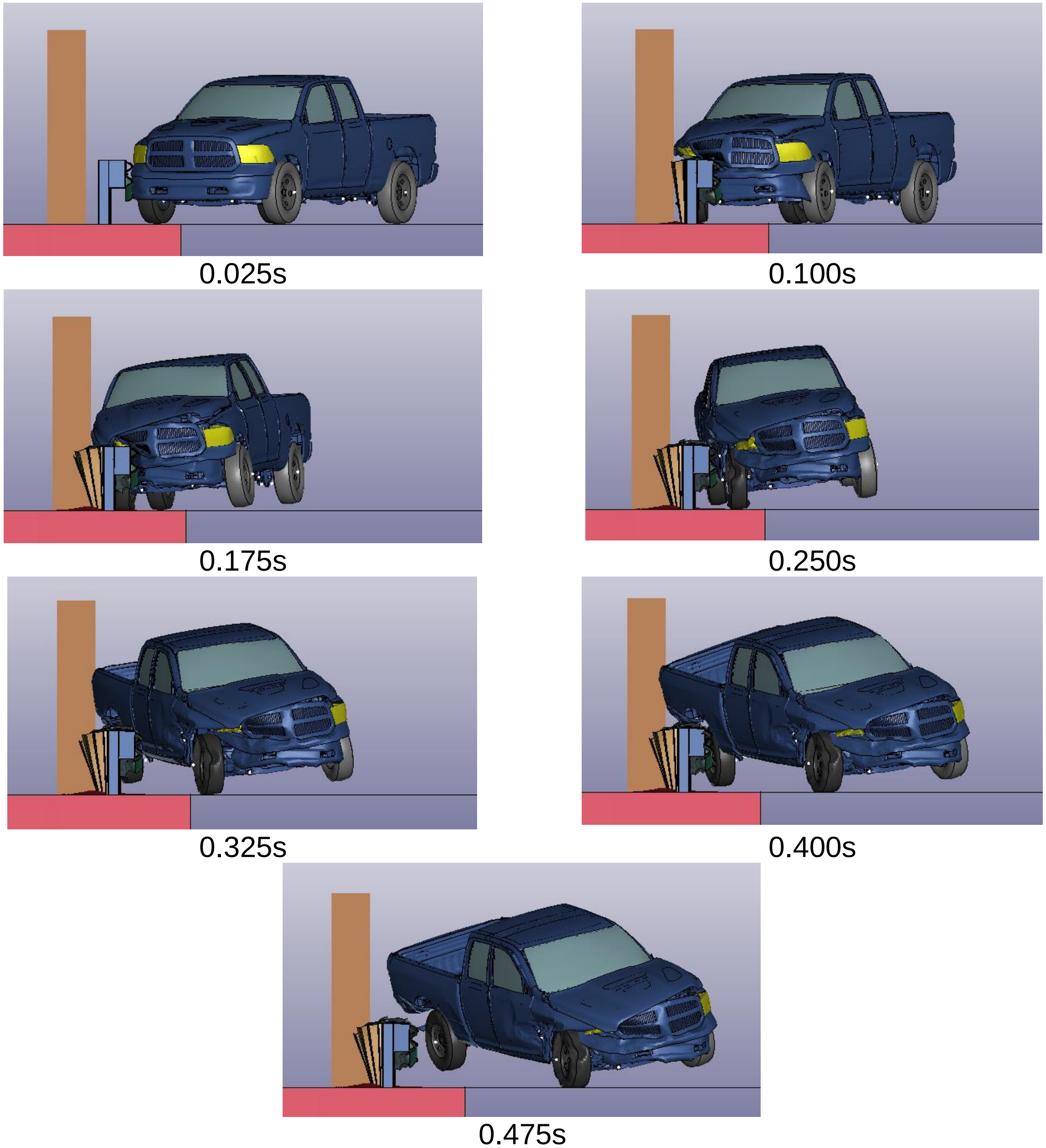


Figure 2.252. ***MASH*** **Test 3-11 Simulation of Quarter-Post Small Gap with Fixed Object 20 inch Offset 2 feet Downstream Impact Variation– Downstream View**

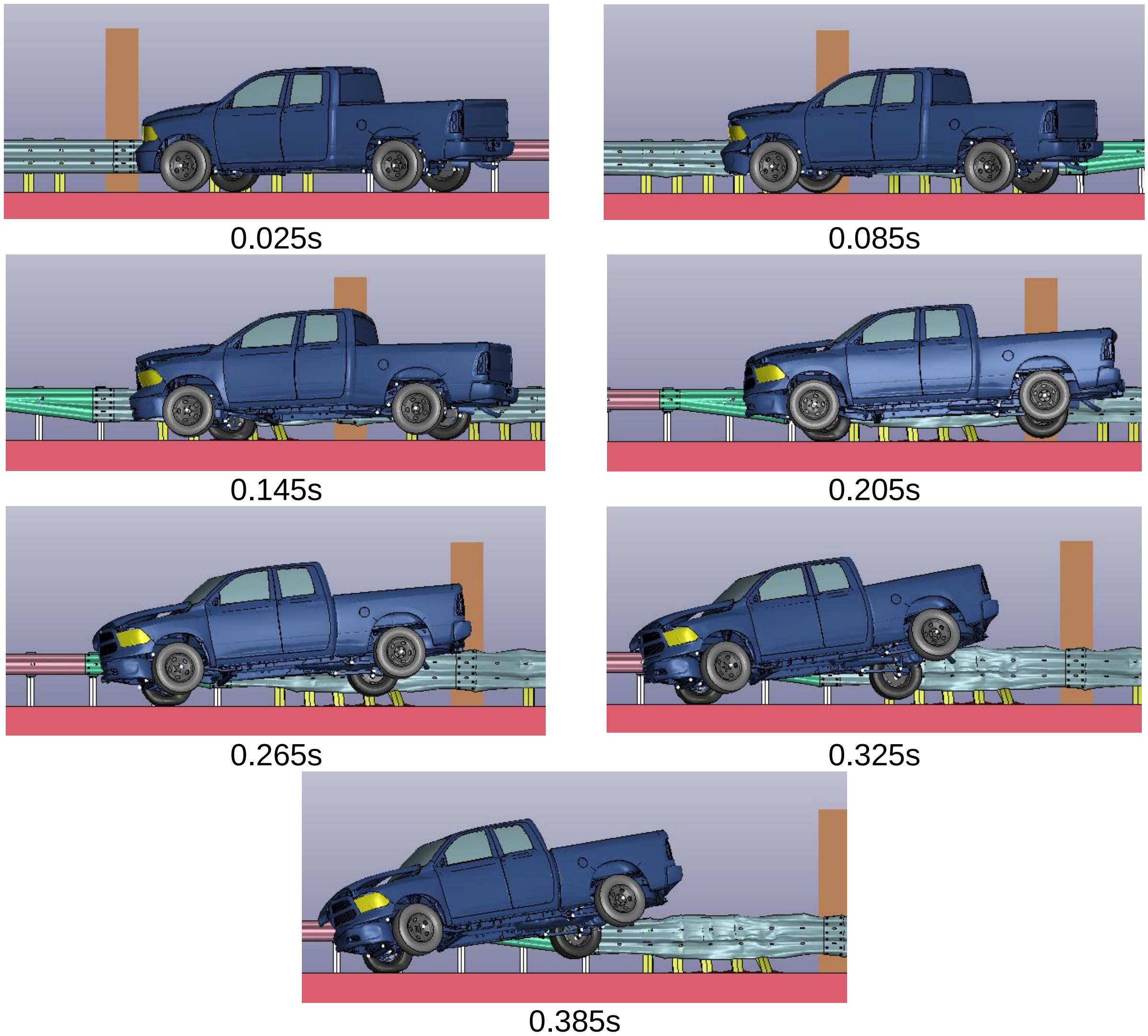
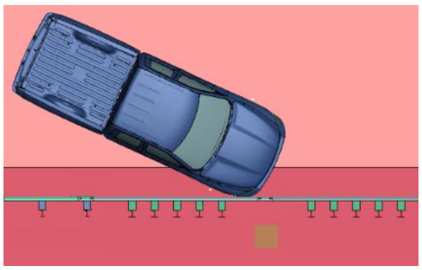


Figure 2.253. *MASH* Test 3-11 Simulation of Quarter-Post Small Gap with Fixed Object 20 inch Offset 2 feet Downstream Impact Variation– Rear View

2.5.2.15. *MASH Test 3-11 Simulation of Quarter-Post Spacing Small Gap with Fixed Object 20 inch Offset and 4 feet Downstream Impact Variation*

Figure 2.254 through Figure 2.256 show the sequential frames of *MASH* test 3-11 with quarter-post spacing, small gap, a fixed object offset of 20 inches, and an impact variation positioned 4 feet downstream. The occupant impact velocity was calculated to be 8.4 m/s (preferred limit is 9.1 m/s). The ridedown acceleration was calculated to be 12.0 g’s (preferred limit is 15.0 g’s). This configuration passed *MASH* test 3-11 by successfully containing and redirecting the vehicle.



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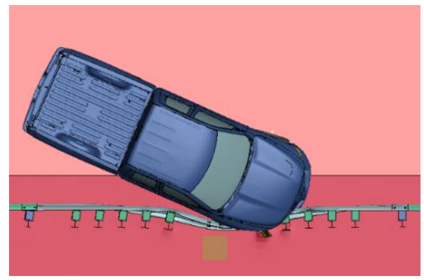

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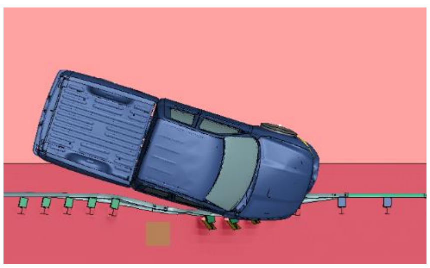

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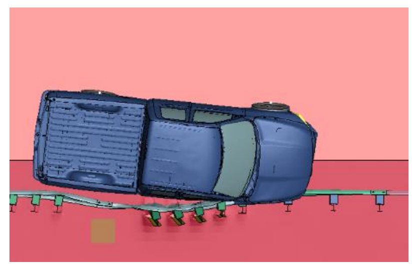

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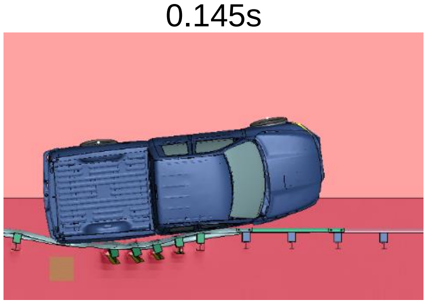
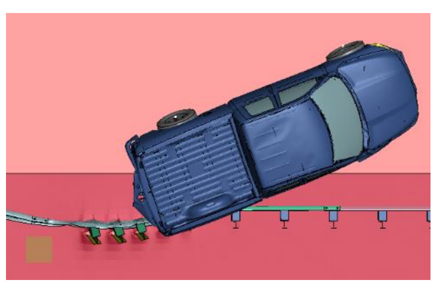


0.265s

0.325s



0.385s

Figure 2.254. *MASH* Test 3-11 Simulation of Quarter-Post Small Gap with Fixed Object 20 inch Offset 4 feet Downstream Impact Variation – Overhead View

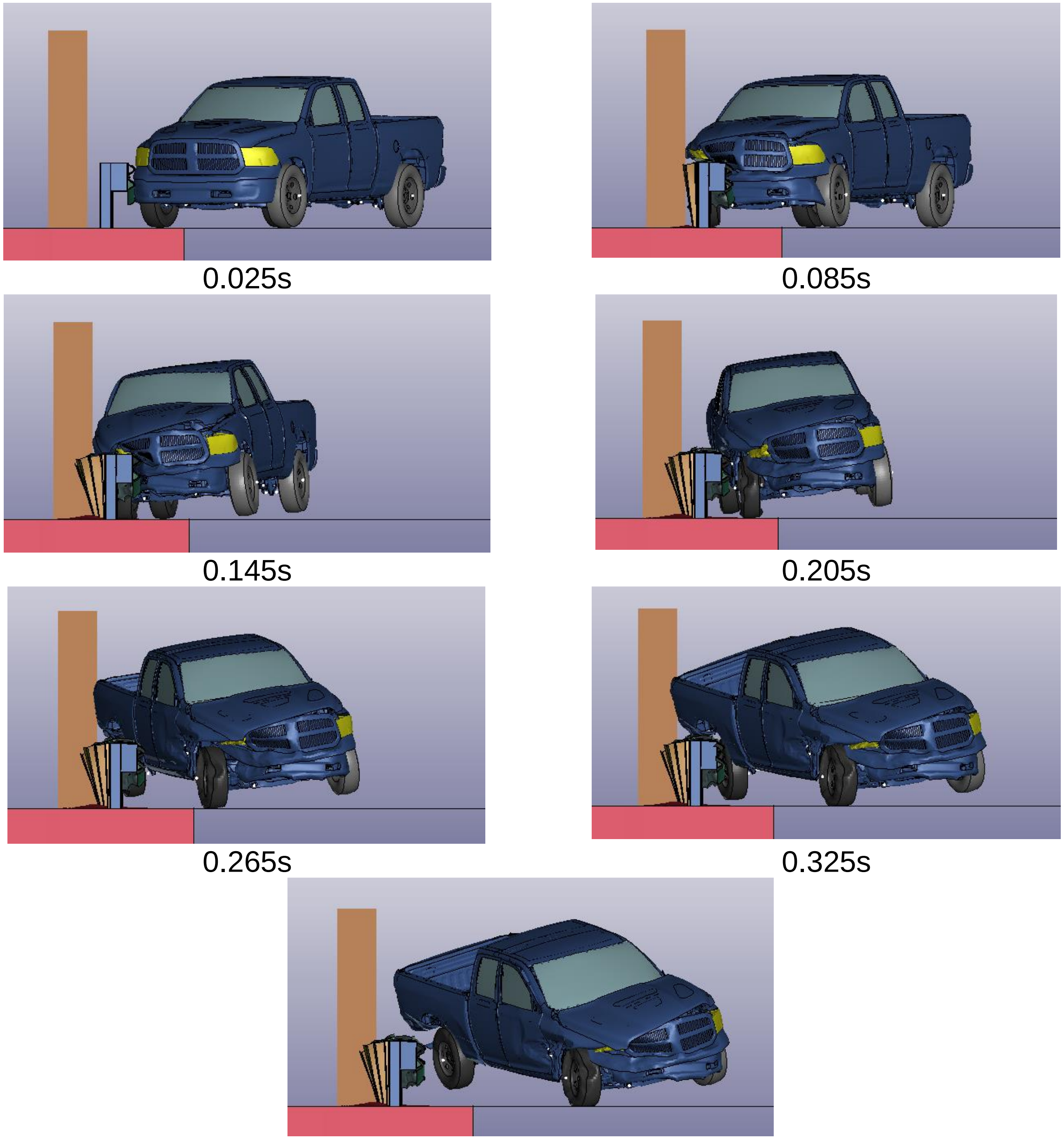


Figure 2.255. *MASH* Test 3-11 Simulation of Quarter-Post Small Gap with Fixed Object 20 inch Offset 4 feet Downstream Impact Variation– Downstream View

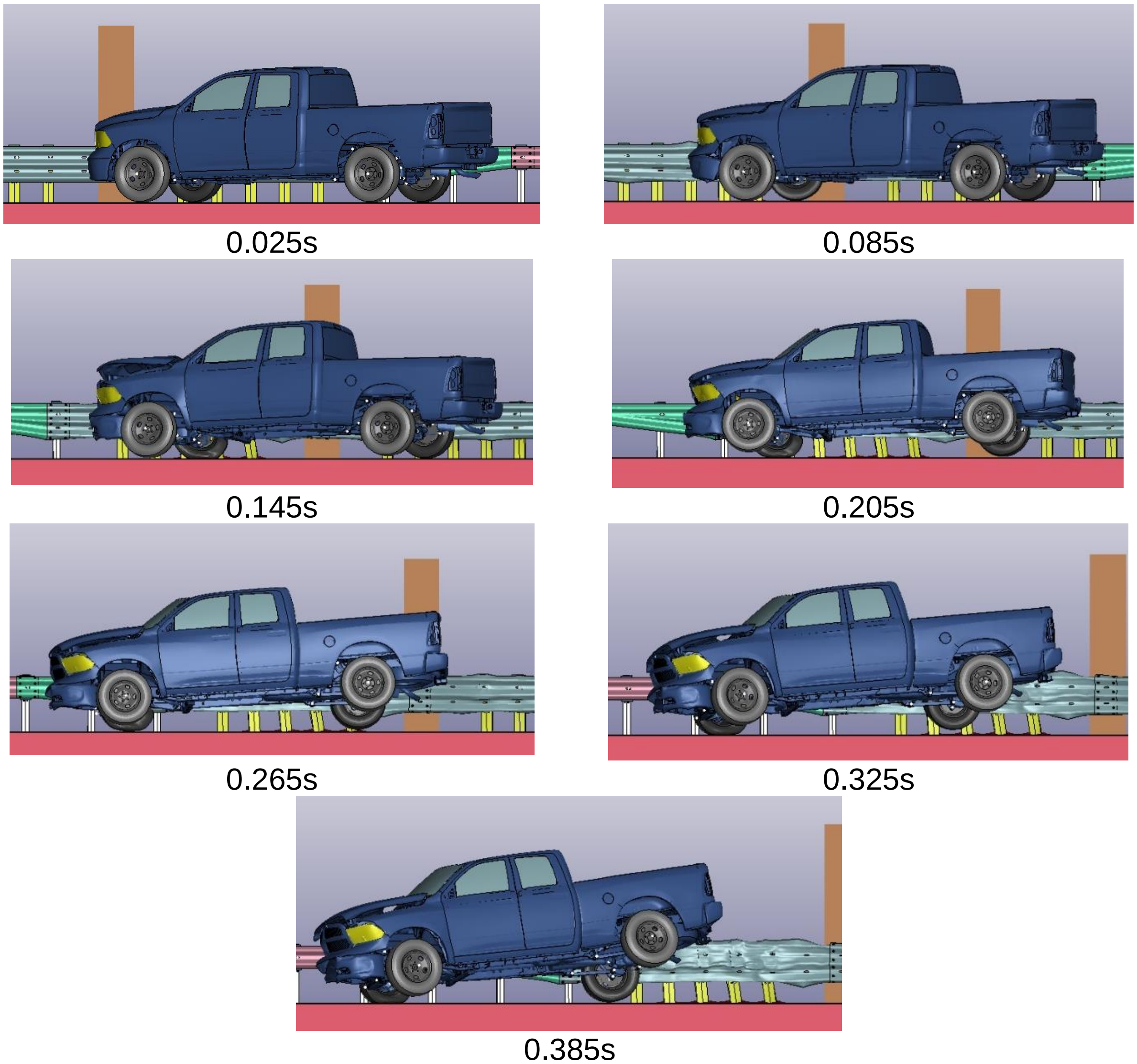


Figure 2.256. ***MASH*** **Test 3-11 Simulation of Quarter-Post Small Gap with Fixed Object 20 inch Offset 4 feet Downstream Impact Variation– Rear View**

2.5.2.16. MASH Test 3-11 Simulation of Quarter-Post Spacing Small Gap with Fixed Object 20 inch Offset and 6 feet Downstream Impact Variation

Figure 2.257 through Figure 2.259 show the sequential frames of *MASH* test 3-11 with quarter-post spacing, small gap, a fixed object offset of 20 inches, and an impact variation positioned 6 feet downstream. The occupant impact velocity was calculated to be 7.7 m/s (preferred limit is 9.1 m/s). The ridedown acceleration was calculated to be 11.8 g's (preferred limit is 15.0 g's). This configuration passed *MASH* test 3-11 by successfully containing and redirecting the vehicle.

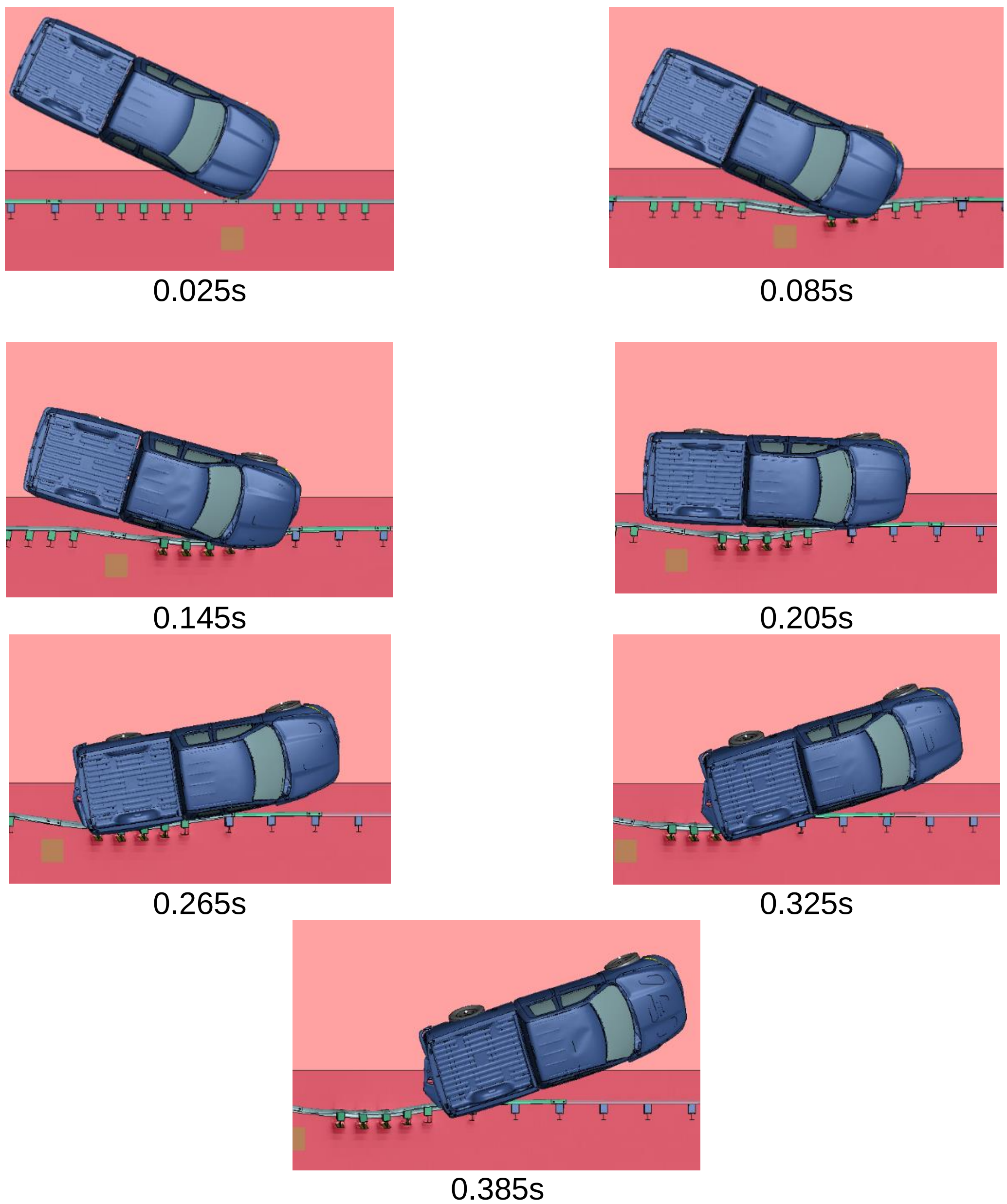


Figure 2.257. *MASH* Test 3-11 Simulation of Quarter-Post Small Gap with Fixed Object 20 inch Offset 6 feet Downstream Impact Variation – Overhead View

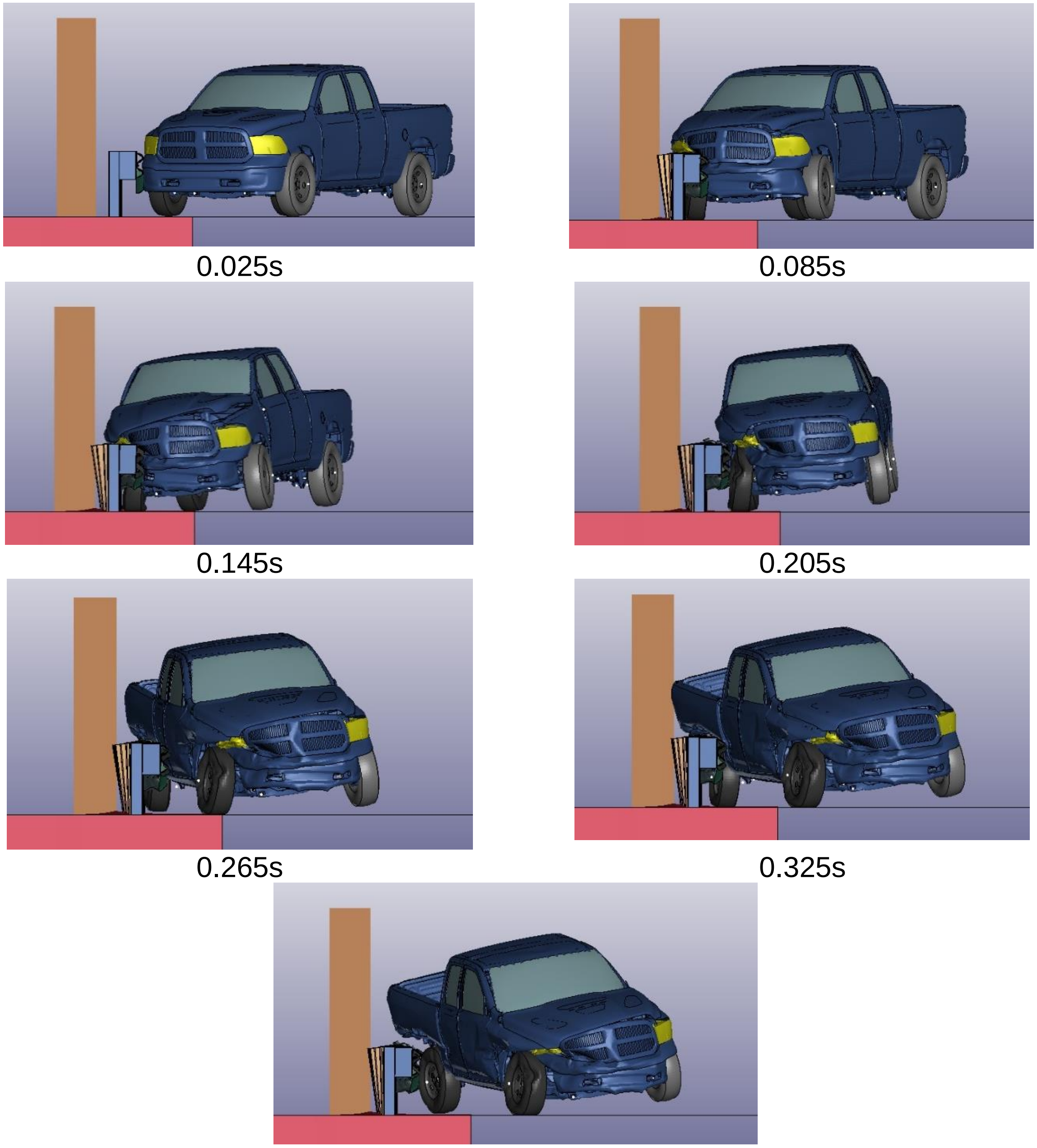
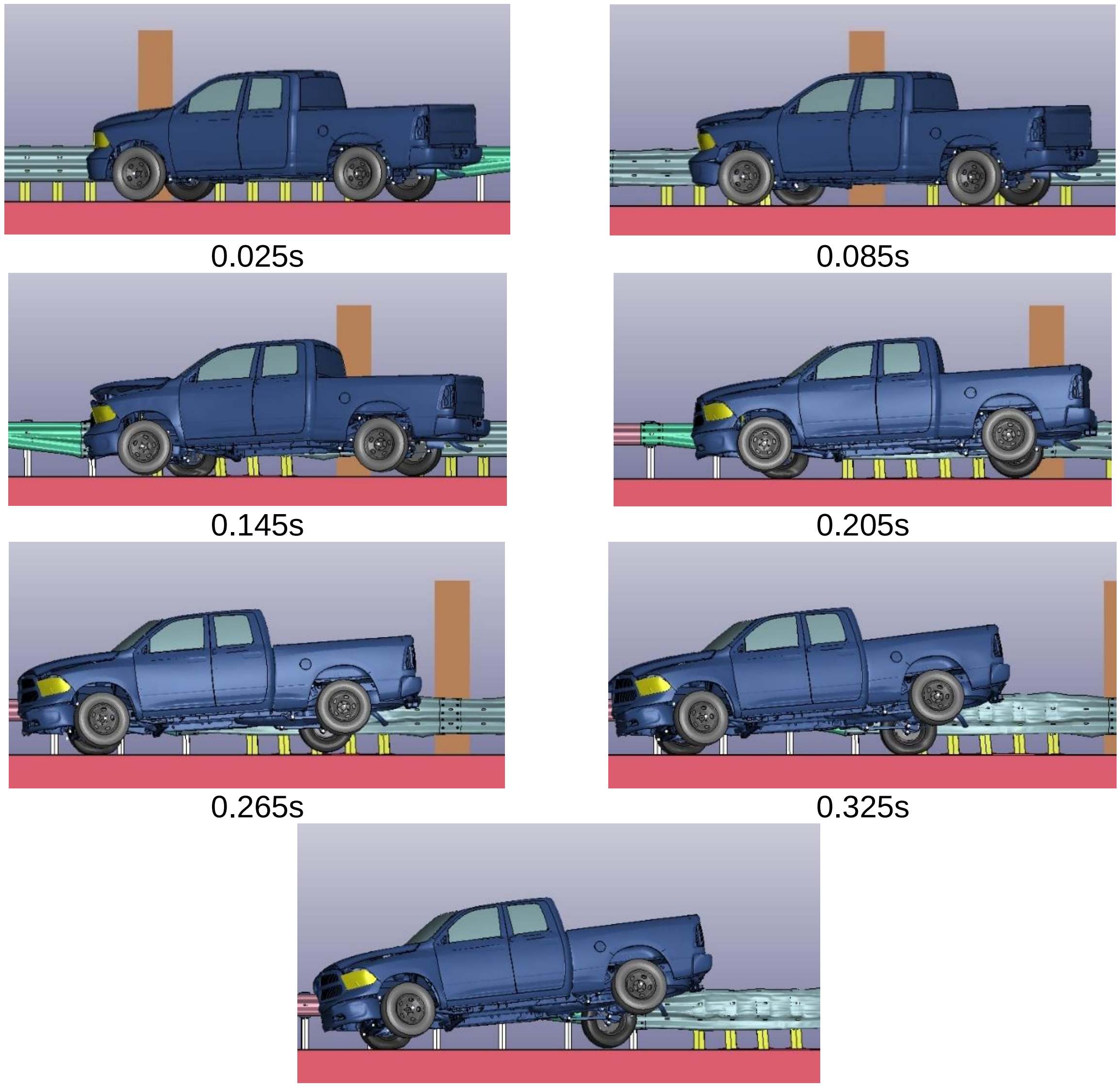


Figure 2.258. *MASH* Test 3-11 Simulation of Quarter-Post Small Gap with Fixed Object 20 inch Offset 6 feet Downstream Impact Variation– Downstream View



0.025s 0.085s

0.145s 0.205s

0.265s 0.325s

0.385s

Figure 2.259. *MASH* Test 3-11 Simulation of Quarter-Post Small Gap with Fixed Object 20 inch Offset 6 feet Downstream Impact Variation– Rear View

2.5.2.17. MASH Test 3-10 Simulation of Quarter-Post Spacing Small Gap with Fixed Object 20 inch Offset

Figure 2.260 through Figure 2.262 show the sequential frames of MASH test 3-10 with quarter-post spacing, small gap, and a fixed object offset of 20 inches. The OIV was calculated to be 7.4 m/s (preferred limit is 9.1 m/s). The RDA was calculated to be 17.4 g's (maximum limit is 20.49 g's). This configuration passed *MASH* test 3-10 by successfully containing and redirecting the vehicle.

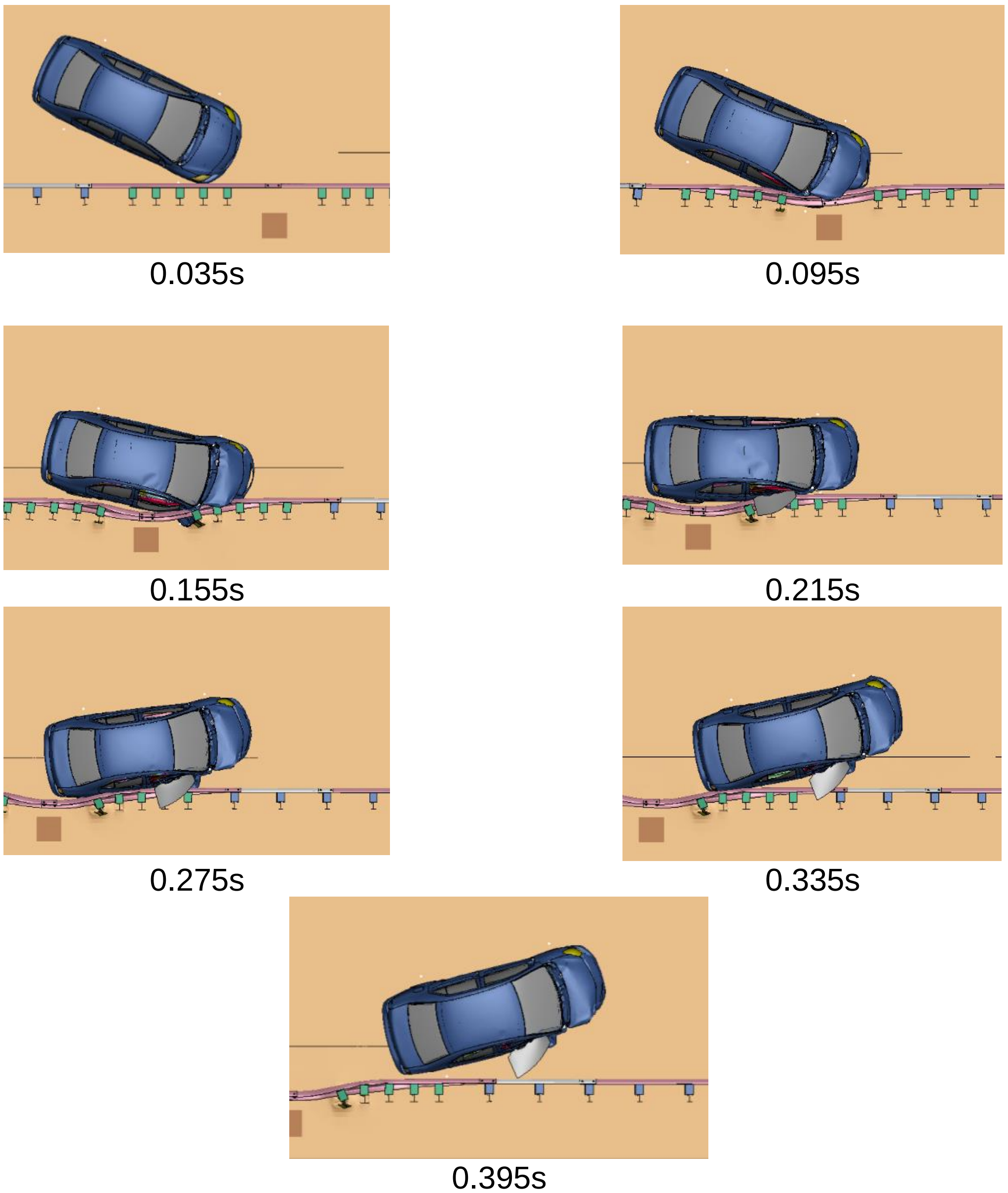


Figure 2.260. *MASH* Test 3-10 Simulation of Quarter-Post Small Gap with Fixed Object 20 inch Offset – Overhead View

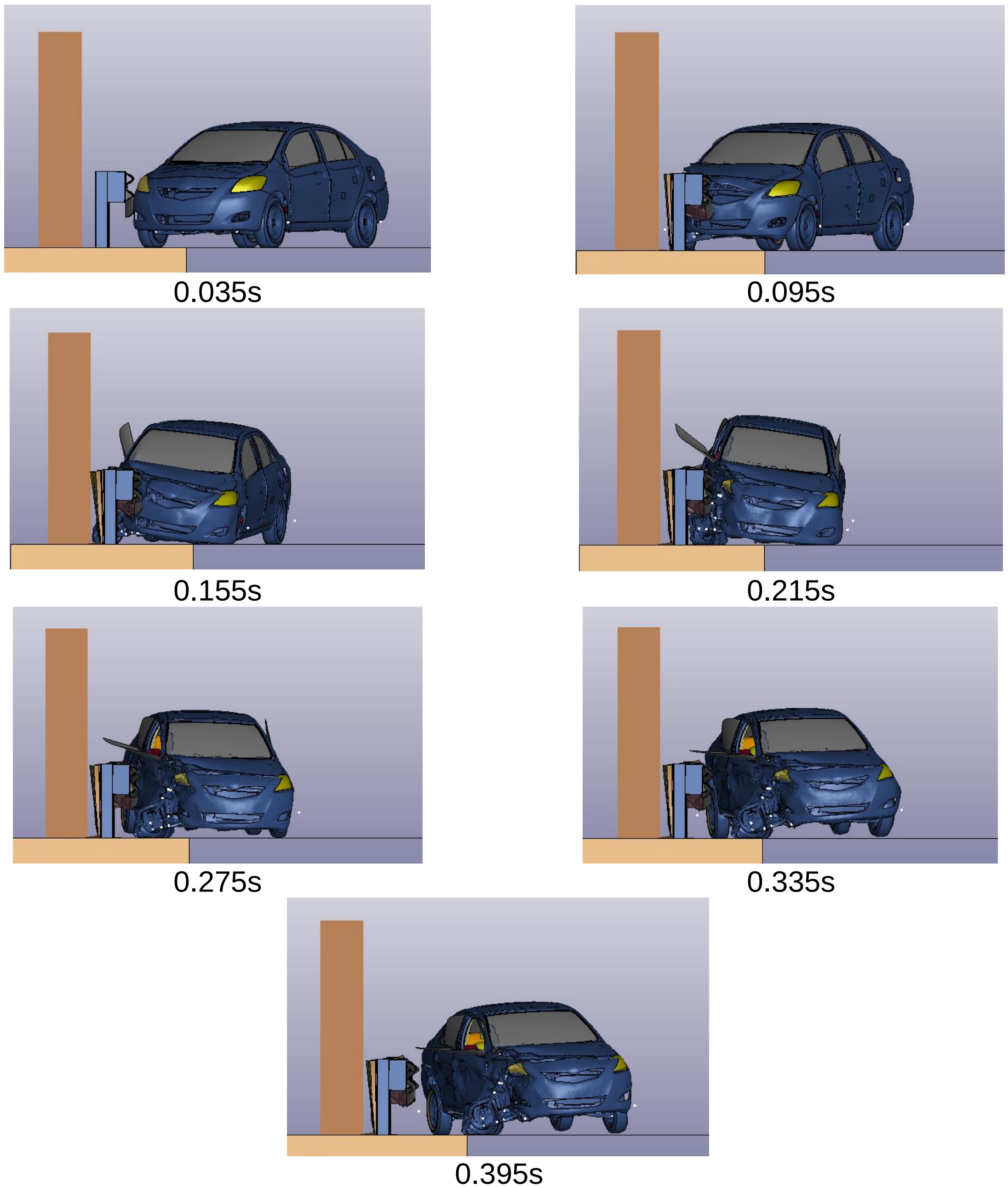


Figure 2.261. *MASH* Test 3-10 Simulation of Quarter-Post Small Gap with Fixed Object 20 inch Offset – Downstream View

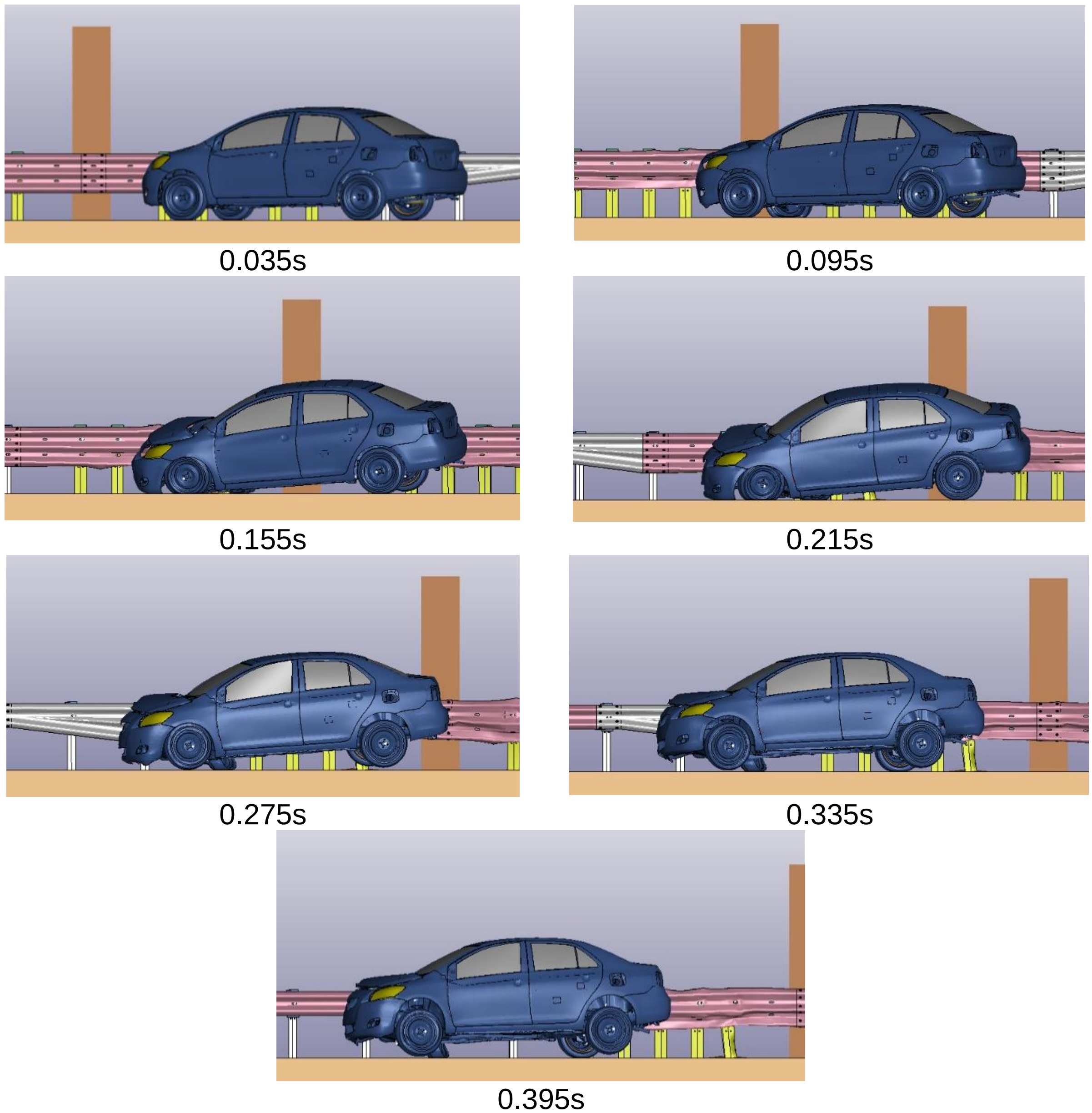


Figure 2.262. ***MASH*** **Test 3-10 Simulation of Quarter-Post Small Gap with Fixed Object 20 inch Offset – Rear View**

2.5.2.18. MASH Test 3-10 Simulation of Quarter-Post Spacing Small Gap with Fixed Object 20 inch Offset and 2 feet Upstream Impact Variation

Figure 2.263 through Figure 2.265 show the sequential frames of MASH test 3-10 with quarter-post spacing, small gap, a fixed object offset of 20 inches, and an impact variation positioned 2 feet upstream. The OIV was calculated to be 8.0 m/s (preferred limit is 9.1 m/s). The RDA was calculated to be 8.8 g's (preferred limit is 15.0 g's). This configuration passed *MASH* test 3-10 by successfully containing and redirecting the vehicle.

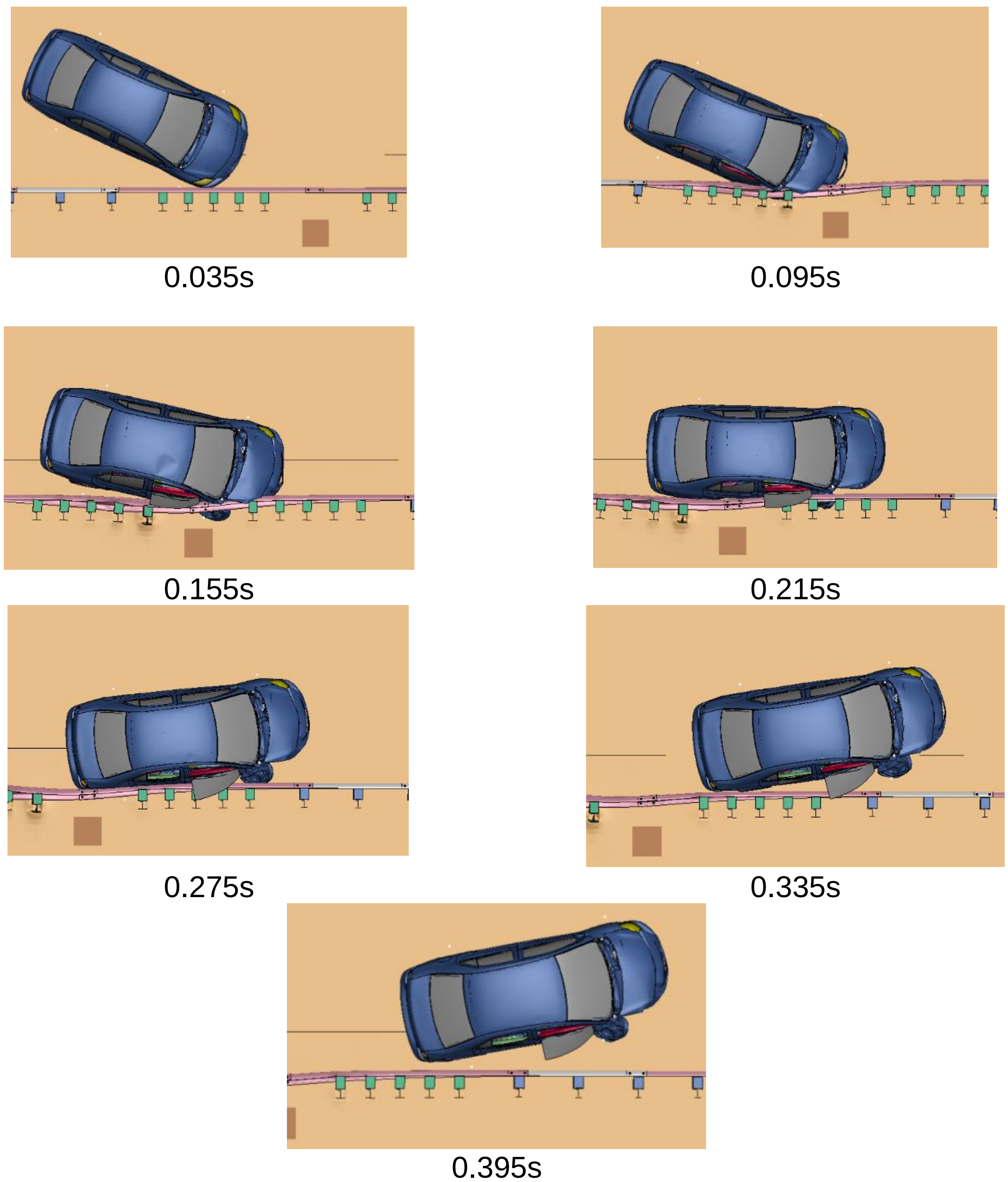


Figure 2.263. *MASH* Test 3-10 Simulation of Quarter-Post Small Gap with Fixed Object 20 inch Offset 2 feet Upstream Impact Variation – Overhead View

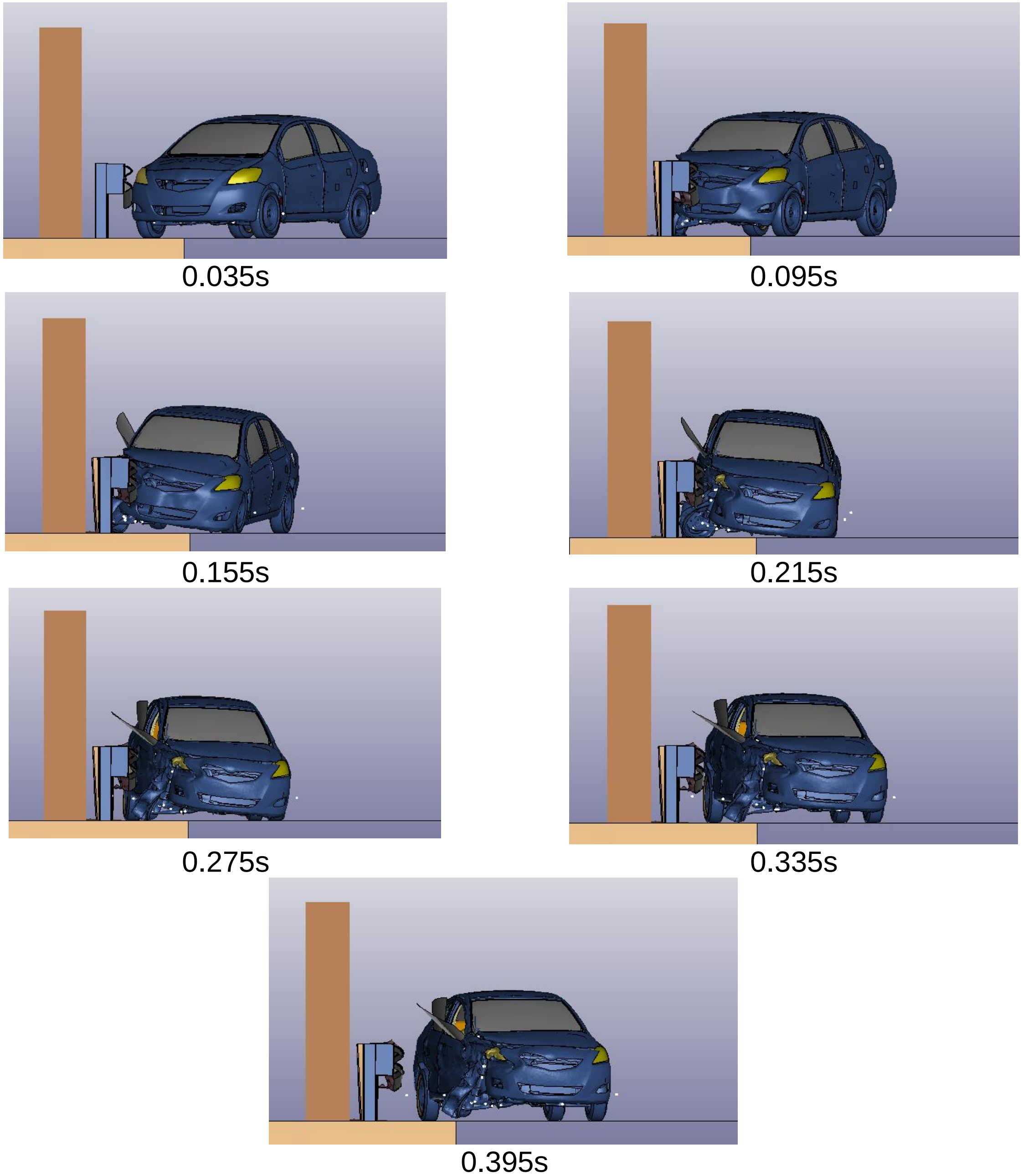


Figure 2.264. *MASH* Test 3-10 Simulation of Quarter-Post Small Gap with Fixed Object 20 inch Offset 2 feet Upstream Impact Variation – Downstream View

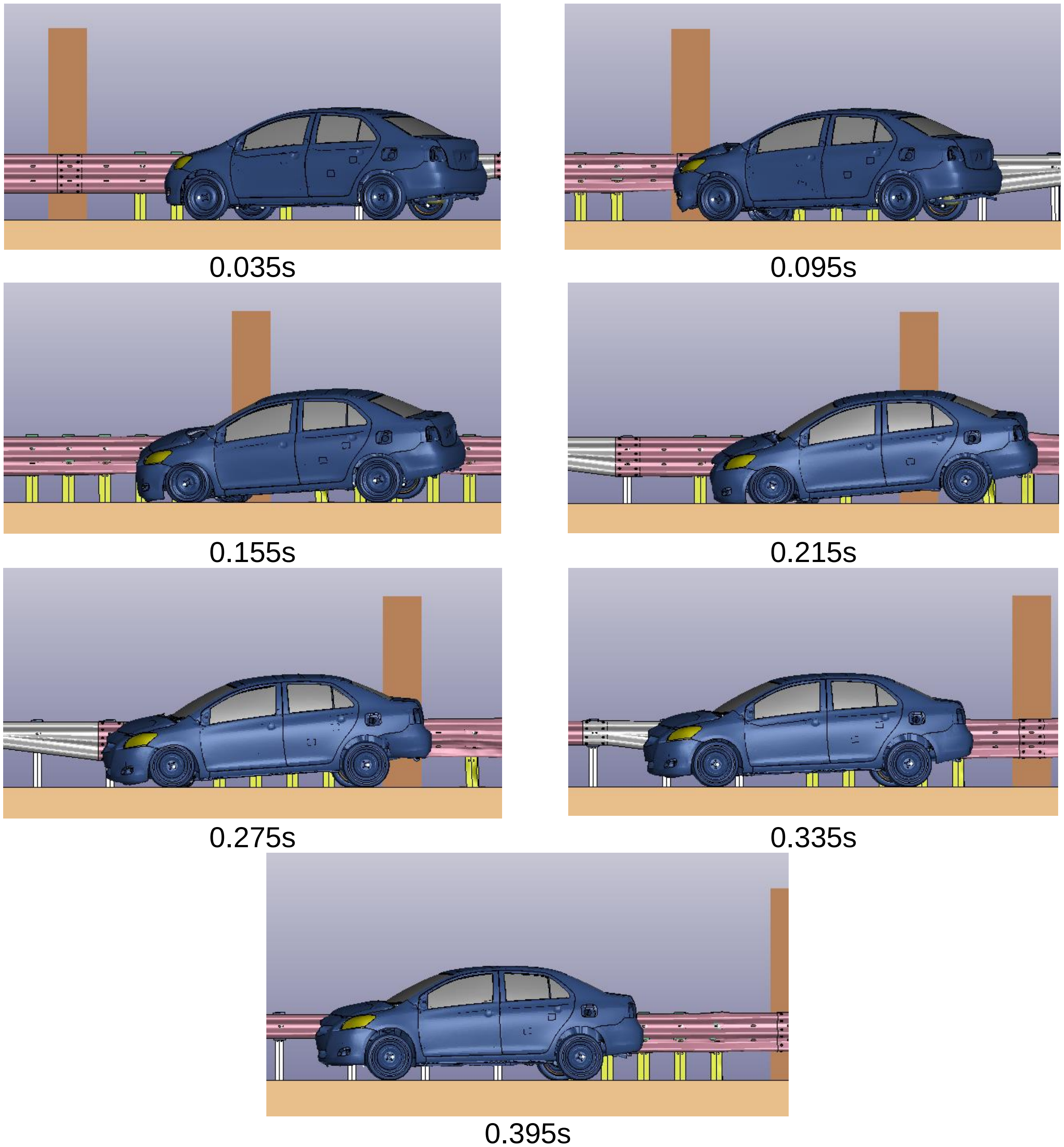


Figure 2.265. *MASH* Test 3-10 Simulation of Quarter-Post Small Gap with Fixed Object 20 inch Offset 2 feet Upstream Impact Variation– Rear View

2.5.2.19. MASH Test 3-10 Simulation of Quarter-Post Spacing Small Gap with Fixed Object 20 inch Offset and 4 feet Upstream Impact Variation

Figure 2.266 through Figure 2.268 show the sequential frames of MASH test 3-10 with quarter-post spacing, small gap, a fixed object offset of 20 inches, and an impact variation positioned 4 feet upstream. The OIV was calculated to be 7.9 m/s (preferred limit is 9.1 m/s). The RDA was calculated to be 17.2 g’s (maximum limit is

20.49 g's). This configuration passed *MASH* test 3-10 by successfully containing and redirecting the vehicle.

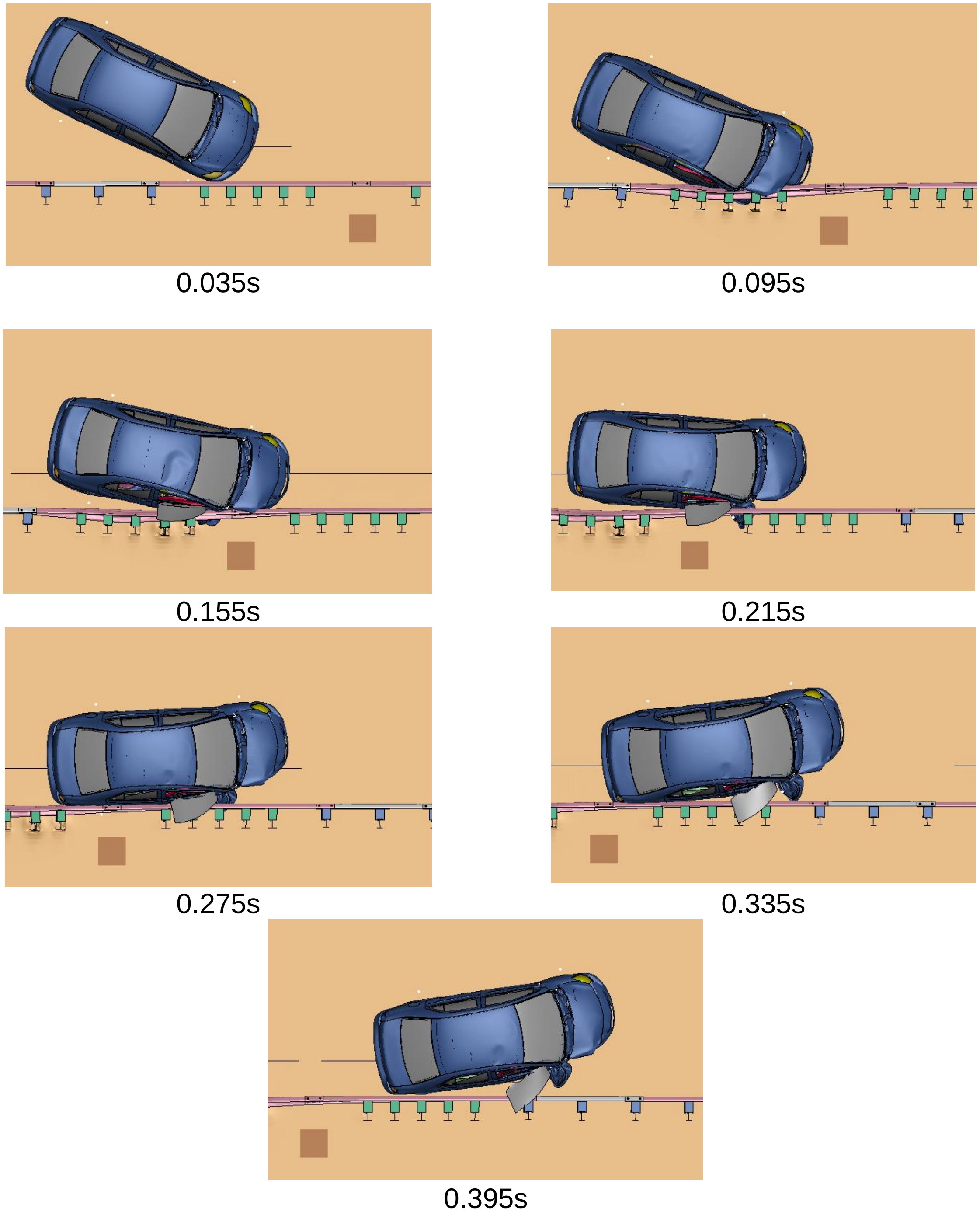


Figure 2.266. *MASH* Test 3-10 Simulation of Quarter-Post Small Gap with Fixed Object 20 inch Offset 4 feet Upstream Impact Variation– Overhead View

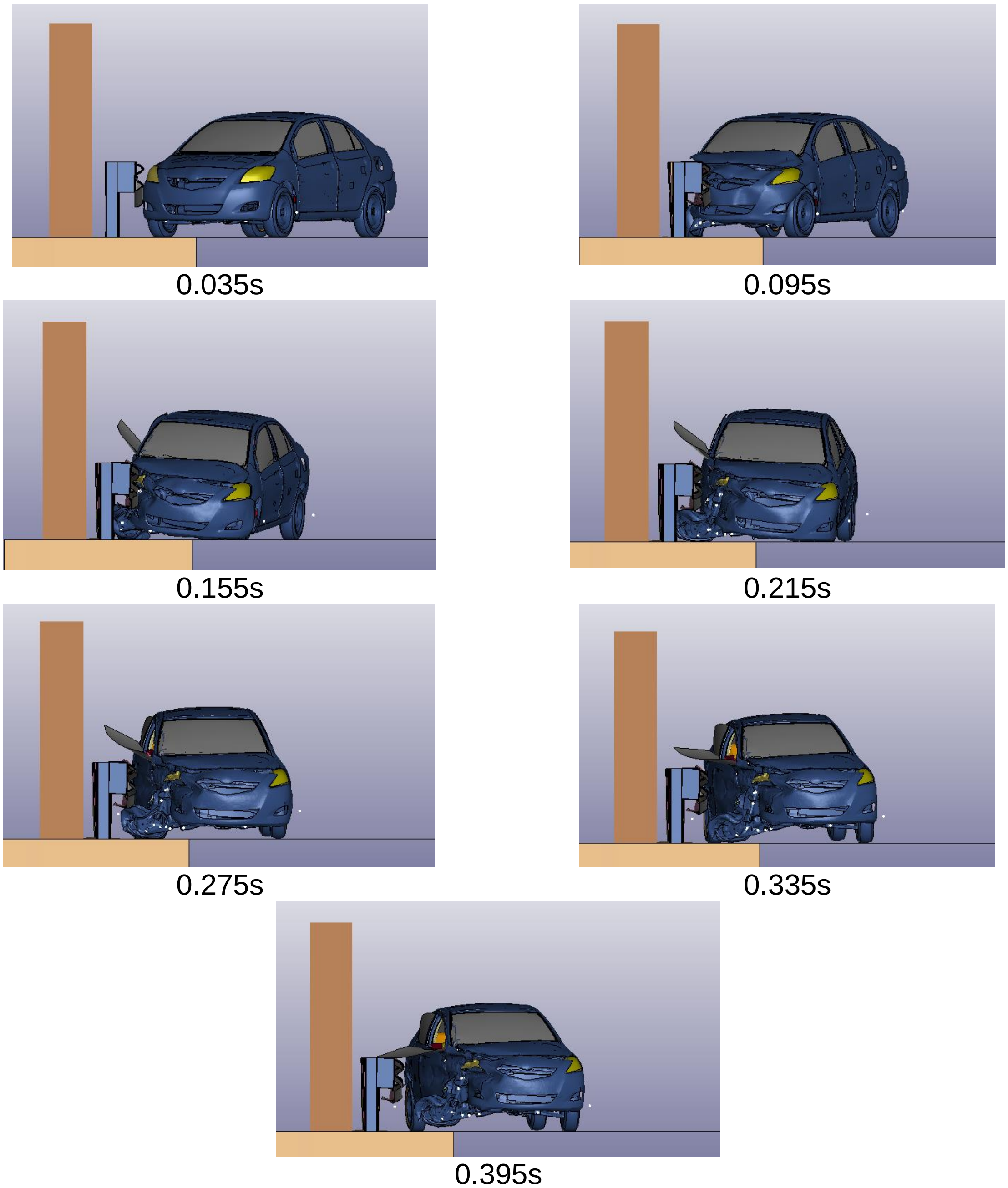


Figure 2.267. *MASH* Test 3-10 Simulation of Quarter-Post Small Gap with Fixed Object 20 inch Offset 4 feet Upstream Impact Variation – Downstream View

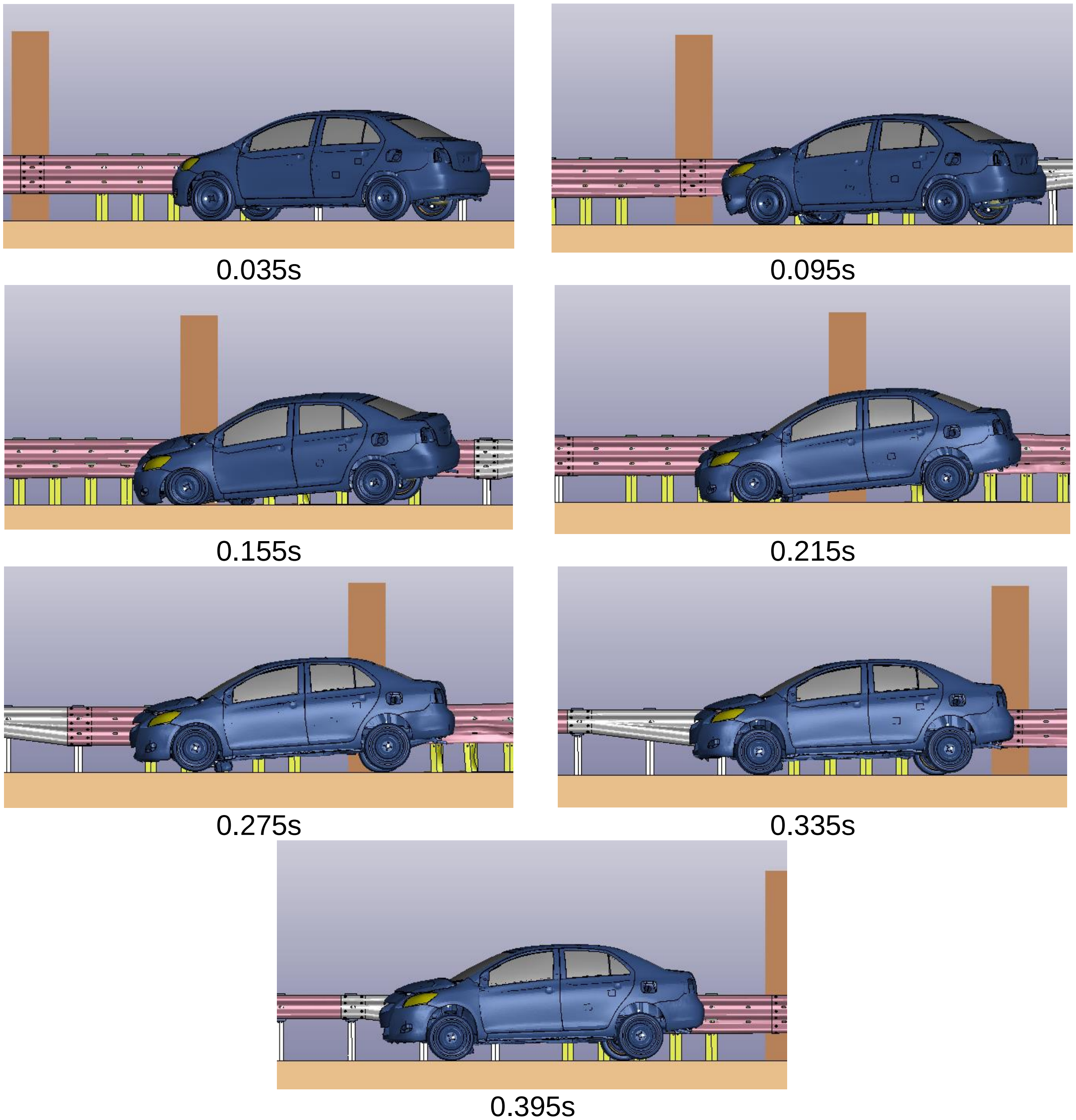


Figure 2.268. *MASH* Test 3-10 Simulation of Quarter-Post Small Gap with Fixed Object 20 inch Offset 4 feet Upstream Impact Variation– Rear View

2.5.2.20. MASH Test 3-10 Simulation of Quarter-Post Spacing Small Gap with Fixed Object 20 inch Offset and 6 feet Upstream Impact Variation

Figure 2.269 through Figure 2.271 show the sequential frames of MASH test 3-10 with quarter-post spacing, small gap, a fixed object offset of 20 inches, and an impact variation positioned 6 feet upstream. The OIV was calculated to be 9.4 m/s (maximum limit is 12.2 m/s). The RDA was calculated to be 10.5 g's (preferred limit is 15.0 g's). This configuration passed *MASH* test 3-10 by successfully containing and redirecting the vehicle.

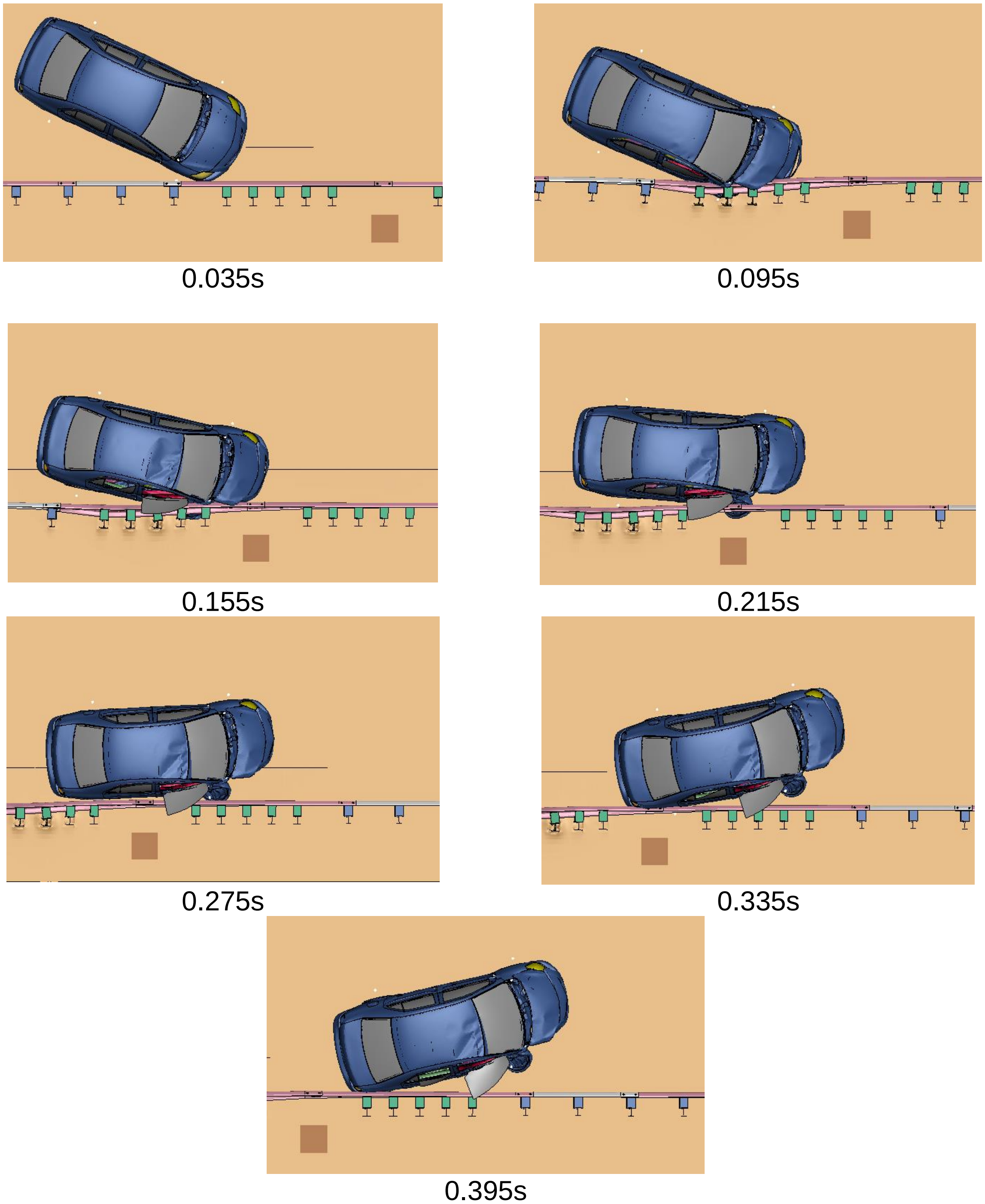


Figure 2.269. *MASH* Test 3-10 Simulation of Quarter-Post Small Gap with Fixed Object 20 inch Offset 6 feet Upstream Impact Variation – Overhead View

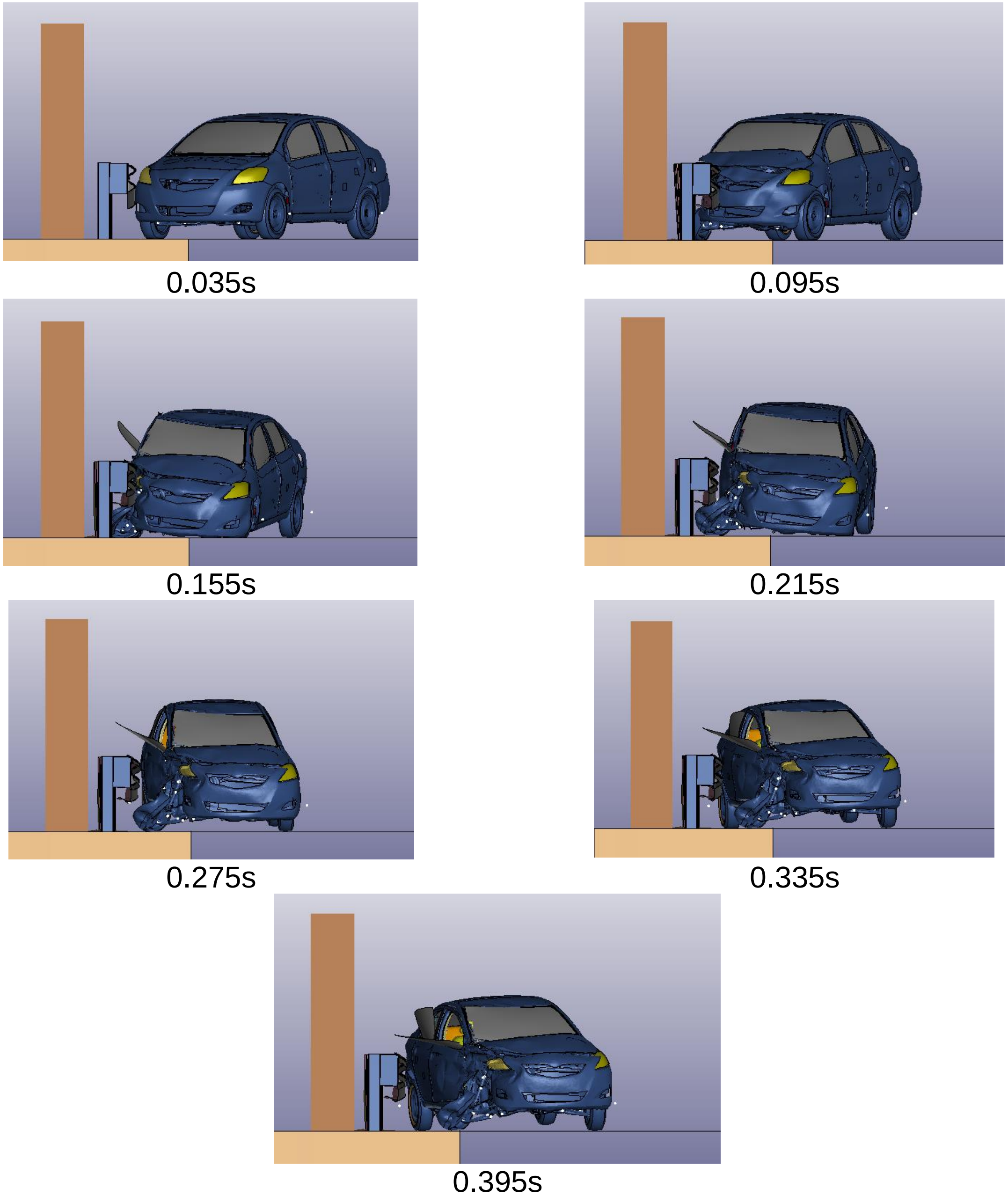


Figure 2.270. ***MASH*** **Test 3-10 Simulation of Quarter-Post Small Gap with Fixed Object 20 inch Offset 6 feet Upstream Impact Variation – Downstream View**

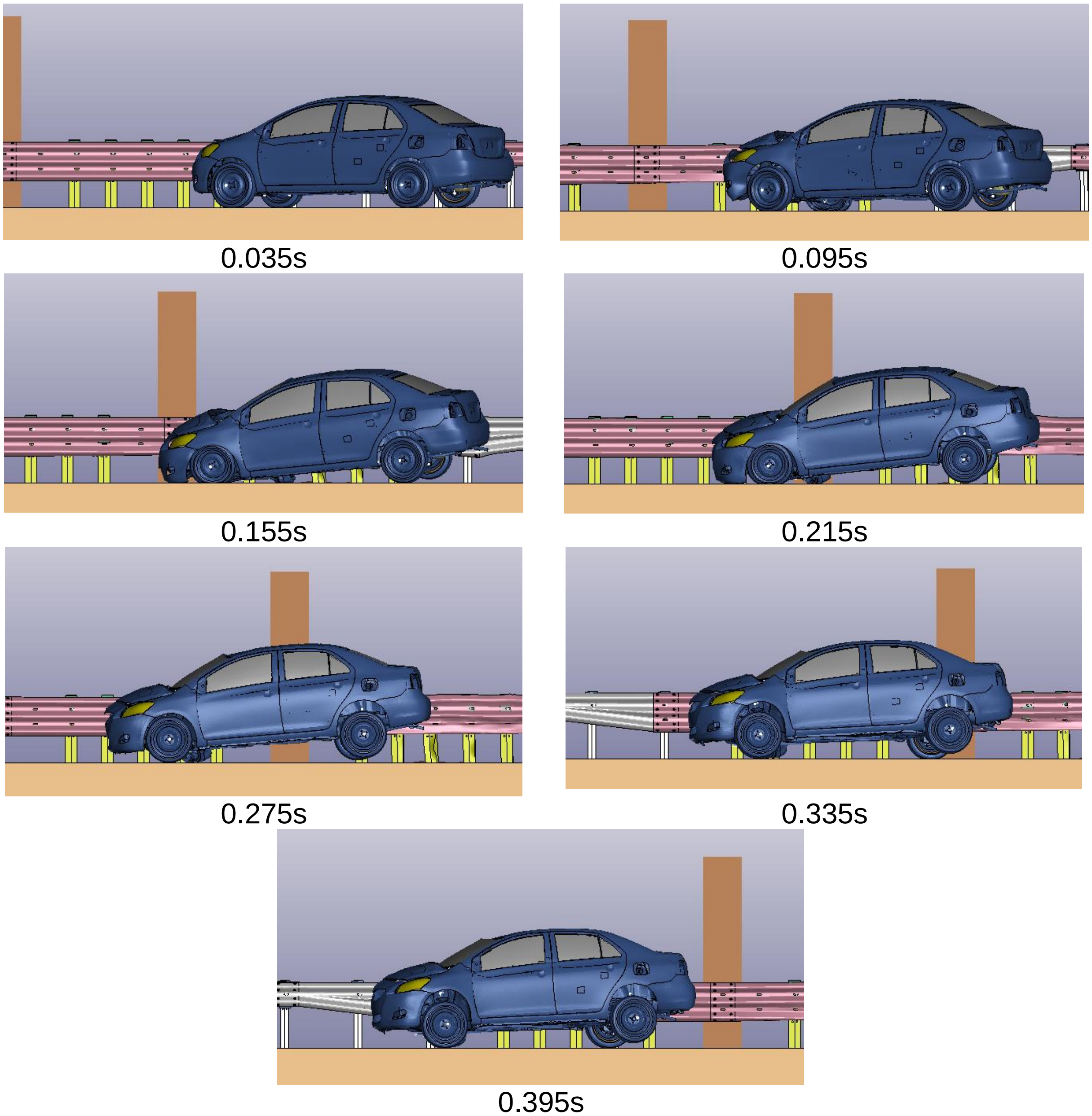
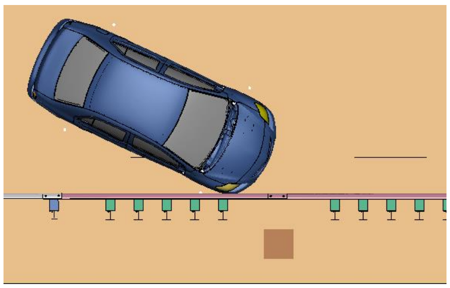


Figure 2.271. ***MASH*** **Test 3-10 Simulation of Quarter-Post Small Gap with Fixed Object 20 inch Offset 6 feet Upstream Impact Variation – Rear View**

2.5.2.21. MASH Test 3-10 Simulation of Quarter-Post Spacing Small Gap with Fixed Object 20 inch Offset and 2 feet Downstream Impact Variation

Figure 2.272 through Figure 2.274 show the sequential frames of MASH test 3-10 with quarter-post spacing, small gap, a fixed object offset of 20 inches, and an impact variation positioned 2 feet downstream. The OIV was calculated to be 9.2 m/s (maximum limit is 12.2 m/s). The RDA was calculated to be 18.9 g’s (maximum limit is 20.49 g’s). This configuration passed *MASH* test 3-10 by successfully containing and redirecting the vehicle.



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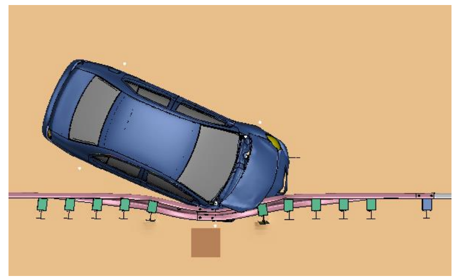

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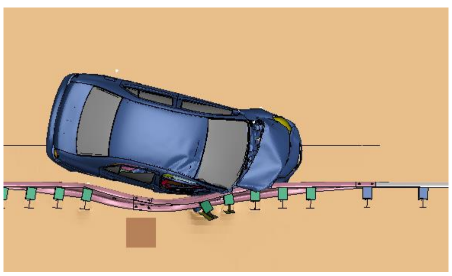

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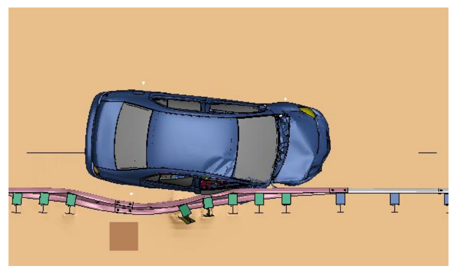

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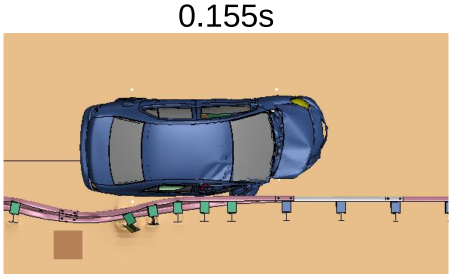

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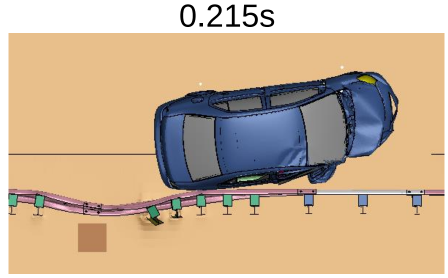

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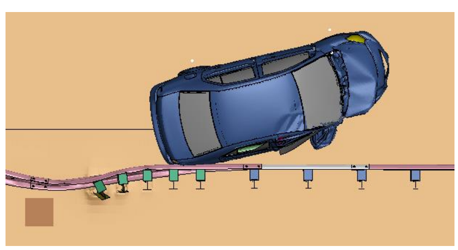

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Figure 2.272. *MASH* Test 3-10 Simulation of Quarter-Post Small Gap with Fixed Object 20 inch Offset 2 feet Downstream Impact Variation – Overhead View

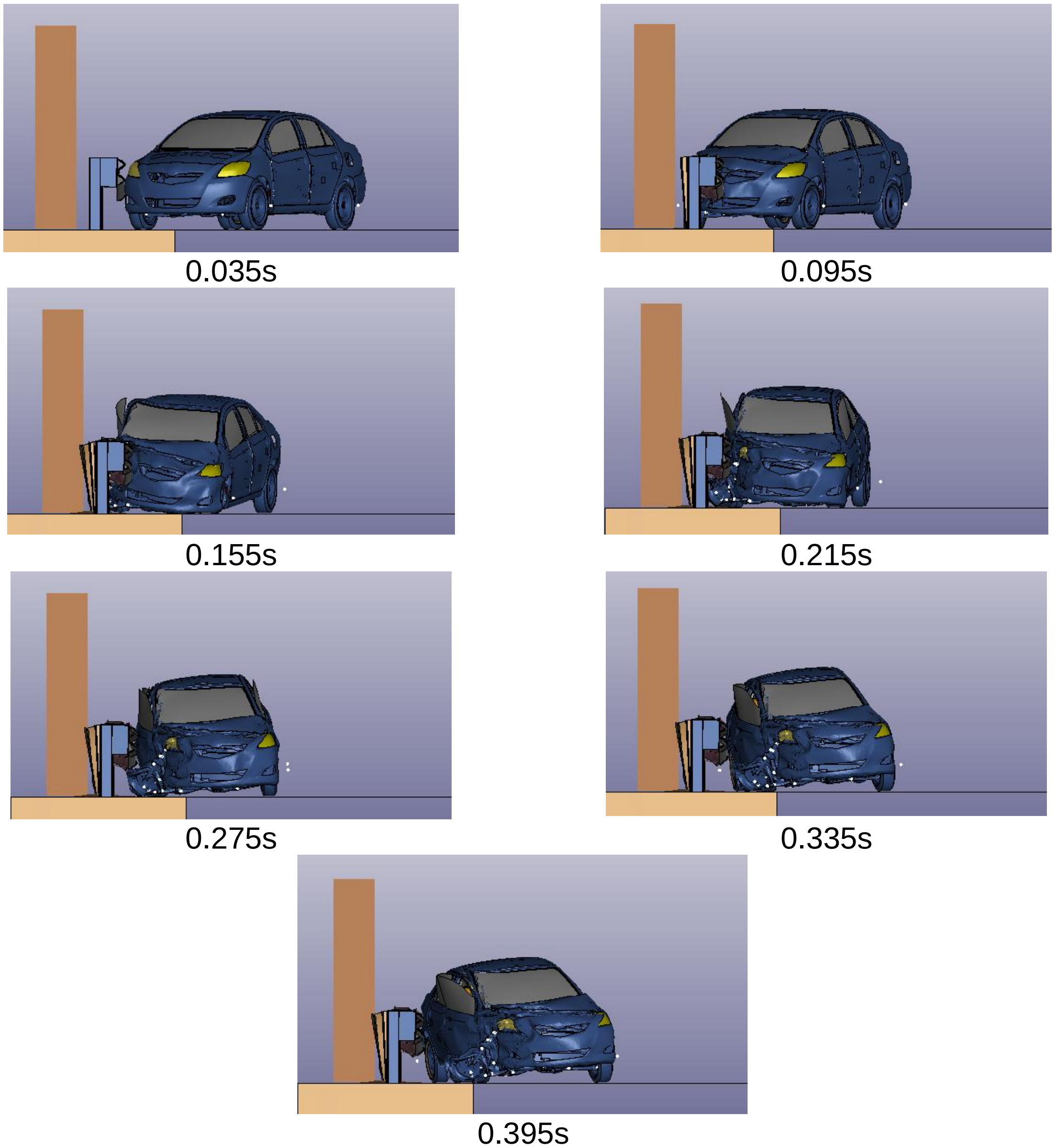
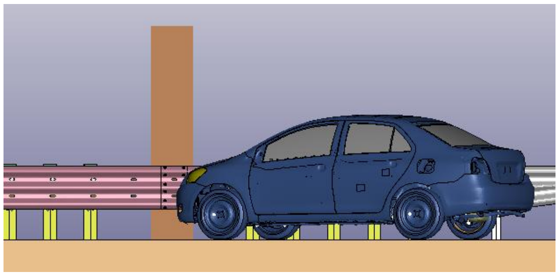


Figure 2.273. *MASH* Test 3-10 Simulation of Quarter-Post Small Gap with Fixed Object 20 inch Offset 2 feet Downstream Impact Variation – Downstream View



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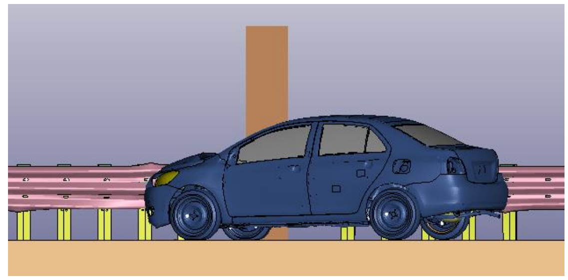

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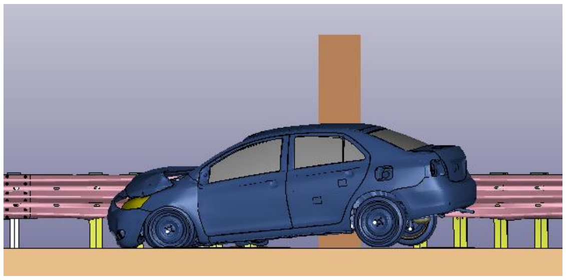

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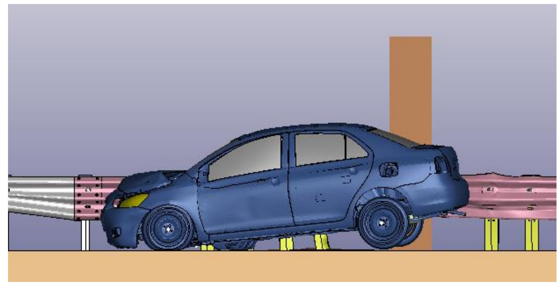

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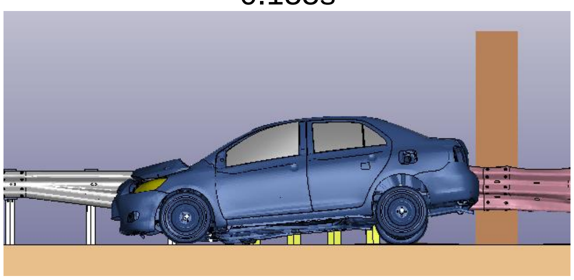

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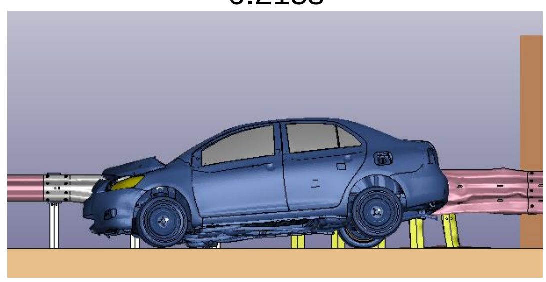

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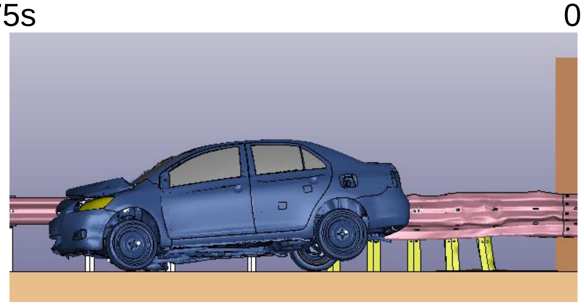


0.395s

Figure 2.274. *MASH* Test 3-10 Simulation of Quarter-Post Small Gap with Fixed Object 20 inch Offset 2 feet Downstream Impact Variation– Rear View

2.5.2.22. MASH Test 3-10 Simulation of Quarter-Post Spacing Small Gap with Fixed Object 20 inch Offset and 4 feet Downstream Impact Variation

Figure 2.275 through Figure 2.277 show the sequential frames of MASH test 3-10 with quarter-post spacing, small gap, a fixed object offset of 20 inches, and an impact variation positioned 4 feet downstream. The OIV was calculated to be 9.6 m/s (maximum limit is 12.2 m/s). The RDA was calculated to be 10.6 g's (preferred limit is 15.0 g's). This configuration passed *MASH* test 3-10 by successfully containing and redirecting the vehicle.

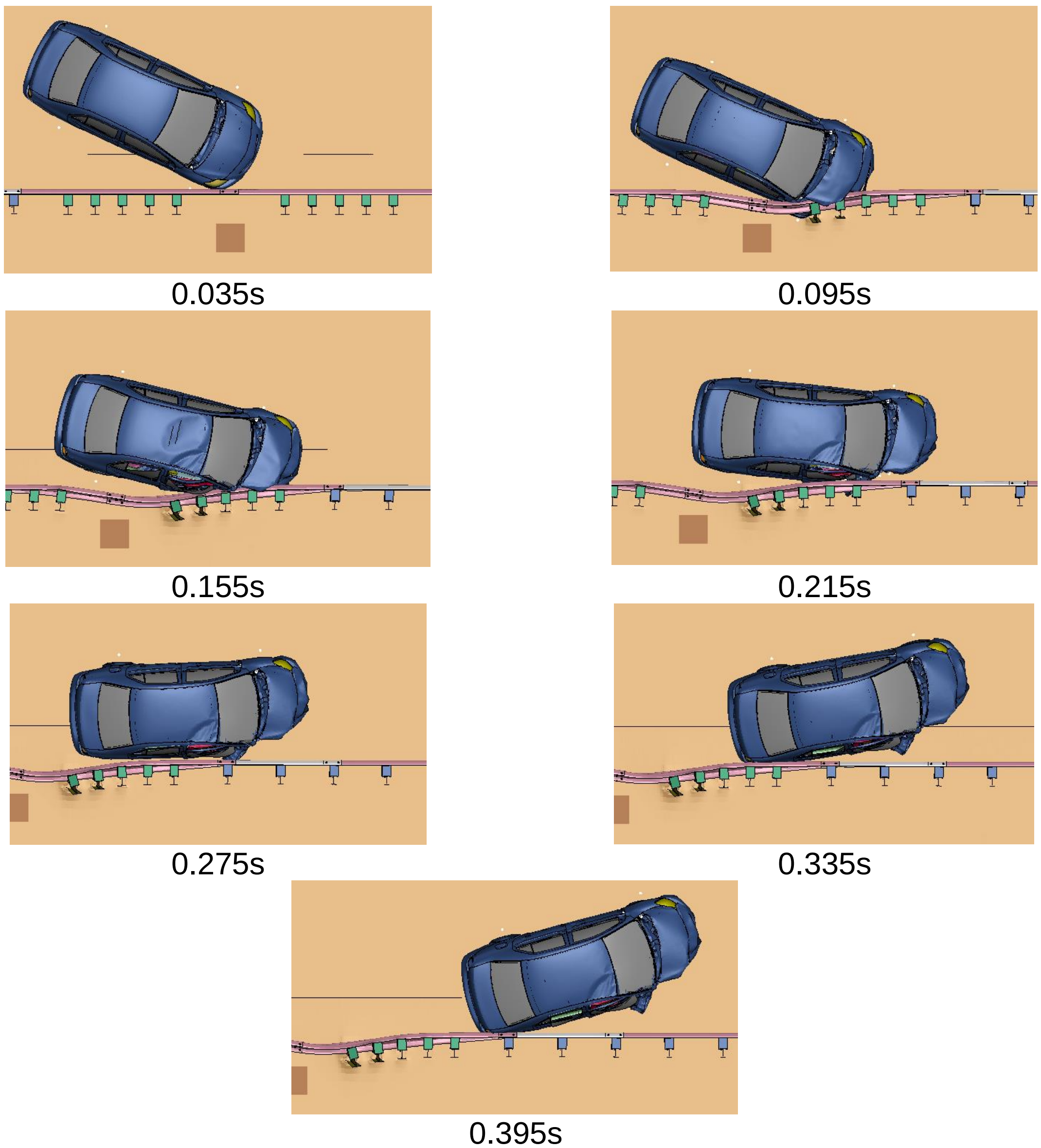


Figure 2.275. *MASH* Test 3-10 Simulation of Quarter-Post Small Gap with Fixed Object 20 inch Offset 4 feet Downstream Impact Variation– Overhead View

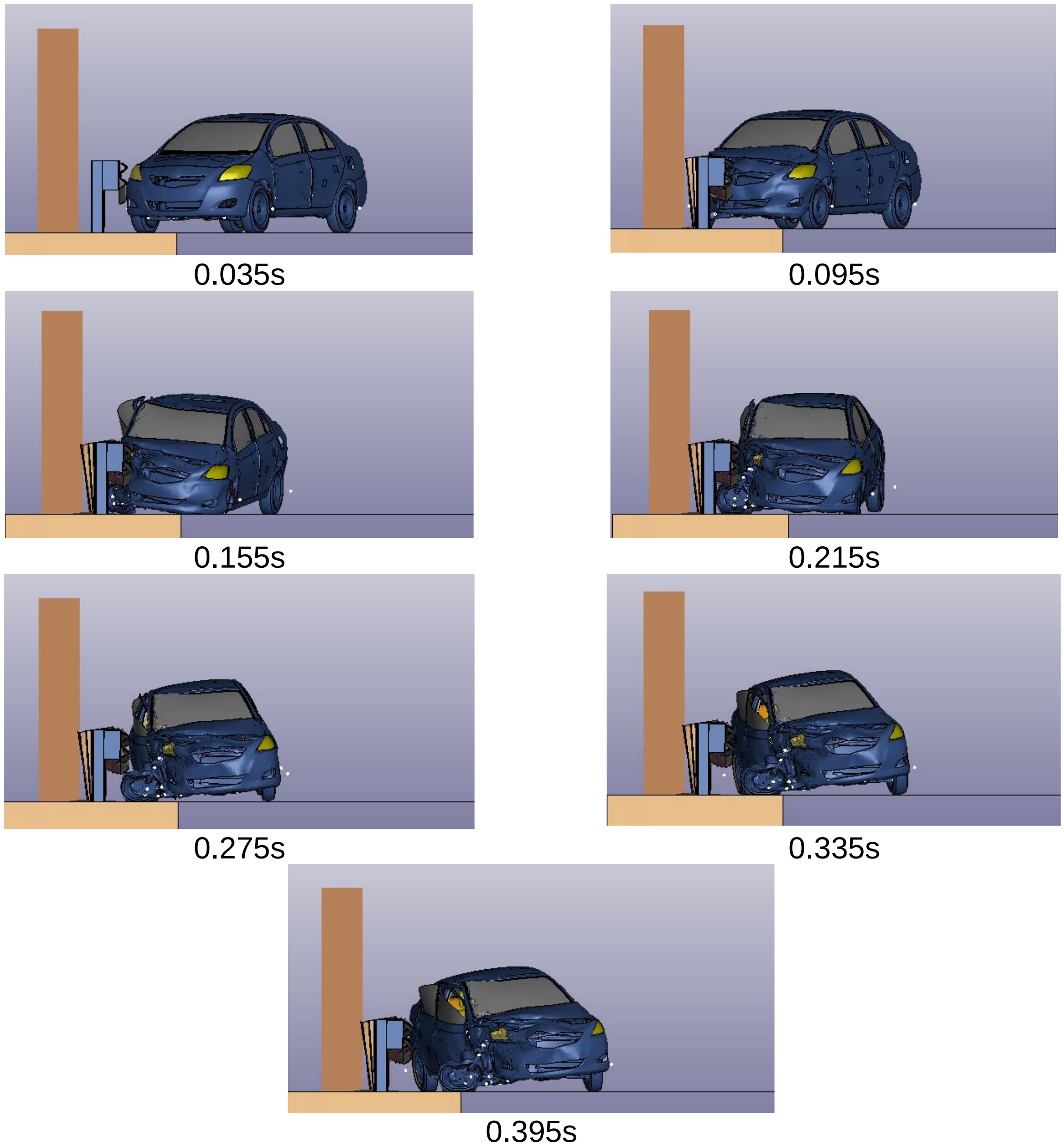
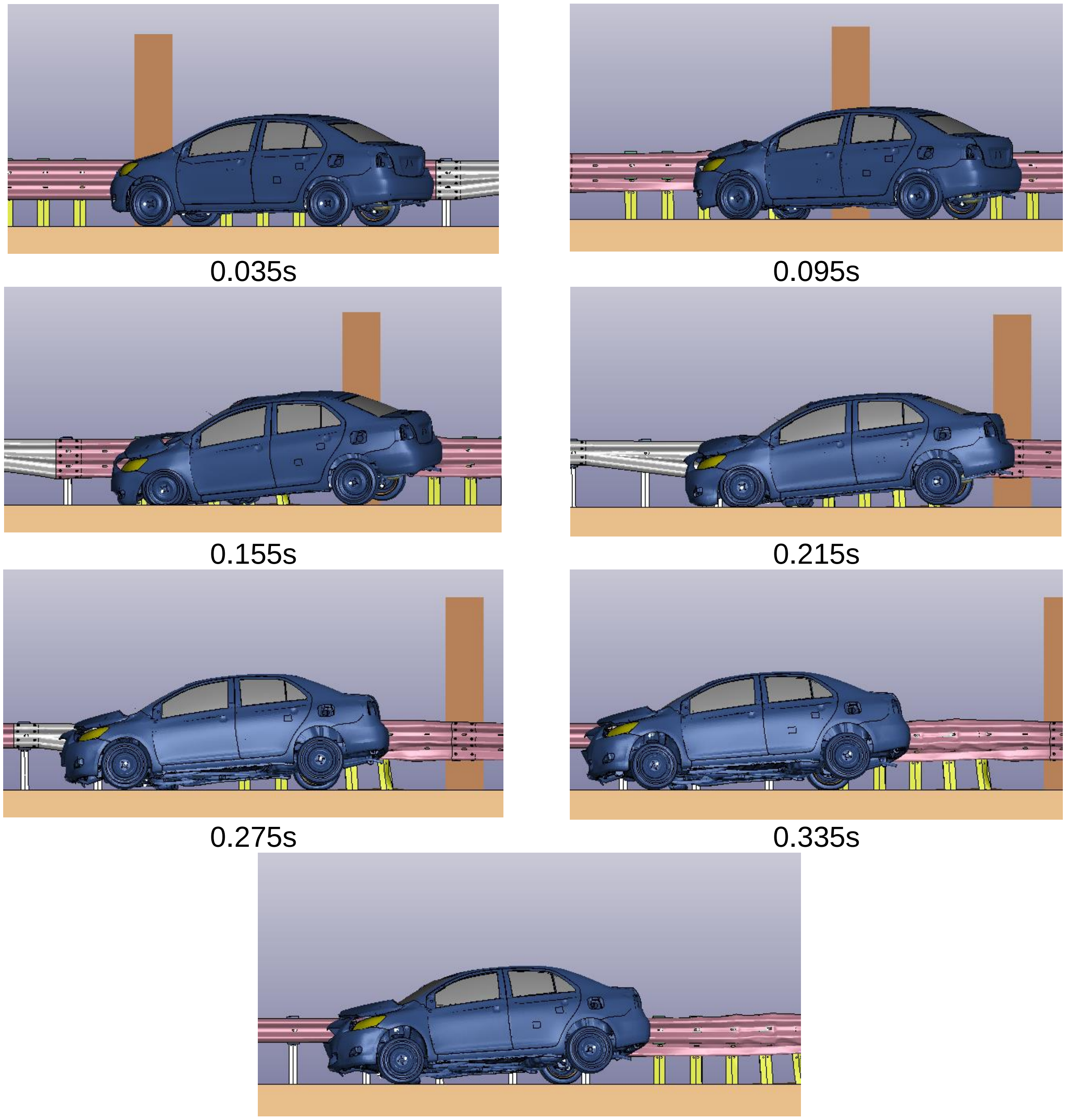


Figure 2.276. *MASH* Test 3-10 Simulation of Quarter-Post Small Gap with Fixed Object 20 inch Offset 4 feet Downstream Impact Variation – Downstream View

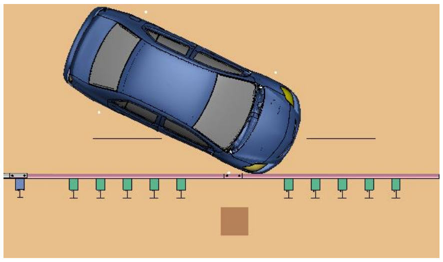


0.035s 0.095s 0.155s 0.215s 0.275s 0.335s 0.395s

Figure 2.277. *MASH* Test 3-10 Simulation of Quarter-Post Small Gap with Fixed Object 20 inch Offset 4 feet Downstream Impact Variation– Rear View

2.5.2.23. MASH Test 3-10 Simulation of Quarter-Post Spacing Small Gap with Fixed Object 20 inch Offset and 6 feet Downstream Impact Variation

Figure 2.278 through Figure 2.280 show the sequential frames of MASH test 3-10 with quarter-post spacing, small gap, a fixed object offset of 20 inches, and an impact variation positioned 6 feet downstream. The OIV was calculated to be 8.7 m/s (preferred limit is 9.1 m/s). The RDA was calculated to be 10.5 g's (preferred limit is 15.0 g's). This configuration passed *MASH* test 3-10 by successfully containing and redirecting the vehicle.



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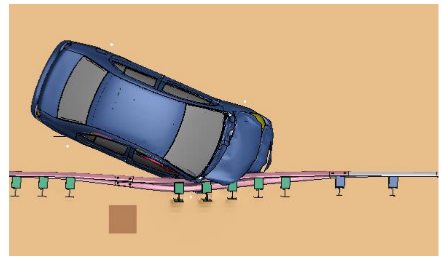

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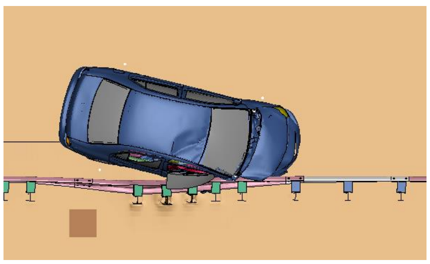

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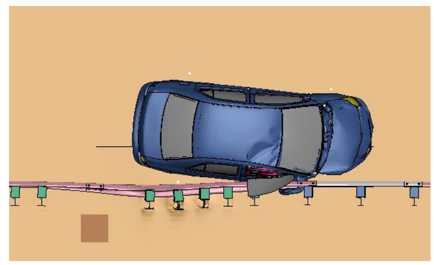

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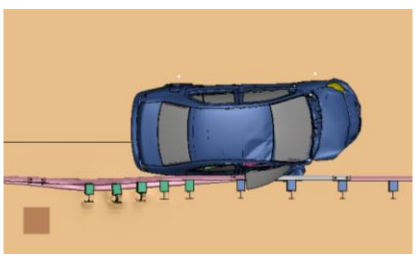

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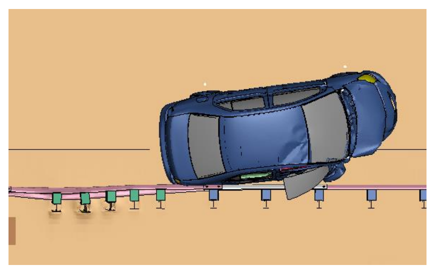
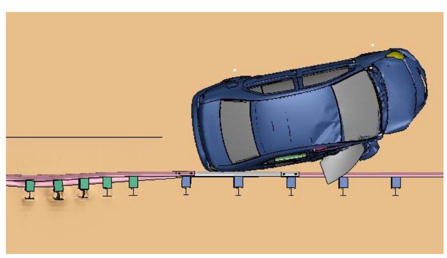


0.335s



0.395s

Figure 2.278. *MASH* Test 3-10 Simulation of Quarter-Post Small Gap with Fixed Object 20 inch Offset 6 feet Downstream Impact Variation – Overhead View

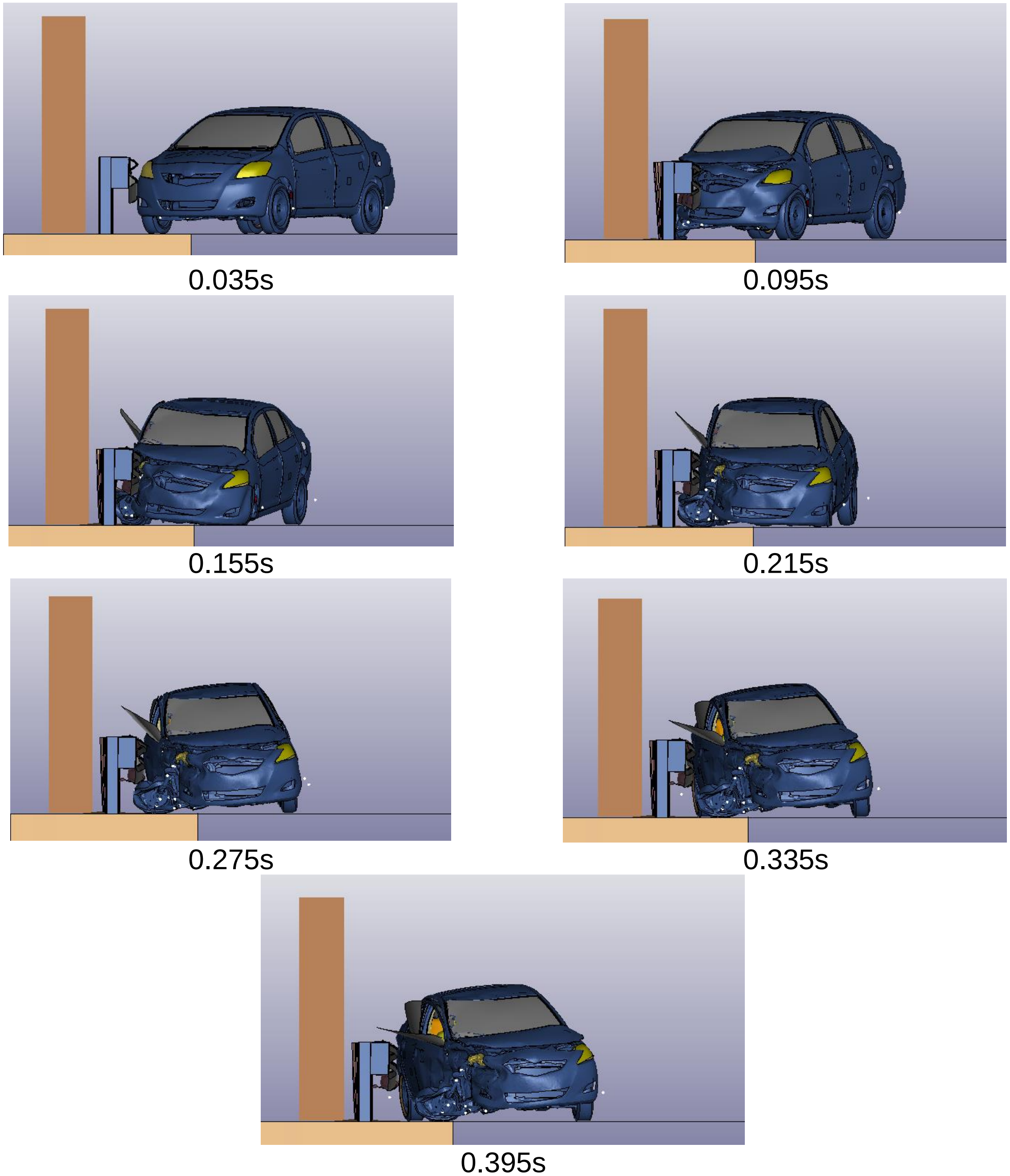


Figure 2.279. *MASH* Test 3-10 Simulation of Quarter-Post Small Gap with Fixed Object 20 inch Offset 6 feet Downstream Impact Variation – Downstream View

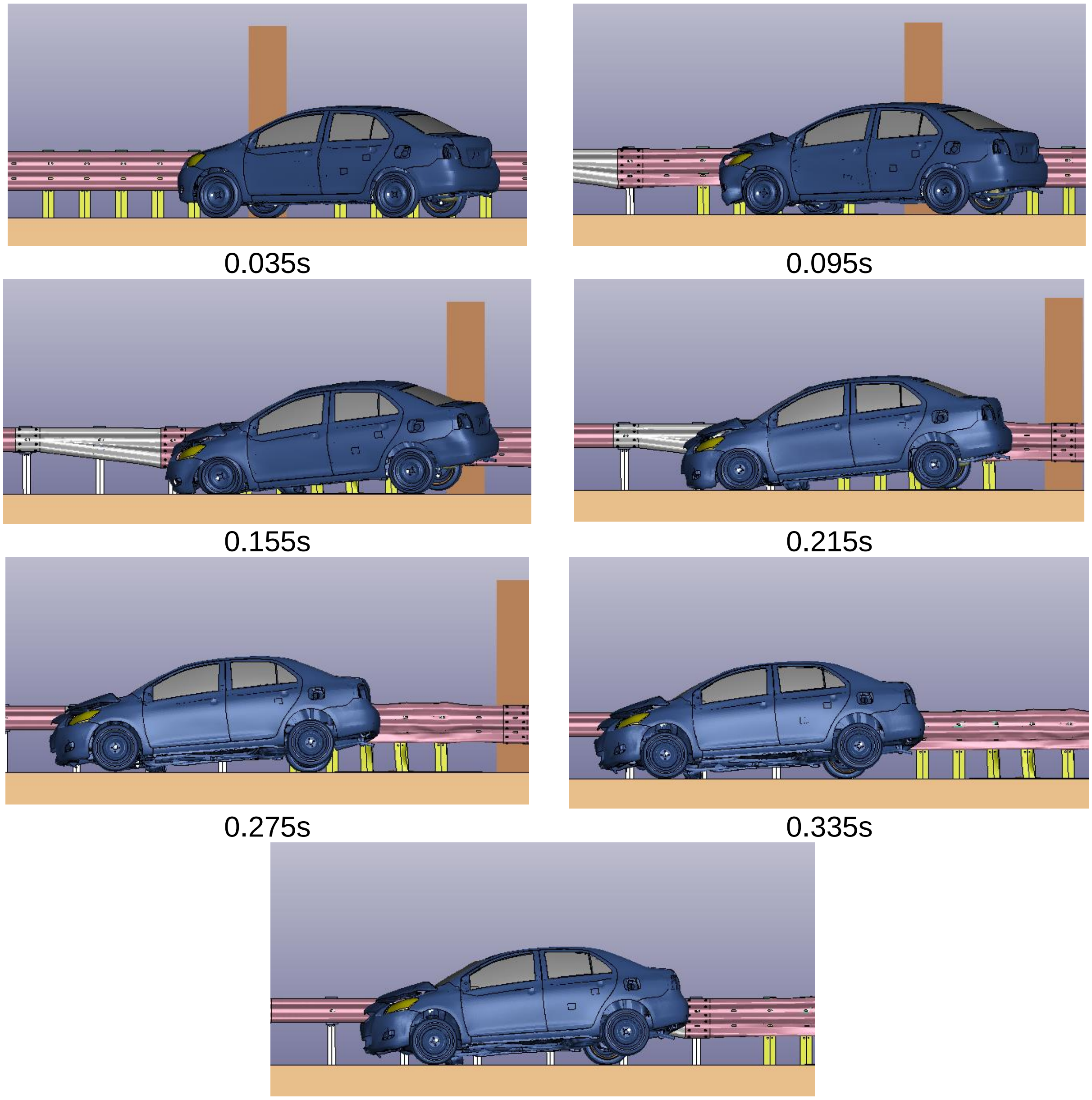


Figure 2.280. *MASH* Test 3-10 Simulation of Quarter-Post Small Gap with Fixed Object 20 inch Offset 6 feet Downstream Impact Variation – Rear View

2.6. SIMULATION CONCLUSIONS

Upon review of the simulation results, the research team, in conjunction with the technical representative of the Roadside Safety Pooled Fund, developed a series of conclusions. First, the configurations with a large 12 ½ ft gap caused vehicle instability and eventually rollover in many cases. Additionally, a number of 12 ½ ft gap simulations showed potential for excessive occupant risk. Therefore, the 12 ½ ft gap systems were not considered for further evaluation with full-scale crash testing. Second, the quarter-post spacing system was deemed more critical than the half-post spacing system from a stiffness perspective. The gap provides no resistance against lateral loads, and quarter-post spacing would provide double the resistance of the half-post spacing. Therefore, the difference in stiffness is greatest with the quarter-post spacing 75-inch gap configuration, and consequently it was deemed most critical for crash testing. Because of this critical nature, the 75-inch gap and quarter-post spacing system was selected for further evaluation through full-scale crash testing. Third, the acceptable offset for the 75-inch gap half-post spacing configuration was selected as 24 inches. The acceptable offset for the 75-inch gap quarter-post spacing configuration was selected as 20 inches. These distances were selected to minimize the interaction between the impacting vehicle and the theoretical fixed object. Lastly, the critical impact points for crash testing were selected based upon occupant risk considerations and maximizing the potential for interaction with the theoretical fixed object. The critical impact point for the 75-inch gap quarter-post spacing configuration was selected as the two feet downstream impact locations for both the *MASH* test 3-11 and 3-10 simulations. These points were targeted in the full-scale testing discussed later.

CHAPTER 3. SYSTEM DETAILS

3.1. TEST ARTICLE AND INSTALLATION DETAILS

The test article was 156 feet 3 inches long and consisted of thrie-beam and W-beam sections, with the top of both rail types at 31 inches above grade. There was a steel post terminal at each end, connected to 37.5 feet section of standard strong-post W-beam guardrail with standard post spacing, connected to 18.75 feet section of standard strong-post W-beam guardrail with half-post spacing including thrie-beam reducer element, connected to 6.25 feet thrie-beam section with quarter post spacing, connecting to the thrie-beam gap. The thrie-beam portion was symmetric and consisted of 25 feet of thrie-beam supported by 84-inch long W6x15 posts. All rails were secured to the posts with standard 6-inch by 8-inch by 14-inch blockouts. There was a 75-inch gap between the W6x15 posts at center.

Figure 3.1 presents the overall information on the thrie-beam guardrail system at a fixed object, and Figure 3.2 provides photographs of the installation. Appendix A provides further details on the thrie-beam guardrail system at a fixed object. Drawings were provided by the Texas A&M Transportation Institute (TTI) Proving Ground, and construction was performed by DMA Construction and supervised by TTI Proving Ground personnel.

3.2. DESIGN MODIFICATIONS DURING TESTS

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

3.3. MATERIAL SPECIFICATIONS

Appendix B provides material certification documents for the materials used to install/construct the thrie-beam guardrail system at a fixed object.

3.4. SOIL CONDITIONS

The test installation was installed in standard soil meeting Type D Grade 1 of AASHTO standard specification M147-17 “Materials for Aggregate and Soil Aggregate Subbase, Base, and Surface Courses.”

In accordance with Appendix B of *MASH*, soil strength was measured the day of the crash test. During installation of the test article for full-scale crash testing, two 6-ft long W6x16 posts were installed in the immediate vicinity of the Thrie-Beam Guardrail System at a Fixed Object using the same fill materials and installation procedures used in the test installation and the standard dynamic test. Table B.1 in Appendix B presents minimum soil strength properties established through the dynamic testing performed in accordance with *MASH* Appendix B.

As determined by the tests summarized in Appendix B, Table B.1, the minimum post loads are shown in Table 3.1.

Table 3.1 shows the post loads versus deflections on the day of Test 3-10, March 11, 2022. The backfill material in which the Thrie-Beam Guardrail System at a Fixed Object was installed met minimum *MASH* requirements for soil strength.

Table 3.1 Soil Strength (Test No. 614031-01-2).

Displacement (in)	Minimum Load (lbs)	Actual Load (lbs)
5	4420	6121
10	4981	6969
15	5282	7272

Table 3.2 shows the post loads versus deflections on the day of Test 3-11, March 24, 2022. The backfill material in which the Thrie-Beam Guardrail System at a Fixed Object was installed met minimum *MASH* requirements for soil strength.

Table 3.2 Soil Strength (Test No. 614031-01-1).

Displacement (in)	Minimum Load (lbs)	Actual Load (lbs)
5	4420	4969
10	4981	5818
15	5282	6333

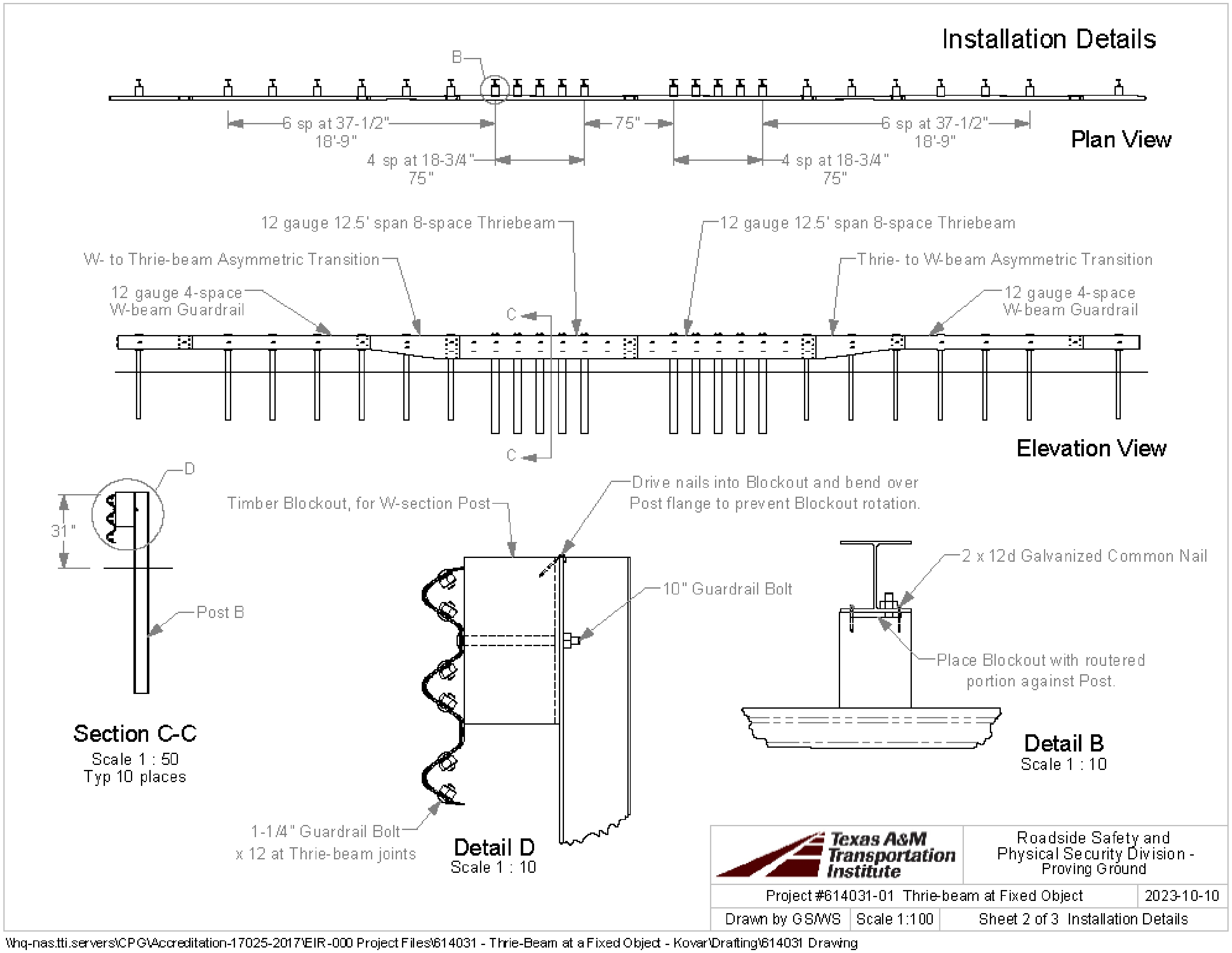


Figure 3.1 Details of Thrie-Beam Guardrail System at a Fixed Object.

Figure 3.2 Thrie-Beam Guardrail System at a Fixed Object 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 computer simulation. Figure 4.1 shows the target CIP for *MASH* Tests 3-10 and 3-11 on the Thrie-Beam Guardrail System at a Fixed Object.

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

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

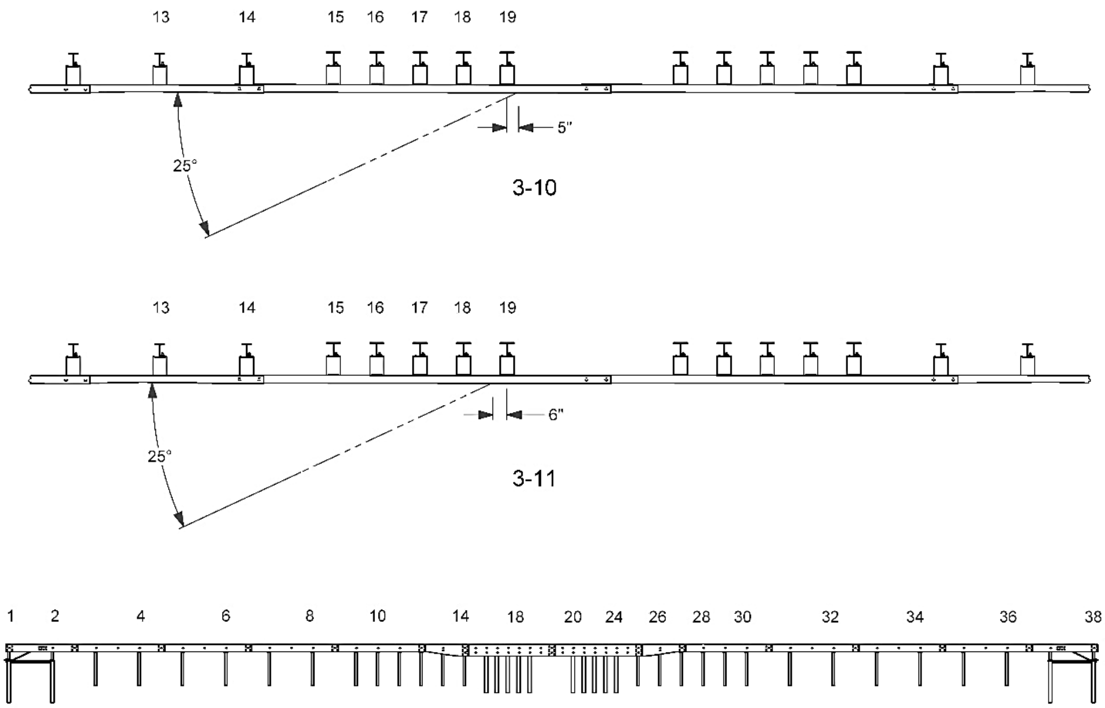


Figure 4.1 Target CIP for *MASH* TL-3 Tests on Thrie-Beam Guardrail System at a Fixed Object.

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
Structural Adequacy	A.	Test article should contain and redirect the vehicle or bring the vehicle to a controlled stop; the vehicle should not penetrate, underride, or override the installation although controlled lateral deflection of the test article is acceptable.	10, 11
Occupant Risk	D.	Detached elements, fragments, or other debris from the test article should not penetrate or show potential for penetrating the occupant compartment, or present undue hazard to other traffic, pedestrians, or personnel in a work zone.	All
		Deformations of, or intrusions into, the occupant compartment should not exceed limits set forth in Section 5.2.2 and Appendix E of *MASH*.	
	F.	The vehicle should remain upright during and after collision. The maximum roll and pitch angles are not to exceed 75 degrees.	All except those listed in G
	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 test(s) 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 sites selected for construction and testing are along the edge of an out-of-service apron. The apron 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

In the crash tests, each vehicle was towed into the test installation using a steel cable guidance and reverse tow system. A steel cable for guiding the test vehicle was tensioned along the path, anchored at each end, and threaded through an attachment to the front wheel of the test vehicle. An additional steel cable was connected to the test vehicle, passed around a pulley near the impact point 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, and no dummy was used in the test.

5.3.3. Photographic Instrumentation Data Processing

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

One overhead with a field of view perpendicular to the ground and directly over the impact point.

One placed upstream from the installation at an angle to have a field of view of the interaction of the rear of the vehicle with the installation.

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 test article. 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 3-10 (CRASH TEST NO. 614031-01-2)

6.1. TEST DESIGNATION AND ACTUAL IMPACT CONDITIONS

See Table 6.1 for details on *MASH* impact conditions for this test. Figure 6.1 depicts the target impact setup.

Figure 6.1 Thrie-Beam Guardrail System at a Fixed Object/Test Vehicle Geometrics for (Crash Test No. 614031-01-2)

Table 6.1 Impact Conditions for *MASH* 3-10 (Crash Test No. 614031-01-2)

Test Parameter	**Specification**	**Tolerance**	**Measured**
Impact Speed (mi/h)	62	± 2.5 mi/h	62.2
Impact Angle (deg)	25	± 1.5°	25.0
Vehicle Inertial Weight (lbs)	2420	± 55 lbs	2427
Impact Severity (kip-ft)	51	≥51 kip-ft	56.1
Impact Location	5 inches downstream of centerline of post 19	± 1 foot	5.4 inches downstream of the center of post 19
Exit Parameters			
Speed (mi/h)	39.9		
Trajectory (degrees)	15.2		
Heading (degrees)	18.0		
Vehicle at rest position	116 ft downstream of impact point 99 ft to the traffic side 95° right		
Comments: Vehicle remained upright and stable. Vehicle crossed exit box* 27 ft d/s from loss of contact.			

*not less than 32.8 ft downstream from loss of contact for cars and pickup trucks is optimal

6.2. WEATHER CONDITIONS

Table 6.2 Weather Conditions (Crash Test No. 614031-01-2.)

Date of Test	Temperature (°F)	Relative Humidity (%)
March 11, 2022 AM	45	68
Wind Direction (degrees)	**Vehicle Traveling (degrees)**	**Wind Speed (mi/h)**
317	325	14

6.3. TEST VEHICLE

Figure 6.2 shows the vehicle used for the crash test. Table 6.3 shows the vehicle measurements. Table C.1 in Appendix C.1 gives additional dimensions and information on the vehicle.

Figure 6.2 Test Vehicle before Test No. 614031-01-2

Table 6.3 Vehicle Measurements Crash Test No. 614031-01-2

Test Parameter	*MASH*	Allowed Tolerance	Measured
Dummy (if applicable)[a](lbs)	165	N/A	165
Gross Static[a] (lbs)	2585	N/A	2592
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	41.4
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 c.g. height requirement

6.4. TEST DESCRIPTION

Table 6.4 lists events that occurred during Test No. 614031-01-2 Figures C.1 and C.2 in Appendix C.2 present sequential photographs during the test.

Table 6.4 Events during Test 614031-01-2

Time (s)	Events
0.0000	Vehicle impacted the installation
0.0200	Post 17, 20 and 21 begin to tilt back toward field side
0.0360	Vehicle began to redirect
0.0313	Post 22 began to tilt back toward field side
0.0425	Post 18 began to tilt back toward field side
0.0750	Driver side front tire impacted post 20 below guardrail
0.1870	Vehicle was parallel with guardrail
0.3600	Vehicle lost contact with the rail and exited the test article traveling 39.9 mi/h at a trajectory of 15.2 degrees and a vehicle heading of 18.0 degrees

6.5. DAMAGE TO TEST INSTALLATION

The soil was disturbed at posts 15 through 17 and post 25. The rails at impact were scuffed and deformed, and the blockout was split at post 7. Figure 6.3 shows the damage to the Thrie-Beam Guardrail System at a Fixed Object. Table 6.5 and Table 6.6 describe the damage to the Thrie-Beam Guardrail System at a Fixed Object.

Table 6.5 Measured Post Lean and Soil Gap Post Impact (614031-01-2)

Post #	Soil Gap (inches)			Post Lean Back from Vertical (degrees)
	U/S	T/S	F/S	
1	¼	-	-	-
18	-	¼	⅛	1.5
19	-	¾	½	3.5
20	-	4	-	7
21	-	-	1¼	4.5
22	-	-	¾	4
23	-	-	¼	2
24	-	⅛	⅛	-

** U/S – upstream; T/S – traffic side; F/S – field side*

Table 6.6 Damage to Thrie-Beam Guardrail System at a Fixed Object 614031-01-2

Test Parameter	Measured
Permanent Deflection/Location	10.3 inches toward field side 12.0 inches upstream of centerline of post 20
Dynamic Deflection	15.7 inches toward field side
Working Width* and Height	28.8 inches, at a height of 32.0 inches

Figure 6.3 Thrie-Beam Guardrail System at a Fixed Object after Test 614031-01-2

6.6. DAMAGE TO TEST VEHICLE

Figure 6.4 and Figure 6.5 shows the damage sustained by the vehicle. Table 6.7 provides details on the interior and exterior damage to the vehicle. Tables C.2 and C.3 in Appendix C.1 provide exterior crush and occupant compartment measurements.

* 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 6.4 Test Vehicle after Test 614031-01-2

Figure 6.5 Interior of Test Vehicle after Test 614031-01-2

Table 6.7 Damage to Vehicle 614031-01-2

<table>
<tr><th colspan="2">Test Parameter</th><th colspan="4">Specification</th><th>Measured</th></tr>
<tr><td colspan="2">Roof</td><td colspan="4">≤ 4.0 inches</td><td>0.0 inches</td></tr>
<tr><td colspan="2">Windshield</td><td colspan="4">≤ 3.0 inches</td><td>0.0 inches</td></tr>
<tr><td colspan="2">A and B Pillars</td><td colspan="4">≤ 5.0 overall / ≤ 3.0 inches lateral</td><td>0.0 inches</td></tr>
<tr><td colspan="2">Foot Well/Toe Pan</td><td colspan="4">≤ 9.0 inches</td><td>0.0 inches</td></tr>
<tr><td colspan="2">Floor Pan/Transmission Tunnel</td><td colspan="4">≤ 12.0 inches</td><td>0.0 inches</td></tr>
<tr><td colspan="2">Side Front Panel</td><td colspan="4">≤ 12.0 inches</td><td>0.0 inches</td></tr>
<tr><td colspan="2">Front Door (above Seat)</td><td colspan="4">≤ 9.0 inches</td><td>0.0 inches</td></tr>
<tr><td colspan="2">Front Door (below Seat)</td><td colspan="4">≤ 12.0 inches</td><td>1.0 inches</td></tr>
<tr><td colspan="2">Side Windows</td><td colspan="5">Intact</td></tr>
<tr><td colspan="2">Maximum Exterior Deformation</td><td colspan="5">10 inches in the front plane at the left front corner at bumper height</td></tr>
<tr><td>VDS</td><td colspan="3">01RFQ6</td><td>CDC</td><td colspan="2">01FREW4</td></tr>
<tr><td colspan="3">Fuel Tank Damage</td><td>None</td><td colspan="3"></td></tr>
<tr><td colspan="7">Description of Damage to Vehicle:
Damage to front bumper hood and grill, radiator and support, left front quarter fender, left front strut and tower, left front tire and rim, windshield cracked due to flexing car body, left front door and glass had a 4-inch gap at top, left rear door, left rear quarter fender, rear bumper and tail light</td></tr>
</table>

6.7. OCCUPANT RISK FACTORS

Data from the accelerometers were digitized for evaluation of occupant risk, and the results are shown in Table 6.8. Figure C.3 in Appendix C.3 shows the vehicle angular displacements, and Figures C.4 through C.6 in Appendix C.4 show acceleration versus time traces.

Table 6.8 Occupant Risk Factors for Test 614031-01-2

Test Parameter	Specification*	Measured	Time
OIV, Longitudinal (ft/s)	≤40.0 *30.0*	27.6	0.1054 s on left side of interior
OIV, Lateral (ft/s)	≤40.0 *30.0*	25.6	0.1054 s on left side of interior
Ridedown, Longitudinal (g)	≤20.49 *15.0*	12.0	0.1085 - 0.1185 s
Ridedown, Lateral (g)	≤20.49 *15.0*	16.8	0.1055 - 0.1155 s
THIV (m/s)	N/A	10.8	0.1024 s on left side of interior
ASI	N/A	1.82	0.0914 - 0.1414 s
50ms MA Longitudinal (g)	N/A	13.8	0.0688 - 0.1188 s
50ms MA Lateral (g)	N/A	11.9	0.0675 - 0.1175 s
50ms MA Vertical (g)	N/A	2.8	0.0641 - 0.1141s
Roll (deg)	≤75	12.9	2.0000 s
Pitch (deg)	≤75	-3.9	0.1911 s
Yaw (deg)	N/A	53.8	2.0000 s

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

0.000 s

0.100 s

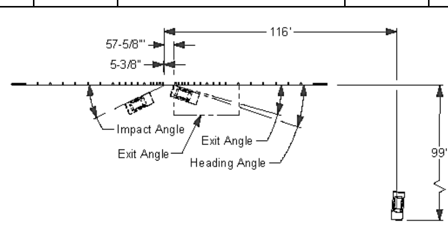
0.200 s

0.300 s

Test Agency	Texas A&M Transportation Institute (TTI)
Test Standard/Test No.	*MASH* 2016, Test 3-10
TTI Project No.	614031-01-2
Test Date	2022-03-11
TEST ARTICLE	
Type	Guardrail
Name	Thrie-beam Guardrail System at a Fixed Object
Length	156 ft-3inches
Key Materials	W-beam Guardrail, Wide-Flange Guardrail post, Timber Blockout
Soil Type and Condition	AASHTO M147-65(2004), Type D, Grade 1 Crushed Concrete
TEST VEHICLE	
Type/Designation	1100C
Year, Make and Model	2016 Nissan Versa
Curb Weight (lbs)	2325
Inertial Weight (lbs)	2427
Dummy (lbs)	165
Gross Static (lbs)	2592
IMPACT CONDITIONS	
Impact Speed (mi/h)	62.2
Impact Angle (deg)	25.0
Impact Location	5.4 inches downstream from the centerline of post 19
Impact Severity (kip-ft)	56.1
EXIT CONDITIONS	
Exit Speed (mi/h)	39.9
Trajectory/Heading Angle (deg)	15.2 / 18.0
Exit Box Criteria	Crossed exit box at 27 ft downstream of loss of contact
Stopping Distance	116 feet downstream 99 feet to the traffic side
TEST ARTICLE DEFLECTIONS	
Dynamic (inches)	15.7
Permanent (inches)	10.3
Working Width / Height (inches)	28.8 at 32.0
VEHICLE DAMAGE	
VDS	01RFQ6
CDC	01FREW4
Max. Ext. Deformation	10 inches
Max Occupant Compartment Deformation	1.0 inches in the front door below the seat

OCCUPANT RISK VALUES

Long.OIV (ft/s)	27.6	Long. Ridedown (g)	12.0	Max 50ms Long. (g)	13.8	Max Roll (deg)	12.9
Lat. OIV (ft/s)	25.6	Lat. Ridedown (g)	16.8	Max 50ms Lat. (g)	11.9	Max Pitch (deg)	-3.9
THIV (m/s)	10.8	ASI	1.82	Max 50ms Vert (g)	2.8	Max Yaw (deg)	53.8



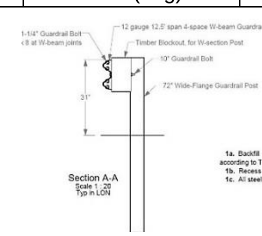


Figure 6.6 Summary of Results for *MASH* Test 3-10 on Thrie-Beam Guardrail System at a Fixed Object.

CHAPTER 7. *MASH* TEST 3-11 (CRASH TEST NO. 614031-01-1)

7.1. TEST DESIGNATION AND ACTUAL IMPACT CONDITIONS

See Table 7.1for details on *MASH* impact conditions for this test. Figure 7.1 depicts the target impact setup.

Figure 7.1 Thrie-Beam Guardrail System at a Fixed Object/Test Vehicle Geometrics for Test 614031-01-1.

Table 7.1 Impact Conditions for *MASH* 3-11 (614031-01-1).

Test Parameter	**Specification**	**Tolerance**	**Measured**
Impact Speed (mi/h)	62 mi/h	± 2.5 mi/h	62.1
Impact Angle (deg)	25°	± 1.5°	24.9
Vehicle Inertial Weight (lbs)	5000 lbs	± 110 lbs	5030
Impact Severity (kip-ft)	106 kip-ft	≥106 kip-ft	115.0
Impact Location	6.5 inches upstream of centerline of post 19	± 12 inches	6.5 inches upstream of the centerline of post 19
Exit Parameters			
Speed	37.7 mi/h		
Trajectory	15.7°		
Heading	15.2°		
Brakes applied post impact	Brakes were not applied		
Vehicle at rest position	127 ft downstream of impact point 36 ft to the field side 100° right		
Comments: Vehicle remained upright and stable. Vehicle crossed exit box* 35 ft d/s from loss of contact.			

*not less than 32.8 ft downstream from loss of contact for cars and pickups is optimal

7.2. WEATHER CONDITIONS

Table 7.2 Weather Conditions 614031-01-1.

Date of Test	Temperature (°F)	Relative Humidity (%)
March 24, 2022 AM	54	63
Wind Direction (degrees)	**Vehicle Traveling (degrees)**	**Wind Speed (mi/h)**
306	325	11

7.3. TEST VEHICLE

Figure 7.2 shows the 2015 RAM 1500 used for the crash test. Table 7.3 shows the vehicle measurements. Table C.1 in Appendix C.1 gives additional dimensions and information on the vehicle.


Figure 7.2 Test Vehicle before Test 614031-01-1.

Table 7.3 Vehicle Measurements 614031-01-1.

Test Parameter	*MASH*	Allowed Tolerance	Actual Measured
Dummy (if applicable)[a](lbs)	165	N/A	N/A
Gross Static[a] (lbs)	5000	± 110	5030
Wheelbase (inches)	148	±12	140.5
Front Overhang (inches)	39	±3	40.0
Overall Length (inches)	237	±13	227.5
Overall Width (inches)	78	±2	78.5
Hood Height (inches)	43	±4	46.0
Track Width[b] (inches)	67	±1.5	68.5
CG aft of Front Axle[c] (inches)	63	±4	62.2
CG above Ground[c,d] (inches)	28	≥28	28.5

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 c.g. height requirement

7.4. TEST DESCRIPTION

Table 7.4 lists events that occurred during Test No. 614031-01-1. Figures C.1 and C.2 in Appendix C.2 present sequential photographs during the test.

Table 7.4 Events during Test 614031-01-1.

Time (s)	Events
0.0000	Vehicle impacted the installation
0.0175	Post 19 began to lean toward field side
0.0300	Vehicle began to redirect
0.0475	The top, upstream bolt at splice pulled through the rail
0.0538	The upstream second and third bolt from top at splice pulled through the hole.
0.1870	Vehicle was parallel with guardrail
0.4650	Vehicle lost contact with the rail and exited the test article traveling 39.9 mi/h at a trajectory of 15.2 degrees and a vehicle heading of 18.0 degrees

7.5. DAMAGE TO TEST INSTALLATION

The rails were scuffed and deformed at impact. There was a tear in the upstream rail at the joint between posts 19 and 20. It extended from the top of the rail to 3½ inches past the top post slot. The bolt slot in the rail tore at posts 22 and 24. None of the tears discussed here tore completely through the rail cross-section. The rail released from posts 7-11, 23, and 24. The soil was disturbed from posts 13 through 16, and 26 through 28. The blockouts at posts 20, 21, 23, and 24 had some cracking, and the blockout at post 22 was crushed.

Figure 7.3 shows the damage to the Thrie-Beam Guardrail System at a Fixed Object. Table 7.5 and Table 7.6 describes the damage to the Thrie-Beam Guardrail System at a Fixed Object.

Table 7.5 Measured Post Lean and Soil Gap Post Impact (614031-01-1)

Post #	Soil Gap (inches)				Post Lean Back from Vertical (degrees)
	U/S	D/S	T/S	F/S	
1	½	-	-	-	-
2	-	⅜	-	-	-
12	-	-	-	⅛	-
17	-	-	⅛	⅛	0.3
18	-	-	⅜	½	0.8
19	-	-	¾	¾	2.7
20	-	-	5	1	17.1
21	-	-	-	1½	11.8
22	-	-	-	1½	6.5
23	-	-	-	¼	7.3
24	-	-	1¼	½	3.3
25	-	-	½	½	1.2
38	-	¼	-	-	-

** U/S – upstream; D/S – downstream; T/S – traffic side; F/S – field side*

Table 7.6 Damage to Thrie-Beam Guardrail System at a Fixed Object (614031-01-1).

Test Parameter	Measured
Permanent Deflection/Location	17.75 inches toward field side 2.0 inches upstream of the centerline of post 20
Dynamic Deflection	20.9 inches toward field side
Working Width* and Height	36.8 inches, at a height of 63.4 inches

[*] 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 7.3 Thrie-Beam Guardrail System at a Fixed Object after Test (614031-01-1).

7.6. DAMAGE TO TEST VEHICLE

Figure 7.4 and Figure 7.5 shows the damage sustained by the vehicle. Table 7.7 provide details on the interior and exterior damage to the vehicle. Tables C.2 and C.3 in Appendix C.1 provide exterior crush and occupant compartment measurements.

Figure 7.4 Test Vehicle after Test 614031-01-1.

Figure 7.5 Interior of Test Vehicle after Test 614031-01-1.

Table 7.7 Damage to Vehicle 614031-01-1.

<table>
<tr><th colspan="2">Test Parameter</th><th colspan="2">Specification</th><th colspan="2">Measured</th></tr>
<tr><td colspan="2">Roof</td><td colspan="2">≤ 4.0 inches</td><td colspan="2">0.0 inches</td></tr>
<tr><td colspan="2">Windshield</td><td colspan="2">≤ 3.0 inches</td><td colspan="2">0.0 inches</td></tr>
<tr><td colspan="2">A and B Pillars</td><td colspan="2">≤ 5.0 overall / ≤ 3.0 inches lateral</td><td colspan="2">0.0 inches</td></tr>
<tr><td colspan="2">Foot Well/Toe Pan</td><td colspan="2">≤ 9.0 inches</td><td colspan="2">1.0 inches</td></tr>
<tr><td colspan="2">Floor Pan/Transmission Tunnel</td><td colspan="2">≤ 12.0 inches</td><td colspan="2">0.0 inches</td></tr>
<tr><td colspan="2">Side Front Panel</td><td colspan="2">≤ 12.0 inches</td><td colspan="2">0.0 inches</td></tr>
<tr><td colspan="2">Front Door (above Seat)</td><td colspan="2">≤ 9.0 inches</td><td colspan="2">0.0 inches</td></tr>
<tr><td colspan="2">Front Door (below Seat)</td><td colspan="2">≤ 12.0 inches</td><td colspan="2">0.0 inches</td></tr>
<tr><td colspan="2">Side Windows</td><td colspan="4">Intact</td></tr>
<tr><td colspan="2">Maximum Exterior Deformation</td><td colspan="4">12.0 inches in the front plane at the front bumper at bumper height</td></tr>
<tr><td>VDS</td><td colspan="2">01RFQ6</td><td>CDC</td><td colspan="2">01FREW4</td></tr>
<tr><td colspan="2">Fuel Tank Damage</td><td>None</td><td colspan="3"></td></tr>
<tr><td colspan="6">Description of Damage to Vehicle:
Damage to front bumper hood and grill, radiator and support, right and left head lights, left frame rail, left front upper and lower control arms, left front quarter fender, left front door had a 2.5 inch gap at top, small dent in floor pan, left rear door, left cab corner, left rear quarter fender, left rear rim (no loss of air), rear bumper</td></tr>
</table>

7.7. OCCUPANT RISK FACTORS

Data from the accelerometers were digitized for evaluation of occupant risk, and the results are shown in Table 7.8 Figure C.3 in Appendix C.3 shows the vehicle angular displacements, and Figures C.4 through C.6 in Appendix C.4 show acceleration versus time traces.

Table 7.8 Occupant Risk Factors for Test 614031-01-1.

Test Parameter	Specification*	Measured	Time
OIV, Longitudinal (ft/s)	≤40.0 *30.0*	29.0	0.1334 s on left side of interior
OIV, Lateral (ft/s)	≤40.0 *30.0*	20.7	0.1334 s on left side of interior
Ridedown, Longitudinal (g)	≤20.49 *15.0*	8.9	0.1427 – 0.1527 s
Ridedown, Lateral (g)	≤20.49 *15.0*	9.3	0.1334 – 0.1434 s
THIV (m/s)	N/A	10.2	0.1290 s on left side of interior
ASI	N/A	1.39	0.1256 – 0.1756 s
50ms MA Longitudinal (g)	N/A	10.7	0.0953 – 0.1453 s
50ms MA Lateral (g)	N/A	9.0	0.1051 – 0.1551 s
50ms MA Vertical (g)	N/A	4.6	0.6995 – 0.7495 s
Roll (deg)	≤75	-17.4	0.6951 s
Pitch (deg)	≤75	-18.0	0.7265 s
Yaw (deg)	N/A	42.6	0.7959 s

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

0.000 s

0.100 s

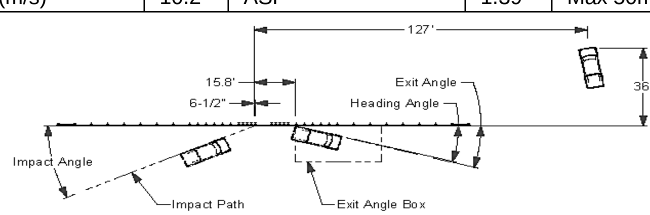
0.200 s

0.300 s

Test Agency	Texas A&M Transportation Institute (TTI)
Test Standard/Test No.	*MASH* 2016, Test 3-11
TTI Project No.	614031-01-1
Test Date	2022-03-24
TEST ARTICLE	
Type	156 ft-3 inches
Name	W-beam Guardrail, Wide-Flange Guardrail post, Timber Blockout
Length	156 ft-3 inches
Key Materials	Thrie-beam Guardrail, Wide-Flange Guardrail post
Soil Type and Condition	AASHTO M147-65(2004), Type D, Grade 1 Crushed Concrete
TEST VEHICLE	
Type/Designation	2270P
Year, Make and Model	2015, RAM 1500
Curb Weight (lbs)	4973
Inertial Weight (lbs)	5030
Dummy (lbs)	N/A
Gross Static (lbs)	5030
IMPACT CONDITIONS	
Impact Speed (mi/h)	62.1
Impact Angle (deg)	24.9
Impact Location	6.5 inches upstream from the centerline of post 19
Impact Severity (kip-ft)	115.0
EXIT CONDITIONS	
Exit Speed (mi/h)	37.7
Trajectory/Heading Angle (deg)	15.2
Exit Box Criteria	Vehicle crossed 35 ft downstream of loss of contact
Stopping Distance	127 feet downstream 36 feet to the field side
TEST ARTICLE DEFLECTIONS	
Dynamic (inches)	20.9
Permanent (inches)	17.75
Working Width / Height (inches)	36.8 inches, at a height of 63.4 inches
VEHICLE DAMAGE	
VDS	01RFQ6
CDC	01FREW4
Max. Ext. Deformation	12.0
Max Occupant Compartment Deformation	1.0 inch in the foot well/toe pan area

OCCUPANT RISK VALUES

Long.OIV (ft/s)	29.0	Long. Ridedown (g)	8.9	Max 50ms Long. (g)	10.7	Max Roll (deg)	-17.4
Lat. OIV (ft/s)	20.7	Lat. Ridedown (g)	9.3	Max 50ms Lat. (g)	9.0	Max Pitch (deg)	-18.0
THIV (m/s)	10.2	ASI	1.39	Max 50ms Vert (g)	4.6	Max Yaw (deg)	42.6



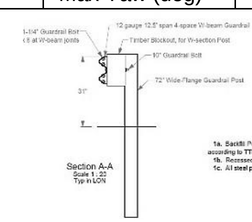


Figure 7.6 Summary of Results for *MASH* Test 3-11 on Thrie-Beam Guardrail System at a Fixed Object.

CHAPTER 8. SUMMARY AND CONCLUSIONS OF CRASH TESTING

8.1. ASSESSMENT OF TEST RESULTS

The two crash tests reported herein were performed in accordance with *MASH* TL-3 on the Thrie-Beam Guardrail System at a Fixed Object. Tables at the end of this section provide an assessment of each test based on the applicable safety evaluation criteria for *MASH* TL-3 longitudinal barriers.

8.2. CRASH TESTING CONCLUSIONS

Table 8.3 shows that the Thrie-Beam Guardrail System at a Fixed Object met the performance criteria for *MASH* TL-3 longitudinal barriers.

Table 8.1 Evaluation Summary for *MASH* Test 3-10 on Thrie-Beam Guardrail System at a Fixed Object.

Test Agency: Texas A&M Transportation Institute | Test No.: 614031-01-2 | Test Date: 2022-03-11

***MASH* Test 3-10 Evaluation Criteria**	**Test Results**	**Assessment**
<u>Structural Adequacy</u> A. *Test article should contain and redirect the vehicle or bring the vehicle to a controlled stop; the vehicle should not penetrate, underride, or override the installation although controlled lateral deflection of the test article is acceptable.*	The Thrie-Beam Guardrail contained and redirected the 1100C vehicle. The vehicle did not penetrate, underride, or override the installation. Maximum dynamic deflection during the test was 15.7 inches.	Pass
<u>Occupant Risk</u> D. *Detached elements, fragments, or other debris from the test article should not penetrate or show potential for penetrating the occupant compartment, or present an undue hazard to other traffic, pedestrians, or personnel in a work zone.*	No detached elements, fragments, or other debris from the transition was present to penetrate or show potential for penetrating the occupant compartment, or present hazard to others in the area.	Pass
Deformations of, or intrusions into, the occupant compartment should not exceed limits set forth in Section 5.2.2 and Appendix E of MASH.	Maximum occupant compartment deformation was 1 inch in the front door above the seat.	
F. *The vehicle should remain upright during and after collision. The maximum roll and pitch angles are not to exceed 75 degrees.*	The 1100C vehicle remained upright during and after the collision event. Maximum roll and pitch angles were 12.9 degrees and -3.9 degrees.	Pass
H. *Occupant impact velocities (OIV) should satisfy the following limits: Preferred value of 30 ft/s (10 ft/s for supports), or maximum allowable value of 40 ft/s (16 ft/s for supports).*	Longitudinal OIV was 27.6 ft/s, and lateral OIV was 25.6 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.*	Longitudinal RDA was 12.0 g, and lateral RDA was 16.8 g.	Pass

Table 8.2 Evaluation Summary for *MASH* Test 3-11 on Thrie-Beam Guardrail System at a Fixed Object.

Test Agency: Texas A&M Transportation Institute | Test No.: 614031-01-1 | Test Date: 2022-03-25

MASH Test 3-11 Evaluation Criteria	Test Results	Assessment
Structural Adequacy A. *Test article should contain and redirect the vehicle or bring the vehicle to a controlled stop; the vehicle should not penetrate, underride, or override the installation although controlled lateral deflection of the test article is acceptable.*	The Thrie-Beam Guardrail contained and redirected the 2270P vehicle. The vehicle did not penetrate, underride, or override the installation. Maximum dynamic deflection during the test was 20.9 inches.	Pass
Occupant Risk D. *Detached elements, fragments, or other debris from the test article should not penetrate or show potential for penetrating the occupant compartment, or present an undue hazard to other traffic, pedestrians, or personnel in a work zone.*	No detached elements, fragments, or other debris from the transition was present to penetrate or show potential for penetrating the occupant compartment, or present hazard to others in the area.	Pass
Deformations of, or intrusions into, the occupant compartment should not exceed limits set forth in Section 5.2.2 and Appendix E of MASH.	Maximum occupant compartment deformation was 1 inch in the foot well.	
F. *The vehicle should remain upright during and after collision. The maximum roll and pitch angles are not to exceed 75 degrees.*	The 1100C vehicle remained upright during and after the collision event. Maximum roll and pitch angles were -17.4 degrees and 9.0 degrees.	Pass
H. *Occupant impact velocities (OIV) should satisfy the following limits: Preferred value of 30 ft/s (10 ft/s for supports), or maximum allowable value of 40 ft/s (16 ft/s for supports).*	Longitudinal OIV was 29.0 ft/s, and lateral OIV was 20.7 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.*	Longitudinal RDA was 8.9 g, and lateral RDA was 9.3 g.	Pass

Table 8.3 Assessment Summary for *MASH* TL-3 Tests on Thrie-Beam Guardrail System at a Fixed Object.

Evaluation Factors	Evaluation Criteria	Test No. 614031-01-2	Test No. 614031-01-1
Structural Adequacy	A	S	S
Occupant Risk	D	S	S
	F	S	S
	H	S	S
	I	S	S
Test No.		*MASH* Test 3-10	*MASH* Test 3-11
Pass/Fail		Pass	Pass

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

CHAPTER 9. PROJECT IMPLEMENTATION

9.1. QUARTER-POST SPACING SYSTEM WITH 75-INCH GAP

The quarter-post spacing system with the 75-inch gap successfully met MASH evaluation criteria for both test 3-11 and 3-10. This system is therefore suitable for implementation on the roadside. During *MASH* test 3-11, the maximum rail deflection or vehicle penetration within the 75-inch gap in the rail system measured from the field side face of the rail was 23.25 in. Therefore, the research team recommends a minimum offset of 24 in between the back edge of rail and the impact side face of the fixed object.

9.2. COMPARISON OF CRASH TESTS TO SIMULATIONS

Following the crash tests, the research team compared the physical testing results to the results of the computer simulations. Table 9.1 shows a summary of the quantitative comparison. The dynamic deflections and working widths correlated well between the crash tests and the computer simulations, which provides confidence in the predictive ability of the computer simulations with respect to defining the minimum offset of the rail from a fixed object.

Table 9.1 Assessment Summary for *MASH* TL-3 Tests on Thrie-Beam Guardrail System at a Fixed Object.

	MASH 3-11		**MASH 3-10**	
Data	**Crash Test**	**Simulation**	**Crash Test**	**Simulation**
OIV (m/s)	8.8	7.5	8.4	9.2
RDA (g's)	9.3	18.2	16.8	18.9
Working Width (in)	36.8	33.5	28.8	26.5
Dynamic Deflection (in)	20.9	19.1	15.7	14.6
Fixed Object Offset (in)	23.25	20.0	N/A	N/A

Figure 9.1 and Figure 9.2 show the sequential frames of the *MASH* Test 3-11 overlayed with the simulated *MASH* Test 3-11. Figure 9.3 and Figure 9.4 show the sequential frames of the *MASH* Test 3-10 overlayed with the simulated *MASH* Test 3-10.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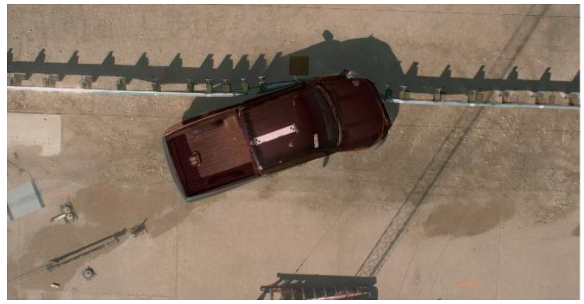
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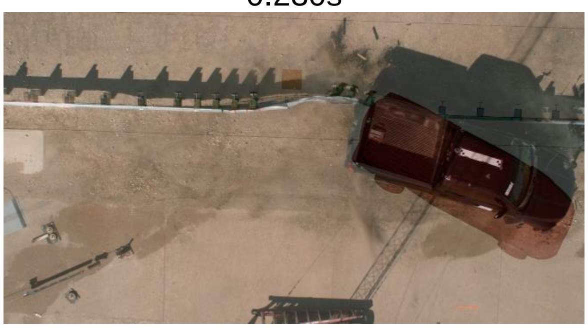
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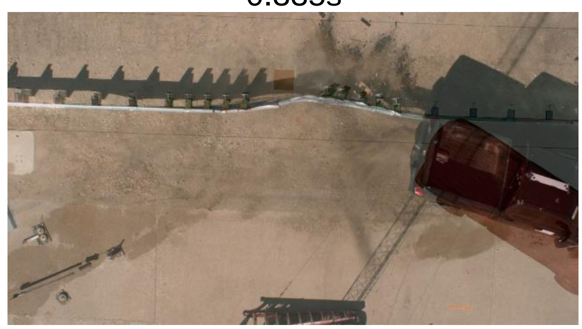
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Figure 9.1. MASH Test 3-11 and Simulated MASH Test 3-11 Overlay Comparison Photos – Overhead View

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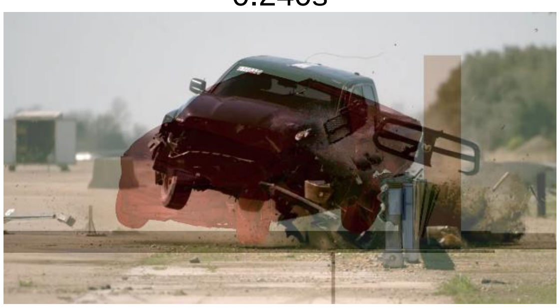

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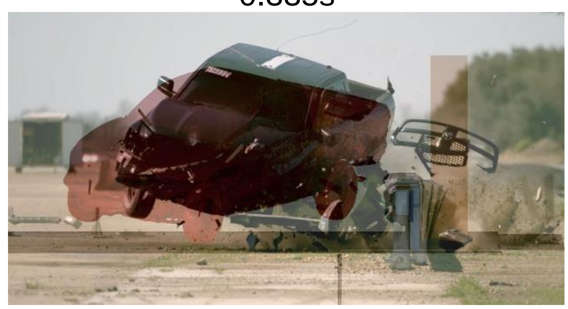

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Figure 9.2. MASH Test 3-11 and Simulated MASH Test 3-11 Overlay Comparison Photos – Downstream View

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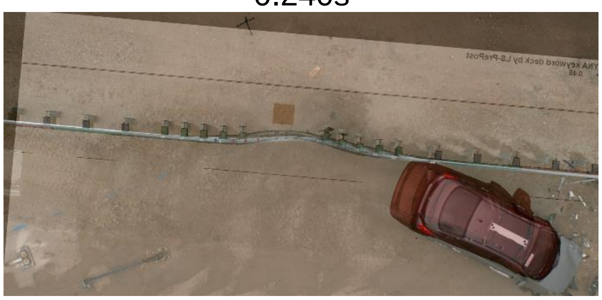

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Figure 9.3. MASH Test 3-10 and Simulated MASH Test 3-10 Overlay Comparison Photos – Overhead View

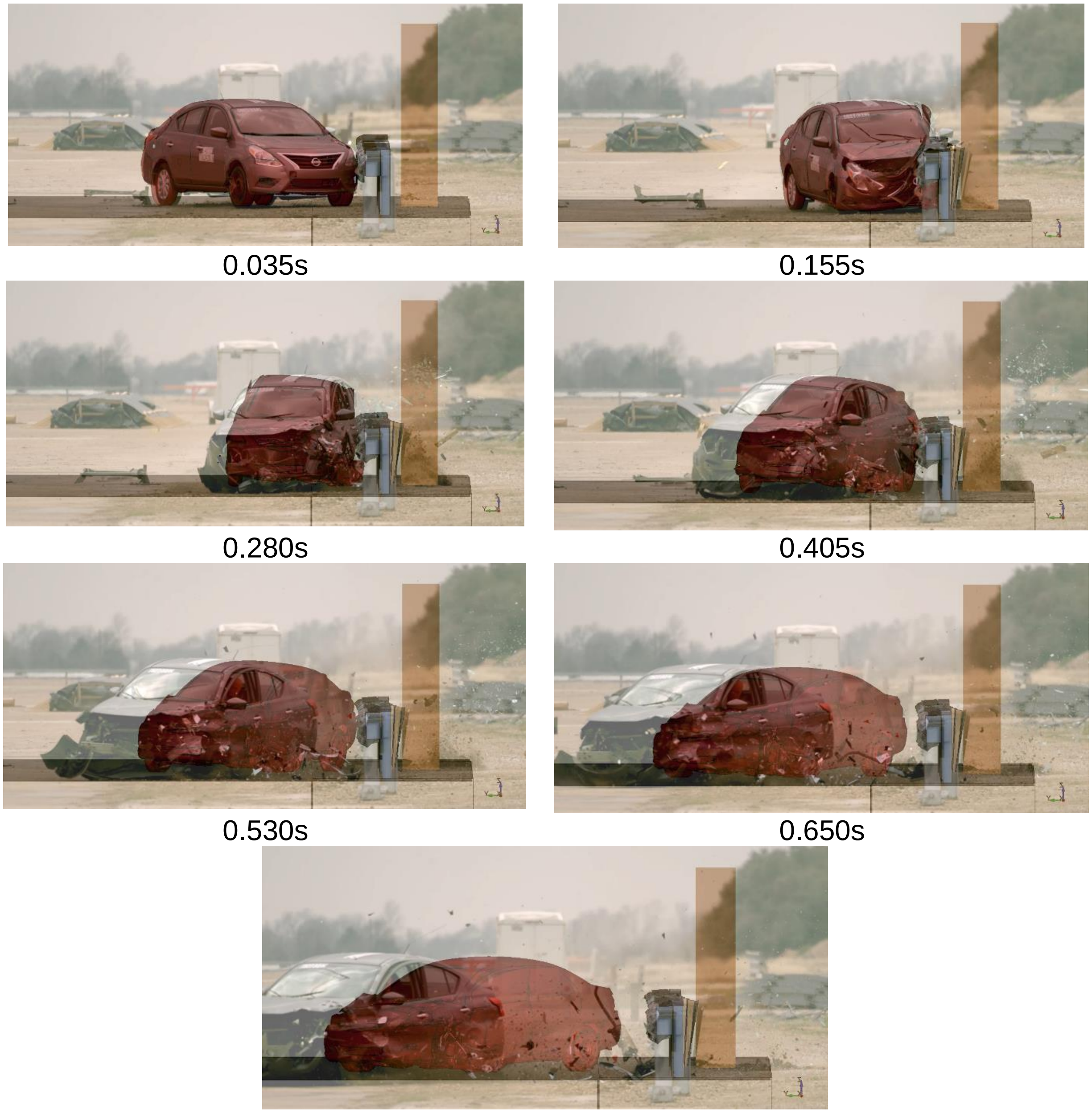

Figure 9.4. MASH Test 3-10 and Simulated MASH Test 3-10 Overlay Comparison Photos – Downstream View

9.3. HALF-POST SPACING SYSTEM WITH 75-INCH GAP

The research team selected the quarter-post spacing system with the 75-inch gap for crash testing as it would provide the largest difference in stiffness when comparing the gap between posts and the stiffened sections on either side of the gap. This stiffness difference resulted in a higher potential for pocketing and rail rupture. The quarter-post spacing system with a 75-inch gap successfully passed *MASH* evaluation criteria.

The successful correlation of the simulation and crash test provided confidence in the predictive ability of the simulations. Based upon the successful simulations of the half-post spacing system with a 75-inch gap and the successful crash testing of the critical quarter-post spacing system with 75-inch gap, the research team concluded the half-post spacing system with 75-inch gap is also MASH compliant and suitable for implementation on the roadside.

The difference between the minimum offset measured from the physical *MASH* test 3-11 and the computer simulations of the quarter-post spacing system with 75-inch gap was 3.25 inches. The computer simulations predicted a minimum offset of 24 inches between the back of rail and the impact side face of the fixed object for the half-post spacing system with the 75-inch gap. Therefore, the research team recommends a minimum offset of 28 inches between the back of the rail and the impact side face of the fixed object for the half-post spacing system with 75-inch gap.

9.4. TRANSITIONS

Approach guardrail stiffness transitions typically use a combination of post spacing and varying rail elements to transition a change in stiffness over a specified distance. A variety of approach guardrail stiffness transitions have been tested to *MASH,* and many connect a standard MGS to a bridge rail or similar structure. These transitions are carefully designed to ensure the transition stiffness is varied over a sufficient length to mitigate pocketing.

The research team is recommending the use of a previously tested design to provide a sufficient stiffness transition from a standard MGS to the stiffened thrie-beam guardrail section described in this report. This transition was previously tested by the Midwest Roadside Safety Facility (MwRSF) at a height of 34 inches (*4*). The MwRSF researchers provided a *MASH* compliance justification for an installation height of 31 inches as it provides a smaller clear opening beneath the transition rail element, and therefore, reduced potential for vehicle snagging on the stiffer system on the downstream end of the transition. Since this stiffness transition successfully met *MASH* evaluation criteria when attached to a rigid concrete buttress on the downstream end, it is considered crashworthy when connected to the less rigid, stiffened thrie-beam guardrail system described in this report.

The section of nested thrie-beam adjacent to the concrete buttress in the previously tested transition was also reviewed. The section of nested thrie-beam provides additional bending stiffness to reduce potential for local deformation and pocketing at the connection to the rigid concrete buttress. In contrast, the transition to the stiffened thrie-beam guardrail section is connected to a thrie-beam rail section supported by soil embedded posts, which represents a smaller change in stiffness compared to the concrete buttress. Furthermore, a single ply of thrie-beam was utilized in the crash testing described in this report, which evaluated a gap between the posts of the stiffened thrie-beam guardrail. These successful tests demonstrated the strength of the single ply of thrie-beam is sufficient to avoid excessive pocketing and snagging.

Because the connection between the transition and the stiffened thrie-beam guardrail has less of a stiffness change, the nested rail is not considered necessary, and a single ply of thrie-beam rail may be used throughout the transition section.

Previous testing has also demonstrated the crashworthiness of the upstream portion of the recommended transition (*5*). These details are similar between the two transitions. Therefore, the recommended transition from MGS to the new stiffened thrie-beam guardrail is viewed as *MASH* compliant.

Figure 9.5 shows the recommended transition detail for connecting the stiffened thrie-beam guardrail system evaluated in this project to a standard MGS.

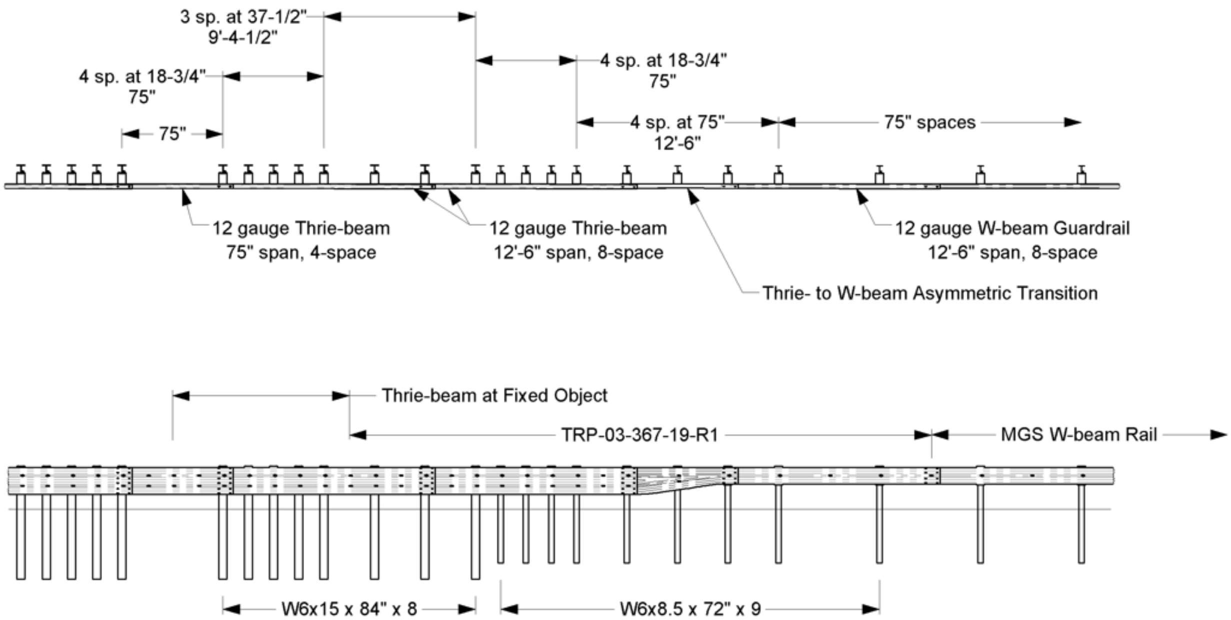

Figure 9.5. Recommended Transition Details

9.5. OTHER CONSIDERATIONS

Figure 9.5 shows the recommended transition detail for a single rail gap. If multiple gaps are required, the research team recommends installing, at a minimum, the posts within the region denoted as “Thrie-beam at Fixed Object” in Figure 9.5 between each gap in the rail.

Grading around the posts is recommended to follow typical grading requirements for MGS. The “Thrie-beam at Fixed Object” portion is intended to be installed with W6x15 steel posts as shown in this report. If use of wood posts is desired, designers are directed to utilize MwRSF report TRP-03-243-11 for specifications regarding wood post AGTs (*6*).

Based on the system damage and the video analysis, the research team recommends the fixed object intended to be shielded be centered in the rail gap and have a maximum width of 75-inches, corresponding to the width of the gap. Lastly, the ends of the installation are recommended to be terminated with *MASH* compliant terminals or anchorages, as appropriate.

9.6. CONCLUSIONS

The objective of this project was to develop a stiffened thrie-beam guardrail system that could be implemented in close proximity to fixed objects on the roadside. In pursuit of this goal, the research team performed numerous computer simulations to determine the minimum required offset to limit the interaction between an impacting vehicle and the fixed object. The research team developed both half-post spacing and quarter-post spacing design alternatives with a 75-inch gap between posts. The critical design option, the quarter-post spacing system with 75-inch gap, was evaluated through full-scale crash testing. This system successfully met *MASH* evaluation criteria for tests 3-11 and 3-10. Having achieved reasonable correlation between the computer simulations and full-scale crash tests, the research team concluded both the quarter-post spacing and half-post spacing alternatives were *MASH* compliant and suitable for implementation on the roadside.

The research team recommends a minimum offset of 24 inches between the back of the thrie-beam rail and the traffic-side face of the fixed object when utilizing the quarter-post spacing alternative. The research team recommends a minimum offset of 28 inches between the back of the thrie-beam rail and the traffic-side face of the fixed object for the half-post spacing option. Lastly, the research team recommended a transition design for connecting the stiffened thrie-beam guardrail systems developed in this project to standard MGS.

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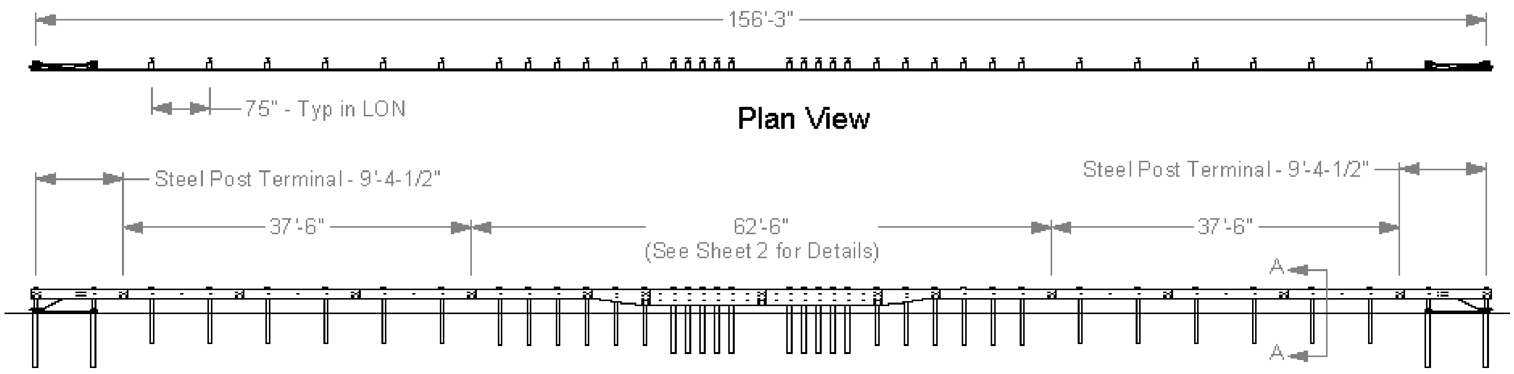
4. S.K. Rosenbaugh, W.G. Fallet, R.K. Faller, R.W. Bielenberg, J.D. Schmidt, “34-in. Tall Thrie Beam Transition to Concrete Buttress,” TRP-03-367-19-R1, Midwest Roadside Safety Facility, University of Nebraska-Lincoln, Lincoln, NE, 2019.

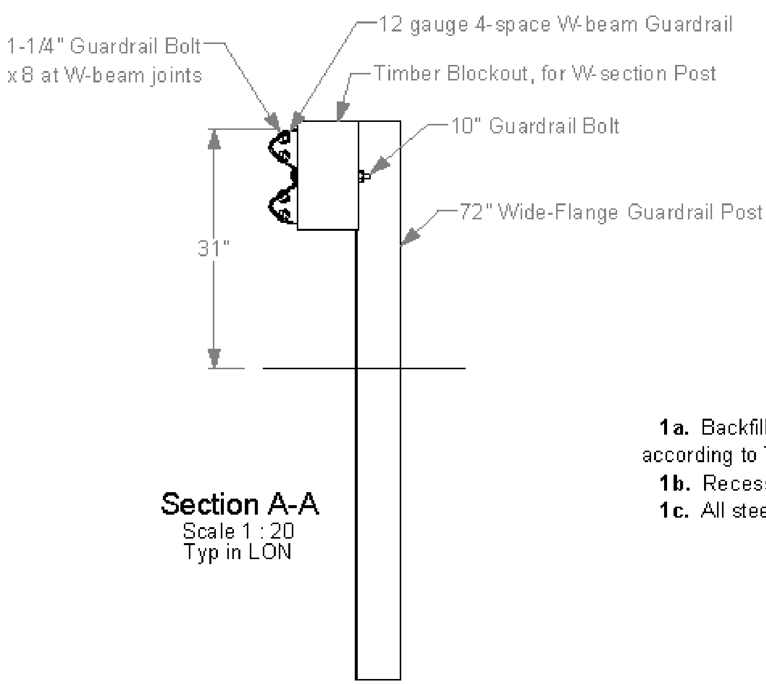
5. S.K. Rosenbaugh, K.A. Lechtenberg, R.K. Faller, D.L. Sicking, R.W. Bielenberg, J.D. Reid, “Development of the MGS Approach Guardrail Transition Using Standardized Steel Posts,” Midwest Roadside Safety Facility, University of Nebraska-Lincoln, Lincoln, NE, 2010.

6. S.K. Rosenbaugh, K.D. Schrum, R.K. Faller, K.A. Lechtenberg, D.L. Sicking, J.D. Reid, “Development of Alternative Wood-Post Mgs Approach Guardrail Transition,” TRP-03-243-11, Midwest Roadside Safety Facility, University of Nebraska-Lincoln, Lincoln, NE, 2011.

APPENDIX A. DETAILS OF THRIE BEAM GUARDRAIL SYSTEM AT A FIXED OBJECT

Test Installation





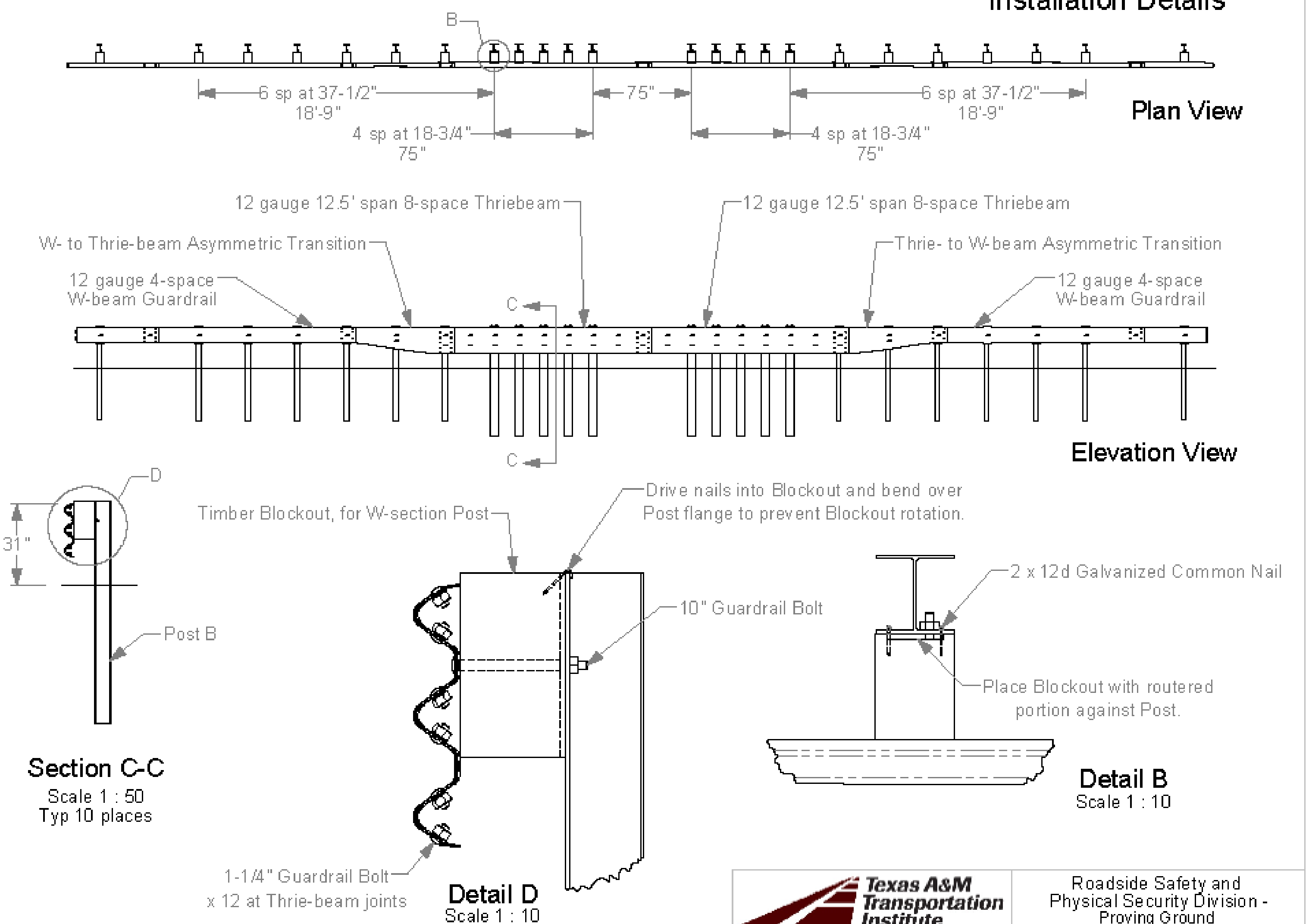
Section A-A
Scale 1 : 20
Typ in LON

1a. Backfill Post holes with Type D grade 1 crushed concrete road base, compacted according to TTI Proving Ground Work Instruction WI-C001.
1b. Recessed Guardrail Nut on all Button-head Guardrail Bolts.
1c. All steel parts shall be galvanized.

Texas A&M Transportation Institute	Roadside Safety and Physical Security Division - Proving Ground	
Project #614031-01 Thrie-beam at Fixed Object		2023-10-10
Drawn by GS/WS	Scale 1:200	Sheet 1 of 3 Test Installation

\\hq-nas.tti.servers\CPG\Accreditation-17025-2017\EIR-000 Project Files\614031 - Thrie-Beam at a Fixed Object - Kovar\Drafting\614031 Drawing

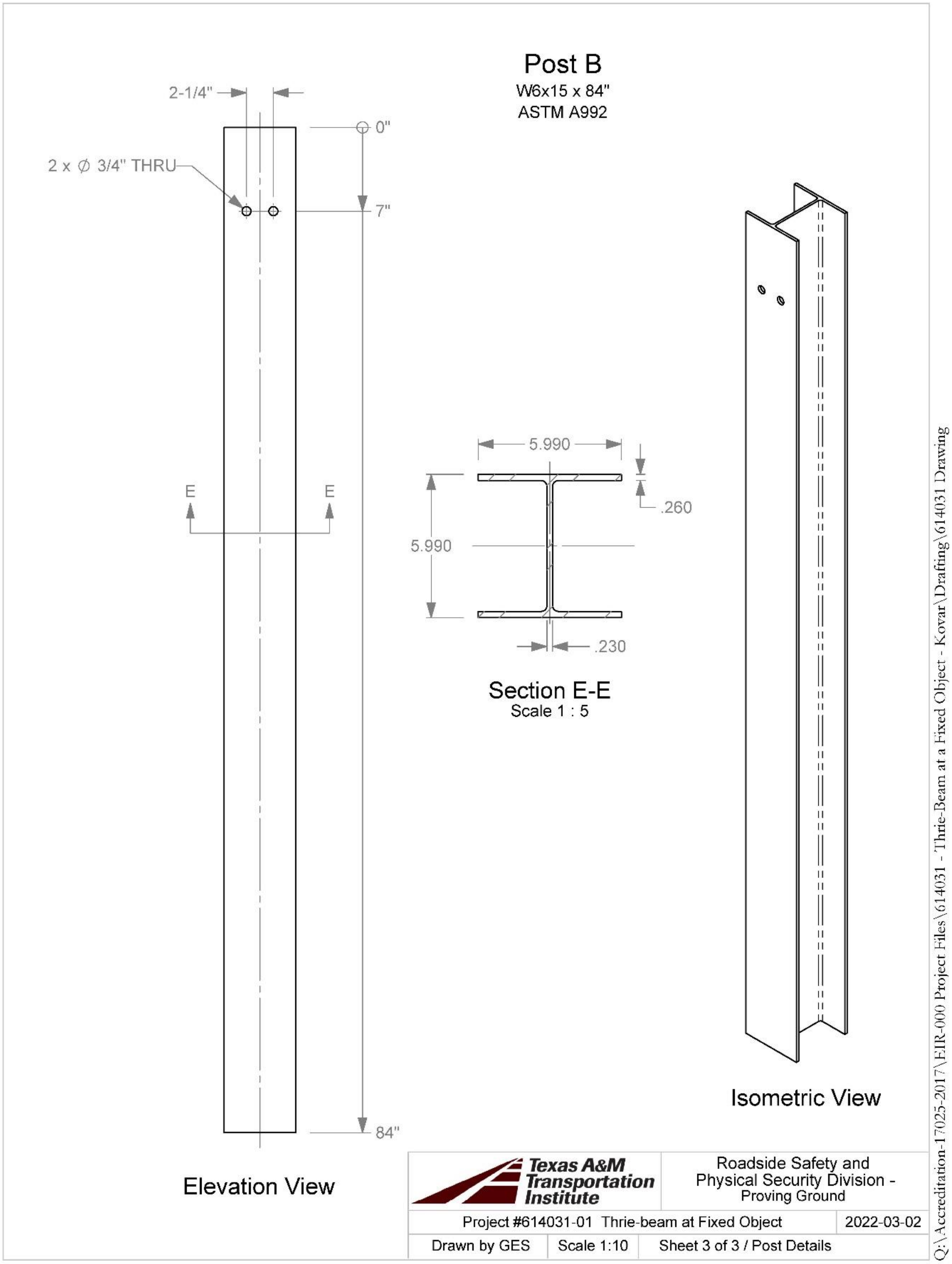
Installation Details



Texas A&M Transportation Institute

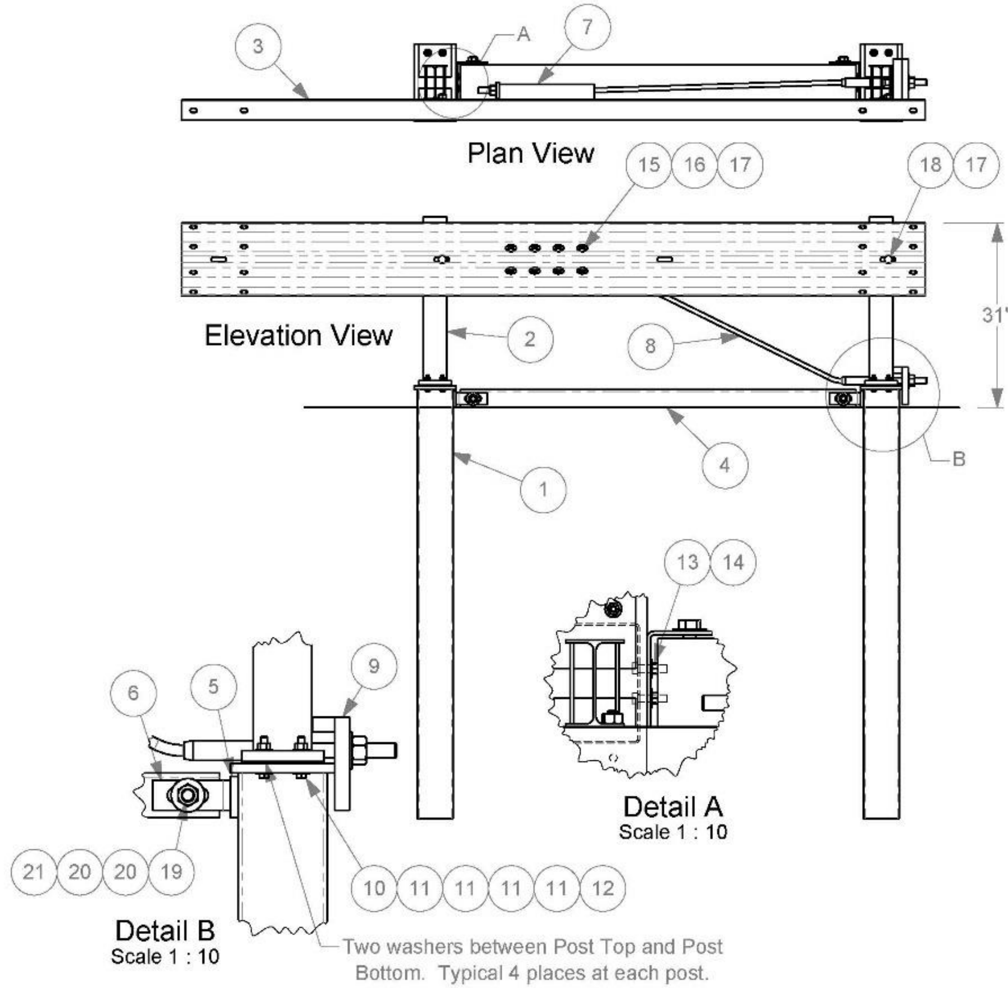
Roadside Safety and Physical Security Division - Proving Ground

Project #614031-01 Thrie-beam at Fixed Object		2023-10-10
Drawn by GS/WS	Scale 1:100	Sheet 2 of 3 Installation Details


Post B
W6x15 x 84"
ASTM A992
2-1/4"
0"
2 x ∅ 3/4" THRU
7"
E
E
84"
Elevation View
5.990
.260
5.990
.230
Section E-E
Scale 1 : 5
Isometric View
Texas A&M Transportation Institute
Roadside Safety and Physical Security Division - Proving Ground
Project #614031-01 Thrie-beam at Fixed Object
2022-03-02
Drawn by GES
Scale 1:10
Sheet 3 of 3 / Post Details
Q:\Accreditation-17025-2017\EIR-000 Project Files\614031 - Thrie-Beam at a Fixed Object - Kovar\Drafting\614031 Drawing

Terminal Details

#	Part Name	QTY.
1	Post Bottom	2
2	Post Top	2
3	9'-4" span Terminal Rail	1
4	Strut	1
5	Strut Spacer	2
6	Strut Bracket	2
7	Guardrail Anchor Bracket	1
8	Anchor Cable Assembly	1
9	Bearing Plate	1
10	Bolt, 7/16 x 2 1/2" hex	8
11	Washer, 7/16 F844	32
12	Nut, 7/16 heavy hex	8
13	Nut, 1/2 hex	4
14	Washer, 1/2 F844	4
15	Bolt, 5/8 x 1 1/2" hex	8
16	Washer, 5/8 F844	8
17	Recessed Guardrail Nut	10
18	1-1/4" Guardrail Bolt	2
19	Bolt, 7/8 x 8 1/2" hex	2
20	Washer, 7/8 F844	4
21	Nut, 7/8 hex	2

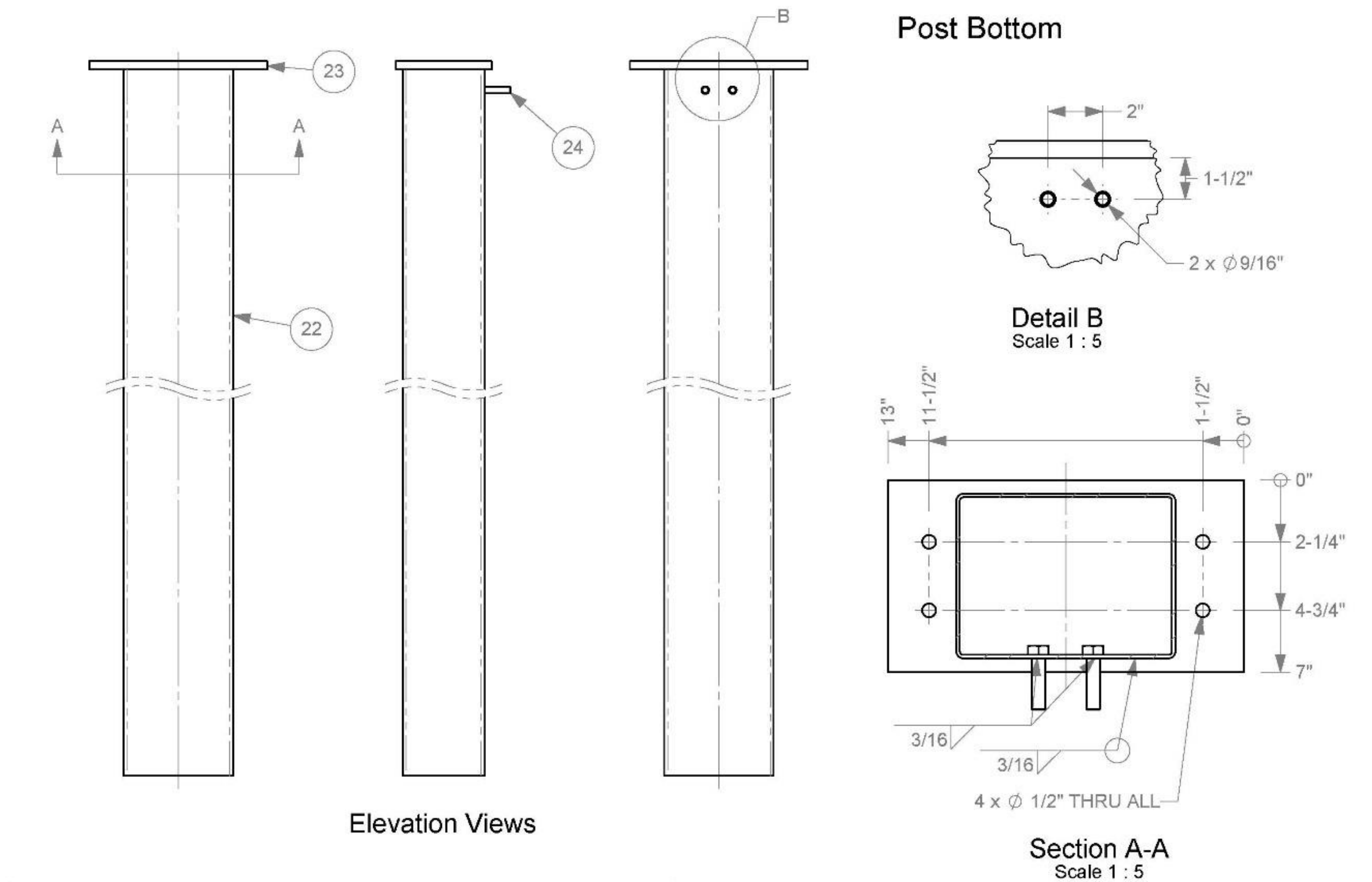


1a. 7/16" x 2-1/2" Bolts are ASTM A449. All other Bolts are ASTM A307. All Nuts (except Recessed Guardrail Nuts) are ASTM A563A unless otherwise indicated.

1c. All steel parts shall be galvanized.

Texas A&M Transportation Institute		Roadside Safety and Physical Security Division - Proving Ground
Project # Terminal		2021-06-01
Drawn by GES	Scale 1:25	Sheet 1 of 6 Terminal Details

T:\Drafting Department\Solidworks\Standard Parts\Guardrail Parts and Subs\Guardrail Drawings\Midwest Terminal



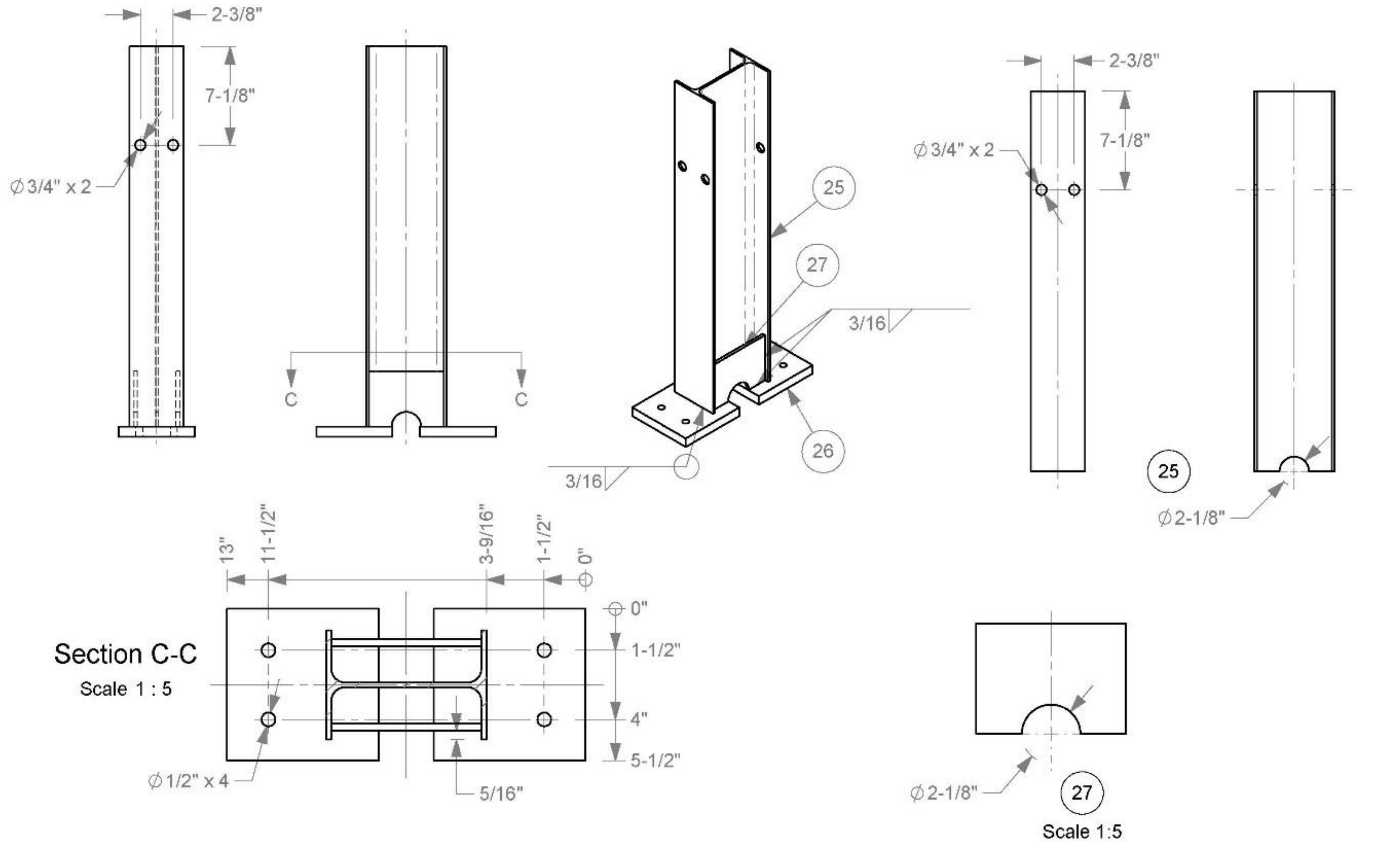
#	Description	Length	Material	Qty
22	HSS 8" x 6" x 1/8"	72"	ASTM A500 Grade B	1
23	Plate, 7" x 5/8"	13"	ASTM A36	1
24	Bolt, 1/2 x 2 hex		ASTM A307	2

Texas A&M Transportation Institute

Roadside Safety and Physical Security Division - Proving Ground

Project # Terminal		2021-06-01
Drawn by GES	Scale 1:10	Sheet 2 of 6 Post Bottom

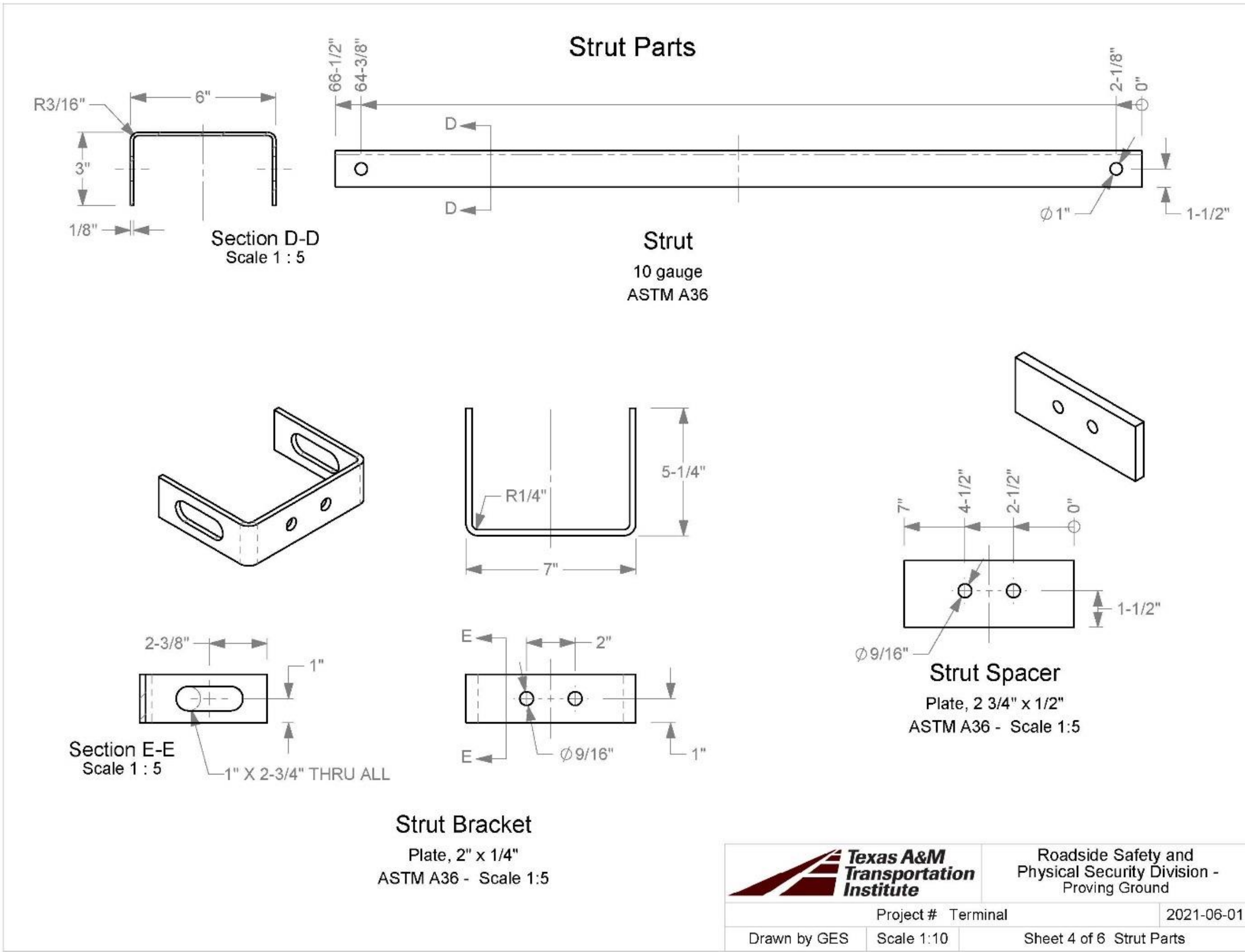
T:\Drafting Department\Solidworks\Standard Parts\Guardrail Parts and Subs\Guardrail Drawings\Midwest Terminal



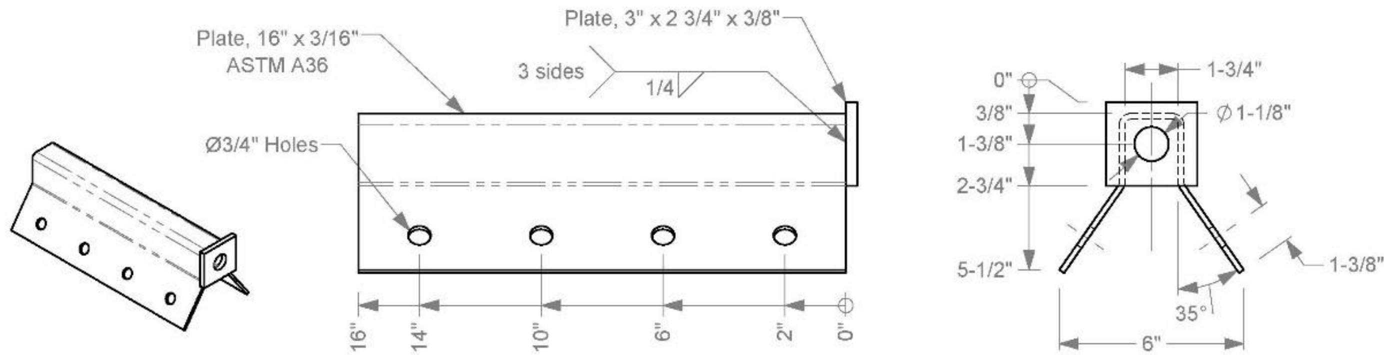
#	Description	Length	Material	Qty
25	W6x8.5	27 1/2"	ASTM A992	1
26	Plate, 5 1/2" x 3/4"	5 1/2"	ASTM A36	2
27	Plate, 5 7/16" x 1/4"	4"	ASTM A36	2

Texas A&M Transportation Institute	Roadside Safety and Physical Security Division - Proving Ground		
	Project # Terminal		2021-06-01
Drawn by GES	Scale 1:10	Sheet 3 of 6 Post Top	

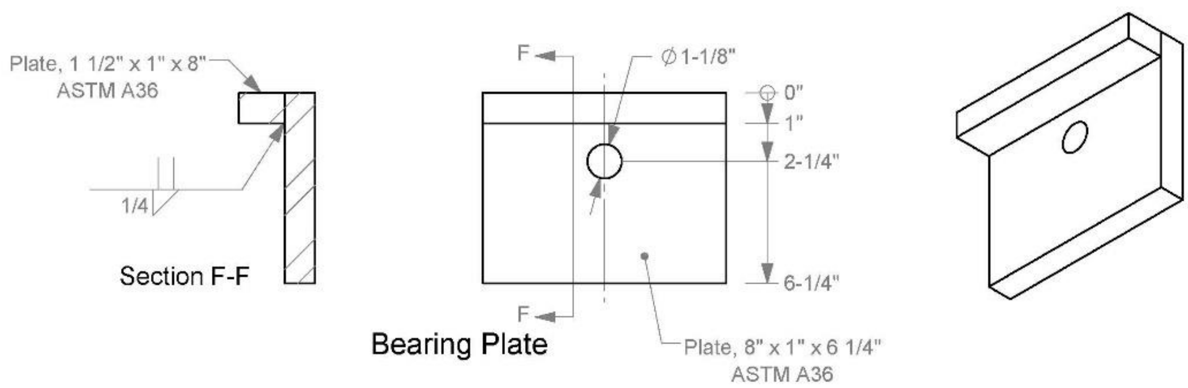
T:\Drafting Department\Solidworks\Standard Parts\Guardrail Parts and Subs\Guardrail Drawings\Midwest Terminal



T:\Drafting Department\Solidworks\Standard Parts\Guardrail Parts and Subs\Guardrail Drawings\Midwest Terminal

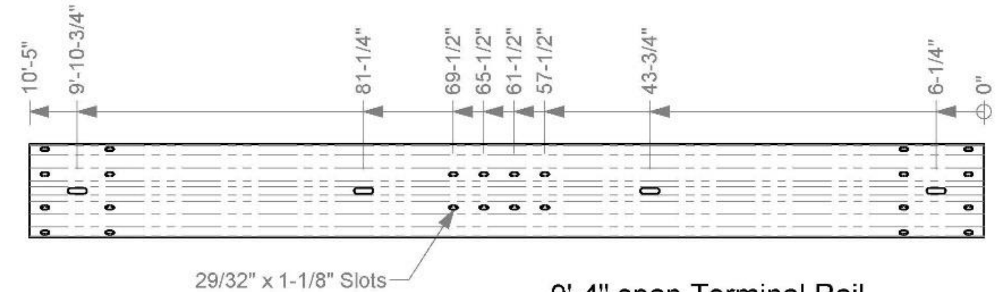


Guardrail Anchor Bracket



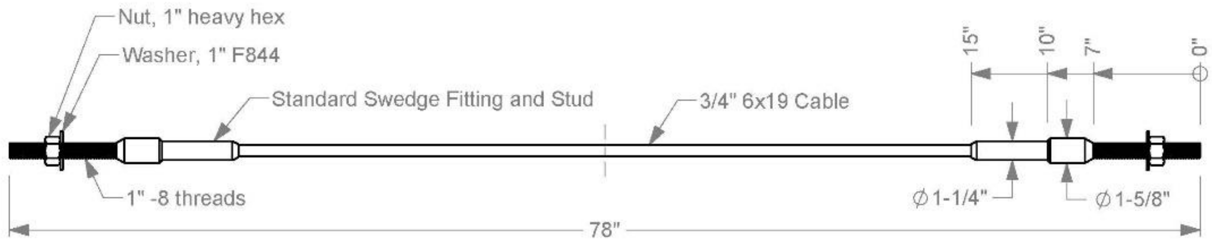
Texas A&M Transportation Institute		Roadside Safety and Physical Security Division - Proving Ground
Project # Terminal		2021-06-01
Drawn by GES	Scale 1:5	Sheet 5 of 6 Assorted Parts A

T:\Drafting Department\Solidworks\Standard Parts\Guardrail Parts and Subs\Guardrail Drawings\Midwest Terminal



9'-4" span Terminal Rail

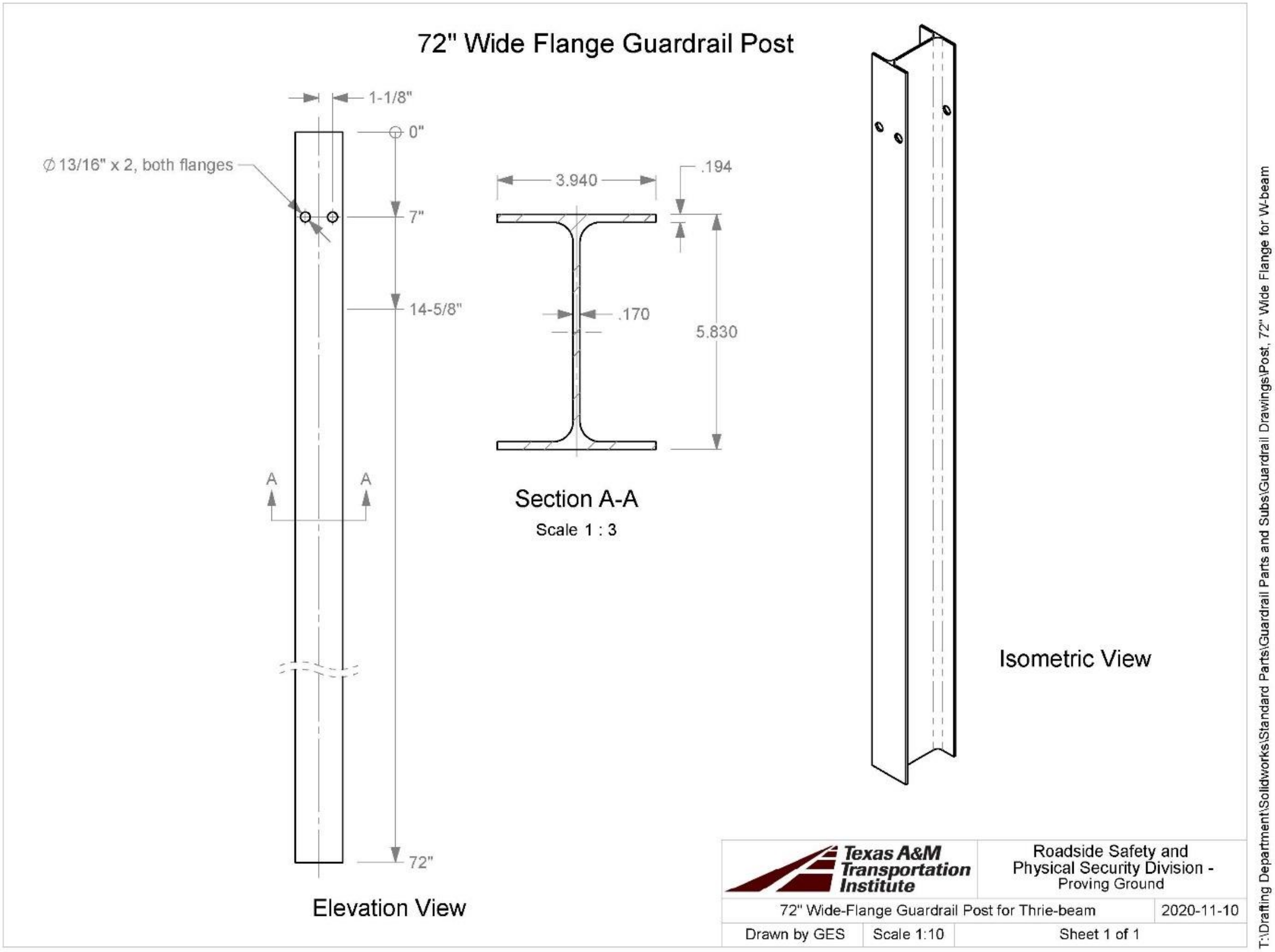
Scale 1:20 - See 4-space W-beam Guardrail drawing for cross-section and other dimensions.



Anchor Cable Assembly

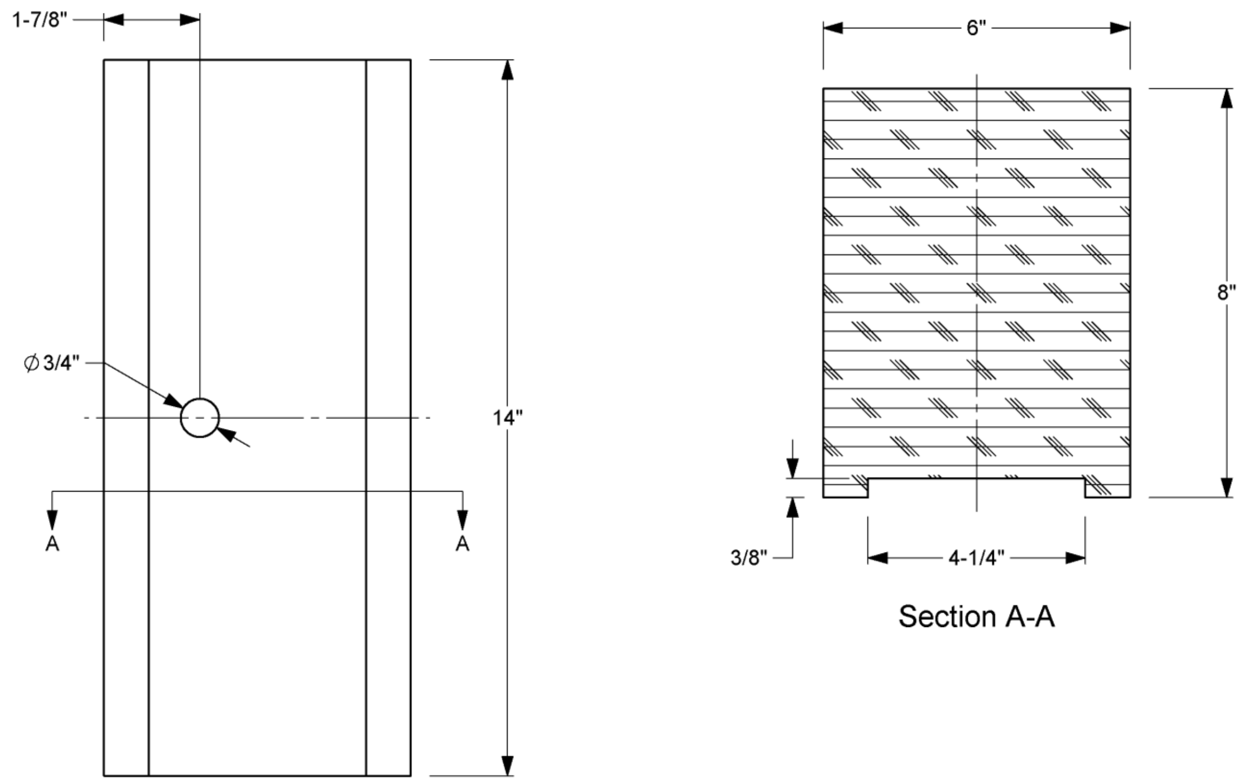
Texas A&M Transportation Institute	Roadside Safety and Physical Security Division - Proving Ground	
Project # Terminal		2021-06-01
Drawn by GES	Scale 1:5	Sheet 6 of 6 Assorted Parts B

T:\Drafting Department\Solidworks\Standard Parts\Guardrail Parts and Subs\Guardrail Drawings\Midwest Terminal


72" Wide Flange Guardrail Post
1-1/8"
0"
∅ 13/16" x 2, both flanges
7"
14-5/8"
72"
A
A
Elevation View
3.940
.194
.170
5.830
Section A-A
Scale 1 : 3
Isometric View
Texas A&M Transportation Institute
Roadside Safety and Physical Security Division - Proving Ground
72" Wide-Flange Guardrail Post for Thrie-beam
2020-11-10
Drawn by GES
Scale 1:10
Sheet 1 of 1
T:\Drafting Department\Solidworks\Standard Parts\Guardrail Parts and Subs\Guardrail Drawings\Post, 72" Wide Flange for W-beam

Timber Blockout for W-section Post

All dimensions except hole diameter are nominal



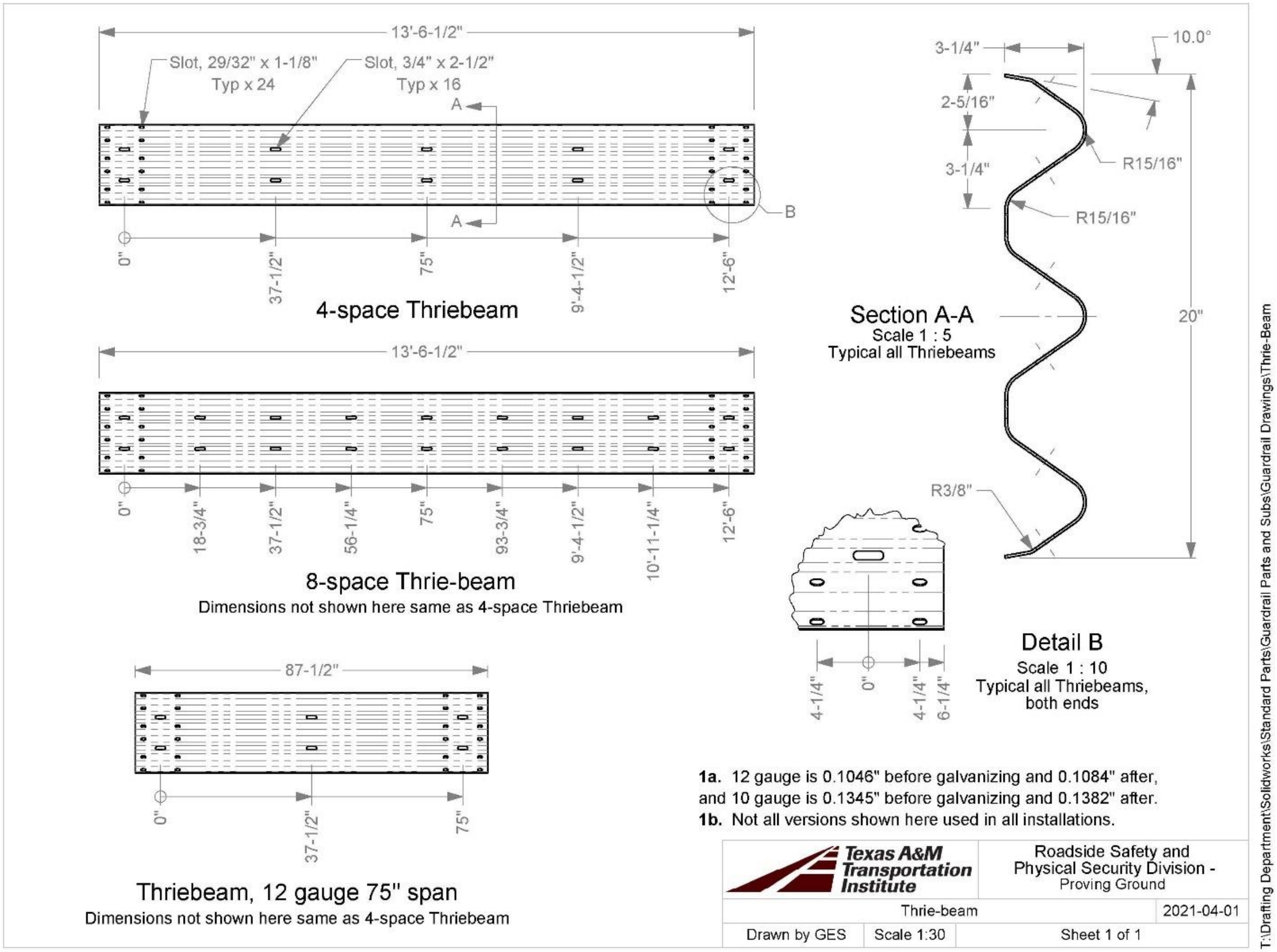
Elevation View

Section A-A

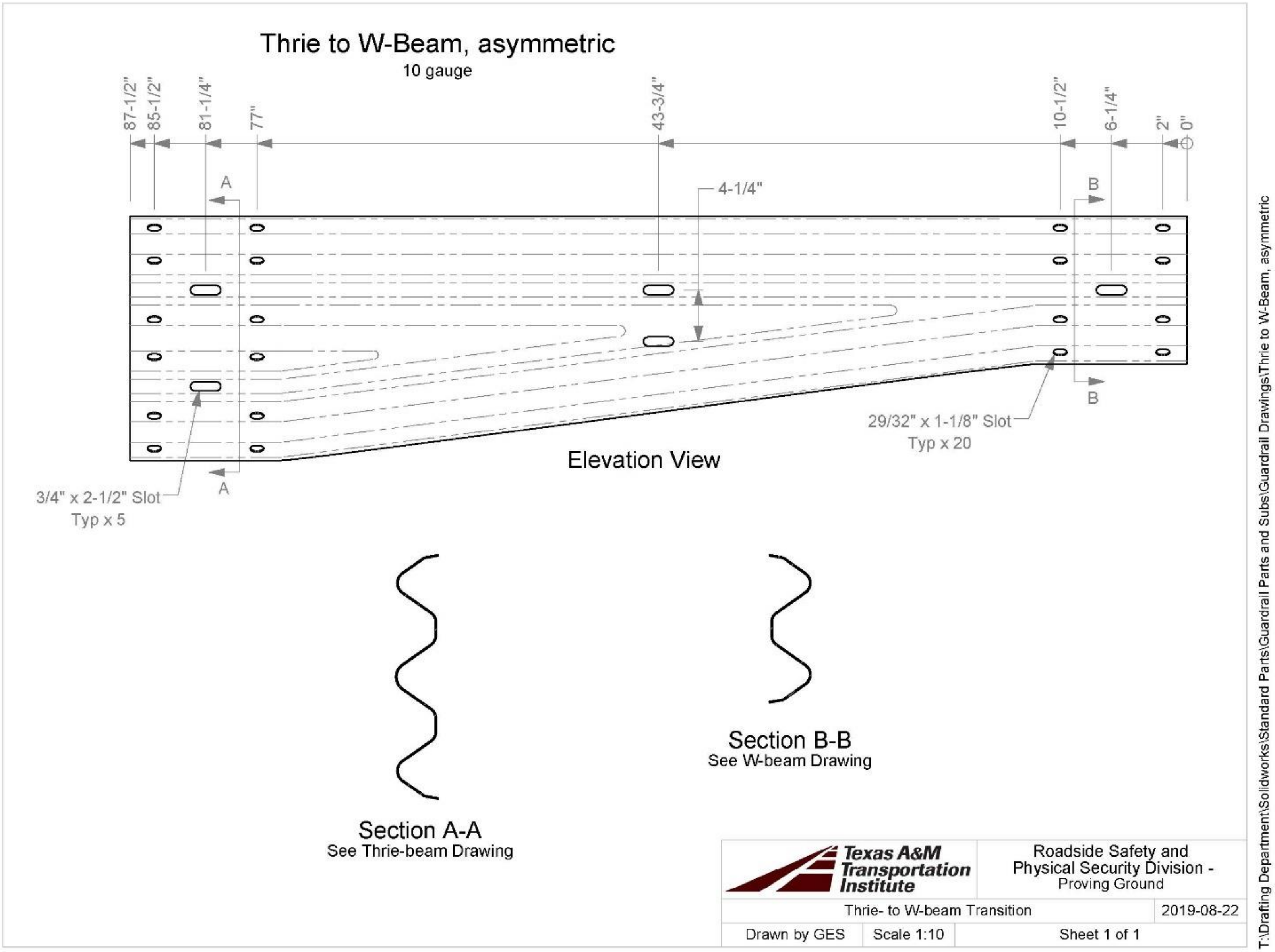
1a. Timber blockouts are treated with a preservative in accordance with AASHTO M 133 after all cutting and drilling.

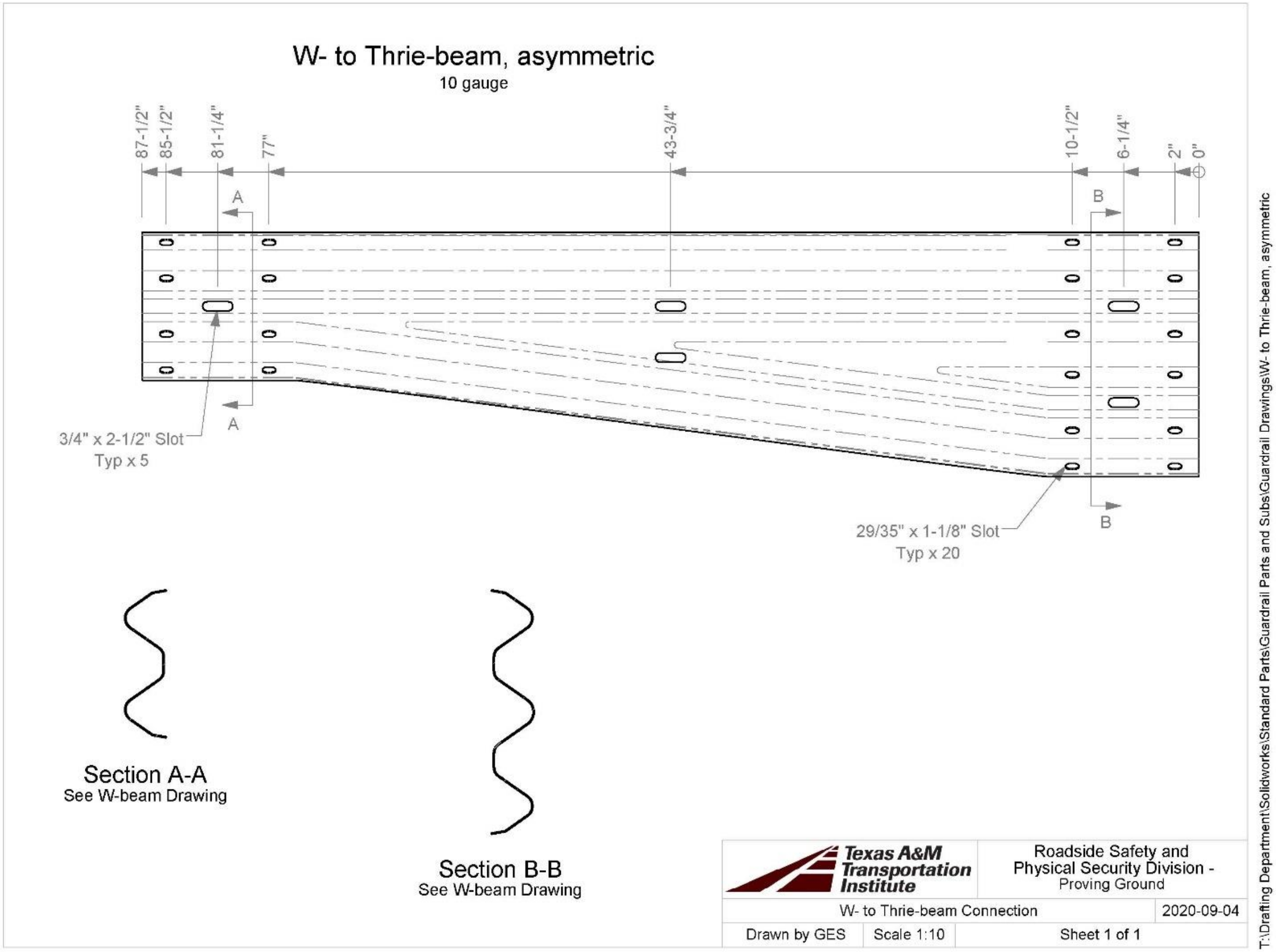
Texas A&M Transportation Institute	Roadside Safety and Physical Security Division - Proving Ground	
Timber Blockout, for W-section Post		2022-12-16
Drawn by GES	Scale 1:3	Sheet 1 of 1

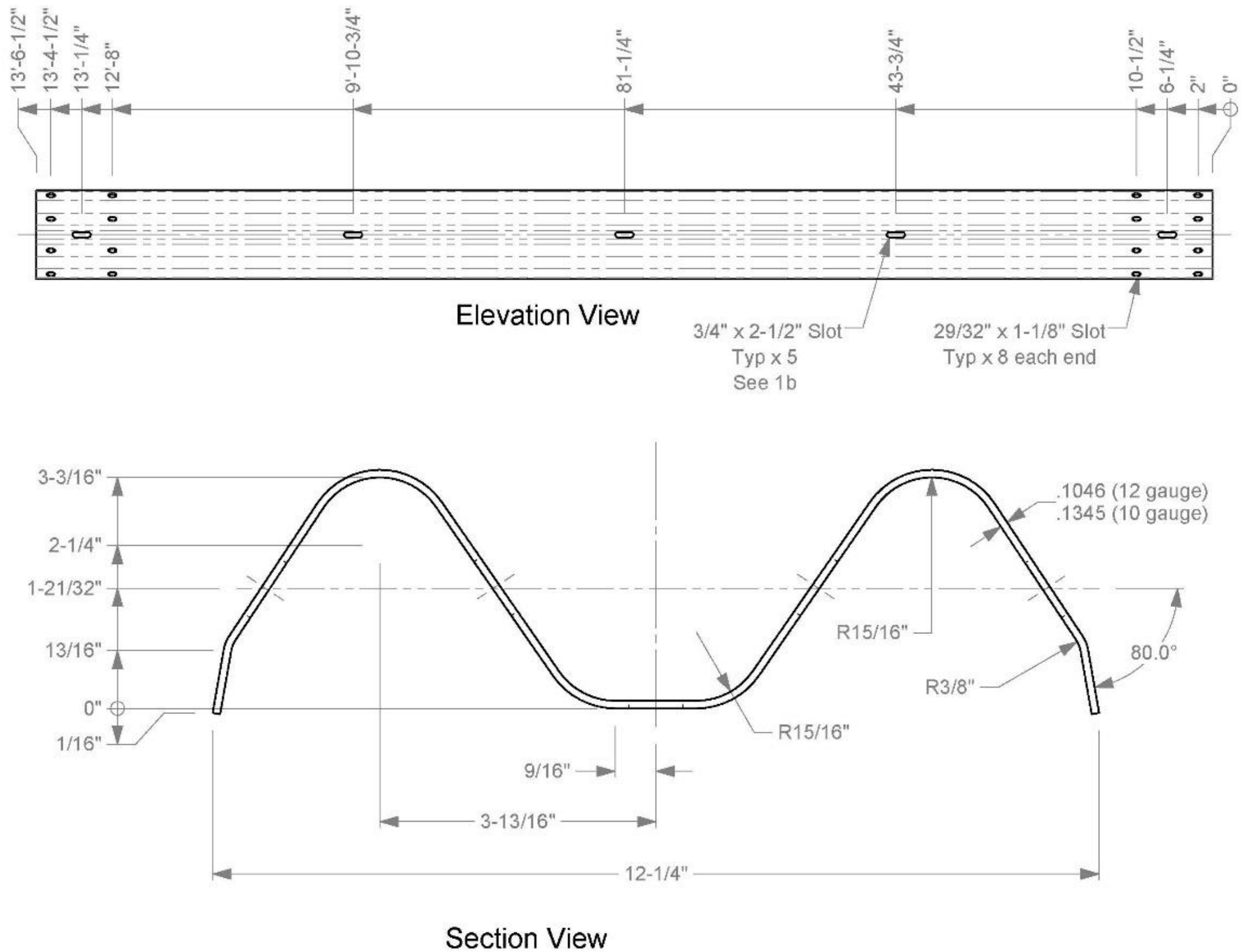
T:\Drafting Department\Solidworks\Standard Parts\Guardrail Parts and Subs\Guardrail Drawings\Timber Blockout for W-section Post



13'-6-1/2"
Slot, 29/32" x 1-1/8" Typ x 24
Slot, 3/4" x 2-1/2" Typ x 16
A
A
B
0"
37-1/2"
75"
9'-4-1/2"
12'-6"
4-space Thriebeam
13'-6-1/2"
0"
18-3/4"
37-1/2"
56-1/4"
75"
93-3/4"
9'-4-1/2"
10'-11-1/4"
12'-6"
8-space Thrie-beam
Dimensions not shown here same as 4-space Thriebeam
87-1/2"
0"
37-1/2"
75"
Thriebeam, 12 gauge 75" span
Dimensions not shown here same as 4-space Thriebeam
3-1/4"
10.0°
2-5/16"
3-1/4"
R15/16"
R15/16"
20"
Section A-A
Scale 1 : 5
Typical all Thriebeams
R3/8"
4-1/4"
0"
4-1/4"
6-1/4"
Detail B
Scale 1 : 10
Typical all Thriebeams, both ends
1a. 12 gauge is 0.1046" before galvanizing and 0.1084" after, and 10 gauge is 0.1345" before galvanizing and 0.1382" after.
1b. Not all versions shown here used in all installations.
Texas A&M Transportation Institute
Roadside Safety and Physical Security Division - Proving Ground
Thrie-beam
2021-04-01
Drawn by GES
Scale 1:30
Sheet 1 of 1
T:\Drafting Department\Solidworks\Standard Parts and Subs\Guardrail Drawings\Thrie-Beam


Thrie to W-Beam, asymmetric
10 gauge
87-1/2"
85-1/2"
81-1/4"
77"
43-3/4"
10-1/2"
6-1/4"
2"
0"
A
4-1/4"
B
29/32" x 1-1/8" Slot
Typ x 20
Elevation View
3/4" x 2-1/2" Slot
Typ x 5
Section B-B
See W-beam Drawing
Section A-A
See Thrie-beam Drawing
Texas A&M Transportation Institute
Roadside Safety and Physical Security Division - Proving Ground
Thrie- to W-beam Transition
2019-08-22
Drawn by GES
Scale 1:10
Sheet 1 of 1
T:\Drafting Department\Solidworks\Standard Parts and Subs\Guardrail Parts\Guardrail Drawings\Thrie to W-Beam, asymmetric


W- to Thrie-beam, asymmetric
10 gauge
87-1/2"
85-1/2"
81-1/4"
77"
43-3/4"
10-1/2"
6-1/4"
2"
0"
A
A
B
B
3/4" x 2-1/2" Slot
Typ x 5
29/35" x 1-1/8" Slot
Typ x 20
Section A-A
See W-beam Drawing
Section B-B
See W-beam Drawing
Texas A&M Transportation Institute
Roadside Safety and Physical Security Division - Proving Ground
W- to Thrie-beam Connection
2020-09-04
Drawn by GES
Scale 1:10
Sheet 1 of 1
T:\Drafting Department\Solidworks\Standard Parts\Guardrail Parts and Subs\Guardrail Drawings\W- to Thrie-beam, asymmetric

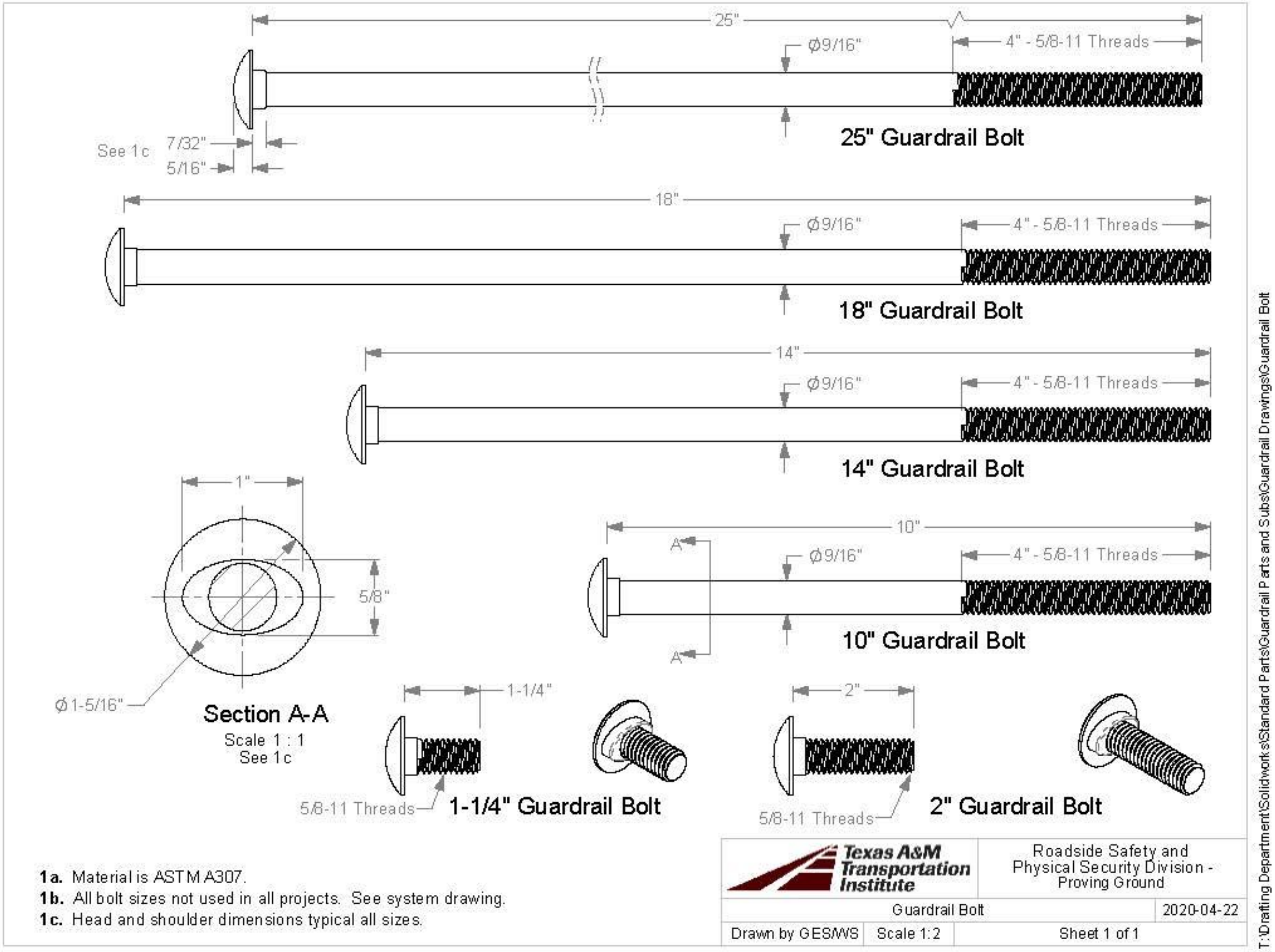


1a. Manufacture per AASHTO M180 specifications.

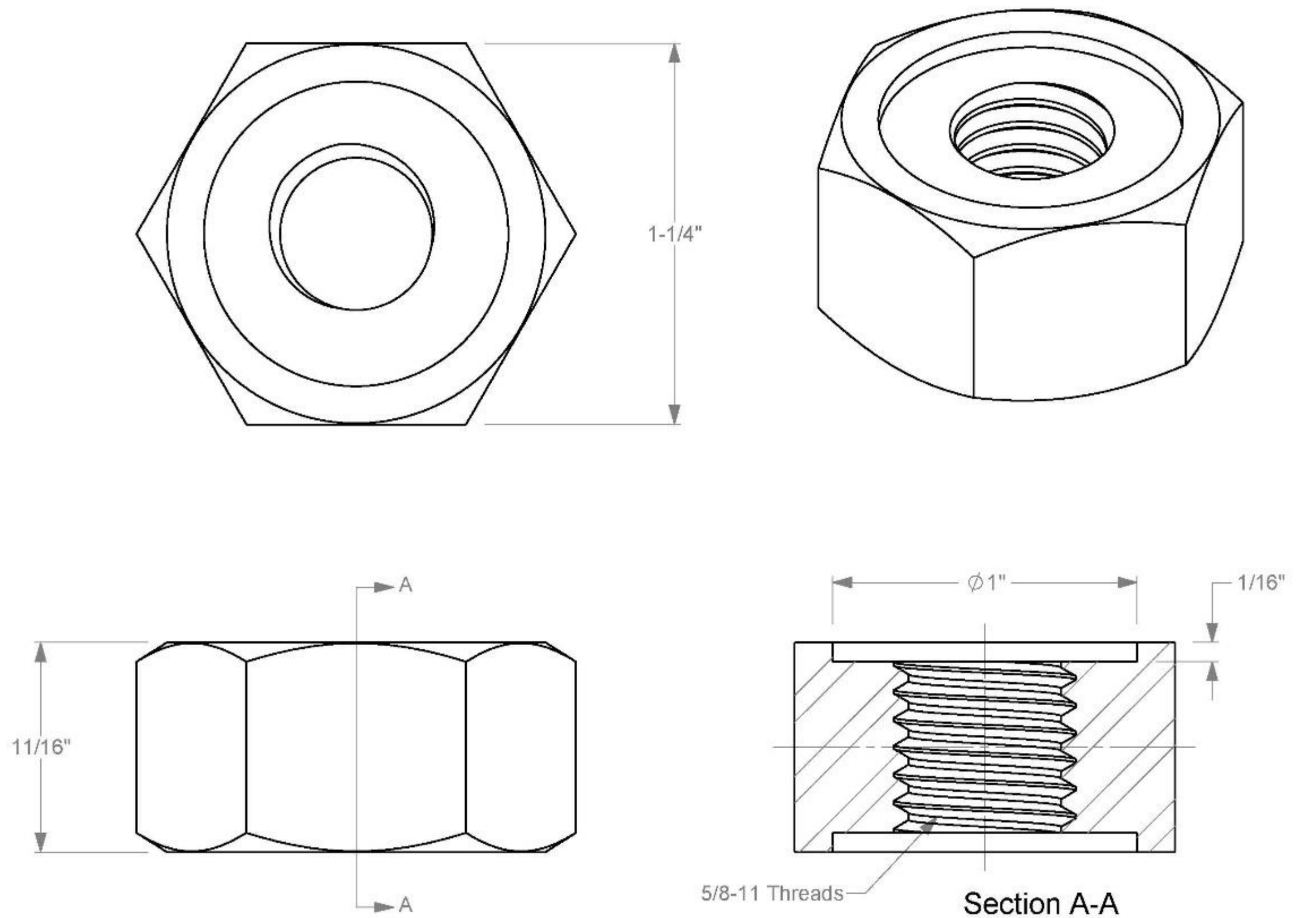
1b. 4-space Guardrail is shown. Slots typical x 3 for 2-space W-beam spaced at 75", and typical x 9 for 8-space W-beam spaced at 18-3/4". Slots are typical x 4 at 37-1/2" for 9'-4-1/2" span W-beam.

Texas A&M Transportation Institute		Roadside Safety and Physical Security Division - Proving Ground	
4-space W-beam Guardrail			2020-06-05
Drawn by GES	Scale 1:20	Sheet 1 of 1	

T:\Drafting Department\Solidworks\Standard Parts and Subs\Guardrail Parts and Subs\Guardrail Drawings\W-Beam Guardrail


25"
ϕ9/16"
4" - 5/8-11 Threads
See 1c
7/32"
5/16"
25" Guardrail Bolt
18"
ϕ9/16"
4" - 5/8-11 Threads
18" Guardrail Bolt
14"
ϕ9/16"
4" - 5/8-11 Threads
14" Guardrail Bolt
1"
5/8"
ϕ1-5/16"
Section A-A
Scale 1 : 1
See 1c
10"
A
ϕ9/16"
4" - 5/8-11 Threads
A
10" Guardrail Bolt
1-1/4"
5/8-11 Threads
1-1/4" Guardrail Bolt
2"
5/8-11 Threads
2" Guardrail Bolt
1a. Material is ASTM A307.
1b. All bolt sizes not used in all projects. See system drawing.
1c. Head and shoulder dimensions typical all sizes.
Texas A&M Transportation Institute
Roadside Safety and Physical Security Division - Proving Ground
Guardrail Bolt
2020-04-22
Drawn by GES/WS
Scale 1:2
Sheet 1 of 1
T:\Drafting Department\Solidworks\Standard Parts\Guardrail Parts and Subs\Guardrail Drawings\Guardrail Bolt

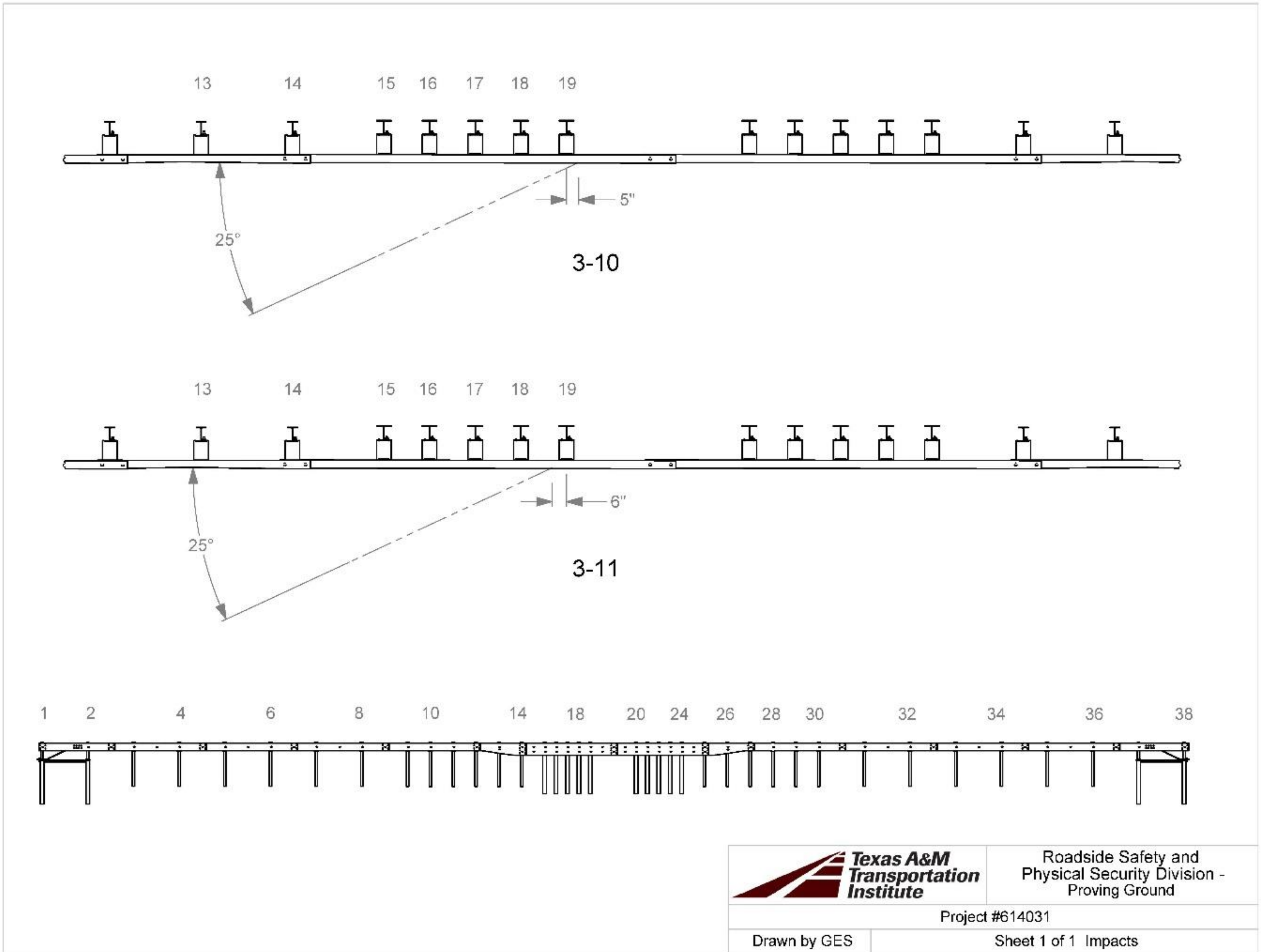
Recessed Guardrail Nut



1a. Material is ASTM A 563 Grade A.

Texas A&M Transportation Institute	Roadside Safety and Physical Security Division - Proving Ground	
Recessed Guardrail Nut		2019-06-27
Drawn by GES	Scale 2:1	Sheet 1 of 1

T:\Drafting Department\Solidworks\Standard Parts\Guardrail Parts and Subs\Guardrail Drawings\Nut, Recessed Guardrail



Q:\Accreditation-17025-2017\EIR-000 Project Files\614031 - Thrie-Beam at a Fixed Object - Kovar\Drafting\614031 Impact

APPENDIX B. SUPPORTING CERTIFICATION DOCUMENTS

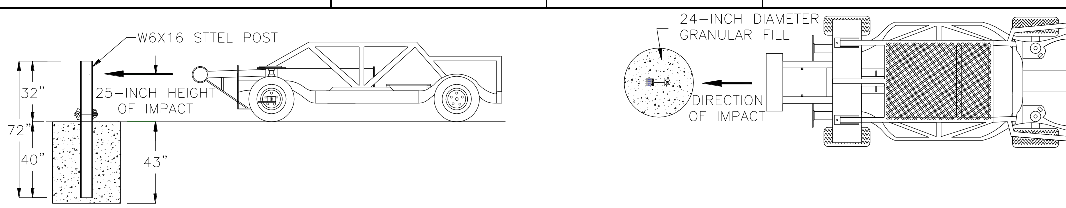
Table B.1. Summary of Strong Soil Test Results for Establishing Installation Procedure.

Dynamic Test Setup

Post-Test Photo of post

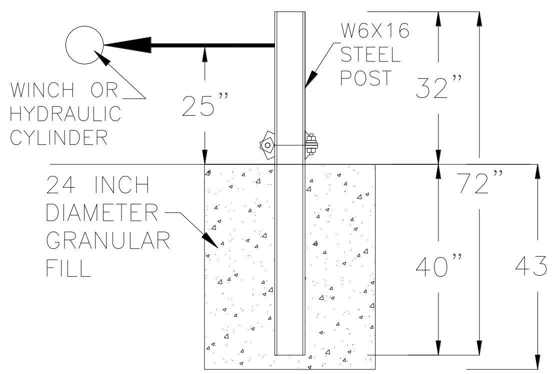
Static Load Test

Post-Test Photo



Dynamic Test Installation Details

Comparison of Load vs. Displacement

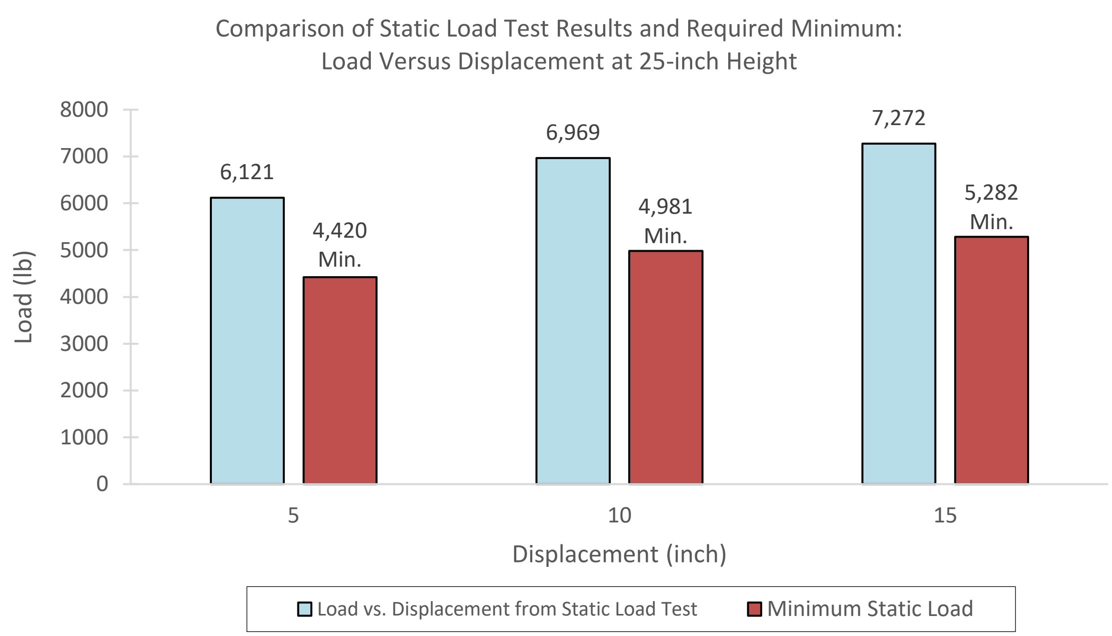


Static Load Test Installation Details

Date	2022-03-11
Test Facility and Site Location	TTI Proving Ground, 3100 SH 47, Bryan, TX 77807
In Situ Soil Description (ASTM D2487)	Sandy gravel with silty fines
Fill Material Description (ASTM D2487) and sieve analysis	AASHTO M147 Grade D or Type 1 Grade D Crushed Concrete Road Base

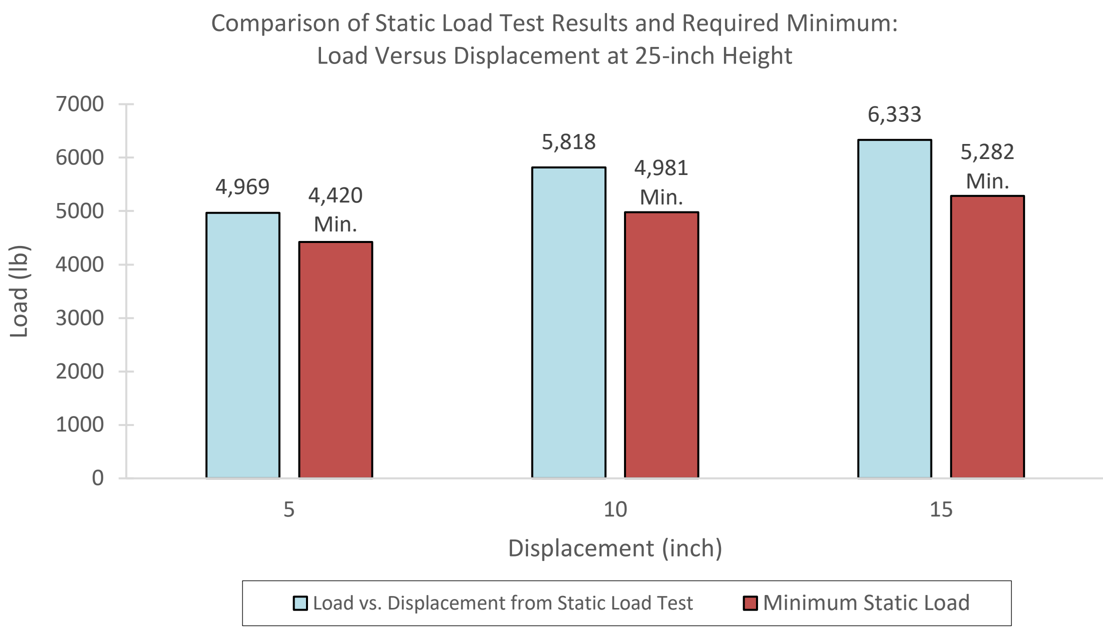
Description of Fill Placement Procedure	12-inch lifts tamped with a pneumatic compactor for 20 sec
Bogie Weight	2020 lb
Impact Velocity	19.2 mph

Table B.2. Test Day Static Soil Strength Documentation for Test No. 614031-01-2.



Date	2022-03-11
Test Facility and Site Location	TTI Proving Ground 3100 SH 47 Bryan, TX 77807
In Situ Soil Description (ASTM D2487)	Sandy gravel with silty fines
Fill Material Description (ASTM D2487) and sieve analysis	AASHTO M147 Grade D or Type 1 Grade D Crushed Concrete Road Base
Description of Fill Placement Procedure	12-inch lifts tamped with a pneumatic compactor for 20 sec

Table B.3. Test Day Static Soil Strength Documentation for Test No. 614031-01-1.



Date	2022-03-24
Test Facility and Site Location	TTI Proving Ground 3100 SH 47 Bryan, TX 77807
In Situ Soil Description (ASTM D2487)	Sandy gravel with silty fines
Fill Material Description (ASTM D2487) and sieve analysis	AASHTO M147 Grade D or Type 1 Grade D Crushed Concrete Road Base
Description of Fill Placement Procedure	12-inch lifts tamped with a pneumatic compactor for 20 sec

APPENDIX C. *MASH* TEST 3-10 (CRASH TEST NO. 614031-01-2)

C.1 VEHICLE PROPERTIES AND INFORMATION

Table C.1. Vehicle Properties for Test No. 614031-01-2

Vehicle Inventory Number: 1613

Date: 2022-03-11 Test No.: 614031-2 VIN No.: 3N1CN7AP5GL819542

Year: 2016 Make: NISSAN Model: VERSA

MASH RECOMMENDED PROPERTIES FOR 1100C

PROPERTY	MASH SPECIFICATION	ACTUAL
MASS:		
Test Inertial	2420 lb ±55 lb	0
Dummy	165 lb	165
Max. Ballast	175 lb	-165
Gross Static	2585 lb ±55 lb	0
DIMENSIONS:		
Wheelbase	98 inches ±5 inches	102.4
Front Overhang	35 inches ±4 inches	32.5
Overall Length	169 inches ±8 inches	175.4
Overall Width	65 inches ±3 inches	66.7
Hood Height	28 inches ±4 inches	30.5
Track Width[a]	59 inches ±2 inches	58.40
CENTER OF MASS LOCATION[b]:		
Aft of Front Axle	39 inches ±4 inches	41.43
Above Ground	N/A	
LOCATION OF ENGINE:	Front	Front
LOCATION OF DRIVE AXLE:	Front	Front
TYPE OF TRANSMISSION:	Manual or Automatic	Automatic
AGE OF TEST VEHICLE:	No more than 6 model years **on day of test**	6

Table C.2. Exterior Crush Measurements for Test No. 614031-01-2

Vehicle Inventory Number: 1613

Date: 2022-03-11 Test No.: 614031-2 VIN No.: 3N1CN7AP5GL819542

Year: 2016 Make: NISSAN Model: VERSA

VEHICLE CRUSH MEASUREMENT SHEET[1]

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

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	12	6	20							-18
2	SAME	12	10	42							62
	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).

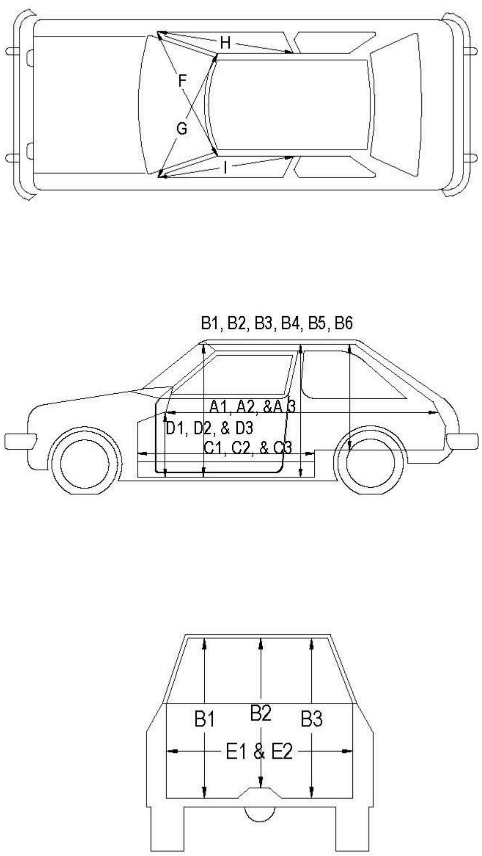
***Measure and document on the vehicle diagram the location of the maximum crush.

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

Table C.3. Occupant Compartment Measurements for Test No. 614031-01-2

Vehicle Inventory Number: 1613

Date:	2022-03-11	Test No.:	614031-2	VIN No.:	3N1CN7AP5GL819542
Year:	2016	Make:	NISSAN	Model:	VERSA

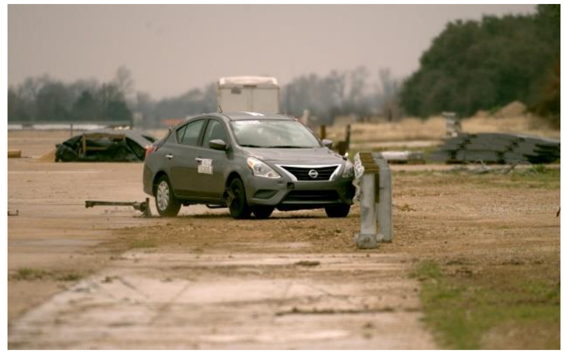


OCCUPANT COMPARTMENT DEFORMATION MEASUREMENT

	Before	After (inches)	Differ.
A1	75	75	0.00
A2	74	74	0.00
A3	74	74	0.00
B1	43	43	0.00
B2	37	37	0.00
B3	43	43	0.00
B4	46.5	46.5	0.00
B5	42.5	42.5	0.00
B6	46.5	46.5	0.00
C1	26	26	0.00
C2	0	0	0.00
C3	26	26	0.00
D1	12.5	12.5	0.00
D2	0	0	0.00
D3	10	10	0.00
E1	45	45	0.00
E2	48.75	47.75	-1.00
F	47.5	47.5	0.00
G	47.5	47.5	0.00
H	39	39	0.00
I	39	39	0.00
J*	48.5	48.5	0.00

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

C.2. SEQUENTIAL PHOTOGRAPHS


0.000 s



0.100 s



0.200 s



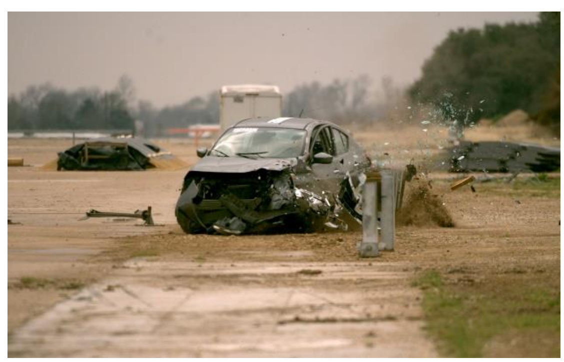
0.300 s


Figure C.1. Sequential Photographs for Test No. 614031-01-2 (Overhead and Frontal Views).

0.400 s

0.500 s

0.600 s

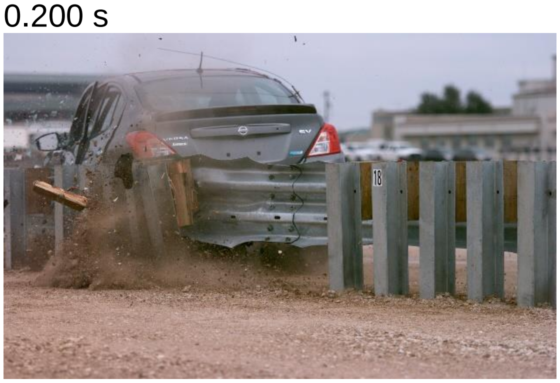
0.700 s

Figure C.1. Sequential Photographs for Test No. 614031-01-2 (Overhead and Frontal Views) (Continued).

0.000 s

0.100 s

0.200 s



0.300 s

0.400 s

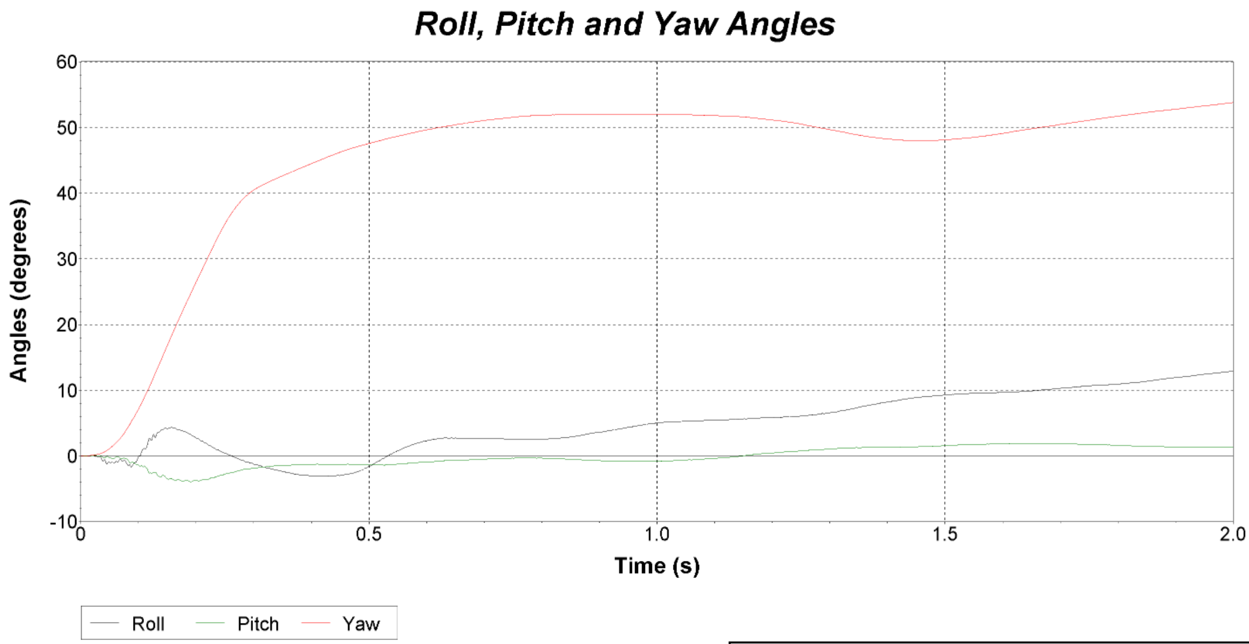
0.500 s

0.600 s

0.700 s

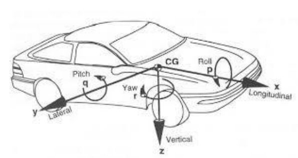
Figure C.2. Sequential Photographs for Test No. 614031-01-2 (Rear View).

C.3. VEHICLE ANGULAR DISPLACEMENTS



Axes are vehicle-fixed.
Sequence for determining orientation:

Z. Yaw.
Y. Pitch.
X. Roll.



Test Number: Test No. 614031-01-2
Test Standard Test Number: *MASH* Test 3-10
Test Article: Thrie-Beam at Fixed Object
Test Vehicle: 1100C Small Car
Inertial Mass: 2420 lb
Gross Mass: 2584 lb
Impact Speed: 62.2 mph
Impact Angle: 25 degrees

Figure C.3. Vehicle Angular Displacements for Test No. 614031-01-1

C.4. VEHICLE ACCELERATIONS

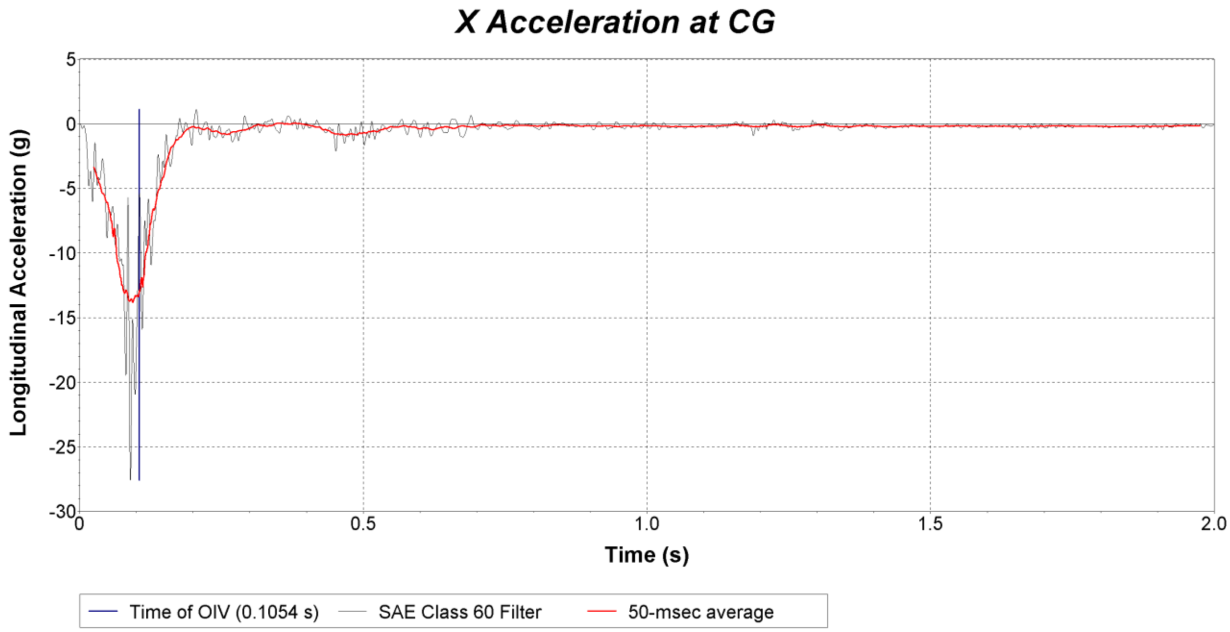


Figure C.4. Vehicle Longitudinal Accelerometer Trace for Test No. 614031-01-2 (Accelerometer Located at Center of Gravity).

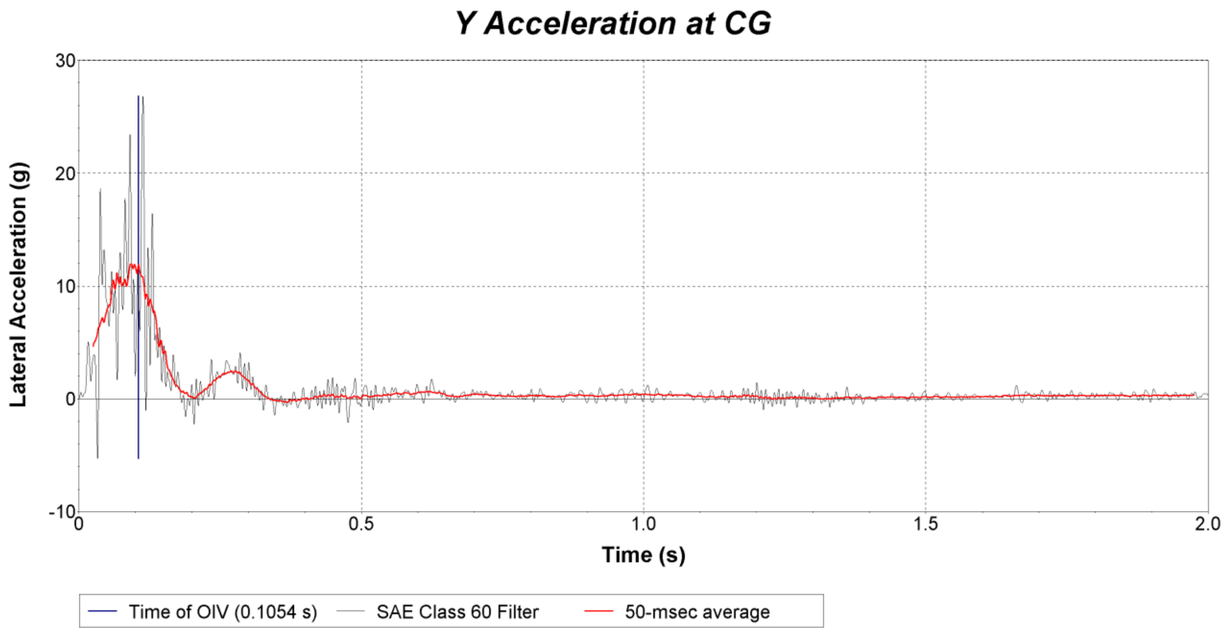


Figure C.5. Vehicle Lateral Accelerometer Trace for Test No. 614031-01-2 (Accelerometer Located at Center of Gravity).

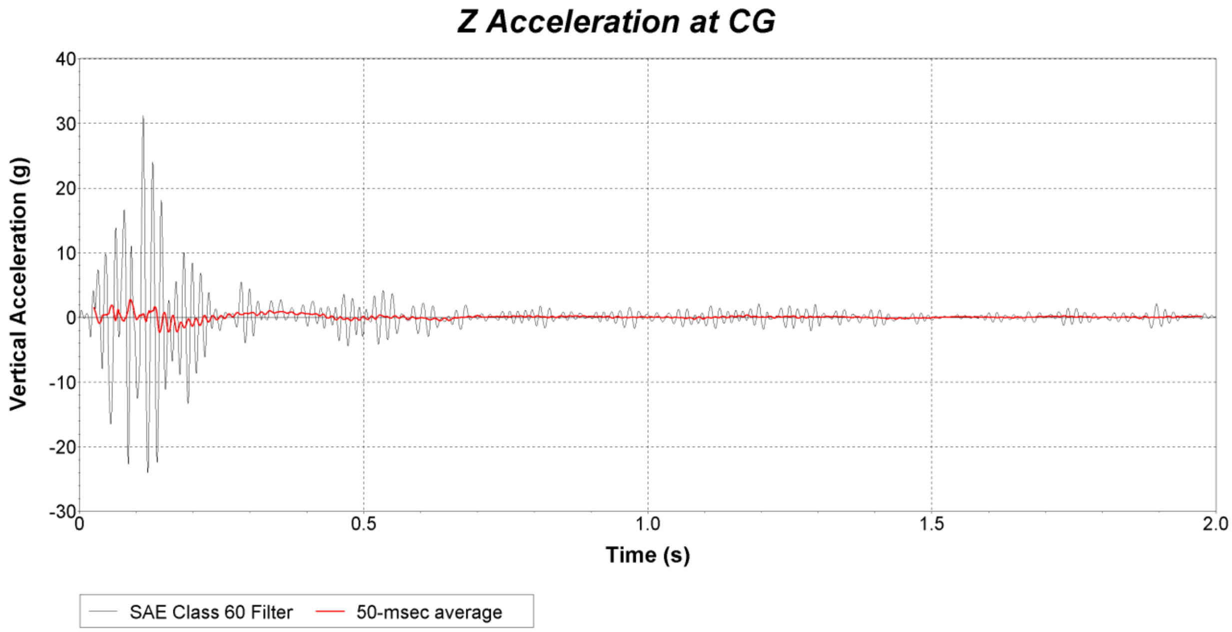


Figure C.6. Vehicle Vertical Accelerometer Trace for Test No. 614031-01-2 (Accelerometer Located at Center of Gravity).

APPENDIX D. *MASH* TEST 3-11 (CRASH TEST NO. 614031-01-1)

D.1 VEHICLE PROPERTIES AND INFORMATION

Table D.1. Vehicle Properties for Test No. 614031-01-1.

Date:	2022-03-24	Test No.:	614031-1	VIN No.:	1C6RRGFT7F5650000
Year:	2015	Make:	RAM	Model:	1500

MASH RECOMMENDED PROPERTIES FOR 2270P

PROPERTY	MASH SPECIFICATION	ACTUAL
MASS:		
Test Inertial	5000 lb ±110 lb	5030
Dummy	Optional	0
Max. Ballast	440 lb	145
Gross Static	5000 lb ±110 lb	0
DIMENSIONS:		
Wheelbase	148 inches ±12 inches	140.50
Front Overhang	39 inches ±3 inches	40.00
Overall Length	237 inches ±13 inches	227.50
Overall Width	78 inches ±2 inches	78.50
Hood Height	43 inches ±4 inches	46.00
Track Width[a]	67 inches ±1.5 inches	68.25
CENTER OF MASS LOCATION[b]:		
Aft of Front Axle	63 inches ±4 inches	62.17
Above Ground[c]	28.0 inches **minimum**	28.50
LOCATION OF ENGINE:	Front	Front
LOCATION OF DRIVE AXLE:	Rear	Rear
TYPE OF TRANSMISSION:	Manual or Automatic	Automatic
AGE OF TEST VEHICLE:	No more than 6 model years **on day of test**	

Table D.2. Exterior Crush Measurements for Test No. 614031-01-1.

Year: ________ Make: ________ Model: ________

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	14	11	50							-7
2	SAME	14	12	60							70
	Measurements recorded										
	☑ **inches or** ☐ **mm**										

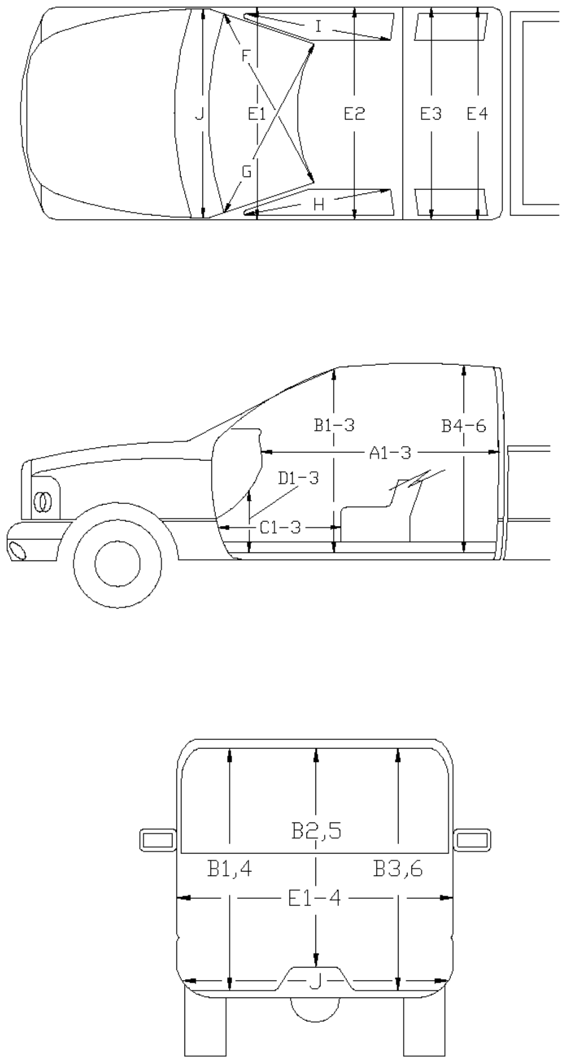
[1]Table taken from National Accident Sampling System (NASS).

*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).

Table D.3. Occupant Compartment Measurements for Test No. 614031-01-1.



OCCUPANT COMPARTMENT DEFORMATION MEASUREMENT

	Before	After (inches)	Differ.
A1	65.00	65.00	0.00
A2	63.00	63	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	25.00	-1.00
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	58.50	0.00
E2	63.50	63.50	0.00
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

D.2. SEQUENTIAL PHOTOGRAPHS

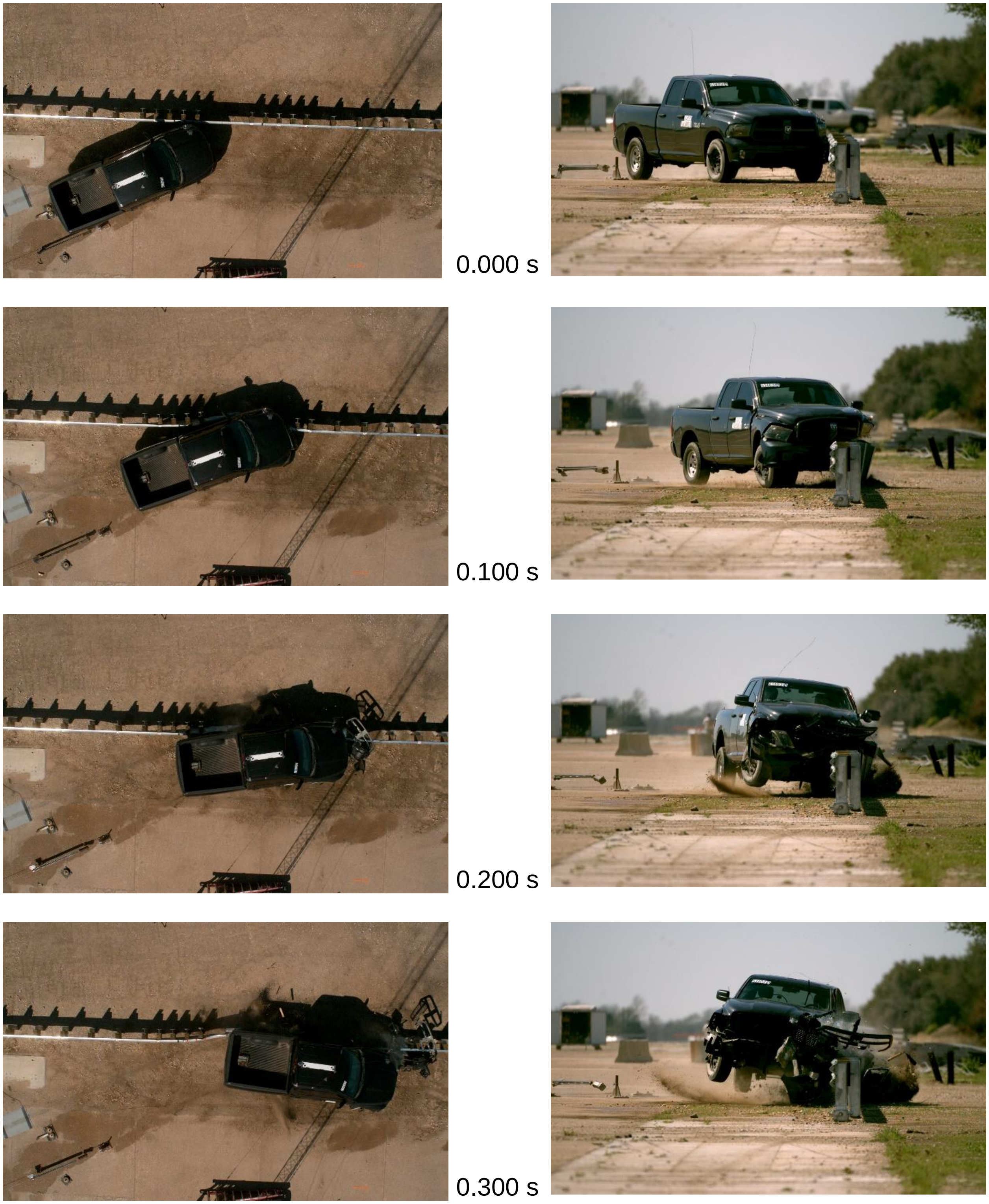
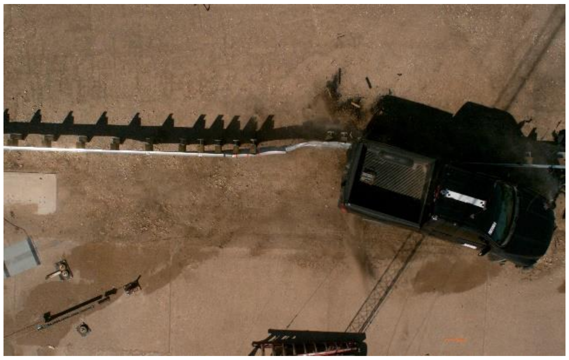


Figure D.1. Sequential Photographs for Test No. 614031-01-1 (Overhead and Frontal Views).


0.400 s



0.500 s



0.600 s



0.700 s


Figure D.1. Sequential Photographs for Test No. 614031-01-1 (Overhead and Frontal Views) (Continued).

0.000 s

0.100 s

0.200 s

0.300 s

0.400 s

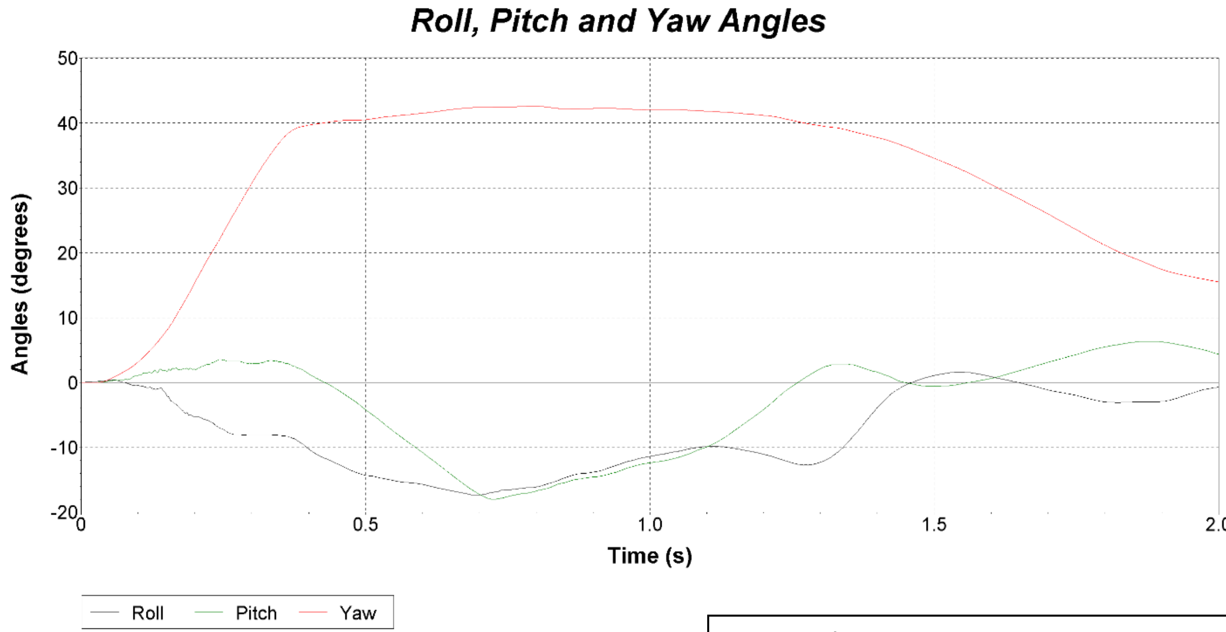
0.500 s

0.600 s

0.700 s

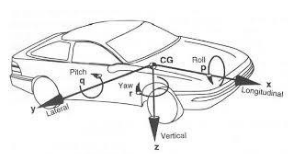
Figure D.2. Sequential Photographs for Test No. 614031-01-1 (Rear View).

D.3. VEHICLE ANGULAR DISPLACEMENTS



Axes are vehicle-fixed.
Sequence for determining orientation:

Z. Yaw.
Y. Pitch.
X. Roll.



Test Number: Test No. 614031-01-1
Test Standard Test Number: *MASH* Test 3-11
Test Article: Thrie-Beam at Fixed Object
Test Vehicle: 2270P Truck
Inertial Mass: 5030 lb
Gross Mass: 5030 lb
Impact Speed: 62.1 mph
Impact Angle: 24.9 degrees

Figure D.3. Vehicle Angular Displacements for Test No. 614031-01-1.

D.4. VEHICLE ACCELERATION

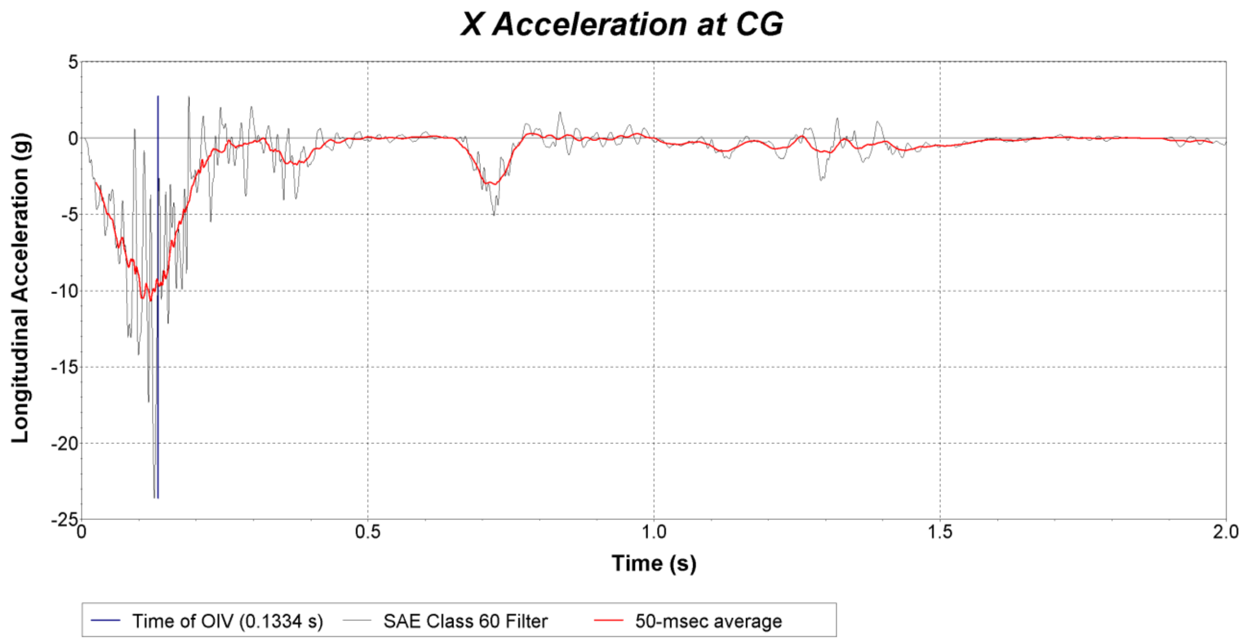


Figure D.4. Vehicle Longitudinal Accelerometer Trace for Test No. 614031-01-1 (Accelerometer Located at Center of Gravity).

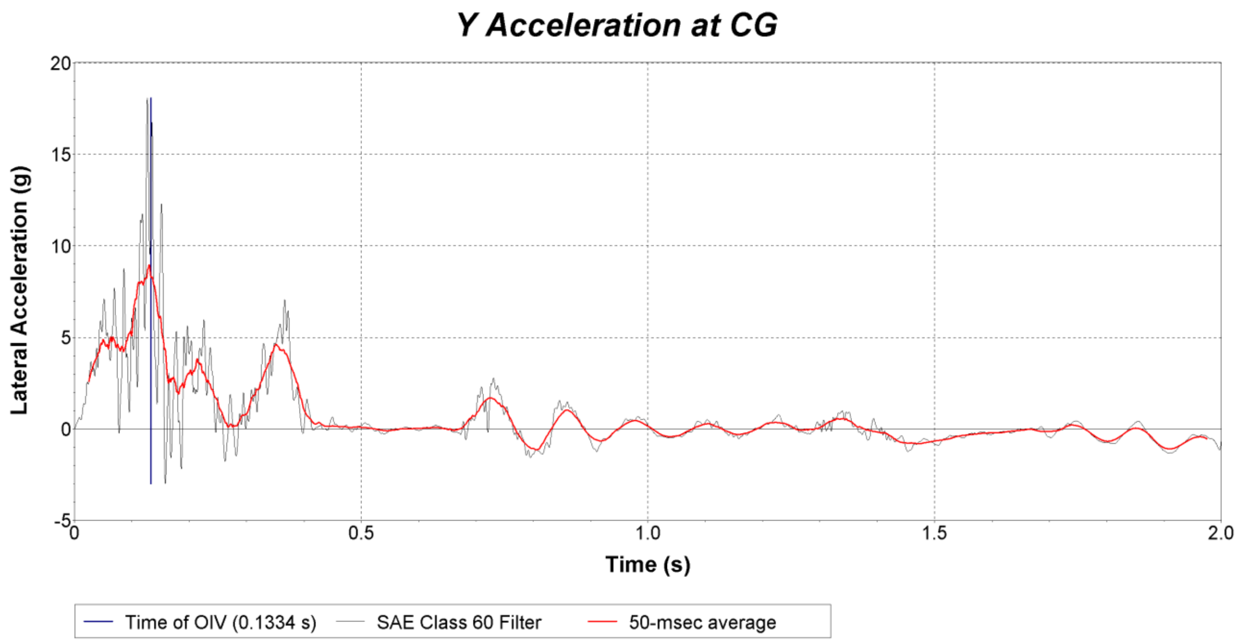


Figure D.5. Vehicle Lateral Accelerometer Trace for Test No. 614031-01-1 (Accelerometer Located at Center of Gravity).

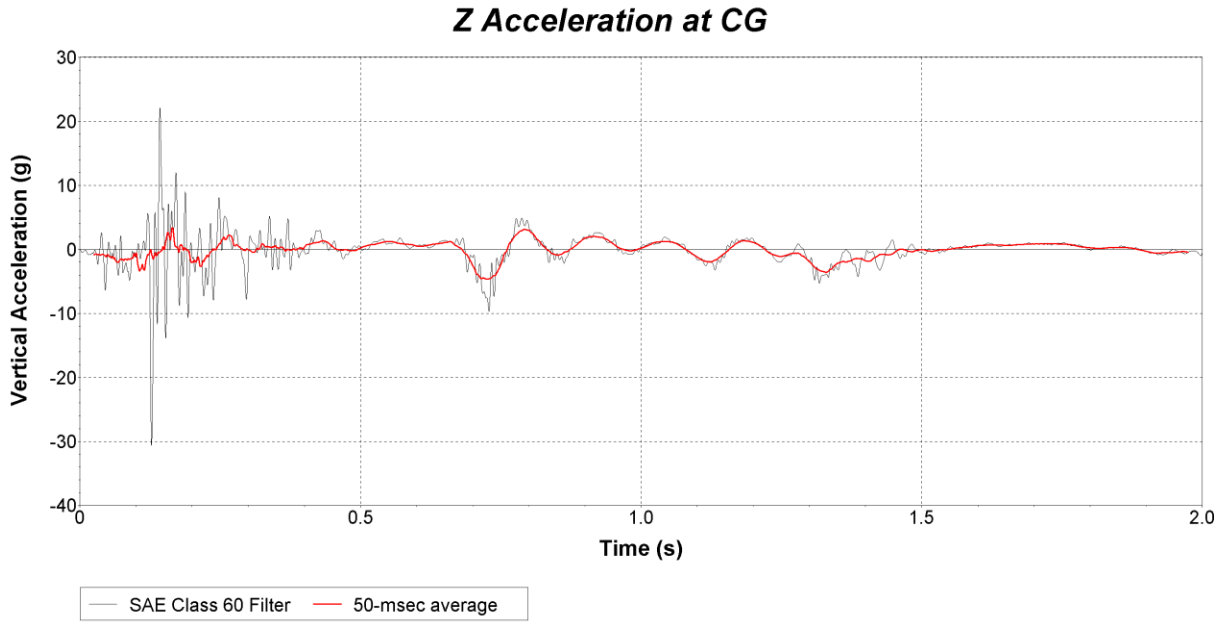


Figure D.6. Vehicle Vertical Accelerometer Trace for Test No. 614031-01-1 (Accelerometer Located at Center of Gravity