APPENDICES

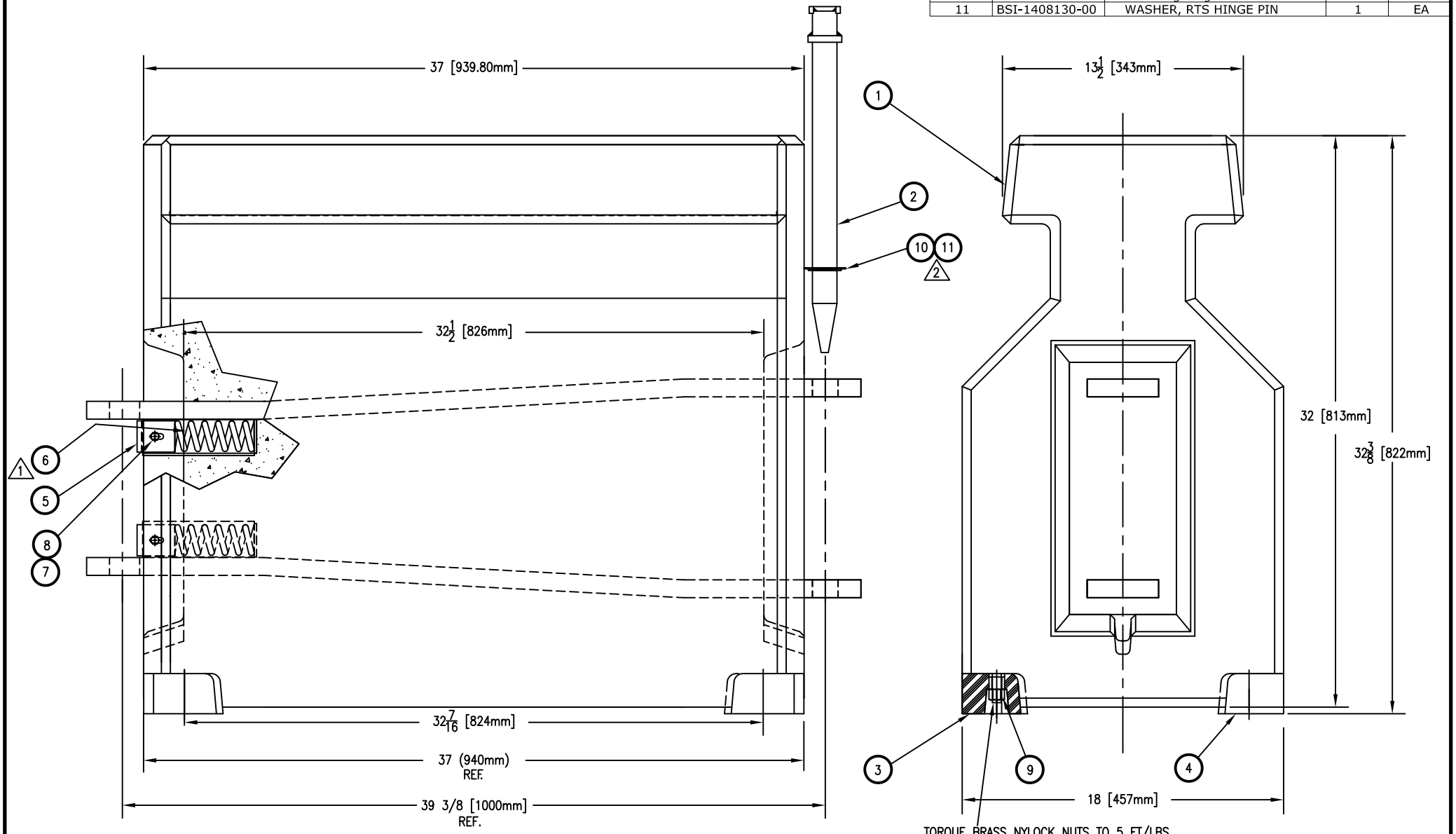
APPENDIX A

Drawings for the Concrete Reaction Tension System (CRTS) Quickchange Movable Barrier (QMB)

NOTE:

1. APPLY LOCTITE 242 (BLUE)
2. WASHER AND RETAINING RING ITEMS 10 AND 11 WILL BE SUPPLIED AND INSTALLED BY LINDSAY TRANSPORTATION SOLUTION.

Find No	No.	Description	QTY	UOM
1	C050234	18" H2 Concrete Barrier RTS	1	EA
2	B021156	BSI, Hinge Pin 2 3/4 Taper	1	EA
3	C060317	Foot Bumper RH	2	EA
4	C060318	Foot Bumper LH	2	EA
5	A990802	BSI, Pusher Plate	2	EA
6	4000145	Spring Narrow Barrier Hinge	2	EA
7	2000114	Nut Nylok 1/4-20 Pltd	2	EA
8	2000172	C-Scr HH 1/4-20x2 1/2 Gr5 Plt	2	EA
9	2001589	Brass Nylok Locknut 1/2-13 NC	4	EA
10	2000085	Retaining Ring E X5133 118 Plt	1	EA
11	BSI-1408130-00	WASHER, RTS HINGE PIN	1	EA



NOTE:
SEE DWG D000922 FOR MOLD DWG PARAMETERS

NOTE:
THICKNESS OF WELD TO BE EQUAL TO THE THINNER OF 2 PIECES BEING JOINED. WELD TO BE ALL

REV.	CHANGES	DATE	BY	REQ'D	NEXT ASSY.	ITEM
C	SEE ECN 2531	12/15/14	ME			
B	SEE ECN 2027	4/18/13	AEM			
A	SEE ECN 764	9/25/06	DGB			

SCALE: QUARTER

	DATE	INT.
DRAWN BY	5/11/05	RGC
APPR'D BY		JSM

Standard Tolerance
Angular ± N/A
Fractional ± N/A
Decimal ± N/A

TITLE: 18" H2 CONCRETE BARRIER REACTIVE TENSION SYSTEM

LINDSAY TRANSPORTATION SOLUTIONS
BARRIER SYSTEMS
180 River Road
Rio Vista, CA 94571
Tel: 800-466-3691
www.barriersystemsinc.com

MODEL	DRAWING NUMBER	REV.
	C050236	C

NOTE:
UNDIMENSIONED FEATURES SHALL
BE "AS CAST" PER MOLD D041028

ITEM	PART No.	Description	Qty	U/M
1	B020204	Mesh, Steel, Upper, 18" Barrier	2	EACH
2	B010737	Rebar Stiffner	2	EACH
3	B050836	Foot Bar Weldment, 18" Barrier	2	EACH
4	B990828	Through Bar Wldmt Galv Narrow	2	EACH
5	4002194	Twist Ties 16gax6 Blk Ann	10	EACH
6	B050415	H2 18" RTS Reinforcement Assy	1	EACH
7	4002239	Spacer Wheel, Rebar, 1-1/2" Cover	2	EACH
8	4000324	Concrete Fill	9	Cu/Ft
9	4002134	Spacer Wheel, Rebar, 1" Cover	8	EACH
10	4000014	Spacer Wheel, Mesh, 1/2" Cover	8	EACH

NOTE: (8)
CONCRETE MIX TO HAVE A
MINIMUM COMPRESSIVE STRENGTH
OF 4,000 PSI @ 28 DAYS

NOTE:
COMPLETELY TRIM CORNERS OUT OF MESH
FOR CLEARANCE BEFORE INSTALLING

(2) 2X

(1) 2X

(5) NOTE:
WIRE TIE REBAR TO WIRE MESH
10 PLACES AS REQUIRED

(6)

NOTE: (9)
USE WHEEL SPACERS
TO ENSURE A 1" MIN
GAP BETWEEN MOLD
AND WIRE MESH

(9)

(4) 2X

9 3/4 +1/16 −1/8 [247.6 +1.6 −3.2 mm]

10 1/4 +1/8 −1/16 [260 +3.2 −1.6 mm]

7 3/8±3/16 [187.3±4.8mm]

7 1/8±3/16 [181±4.8mm]

(9) (3) 2X (7) INSERT PLASTIC REBAR SPACERS TO KEEP FOOTBAR FROM SAGGING (9)

33 3/16±3/16 [843±4.8mm]

37±3/16 [939.8±4.8mm]

39 3/8 [1000mm] REF

13 1/2 +1/8 −1/4 [342.9 +3.2 −6.4 mm]

1±1/2 [26±12.7mm]

10 5/8 [270mm] REF

1/2±3/8 [13±9.5mm]

4 15/16±3/16 [125±4.8mm]

NOTE: (10)
USE WHEEL SPACERS TO
ENSURE A 1/2" MIN
GAP BETWEEN MOLD
AND WIRE MESH

8 1/8±3/16 [206±4.8mm]

(10)

32±1/4 [813±6.4mm]

1/4±3/16 [6mm±4.8]

5 1/8 [130mm] REF

14 1/8±3/16 [359±4.8mm]

18±3/16 [457±4.8mm]

NOTE:
THICKNESS OF WELD TO BE EQUAL
TO THE THINNER OF 2 PIECES
BEING JOINED. WELD TO BE ALL

REV.	CHANGES	DATE	BY	REQ'D	NEXT ASSY.	ITEM
C	SEE ECN 2759	7/1/15	JD			
B	SEE ECN 2065	5/7/13	JN			
A	SEE ECN #00687	8/30/05	RGC	1	C000205	1

SCALE: QUARTER

	DATE	INT.
DRAWN BY	05/06/05	RGC
APPR'D BY		

Standard Tolerance
Angular ± 1/2°
Fractional ± 1/16
Dec .XXX= ± .010
Dec .XX= ± .03

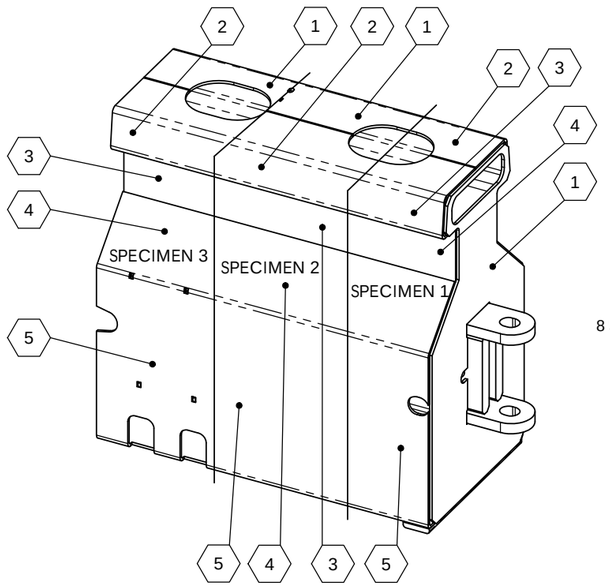
TITLE : H2
BARRIER MODULE 18"
REACTIVE TENSION SYSTEM

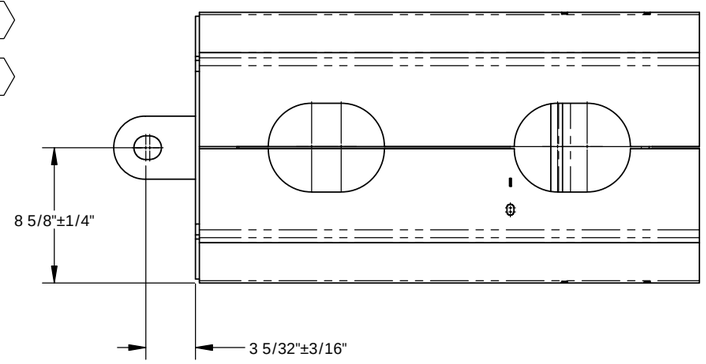
MODEL	DRAWING NUMBER	REV.
	C050234	C

APPENDIX B

Drawings for the 18-Inch Tall Variable Length Barrier

Type	No.	Description	QTY	UOM
Item	BSI-1303002-00	InnerShellWldt18VLB Shot Blast	1	EA





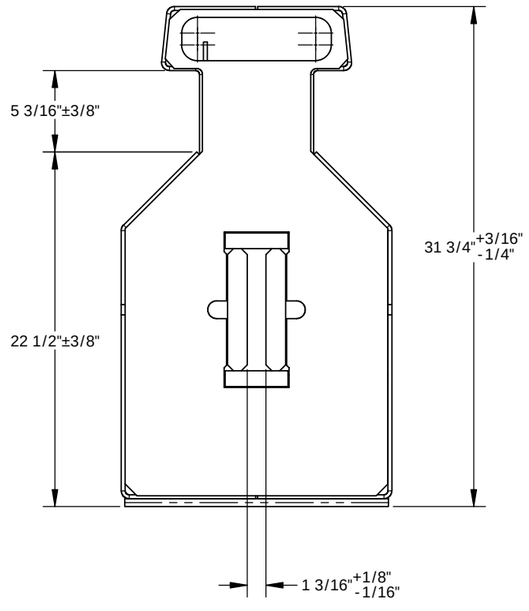
NOTES: UNLESS OTHERWISE SPECIFIED.

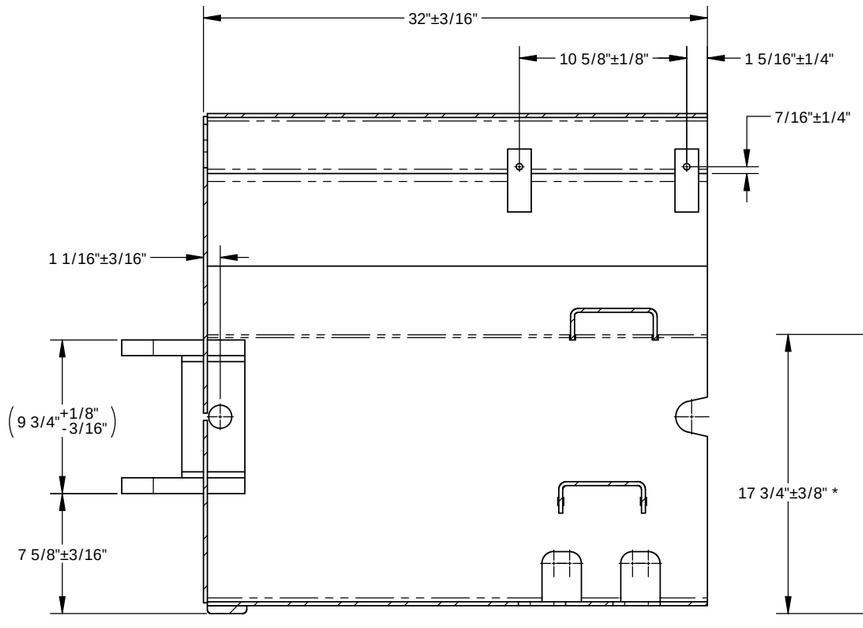
-LEGEND: (X) APPROXIMATE LOCATION OF MAGNETIC THICKNESS MEASUREMENT.

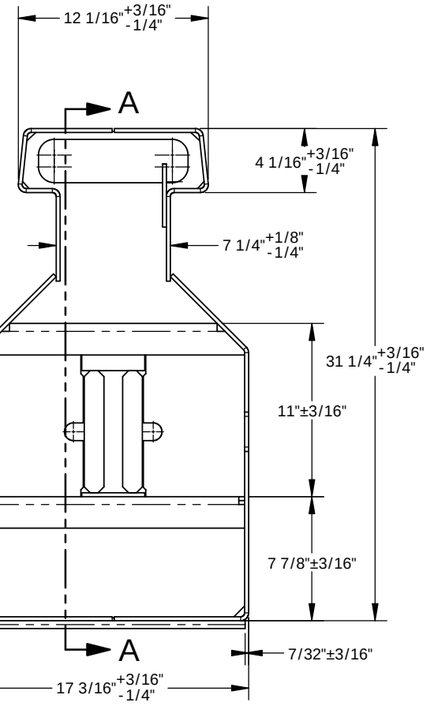
-FINISH: HOT DIPPED GALVANIZED IN ACCORDANCE WITH ASTM A123.

-THICKNESS - THIS PART IS OVER 160 SQ IN, ALL MATERIAL IS A36 1/4" OR HEAVIER & IS CLASSIFIED AS GRADE 100. THIS REQUIRES THE ARTICLE (PART) TO HAVE A MINIMUM AVERAGE THICKNESS COATING AS SPECIFIED IN ASTM A123 AND THE PART DIVIDED INTO THREE SECTIONS(SPECIMENS) WITH A MINIMUM AVERAGE (5 OR MORE MEASUREMENTS WIDELY DISPERSED) THICKNESS COATING OF 1 GRADE LESS FOR EACH SPECIMEN.

-WHEN REQUIRED BY PROJECT ALL METALLIC PARTS MUST BE MADE OF MATERIALS MELTED AND MANUFACTURED IN THE USA.







SECTION A-A

WEIGHT: 296 LBS/134 KG

* THEORETICAL POINT

CE

THIS COMPONENT AND/OR ASSEMBLY IS PART OF A PRODUCT THAT IS "**CE**" CERTIFIED. ALL CHANGES TO THIS DOCUMENT MUST BE APPROVED BY LINDSAY TRANSPORTATION SOLUTIONS ENGINEERING MANAGEMENT, AND MUST BE ACCOMPANIED BY A "**CE**" MODIFICATION REPORT THAT GETS LOADED INTO THE PRODUCTS TECHNICAL FILE.

APPROVALS

DRAWN BY: JOSEPH NAGY

DRAWN DATE: 10/18/10

APP'D BY: SAD

APP'D DATE: 10/18/10

UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES. TOLERANCES ARE:

FRACTIONS ±1/16 DECIMAL .XX = ±.03 .XXX = ±.010 ANGLES ±1/2°

INTERPRET DIMENSIONS AND TOLERANCES PER ASME Y14.5-1994

THIRD ANGLE PROJECTION

DO NOT SCALE DRAWING

REV	ECN#	DATE
F	2686	04/22/15
E	2287	08/05/14
D	2013	2/5/13
C	1958	11/30/12
B	1893	5/8/12
A	1652	02/09/11
-	1596	10/18/10

LINDSAY TRANSPORTATION SOLUTIONS

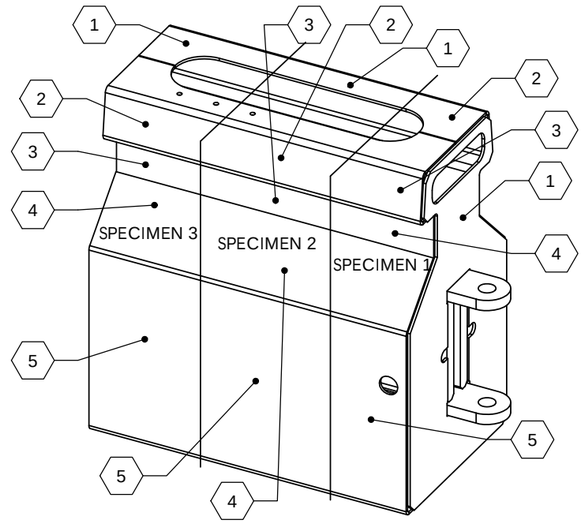
BARRIER SYSTEMS
180 River Road
Rio Vista, CA 94571
Tel: 888-800-3691
www.barriersystemsinc.com

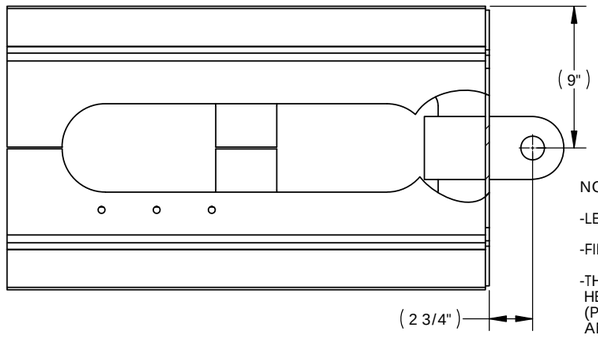
TITLE: **INNER SHELL, 18" VLB, GALV**

SIZE: C | DWG NO.: BSI-1010076-00 | REV.: F

SCALE: 1:6 | SHEET: 1 OF 1

Type	No.	Description	QTY	UOM
Item	BSI-1303001-00	OuterShellWldt18VLB Shot Blast	1	EA





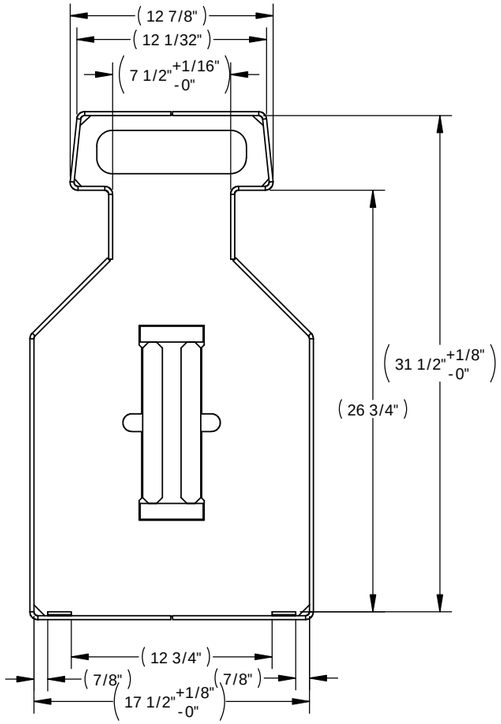
NOTES: UNLESS OTHERWISE SPECIFIED.

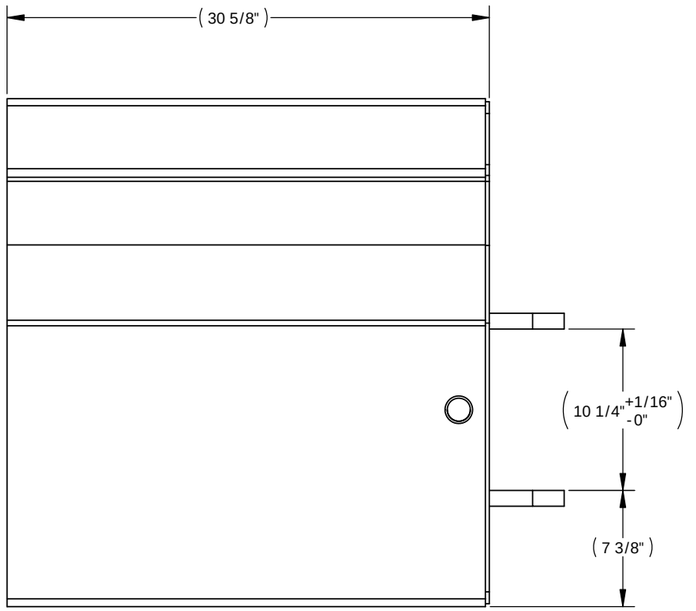
-LEGEND: (X) APPROXIMATE LOCATION OF MAGNETIC THICKNESS MEASUREMENT.

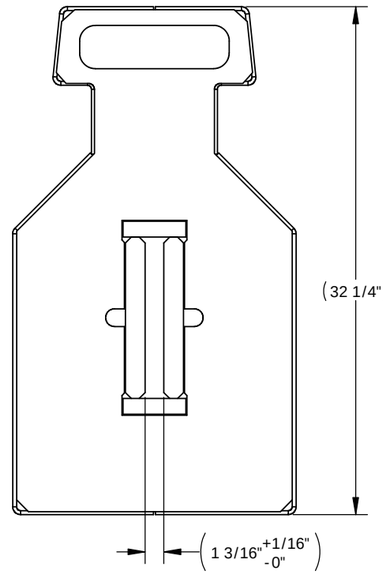
-FINISH: HOT DIPPED GALVANIZED IN ACCORDANCE WITH ASTM A123.

-THICKNESS - THIS PART IS OVER 160 SQ IN, ALL MATERIAL IS A36 1/4" OR HEAVIER & IS CLASSIFIED AS GRADE 100. THIS REQUIRES THE ARTICLE (PART) TO HAVE A MINIMUM AVERAGE THICKNESS COATING AS SPECIFIED IN ASTM A123 AND THE PART DIVIDED INTO THREE SECTIONS(SPECIMENS) WITH A MINIMUM AVERAGE (5 OR MORE MEASUREMENTS WIDELY DISPERSED) THICKNESS COATING 1 GRADE LESS FOR EACH SPECIMEN.

- WHEN REQUIRED BY PROJECT ALL METALLIC PARTS MUST BE MADE OF MATERIALS MELTED AND MANUFACTURED IN THE USA.







WEIGHT: 279 LBS/127 KG

APPROVALS

DRAWN BY:	JOSEPH NAGY
DRAWN DATE:	10/18/10
APPR'D BY:	SAD
APPR'D DATE:	10/18/10

UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES. TOLERANCES ARE:

FRACTIONS ±1/16 DECIMAL .XX = ±.03 .XXX = ±.010 ANGLES ±1/2°

INTERPRET DIMENSIONS AND TOLERANCES PER ASME Y14.5-1994

THIRD ANGLE PROJECTION

DO NOT SCALE DRAWING

REV	ECN#	DATE
E	2686	04/22/15
D	2013	3/5/13
C	1958	11/30/12
B	1893	5/8/12
A	1652	02/09/11
-	1596	10/18/10

CE

THIS COMPONENT AND/OR ASSEMBLY IS PART OF A PRODUCT THAT IS "**CE**" CERTIFIED. ALL CHANGES TO THIS DOCUMENT MUST BE APPROVED BY LINDSAY TRANSPORTATION SOLUTIONS ENGINEERING MANAGEMENT, AND MUST BE ACCOMPANIED BY A "CE" MODIFICATION REPORT THAT GETS LOADED INTO THE PRODUCTS TECHNICAL FILE.

LINDSAY TRANSPORTATION SOLUTIONS

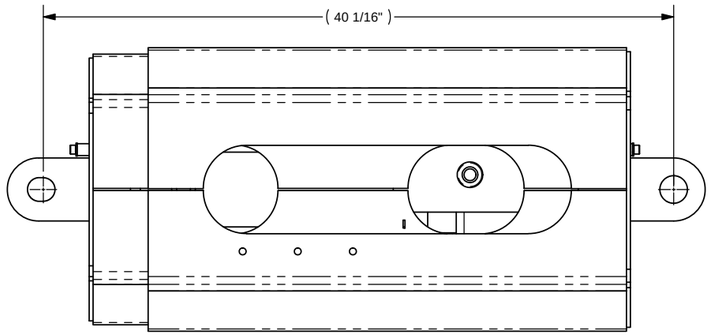
BARRIER SYSTEMS
180 River Road
Rio Vista, CA 94571
Tel: 888-800-3691
www.barriersdemsinc.com

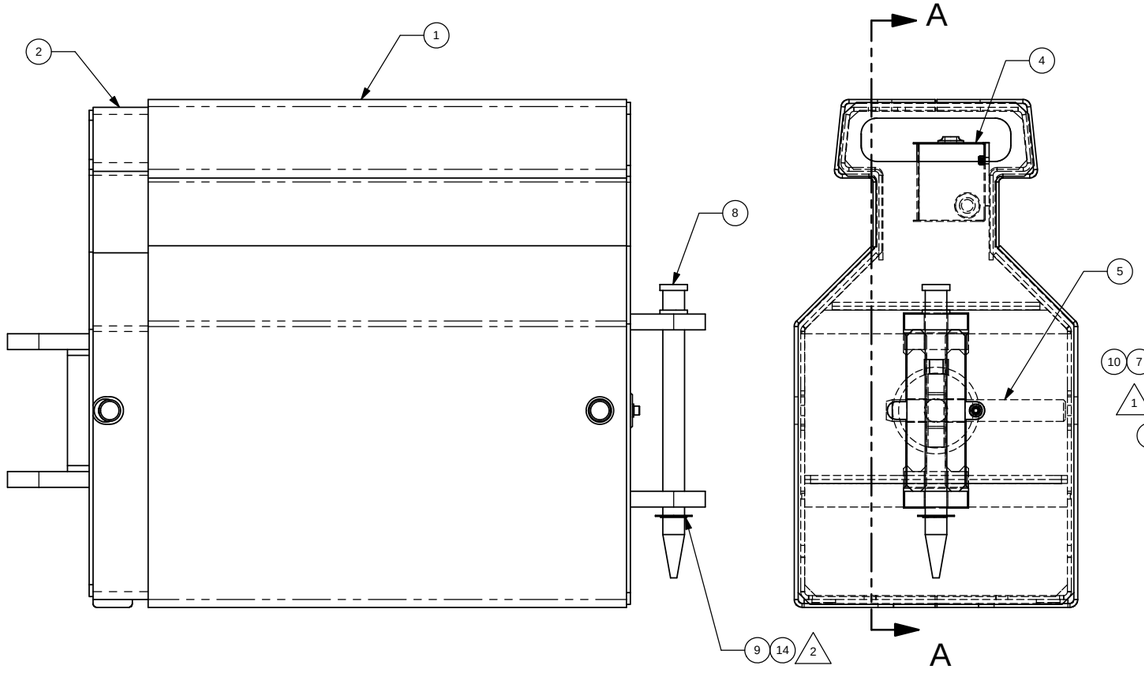
TITLE: **OUTER SHELL, 18" VLB, GALV**

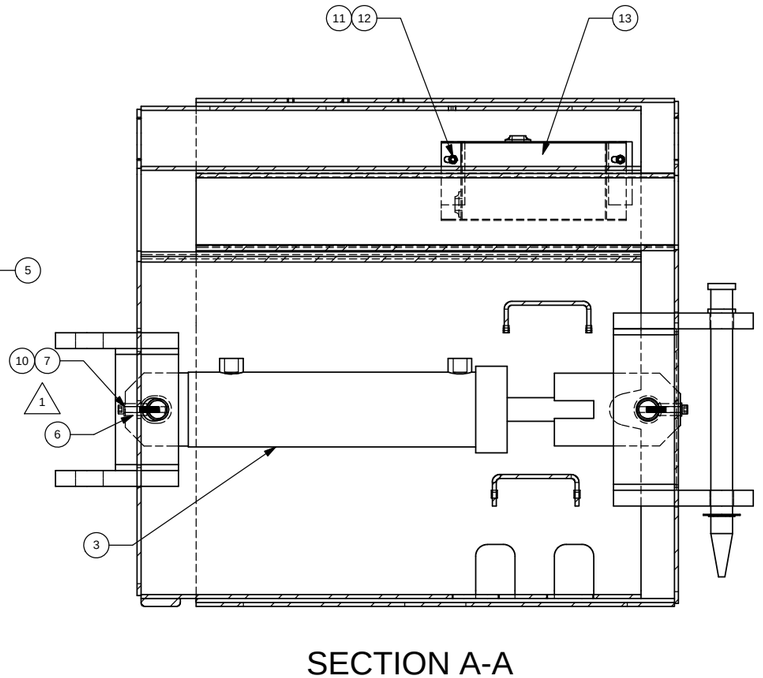
SIZE: C | DWG NO.: BSI-1010077-00 | REV.: E

SCALE: 1:6 | SHEET: 1 OF 1

No.	Part No.	Description	Qty	UoM.
1	BSI-1010077-00	OUTER SHELL WELDMENT, 18" VLB	1.00	EA
2	BSI-1010076-00	INNER SHELL WELDMENT, 18" VLB	1.00	EA
3	B050609	VLB Hyd Cyl 4 rev C	1.00	EA
4	B050802	PLUMBING DIAGRAM 18 VLB	1.00	EA
5	A050539	Cyl Connect Pin 18" VLB, ZINC	2.00	EA
6	A050802	Pin-Lock Spacer rev A	2.00	EA
7	2000228	Wshr SAE 3/8 Plt	2.00	EA
8	B021156	BSI, Hinge Pin 2 3/4 Taper	1.00	EA
9	2000085	Retaining Ring E X5133 118 Plt	1.00	EA
10	2001043	C-Scr SH 3/8-16x2 1/4 AlyStl	2.00	EA
11	2000363	C-Scr HH 5/16-18x1 Gr5 Pltd	2.00	EA
12	2000131	Nut Nylok 5/16-18 Plt	2.00	EA
13	1405610	BSI,PREMIUM,ISO32,OIL,55GAL	1.62	GA
14	BSI-1408130-00	WASHER, RTS HINGE PIN	1.00	EA







SECTION A-A

WEIGHT: 720 LBS/330 KG

3. WHEN REQUIRED BY PROJECT ALL METALLIC PARTS MUST BE MADE OF MATERIALS MELTED AND MANUFACTURED IN THE USA.

2 WASHER AND RETAINING RING ITEMS 9 AND 14 WILL BE SUPPLIED AND INSTALLED BY LINDSAY TRANSPORTATION SOLUTION.

1 APPLY LOCTITE 242 (BLUE)

NOTES: UNLESS OTHERWISE SPECIFIED.

CE

THIS COMPONENT AND/OR ASSEMBLY IS PART OF A PRODUCT THAT IS "**CE**" CERTIFIED. ALL CHANGES TO THIS DOCUMENT MUST BE APPROVED BY LINDSAY TRANSPORTATION SOLUTIONS ENGINEERING MANAGEMENT, AND MUST BE ACCOMPANIED BY A "CE" MODIFICATION REPORT THAT GETS LOADED INTO THE PRODUCTS TECHNICAL FILE.

APPROVALS

DRAWN BY:	JOSEPH NAGY
DRAWN DATE:	2/10/2011
APPR'D BY:	GAD
APPR'D DATE:	01/03/2013

UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES. TOLERANCES ARE:
FRACTIONS ±1/16 DECIMAL .XX = ±.03 .XXX = ±.010 ANGLES ±1/2°
INTERPRET DIMENSIONS AND TOLERANCES PER ASME Y14.5-1994
THIRD ANGLE PROJECTION
DO NOT SCALE DRAWING

REV	ECN#	DATE
D	2531	11/21/14
C	2027	4/17/13
B	2032	3/20/13
A	1958	11/30/12
-	1652	2/10/2011

LINDSAY™ TRANSPORTATION SOLUTIONS

BARRIER SYSTEMS
180 River Road
Rio Vista, CA 94571
Tel: 888-800-3691
www.barriersystemsinc.com

TITLE: **18" RTS VLB**

SIZE C | DWG NO. BSI-1102006-00 | REV. D

SCALE 1:6 | SHEET 1 OF 1

Doc. B100109

Appendix C

Verification & Validation Forms

Modified Design (FEA)

Compared to

Baseline Design (Test 690900-LTS2)

MASH Test 3-11

FEA VALIDATION/VERIFICATION REPORT FORMS

MASH Test 3-11_____ (Report 350 or MASH08 or EN1317 Vehicle Type)
Impact of the
LTS Road Zipper Moveable Barrier (Roadside hardware type and name)

Report Date: _11/7/2016_____

Type of Report (check one)

☐ Verification (known numerical solution compared to new numerical solution).
☒ Validation (physical test compared to a numerical solution).
☐ Extrapolation (validated numerical solution compared to modified numerical solution).

General Information	**Known Solution**	**Analysis Solution**
Performing Organization	TTI	Roadsafe LLC
Analyst/Engineer	**Dean Alberson**	Chuck Plaxico
Test/Run Number:	690900-LTS2	CRTS_Seg170_IP84
Vehicle:	2270P – 2009 Dodge RAM 1500	510_SilveradoC_V3a(160526)
Reference:	Test 3-11	Test 3-11
Impact Conditions		
Vehicle Mass:	4,928-lb	5,006-lb
Speed:	62.6 mph	62.6 mph
Angle:	25.4 degrees	25.4 degrees
Impact Point:	Middle of Segment 84	Middle of Segment 84

Composite Validation/Verification Score

List the Report 350/MASH08 or EN1317 Test Number: ____3-11_____		Pass?
Part I	Did all solution verification criteria in Table E-1 pass?	Yes
Part II	Do all the time history evaluation scores from Table E-2 result in a satisfactory comparison (i.e., the comparison passes the criterion)? If all the values in Table E-2 did not pass, did the weighted procedure shown in Table E-3 result in an acceptable comparison. If all the criteria in Table E-2 pass, enter "yes." If all the criteria in Table E-2 did not pass but Table E-3 resulted in a passing score, enter "yes."	Yes
Part III	All the criteria in Table E-4 (Test-PIRT) passed? Not Required for Component Tests	Yes
	Are the results of Steps I through III all affirmative (i.e., YES)? If all three steps result in a "YES" answer, the comparison can be considered validated or verified. If one of the steps results in a negative response, the result cannot be considered validated or verified.	Yes

The analysis solution (check one):

☒ Is verified/validated against the known solution.
☐ Is NOT verified/validated against the known solution.

PART I: BASIC INFORMATION

1. What type of roadside hardware is being evaluated (check one)?
   - ☒ Longitudinal barrier or transition
   - ☐ Terminal or crash cushion
   - ☐ Breakaway support or work zone traffic control device
   - ☐ Truck-mounted attenuator
   - ☐ Other hardware or component: _____

2. What test guidelines were used to perform the full-scale crash test (check one)?
   - ☐ NCHRP Report 350
   - ☒ MASH
   - ☐ EN1317
   - ☐ Other: _____

3. Indicate the test level and number being evaluated (fill in the blank): _____3-11_____

4. Indicate the vehicle type appropriate for the test level and number indicated in item 3 according to the testing guidelines indicated in item 2.

NCHRP Report 350/MASH08

☐ 700C	☐ 820C	☐ 1100C	☐ 2000P
☒ 2270P	☐ 8000S	☐ 10000S	☐ 36000V
☐ 36000T			

EN1317

☐ Car (900 kg)	☐ Car (1300 kg)	☐ Car (1500 kg)
☐ Rigid HGV (10 ton)	☐ Rigid HGV (16 ton)	☐ Rigid HGV (30 ton)
☐ Bus (13 ton)	☐ Articulated HGV (38 ton)	

☐ Other:_____

PART II: ANALYSIS SOLUTION VERIFICATION

Table E-1. Analysis Solution Verification Table.

Verification Evaluation Criteria	Change (%)	Pass?
Total energy of the analysis solution (i.e., kinetic, potential, contact, etc.) must not vary more than 10 percent from the beginning of the run to the end of the run.	0.3	Y
Hourglass Energy of the analysis solution at the end of the run is less than *five percent* of the total *initial energy* at the *beginning* of the run.	4.5	Y
Hourglass Energy of the analysis solution at the end of the run is less than *ten percent* of the total *internal energy* at the *end* of the run.	18.7	N
The part/material with the highest amount of hourglass energy at the end of the run is less than ten percent of the total internal energy of the part/material at the end of the run.	-	N
Mass added to the total model is less than five percent of the total model mass at the beginning of the run.	0	Y
The part/material with the most mass added had less than 10 percent of its initial mass added.	0	Y
The moving parts/materials in the model have less than five percent of mass added to the initial moving mass of the model.	0	Y
There are no shooting nodes in the solution?	Y	Y
There are no solid elements with negative volumes?	Y	Y

Exception Notes: The hourglass energy was less than 1 percent of the internal energy for all barrier components. The majority of the hourglass energy occurring in the analysis was related to the vehicle model (see Figure 2**). The parts with the highest hourglass energies included the inner and outer rim components on the rear, impact side of the vehicle. From the image of these parts at the end of the analysis, as shown in** Figure 2**, it is evident that the hourglassing had negligible influence on the deformation of these parts.**

☐ Analysis solution passes all the criteria in Table E-1 ☐ without exceptions.

☐ with exceptions as noted in Table E-1.

☒ Analysis solution does NOT pass all the criteria in Table E-1.

☐ Table E-1 is not applicable because _____

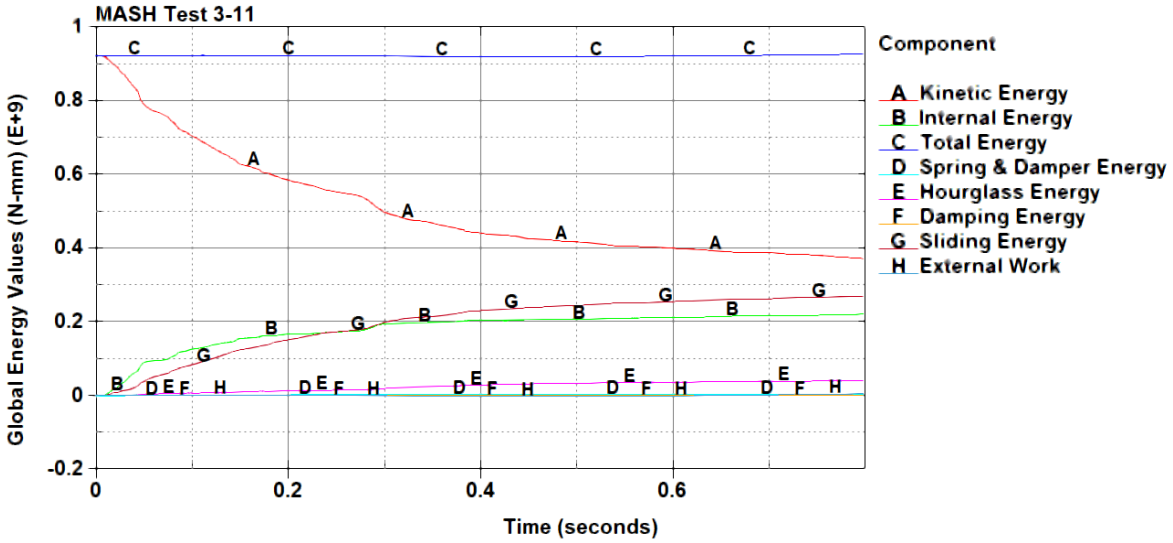


Figure 1. Global energy statistics from analysis.

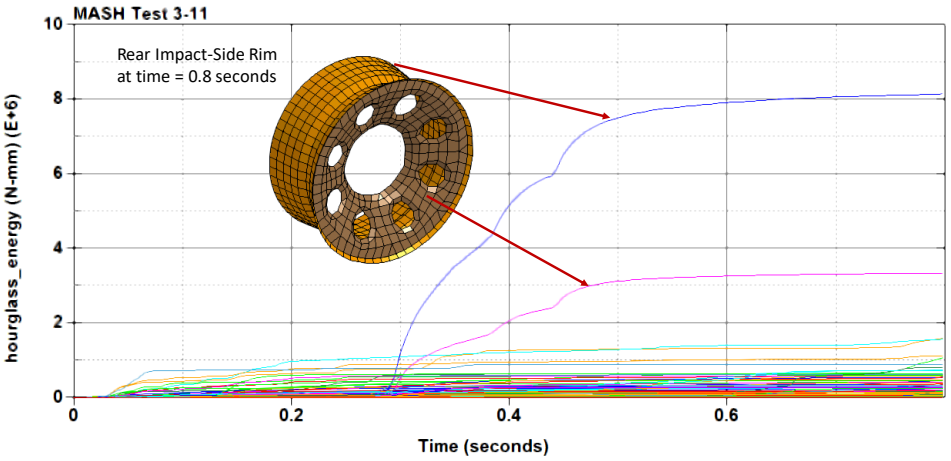


Figure 2. Hourglass energy from vehicle parts.

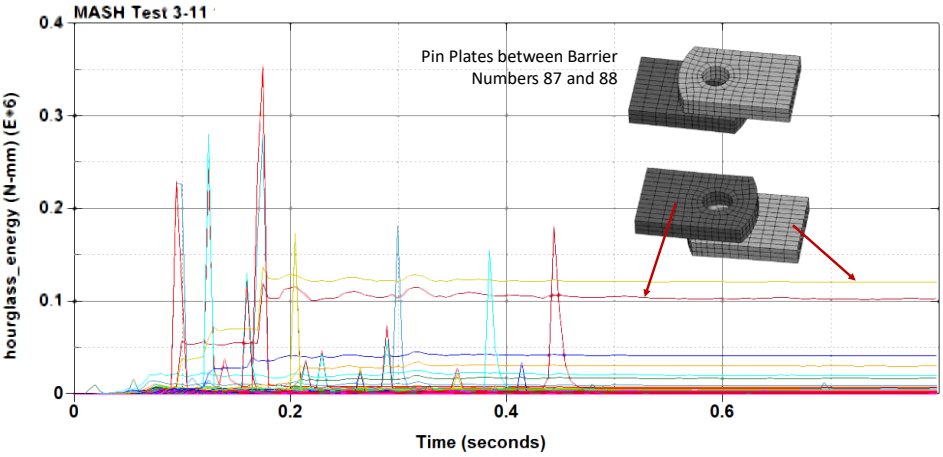


Figure 3. Hourglass energy from barrier parts.

PART III: HISTORY EVALUTION TABLES

Table E-2. Roadside Safety Validation Metrics Rating Table (single channel option).

Evaluation Criteria								Time interval [0.8 seconds]		
O	***Sprague-Geers Metrics*** List all the data channels being compared. Calculate the M and P metrics using RSVVP and enter the results. Values less than or equal to 40 are acceptable.									
	Channel	**RSVVP Curve Preprocessing Options**						**M**	**P**	**Pass?**
		Filter Option	**Sync. Option**	**Shift**		**Drift**				
				True Curve	**Test Curve**	**True Curve**	**Test Curve**			
	x-acceleration	CFC 60	Y	none	none	none	none	63.4	36.9	N
	y-acceleration	CFC 60	Y	none	none	none	none	21.5	30.9	Y
	z-acceleration	CFC 60	Y	none	none	none	none	36.3	46.4	N
	Yaw-rate	CFC 60	Y	none	none	none	none	4	8.4	Y
	Roll-rate	CFC 60	Y	none	none	none	none	28.3	31.4	Y
	Pitch-rate	CFC 60	Y	none	none	none	none	8.5	37.4	Y
P	***ANOVA Metrics*** List all the data channels being compared. Calculate the ANOVA metrics using RSVVP and enter the results. Both of the following criteria must be met: • The mean residual error must be less than five percent of the peak acceleration ($\bar{e} \leq 0.05 \cdot a_{Peak}$) and • The standard deviation of the residuals must be less than 35 percent of the peak acceleration ($\sigma \leq 0.35 \cdot a_{Peak}$).							**Mean Residual**	**Standard Deviation of Residuals**	**Pass?**
	x-acceleration							1.15	26.41	Y
	y-acceleration							-2.04	23.98	Y
	z-acceleration							2.34	31.51	Y
	Yaw-rate							-4.95	11.05	Y
	Roll-rate							-7.06	22.91	N
	Pitch-rate							-10.64	23.42	N
Exception Notes:										

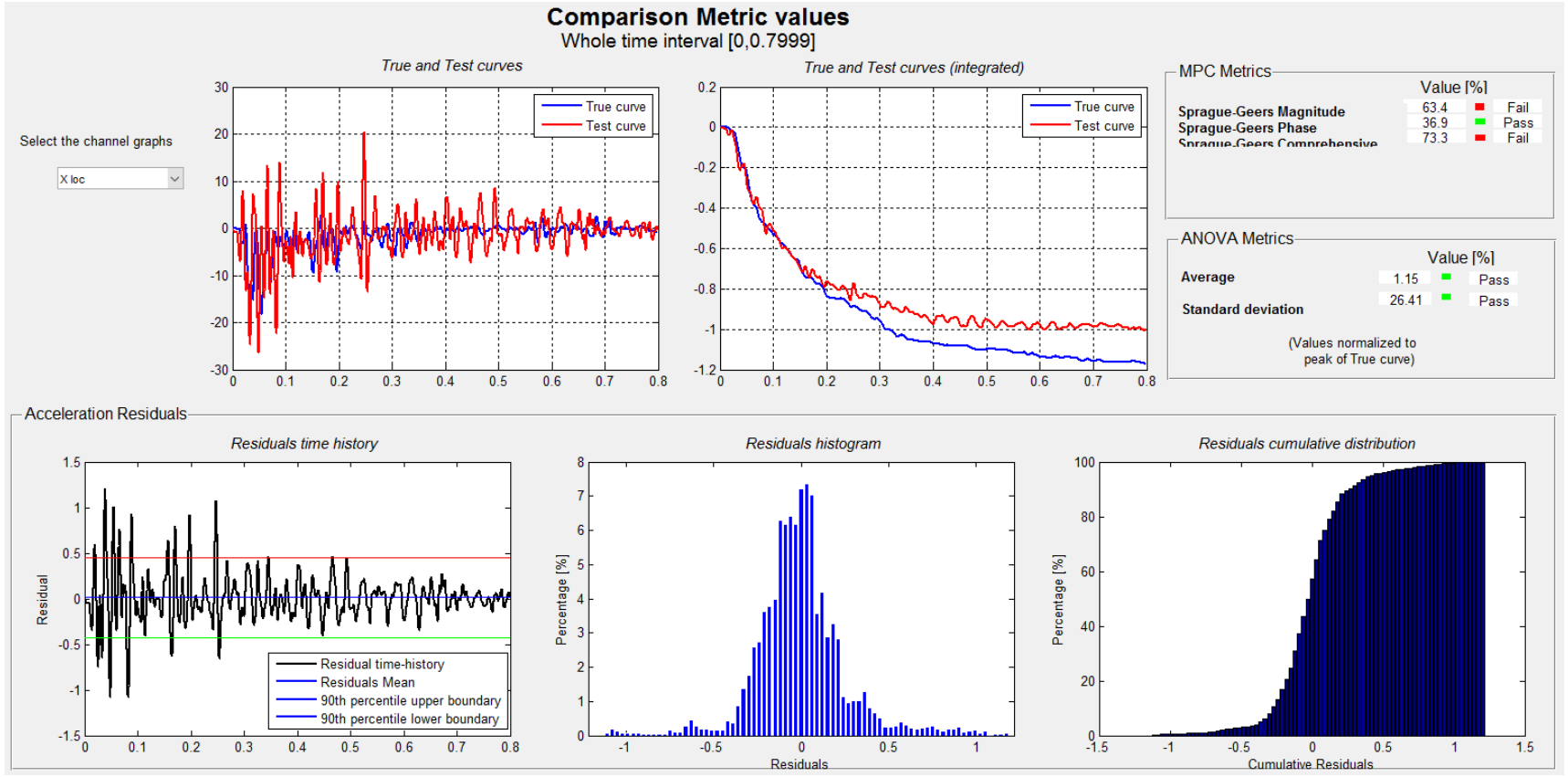
☐ Analysis solution passes all the criteria in Table E-2 ☐ without exceptions.

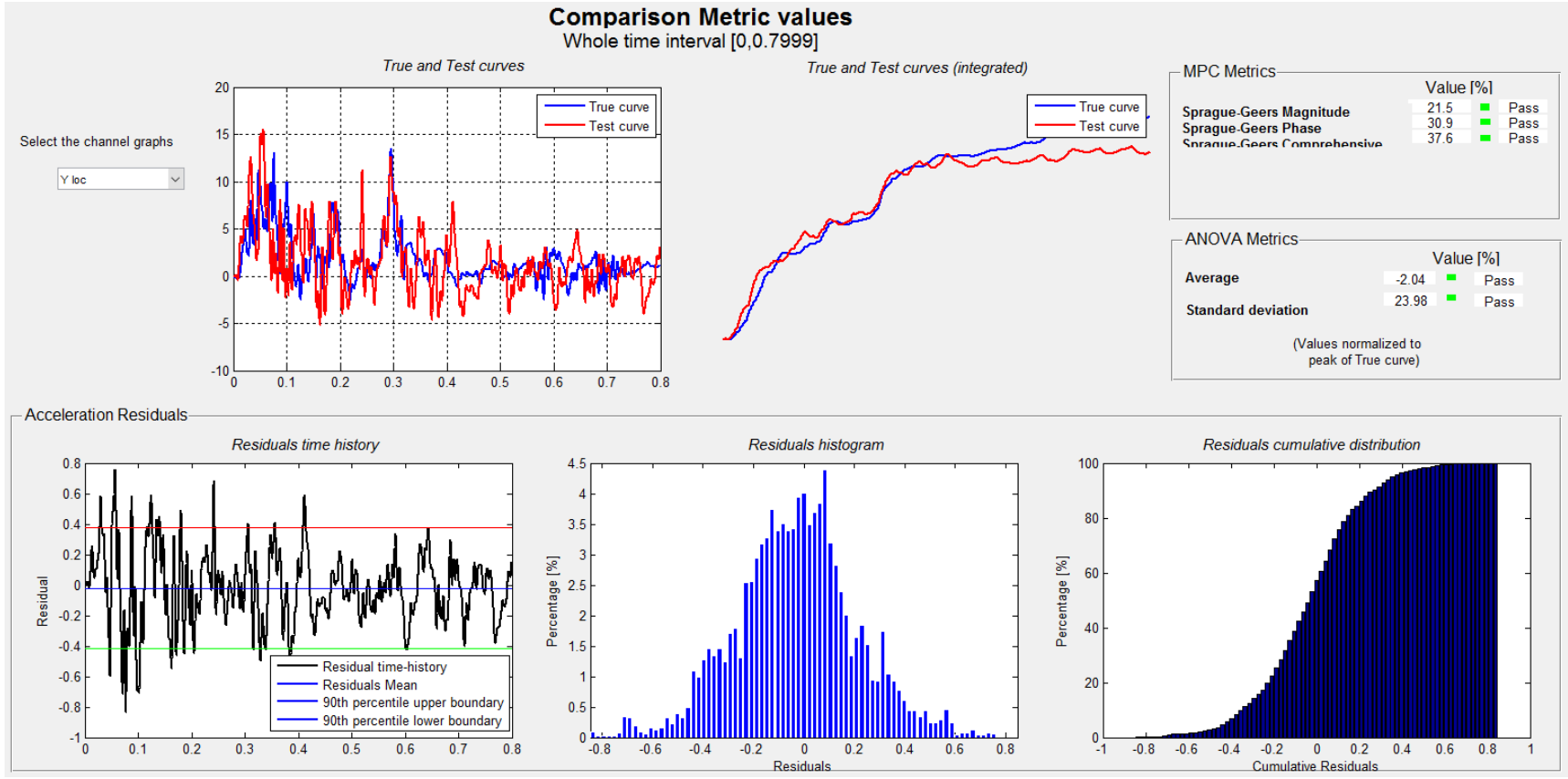
☐ with exceptions as noted in Table E-2.

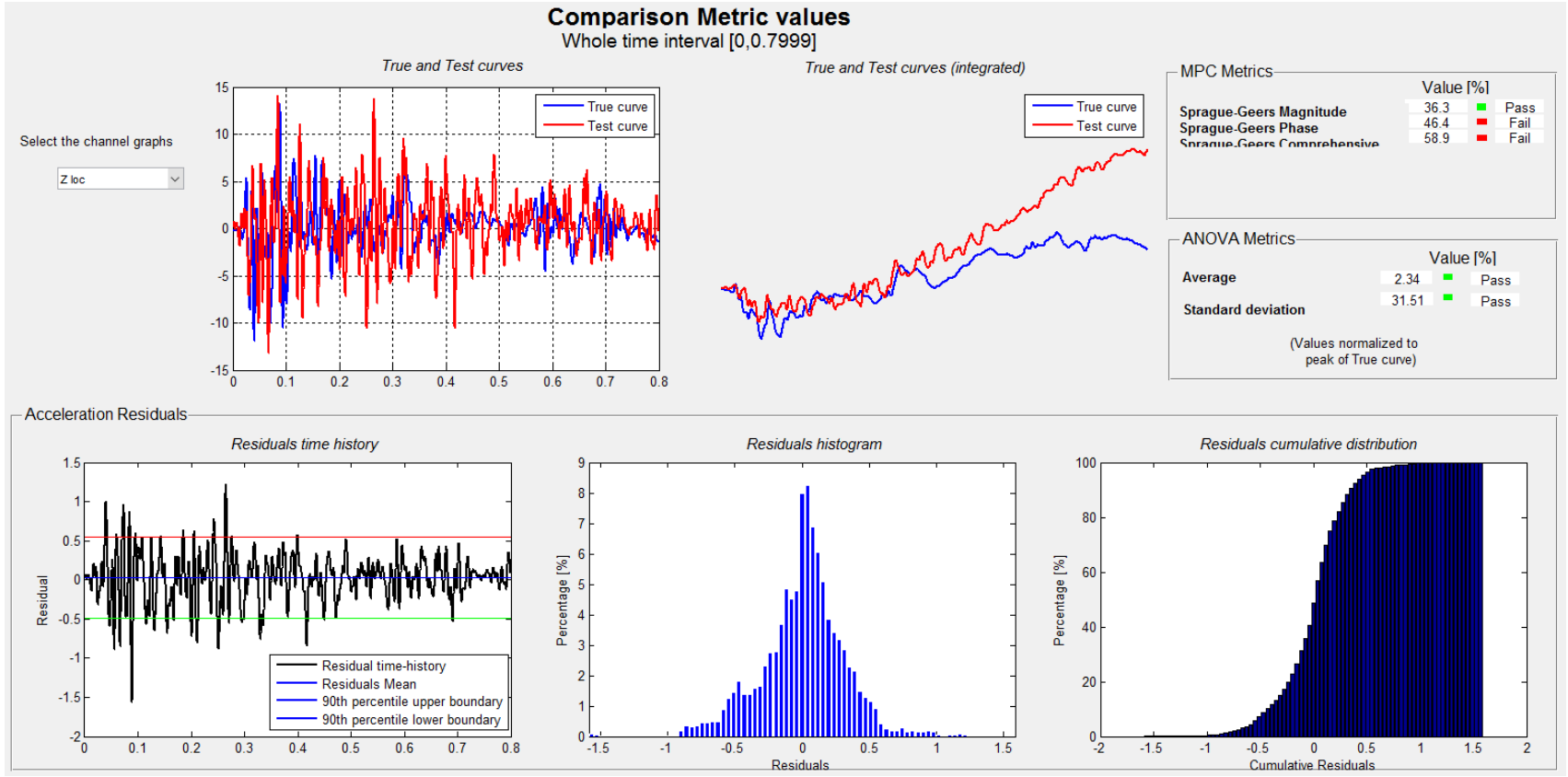
☒ Analysis solution does NOT pass all the criteria in Table E-2.

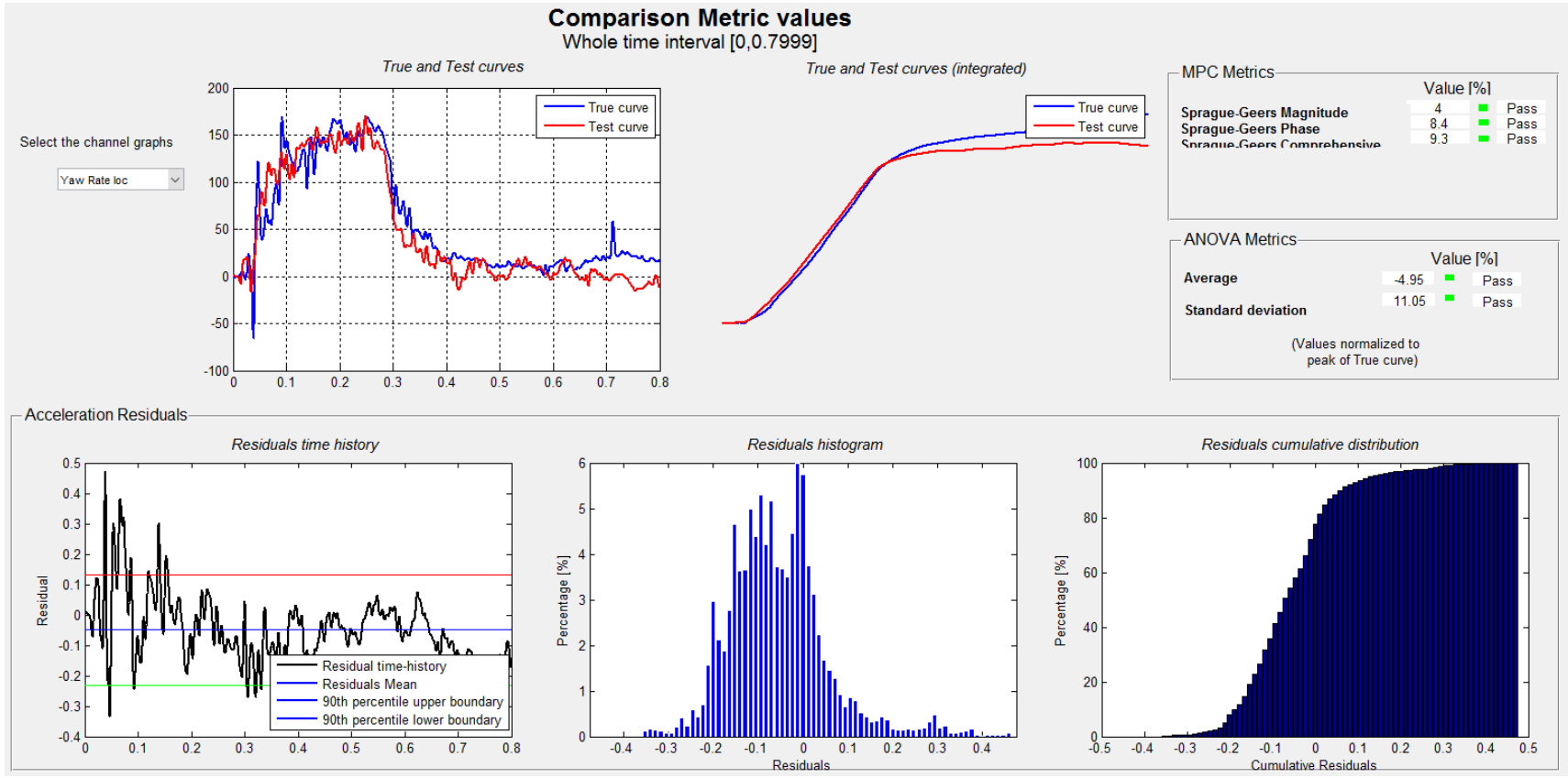
☐ Table E-2 is not applicable because _____

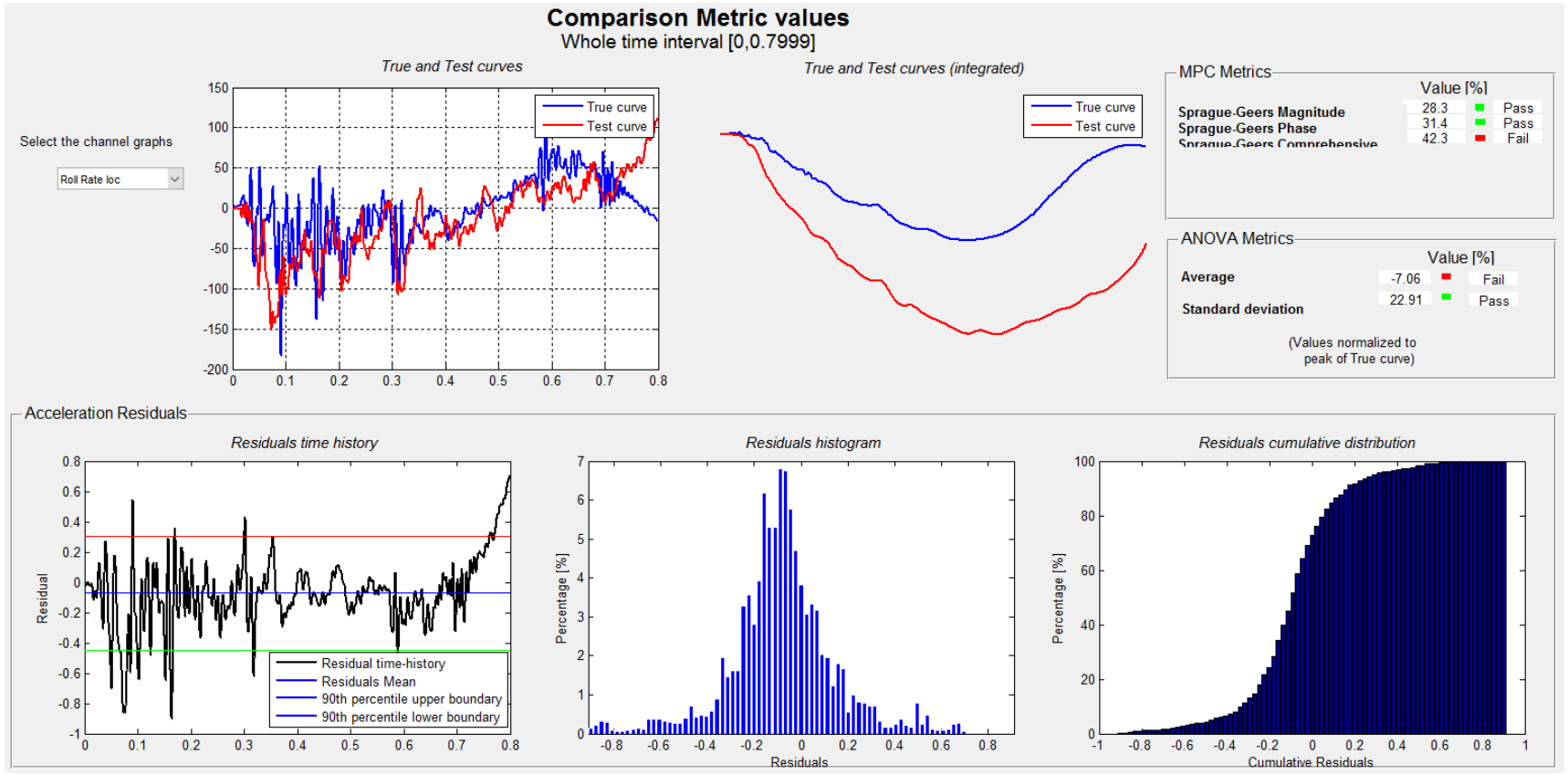
☒ RSVVP Single-Channel Comparison Metric Values Screens for each channel are attached on the following pages.


Comparison Metric values
Whole time interval [0,0.7999]
Select the channel graphs
X loc
True and Test curves
True curve
Test curve
True and Test curves (integrated)
True curve
Test curve
MPC Metrics
Value [%]
Sprague-Geers Magnitude 63.4 Fail
Sprague-Geers Phase 36.9 Pass
Sprague-Geers Comprehensive 73.3 Fail
ANOVA Metrics
Value [%]
Average 1.15 Pass
Standard deviation 26.41 Pass
(Values normalized to peak of True curve)
Acceleration Residuals
Residuals time history
Residual
Residual time-history
Residuals Mean
90th percentile upper boundary
90th percentile lower boundary
Residuals histogram
Percentage [%]
Residuals
Residuals cumulative distribution
Percentage [%]
Cumulative Residuals


Comparison Metric values
Whole time interval [0,0.7999]
Select the channel graphs
Y loc
True and Test curves
True curve
Test curve
True and Test curves (integrated)
True curve
Test curve
MPC Metrics
Value [%]
Sprague-Geers Magnitude 21.5 Pass
Sprague-Geers Phase 30.9 Pass
Sprague-Geers Comprehensive 37.6 Pass
ANOVA Metrics
Value [%]
Average -2.04 Pass
Standard deviation 23.98 Pass
(Values normalized to peak of True curve)
Acceleration Residuals
Residuals time history
Residual
Residual time-history
Residuals Mean
90th percentile upper boundary
90th percentile lower boundary
Residuals histogram
Percentage [%]
Residuals
Residuals cumulative distribution
Percentage [%]
Cumulative Residuals


Comparison Metric values
Whole time interval [0,0.7999]
Select the channel graphs
Z loc
True and Test curves
True curve
Test curve
True and Test curves (integrated)
True curve
Test curve
MPC Metrics
Value [%]
Sprague-Geers Magnitude 36.3 Pass
Sprague-Geers Phase 46.4 Fail
Sprague-Geers Comprehensive 58.9 Fail
ANOVA Metrics
Value [%]
Average 2.34 Pass
Standard deviation 31.51 Pass
(Values normalized to peak of True curve)
Acceleration Residuals
Residuals time history
Residual
Residual time-history
Residuals Mean
90th percentile upper boundary
90th percentile lower boundary
Residuals histogram
Percentage [%]
Residuals
Residuals cumulative distribution
Percentage [%]
Cumulative Residuals


Comparison Metric values
Whole time interval [0,0.7999]
Select the channel graphs
Yaw Rate loc
True and Test curves
True curve
Test curve
True and Test curves (integrated)
MPC Metrics
Value [%]
Sprague-Geers Magnitude 4 Pass
Sprague-Geers Phase 8.4 Pass
Sprague-Geers Comprehensive 9.3 Pass
ANOVA Metrics
Value [%]
Average -4.95 Pass
Standard deviation 11.05 Pass
(Values normalized to peak of True curve)
Acceleration Residuals
Residuals time history
Residual
Residual time-history
Residuals Mean
90th percentile upper boundary
90th percentile lower boundary
Residuals histogram
Percentage [%]
Residuals
Residuals cumulative distribution
Percentage [%]
Cumulative Residuals


Comparison Metric values
Whole time interval [0,0.7999]
Select the channel graphs
Roll Rate loc
True and Test curves
True curve
Test curve
True and Test curves (integrated)
True curve
Test curve
MPC Metrics
Value [%]
Sprague-Geers Magnitude 28.3 Pass
Sprague-Geers Phase 31.4 Pass
Sprague-Geers Comprehensive 42.3 Fail
ANOVA Metrics
Value [%]
Average -7.06 Fail
Standard deviation 22.91 Pass
(Values normalized to peak of True curve)
Acceleration Residuals
Residuals time history
Residual
Residual time-history
Residuals Mean
90th percentile upper boundary
90th percentile lower boundary
Residuals histogram
Percentage [%]
Residuals
Residuals cumulative distribution
Percentage [%]
Cumulative Residuals

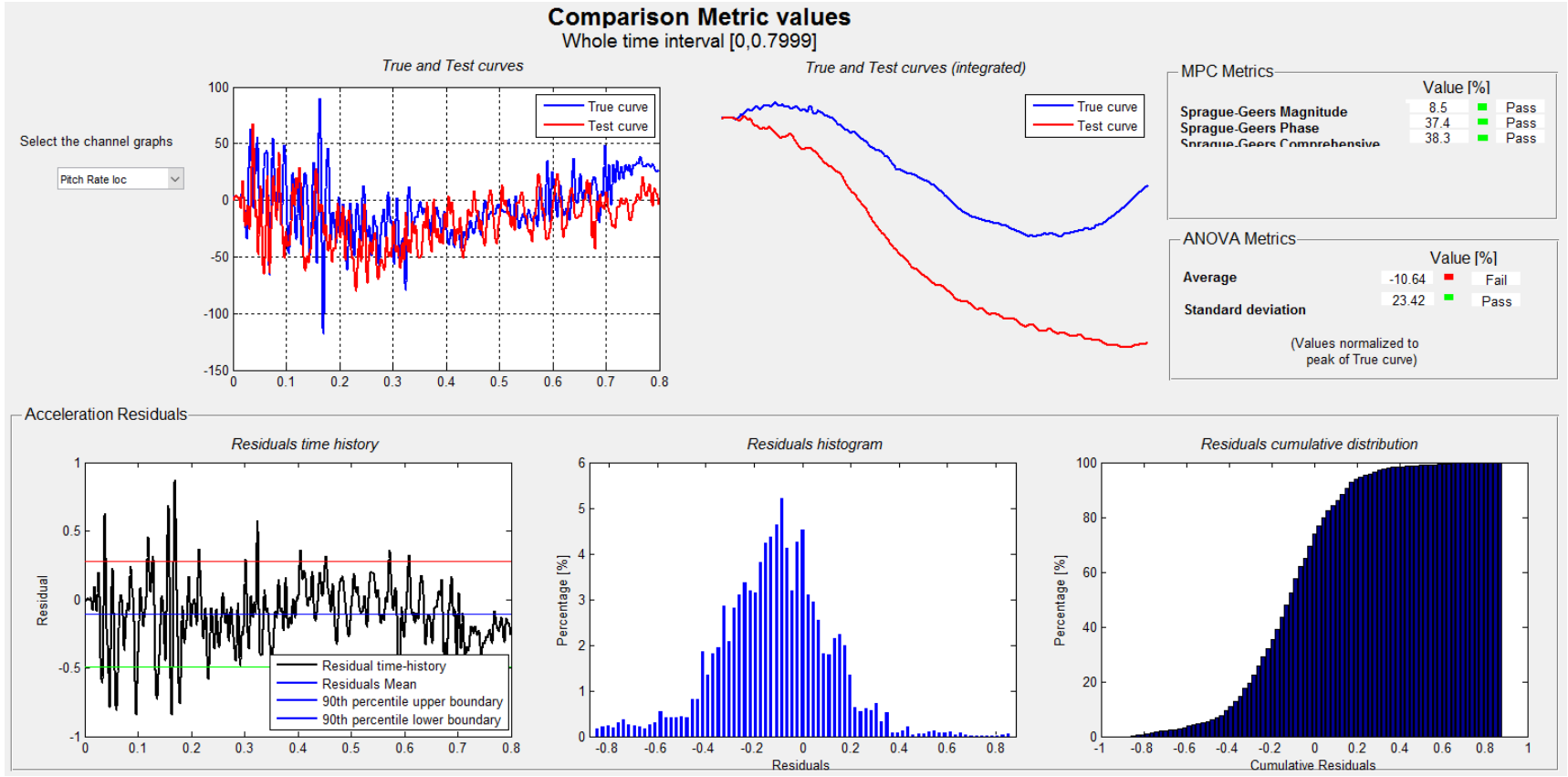
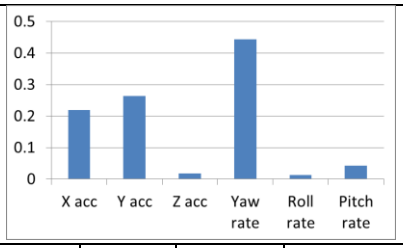


Figure 4. Multi-Channel Area II Weighting Method for Data Channels.

Table E-3. Roadside Safety Validation Metrics Rating Table (multi-channel option AREA II Method).

Evaluation Criteria (time interval [0.8 seconds])					
Channels (Select which were used)					
☒ **X Acceleration**	☒ **Y Acceleration**	☒ **Z Acceleration**			
☒ **Roll rate**	☒ **Pitch rate**	☒ **Yaw rate**			
Multi-Channel Weights (Area II Method)	**X Channel: 0.219** **Y Channel: 0.263** **Z Channel: 0.018** **Yaw Channel: 0.444** **Roll Channel: 0.013** **Pitch Channel: 0.042**				
O	***Sprague-Geer Metrics*** Values less than or equal to 40 are acceptable.		**M** 22.7	**P** 22.8	**Pass?** **Y**
P	***ANOVA Metrics*** Both of the following criteria must be met: • The mean residual error must be less than five percent of the peak acceleration ($\bar{e} \le 0.05 \cdot a_{Peak}$) • The standard deviation of the residuals must be less than 35 percent of the peak acceleration ($\sigma \le 0.35 \cdot a_{Peak}$)		**Mean Residual** -3	**Standard Deviation of Residuals** 18.9	Pass? **Y**
Exception Notes:					

☒ Analysis solution passes all the criteria in Table E-3 ☒ without exceptions

☐ with exceptions as noted in Table E-3.

☐ Analysis solution does NOT pass all the criteria in Table E-3.

☐ Table E-3 does not contain sufficient information for assessment.

☐ Table E-3 is not applicable because criteria were satisfied in Table E-2.

☒ RSVVP Multi-Channel Comparison Metric Values Screen is attached on the following page.

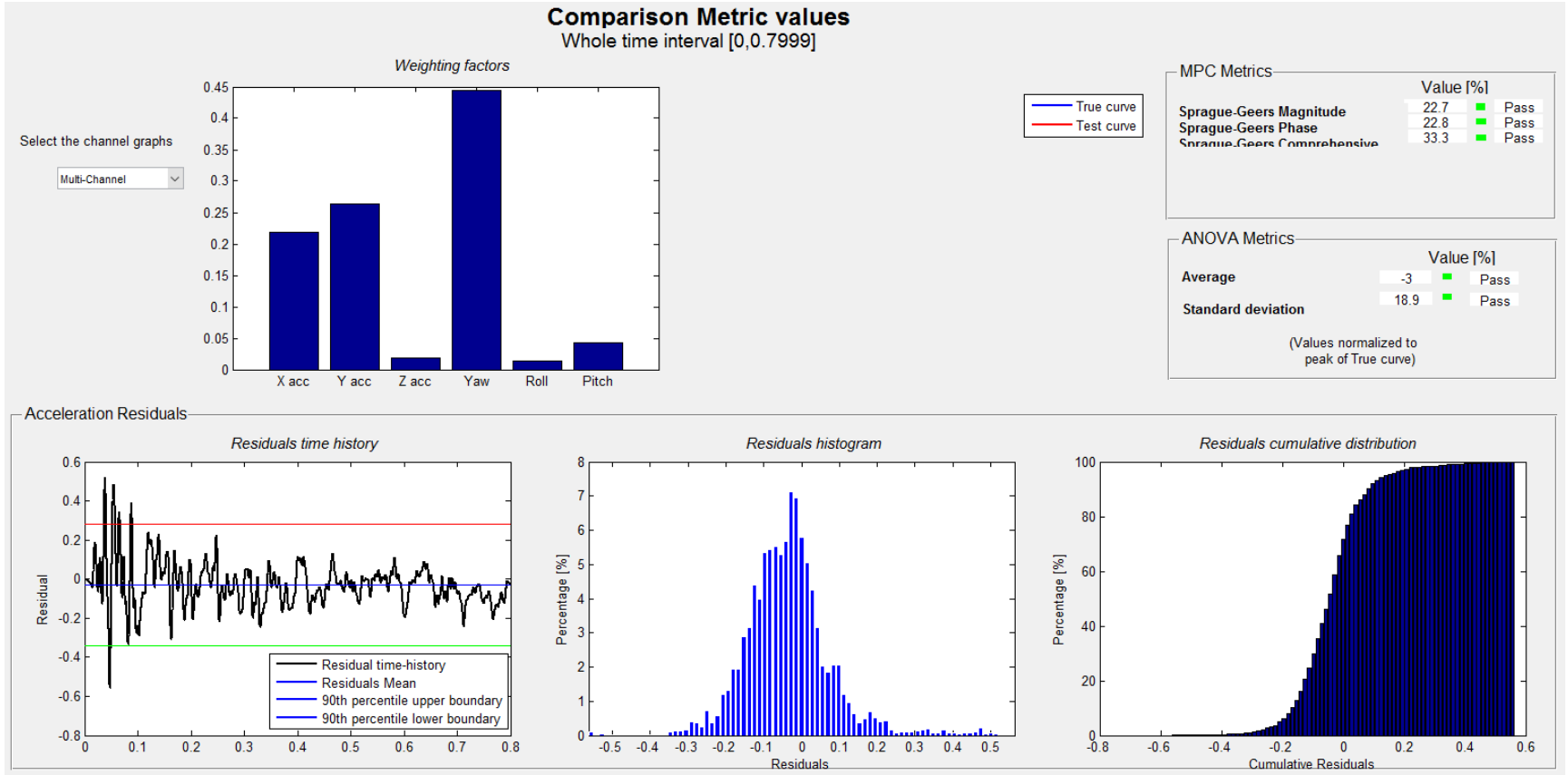
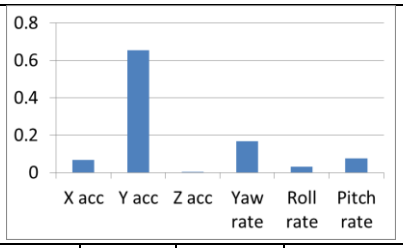


Figure 5. Multi-Channel Energy Weighting Method for data channels.

Table E-3. Roadside Safety Validation Metrics Rating Table (multi-channel option Energy Method).

Evaluation Criteria (time interval [0.8 seconds])					
Channels (Select which were used)					
☒ **X Acceleration**	☒ **Y Acceleration**	☒ **Z Acceleration**			
☒ **Roll rate**	☒ **Pitch rate**	☒ **Yaw rate**			
Multi-Channel Weights (Energy Method)	**X Channel: 0.068** **Y Channel: 0.655** **Z Channel: 0.003** **Yaw Channel: 0.167** **Roll Channel: 0.031** **Pitch Channel: 0.076**				
O	***Sprague-Geer Metrics*** Values less than or equal to 40 are acceptable.		**M**	**P**	**Pass?**
			20.7	28.1	**Y**
P	***ANOVA Metrics*** Both of the following criteria must be met: • The mean residual error must be less than five percent of the peak acceleration ($\bar{e} \le 0.05 \cdot a_{Peak}$) • The standard deviation of the residuals must be less than 35 percent of the peak acceleration ($\sigma \le 0.35 \cdot a_{Peak}$)		**Mean Residual**	**Standard Deviation of Residuals**	Pass?
			-3.1	21.9	**Y**
Exception Notes:					

☒ Analysis solution passes all the criteria in Table E-3 ☒ without exceptions

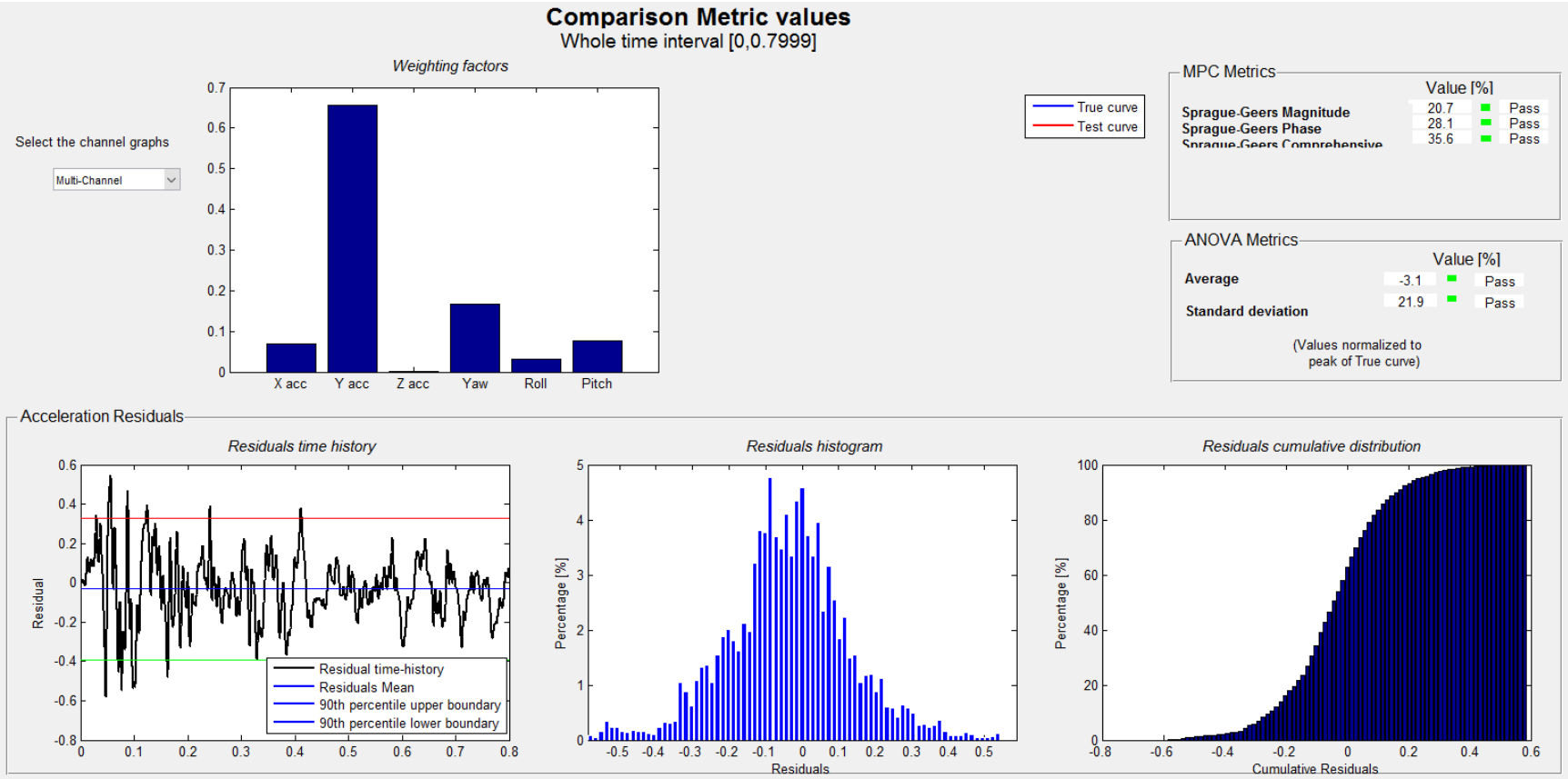
☐ with exceptions as noted in Table E-3.

☐ Analysis solution does NOT pass all the criteria in Table E-3.

☐ Table E-3 does not contain sufficient information for assessment.

☐ Table E-3 is not applicable because criteria were satisfied in Table E-2.

☒ RSVVP Multi-Channel Comparison Metric Values Screen is attached on the following page.


Comparison Metric values
Whole time interval [0,0.7999]
Weighting factors
Select the channel graphs
Multi-Channel
X acc
Y acc
Z acc
Yaw
Roll
Pitch
True curve
Test curve
MPC Metrics
Value [%]
Sprague-Geers Magnitude
20.7
Pass
Sprague-Geers Phase
28.1
Pass
35.6
Pass
ANOVA Metrics
Value [%]
Average
-3.1
Pass
Standard deviation
21.9
Pass
(Values normalized to peak of True curve)
Acceleration Residuals
Residuals time history
Residual
Residual time-history
Residuals Mean
90th percentile upper boundary
90th percentile lower boundary
Residuals histogram
Percentage [%]
Residuals
Residuals cumulative distribution
Percentage [%]
Cumulative Residuals

PART IV: PHENOMENA IMPORTANCE RANKING TABLES

Table E-4. Evaluation Criteria Test Applicability Table.

<table>
<tr><th>Evaluation Factors</th><th colspan="2">Evaluation Criteria</th><th>Applicable Tests</th></tr>
<tr><td rowspan="3">Structural Adequacy</td><td>A</td><td>Test article should contain and redirect the vehicle; the vehicle should not penetrate, under-ride, or override the installation although controlled lateral deflection of the test article is acceptable.</td><td>10, 11, 12, 20, 21, 22, 35, 36, 37, 38</td></tr>
<tr><td>B</td><td>The test article should readily activate in a predictable manner by breaking away, fracturing or yielding.</td><td>60, 61, 70, 71, 80, 81, 82</td></tr>
<tr><td>C</td><td>Acceptable test article performance may be by redirection, controlled penetration or controlled stopping of the vehicle.</td><td>30, 31, 32, 33, 34, 37, 38, 40, 41, 42, 43, 44, 50, 51, 52, 53, 90, 91</td></tr>
<tr><td rowspan="7">Occupant Risk</td><td>D</td><td>Detached elements, fragments or other debris from the test article should not penetrate or show potential for penetrating the occupant compartment, or present an undue hazard to other traffic, pedestrians or personnel in a work zone.
Deformations of, or intrusions into, the occupant compartment should not exceed limits set forth in Section 5.3 and Appendix E of MASH.</td><td>All</td></tr>
<tr><td>E</td><td>Detached elements, fragments or other debris from the test article, or vehicular damage should not block the driver’s vision or otherwise cause the driver to lose control of the vehicle. (Answer Yes or No)</td><td>70, 71, 72</td></tr>
<tr><td>F</td><td>The vehicle should remain upright during and after the collision. The maximum roll and pitch angles are not to exceed 75 degrees.</td><td>All except those listed in criterion G</td></tr>
<tr><td>G</td><td>It is preferable, although not essential, that the vehicle remain upright during and after collision.</td><td>12, 22</td></tr>
<tr><td rowspan="2">H</td><td>Occupant impact velocities should satisfy the following:
<table>
<tr><th colspan="3">Occupant Impact Velocity Limits (m/s)</th></tr>
<tr><th>Component</th><th>Preferred</th><th>Maximum</th></tr>
<tr><td>Longitudinal and Lateral</td><td>9.1</td><td>12.2</td></tr>
<tr><td>Longitudinal</td><td>3</td><td>4.9</td></tr>
</table></td><td>10, 11, 20, 21, 30, 31, 32, 33, 34, 35, 36, 37, 38, 40, 41, 42, 43, 44, 50, 51, 52, 53, 80, 81, 90, 91
60, 61, 70, 71, 72</td></tr>
<tr><td>I</td><td>Occupant ridedown accelerations should satisfy the following:
<table>
<tr><th colspan="3">Occupant Ridedown Acceleration Limits (g’s)</th></tr>
<tr><th>Component</th><th>Preferred</th><th>Maximum</th></tr>
<tr><td>Longitudinal and Lateral</td><td>15</td><td>20.49</td></tr>
</table></td><td>10, 11, 20, 21, 30, 31, 32, 33, 34, 35, 36, 37, 38, 40, 41, 42, 43, 44, 50, 51, 52, 53, 80, 81, 90, 91</td></tr>
<tr><td rowspan="3">Vehicle Trajectory</td><td>J</td><td>“Reserved”</td><td></td></tr>
<tr><td>M</td><td>“Reserved”</td><td></td></tr>
<tr><td>N</td><td>Vehicle trajectory behind the test article is acceptable.</td><td>30, 31, 32, 33, 34, 42, 43, 44, 60, 61, 70, 71, 80, 81</td></tr>
</table>

☐ Table E-4 is not applicable because _____.

Table E-5(a). Roadside Safety Phenomena Importance Ranking Table (Structural Adequacy).

Evaluation Criteria				Known Result	Analysis Result	Difference Relative/ Absolute	Agree?
Structural Adequacy	A	A1	Test article should contain and redirect the vehicle; the vehicle should not penetrate, under-ride, or override the installation although controlled lateral deflection of the test article is acceptable. (Answer Yes or No)	Y	Y		Y
		A2	Maximum dynamic deflection: - Relative difference is less than 20 percent or - Absolute difference is less than 6 inches	41.4 in.	40.4 in.	2.4% 1 in.	Y
		A3	Maximum permanent deflection: - Relative difference is less than 20 percent or - Absolute difference is less than 6 inches	39 in.	40.21 in	3.1% 1.21 in.	Y
		A4	Number of broken or significantly bent posts is less than 20 percent.	0	0		Y
		A5	Did the rail element rupture or tear (Answer Yes or No)	No	No		Y
		A6	Concrete curb/deck failure	No	No		Y
		A7	Was there significant snagging between the vehicle wheels and barrier elements (Answer Yes or No).	No	No		Y
		A8	Was there significant snagging between vehicle body components and barrier elements (Answer Yes or No).	No	No		Y

Note: Additional phenomena can be added to the tables in deemed appropriate by the analyst.

Table E-5(b). Roadside Safety Phenomena Importance Ranking Table (Occupant Risk).

Evaluation Criteria				Known Result	Analysis Result	Difference Relative/ Absolute	Agree?
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. (Answer Yes or No)	N	N		Y
	F	F1	The vehicle should remain upright during and after the collision although moderate roll, pitching and yawing are acceptable. (Answer Yes or No)	Y	Y		Y
		F2	Maximum roll of the vehicle through 0.8 seconds: - Relative difference is less than 20 percent or - Absolute difference is less than 5 degrees.	-10.9 deg	-24.9 deg	128.4% 14 deg	N
		F3	Maximum pitch of the vehicle through 0.8 seconds: - Relative difference is less than 20 percent or - Absolute difference is less than 5 degrees.	-3.6 deg	-6.7 deg	86.4% 3.1 deg	Y
		F4	Maximum yaw of the vehicle through 0.8 seconds: - Relative difference is less than 20 percent or - Absolute difference is less than 5 degrees.	45.3 deg	41.2 deg	9.1% 4.1 deg	Y
	H	L	Occupant impact velocities: - Relative difference is less than 20 percent or - Absolute difference is less than 2 m/s.				
		1	• Longitudinal OIV (m/s)	5.7	5.4	5.3% 0.3 m/s	Y
		2	• Lateral OIV (m/s)	-5.3	-4.8	9.4% 0.5 m/s	Y
		3	• THIV (m/s)	7.9	7	11.4% 0.9 m/s	Y
	I		Occupant accelerations: - Relative difference is less than 20 percent or - Absolute difference is less than 4 g's.				
		1	• Longitudinal ORA	-7.1	-7.8	9.9 % 0.7 g	Y
		2	• Lateral ORA	11.1	10.6	4.5 % 0.5 g	Y
		3	• PHD	11.1	11.9	7.2 % 0.8 g	Y
		4	• ASI	1.1	1.09	0.9% .01	Y

Table E-5(c). Roadside Safety Phenomena Importance Ranking Table (Vehicle Trajectory).

Evaluation Criteria				Known Result	Analysis Result	Difference Relative/ Absolute	Agree?
Vehicle Trajectory	M	M1	Exit angle at loss of contact: - Relative difference is less than 20 percent or - Absolute difference is less than 5 degrees.	19.9* deg	15.2** Deg	24% 4.7 deg	Y
		M2	Exit velocity at loss of contact: - Relative difference is less than 20 percent or - Absolute difference is less than 6.2 mph.	36.6 mph	40.5** mph	9.9% 3.9 mph	Y
		M3	One or more vehicle tires failed or de-beaded during the collision event (Answer Yes or No).	Y	N.A.		-
		M4	One or more vehicle tires failed or de-beaded during the collision event (Answer Yes or No).	Y	N.A.		-

*** Result from test data at 0.8 seconds (for direct correlation with analysis)**

**** Result from FEA at 0.8 seconds (analysis termination time)**

Exception Notes: The roll angle in the FEA was significantly higher than the roll angle that occurred in the full-scale test. It isn't exactly clear what this difference is related to; it may be related to the fact that the test vehicle was a Dodge Ram and the model vehicle was based on a Chevrolet. However, the model matches well with the test in all other respects. The results from the model are therefore considered to be valid, although somewhat conservative for this impact scenario with the CRTS barrier.

Note: Additional phenomena can be added to the tables in deemed appropriate by the analyst.

☒ Analysis solution passes all the criteria in Tables E-5(a) through E-5(c)

☐ without exceptions.

☒ with exceptions as noted in Tables E-5(a) through E-5(c).

☐ Does NOT pass all the criteria in Tables E-5(a) through 5(c).

☐ Tables E-5(a) through E-5(c) does not contain sufficient information for assessment.

☐ Tables E-5(a) through E-5(c) are not applicable because _____

☒ Synchronized side-by-side views of the known and analysis solutions are attached on the following pages.

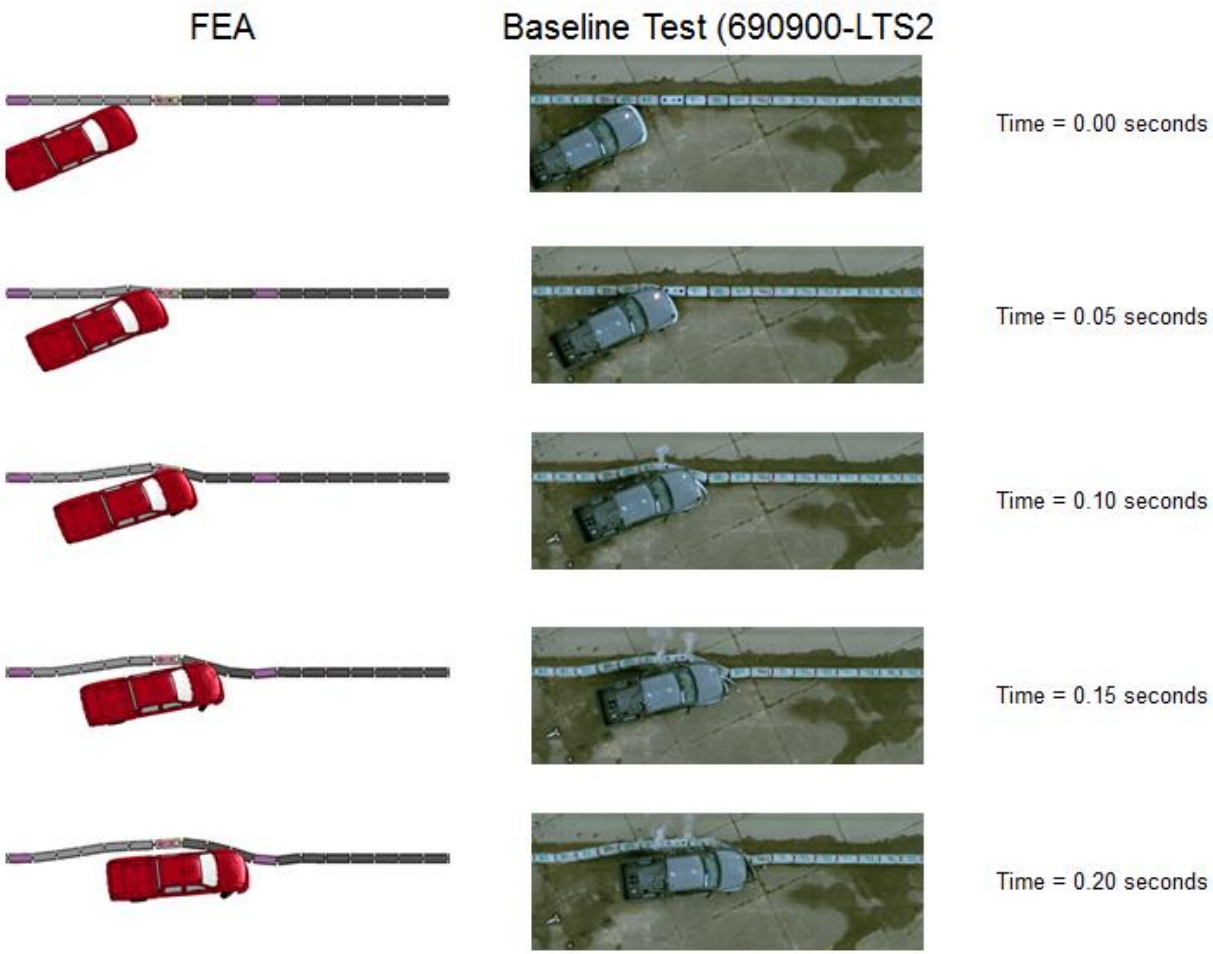


Figure 6. Sequential views for FEA and Test 690900-LTS2 under MASH Test 3-11 impact conditions from an overhead viewpoint.

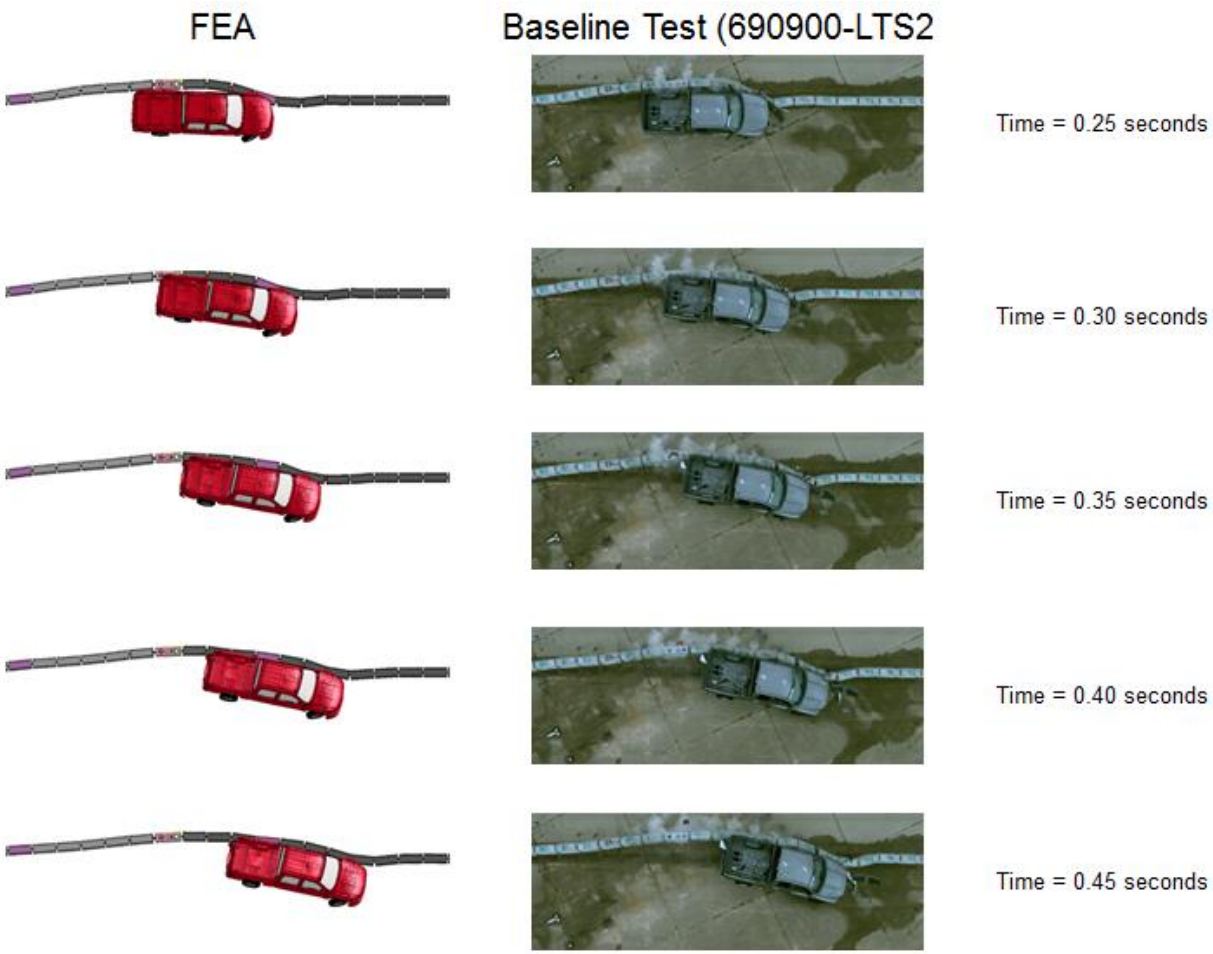


Figure 6. [Continued] Sequential views for FEA and Test 690900-LTS2 under MASH Test 3-11 impact conditions from an overhead viewpoint.

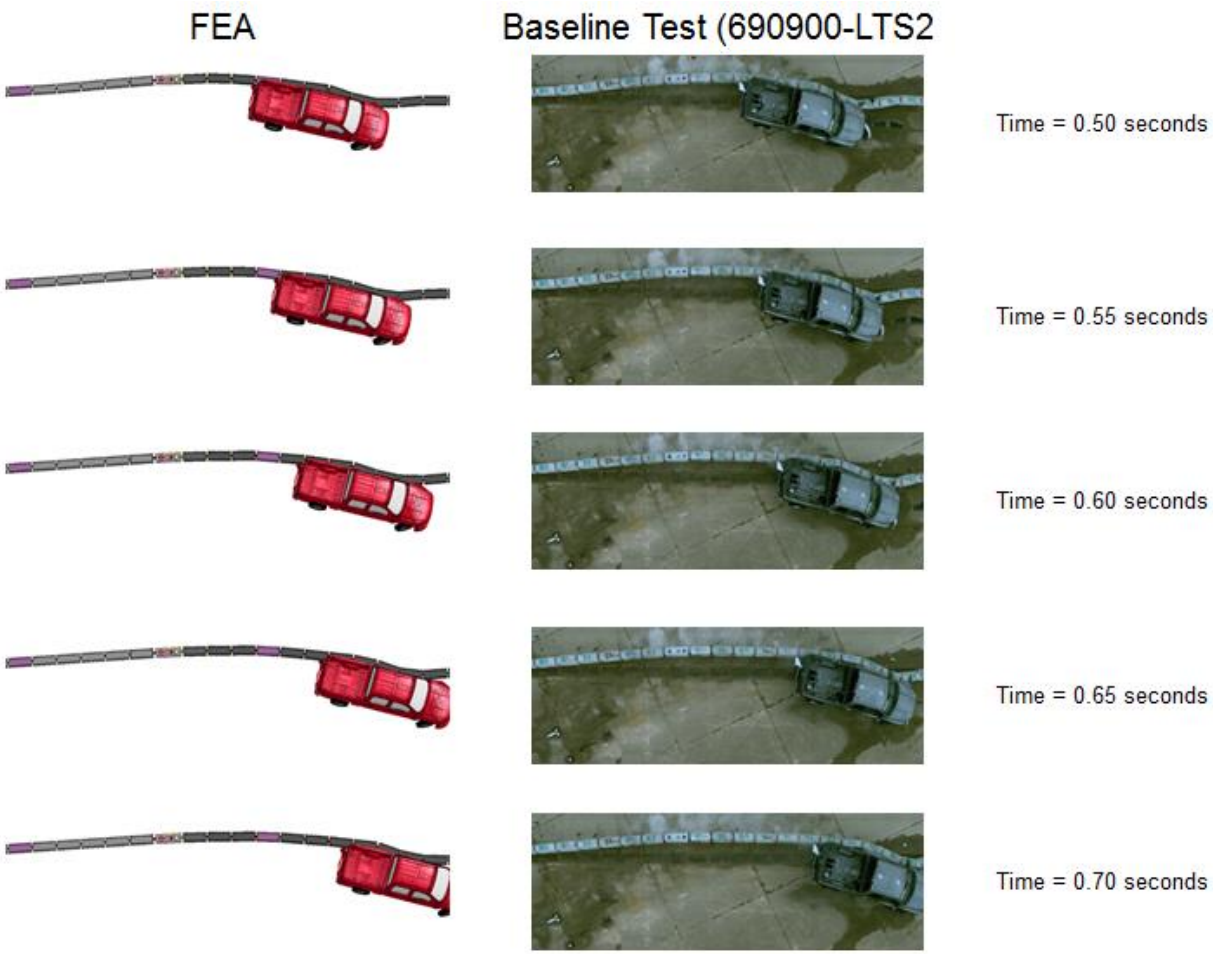


Figure 6. [Continued] Sequential views for FEA and Test 690900-LTS2 under MASH Test 3-11 impact conditions from an overhead viewpoint.

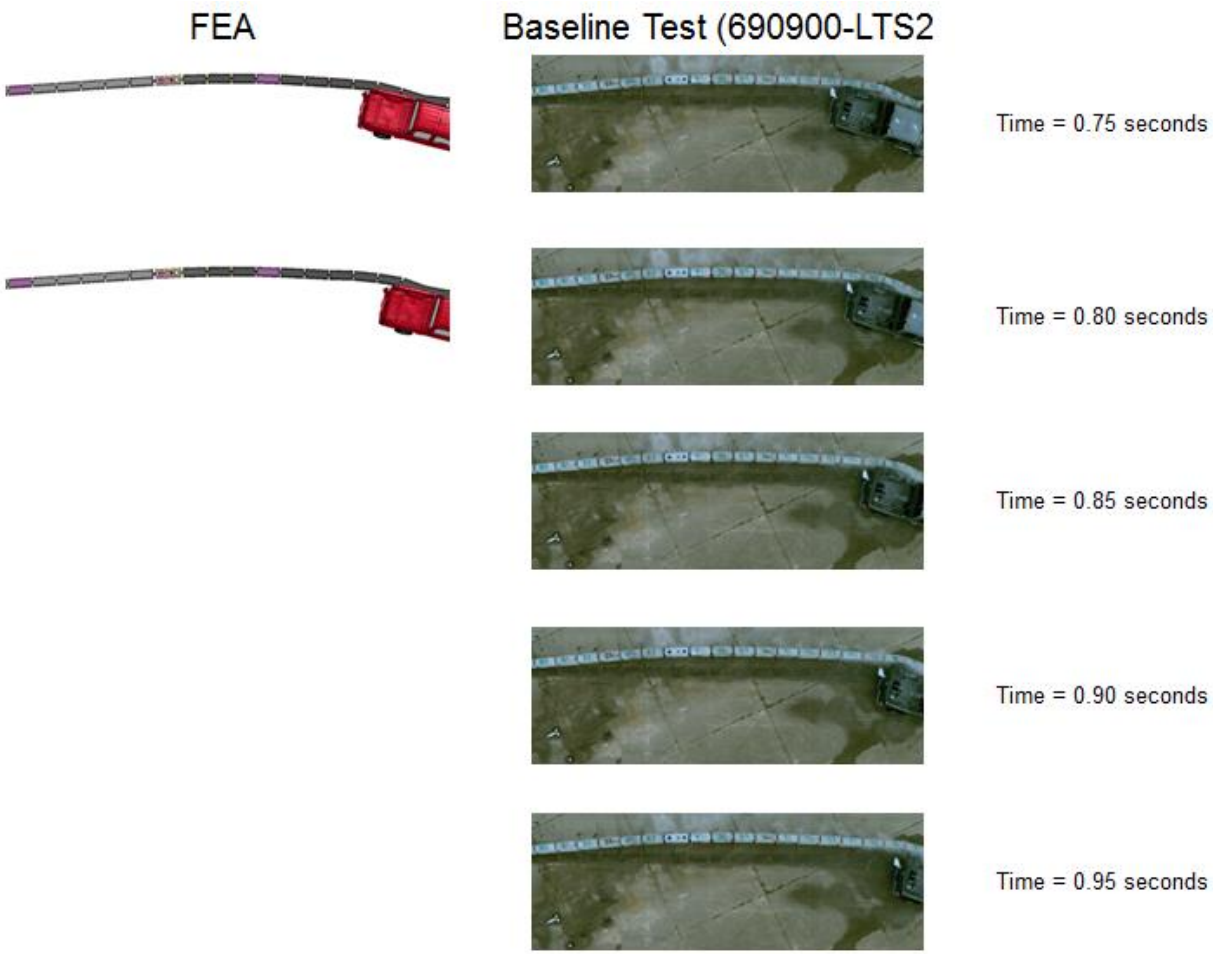


Figure 6. [Continued] Sequential views for FEA and Test 690900-LTS2 under MASH Test 3-11 impact conditions from an overhead viewpoint.

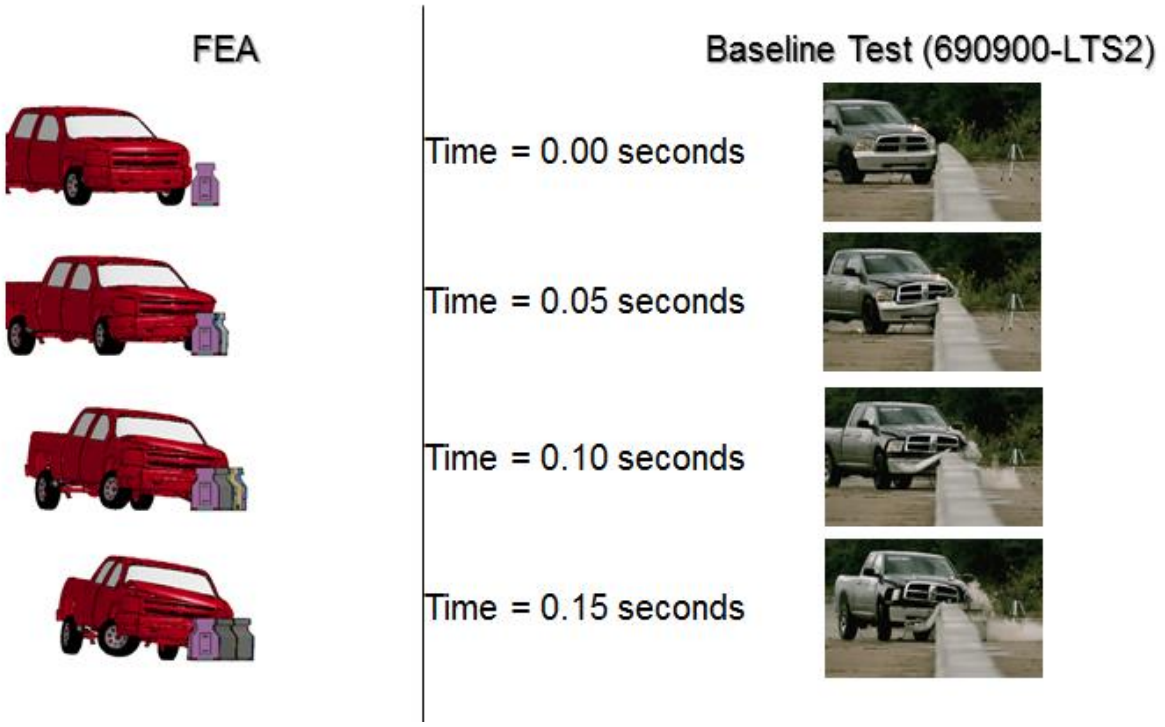


Figure 7. Sequential views for FEA and Test 690900-LTS2 under MASH Test 3-11 impact conditions from a downstream viewpoint.

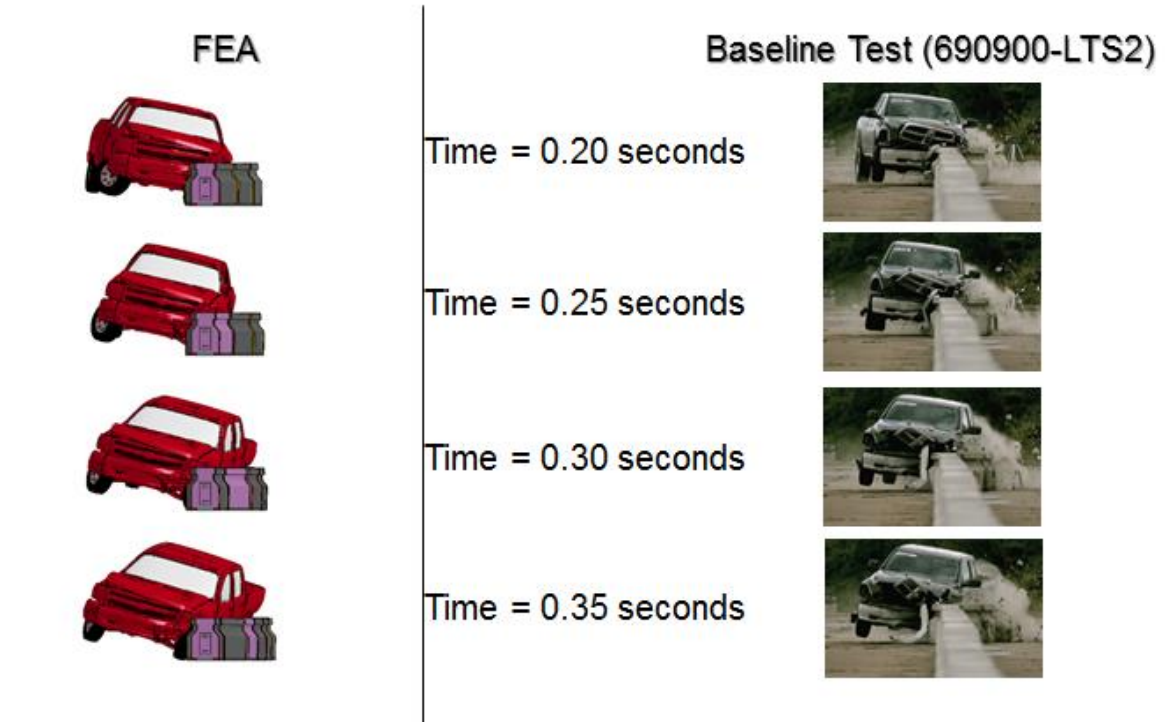


Figure 7. [Continued] Sequential views for FEA and Test 690900-LTS2 under MASH Test 3-11 impact conditions from a downstream viewpoint.

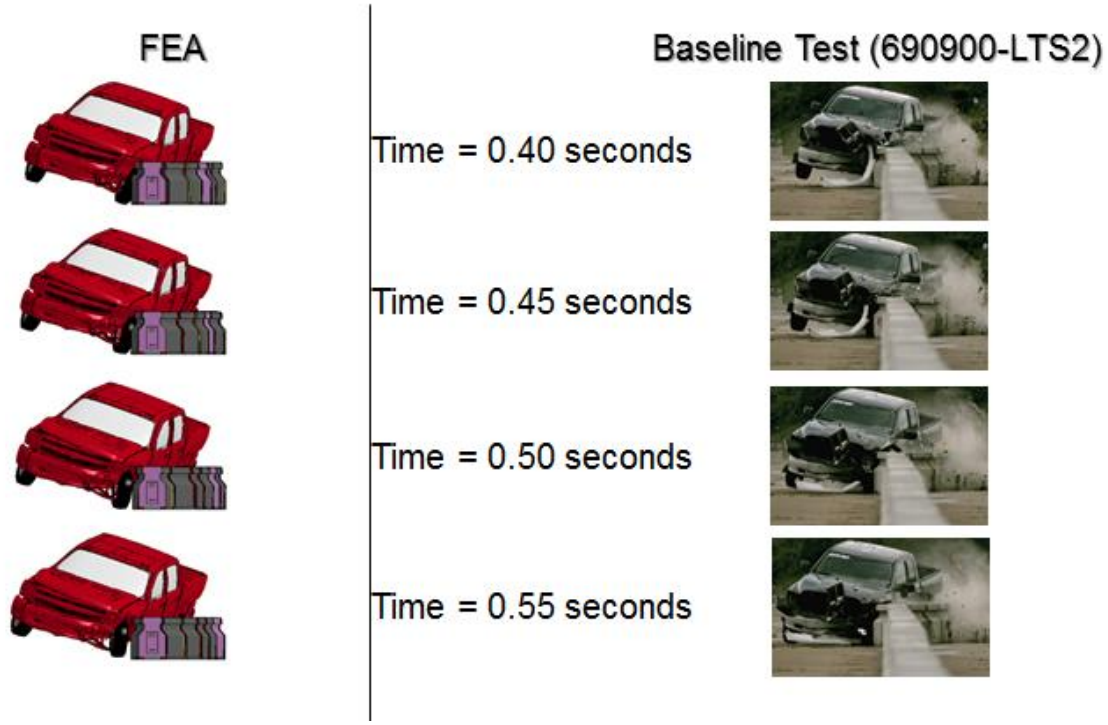


Figure 7. [Continued] Sequential views for FEA and Test 690900-LTS2 under MASH Test 3-11 impact conditions from a downstream viewpoint.

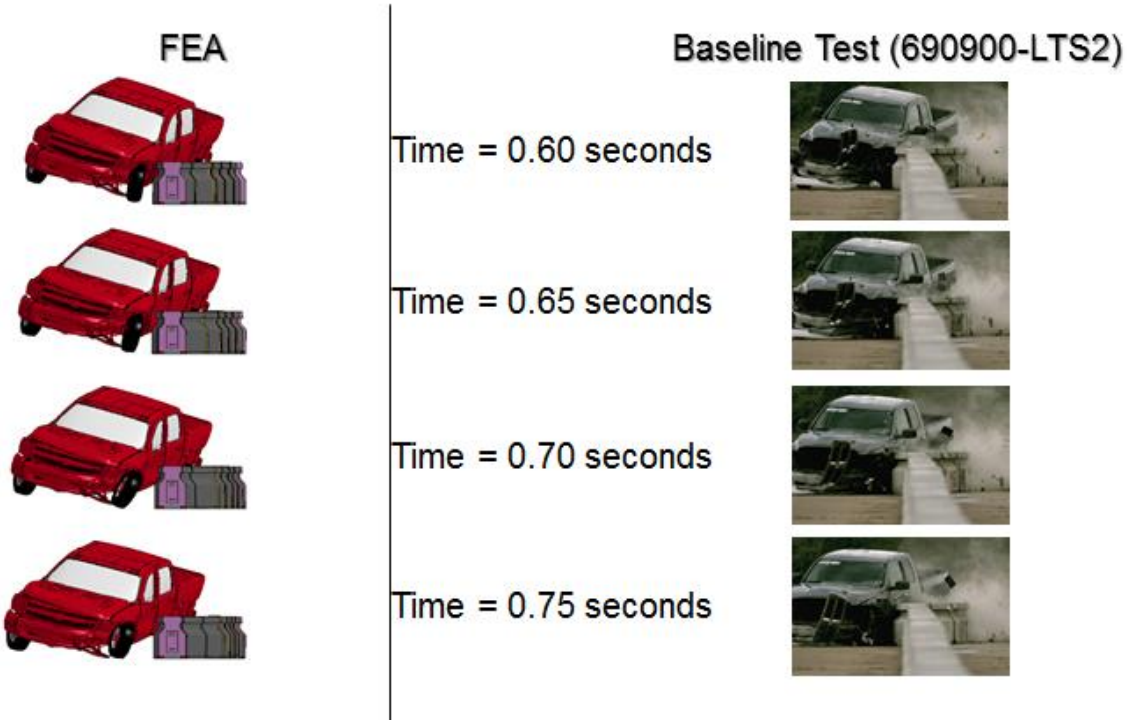


Figure 7. [Continued] Sequential views for FEA and Test 690900-LTS2 under MASH Test 3-11 impact conditions from a downstream viewpoint.

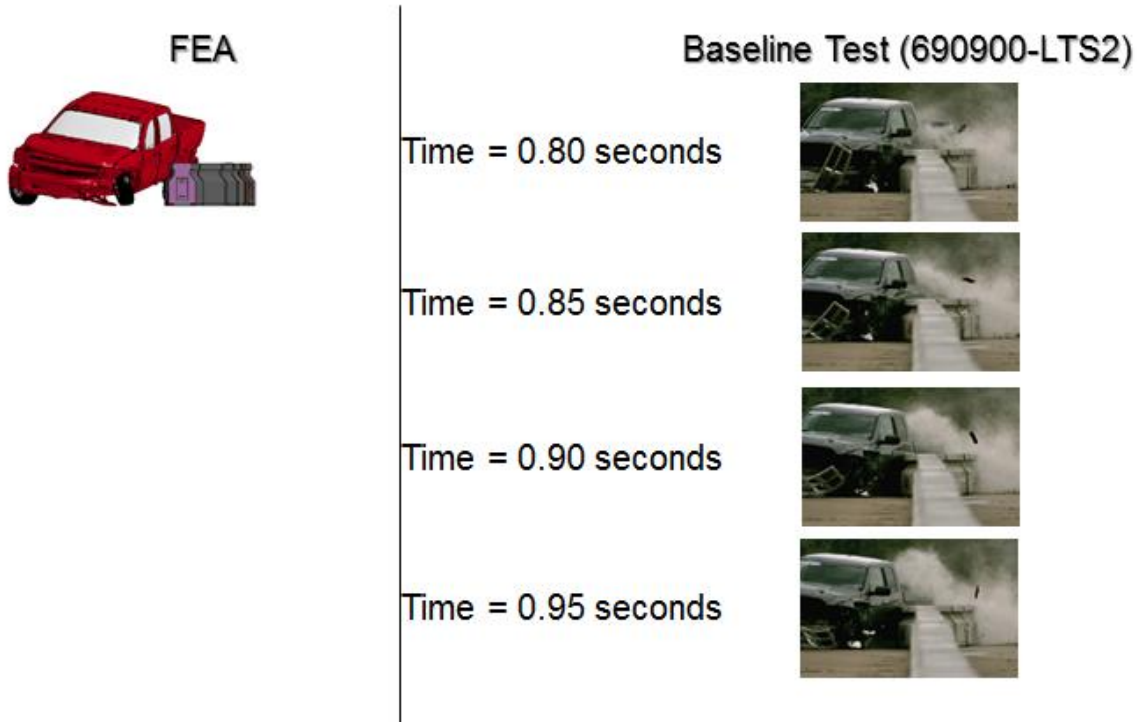


Figure 7. [Continued] Sequential views for FEA and Test 690900-LTS2 under MASH Test 3-11 impact conditions from a downstream viewpoint.

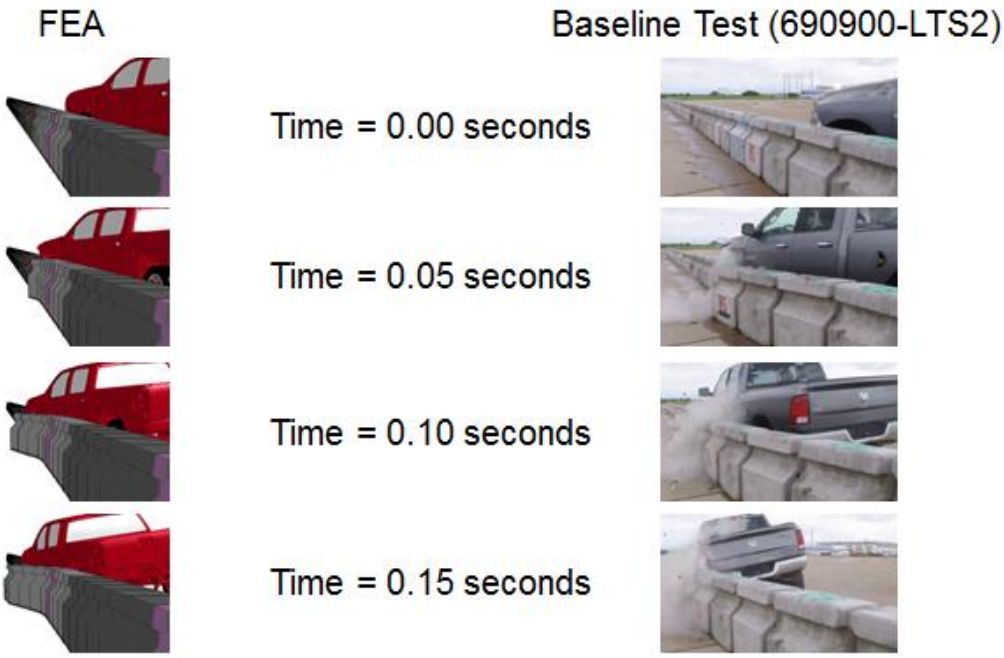


Figure 8. Sequential views for FEA and Test 690900-LTS2 under MASH Test 3-11 impact conditions from a viewpoint behind the rail.

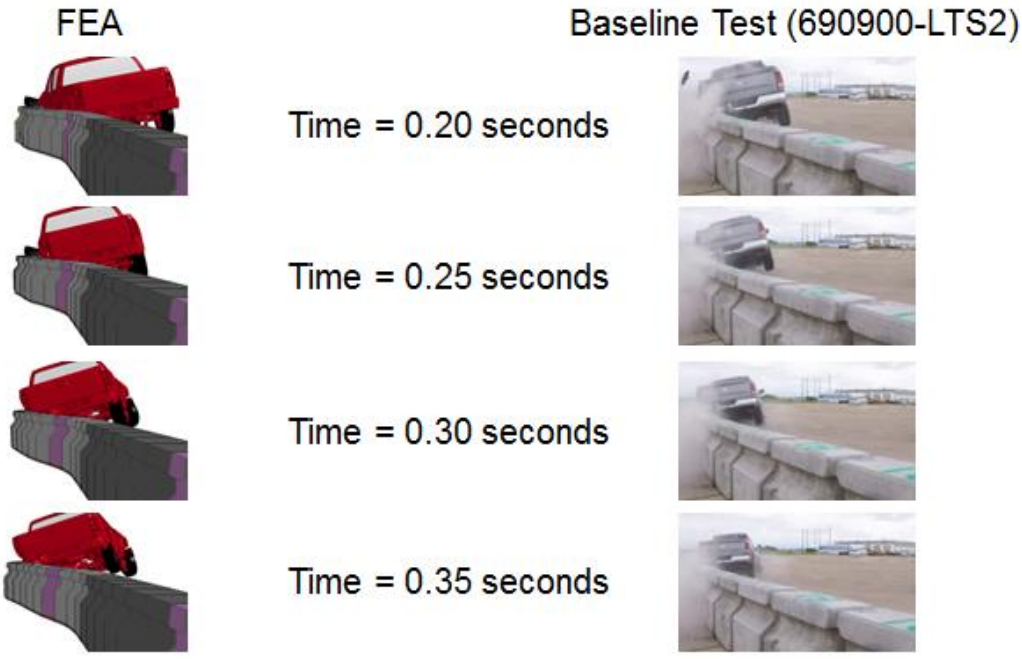


Figure 8. [Continued] Sequential views for FEA and Test 690900-LTS2 under MASH Test 3-11 impact conditions from a viewpoint behind the rail.

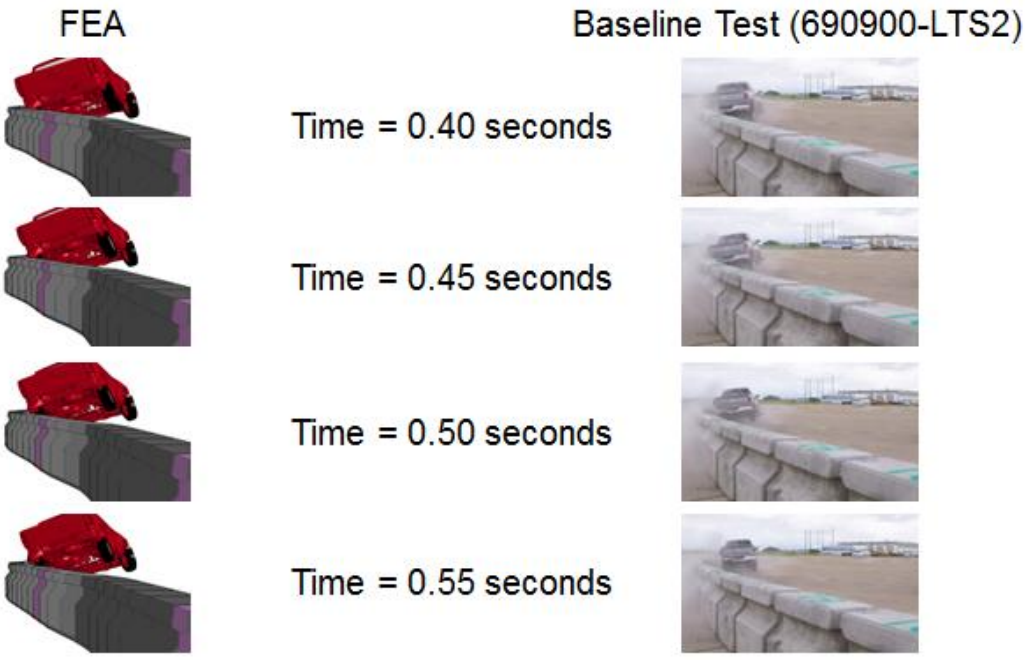


Figure 8. [Continued] Sequential views for FEA and Test 690900-LTS2 under MASH Test 3-11 impact conditions from a viewpoint behind the rail.

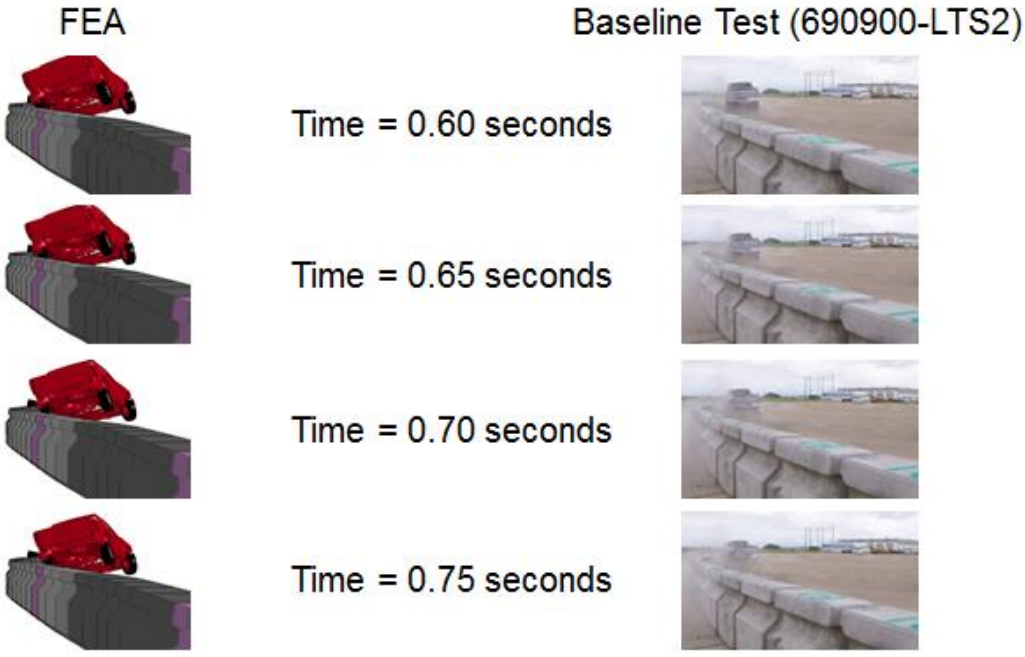


Figure 8. [Continued] Sequential views for FEA and Test 690900-LTS2 under MASH Test 3-11 impact conditions from a viewpoint behind the rail.

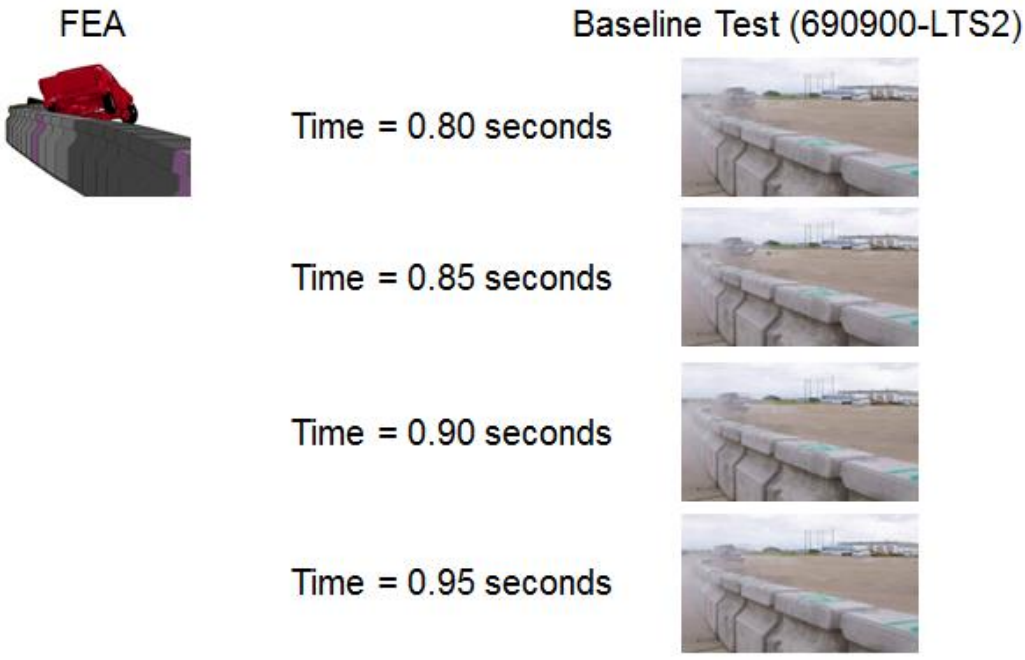


Figure 8. [Continued] Sequential views for FEA and Test 690900-LTS2 under MASH Test 3-11 impact conditions from a viewpoint behind the rail.

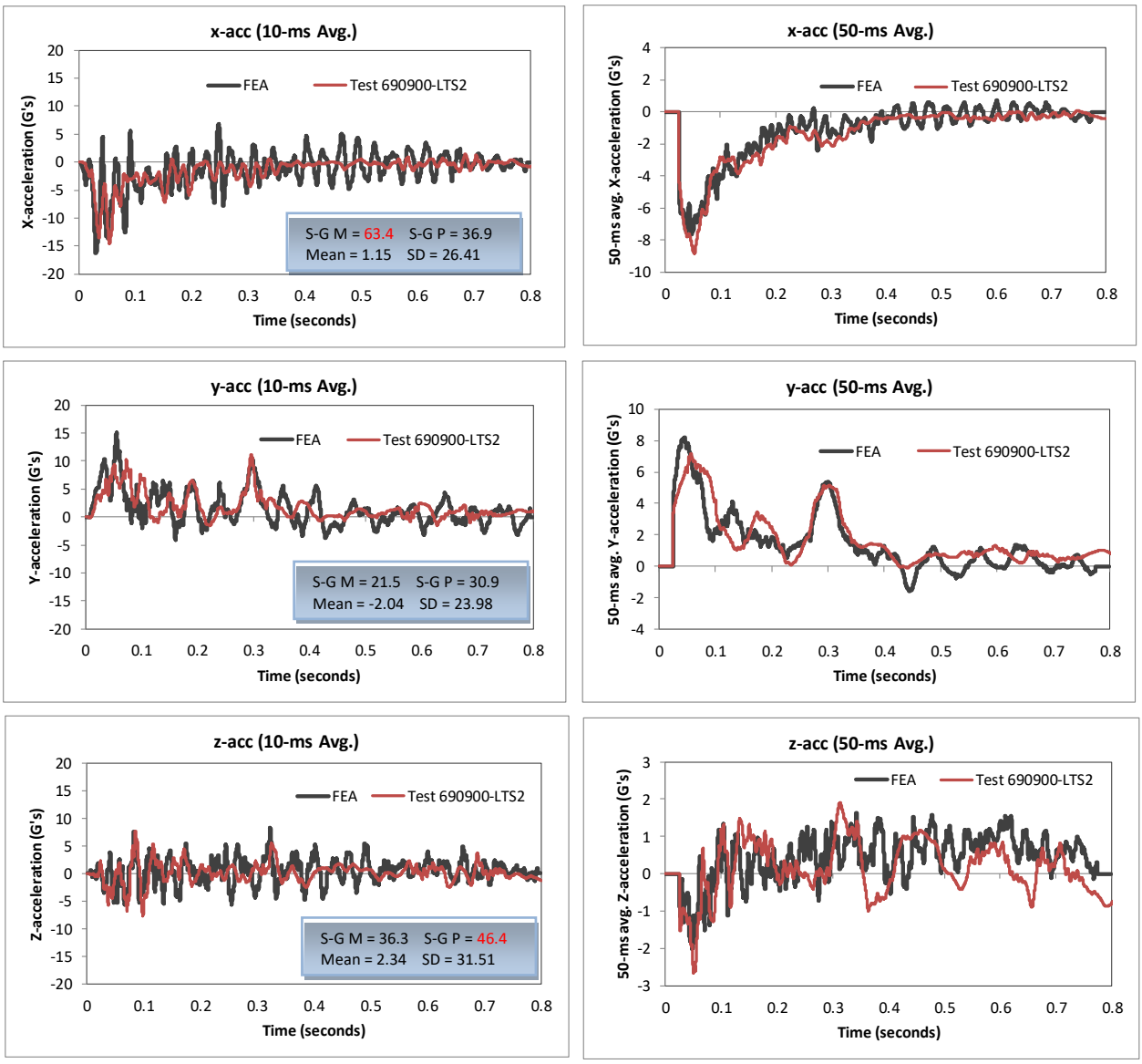


Figure 9. Comparison of acceleration-time histories for the FEA and Test 690900-LTS2 under MASH Test 3-11 impact conditions.

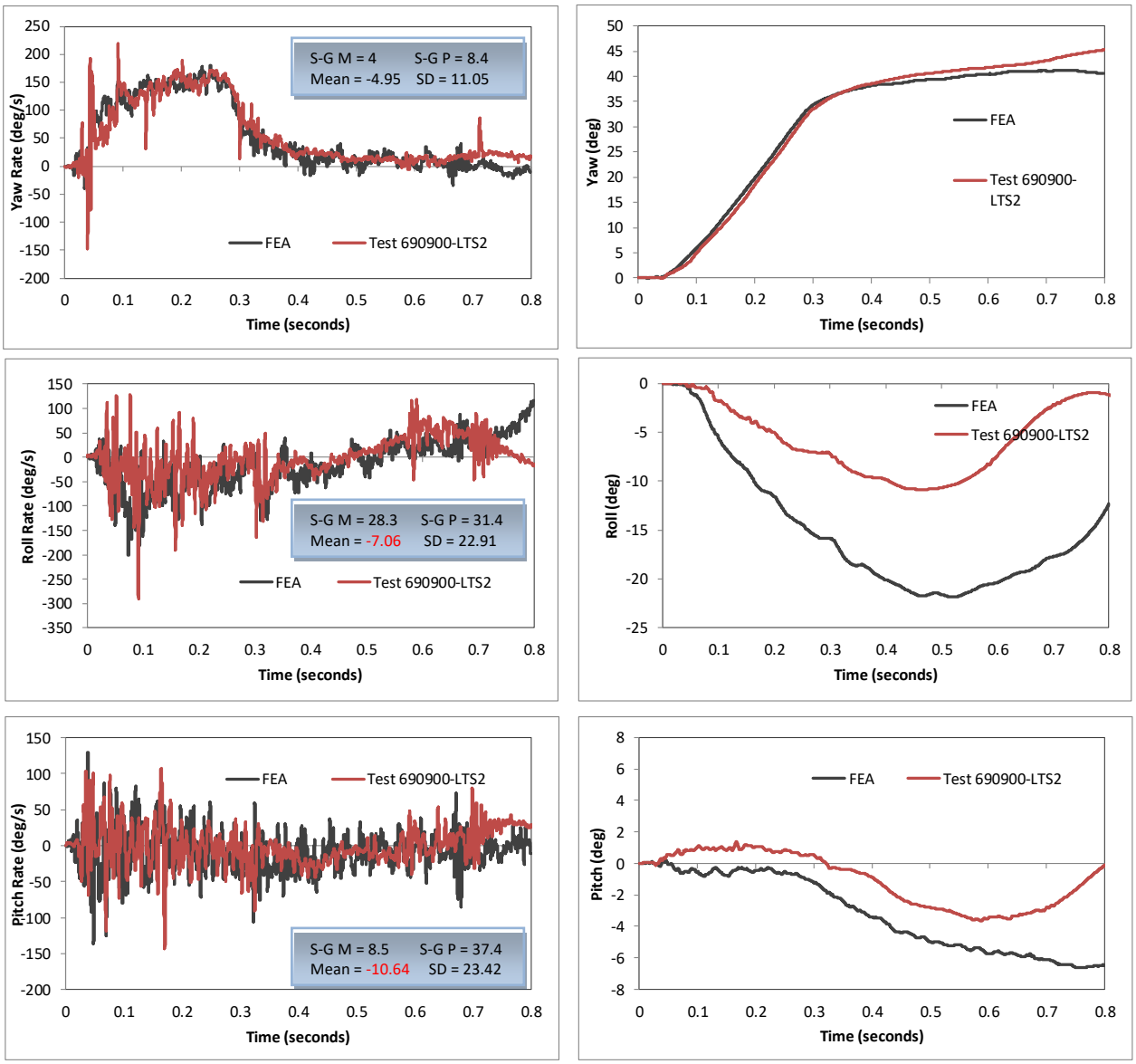


Figure 10. Comparison of angular rate and displacement time histories for the FEA and Test 690900-LTS2 under MASH Test 3-11 impact conditions.

Occupant Risk Factors		MASH Test 4-11			Error		W179 Criteria	
		FEA (0 - 0.8 sec)	Test 690900-LTS2 (0 - 0.8sec)	Test 690900-LTS2 (0 - 2.0 sec)	%	Absolute	Criteria	Pass
Occupant Impact Velocity (m/s)	x-direction	5.4	5.7	5.7	5.3%	0.3	<20% or < 2m/s	Y
	y-direction	-4.8	-5.3	-5.3	9.4%	0.5	<20% or < 2m/s	Y
	at time	at 0.1109 seconds on left side of interior	at 0.1152 seconds on left side of interior	at 0.1152 seconds on left side of interior				
THIV (m/s)		7 at 0.1056 seconds on left side of interior	7.9 at 0.1152 seconds on left side of interior	7.9 at 0.1152 seconds on left side of interior	11.4%	0.9	<20% or < 2m/s	Y
Ridedown Acceleration (g's)	x-direction	-7.8 (0.2509 - 0.2609 seconds)	-7.1 (0.1472 - 0.1572 seconds)	-7.1 (0.1472 - 0.1572 seconds)	9.9%	0.7	<20% or < 4G	Y
	y-direction	10.6 (0.2923 - 0.3023 seconds)	11.1 (0.2908 - 0.3008 seconds)	11.1 (0.2908 - 0.3008 seconds)	4.5%	0.5	<20% or < 4G	Y
PHD (g's)		11.9 (0.2923 - 0.3023 seconds)	11.1 (0.2909 - 0.3009 seconds)	11.1 (0.2909 - 0.3009 seconds)	7.2%	0.8	<20% or < 4G	Y
ASI		1.09 (0.0214 - 0.0714 seconds)	1.1 (0.0279 - 0.0779 seconds)	1.1 (0.0279 - 0.0779 seconds)	0.9%	0.01	<20% or < 0.2	Y
Max 50-ms moving avg. acc. (g's)	x-direction	-7.6 (0.0227 - 0.0727 seconds)	-8.8 (0.0278 - 0.0778 seconds)	-8.8 (0.0278 - 0.0778 seconds)	13.6%	1.2	<20% or < 4G	Y
	y-direction	8.2 (0.0199 - 0.0699 seconds)	7.2 (0.0313 - 0.0813 seconds)	7.2 (0.0313 - 0.0813 seconds)	13.9%	1	<20% or < 4G	Y
	z-direction	-2 (0.0233 - 0.0733 seconds)	-2.7 (0.0254 - 0.0754 seconds)	-2.7 (0.0254 - 0.0754 seconds)	25.9%	0.7	<20% or < 4G	Y
Maximum Angular Disp. (deg)	Roll	-21.9 (0.5216 seconds)	-10.9 (0.4692 seconds)	-10.9 (0.4692 seconds)	100.9%	11		
	Pitch	-6.7 (0.7664 seconds)	-3.6 (0.5877 seconds)	5.5 (1.9999 seconds)	86.1%	3.1		
	Yaw	41.2 (0.7350 seconds)	45.3 (0.7999 seconds)	46.2 (0.9078 seconds)	9.1%	4.1		

APPENDIX D

Sequential Views for Case 1 from FEA for Leading-End Impact Cases on the CRTS Barrier

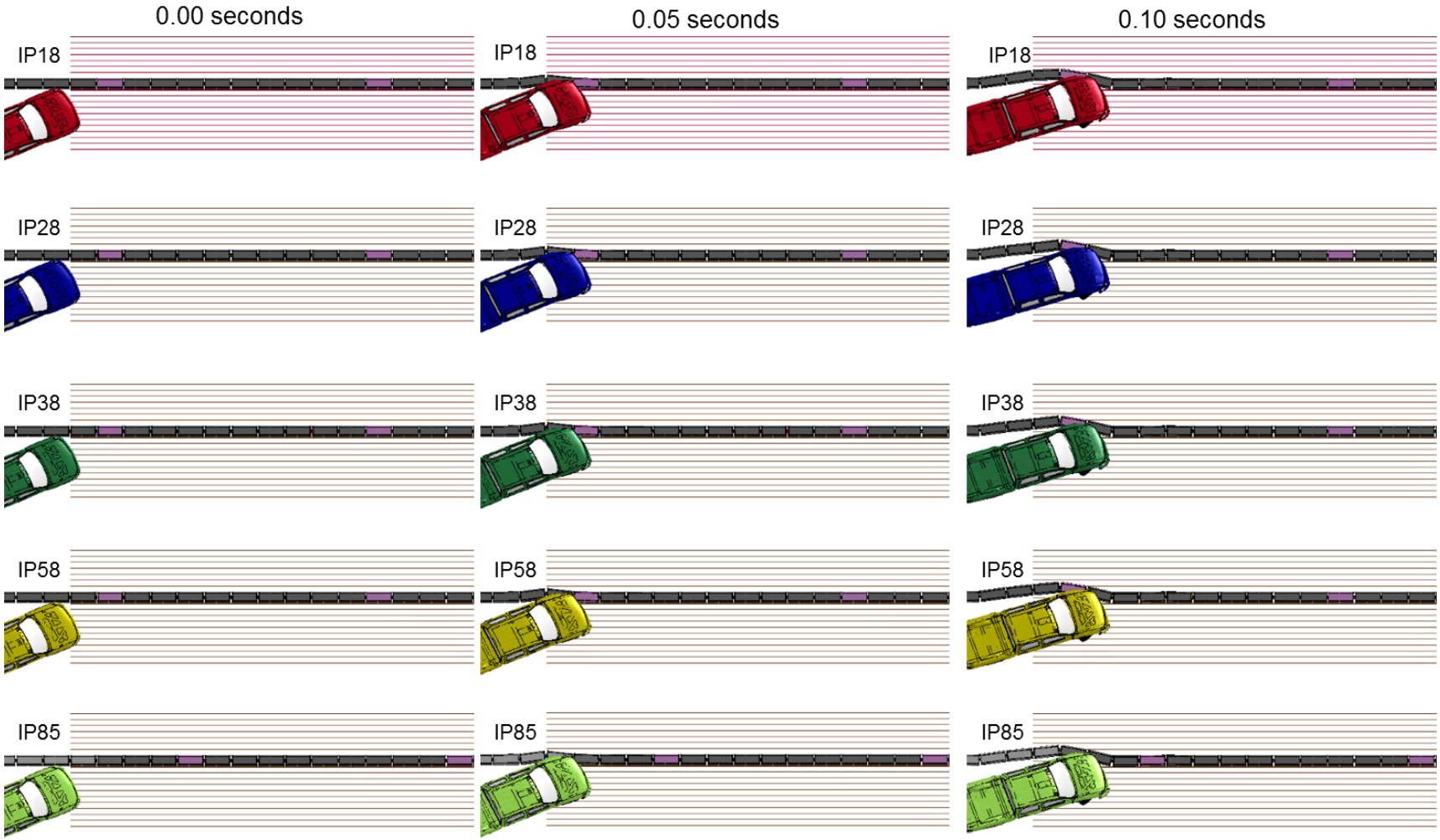


Figure D-1. Sequential views from an overhead viewpoint for IP18 through IP85.

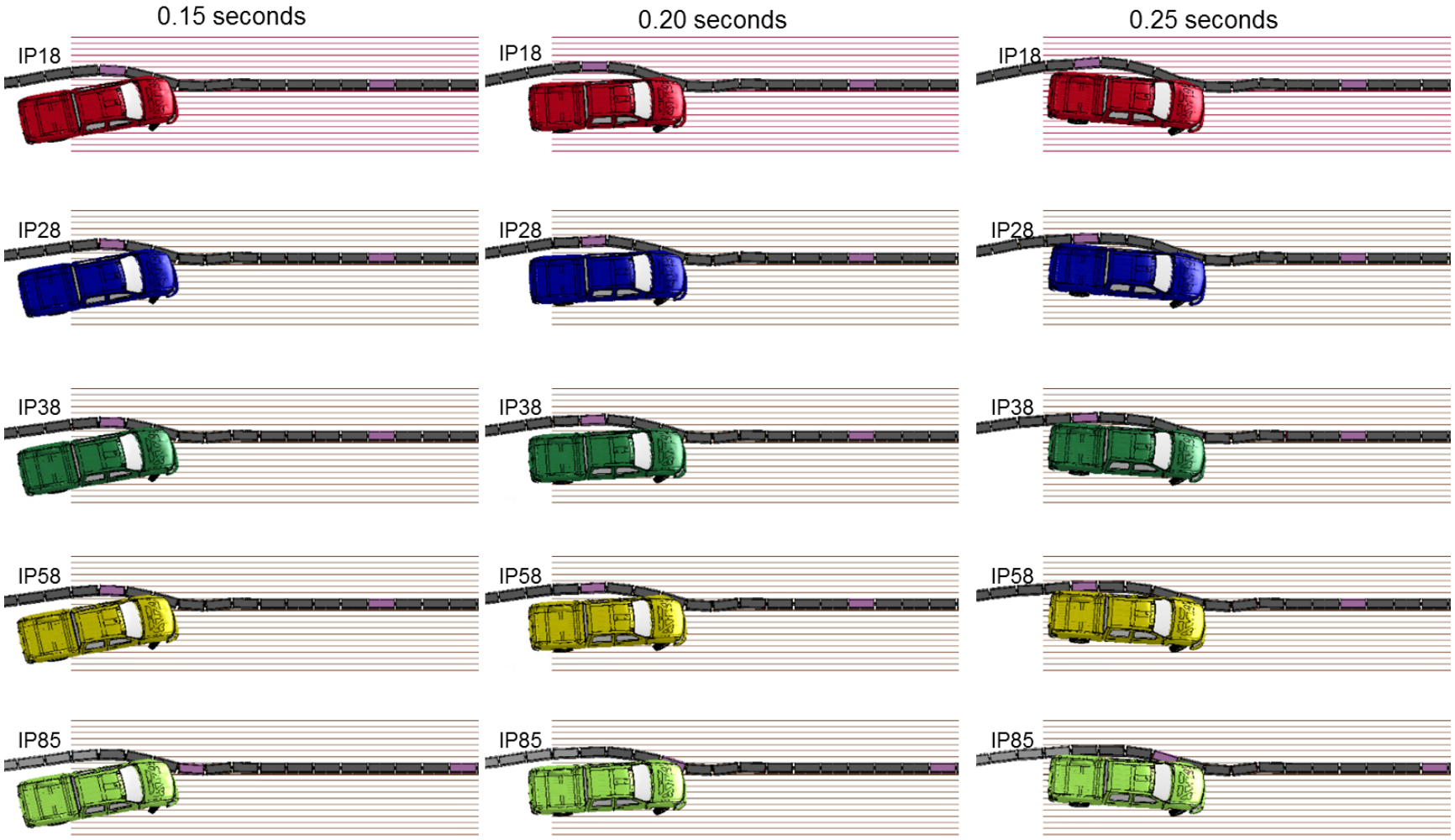


Figure D-1. [CONTINUED] **Sequential views from an overhead viewpoint for IP18 through IP85.**

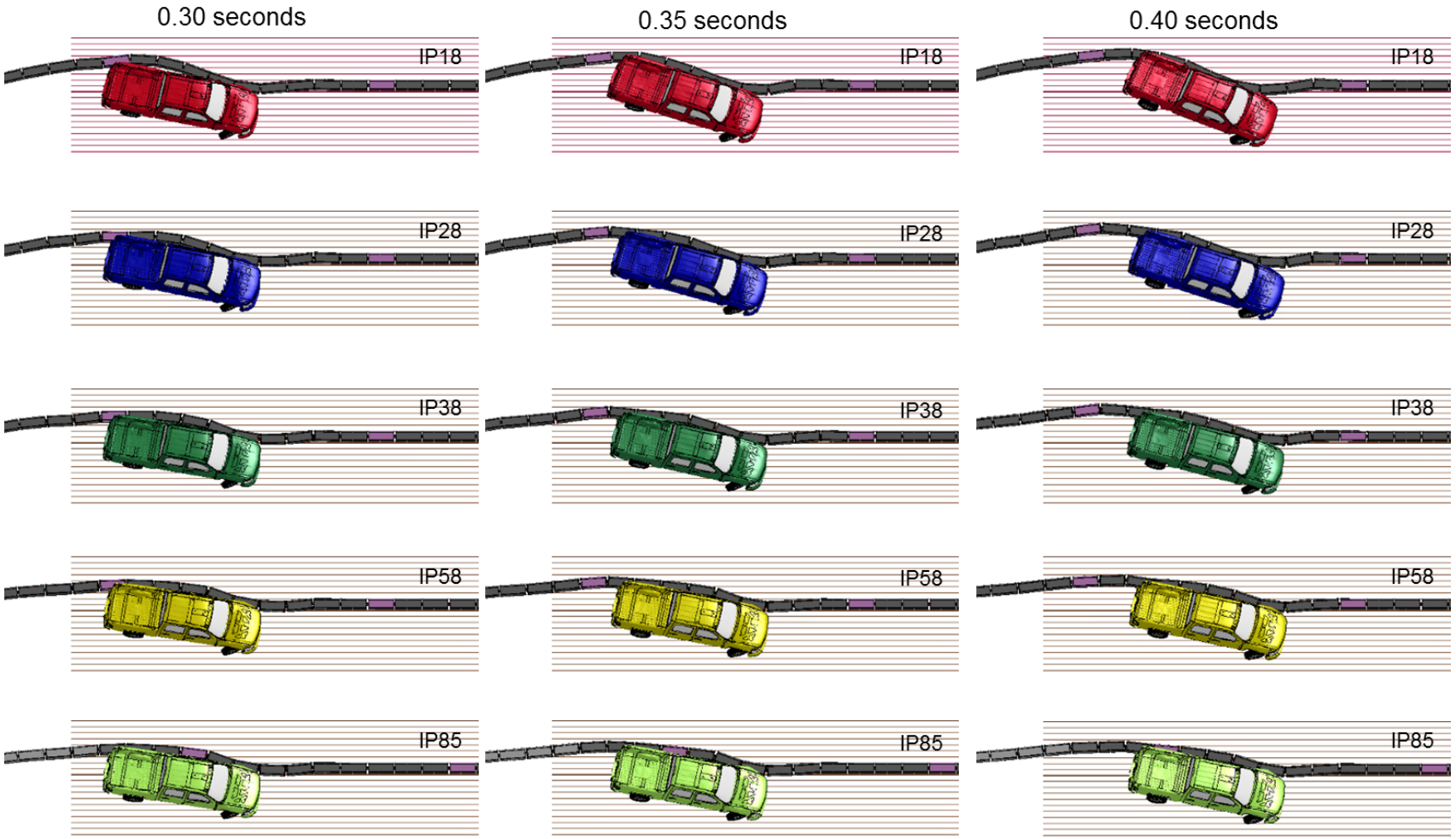


Figure D-1. [CONTINUED] **Sequential views from an overhead viewpoint for IP18 through IP85.**

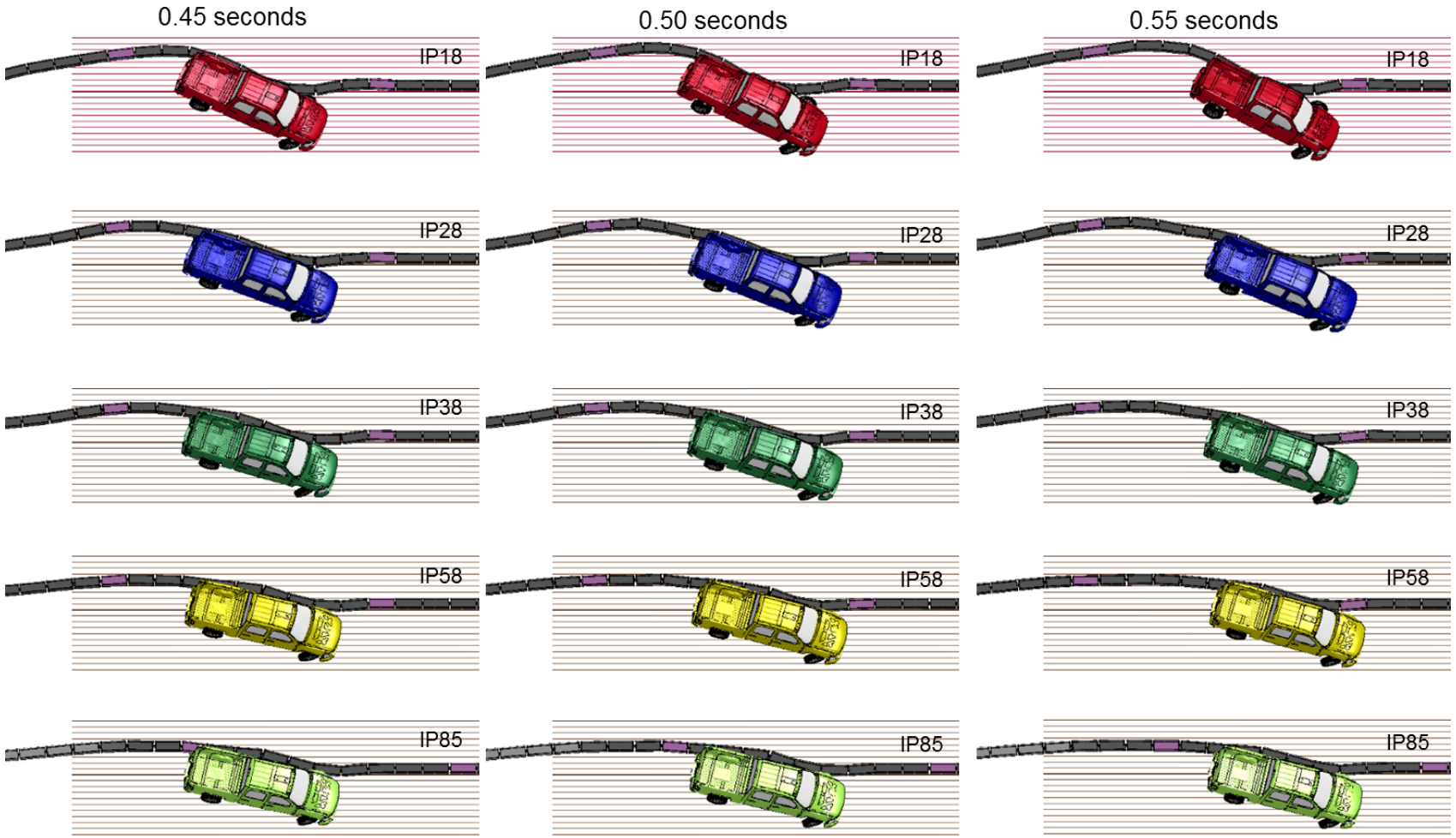


Figure D-1. [CONTINUED] **Sequential views from an overhead viewpoint for IP18 through IP85.**

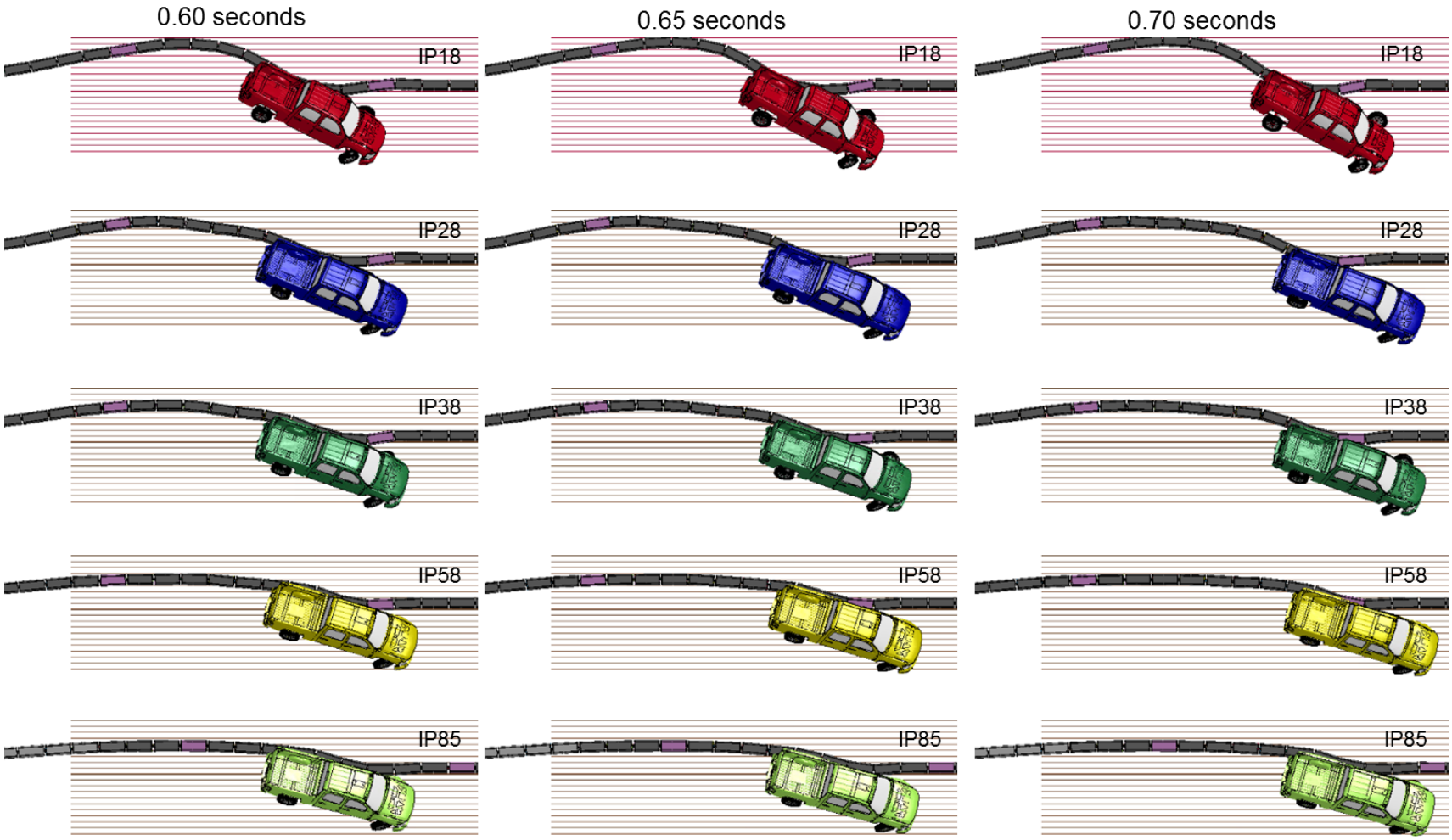


Figure D-1. [CONTINUED] **Sequential views from an overhead viewpoint for IP18 through IP85.**

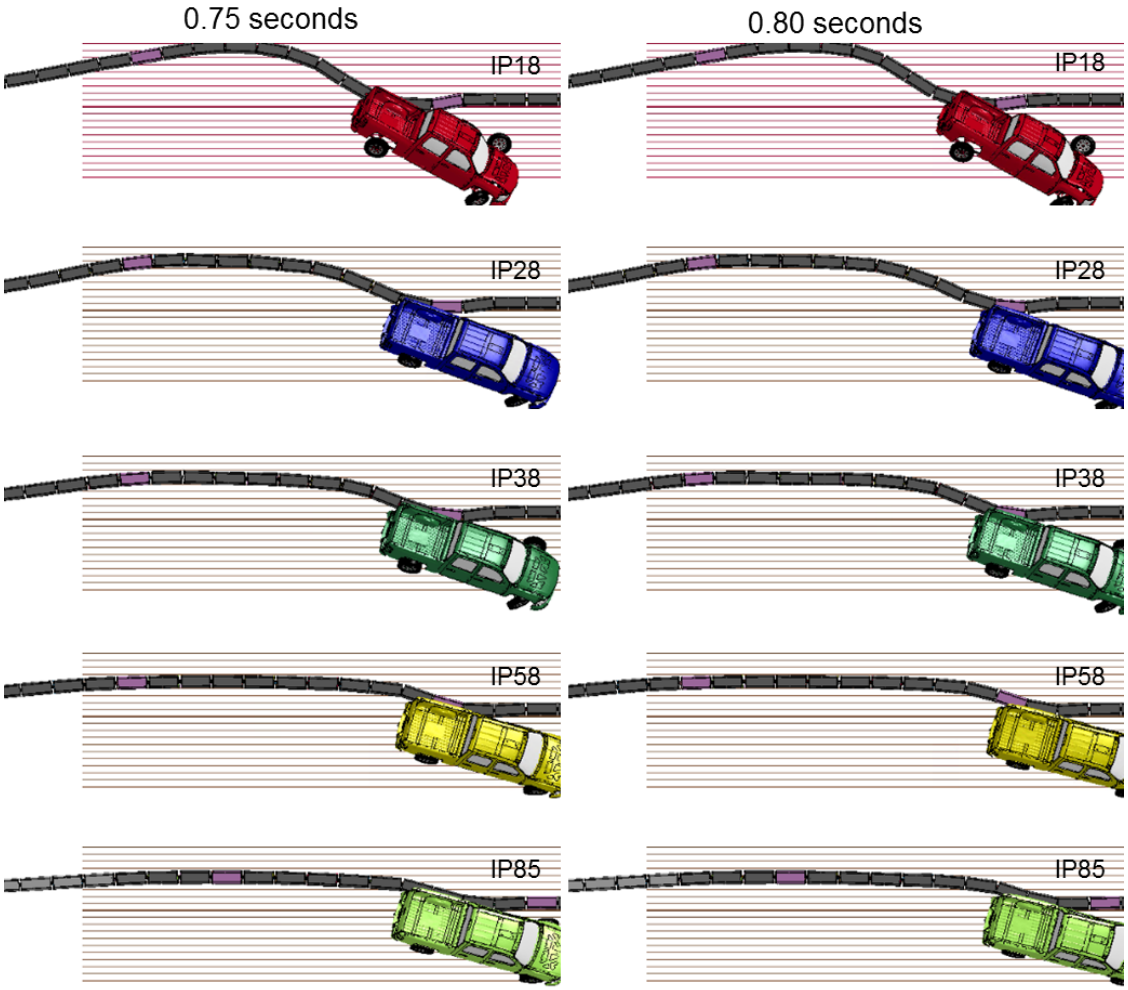


Figure D-1. [CONTINUED] **Sequential views from an overhead viewpoint for IP18 through IP85.**

Figure D-2. Sequential views from a downstream viewpoint for IP18 through IP85.

Figure D-2. [CONTINUED] Sequential views from a downstream viewpoint for IP18 through IP85.

Figure D-2. [CONTINUED] Sequential views from a downstream viewpoint for IP18 through IP85.

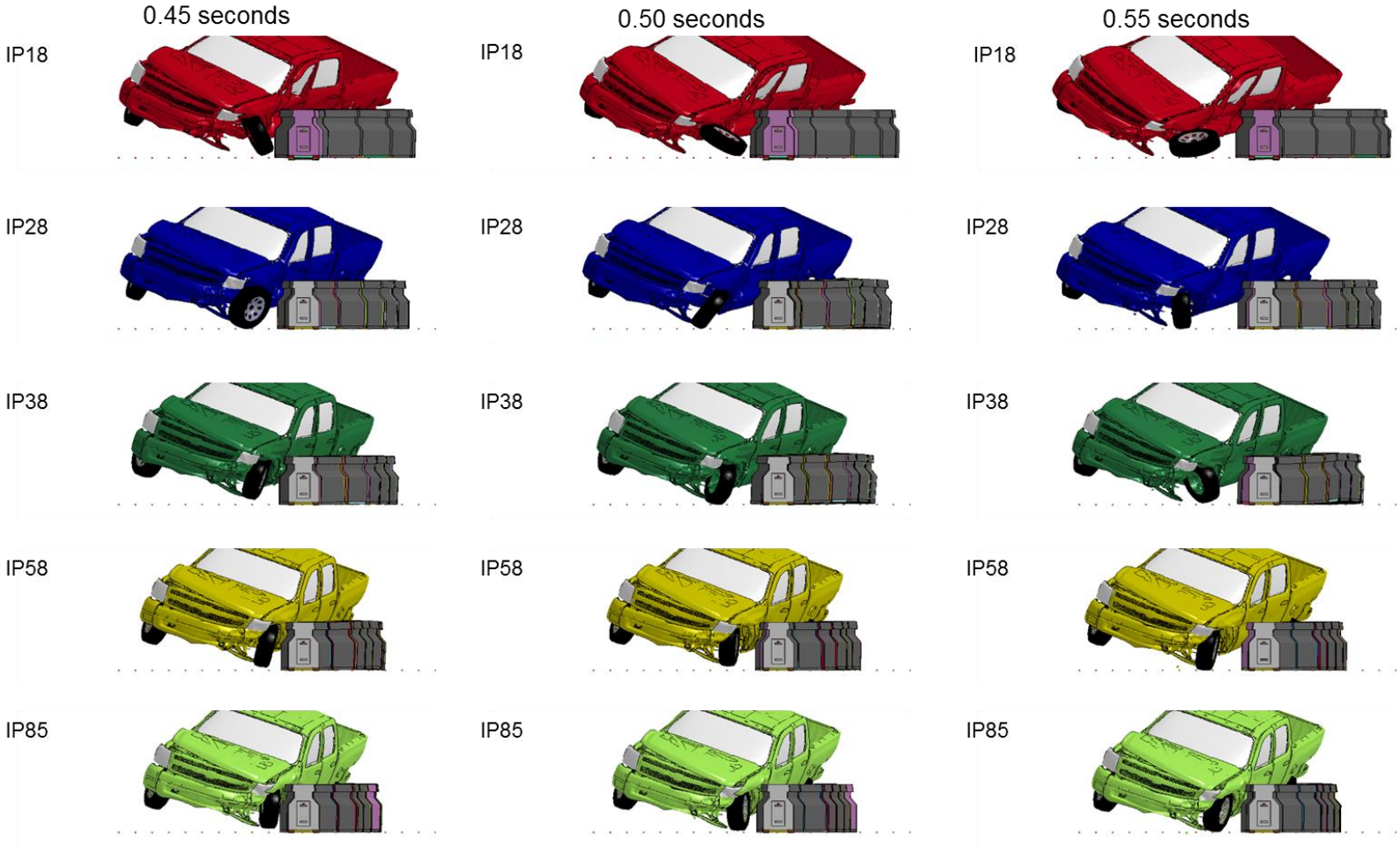


Figure D-2. [CONTINUED] Sequential views from a downstream viewpoint for IP18 through IP85.

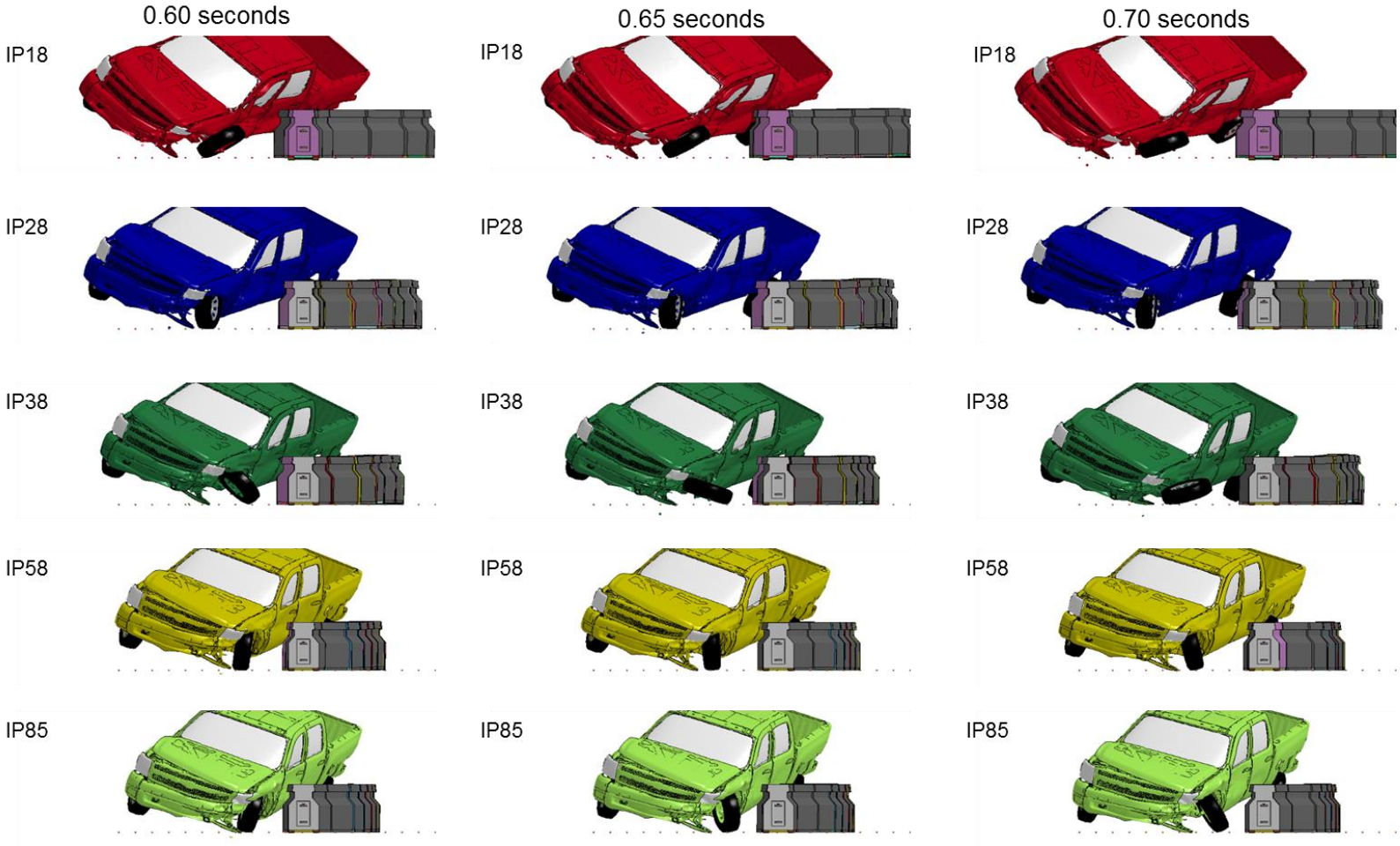


Figure D-2. [CONTINUED] Sequential views from a downstream viewpoint for IP18 through IP85.

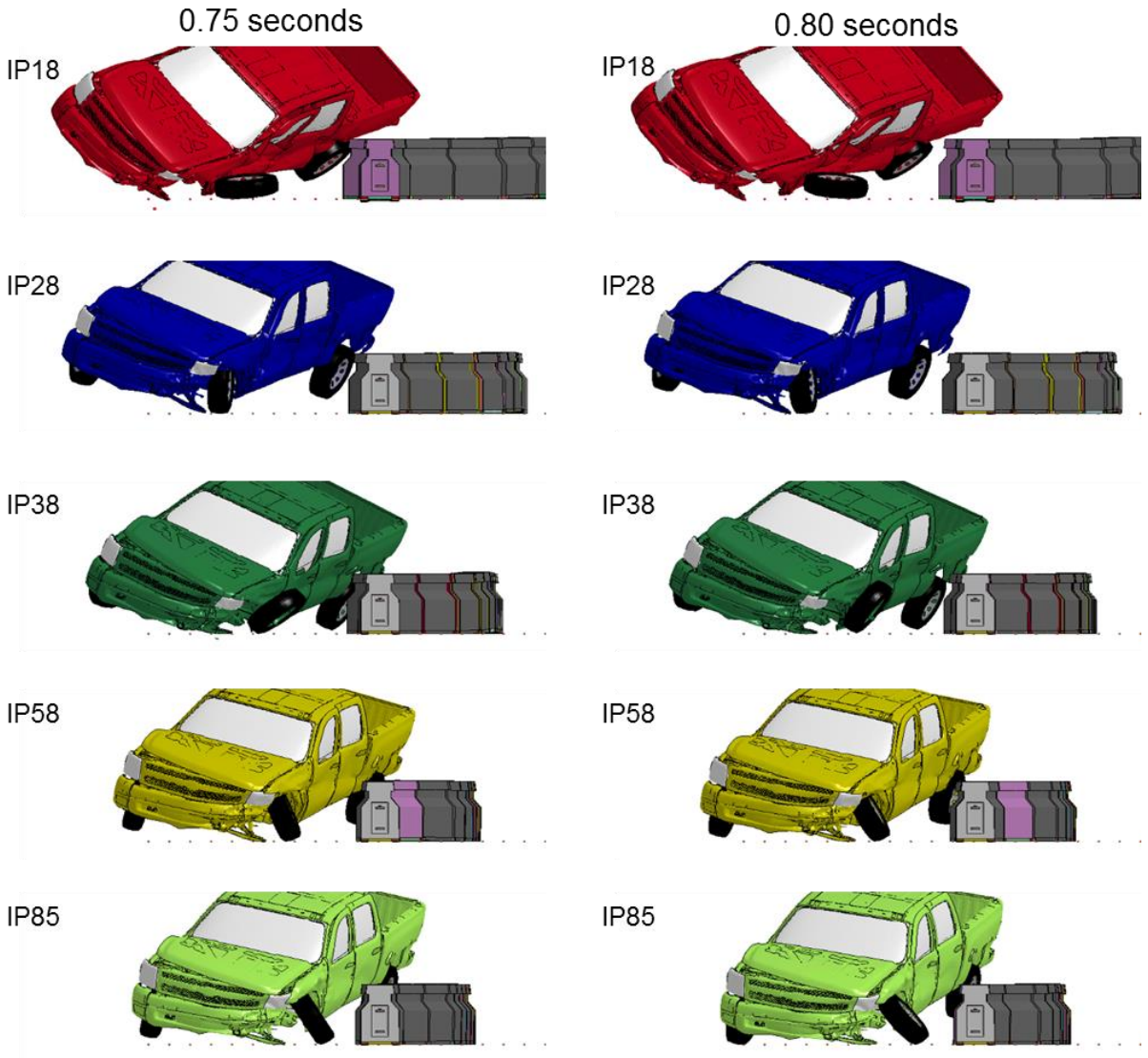


Figure D-2. [CONTINUED] Sequential views from a downstream viewpoint for IP18 through IP85.

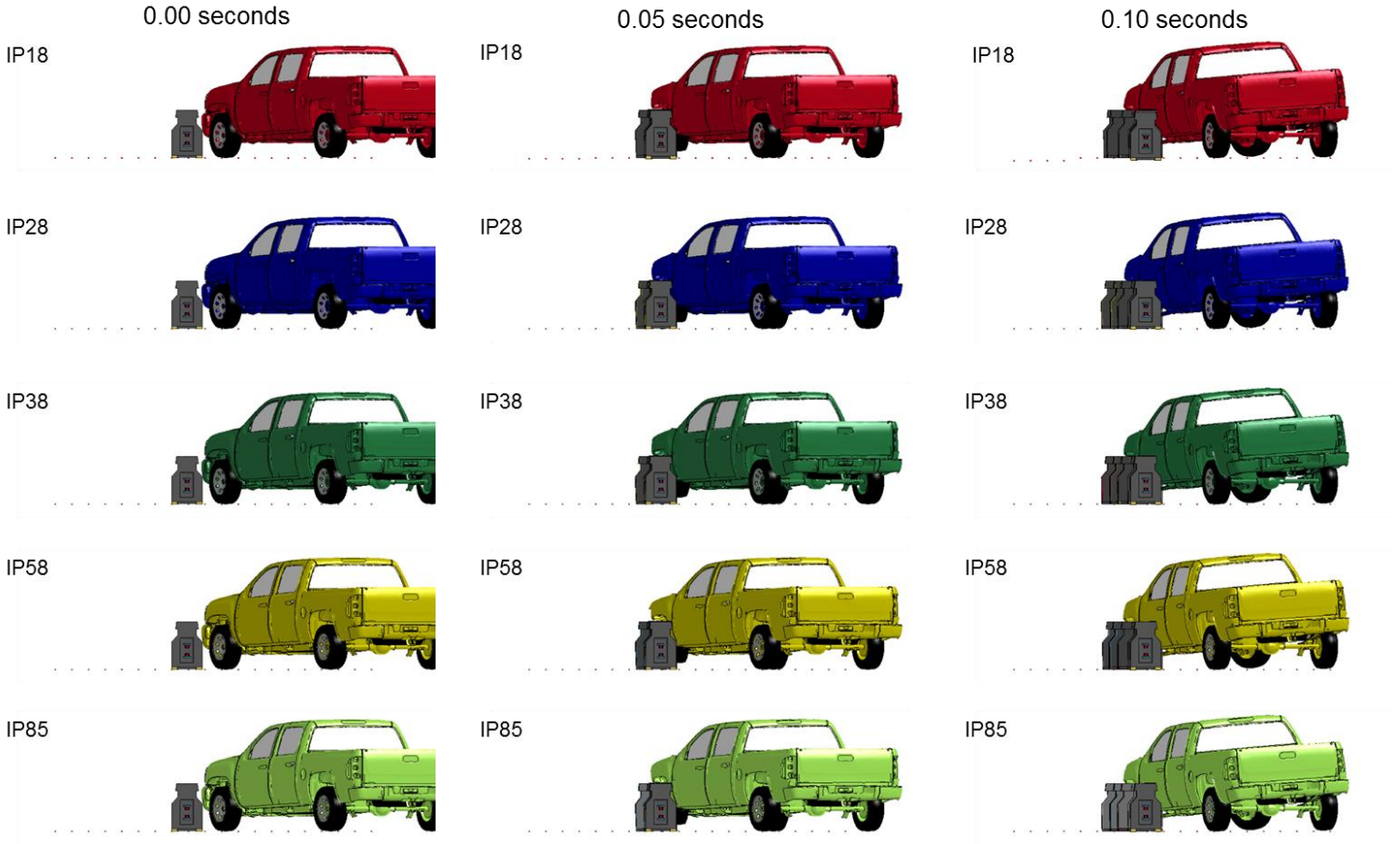


Figure D-3. Sequential views from an upstream viewpoint for IP18 through IP85.

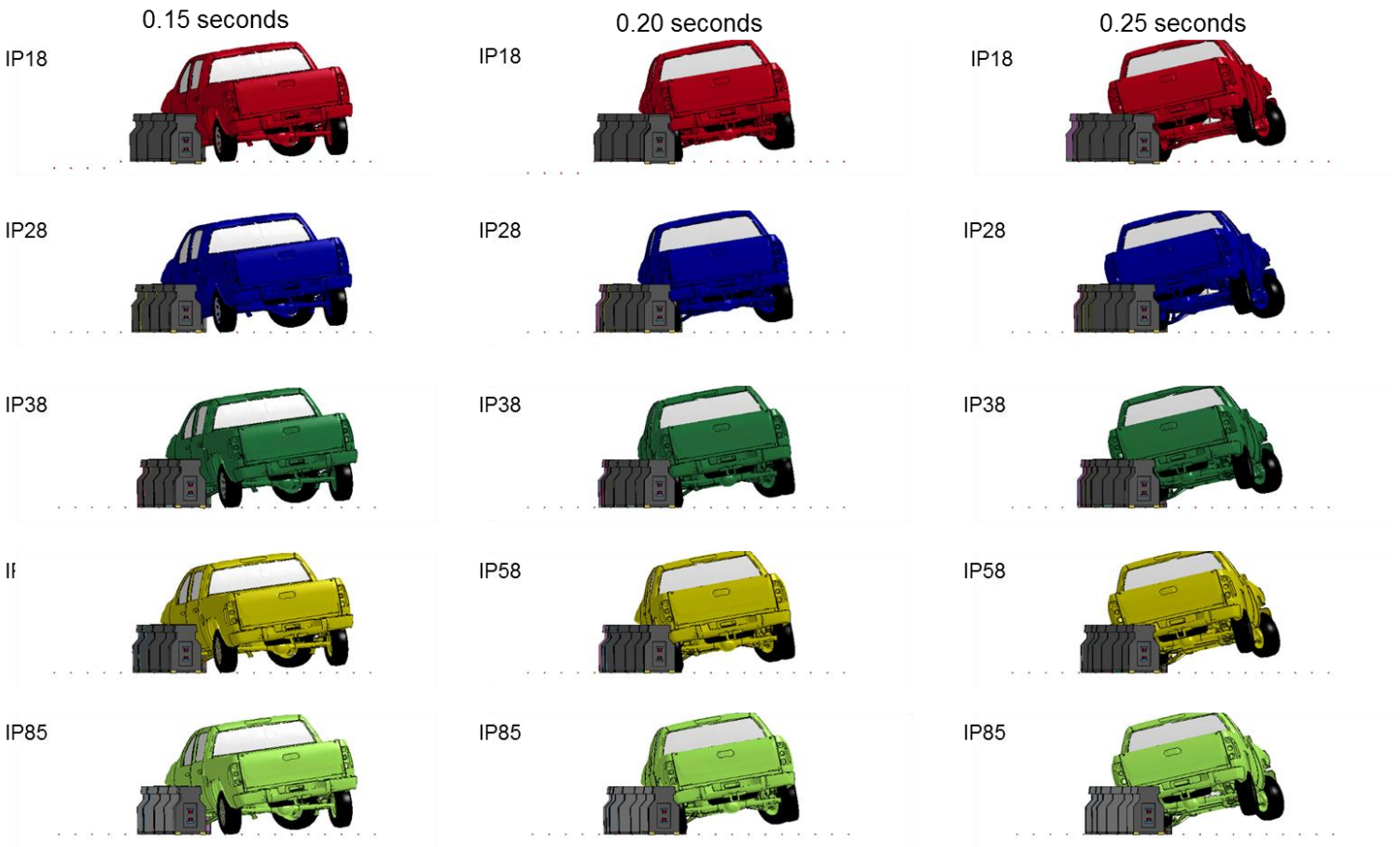


Figure D-3. [CONTINUED] Sequential views from an upstream viewpoint for IP18 through IP85.

Figure D-3. [CONTINUED] Sequential views from an upstream viewpoint for IP18 through IP85.

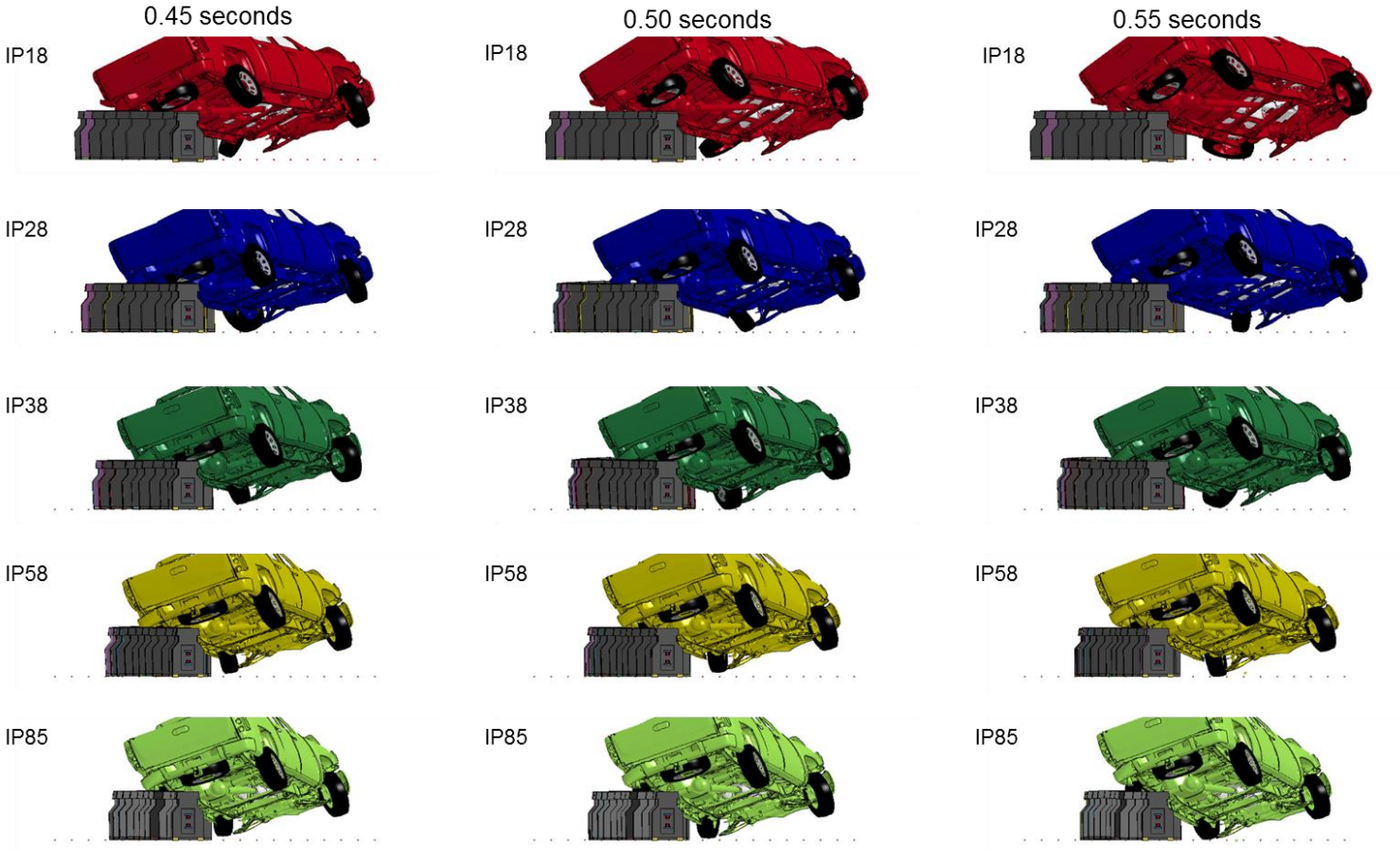


Figure D-3. [CONTINUED] Sequential views from an upstream viewpoint for IP18 through IP85.

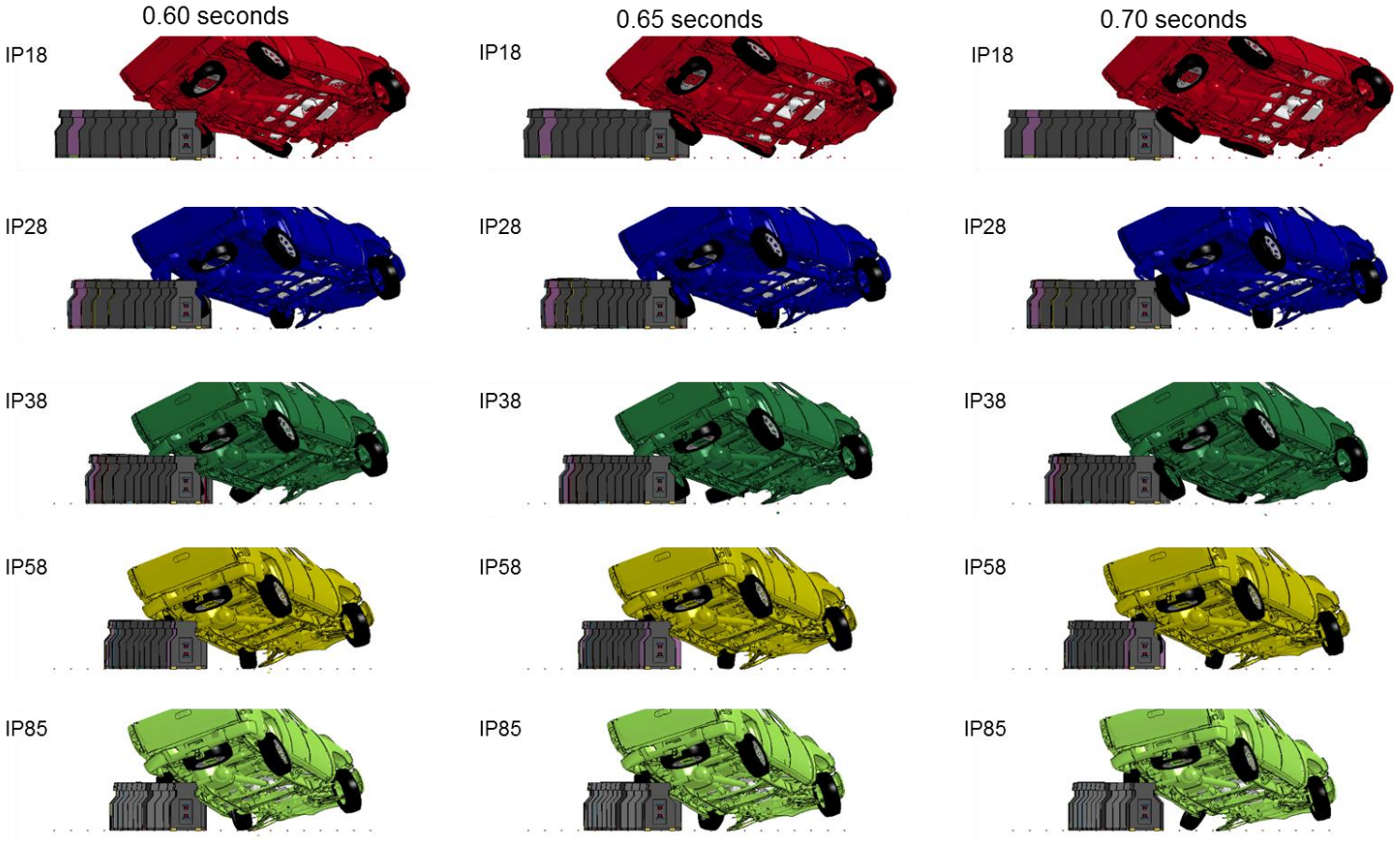


Figure D-3. [CONTINUED] Sequential views from an upstream viewpoint for IP18 through IP85.

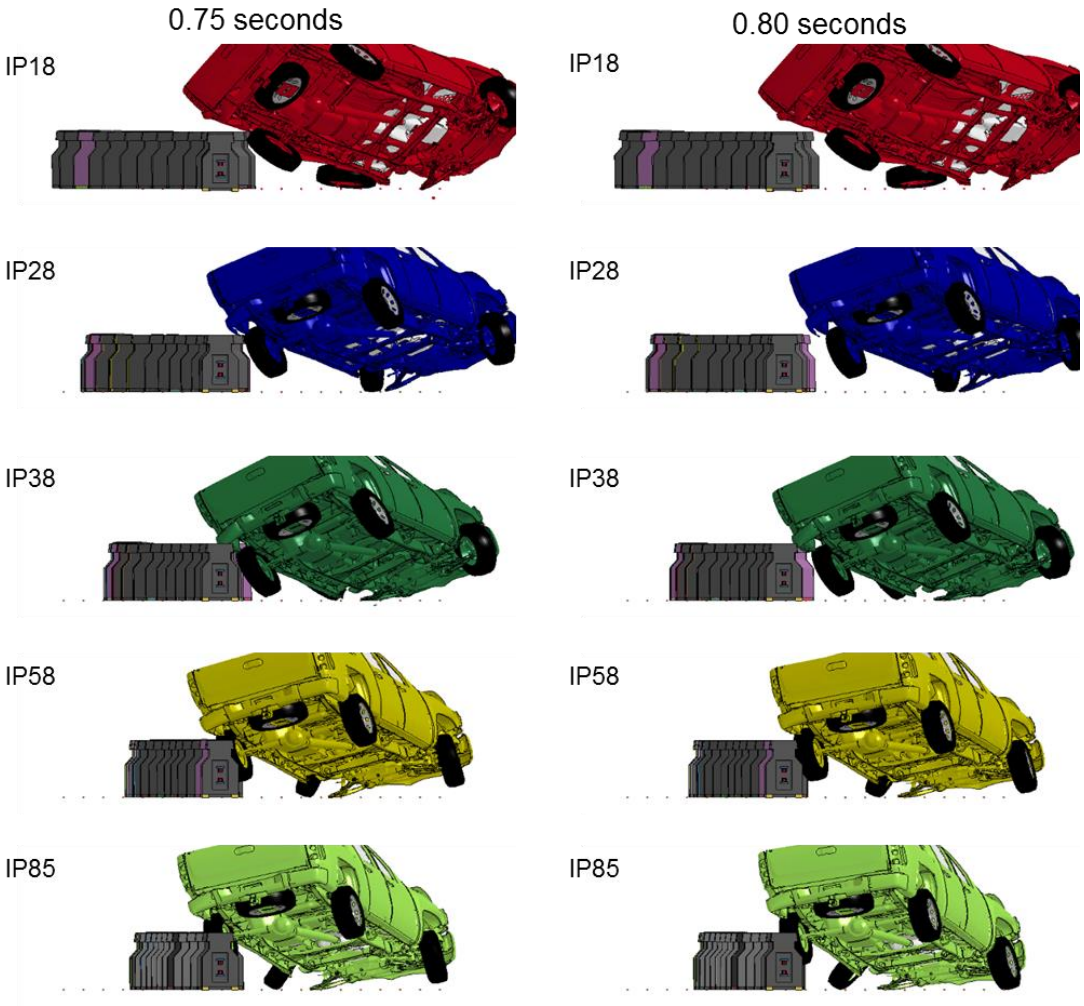


Figure D-3. [CONTINUED] Sequential views from an upstream viewpoint for IP18 through IP85.

APPENDIX E

Sequential Views for Case 1 from FEA for Trailing-End Impact Cases on the CRTS Barrier

Figure E-1. Sequential views from an overhead viewpoint for IP85 through IP159_T12.

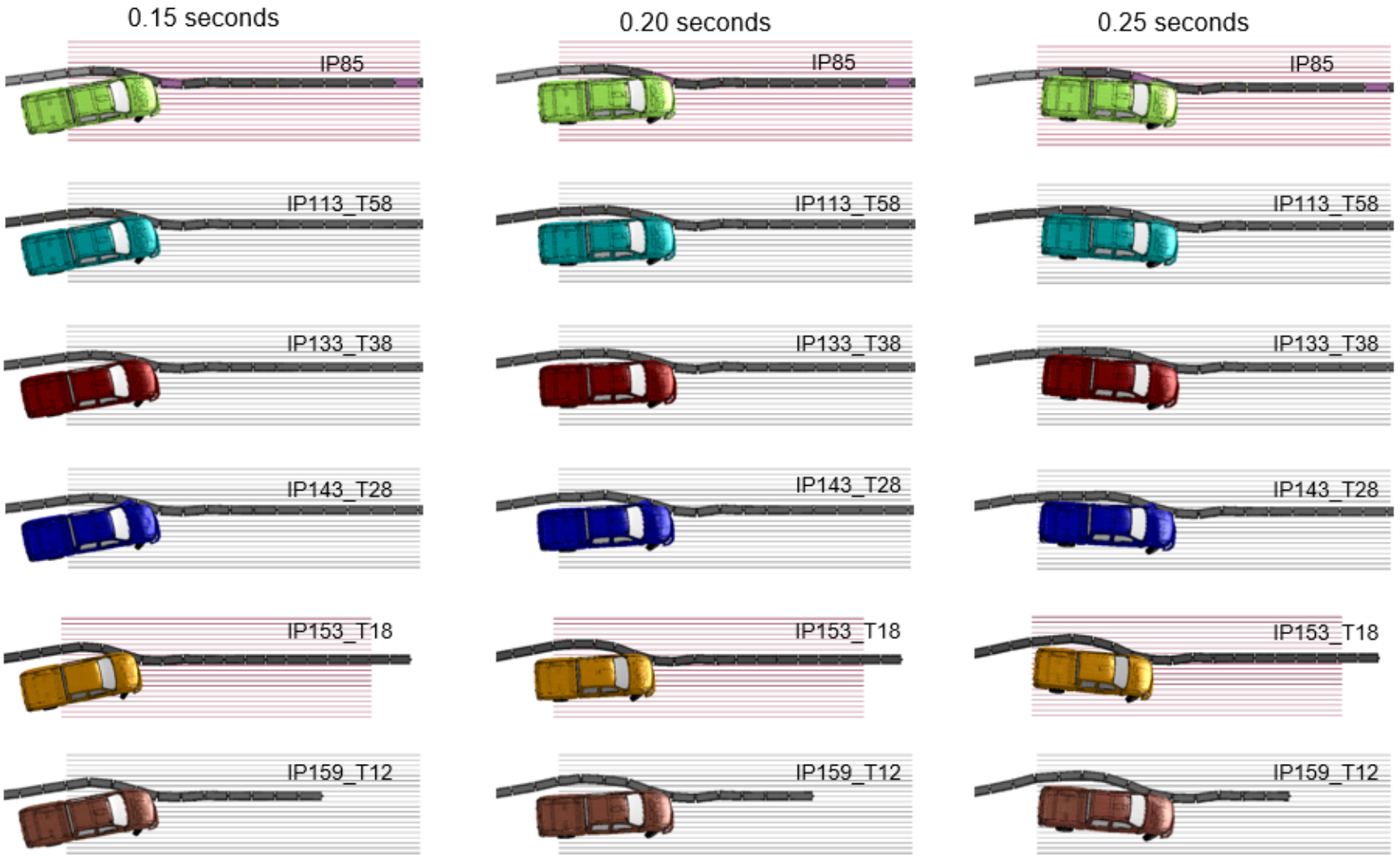


Figure E-1. [CONTINUED] Sequential views from an overhead viewpoint for IP85 through IP159_T12.

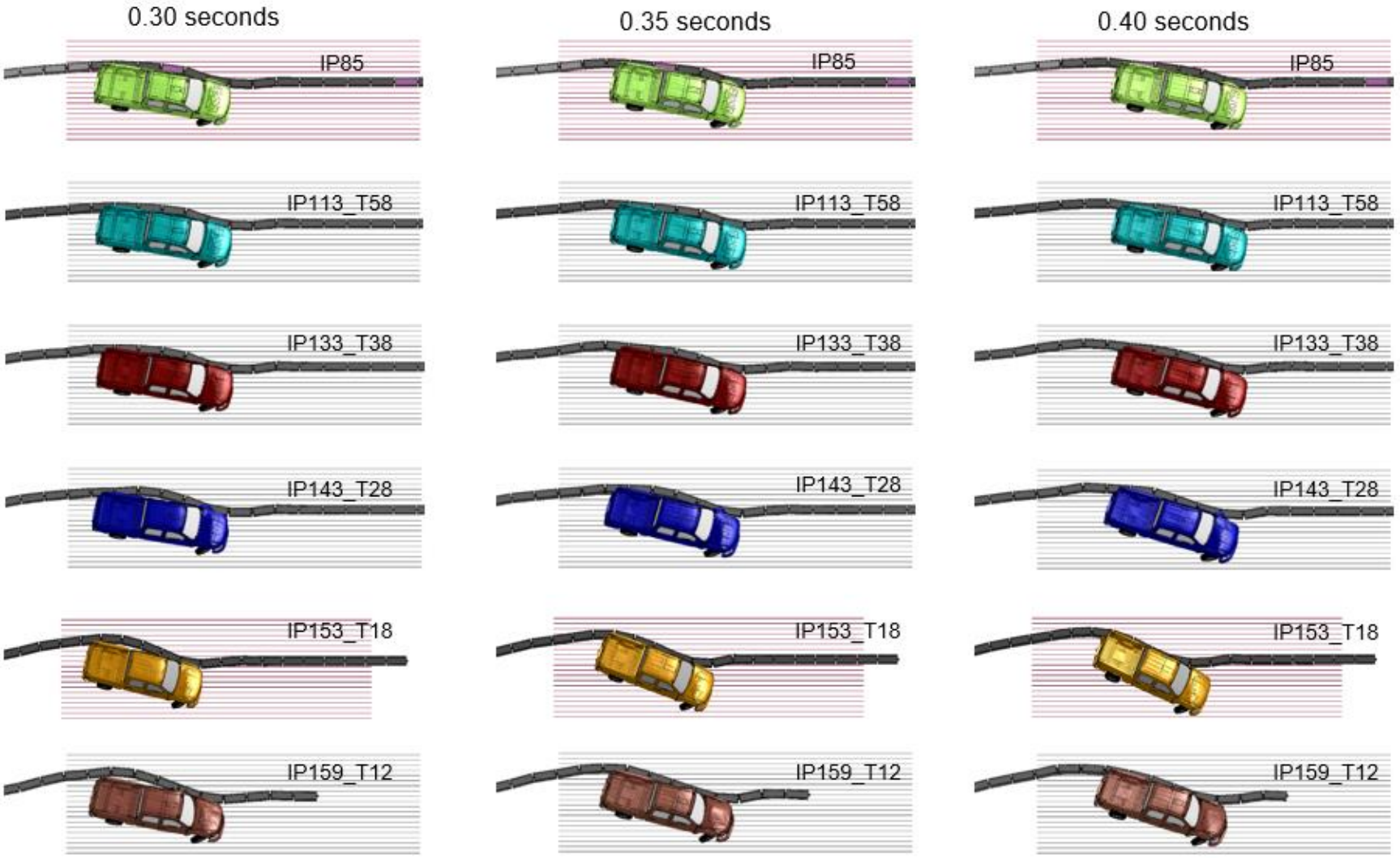


Figure E-1. [CONTINUED] Sequential views from an overhead viewpoint for IP85 through IP159_T12.

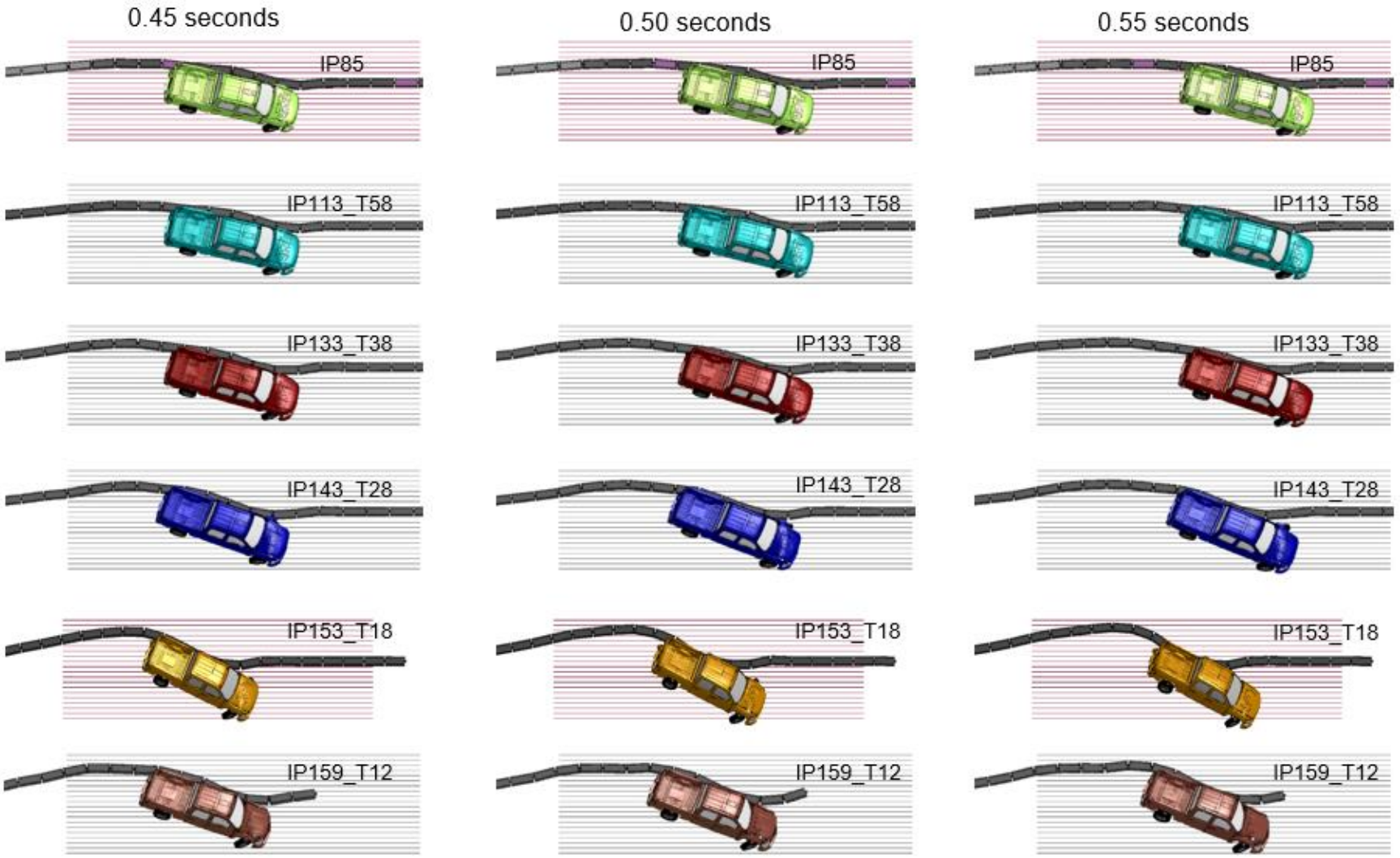


Figure E-1. [CONTINUED] Sequential views from an overhead viewpoint for IP85 through IP159_T12.

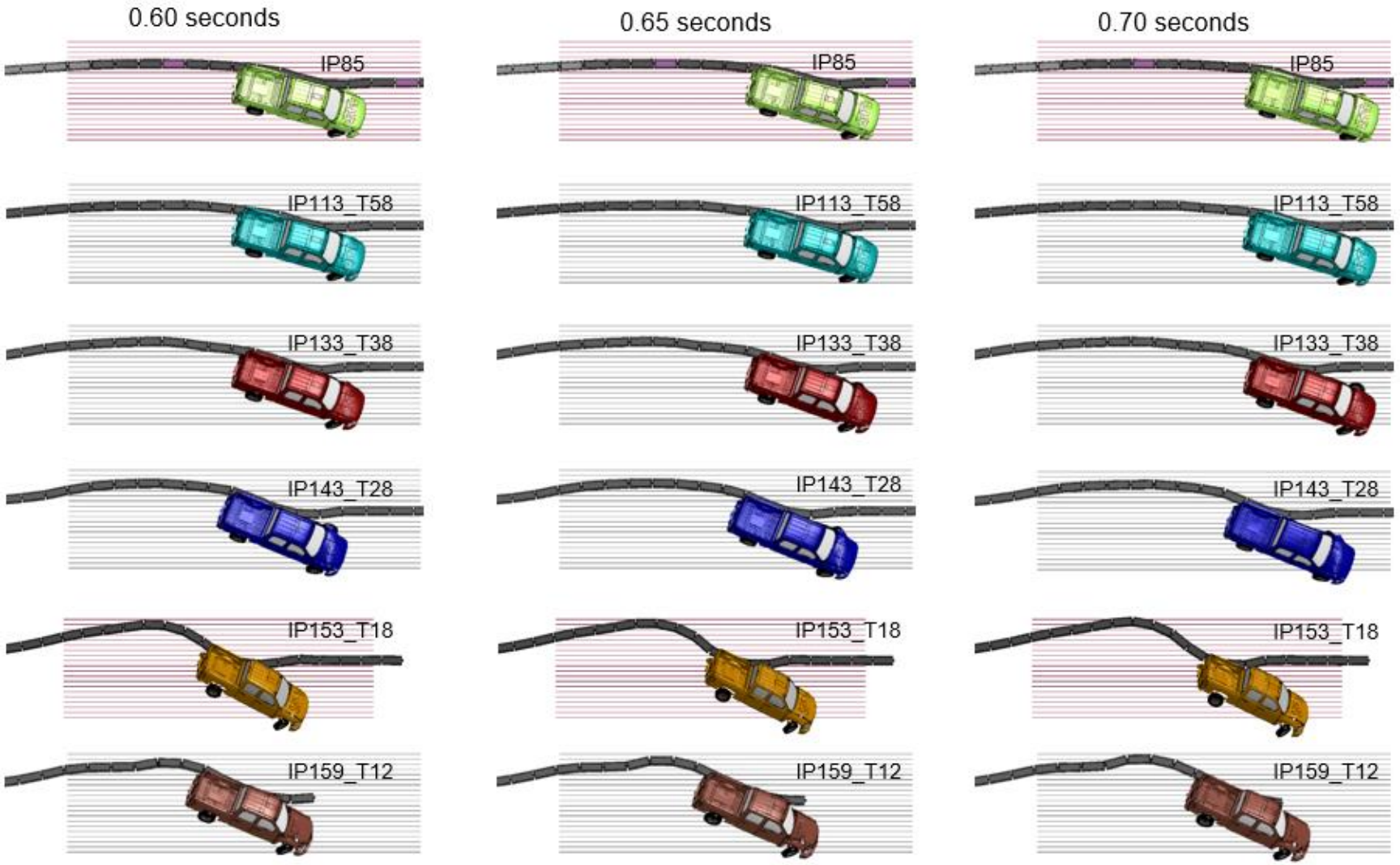


Figure E-1. [CONTINUED] Sequential views from an overhead viewpoint for IP85 through IP159_T12.

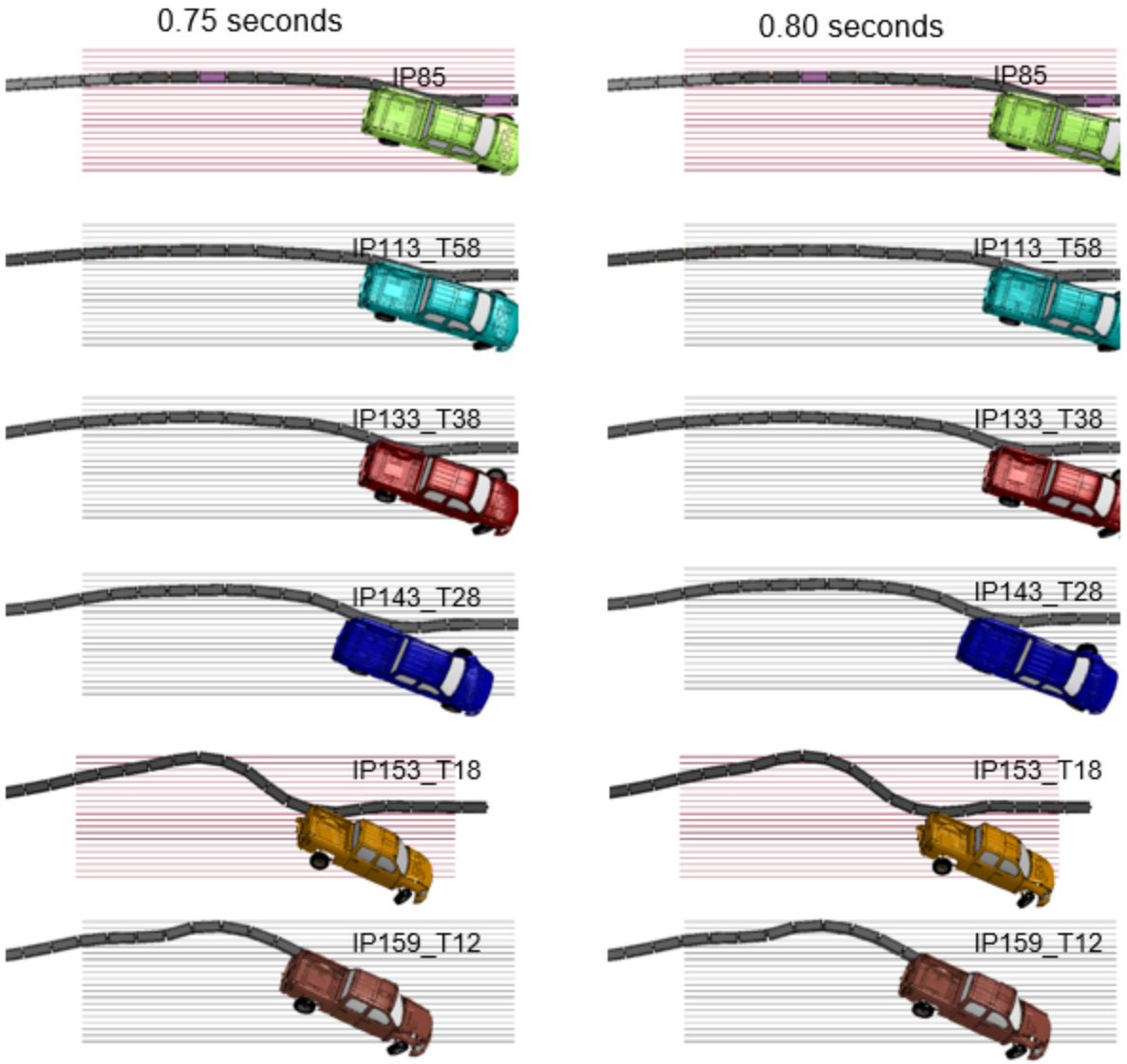


Figure E-1. [CONTINUED] Sequential views from an overhead viewpoint for IP85 through IP159_T12.

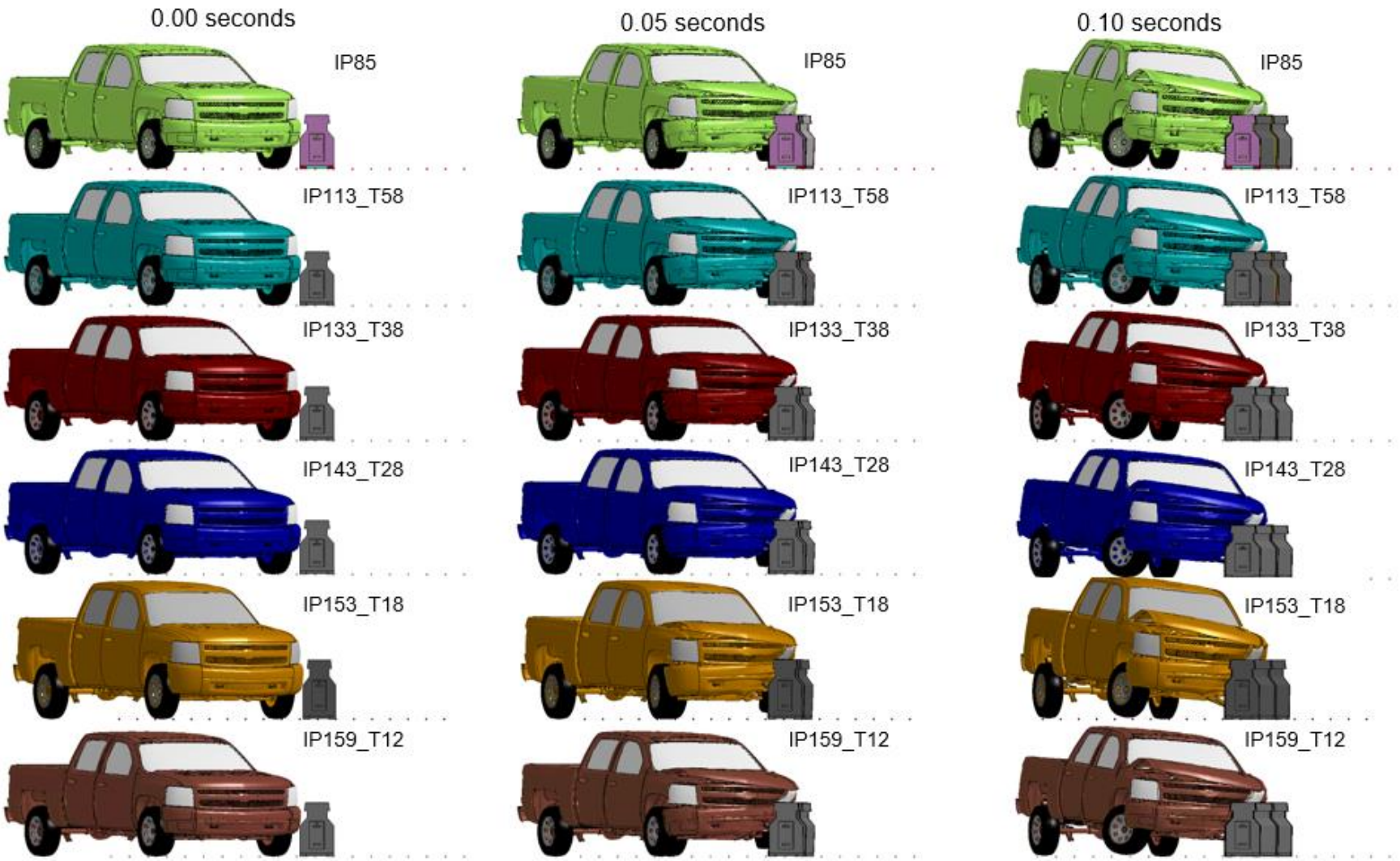


Figure E-2. Sequential views from a downstream viewpoint for IP85 through IP159_T12.

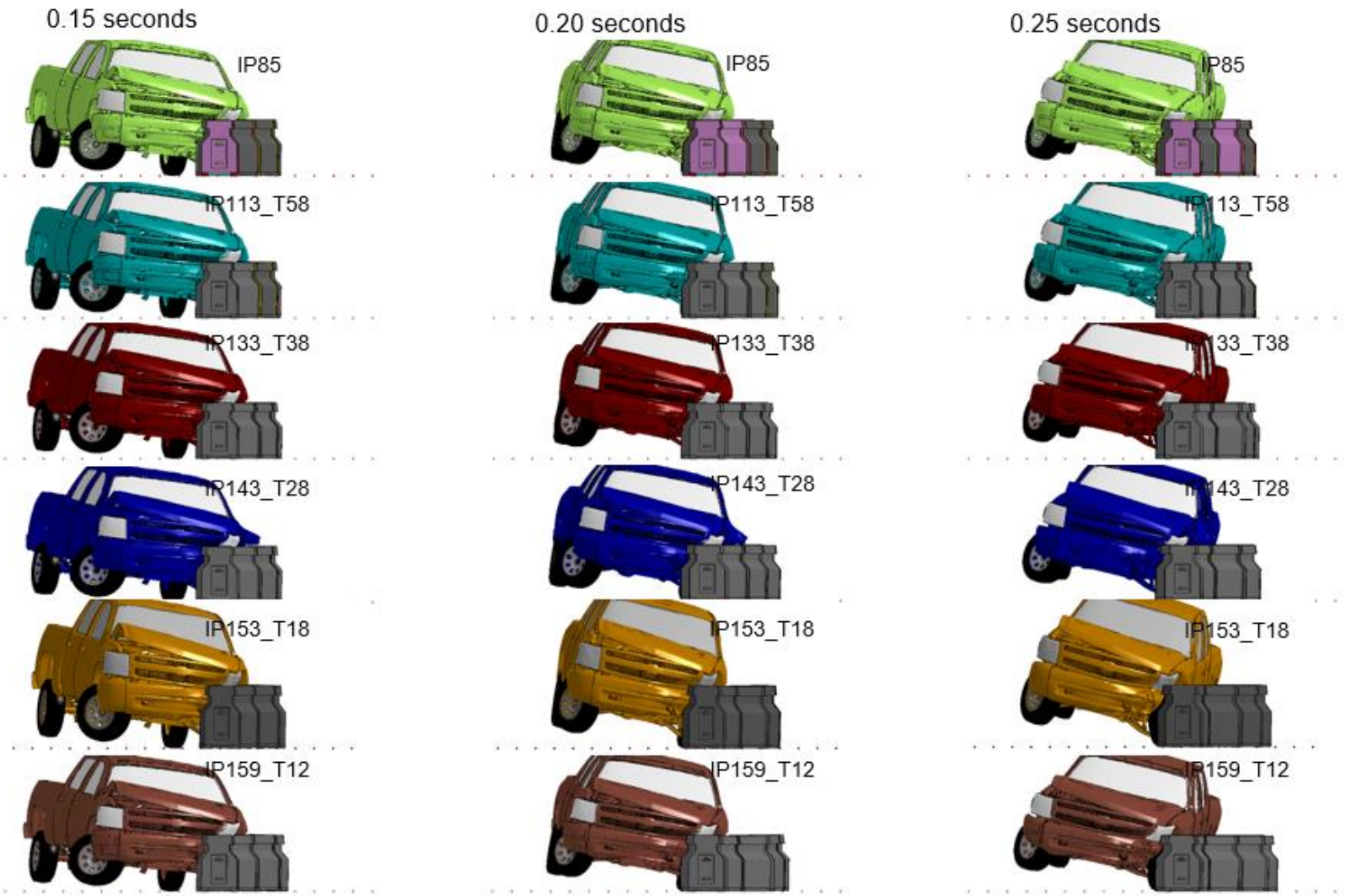


Figure E-2. [CONTINUED] Sequential views from a downstream viewpoint for IP85 through IP159_T12.

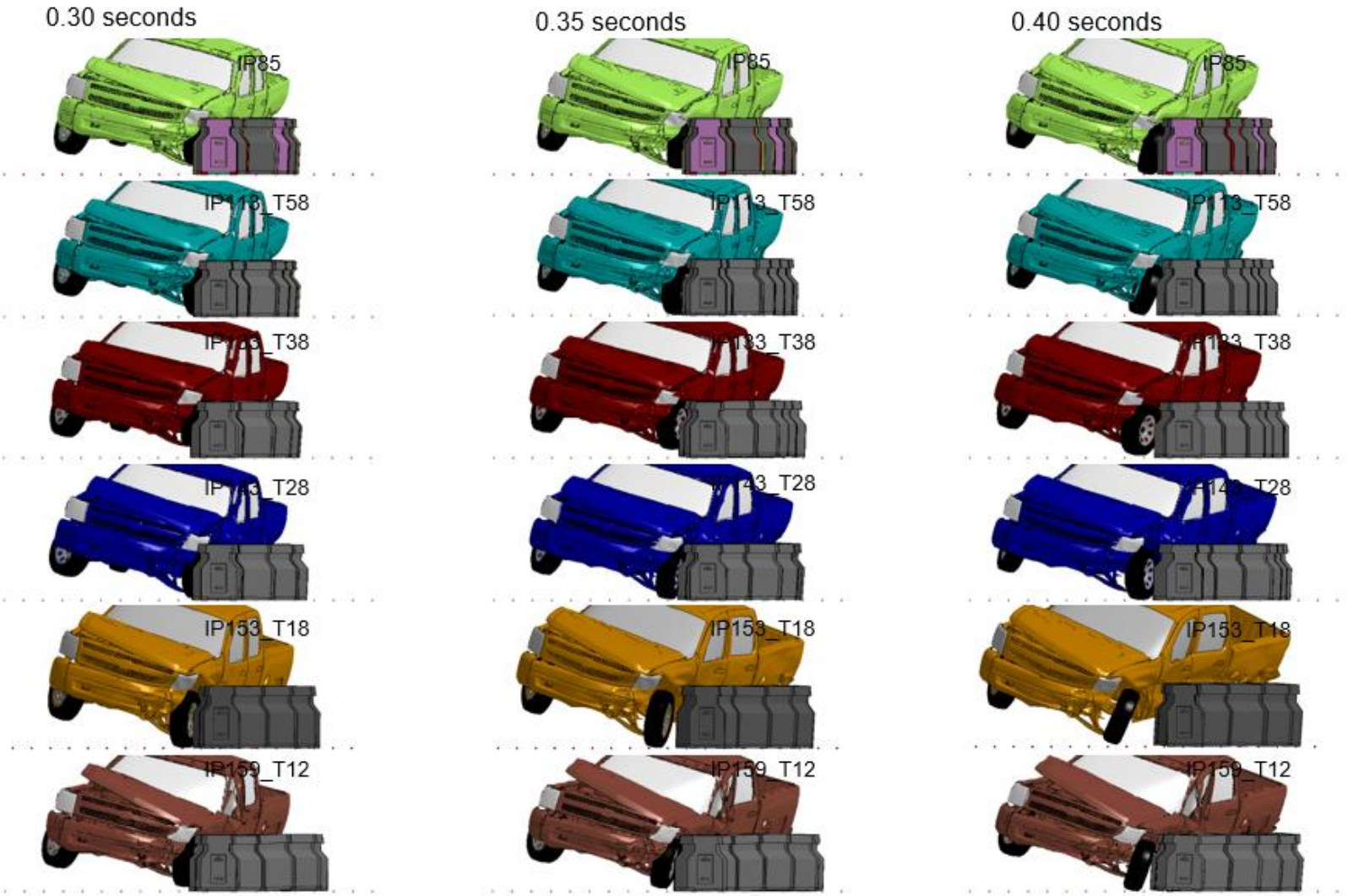


Figure E-2. [CONTINUED] Sequential views from a downstream viewpoint for IP85 through IP159_T12.

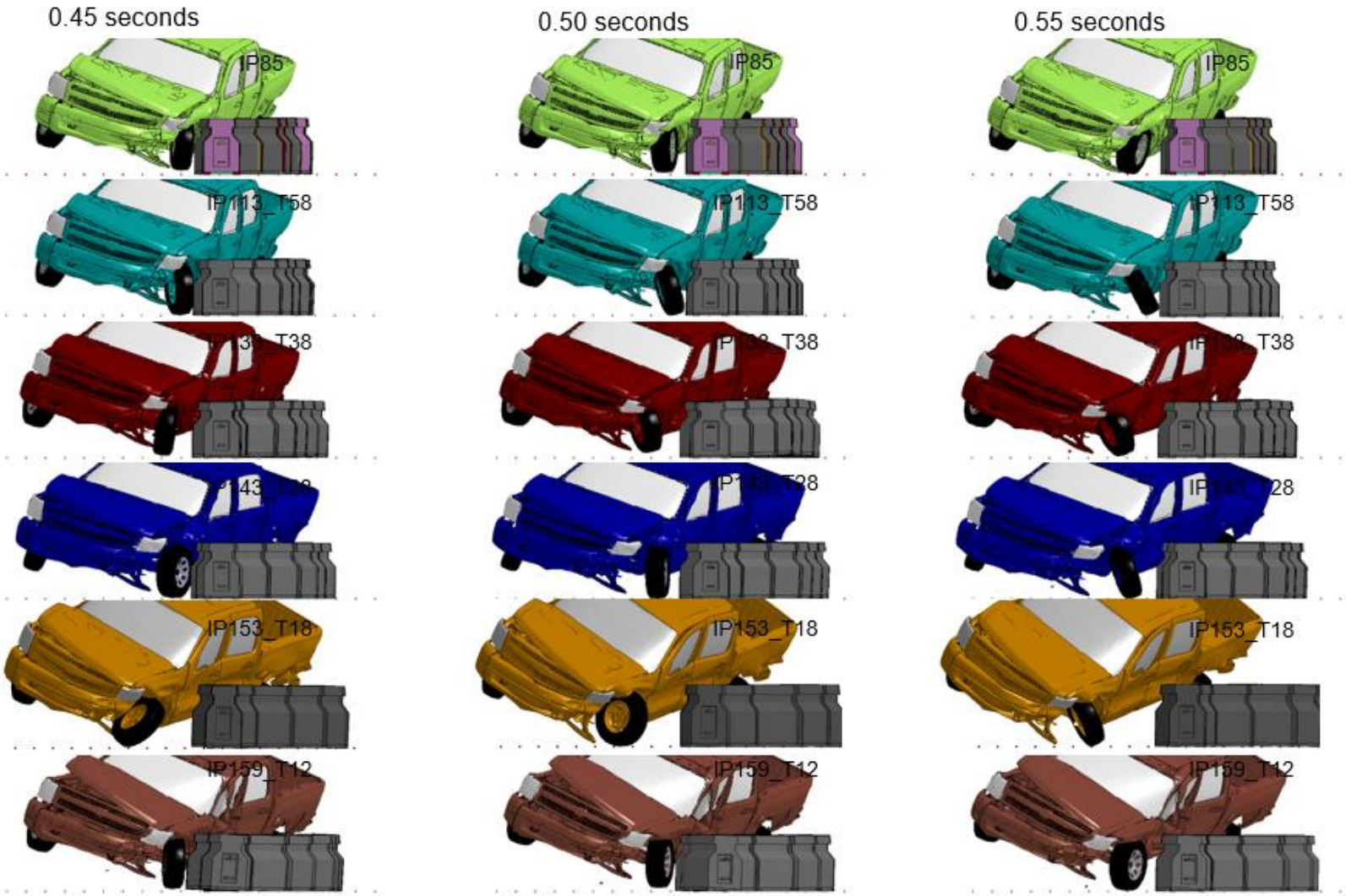


Figure E-2. [CONTINUED] Sequential views from a downstream viewpoint for IP85 through IP159_T12.

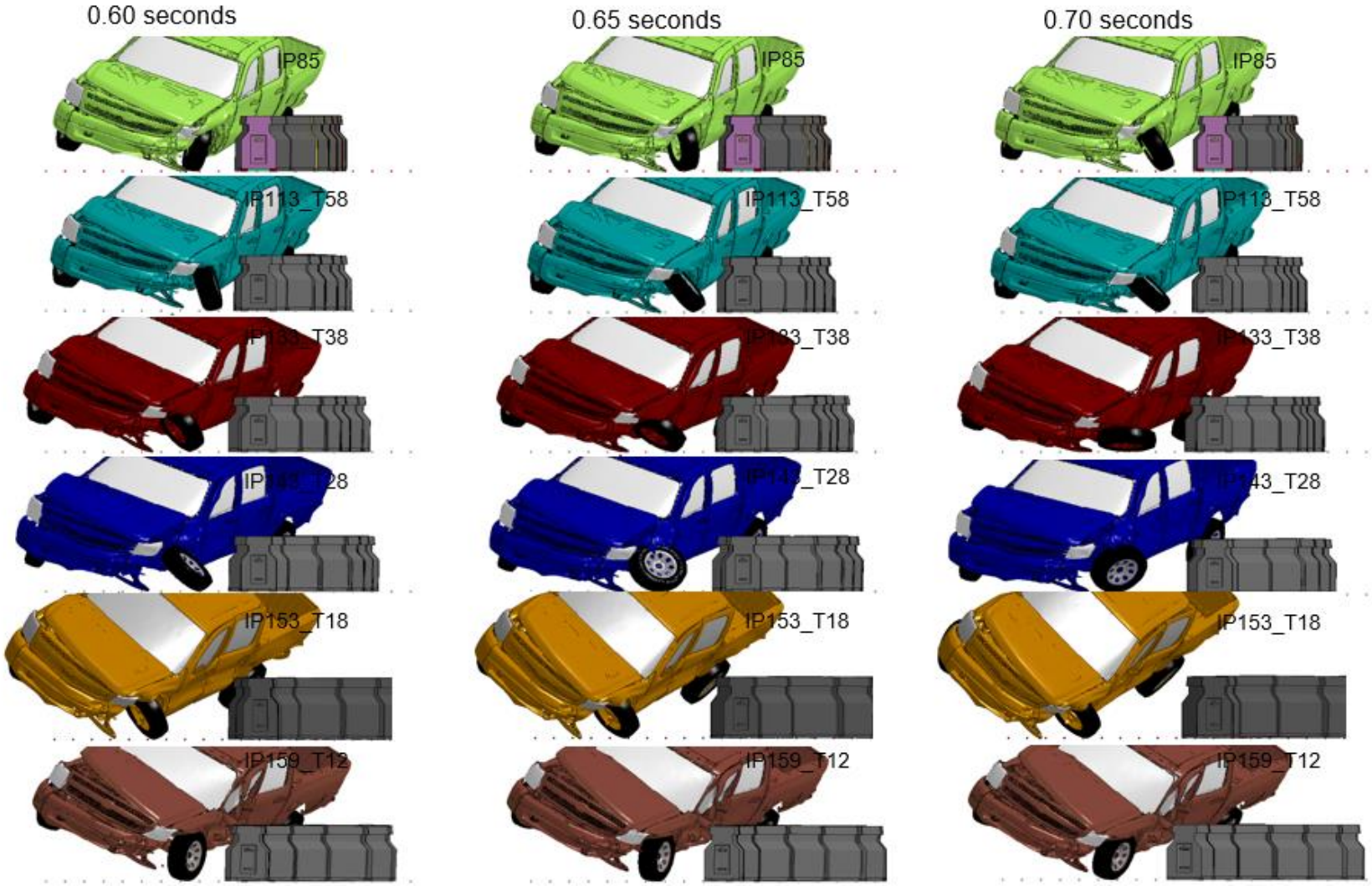


Figure E-2. [CONTINUED] Sequential views from a downstream viewpoint for IP85 through IP159_T12.

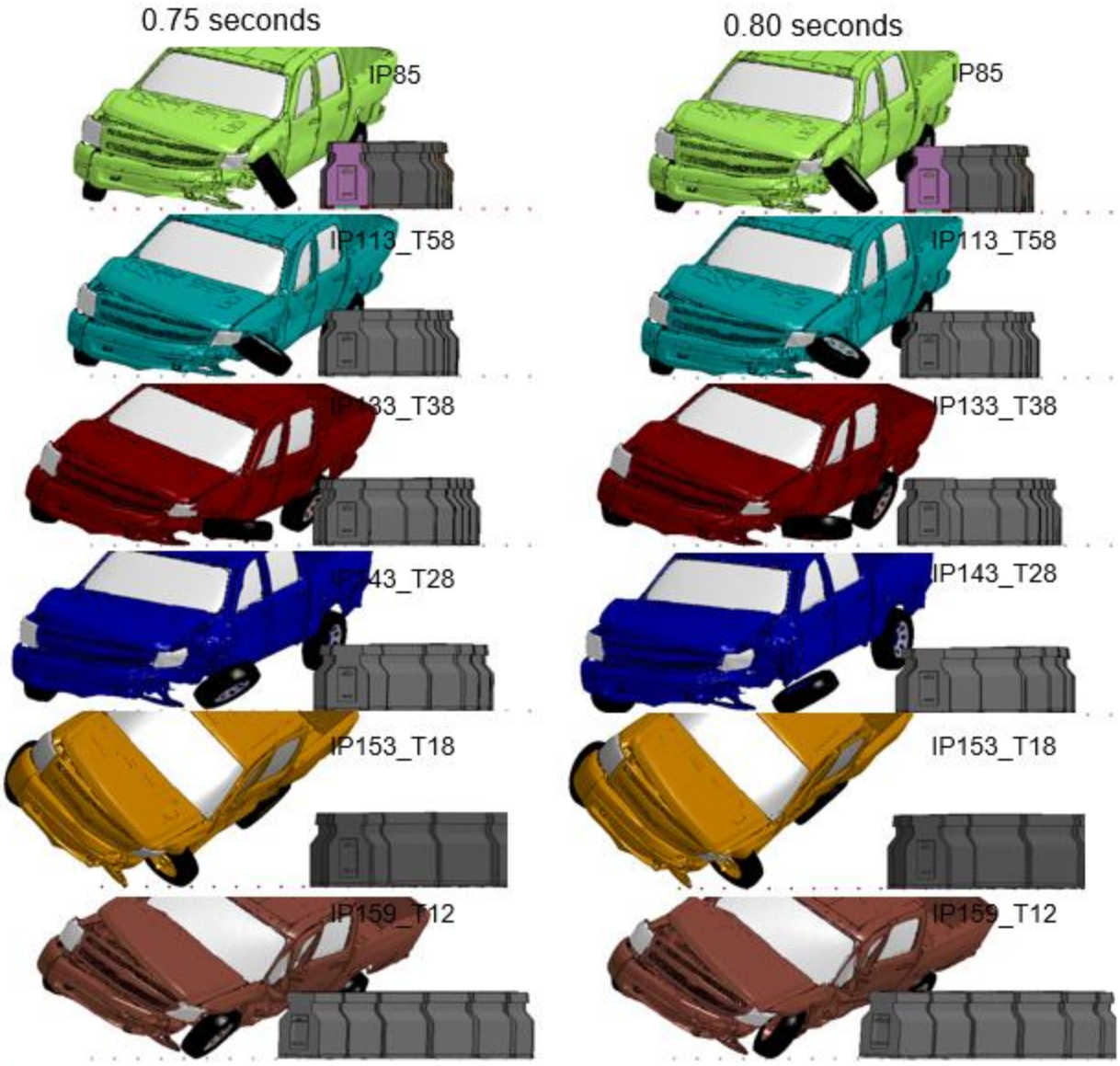


Figure E-2. [CONTINUED] Sequential views from a downstream viewpoint for IP85 through IP159_T12.

Figure E-3. Sequential views from an upstream viewpoint for IP85 through IP159_T12.

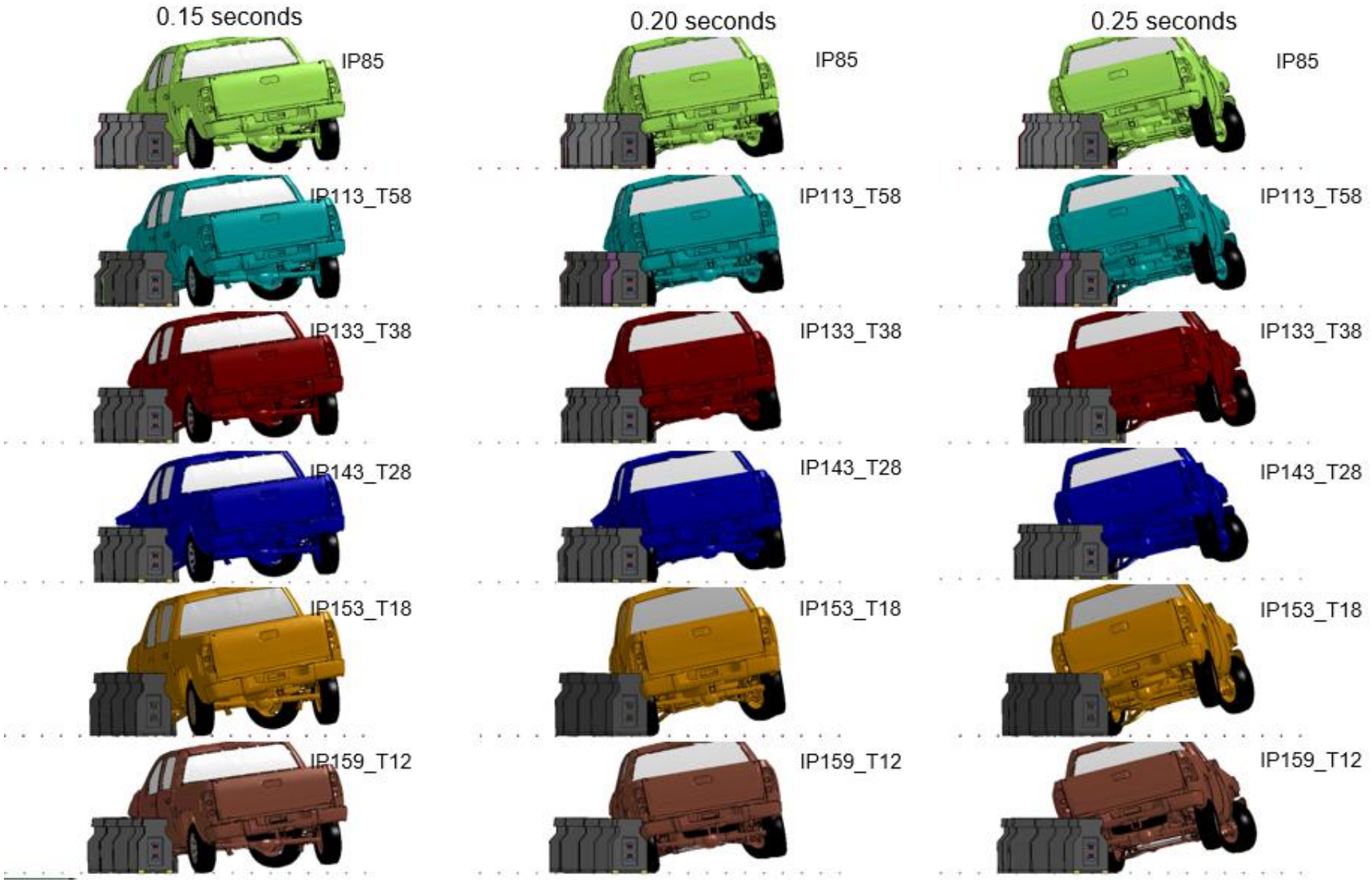


Figure E-3. [CONTINUED] Sequential views from an upstream viewpoint for IP85 through IP159_T12.

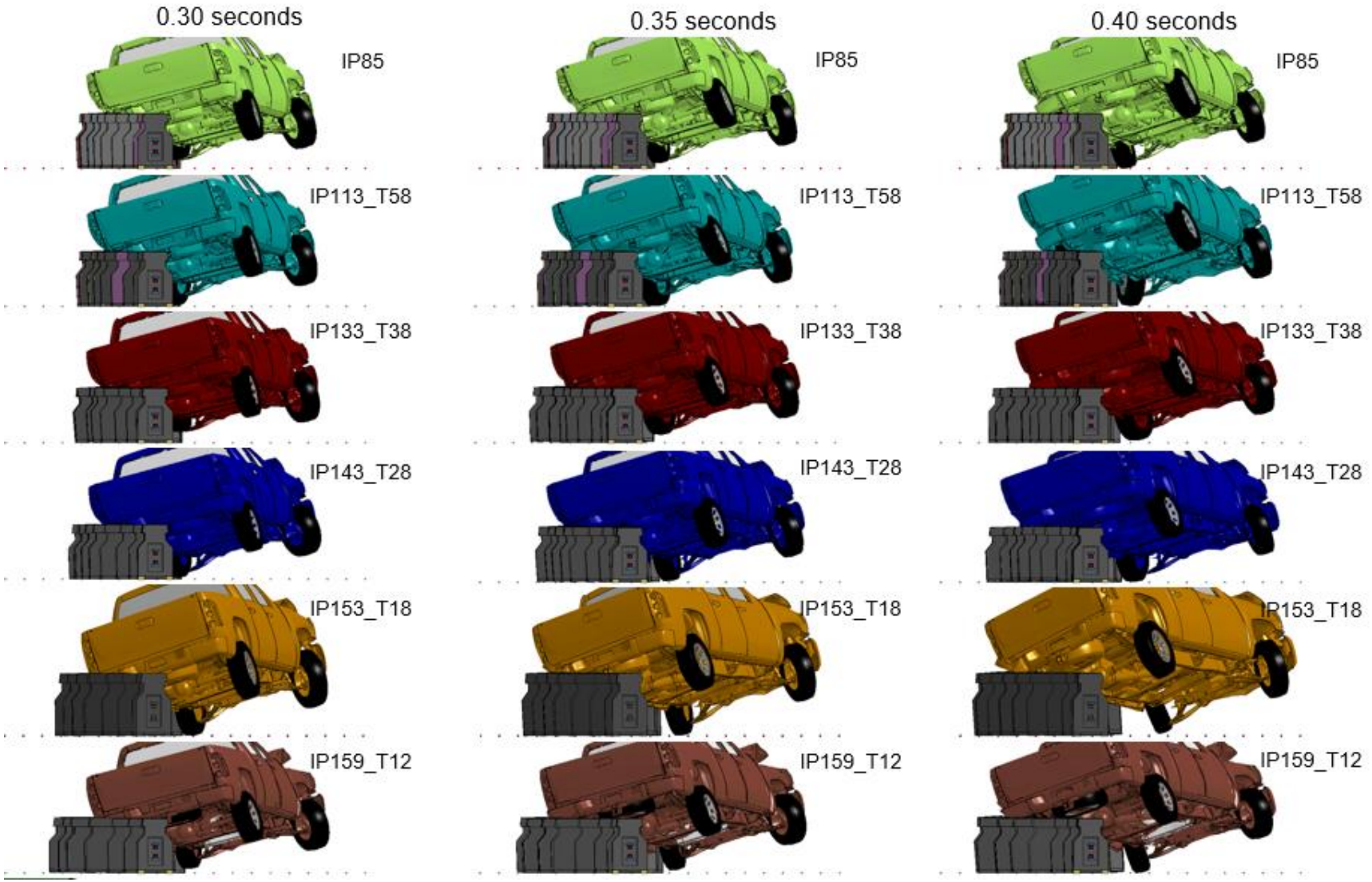


Figure E-3. [CONTINUED] Sequential views from an upstream viewpoint for IP85 through IP159_T12.

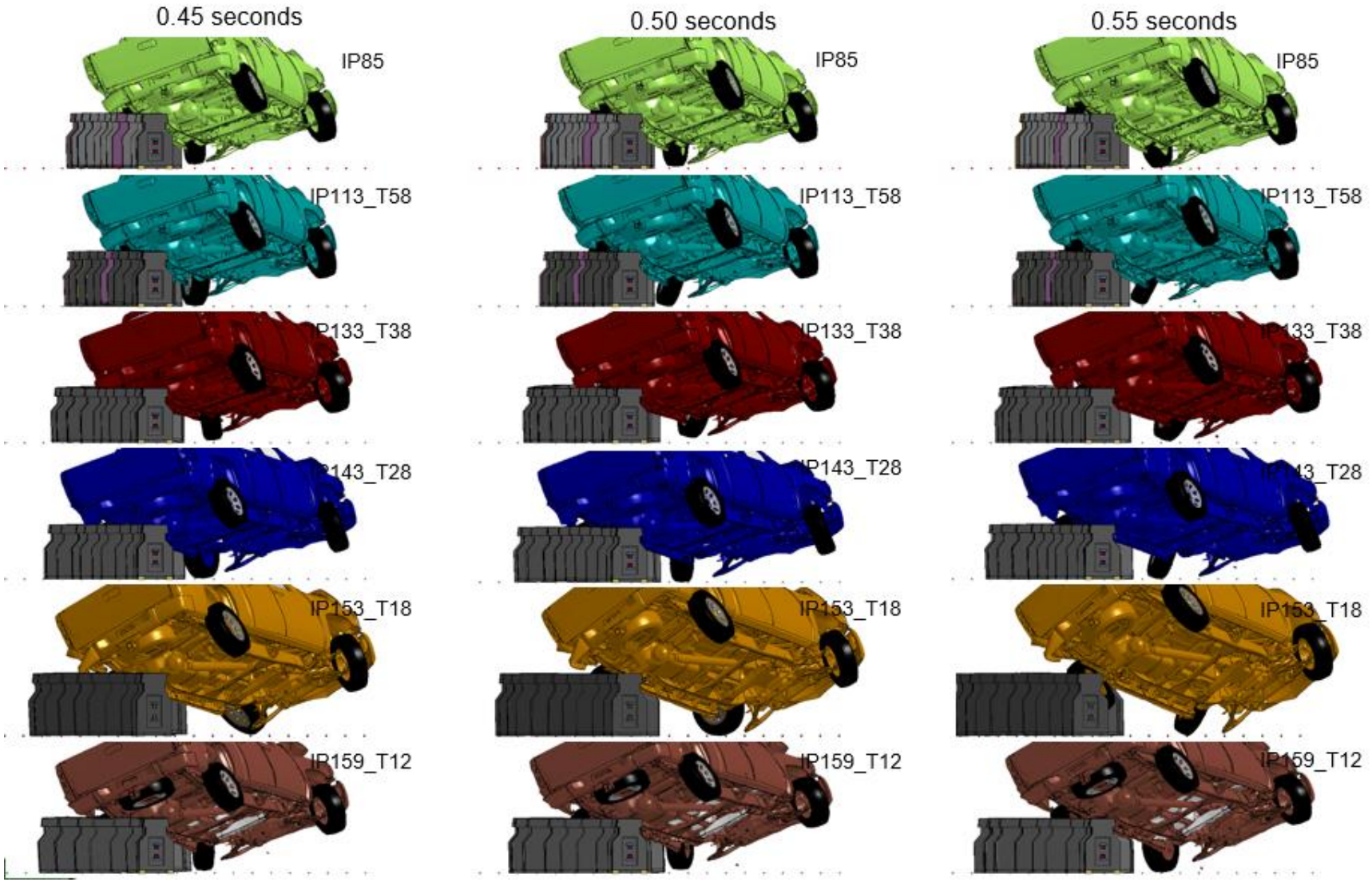


Figure E-3. [CONTINUED] Sequential views from an upstream viewpoint for IP85 through IP159_T12.

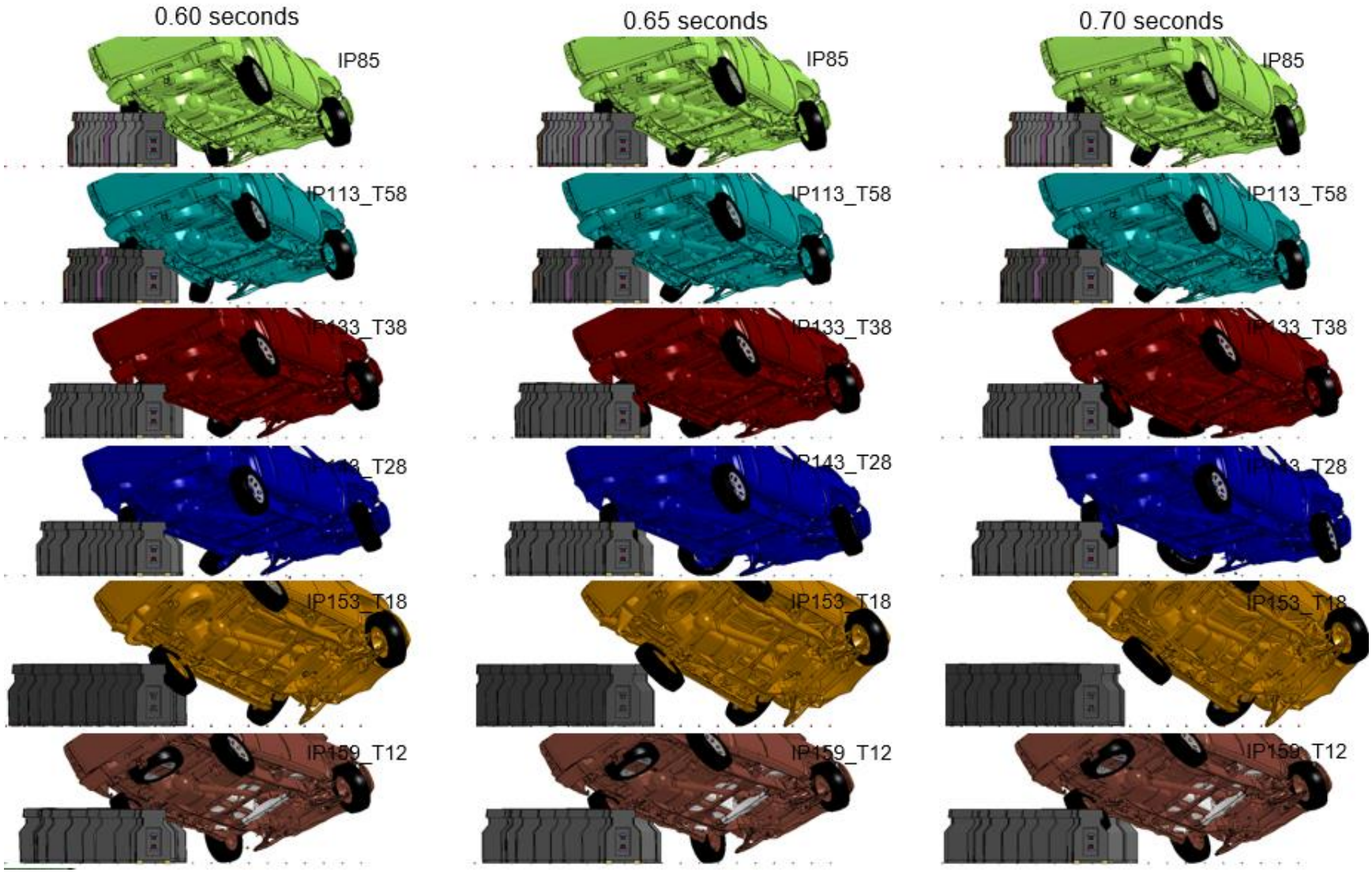


Figure E-3. [CONTINUED] Sequential views from an upstream viewpoint for IP85 through IP159_T12.

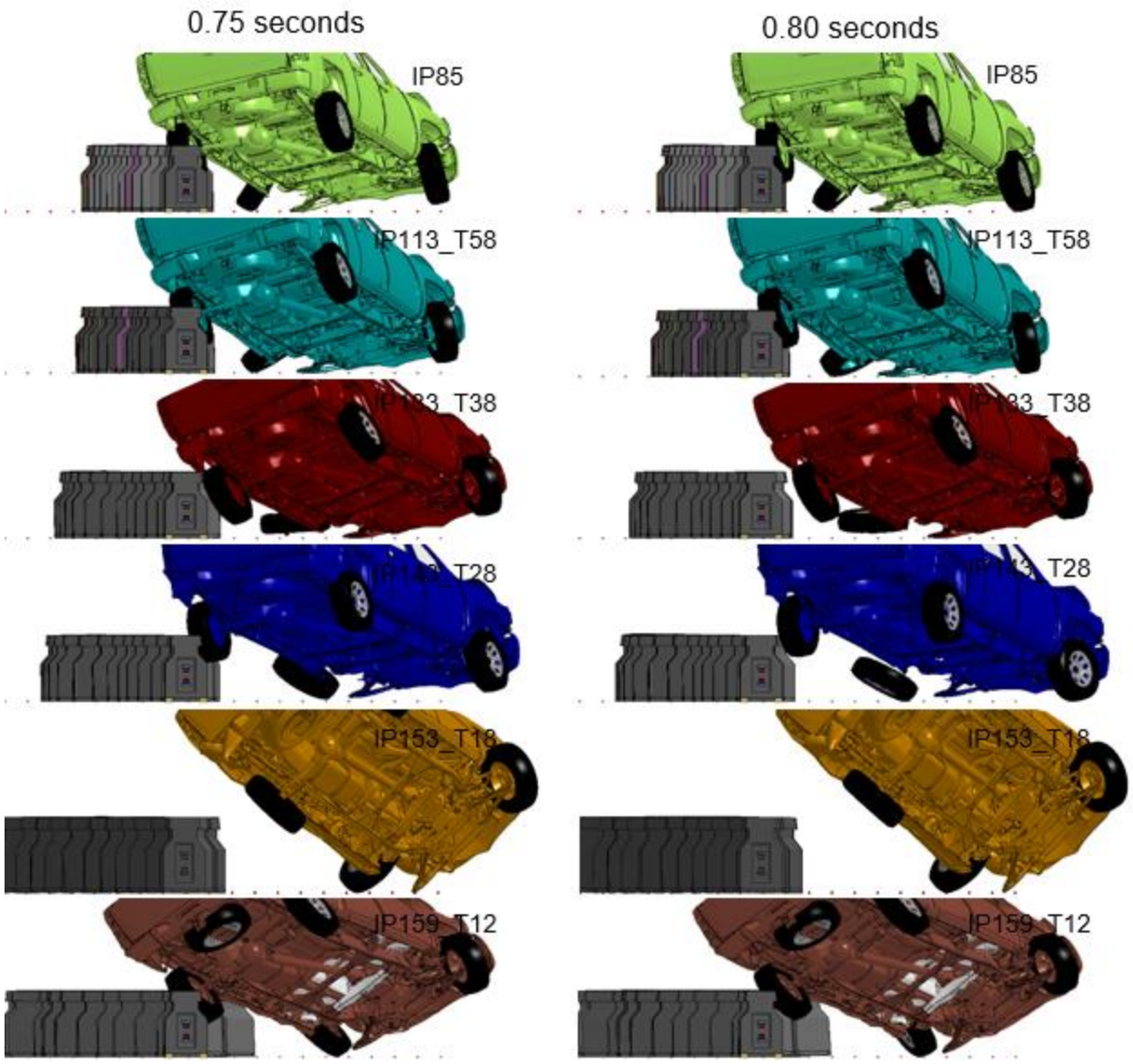


Figure E-3. [CONTINUED] Sequential views from an upstream viewpoint for IP85 through IP159_T12.

APPENDIX F

Exit Box for Case 1 (without VLB's)

Exit Box – Criteria

*Taken from MASH, pg. 98

Distance for Exit Box Criterion

Vehicle Type	A ft (m)	B ft (m)
Car/Pickup	$7.2 + V_W + 0.16V_L$ $(2.2 + V_W + 0.16V_L)$	32.8 (10.0)
Other Vehicles	$14.4 + V_W + 0.16V_L$ $(4.4 + V_W + 0.16V_L)$	65.6 (20.0)

V_W = Vehicle Width
V_L = Vehicle Length

V_W = 6.5 ft. (measured from model)
V_L = 19.06 ft. (measured from model)
A = 16.78 ft.
B = 32.8 ft.

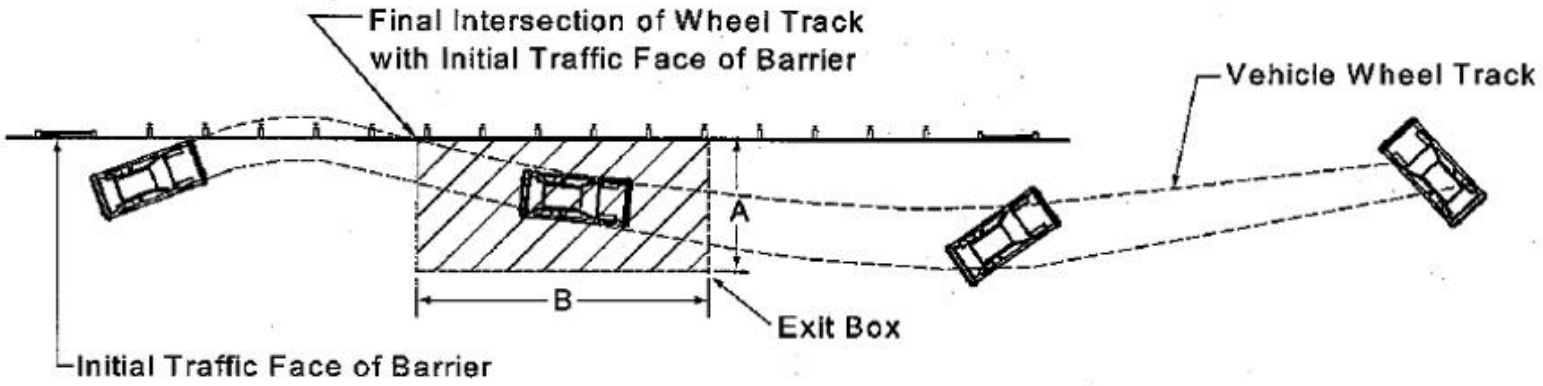


Figure 5-1. Exit Box for Longitudinal Barriers

Figure F-1. Exit box criteria.

The driver-side rear tire wheel track was used to determine the beginning location of the exit box. From MASH pg. 97: "All wheel tracks of the vehicle should not cross the parallel line within the distance B." In all cases, the passenger-side front tire wheel track was most likely to cross the parallel line within distance B, and was used to visually extrapolate vehicle wheel-track trajectory.

	Impact Conditions	
Case	Point	Within Exit Box?
1	18	Questionable
2	28	Yes
3	38	Yes
4	58	Yes
5	85	Yes
6	113_T58	Yes
7	133_T38	Yes
8	143_T28	Yes
9	153_T18	Yes
10	159_T12	Questionable

Figure F-2. Exit box results.

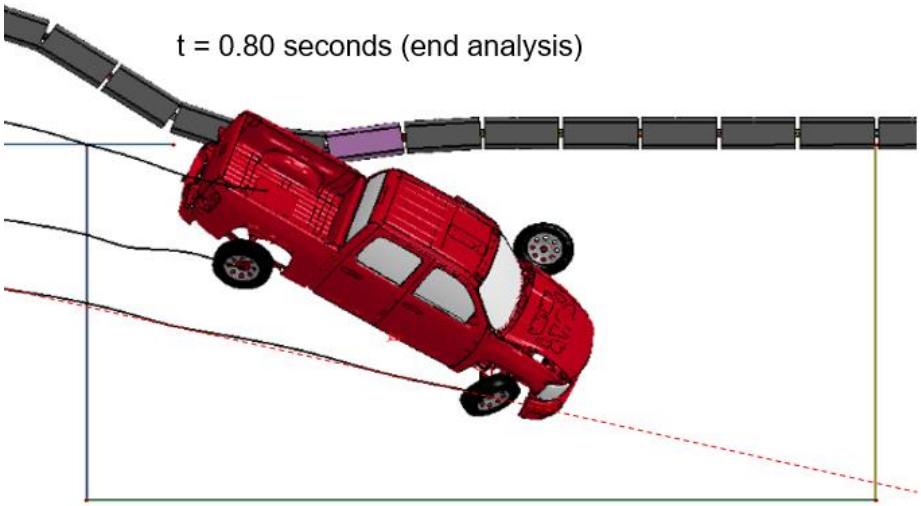


Figure F-3. Exit box for Impact Point 18.

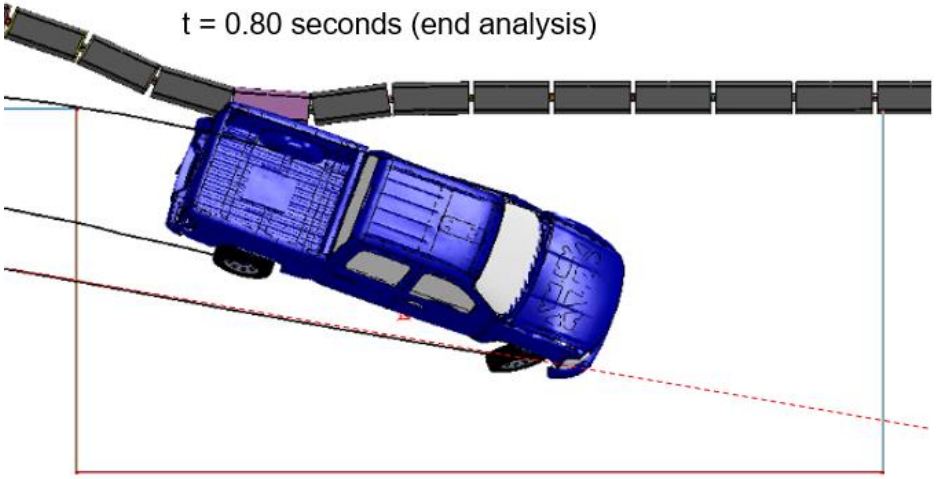


Figure F-4. Exit box for Impact Point 28.

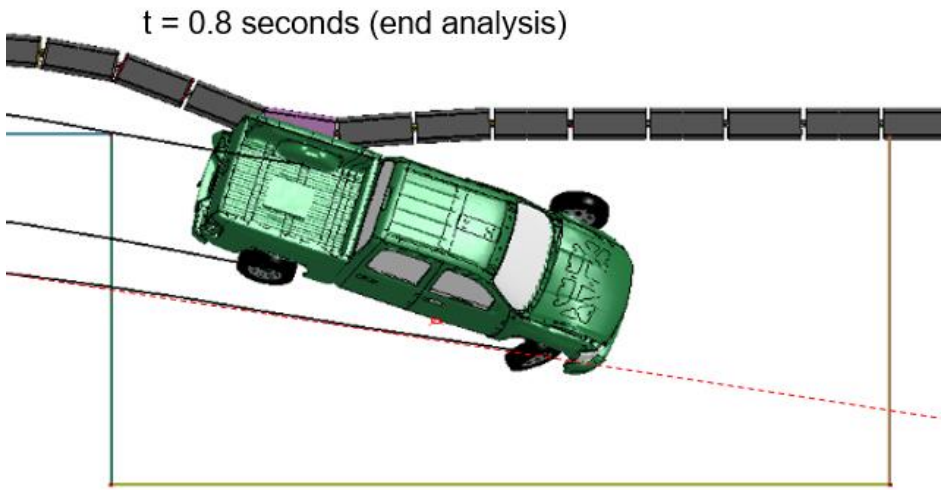


Figure F-5. Exit box for Impact Point 38.

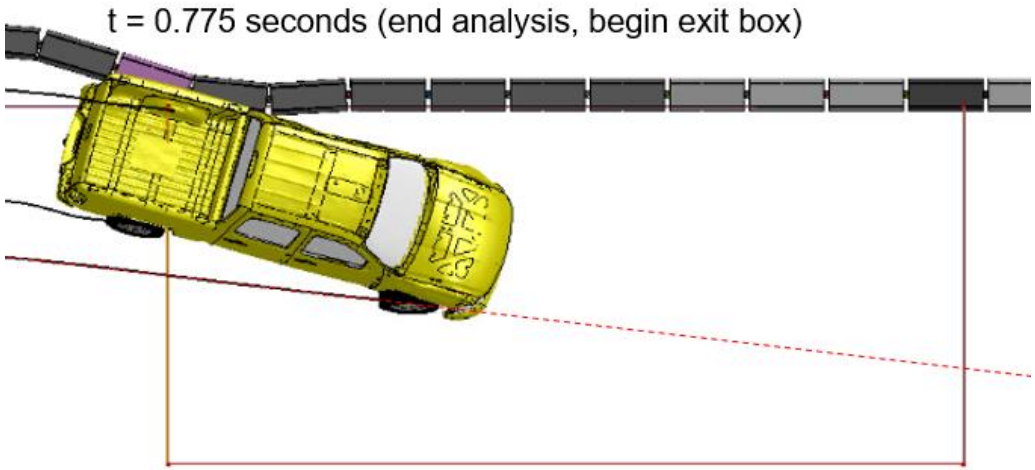


Figure F-6. Exit box for Impact Point 58.

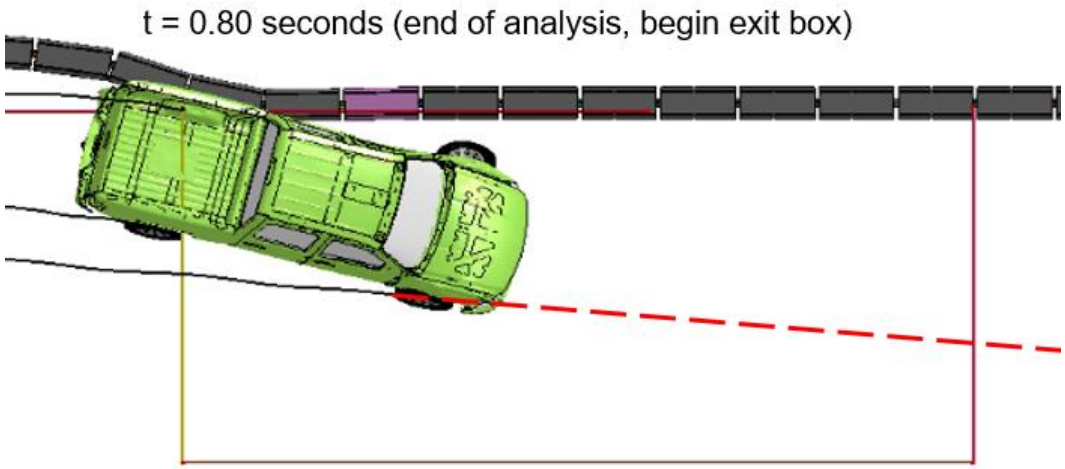


Figure F-7. Exit box for Impact Point 85.

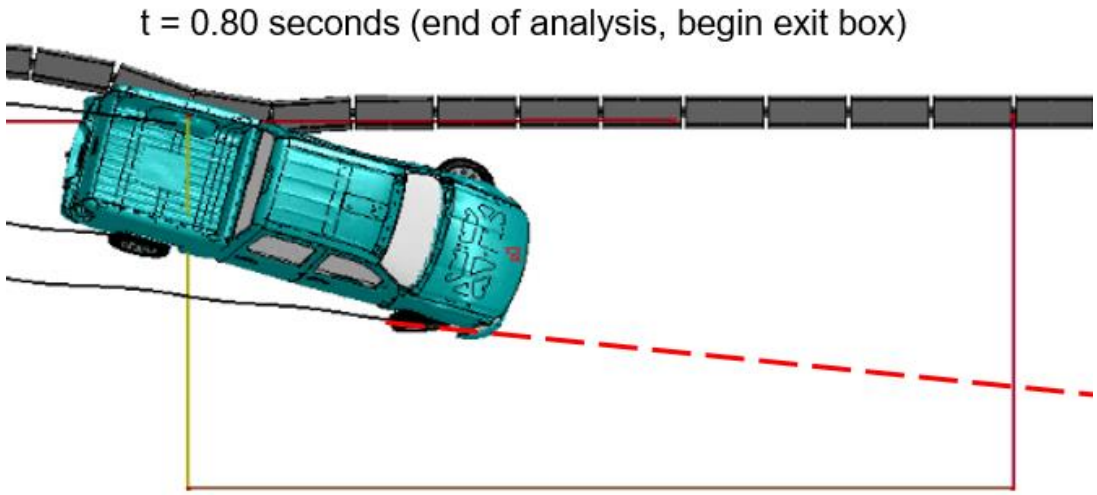


Figure F-8. Exit box for Impact Point 113_T58.

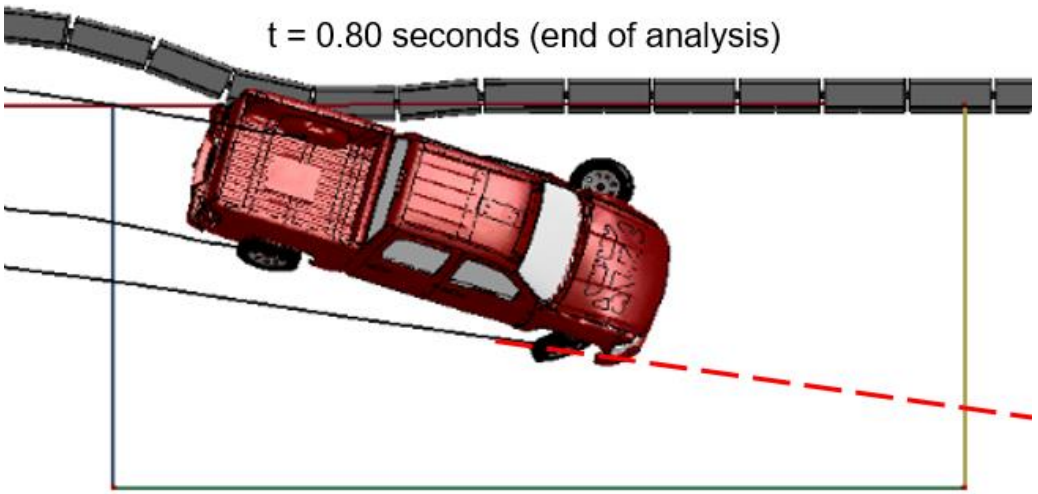


Figure F-9. Exit box for Impact Point 133_T38.

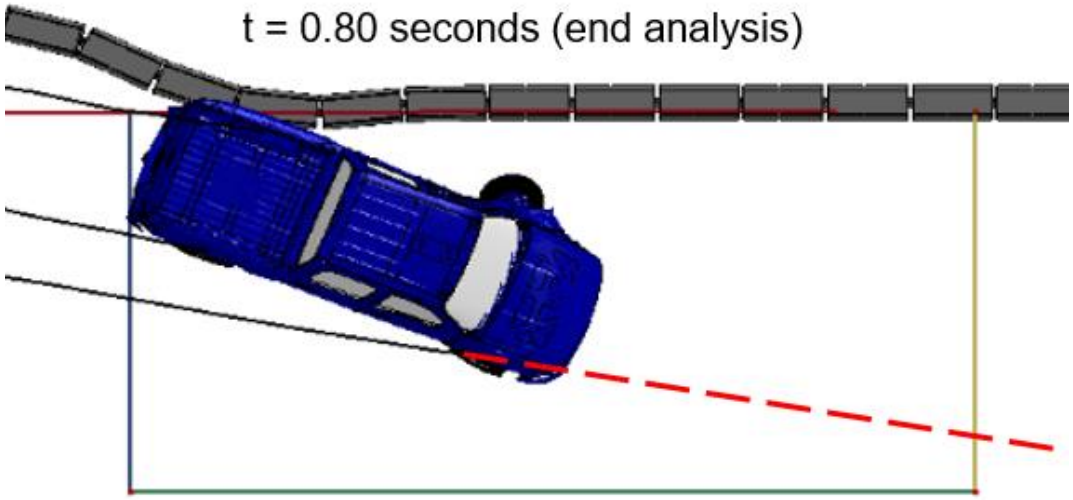


Figure F-10. Exit box for Impact Point 143_T28.

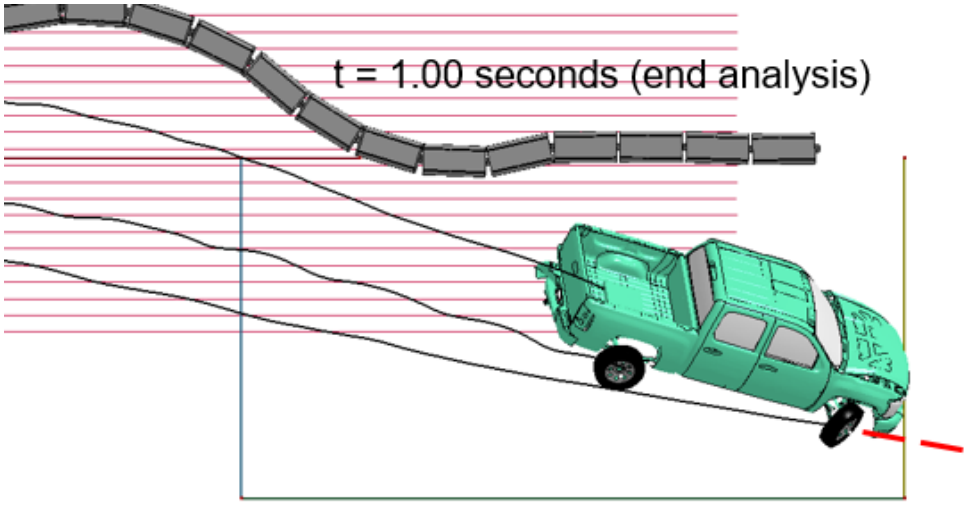


Figure F-11. Exit box for Impact Point 153_T18.

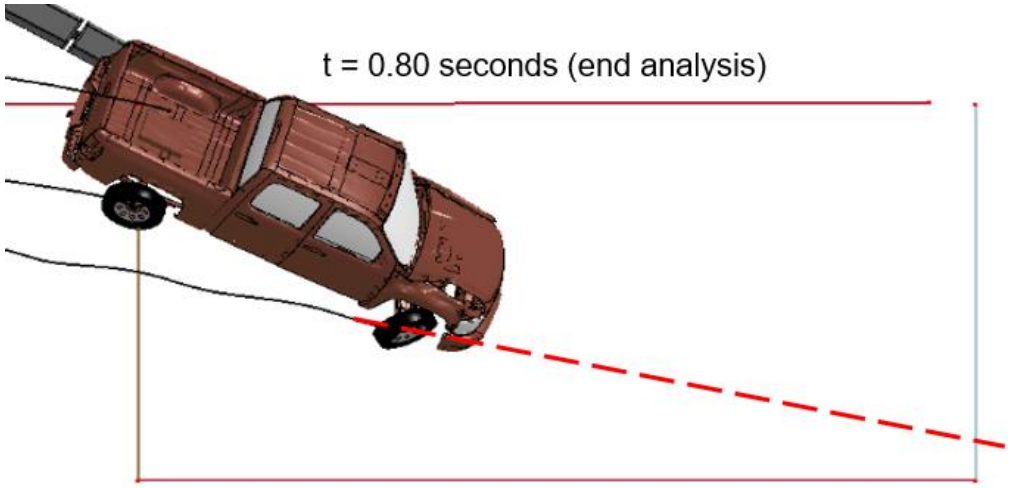


Figure F-12. Exit box for Impact Point 159_T12.

APPENDIX G

Sequential Views for Case 2 from FEA for Leading-End Impact Cases on the CRTS Barrier

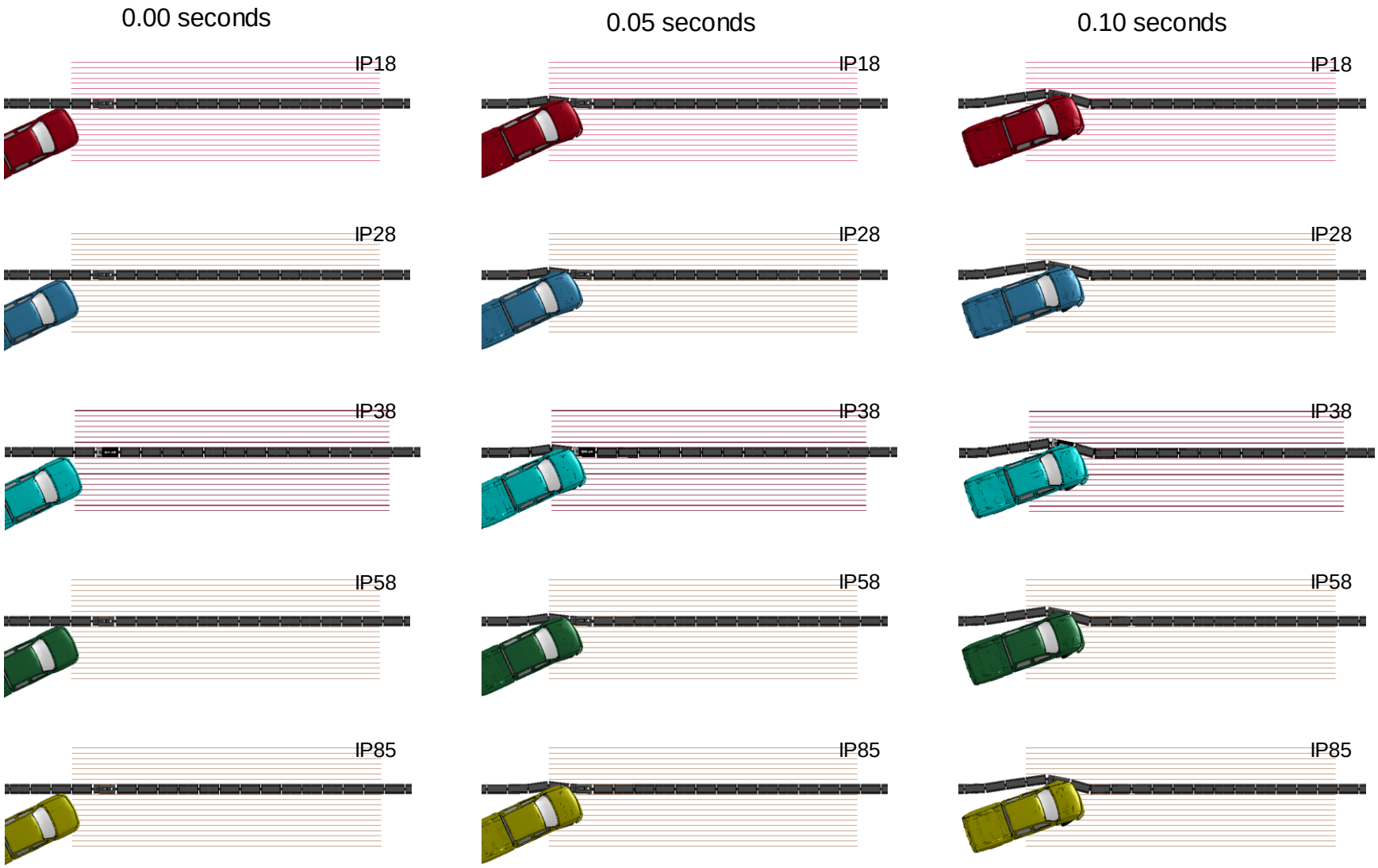


Figure G-1. Sequential views from an overhead viewpoint for IP18 through IP85.

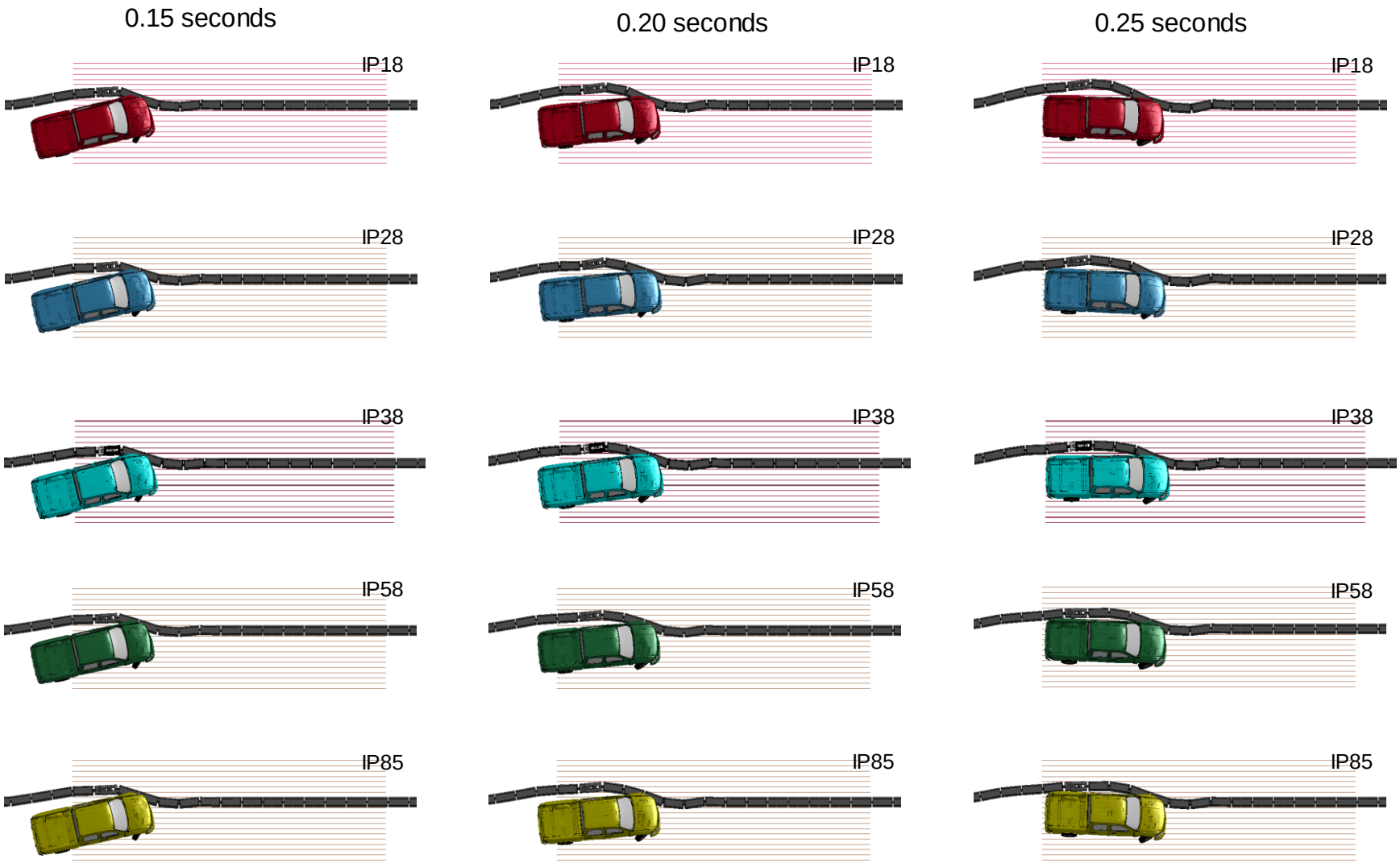


Figure G-1. [CONTINUED] **Sequential views from an overhead viewpoint for IP18 through IP85.**

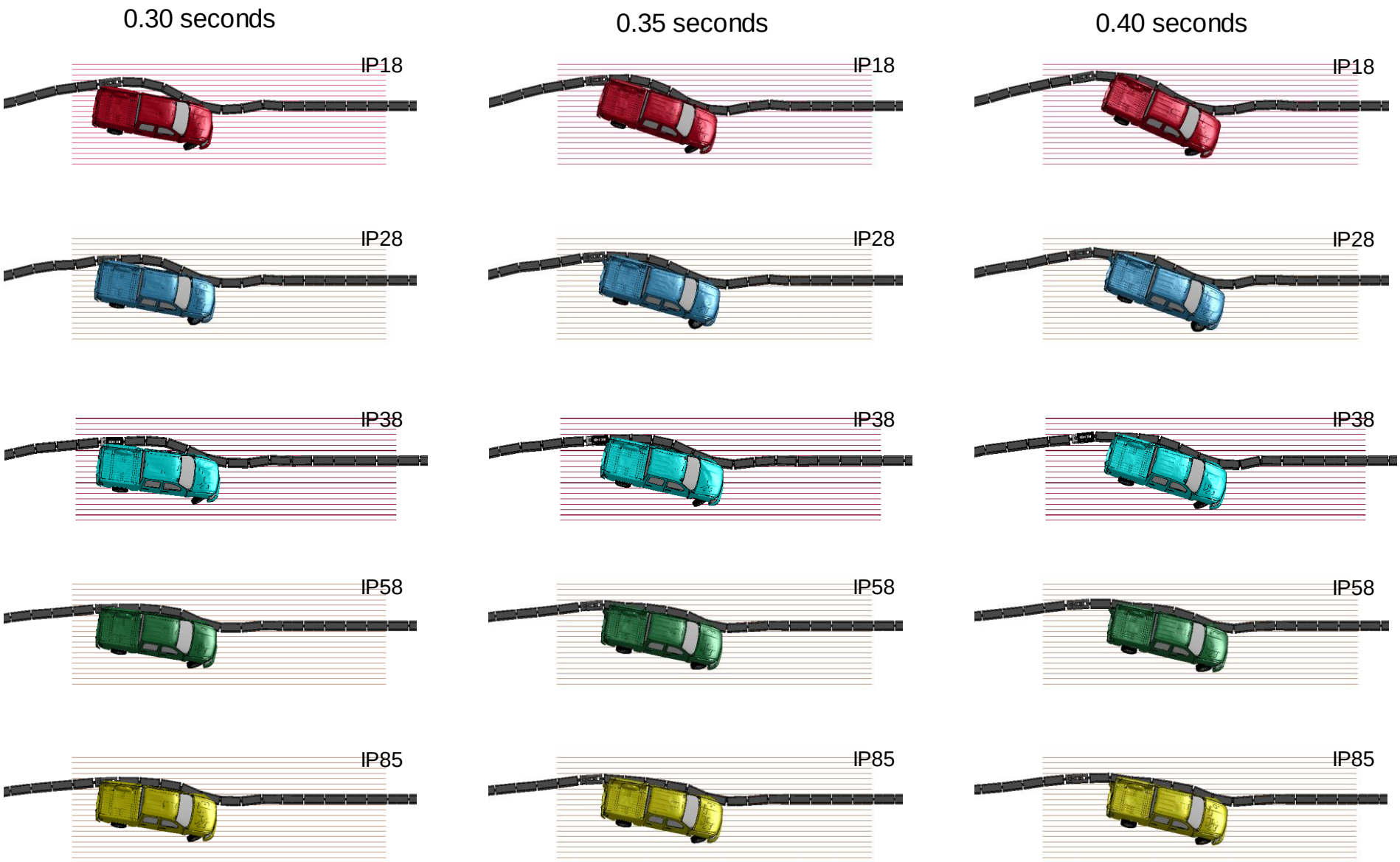


Figure G-1. [CONTINUED] **Sequential views from an overhead viewpoint for IP18 through IP85.**

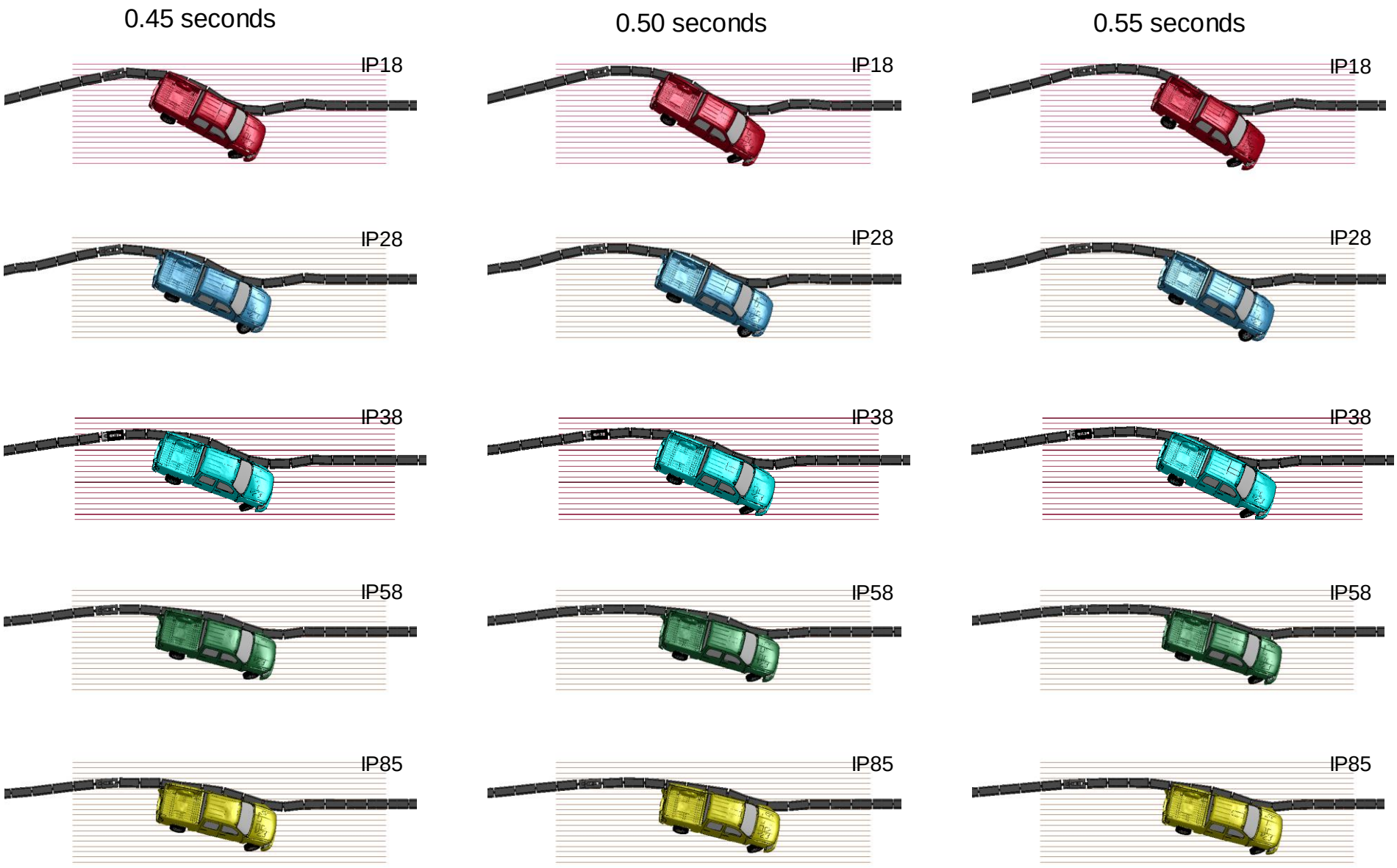


Figure G-1. [CONTINUED] **Sequential views from an overhead viewpoint for IP18 through IP85.**

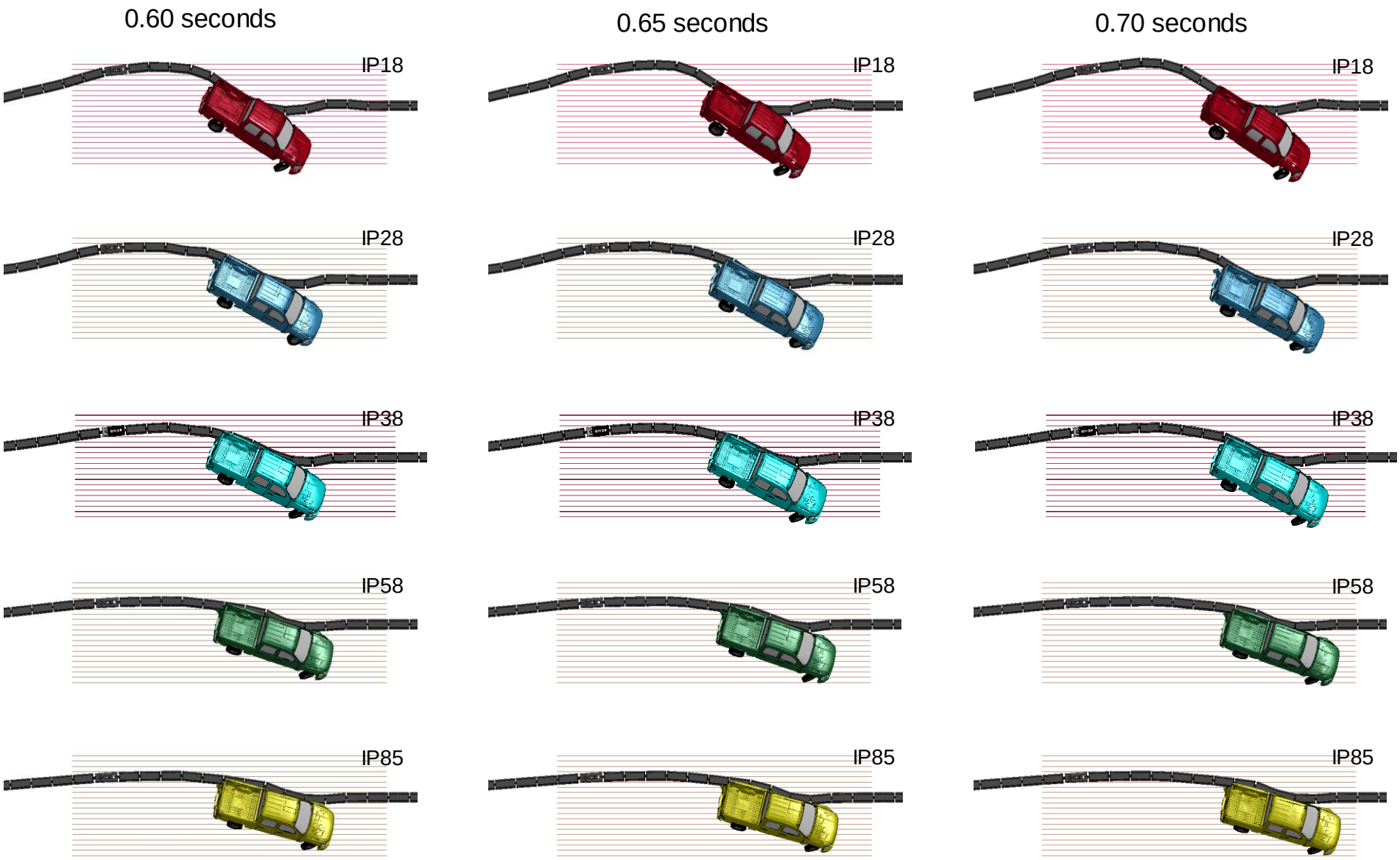


Figure G-1. [CONTINUED] **Sequential views from an overhead viewpoint for IP18 through IP85.**

Figure G-2. Sequential views from a downstream viewpoint for IP18 through IP85.

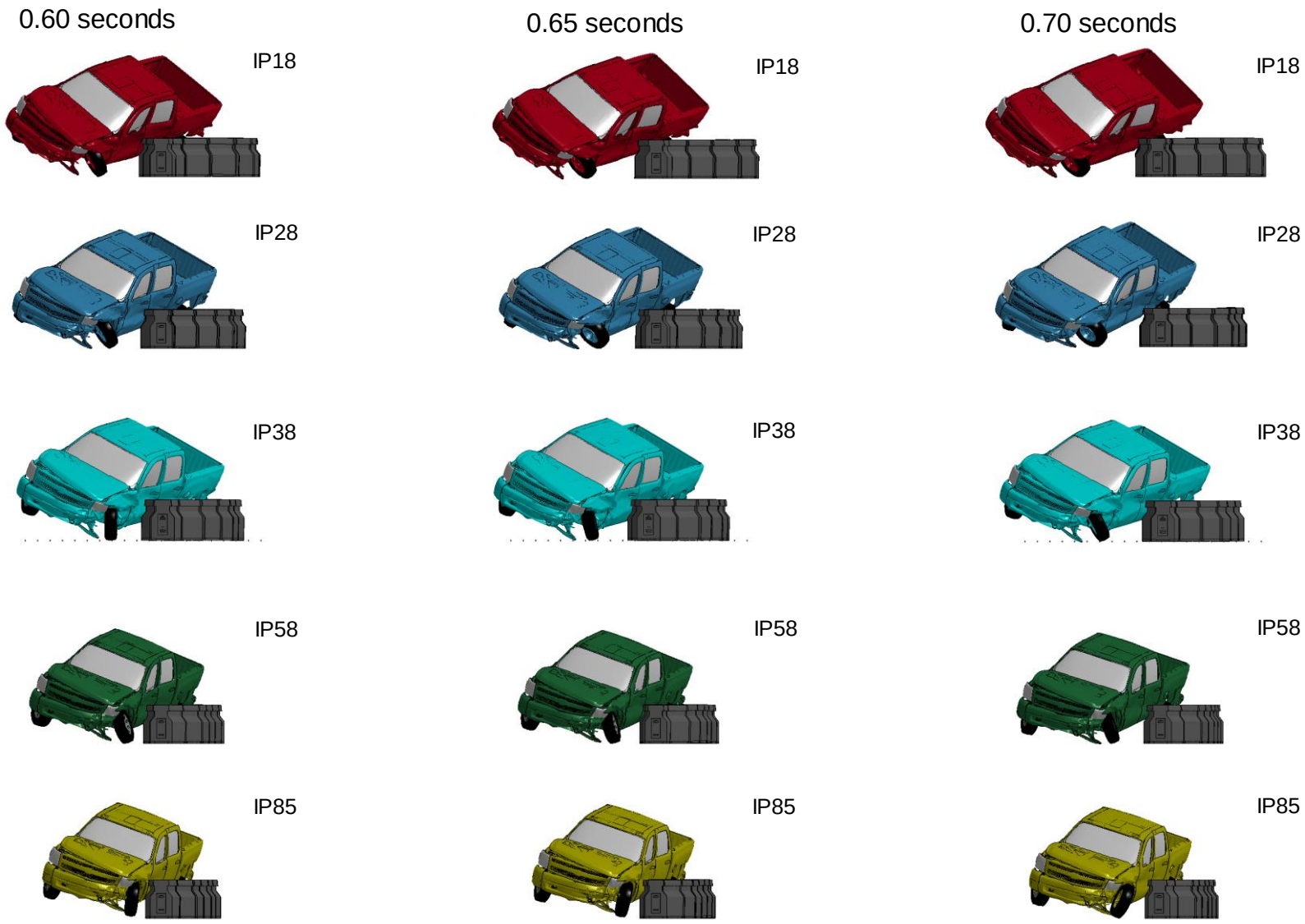
Error! Not a valid bookmark self-reference.. **[CONTINUED] Sequential views from a downstream viewpoint for IP18 through IP85.**

Error! Not a valid bookmark self-reference.. **[CONTINUED] Sequential views from a downstream viewpoint for IP18 through IP85.**

. [CONTINUED] Sequential views from a downstream viewpoint for IP18 through IP85.

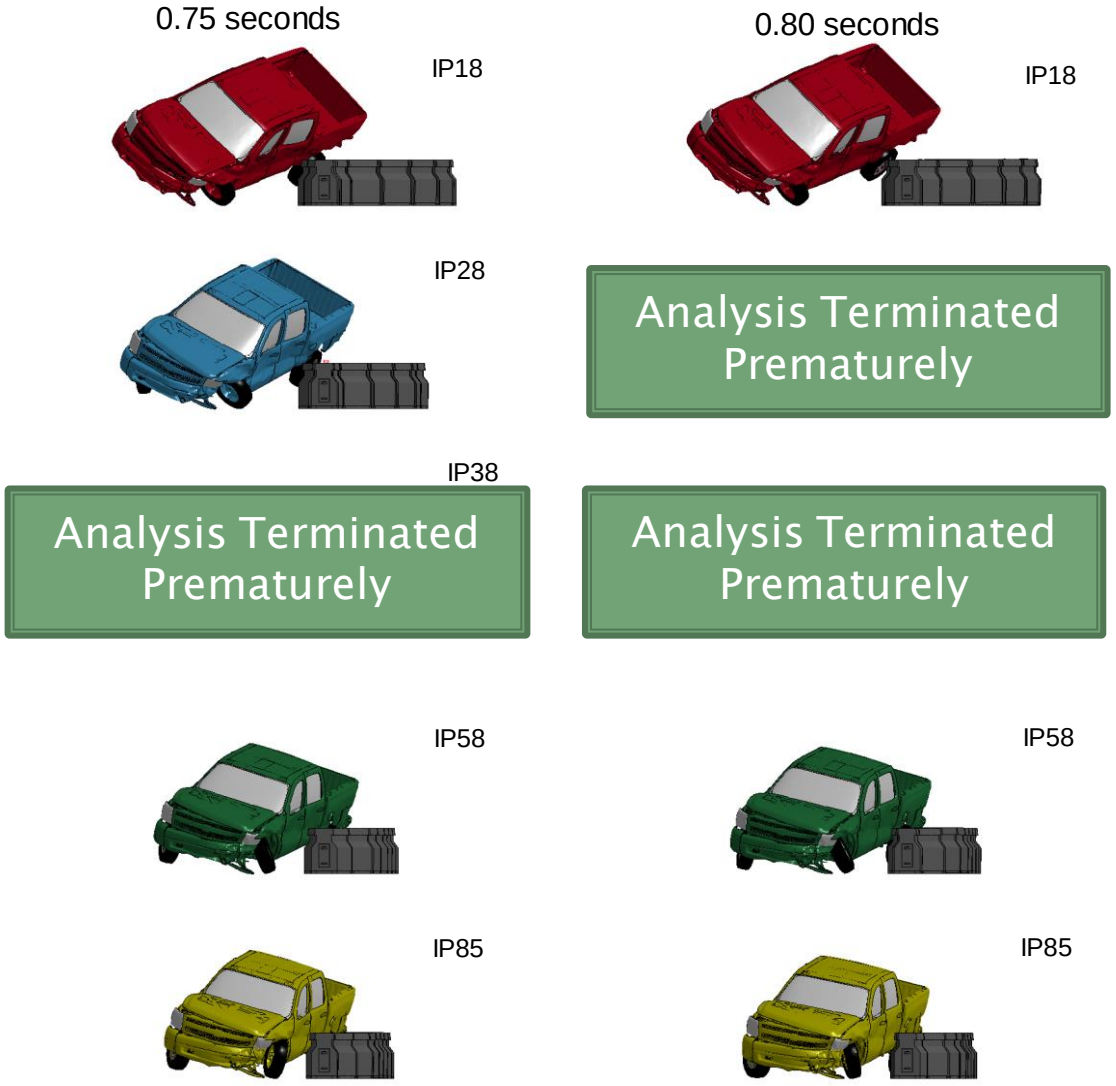
Error! Not a valid bookmark self-reference.. **[CONTINUED] Sequential views from a downstream viewpoint for IP18 through IP85.**

. [CONTINUED] Sequential views from a downstream viewpoint for IP18 through IP85.



Error! Not a valid bookmark self-reference.. **[CONTINUED] Sequential views from a downstream viewpoint for IP18 through IP85.**

. [CONTINUED] Sequential views from a downstream viewpoint for IP18 through IP85.



Error! Not a valid bookmark self-reference.**. [CONTINUED] Sequential views from a downstream viewpoint for IP18 through IP85.**

. [CONTINUED] Sequential views from a downstream viewpoint for IP18 through IP85.

Figure G-3. Sequential views from an upstream viewpoint for IP18 through IP85.

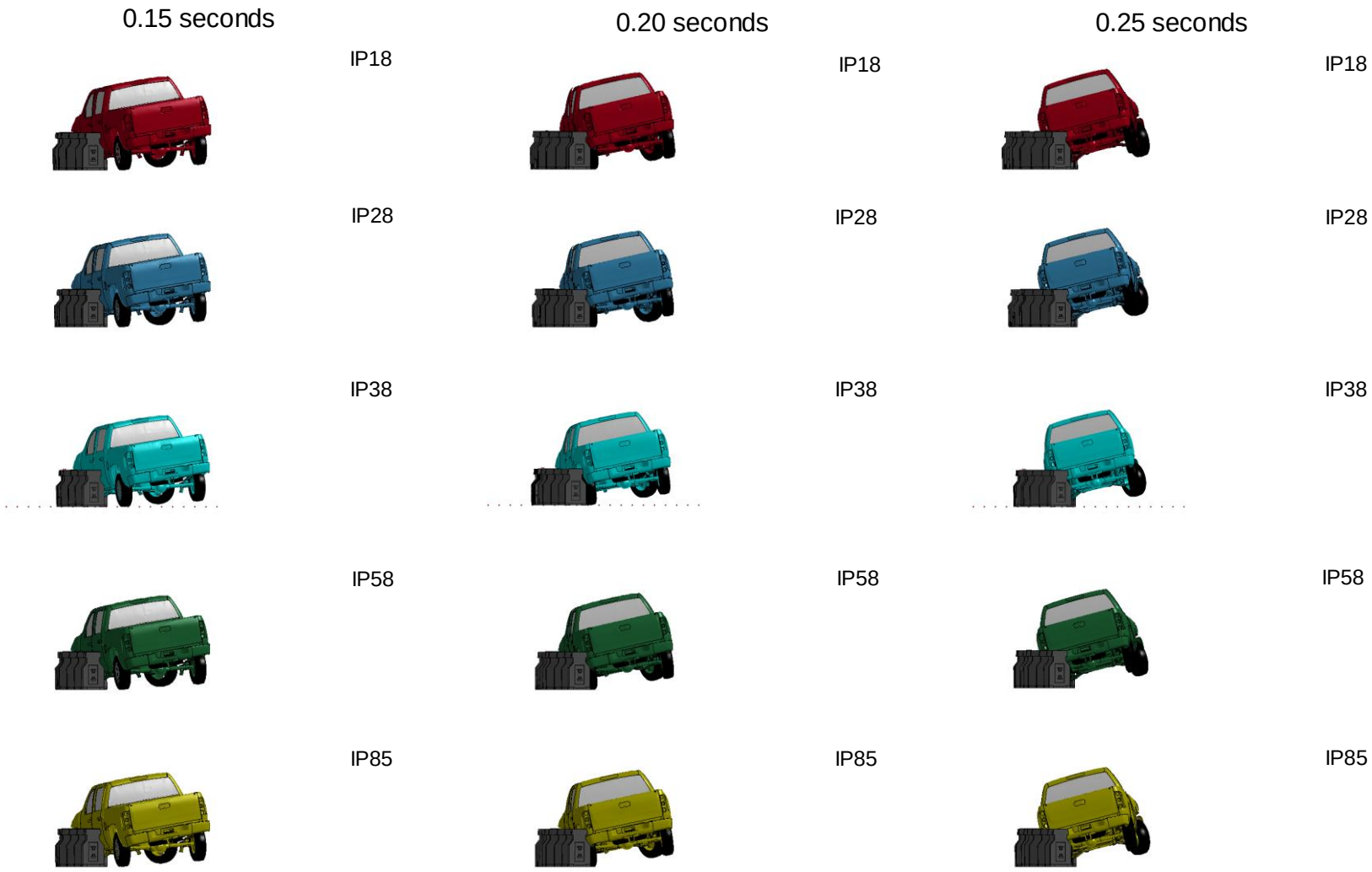


Figure G-3. [CONTINUED] Sequential views from an upstream viewpoint for IP18 through IP85.

Figure G-3. [CONTINUED] Sequential views from an upstream viewpoint for IP18 through IP85.

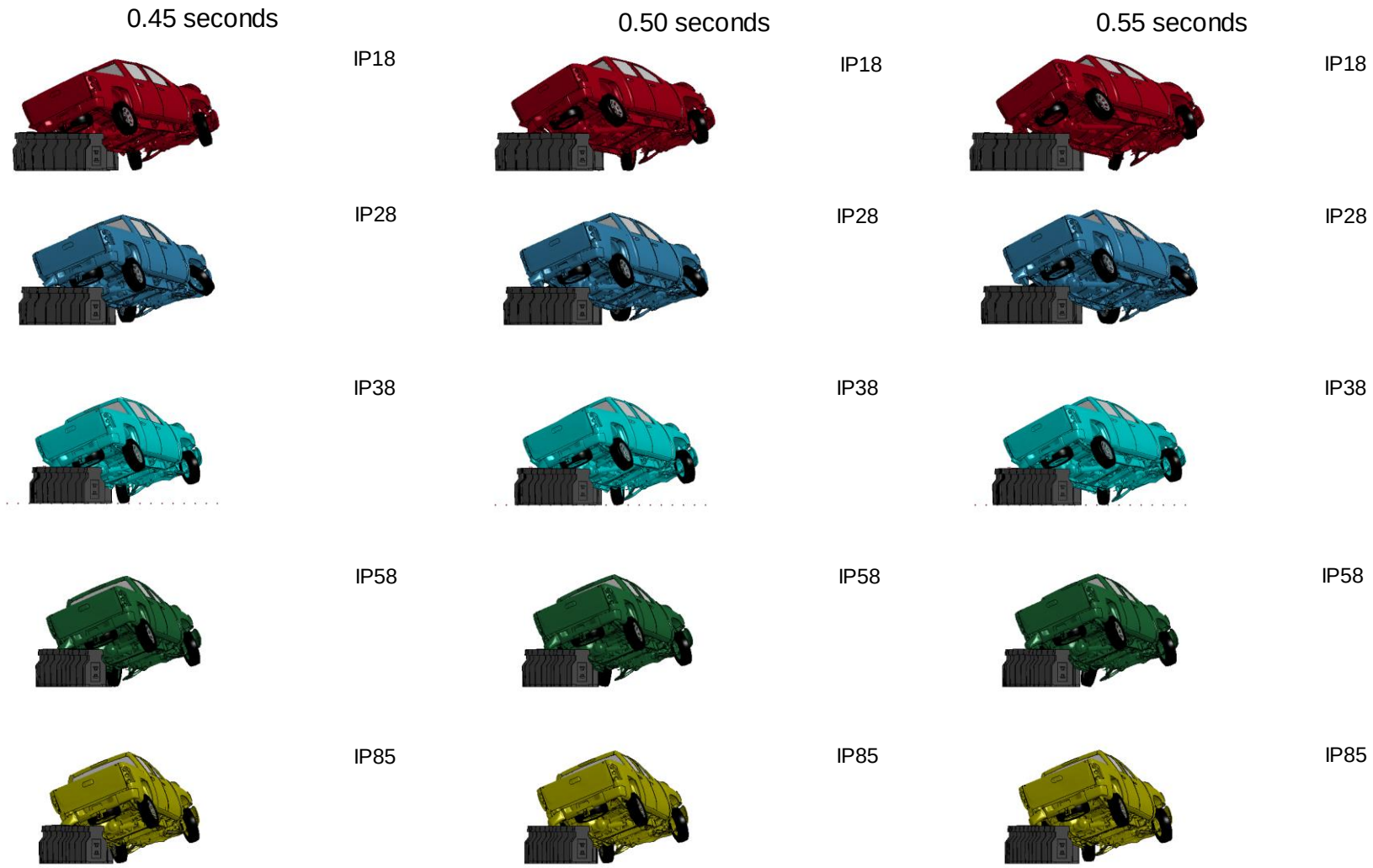


Figure G-3. [CONTINUED] Sequential views from an upstream viewpoint for IP18 through IP85.

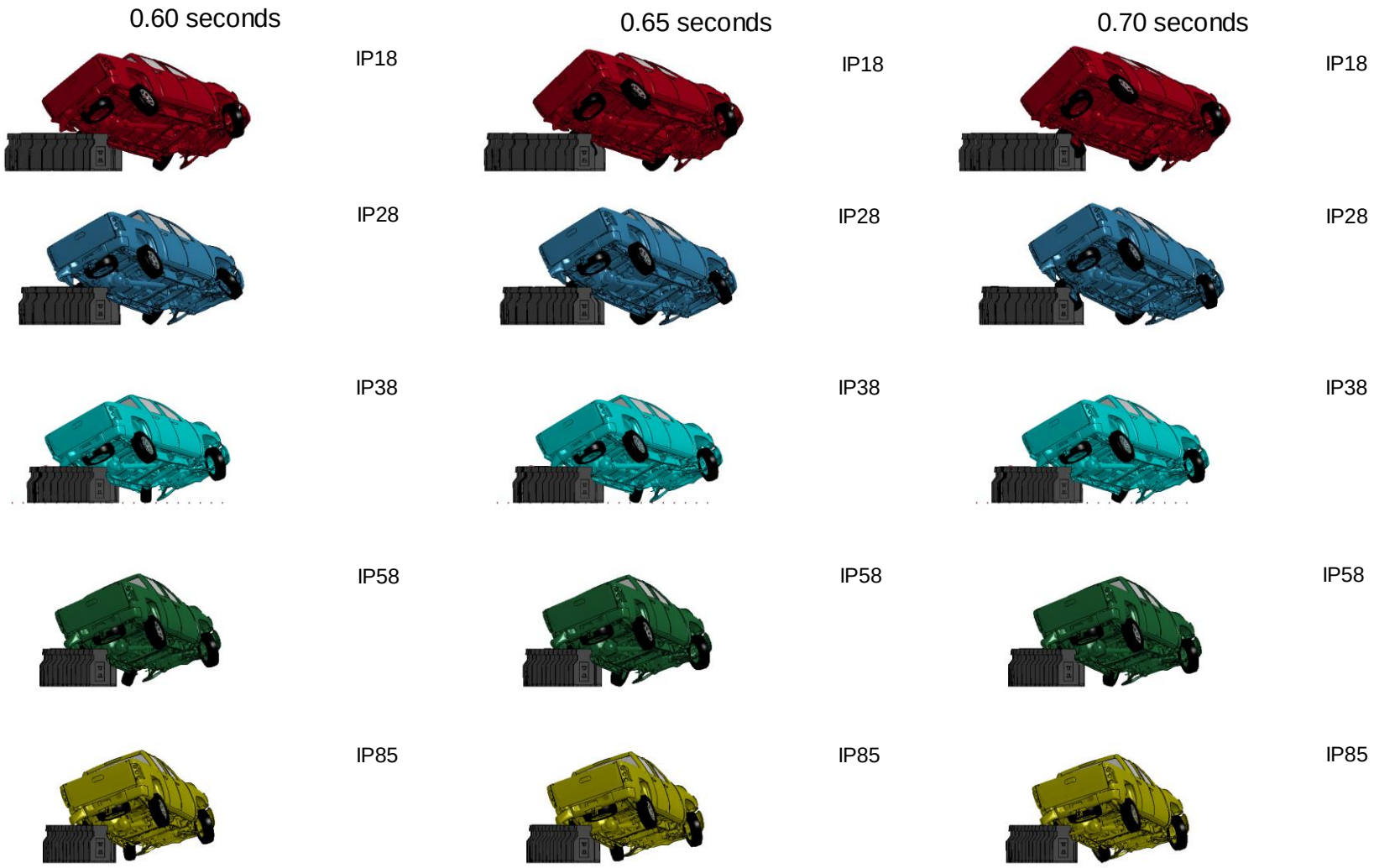


Figure G-3. [CONTINUED] Sequential views from an upstream viewpoint for IP18 through IP85.

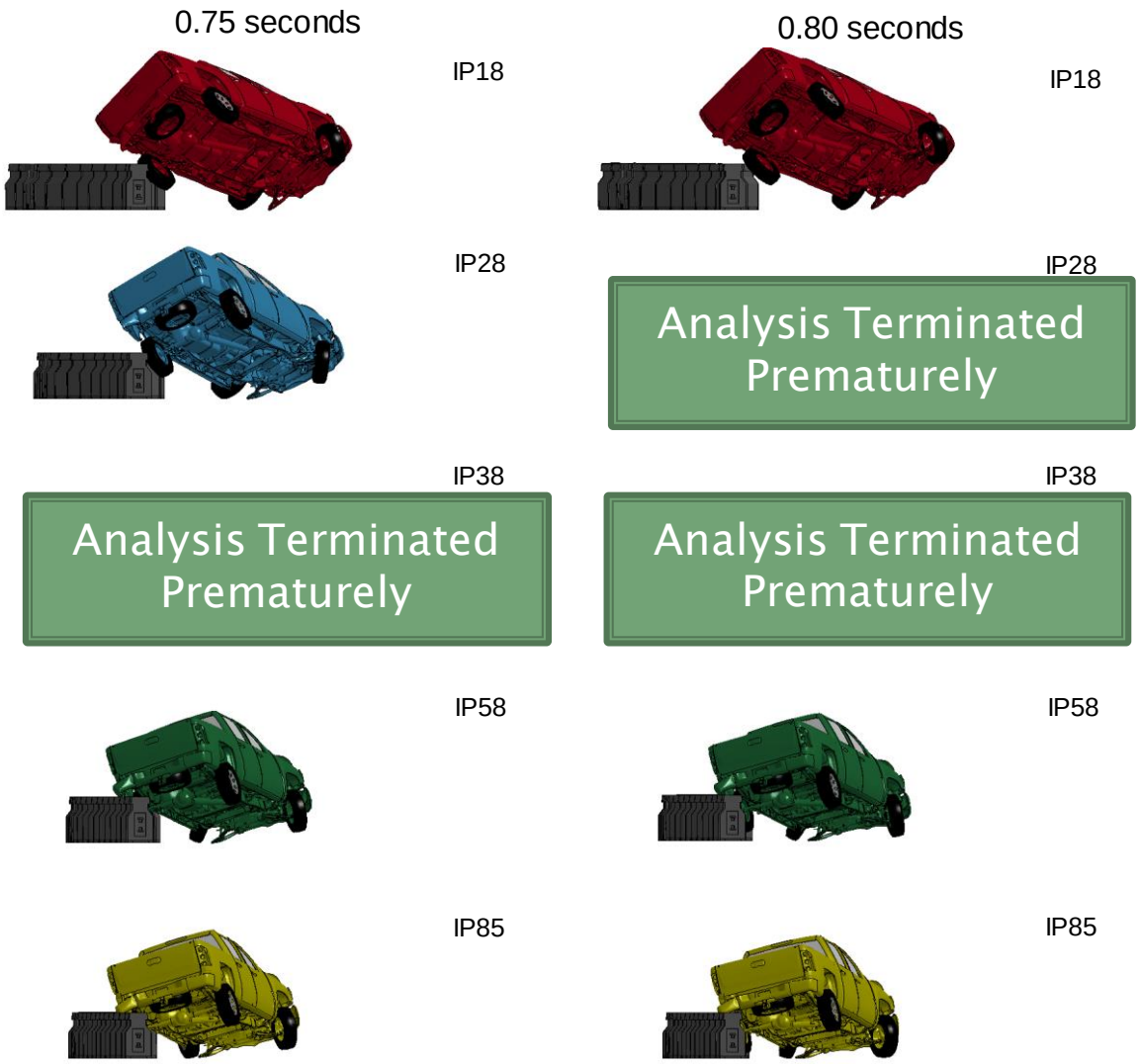


Figure G-3. [CONTINUED] Sequential views from an upstream viewpoint for IP18 through IP85.

APPENDIX H

Sequential Views for Case 2 from FEA for Trailing-End Impact Cases on the CRTS Barrier

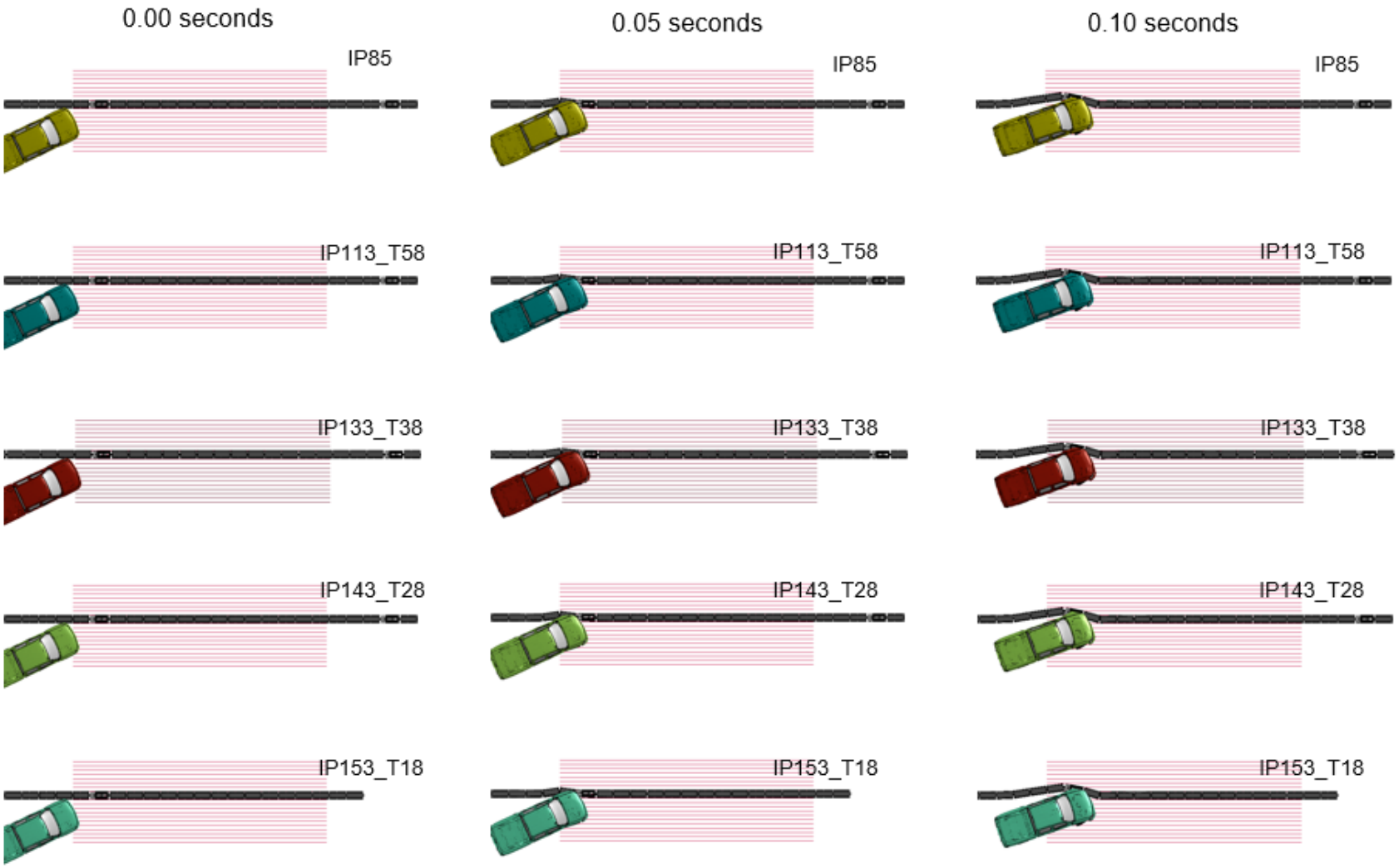


Figure H-1. Sequential views from an overhead viewpoint for IP85 through IP153_T18.

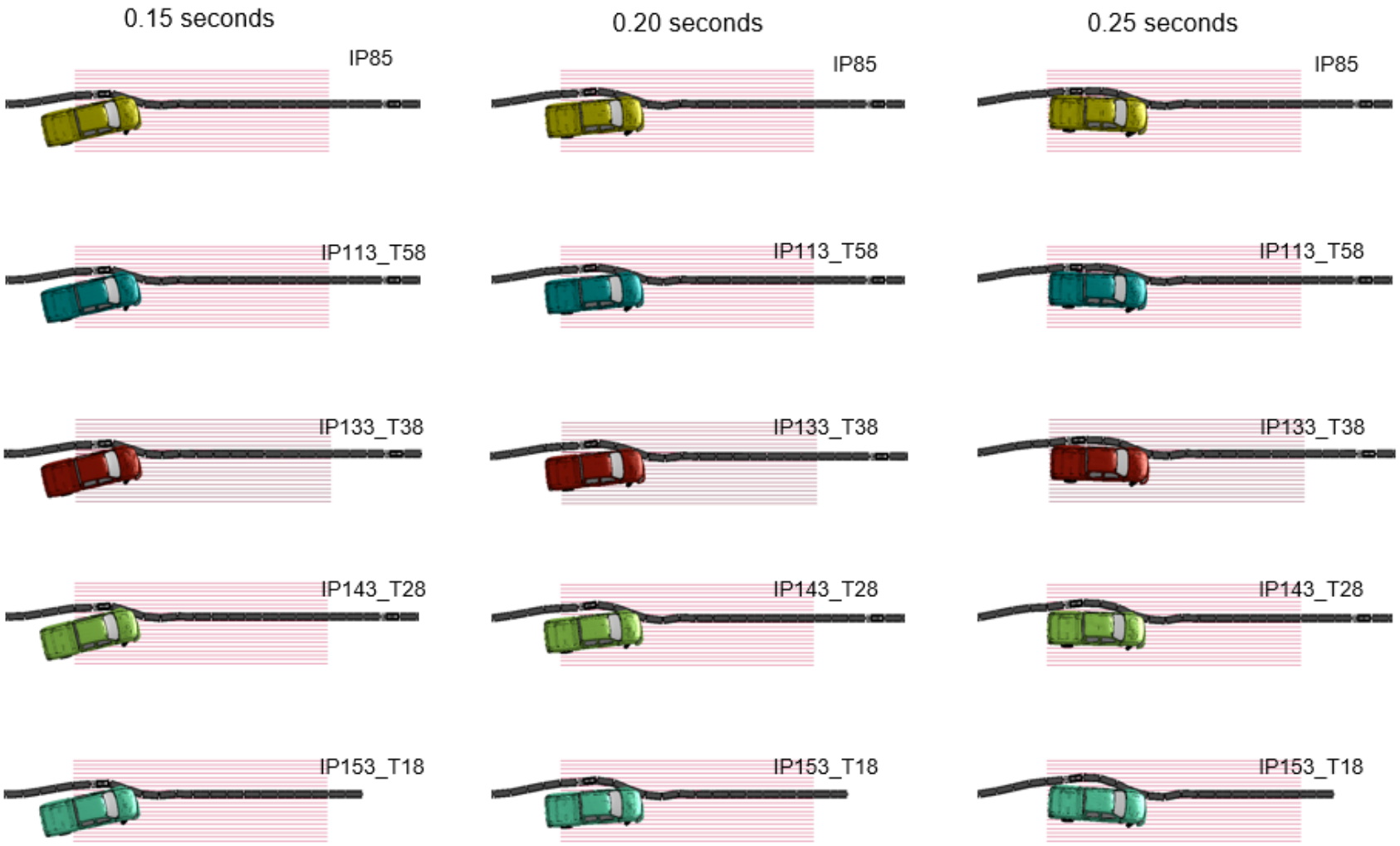


Figure H-1. [CONTINUED] Sequential views from an overhead viewpoint for IP85 through IP153_T18.

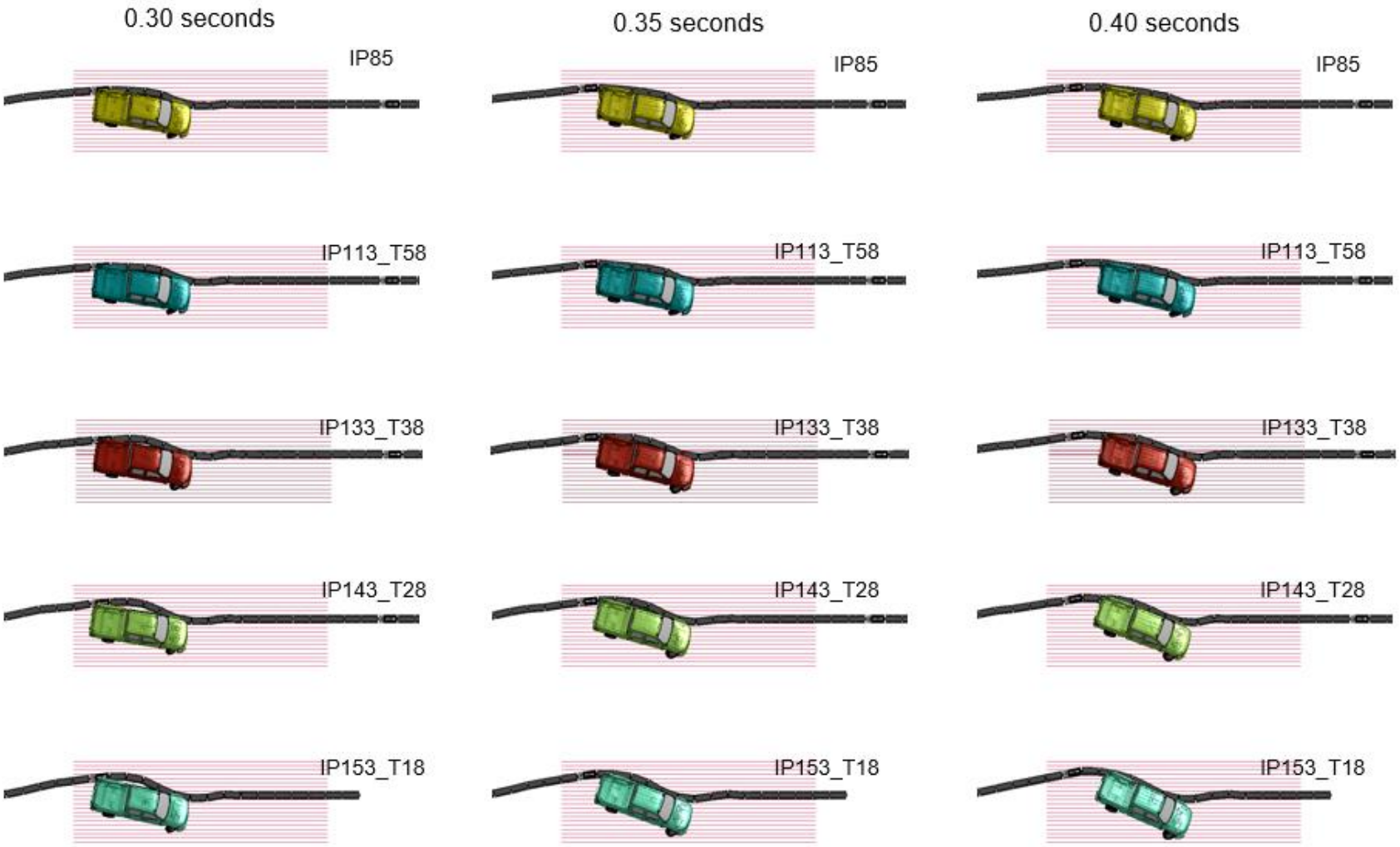


Figure H-1. [CONTINUED] Sequential views from an overhead viewpoint for IP85 through IP153_T18.

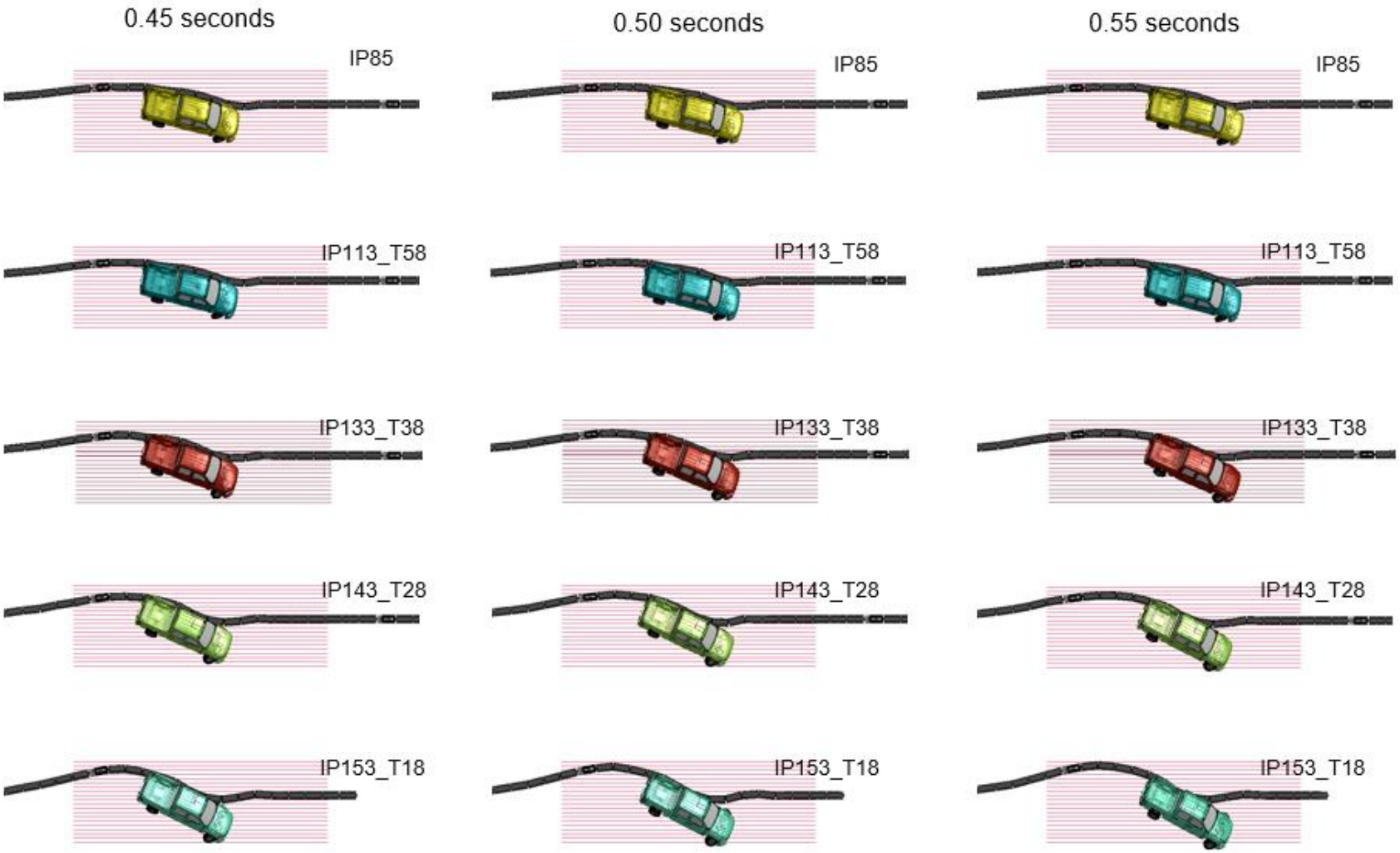


Figure H-1. [CONTINUED] Sequential views from an overhead viewpoint for IP85 through IP153_T18.

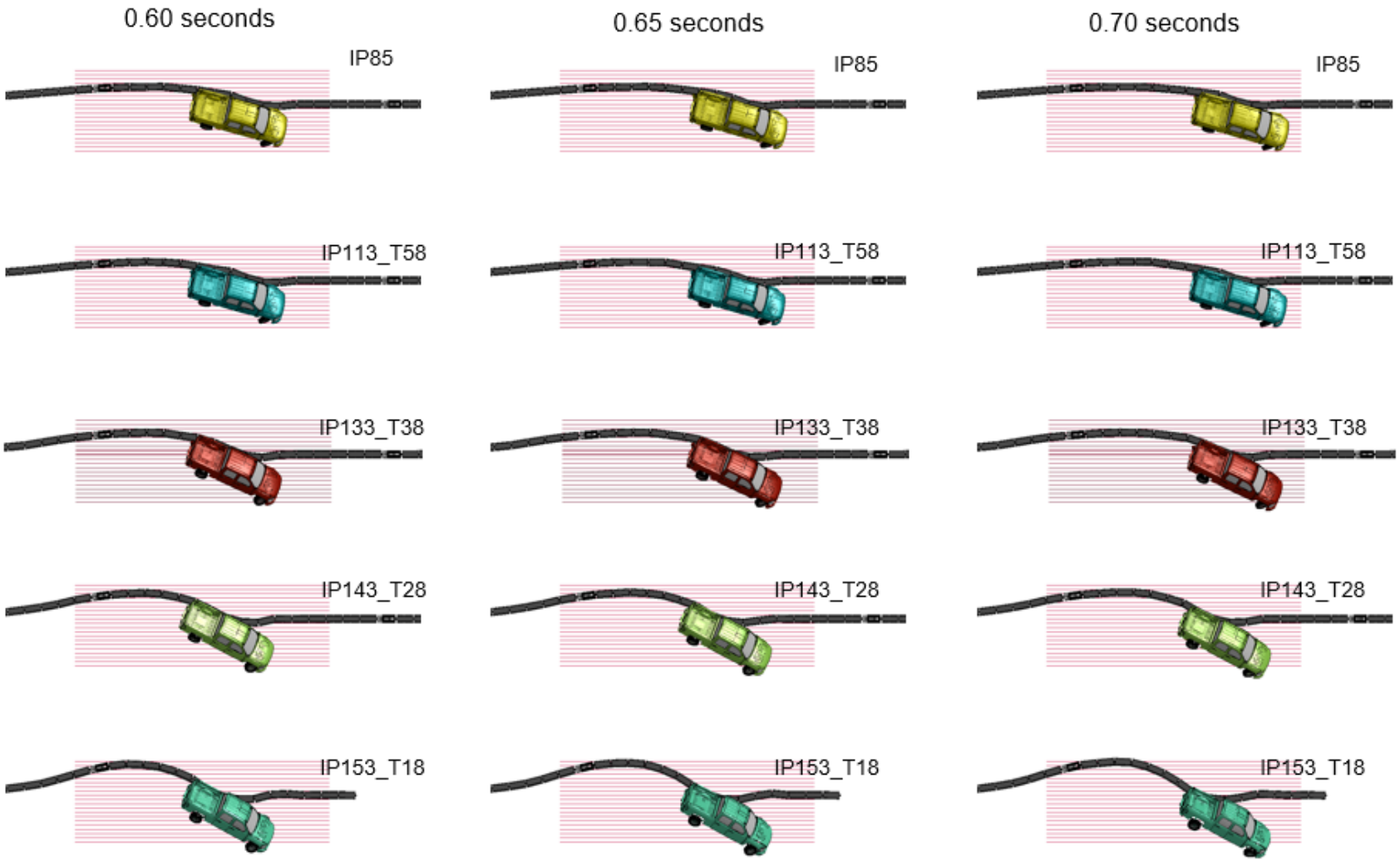


Figure H-1. [CONTINUED] Sequential views from an overhead viewpoint for IP85 through IP153_T18.

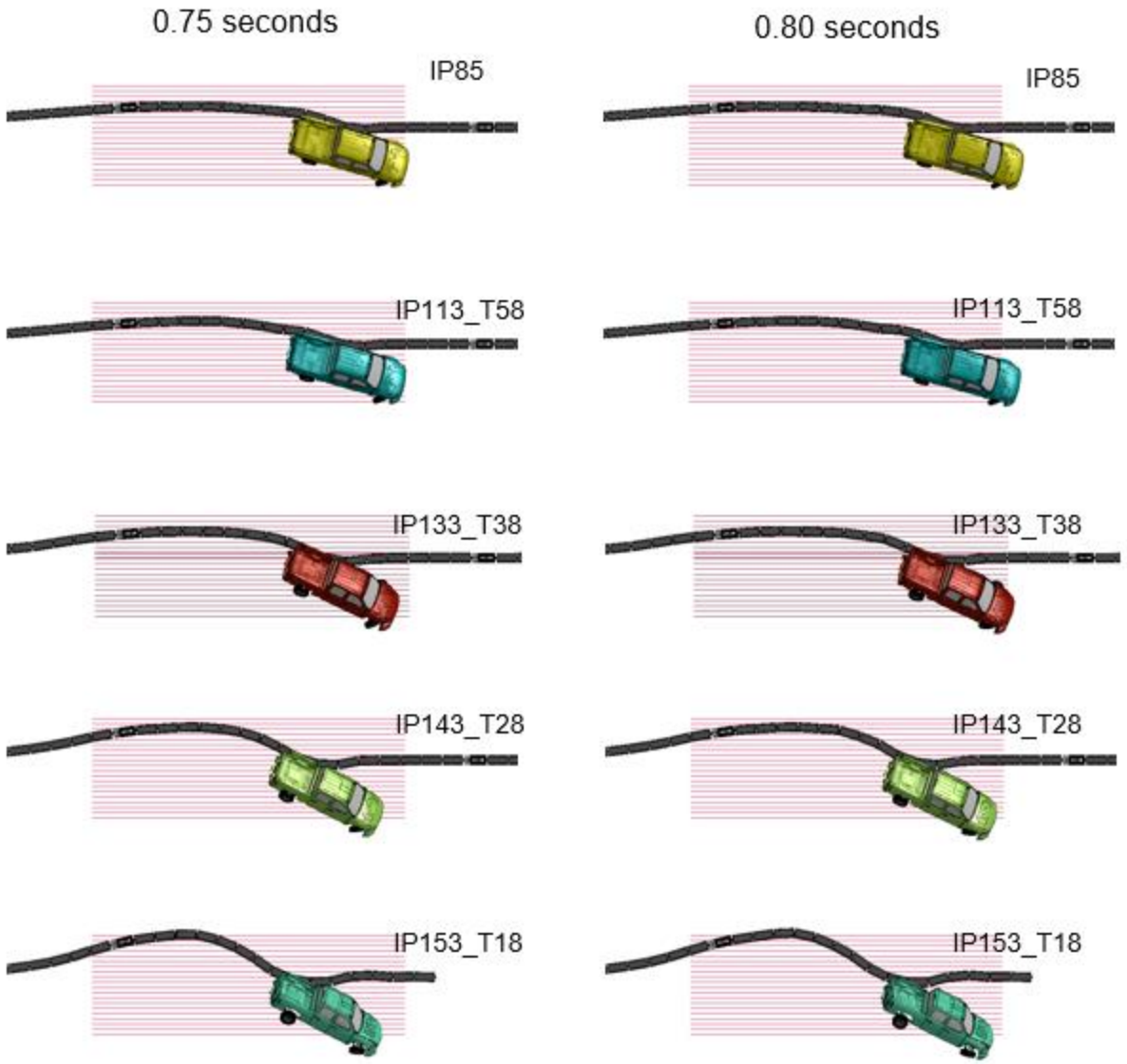


Figure H-1. [CONTINUED] Sequential views from an overhead viewpoint for IP85 through IP153_T18.

Figure H-2. Sequential views from a downstream viewpoint for IP85 through IP153_T18.

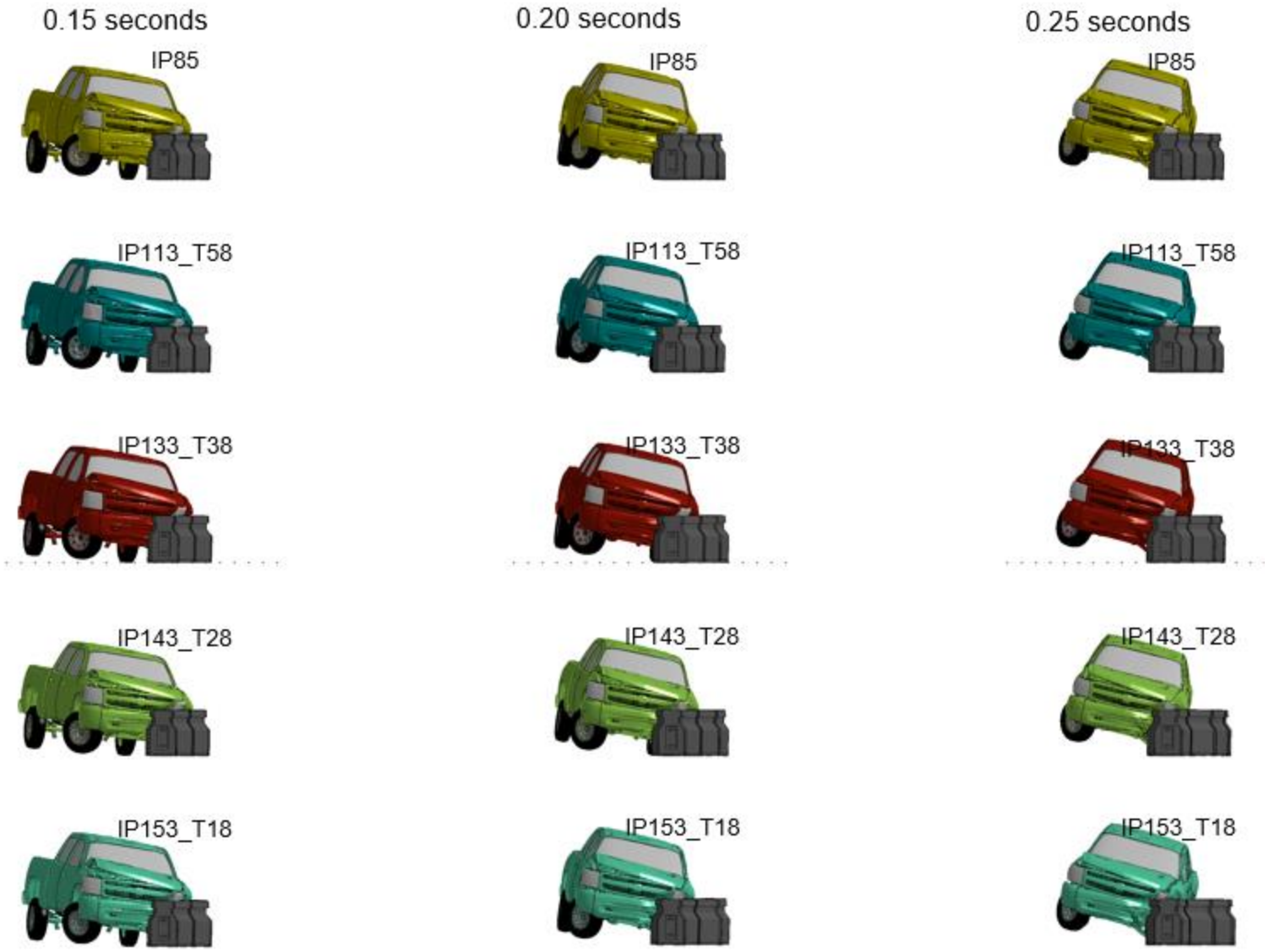


Figure H-2. [CONTINUED] Sequential views from a downstream viewpoint for IP85 through IP153_T18.

Figure H-2. [CONTINUED] Sequential views from a downstream viewpoint for IP85 through IP153_T18.

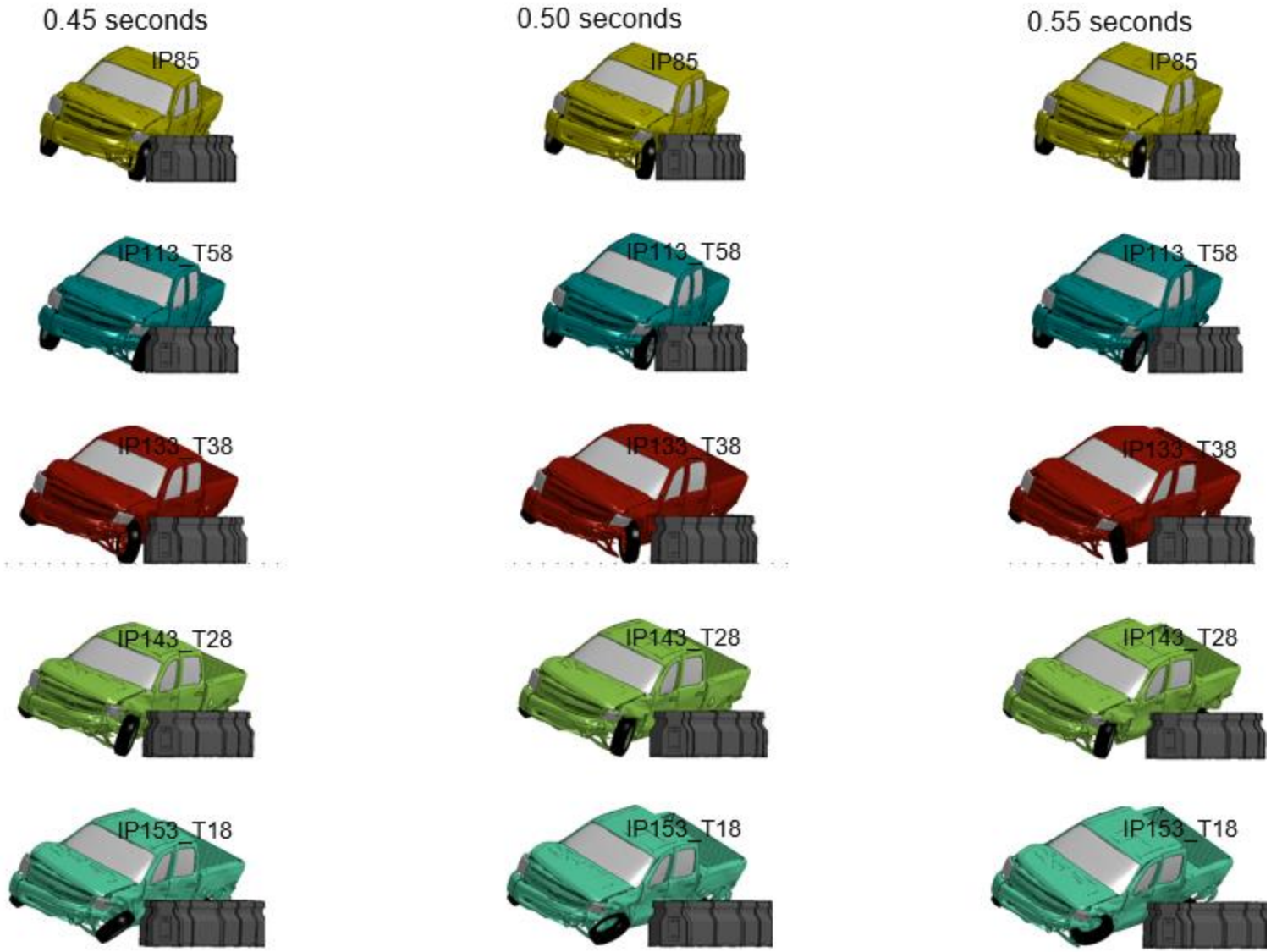


Figure H-2. [CONTINUED] Sequential views from a downstream viewpoint for IP85 through IP153_T18.

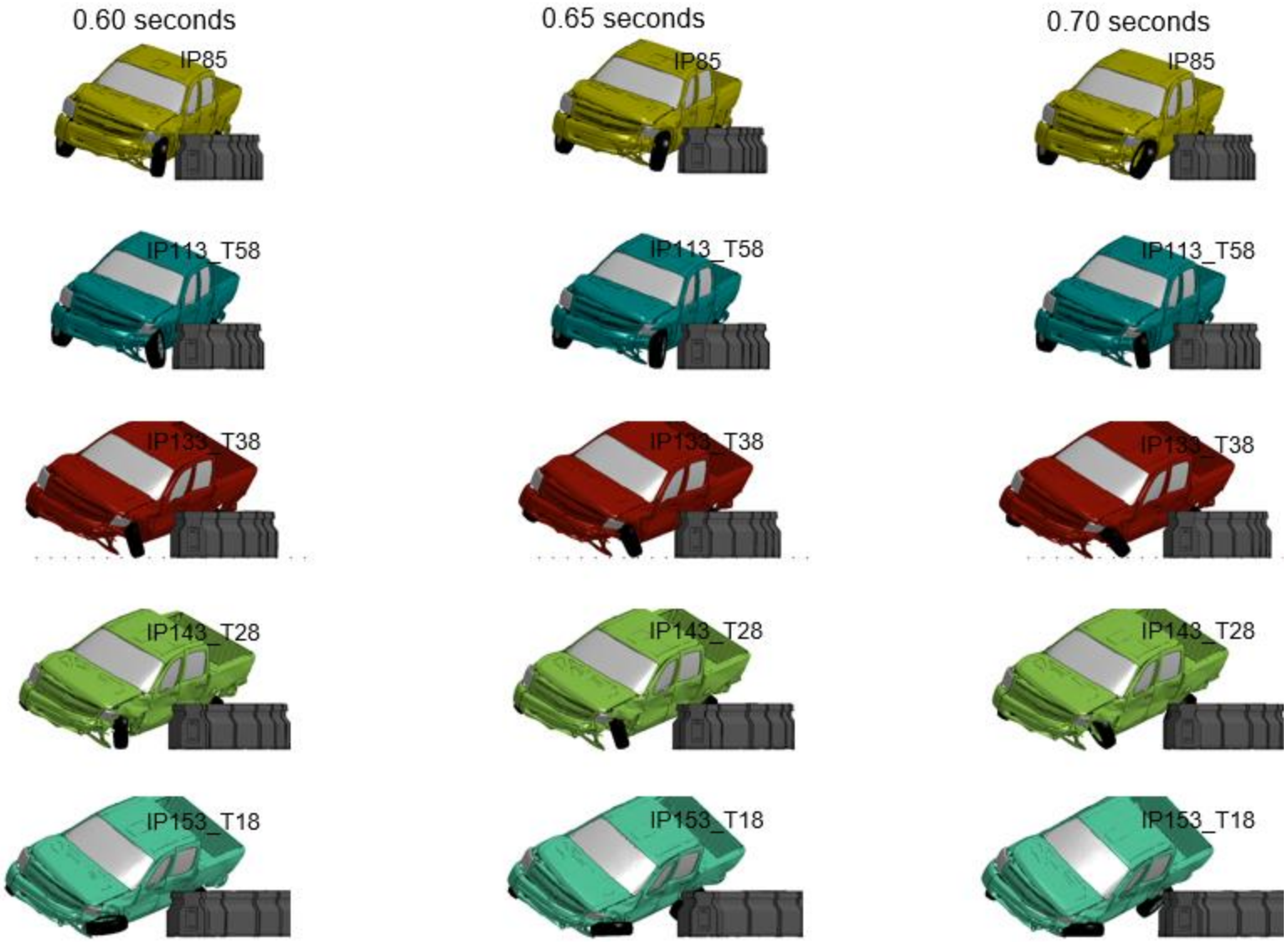


Figure H-2. [CONTINUED] Sequential views from a downstream viewpoint for IP85 through IP153_T18.

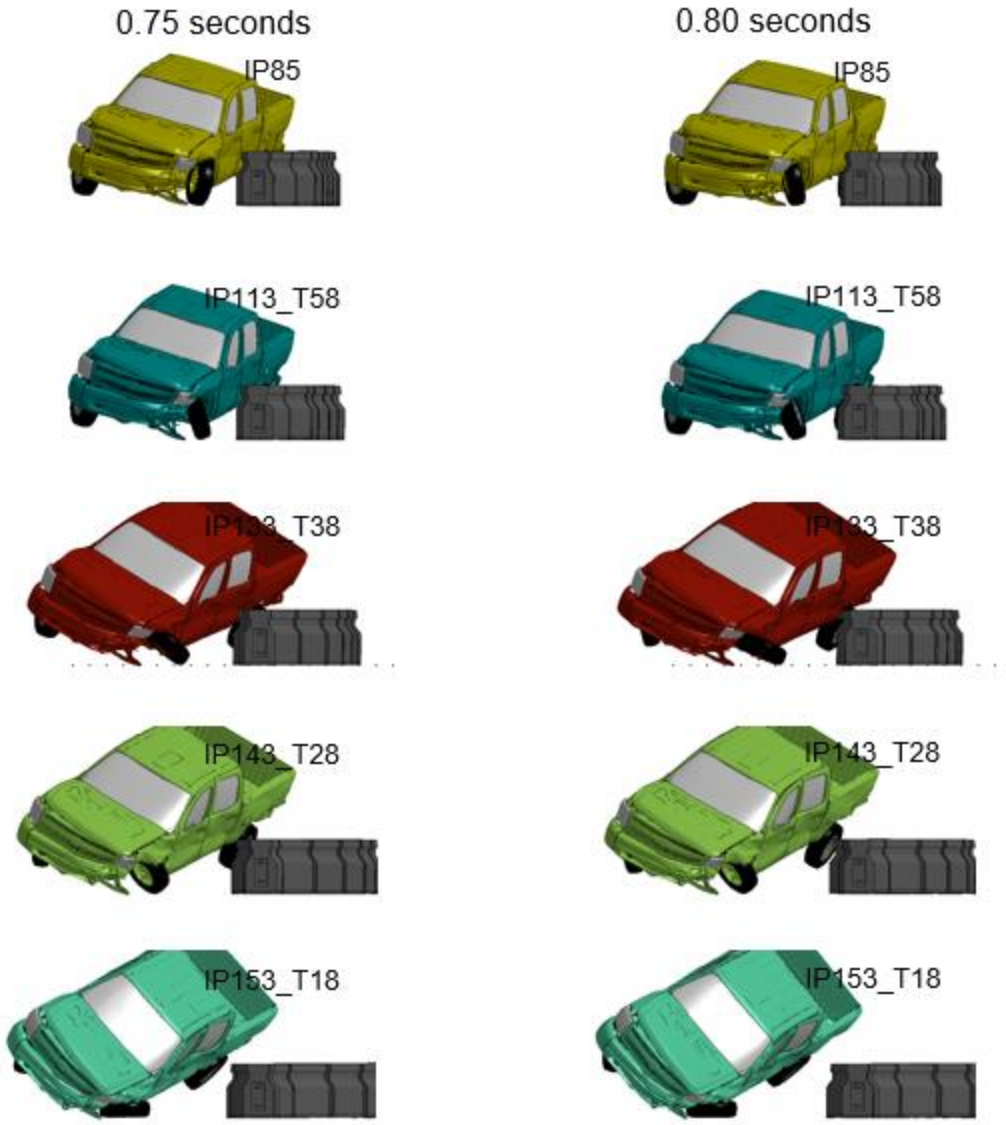


Figure H-2. [CONTINUED] Sequential views from a downstream viewpoint for IP85 through IP153_T18.

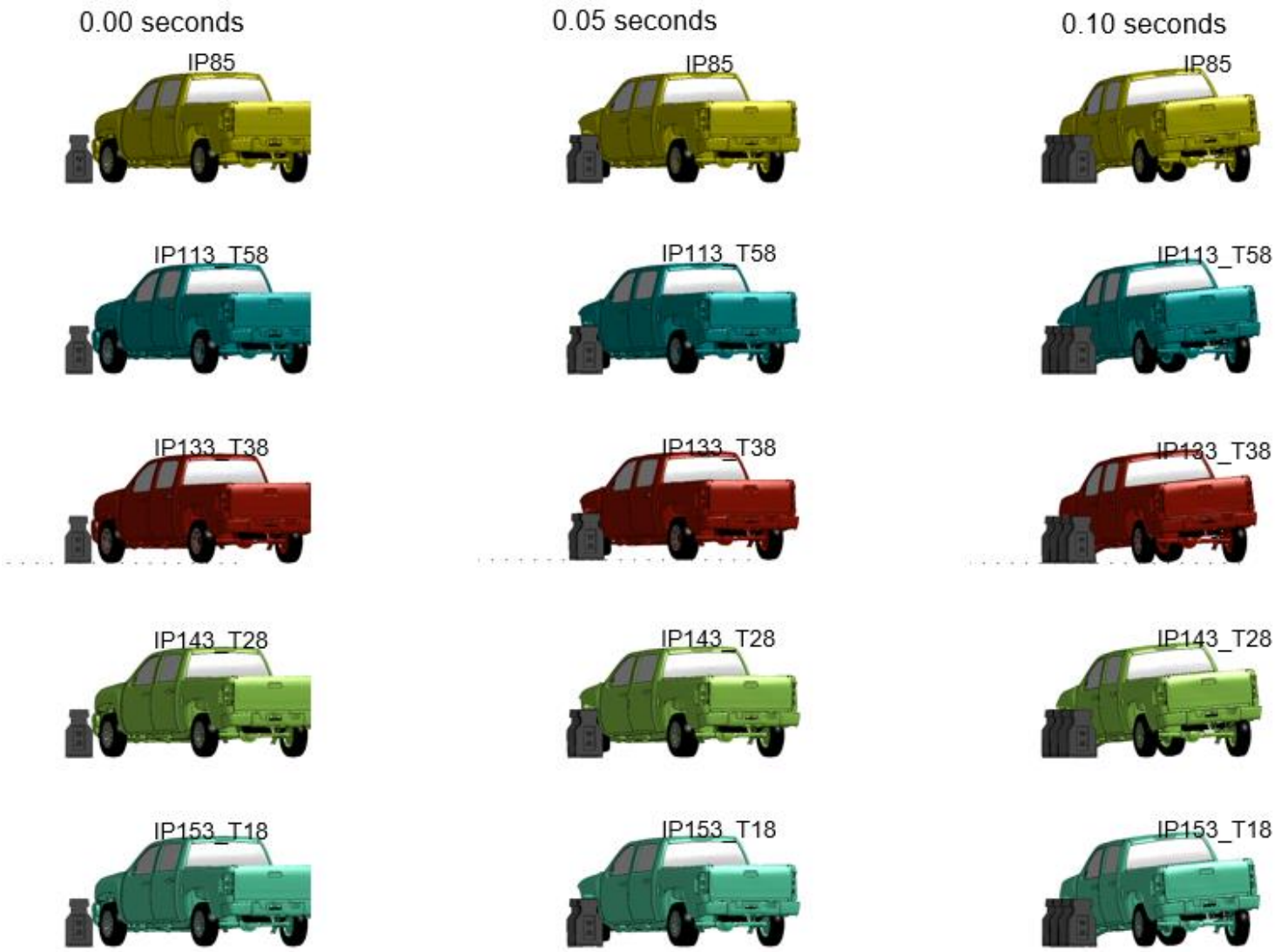


Figure H-3. Sequential views from an upstream viewpoint for IP85 through IP153_T18.

Figure H-3. [CONTINUED] Sequential views from an upstream viewpoint for IP85 through IP153_T18.

Figure H-3. [CONTINUED] Sequential views from an upstream viewpoint for IP85 through IP153_T18.

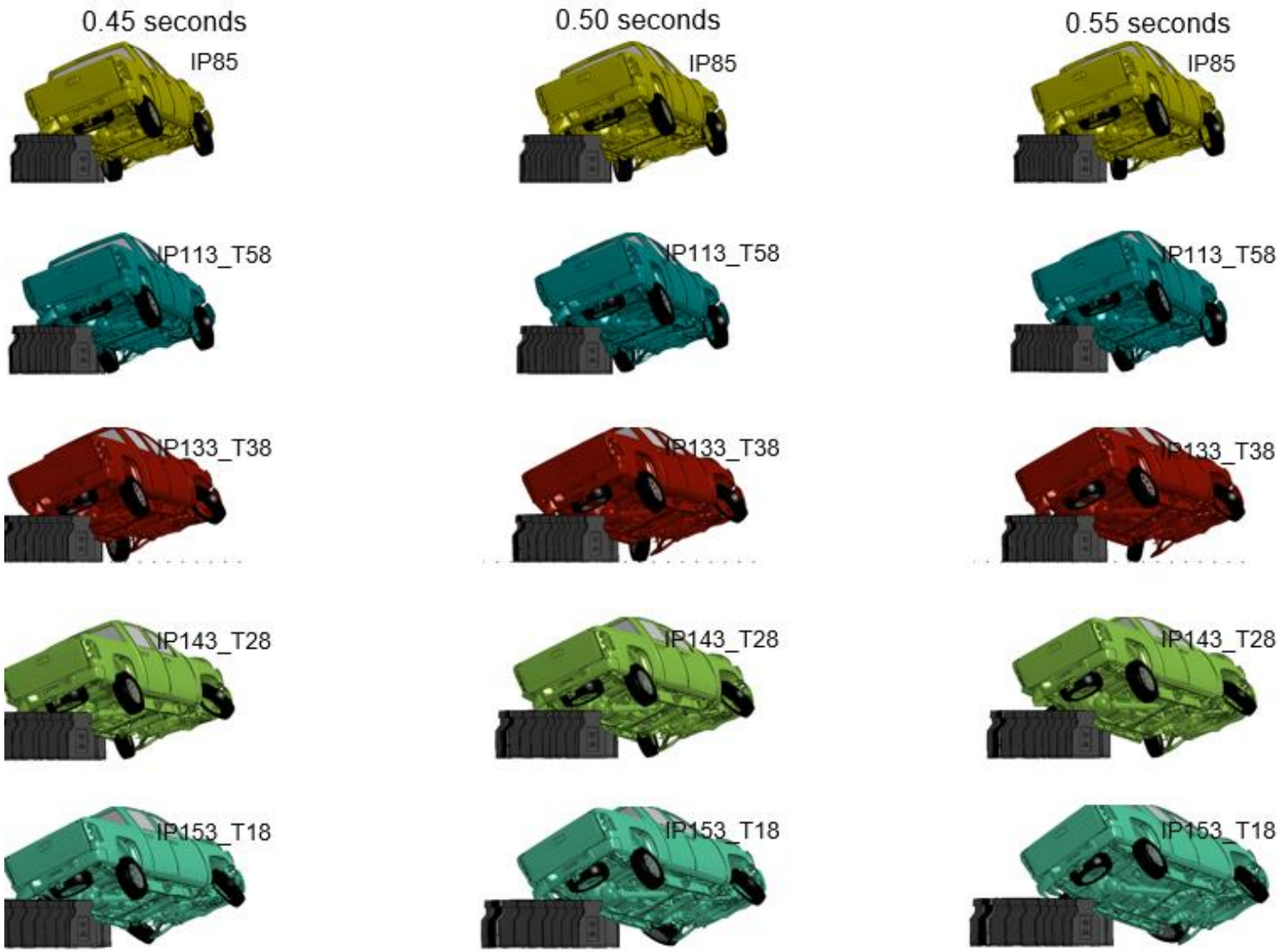


Figure H-3. [CONTINUED] Sequential views from an upstream viewpoint for IP85 through IP153_T18.

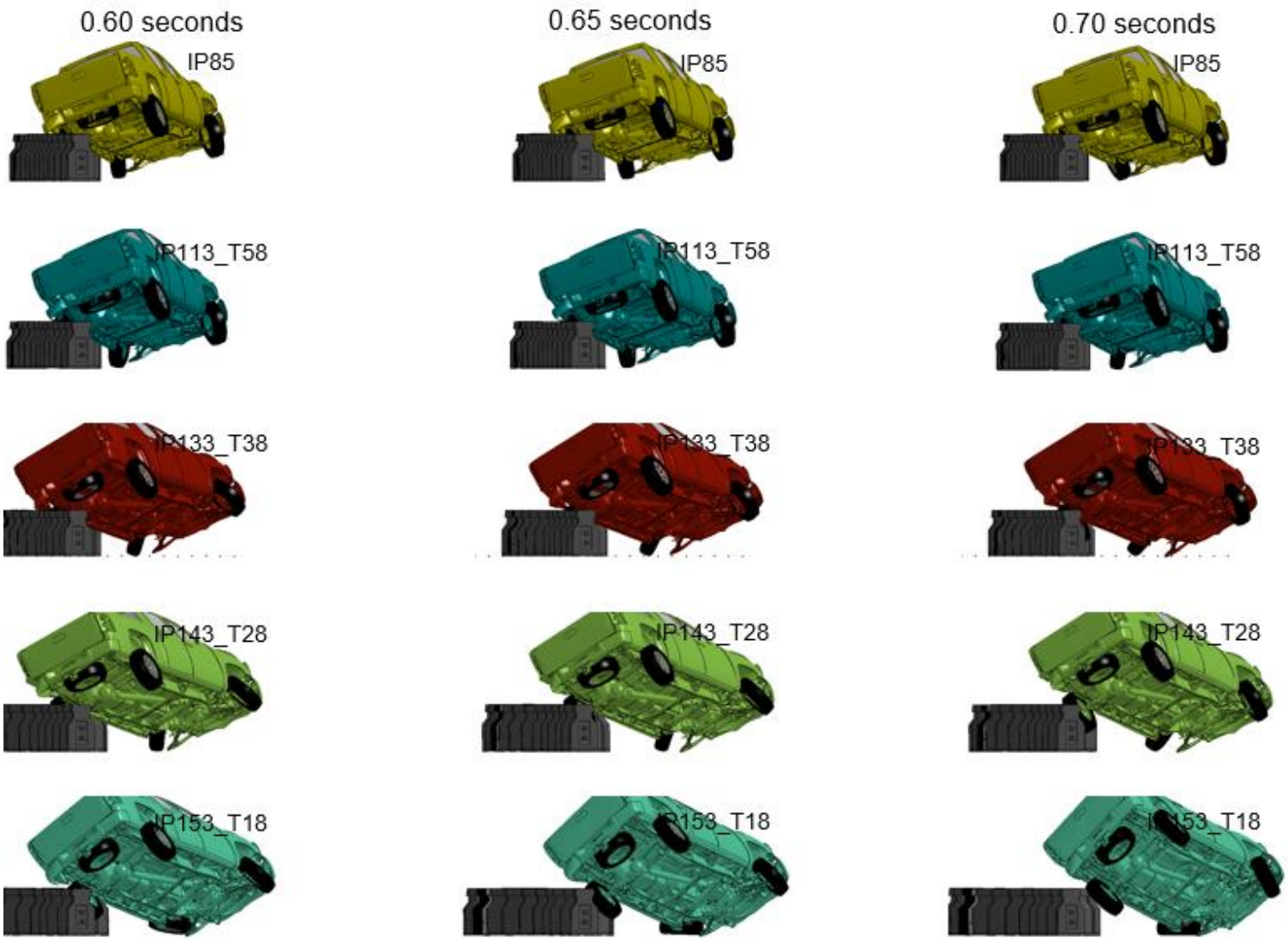


Figure H-3. [CONTINUED] Sequential views from an upstream viewpoint for IP85 through IP153_T18.

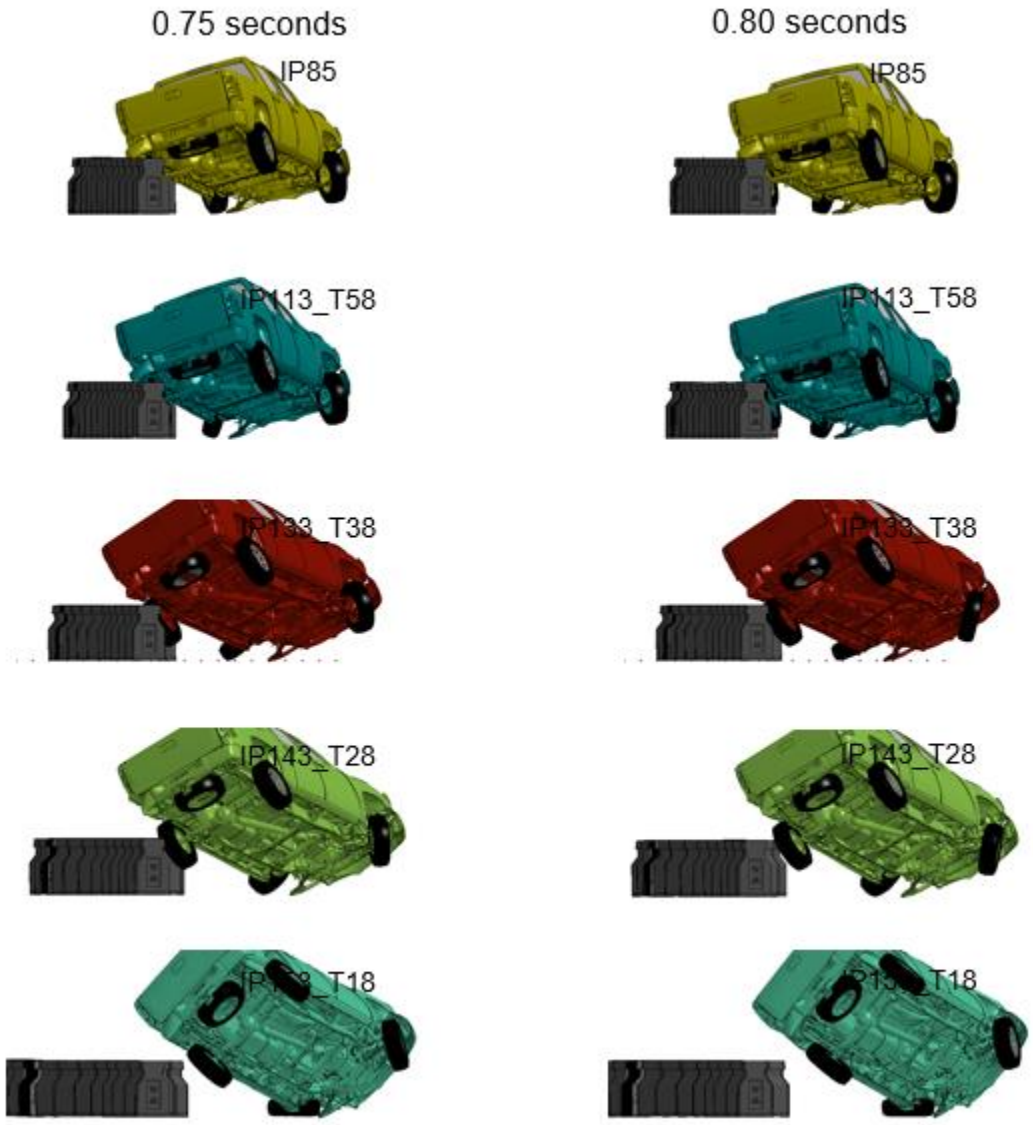


Figure H-3. [CONTINUED] Sequential views from an upstream viewpoint for IP85 through IP153_T18.

APPENDIX I

Exit Box for Case 2 (with VLB's)

Exit Box – Criteria

*Taken from MASH, pg. 98

Distance for Exit Box Criterion

Vehicle Type	A ft (m)	B ft (m)
Car/Pickup	$7.2 + V_W + 0.16V_L$ ($2.2 + V_W + 0.16V_L$)	32.8 (10.0)
Other Vehicles	$14.4 + V_W + 0.16V_L$ ($4.4 + V_W + 0.16V_L$)	65.6 (20.0)

V_W = Vehicle Width
V_L = Vehicle Length

V_W = 6.5 ft. (measured from model)
V_L = 19.06 ft. (measured from model)
A = 16.78 ft.
B = 32.8 ft.

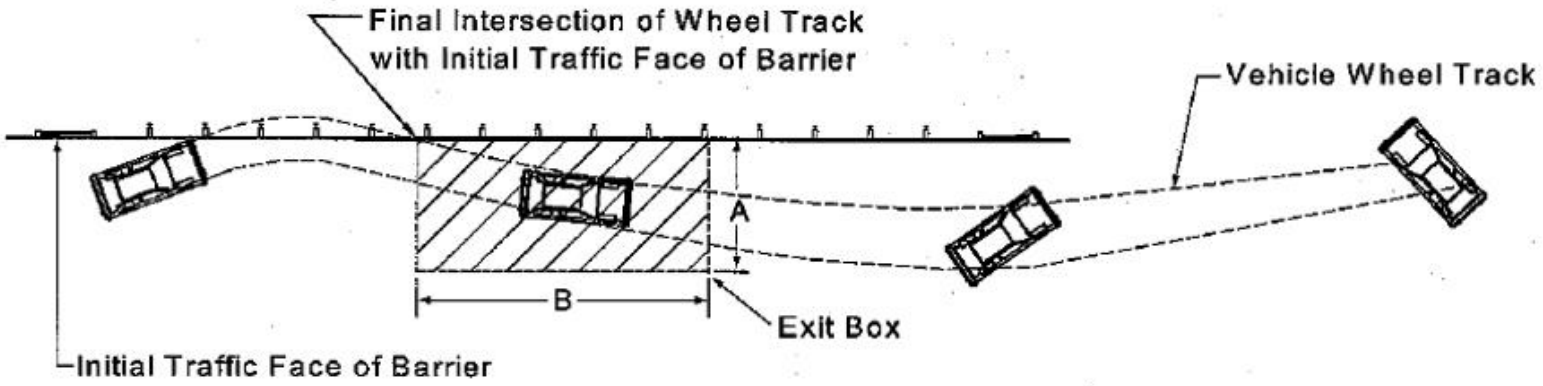


Figure 5-1. Exit Box for Longitudinal Barriers

Figure I-1. Exit box criteria.

The driver-side rear tire wheel track was used to determine the beginning location of the exit box. From MASH pg. 97: "All wheel tracks of the vehicle should not cross the parallel line within the distance B." In all cases, the passenger-side front tire wheel track was most likely to cross the parallel line within distance B, and was used to visually extrapolate vehicle wheel-track trajectory.

	Impact Conditions	
Case	Point	Within Exit Box?
1	18	Questionable
2	28	Yes
3	38	Yes
4	58	Yes
5	85	Yes
6	113_T58	Yes
7	133_T38	Questionable
8	143_T28	Questionable
9	153_T18	Questionable

Figure I-2. Exit box results.

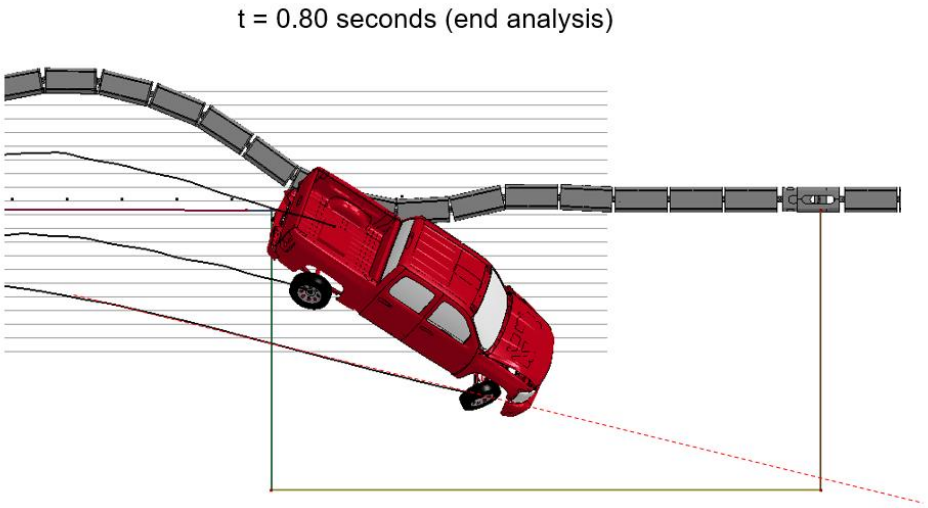


Figure I-3. Exit box for Impact Point 18.

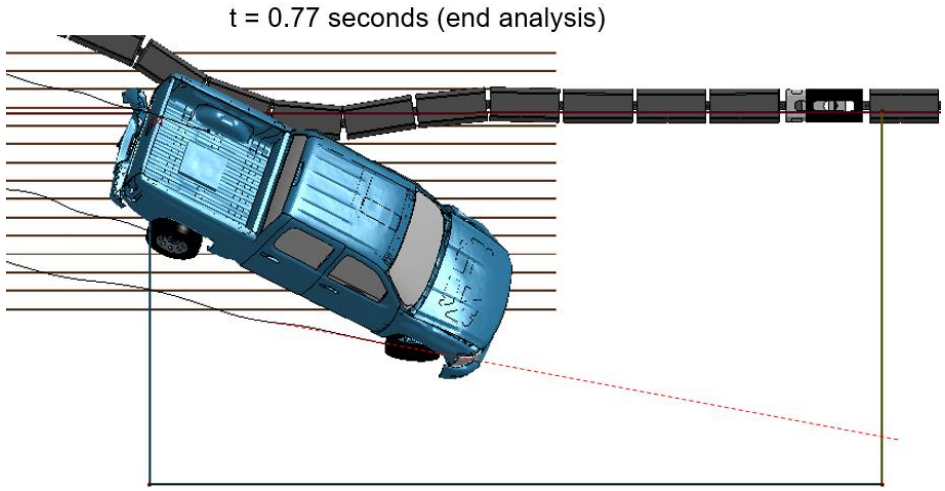


Figure I-4. Exit box for Impact Point 28.

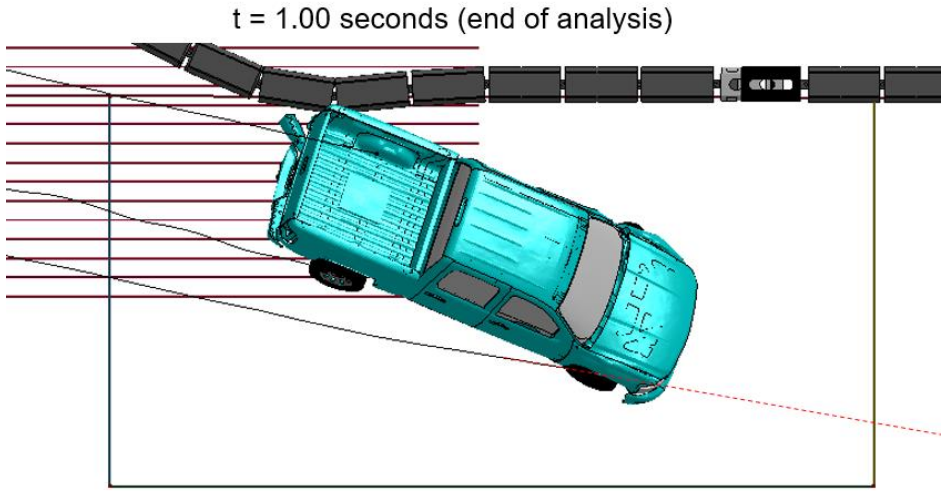


Figure I-5. Exit box for Impact Point 38.

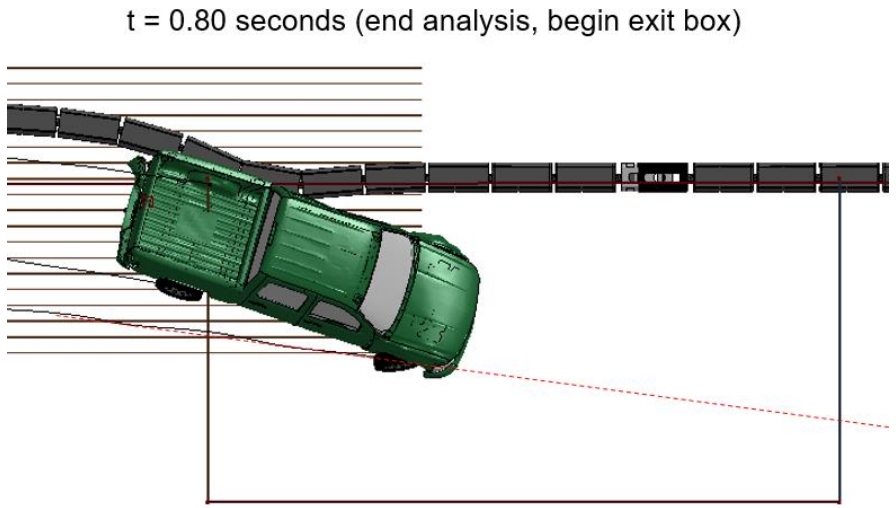


Figure I-6. Exit box for Impact Point 58.

t = 1.20 seconds (end analysis)

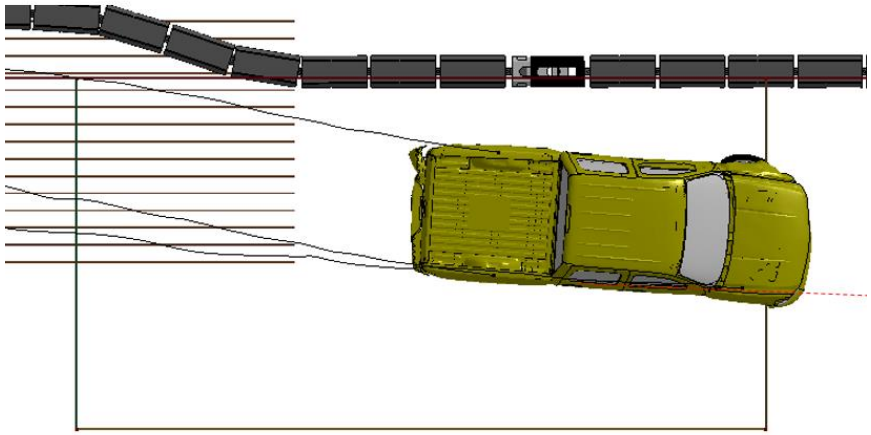


Figure I-7. Exit box for Impact Point 85.

t = 0.80 seconds (end of analysis, begin exit box)

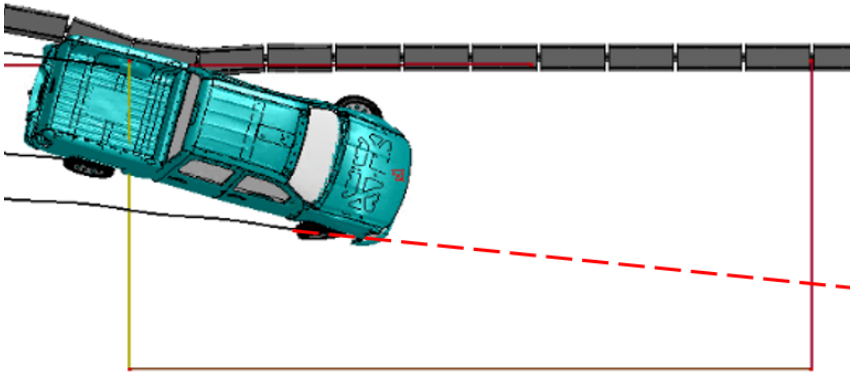


Figure I-8. Exit box for Impact Point 113_T58.

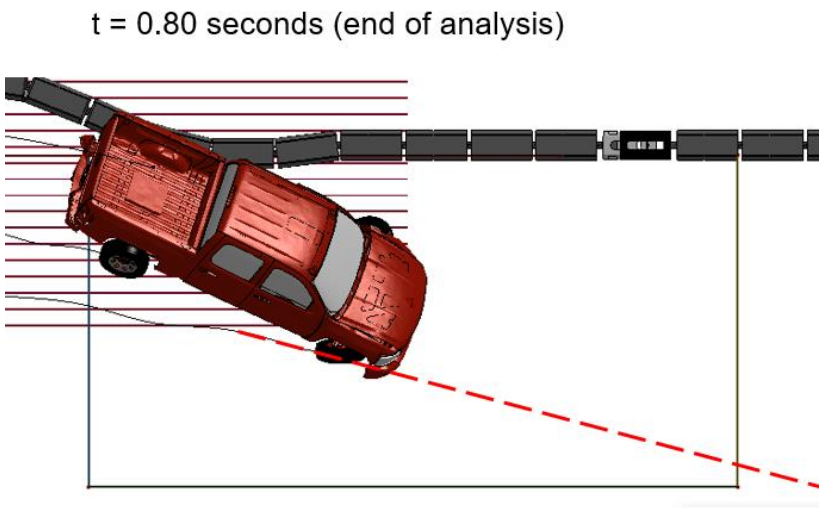


Figure I-9. Exit box for Impact Point 133_T38.

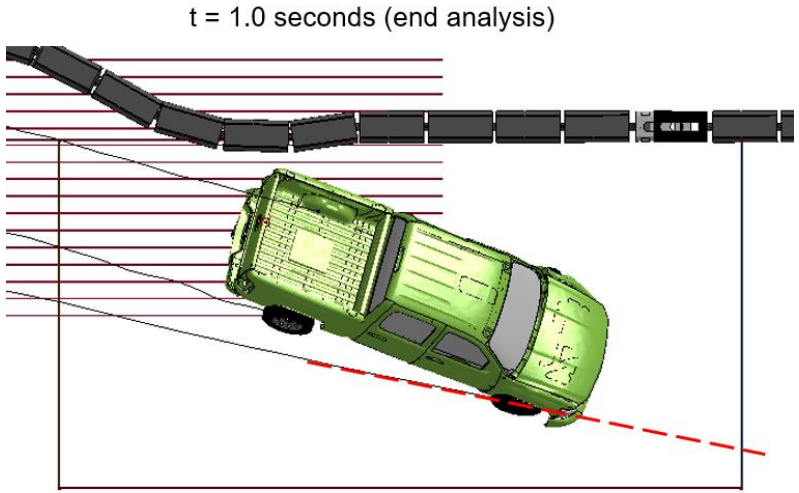


Figure I-10. Exit box for Impact Point 143_T28.

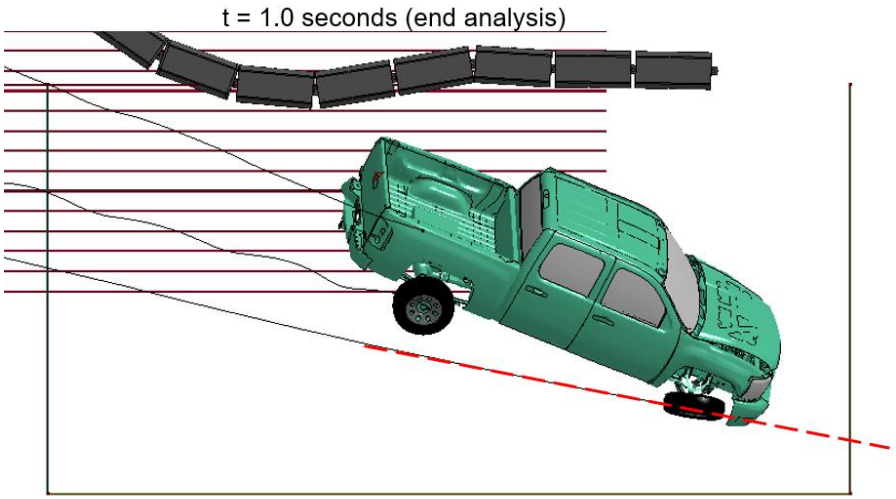


Figure I-11. Exit box for Impact Point 153_T18.

APPENDIX J

VERIFICATION & VALIDATION REPORTS

Validation Reports

- **Appendix J-1: NJ Concrete Barrier Impact with 2270P Vehicle**
- **Appendix J-2: G4(1S) Barrier Impact with 2270P Vehicle**
- **Appendix J-3: MGS Barrier Impact with 2270P Vehicle**

Each of the Reports Includes:

- **Table 1A – V&V Summary Table (Page 1 of 4)**
- **Table 1B – V&V Analysis Solution Verification Summary Table & RSVVP Results (Page 2 of 4)**
- **Figure 1 – Energy Balance Diagram**
- **Figure 2A – RSVVP Multi-Channel Comparison**
- **Figure 2B – RSVVP Longitudinal Acceleration Comparison**
- **Figure 2C – RSVVP Lateral Acceleration Comparison**
- **Figure 2D – RSVVP Vertical Acceleration Comparison**
- **Figure 2E – RSVVP Roll Angle Comparison**
- **Figure 2F – RSVVP Pitch Angle Comparison**
- **Figure 2G– RSVVP Yaw Angle Comparison**
- **Figure 3 – Comparison of Changes in Vehicle Velocities**
- **Figure 4 – Comparison of Changes in Vehicle Angles**
- **Table 1C – V&V PIRTs Summary Table (Page 3 of 4)**
- **Figure 5 – Full-Scale Test Summary**
- **Figure 6 – Sequential Comparisons (Front, rear, and top views)**
- **Table 1D – V&V Overall Summary Table (Page 4 of 4)**

Appendix J-1: New Jersey Concrete Barrier Impact with 2270P Vehicle

CCSA VALIDATION/VERIFICATION REPORT

Project: **CCSA Longitudinal Barriers on Curved, Superelevated Roadway Sections**
Comparison Case: **2270P Vehicle with New Jersey Safety Shape Barrier**
Impact Description: **25 degree impact into barrier at 100 km/h (62 mph)**
Governing Criteria: **MASH TL-3**
Report Date: **February 2013**

Table A – Information Sources:

General Information	Known Solution	Analysis Solution
Performing Organization	TTI	CCSA-GWU
Test/Run Number	RF476460-1-4	
Vehicle	2007 Chevrolet Silverado	CCSA - 2007 Silverado Model
Vehicle Mass (lb/kg)	5049 / 2290	5005 / 2270
Impact Speed (mph/kph)	62.6 / 100.75	62.6 / 100.75
Impact Angle (degrees)	25.2	25.2

Table B - Evaluation Parameters Summary:

Category	Subset	Values
Evaluation Method	MASH (V1, 2009)	
Hardware Type	Longitudinal	
Test Number	3-11	
Test Vehicle Required	2270P	
Criterion to be Applied	**Structural Adequacy**	**A -** Test article should contain and redirect the vehicle; the vehicle should not penetrate, under-ride, or override the installation although controlled lateral deflection of the test article is acceptable.
	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.
		F - The vehicle should remain upright during and after the collision although moderate roll, pitching and yawing are
		H - The occupant impact velocity in the longitudinal direction should not exceed 40 ft/sec and the occupant ride-down acceleration in the longitudinal direction should not exceed 20 G"s.
		I - Longitudinal & lateral occupant ridedown accelerations (ORA) should fall below the preferred value of 15.0 g, or at least below the maximum allowed value of 20.49 g.
	Vehicle Trajectory	For redirective devices the vehicle shall exit within the prescribed box.

Project: CCSA Longitudinal Barriers on Curved, Superelevated Roadway Sections
Comparison Case: 2270P Vehicle with New Jersey Safety Shape Barrier

Table C – Analysis Solution Verification Summary

Verification Evaluation Criteria	Change (%)	Pass?
Total energy of the analysis solution (i.e., kinetic, potential, contact, etc.) must not vary more than 10 percent from the beginning of the run to the end of the run.	<1%	YES
Hourglass Energy of the analysis solution at the end of the run is less than 5 % of the total initial energy at the beginning of the run	<1%	YES
The part/material with the highest amount of hourglass energy at any time during the run is less than 5 % of the total initial energy at the beginning of the run.	<1%	YES
Mass added to the total model is less than 5 % the total model mass at the start of the run.	<1%	YES
The part/material with the most mass added had less than 10 % of its initial mass added.	<1%	YES
The moving parts/materials in the model have less than 5 % of mass added to the initial moving mass of the model.	<1%	YES
There are no shooting nodes in the solution?	NA	YES
There are no solid elements with negative volumes?	NA	YES

Table D - RSVVP Results

Single Channel Time History Comparison Results			Time interval [0 sec - 0.5 sec]		
O	***Sprague-Geer Metrics***		**M**	**P**	**Pass?**
	X acceleration		52.9	35.6	NO
	Y acceleration		3.2	16.2	YES
	Z acceleration		71.7	45.3	NO
	Yaw rate		13.4	9.5	YES
	Roll rate		16.8	24.4	YES
	Pitch rate		35.4	39.9	YES
P	***ANOVA Metrics***		**Mean**	**SD**	**Pass?**
	X acceleration/Peak		1.32	29.37	YES
	Y acceleration/Peak		0.84	12.15	YES
	Z acceleration/Peak		0.66	44.94	NO
	Yaw rate		0.2	14.87	YES
	Roll rate		0.21	17.28	YES
	Pitch rate		10.86	53.95	NO
Multi-Channel Weighting Factors			**Time interval [0 sec; 0.5 sec]**		
Multi-Channel Weighting Method		**X Channel**	0.142263141		
Peaks Area I		**Y Channel**	0.312496147		
Area II Inertial		**Z Channel**	0.045240712		
		Yaw Channel	0.19476326		
		Roll Channel	0.200826808		
		Pitch Channel	0.104409933		
Sprague-Geer Metrics			**M**	**P**	**Pass?**
	All Channels (weighted)		21.4	23.1	YES
ANOVA Metrics			**Mean**	**SD**	**Pass?**
	All Channels (weighted)		1.5	22	YES

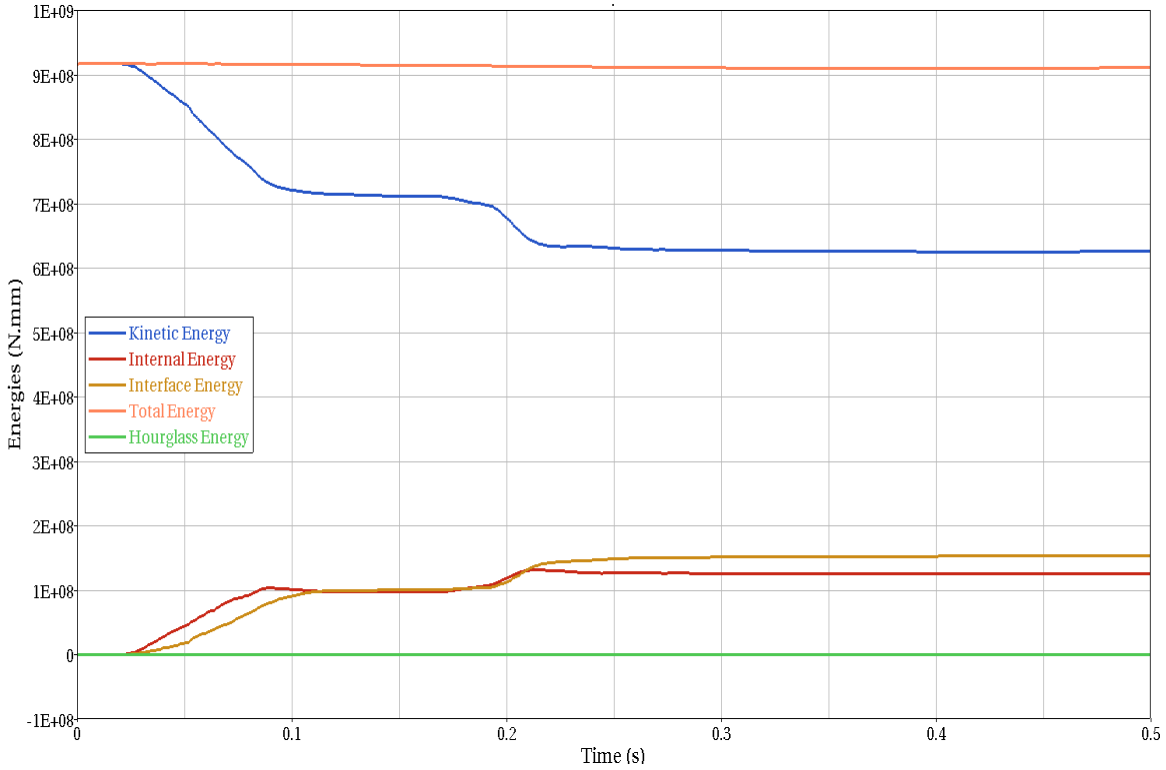


Figure 1: Simulations Energies

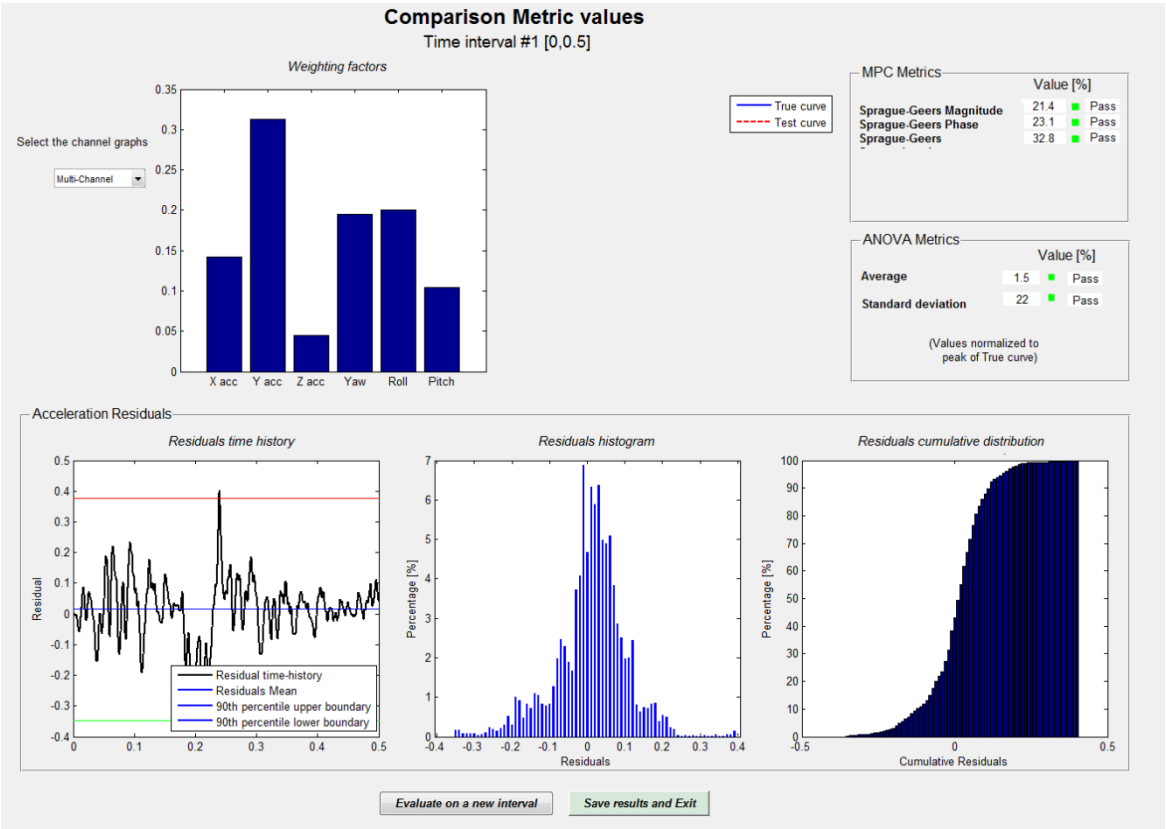


Figure 2a: RSVVP Results – All Channels

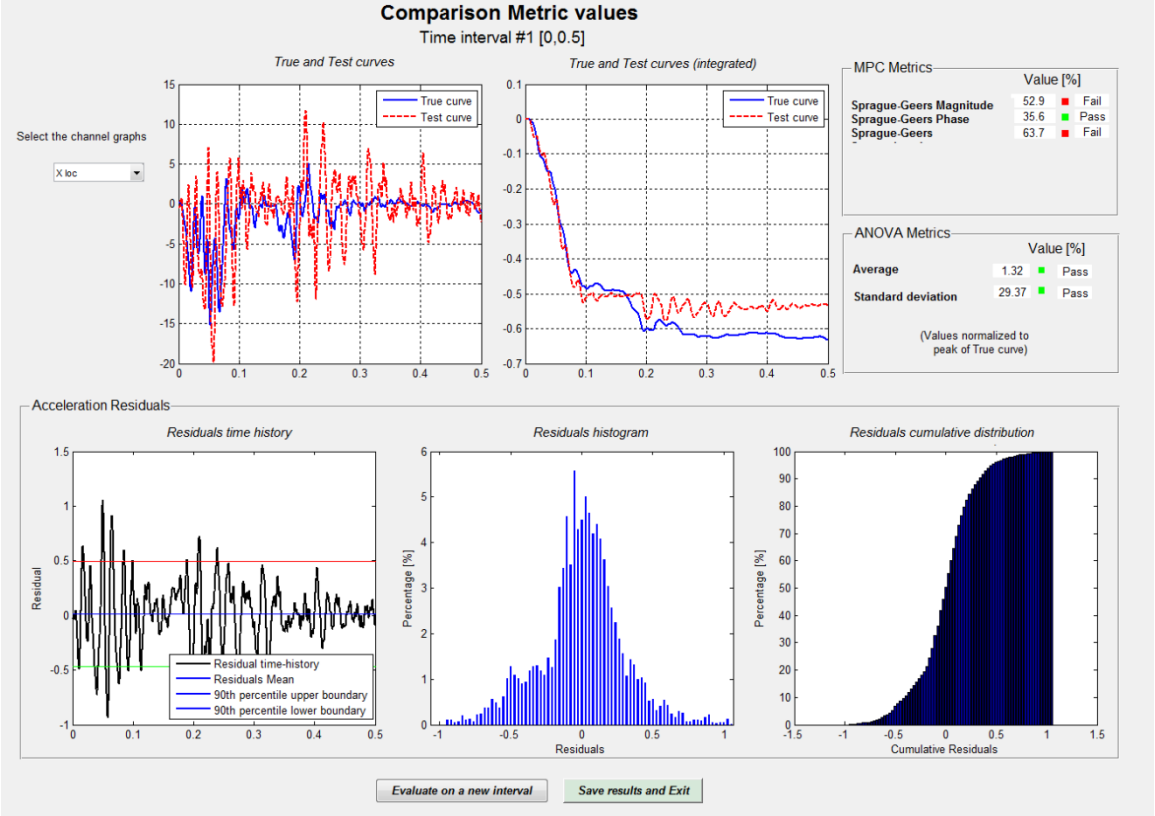


Figure 2b: RSVVP Results – Longitudinal Acceleration

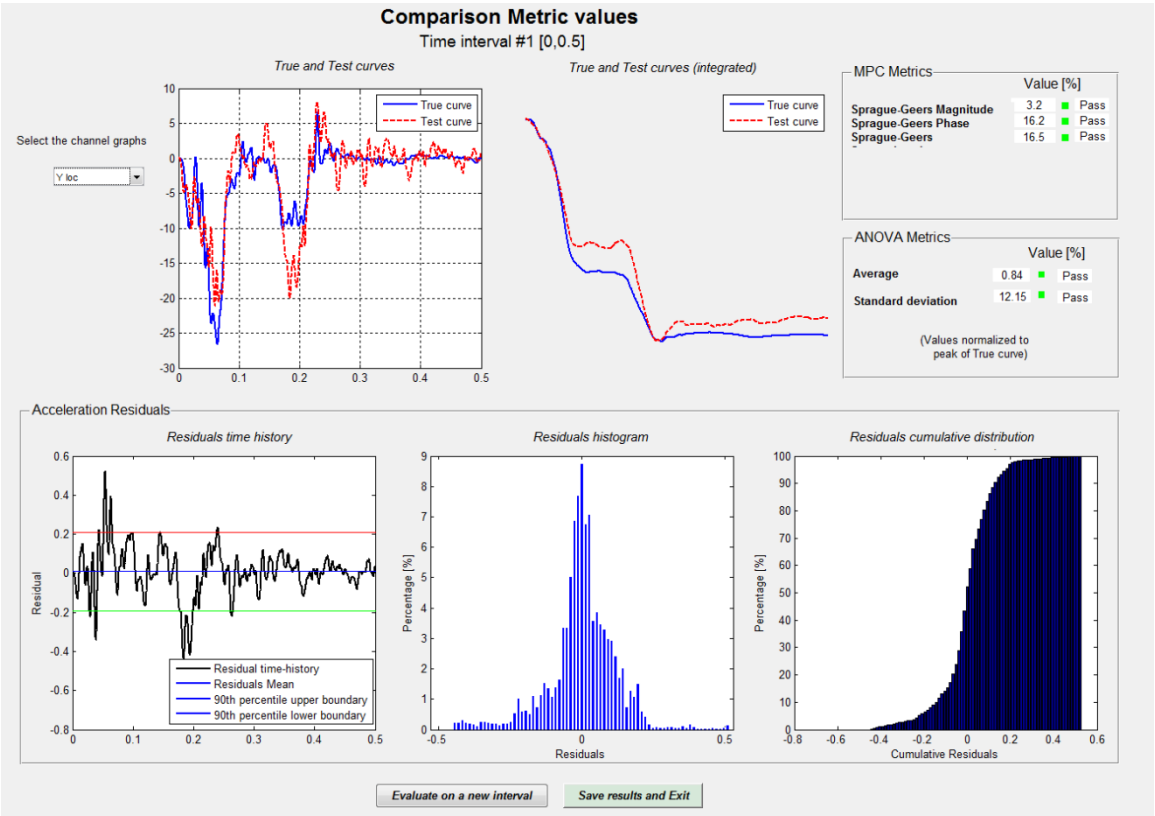


Figure 2c: RSVVP Results – Lateral Acceleration

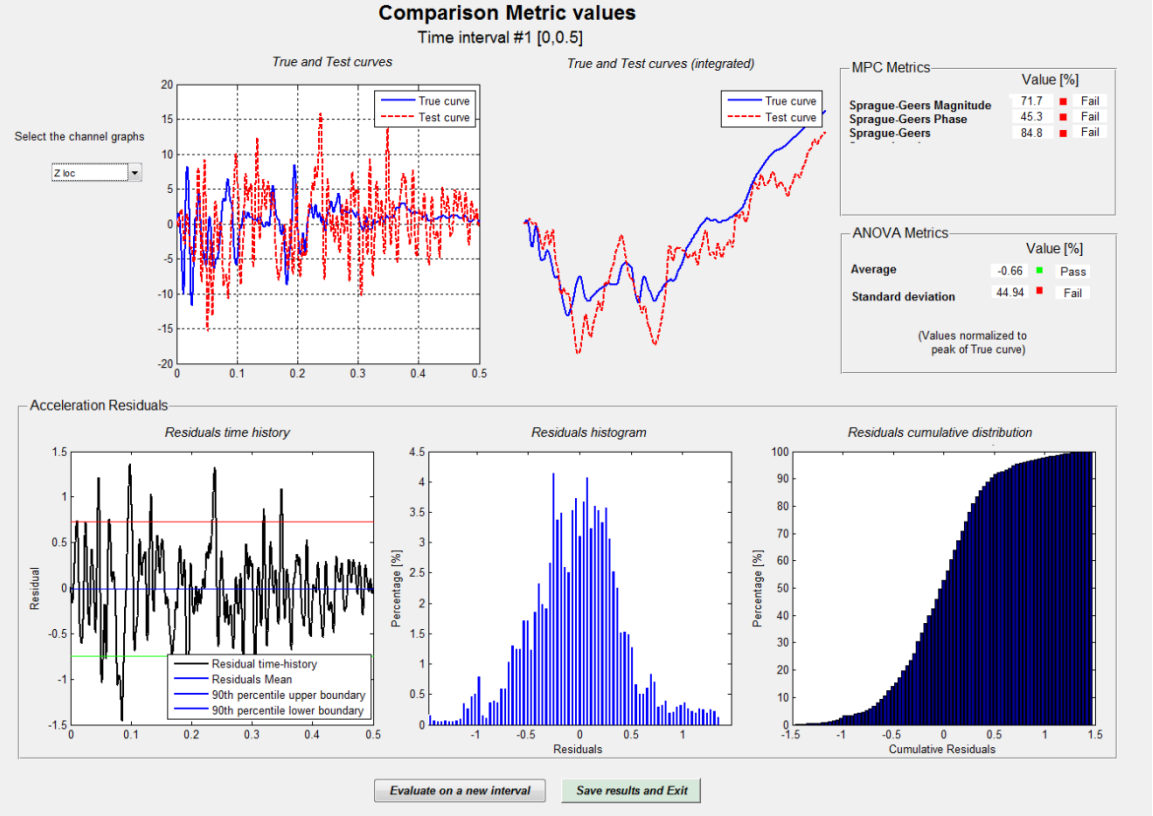


Figure 2d: RSVVP Results – Vertical Acceleration

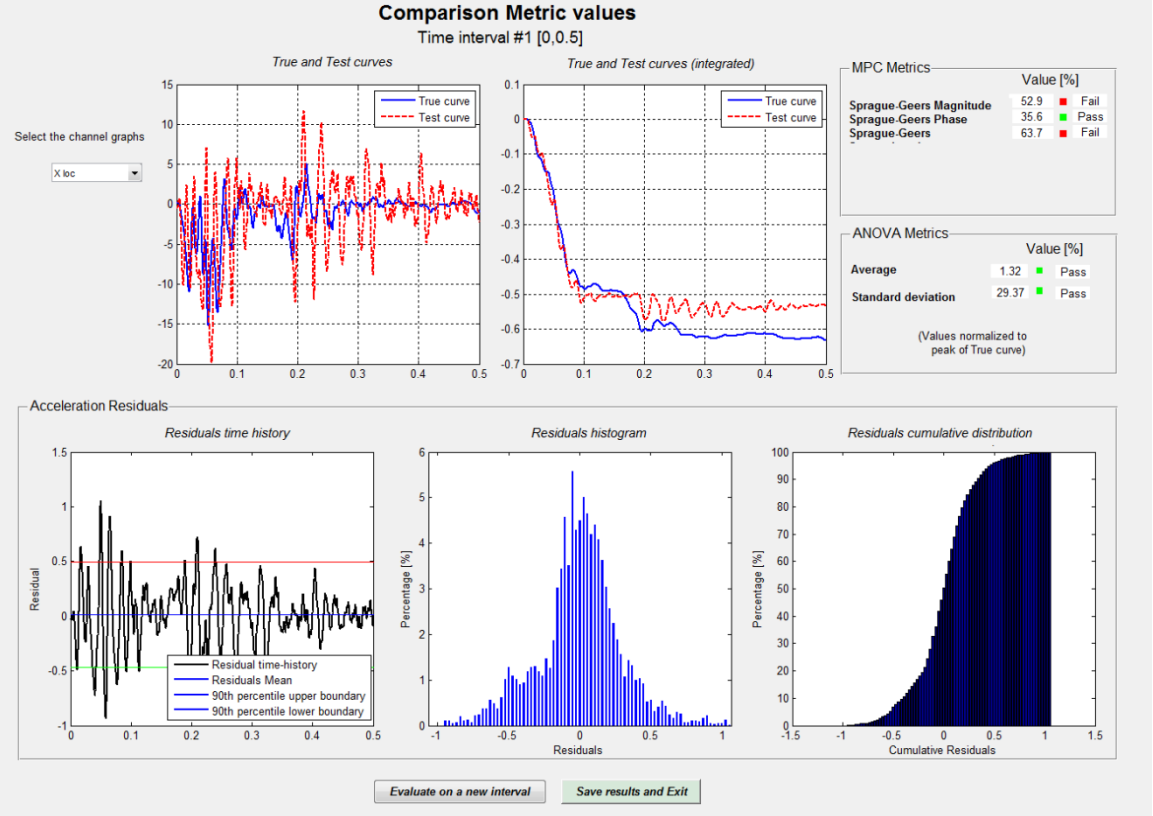


Figure 2e: RSVVP Results – Roll Angle

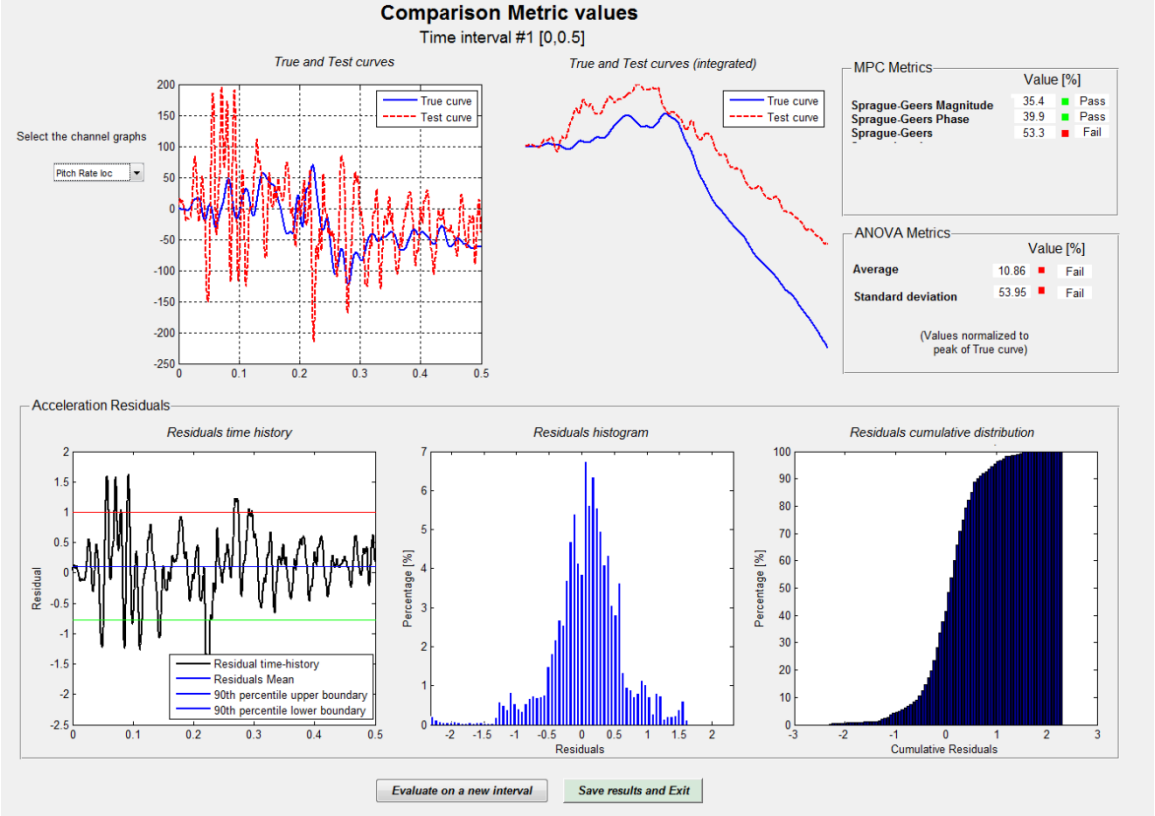


Figure 2f: RSVVP Results – Pitch Angle

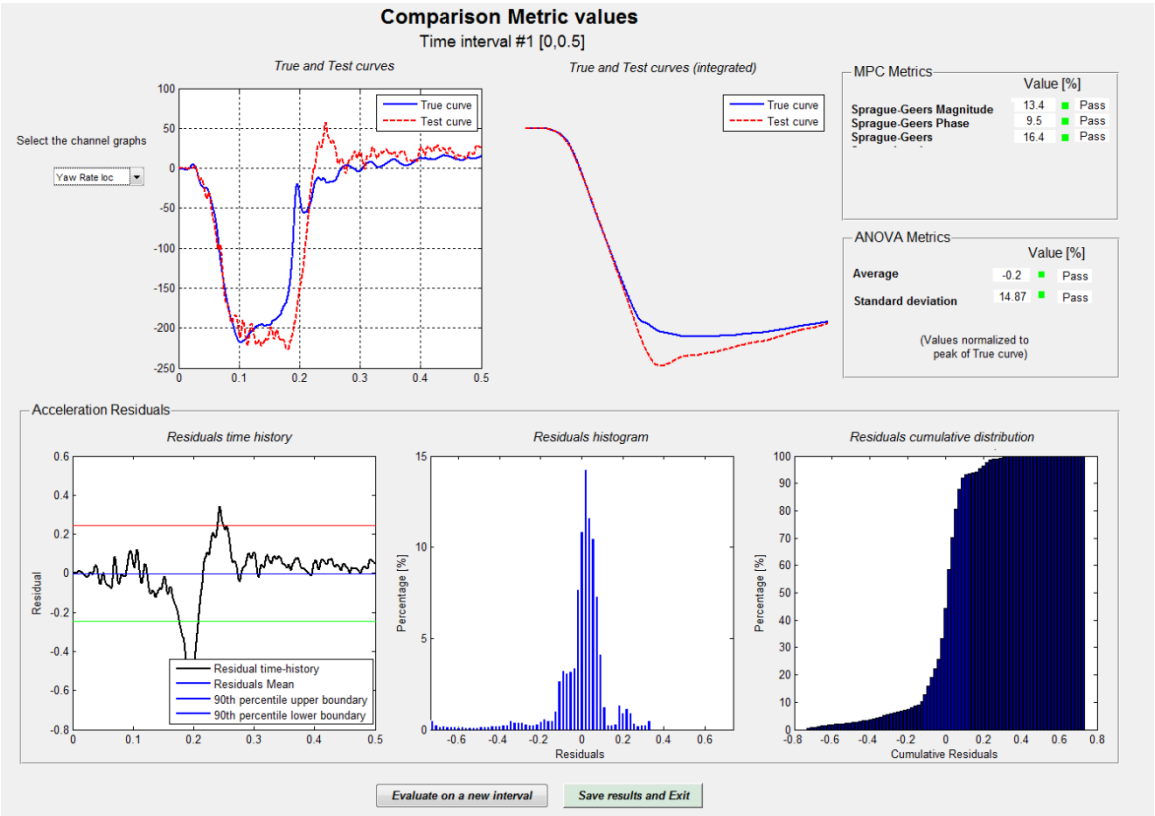


Figure 2g: RSVVP Results – Yaw Angle

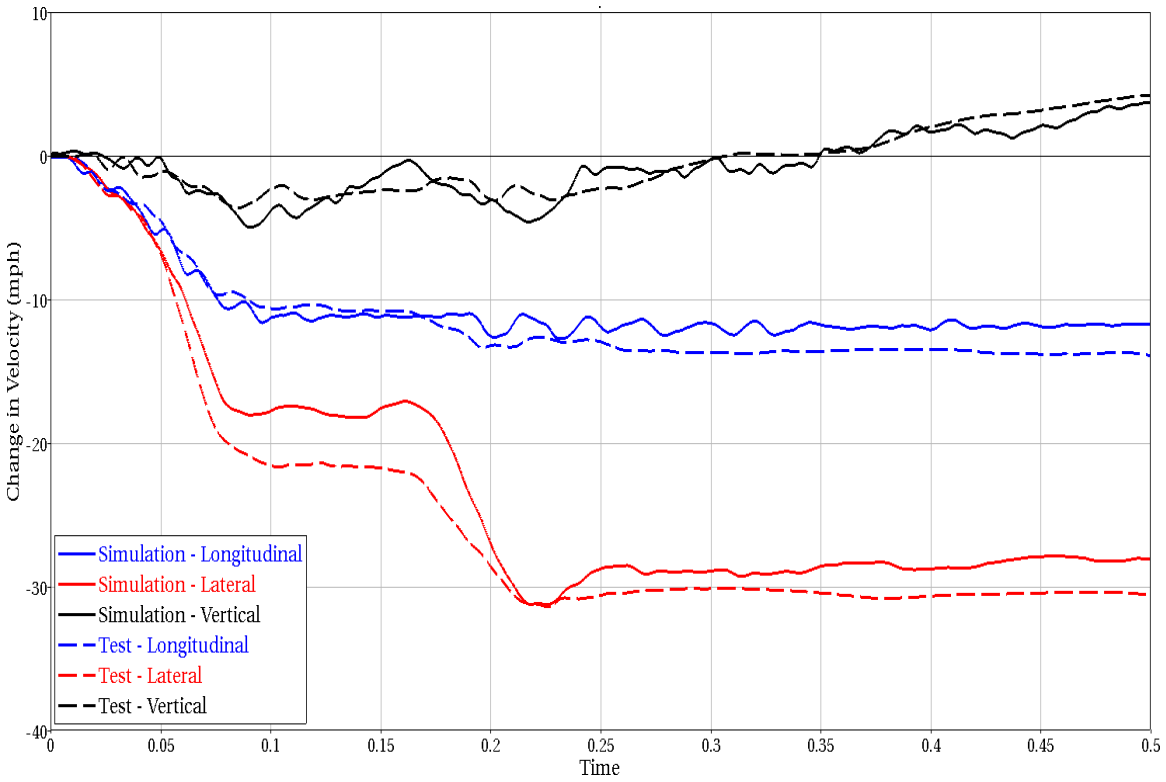


Figure 3: Change in Vehicle Velocities

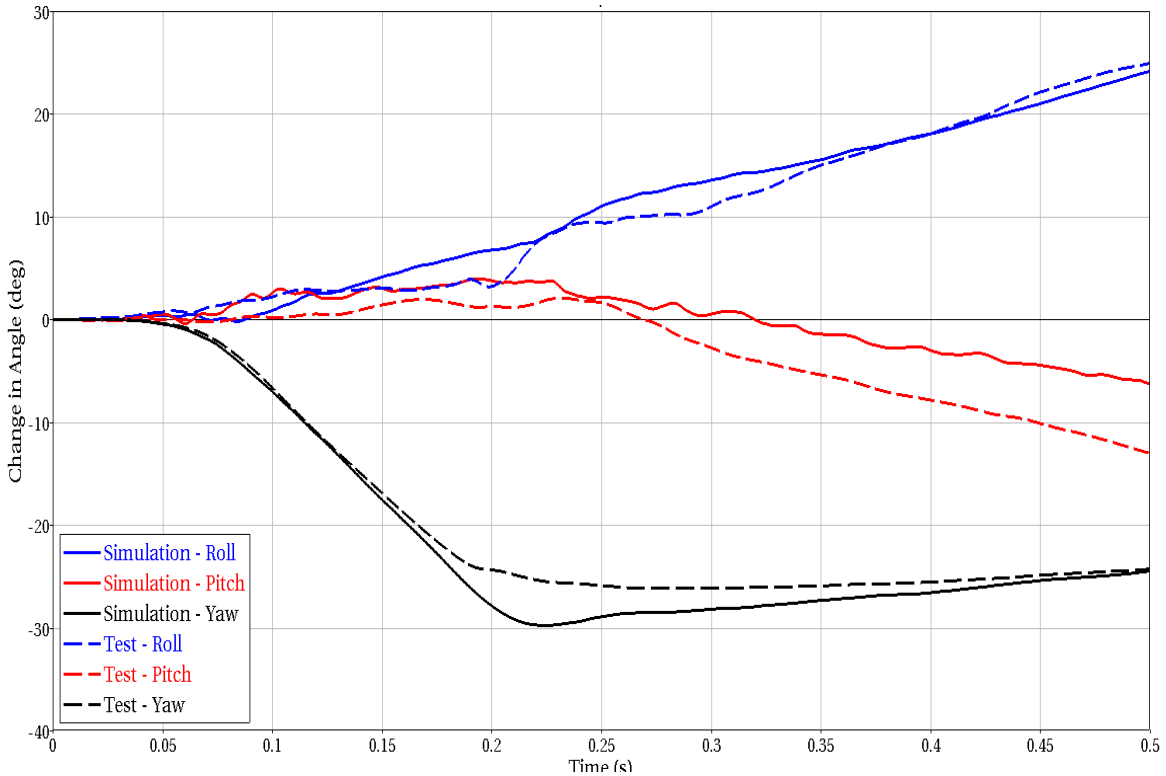


Figure 4: Change in Vehicle Angles

Project: CCSA Longitudinal Barriers on Curved, Superelevated Roadway Sections
Comparison Case: 2270P Vehicle with New Jersey Safety Shape Barrier

Table E - Roadside Safety Phenomena Importance Ranking Table (MASH Evaluation)

Evaluation Criteria				Known Result	Analysis Result	Relative Diff. (%)	Agree?
Structural Adequacy	A	A1	Test article should contain and redirect the vehicle; the vehicle should not penetrate, under-ride, or override the installation although controlled lateral deflection of the test article is acceptable.	Yes	Yes		YES
		A2	The relative difference in the maximum dynamic deflection is less than 20 percent.	0.0 m	0.0 m	0%	YES
		A3	The relative difference in the time of vehicle-barrier contact is less than 20 percent.	0.238 s	0.214 s	10%	YES
		A4	The relative difference in the number of broken or significantly bent posts is less than 20 percent.	Yes	Yes		YES
		A5	Barrier did not fail (Answer Yes or No).	Yes	Yes		YES
		A6	There were no failures of connector elements (Answer Yes or No).	Yes	Yes		YES
		A7	There was no significant snagging between the vehicle wheels and barrier elements (Answer Yes or No).	Yes	Yes		YES
		A8	There was no significant snagging between vehicle body components and barrier elements (Answer Yes or No).	Yes	Yes		YES
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 (Answer Yes or No).	Yes	Yes		YES
	F	F1	The vehicle should remain upright during and after the collision. The maximum pitch & roll angles are not to exceed 75 degrees.	Yes	Yes		YES
		F2	Maximum vehicle roll – relative difference is less than 20% or absolute difference is less than 5 degrees.	25 (.5s)	24 (.5s)	4% 1 deg	YES
		F3	Maximum vehicle pitch – relative difference is less than 20% or absolute difference is less than 5 deg.	12 (.5s)	7 (.5s)	41% 5 deg	YES
		F4	Maximum vehicle yaw – relative difference is less than 20% or absolute difference is less than 5 deg.	30 (.5s)	26 (.5s)	13% 4 deg	YES
	H	H1	Longitudinal & lateral occupant impact velocities (OIV) should fall below the preferred value of 30 ft/s (9.1 m/s), or at least below the maximum allowed value of 40 ft/s (12.2 m/s)	Yes	Yes		YES
		H2	Longitudinal OIV (m/s) - Relative difference is less than 20%t or absolute difference is less than 2 m/s	4.3	4.7	9% 0.4 m/s	YES
		H3	Lateral OIV (m/s - Relative difference is less than 20% or absolute difference is less than 2 m/s	9.2	7.9	14% 1.3 m/s	YES
	I	I1	Longitudinal & lateral occupant ridedown accelerations (ORA) should fall below the preferred value of 15.0 g, or at least below the maximum allowed value of 20.49 g.	Yes	Yes		YES
		I2	Longitudinal ORA (g) - Relative difference is less than 20% or absolute difference is less than 4 g's	5.6	7.6	35% 2 g	YES
		I3	Lateral ORA (g) - Relative difference is less than 20% or absolute difference is less than 4 g's	9.6	12.9	34% 3 g	YES
Vehicle Trajectory			The vehicle rebounded within the exit box. (Answer Yes or No)	Yes	Yes		YES

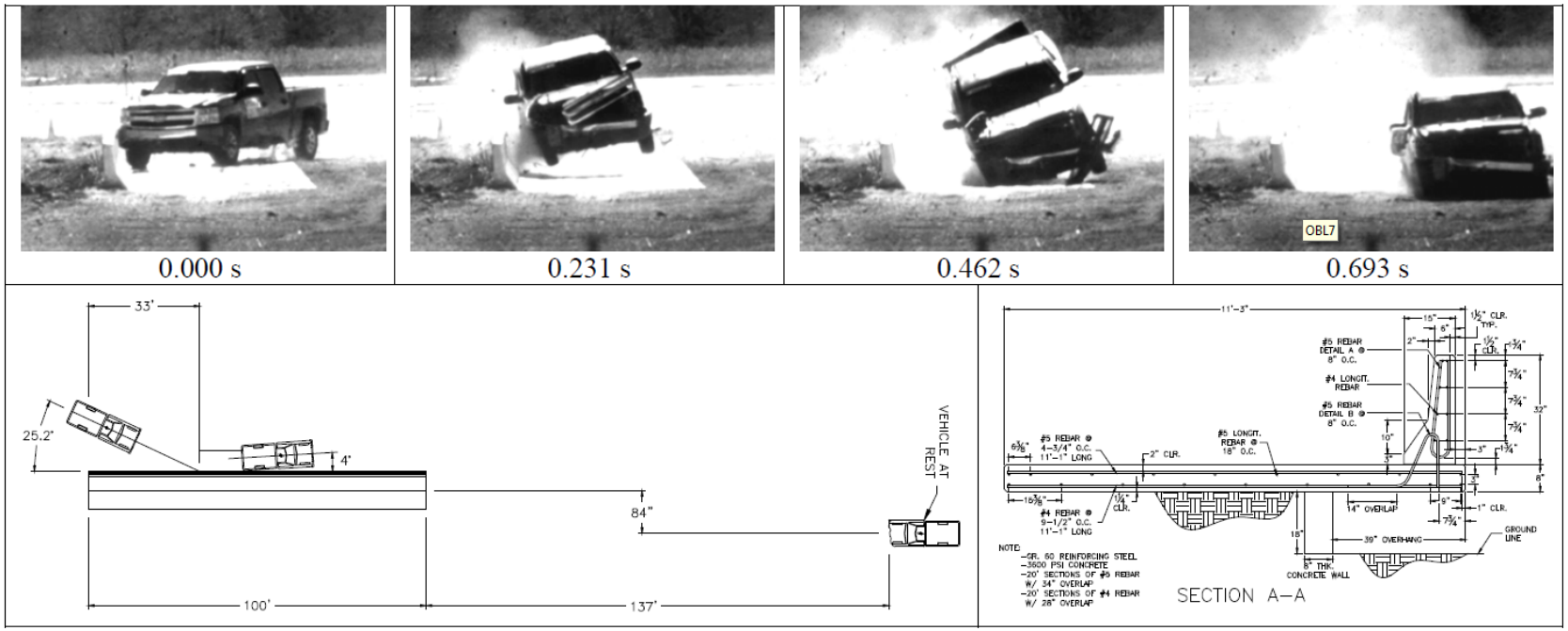


Figure 5: Full-Scale Test Summary

General Information
- Test Agency: Texas Transportation Institute
- Test No.: RF476460-1-4
- Date: 2009-01-30

Test Article
- Type: Concrete Barrier
- Name: 32-inch New Jersey Safety Shape Barrier
- Installation Length: 100 ft-1 in
- Material or Key Elements: Concrete

Soil Type and Condition: Concrete Deck, Dry

Test Vehicle
- Type/Designation: 2270P
- Make and Model: 2007 Chevrolet Silverado Pickup
- Mass
  - Curb: 5000 lb
  - Test Inertial: 5049 lb
  - Gross Static: 5049 lb

Impact Conditions
- Speed: 62.6 mi/h
- Angle: 25.2 degrees

Exit Conditions
- Speed: 52.6 mi/h
- Angle: 4.0 degrees

Occupant Risk Values
- Impact Velocity
  - Longitudinal: 14.1 ft/s
  - Lateral: 30.2 ft/s
- Ridedown Accelerations
  - Longitudinal: -5.6 G
  - Lateral: -9.6 G
- THIV: 36.0 km/h
- PHD: 10.2 G
- Max. 0.050-s Average
  - Longitudinal: -6.8 G
  - Lateral: -15.7 G
  - Vertical: -3.2 G

Post-Impact Trajectory
- Stopping Distance: 204 ft

Vehicle Stability
- Maximum Yaw Angle: -29 degrees
- Maximum Pitch Angle: -16 degrees
- Maximum Roll Angle: 29 degrees
- Vehicle Snagging: No
- Vehicle Pocketing: No

Test Article Deflections
- Dynamic: 0
- Permanent: 0
- Working Width: 0

Vehicle Damage
- VDS: 01RFQ5
- CDC: 01RFEW4
- Max. Exterior Vehicle Crush (inches): 14.0 inches
- Max. Occupant Compartment Deformation (inches): 2.0 inches

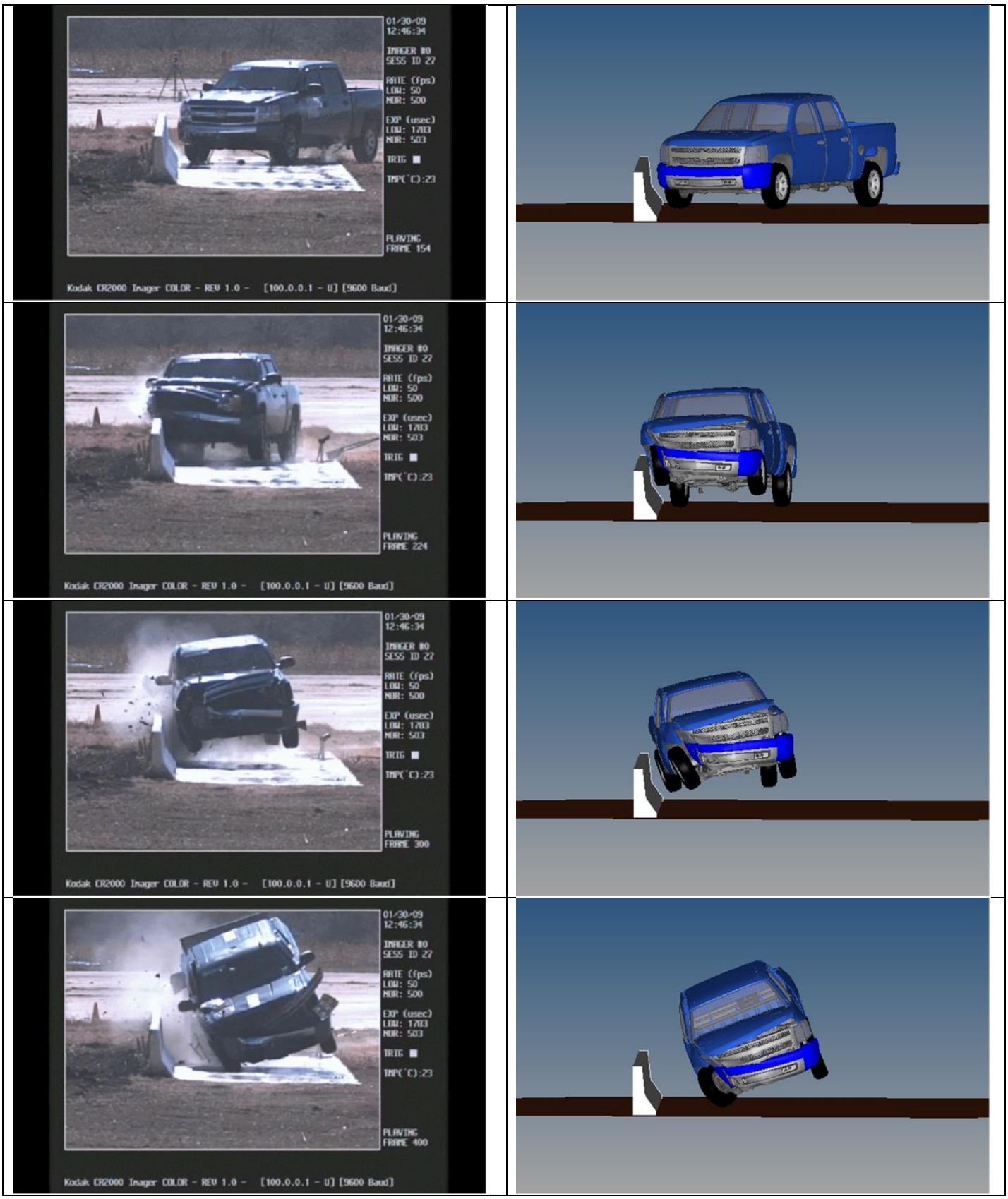


Figure 6a: Sequential Comparisons – Front View

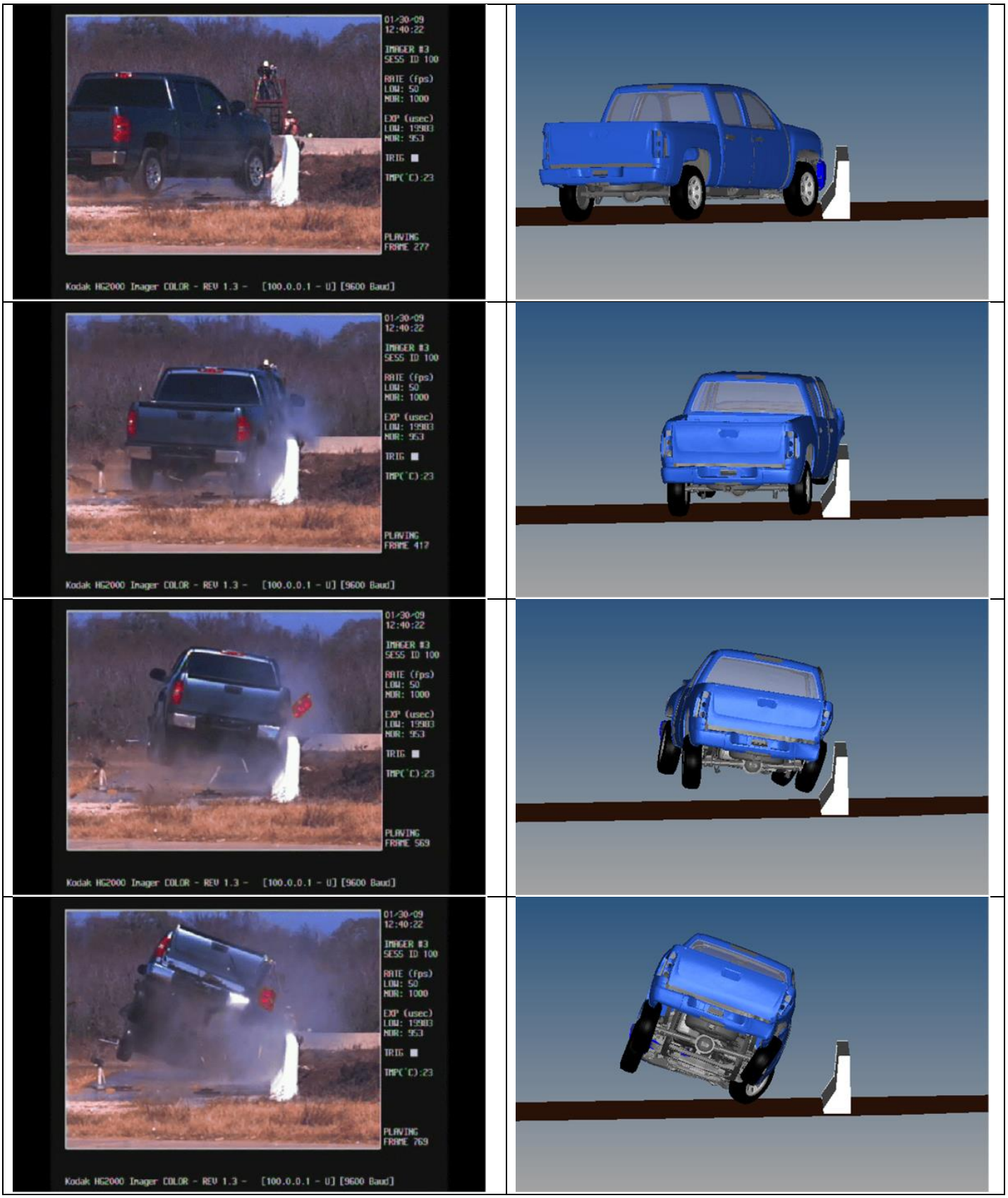


Figure 6b: Sequential Comparisons – Rear View

Figure 6c: Sequential Comparisons – Top View

CCSA VALIDATION/VERIFICATION REPORT

Project: CCSA Longitudinal Barriers on Curved, Superelevated Roadway Sections
Comparison Case: 2270P Vehicle with New Jersey Safety Shape Barrier

Table F - Composite Verification and Validation Summary:

List the Report MASH08 Test Number		
Table C – Analysis Solution Verification	Did all solution verification criteria in table pass?	**YES**
Table D - RSVVP Results	Do all the time history evaluation scores from the single channel factors result in a satisfactory comparison (i.e., the comparison passes the criterion)?	**NO**
	If all the values for Single Channel comparison did not pass, did the weighted procedure result in an acceptable	**YES**
Table E - Roadside Safety Phenomena Importance Ranking Table	Did all the critical criteria in the PIRT Table pass? Note: Tire deflation was observed in the test but not in the simulation. This due to the fact that tire deflation in not incorporated in the model. This is considered not to have a critical effect on the outcome of the test	**YES**
Overall	Are the results of Steps I through III all affirmative (i.e., YES)? If all three steps result in a "YES" answer, the comparison can be considered validated or verified. If one of the steps results in a negative response, the result cannot be considered validated or verified.	**YES**

NOTES:
(none)

Appendix J-2: G4(1S) Barrier Impact with 2270P Vehicle

CCSA VALIDATION/VERIFICATION REPORT

Project: **CCSA Longitudinal Barriers on Curved, Superelevated Roadway Sections**
Comparison Case: **2270P (Pickup Truck) with G41S Barrier**
Impact Description: **25.8 degree impact into barrier at 100.4 km/h (62.4 mph)**
Governing Criteria: **MASH TL-3**
Report Date: **March 2013**

Table A – Information Sources:

General Information	Known Solution	Analysis Solution
Performing Organization	MwRSF	CCSA-GWU
Test/Run Number	2214WB-2	RR130422b
Vehicle	Dodge Ram 1500 Quad Cab	Silverado C
Vehicle Mass (lb/kg)	5000 / 2268	4918 / 2231
Impact Speed (mph/kph)	62.4 / 100.4	62.4 / 100.4
Impact Angle (degrees)	25.8	25.8

Table B - Evaluation Parameters Summary:

Category	Subset	Values
Evaluation Method	MASH (V1, 2009)	
Hardware Type	Longitudinal	
Test Number	3-11	
Test Vehicle	2270C	
Criterion to be Applied	**Structural Adequacy**	**A -** Test article should contain and redirect the vehicle; the vehicle should not penetrate, under-ride, or override the installation although controlled lateral deflection of the test article is acceptable.
	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.
		F - The vehicle should remain upright during and after the collision although moderate roll, pitching and yawing are
		H - The occupant impact velocity in the longitudinal direction should not exceed 40 ft/sec and the occupant ride-down acceleration in the longitudinal direction should not exceed 20 G‟s.
		I - Longitudinal & lateral occupant ridedown accelerations (ORA) should fall below the preferred value of 15.0 g, or at least below the maximum allowed value of 20.49 g.
	Vehicle Trajectory	For redirective devices the vehicle shall exit within the prescribed box.

Project: CCSA Longitudinal Barriers on Curved, Superelevated Roadway Sections
Comparison Case: 2270P (Pickup Truck) with G41S Barrier

Table C – Analysis Solution Verification Summary

Verification Evaluation Criteria	Change (%)	Pass?
Total energy of the analysis solution (i.e., kinetic, potential, contact, etc.) must not vary more than 10 percent from the beginning of the run to the end of the run.	< 1%	YES
Hourglass Energy of the analysis solution at the end of the run is less than 5 % of the total initial energy at the beginning of the run	< 1%	YES
The part/material with the highest amount of hourglass energy at any time during the run is less than 5 % of the total initial energy at the beginning of the run.	< 1%	YES
Mass added to the total model is less than 5 % the total model mass at the start of the run.	< 1%	YES
The part/material with the most mass added had less than 10 % of its initial mass added.	< 1%	YES
The moving parts/materials in the model have less than 5 % of mass added to the initial moving mass of the model.	< 1%	YES
There are no shooting nodes in the solution?	NA	YES
There are no solid elements with negative volumes?	NA	YES

Table D - RSVVP Results

Single Channel Time History Comparison Results			**Time interval [0 sec - 0.89**		
O	***Sprauge-Geer Metrics***		**M**	**P**	**Pass?**
	X acceleration		75	38.3	NO
	Y acceleration		29.9	32.6	YES
	Z acceleration		168.7	45.3	NO
	Yaw rate		14.1	12.7	YES
	Roll rate (test data not available)				
	Pitch rate (test data not available)				
P	***ANOVA Metrics***		**Mean**	**SD**	**Pass?**
	X acceleration/Peak		-1.79	41.87	NO
	Y acceleration/Peak		1.54	31.86	YES
	Z acceleration/Peak		0.16	73.73	NO
	Yaw rate		-.32	18.97	YES
	Roll rate (test data not available)				
	Pitch rate (test data not available)				
Multi-Channel Weighting Factors			**Time interval [0 sec; 0.89**		
Multi-Channel Weighting Method		**X Channel**	0.22878683		
Peaks Area I		**Y Channel**	0.225135792		
Area II Inertial		**Z Channel**	0.046077378		
		Yaw Channel	0.5		
		Roll Channel	(test data not available)		
		Pitch Channel	(test data not available)		
Sprauge-Geer Metrics			**M**	**P**	**Pass?**
	All Channels (weighted)		36.7	24.6	YES
ANOVA Metrics			**Mean**	**SD**	**Pass?**
	All Channels (weighted)		-.02	29.6	YES

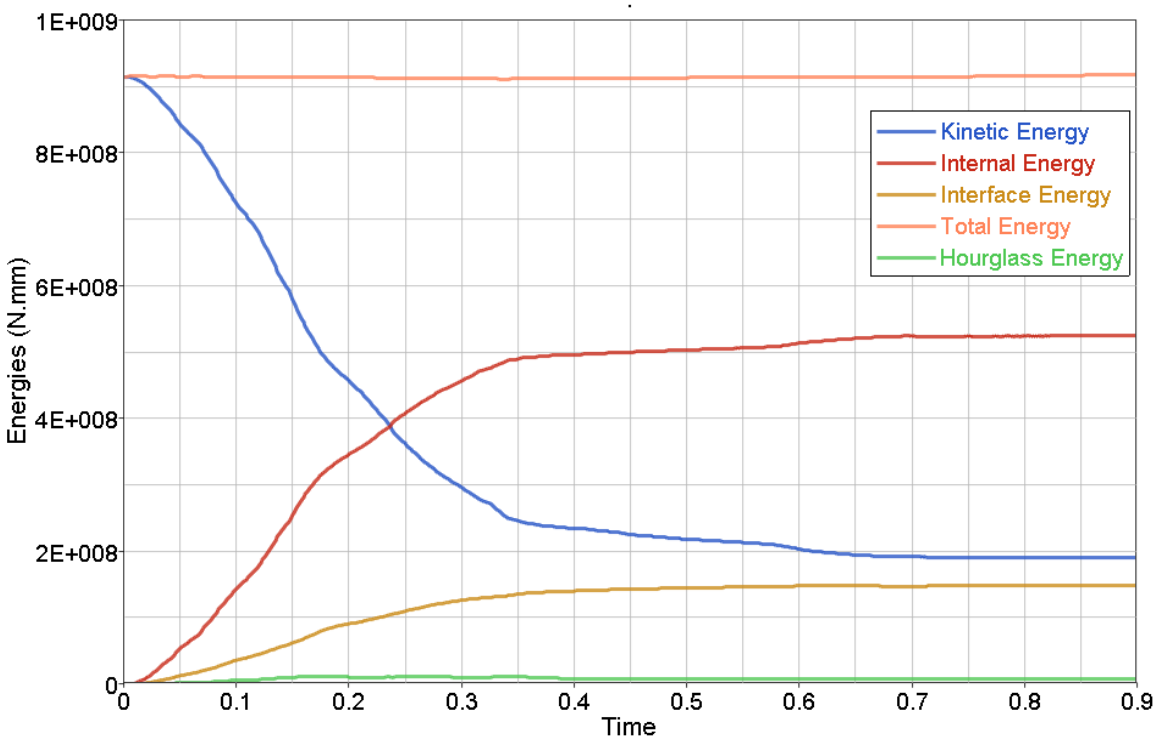


Figure 1: Simulations Energies

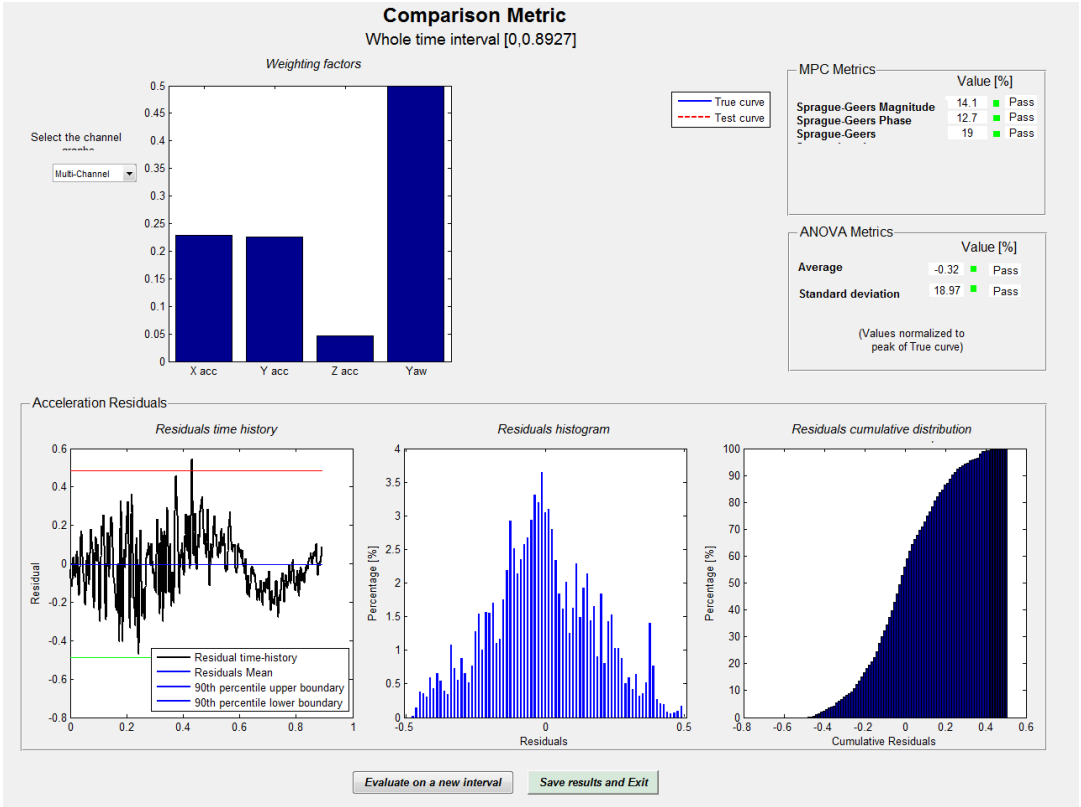


Figure 2a: RSVVP Results – All Channels

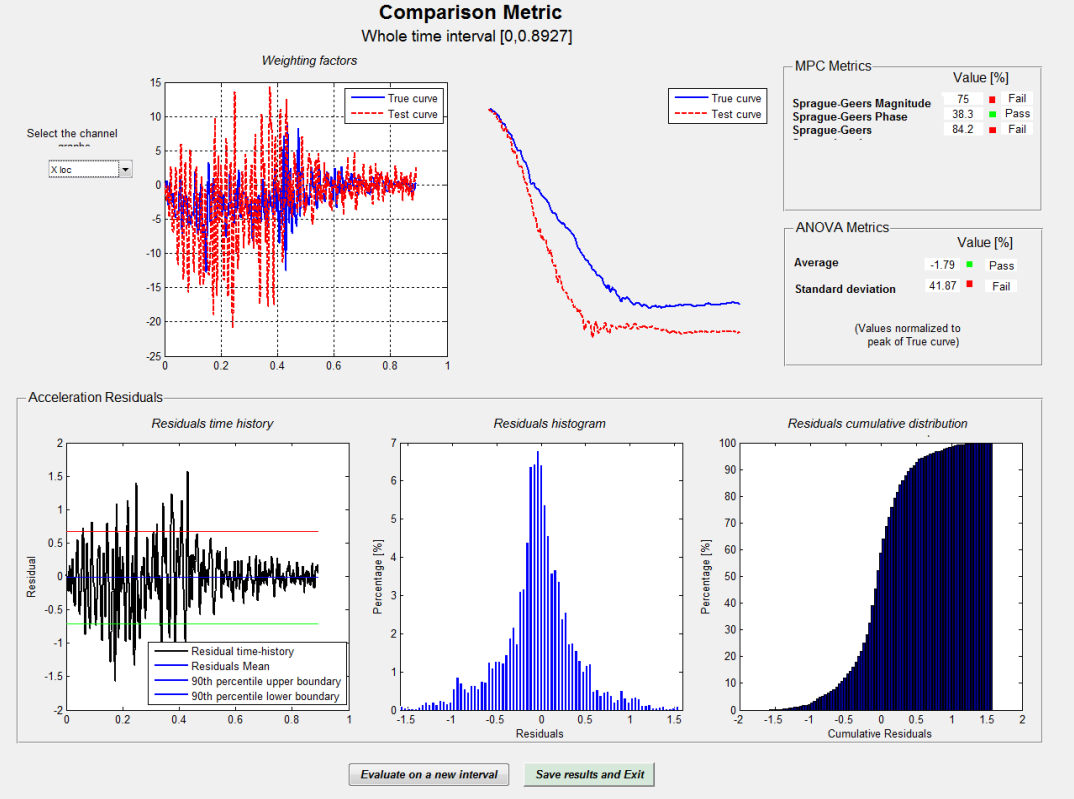


Figure 2b: RSVVP Results – Longitudinal Acceleration

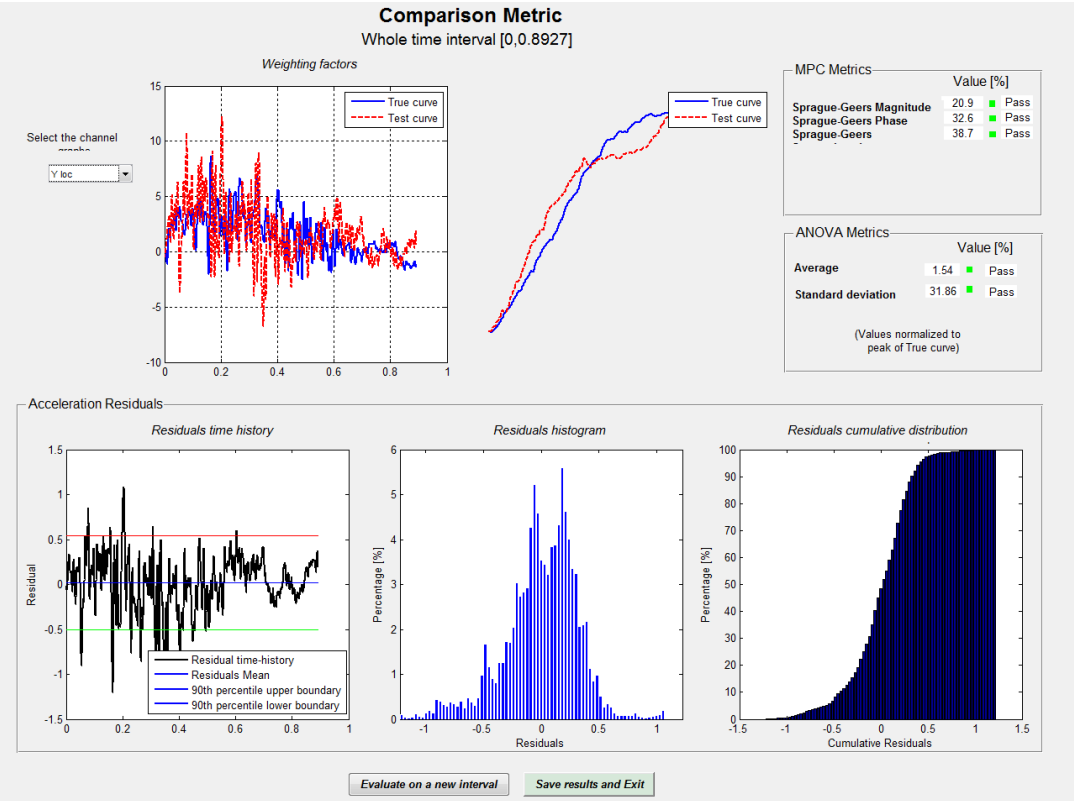


Figure 2c: RSVVP Results – Lateral Acceleration

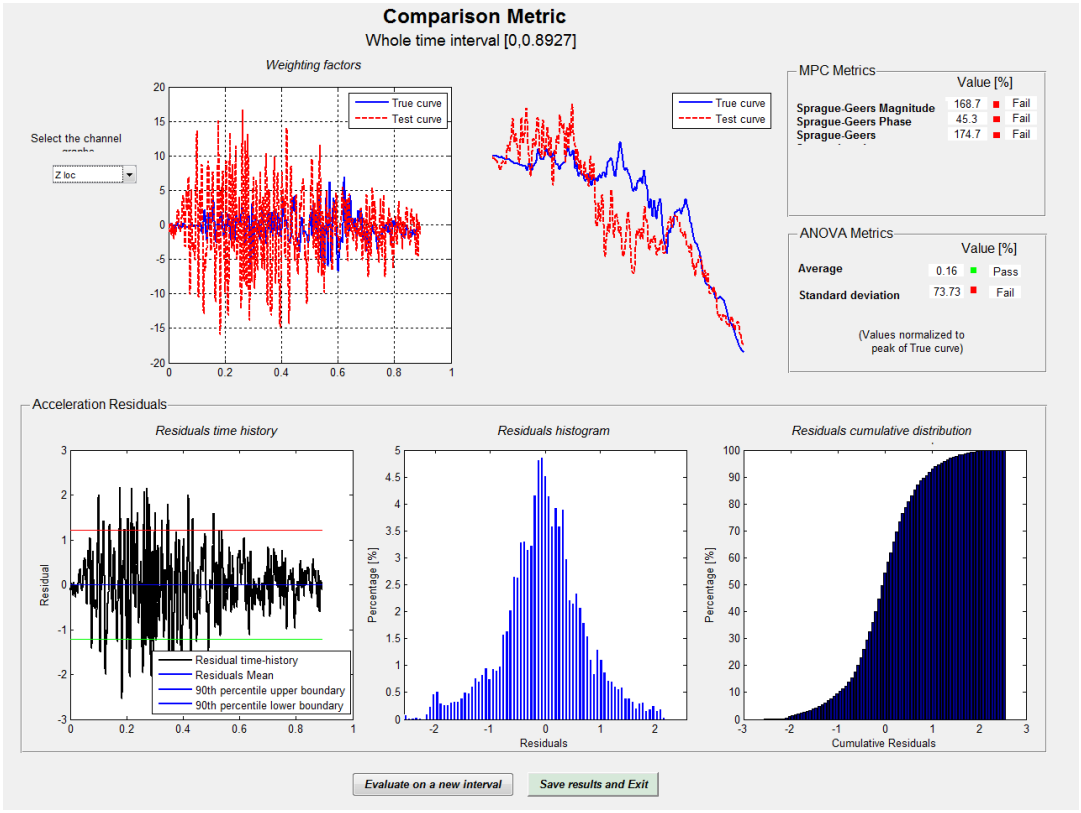


Figure 2d: RSVVP Results – Vertical Acceleration

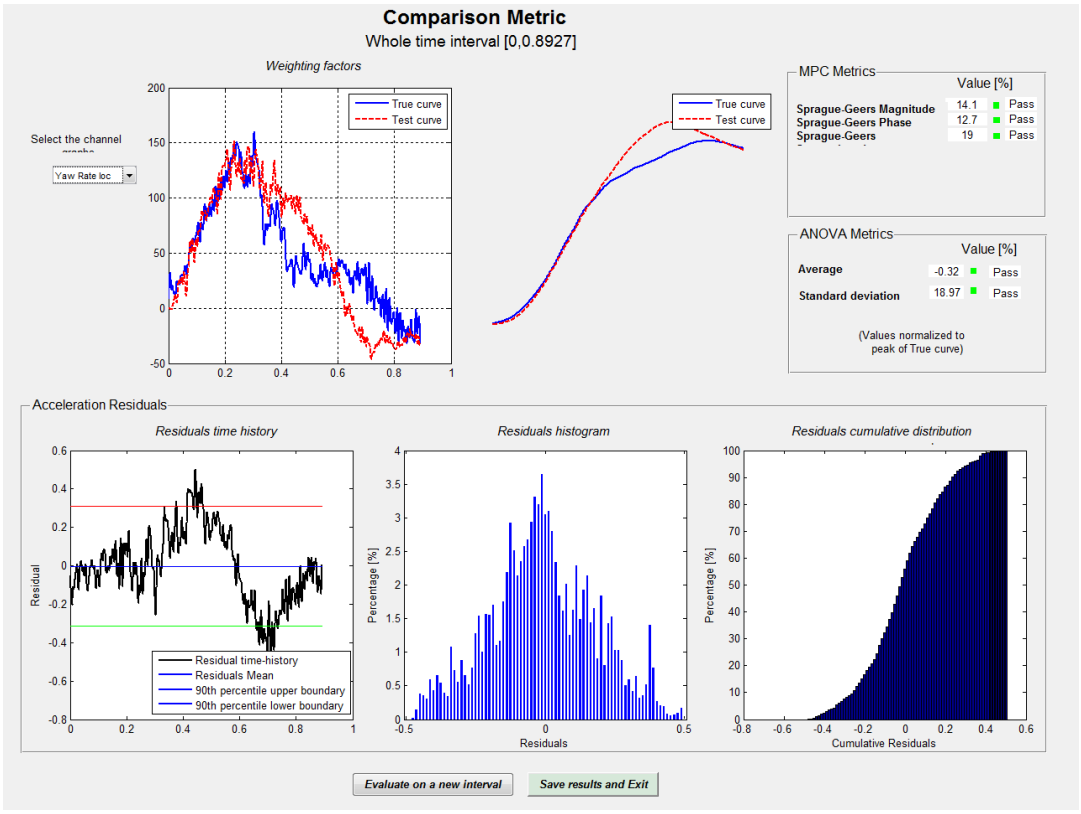


Figure 2e: RSVVP Results – Yaw Angle

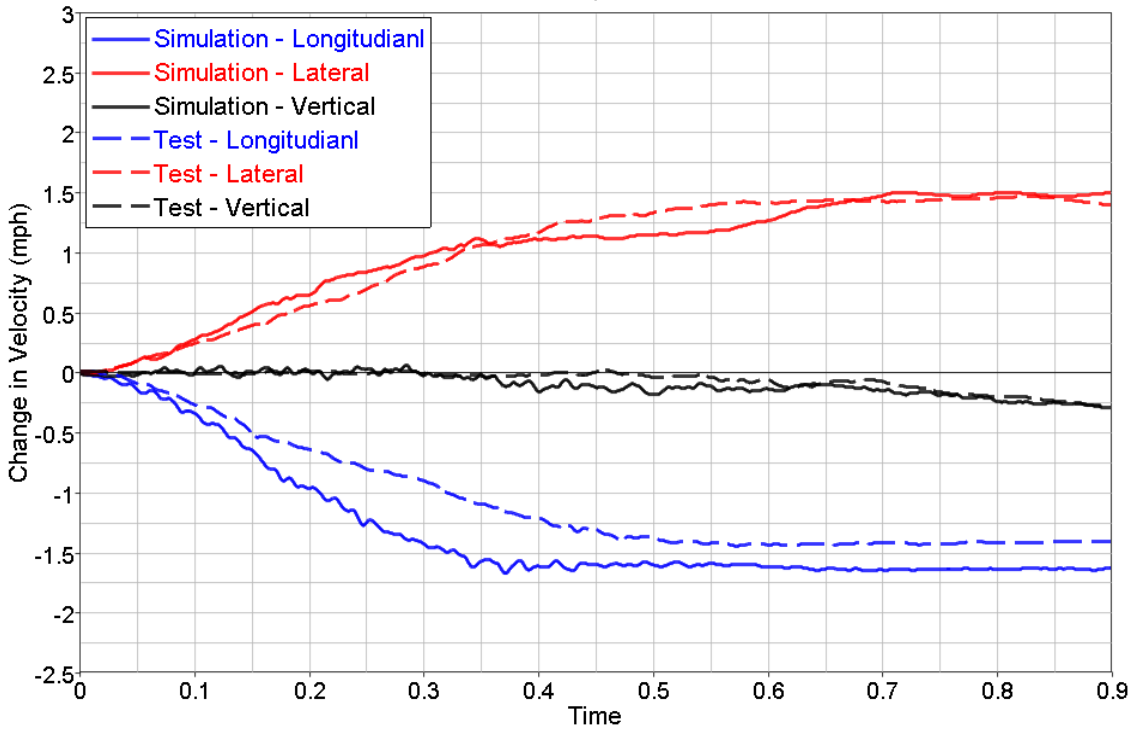


Figure 3: Change in Vehicle Velocities

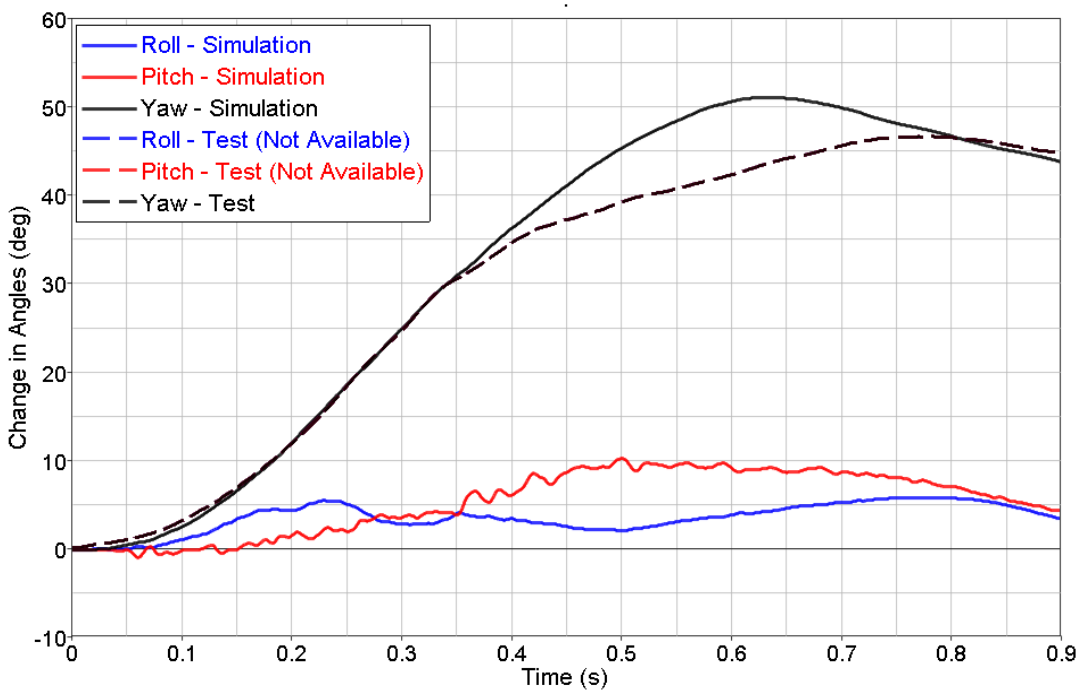
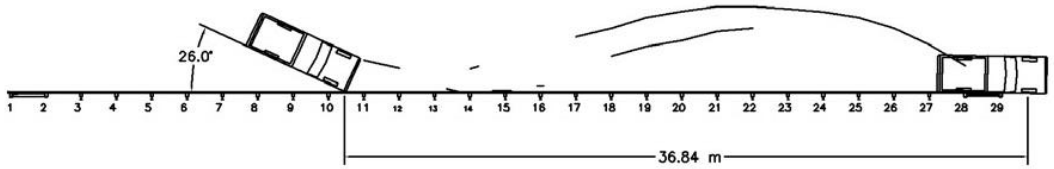


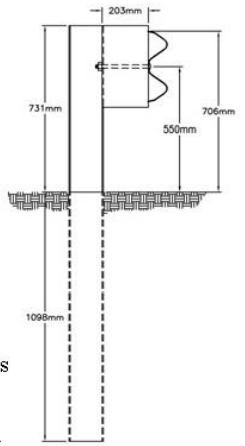
Figure 4: Change in Vehicle Angle

Project: CCSA Longitudinal Barriers on Curved, Superelevated Roadway Sections
Comparison Case: 2270P (Pickup Truck) with G41S Barrier

Table E - Roadside Safety Phenomena Importance Ranking Table (MASH Evaluation)

Evaluation Criteria				Known Result	Analysis Result	Relative Diff. (%)	Agree?
Structural Adequacy	A	A1	Test article should contain and redirect the vehicle; the vehicle should not penetrate, under-ride, or override the installation although controlled lateral deflection of the test article is acceptable.	Yes	Yes		YES
		A2	The relative difference in the maximum dynamic deflection is less than 20 percent.	1.196 m	0.980 m	18.0 %	YES
		A3	The relative difference in the time of vehicle-barrier contact is less than 20 percent.	0.84 s	0.72 s	7.1 %	YES
		A4	The relative difference in the number of broken or significantly bent posts is less than 20 percent.	3	3		YES
		A5	Barrier did not fail (Answer Yes or No).	Yes	Yes		YES
		A6	There were no failures of connector elements (Answer Yes or No).	Yes	Yes		YES
		A7	There was no significant snagging between the vehicle wheels and barrier elements (Answer Yes or No).	Yes	Yes		YES
		A8	There was no significant snagging between vehicle body components and barrier elements (Answer Yes or No).	Yes	Yes		YES
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 (Answer Yes or No).	Yes	Yes		YES
	F	F1	The vehicle should remain upright during and after the collision. The maximum pitch & roll angles are not to exceed 75 degrees.	Yes	Yes		YES
		F2	Maximum vehicle roll – relative difference is less than 20% or absolute difference is less than 5 degrees.	NA	NA	NA	
		F3	Maximum vehicle pitch – relative difference is less than 20% or absolute difference is less than 5 deg.	NA	NA	NA	
		F4	Maximum vehicle yaw – relative difference is less than 20% or absolute difference is less than 5 deg.	51 (.62s)	47 (.78s)	7.8% 4 deg	YES
	H	H1	Longitudinal & lateral occupant impact velocities (OIV) should fall below the preferred value of 30 ft/s (9.1 m/s), or at least below the maximum allowed value of 40 ft/s (12.2 m/s)	Yes	Yes		YES
		H2	Longitudinal OIV (m/s) - Relative difference is less than 20%t or absolute difference is less than 2 m/s	5.38	6.1	13.4% 0.72 m/s	YES
		H3	Lateral OIV (m/s) - Relative difference is less than 20% or absolute difference is less than 2 m/s	3.99	5.0	25.3% 1.01 m/s	YES
	I	I1	Longitudinal & lateral occupant ridedown accelerations (ORA) should fall below the preferred value of 15.0 g, or at least below the maximum allowed value of 20.49 g.	Yes	Yes		YES
		I2	Longitudinal ORA (g) - Relative difference is less than 20% or absolute difference is less than 4 g's	6.92	10.72	54.9% 3.8 g	YES
		I3	Lateral ORA (g) - Relative difference is less than 20% or absolute difference is less than 4 g's	6.61	9.86	49.2% 3.25 g	YES
Vehicle Trajectory			The vehicle rebounded within the exit box. (Answer Yes or No)	Yes	Yes		YES





- Test Agency ..... MwRSF
- Test Number 2214WB-2
- Date 4/8/05
- NCHRP 350 Update Test Designation .. 3-11
- Appurtenance ..... Modified G4(1S) Guardrail
- Total Length ..... 53.34 m
- Key Elements - Steel W-Beam
  - Thickness ..... 2.66 mm
  - Top Mounting Height ..... 706 mm
- Key Elements - Steel Posts
  - Post Nos. 3 - 27 ..... W152x13.4 by 1,829 mm long
  - Spacing ..... 1,905 mm
- Key Elements - Wood Posts
  - Post Nos. 1 - 2, 28 - 29 (BCT) .... 140 mm x 190 mm by 1,080 mm long
- Key Elements - Steel Foundation Tube . 1,524 mm long with soil plate
- Key Elements - Wood Spacer Blocks
  - Post Nos. 3 - 27 ..... 152 mm x 203 mm by 362 mm long
- Type of Soil ..... Grading B - AASHTO M 147-65 (1990)
- Test Vehicle
  - Type/Designation 2270P
  - Make and Model ..... 2002 Dodge Ram 1500 Quad Cab Pickup
  - Curb ..... 2,321 kg
  - Test Inertial ..... 2,268 kg
  - Gross Static ..... 2,268 kg
- Impact Conditions
  - Speed ..... 100.4 km/h
  - Angle ..... 25.8 degrees
  - Impact Location ..... 940 mm upstream centerline post no. 11
- Exit Conditions
  - Speed ..... 50.2 km/h
  - Angle ..... 20.7 degrees
  - Exit Box Criterion ..... Pass
- Post-Impact Trajectory
  - Vehicle Stability ..... Satisfactory
  - Stopping Distance ..... 36.84 m downstream Against traffic-side face
- Occupant Impact Velocity (350 Update)
  - Longitudinal ..... 5.38 m/s < 12 m/s
  - Lateral ..... 3.99 m/s < 12 m/s
- Occupant Ridedown Deceleration (350 Update)
  - Longitudinal ..... -6.92 Gs < 20 Gs
  - Lateral ..... 6.61 Gs < 20 Gs
- THIV (not required) ..... 6.91 m/s
- PHD (not required) ..... 8.19 Gs
- Test Article Damage ..... Moderate
- Test Article Deflections
  - Permanent Set ..... 845 mm
  - Dynamic ..... 1,196 mm
  - Working Width ..... 1,395 mm
- Vehicle Damage ..... Moderate
  - VDS[5] 1-RFQ-4
  - CDC[6] 1-RFEN3
  - Maximum Deformation ..... 13 mm at front floorpan

Figure 15. Summary of Test Results and Sequential Photographs, Test 2214WB-2

Figure 5: Full-Scale Test Summary

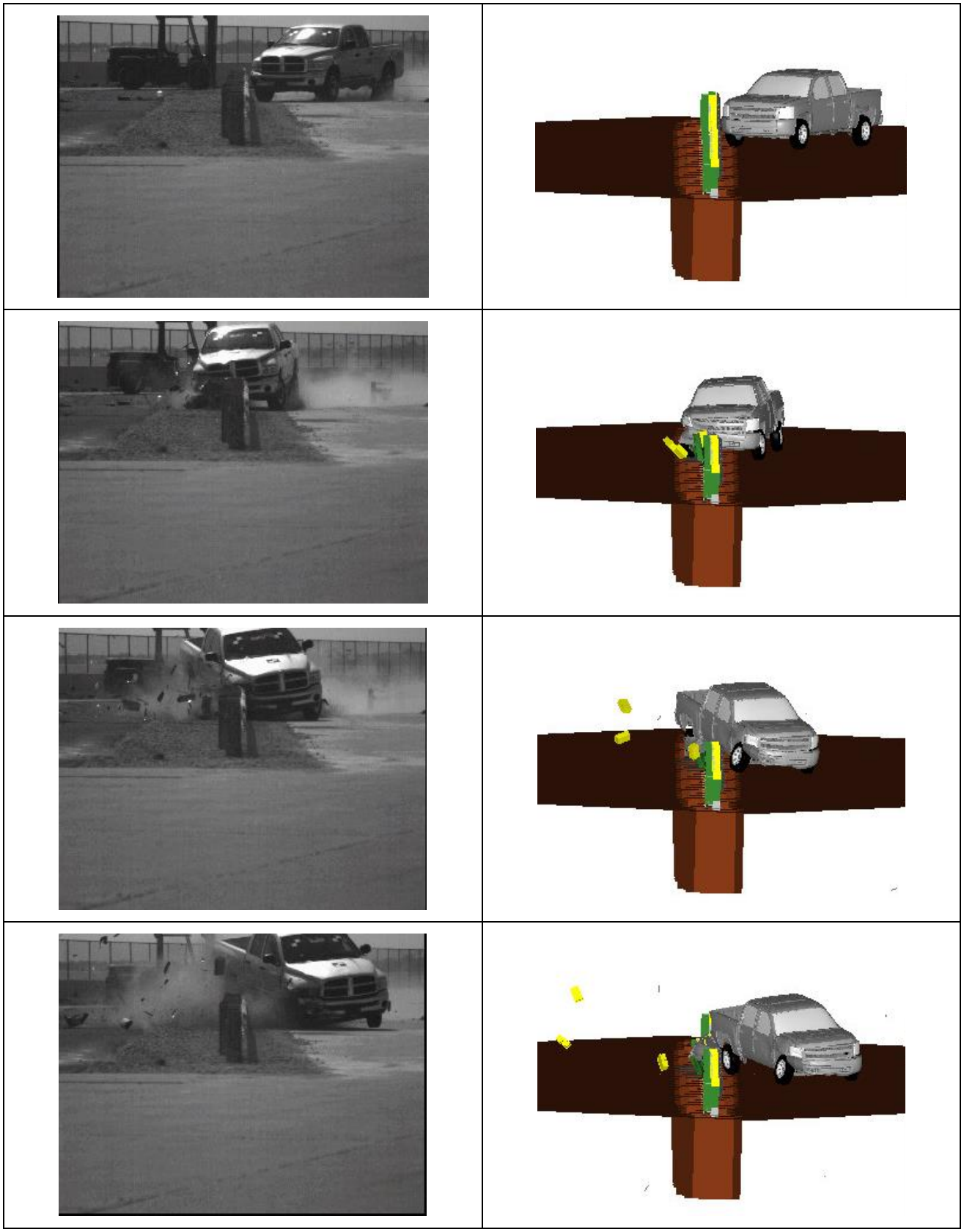
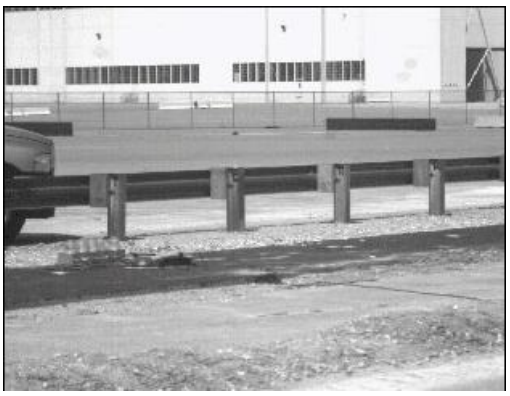
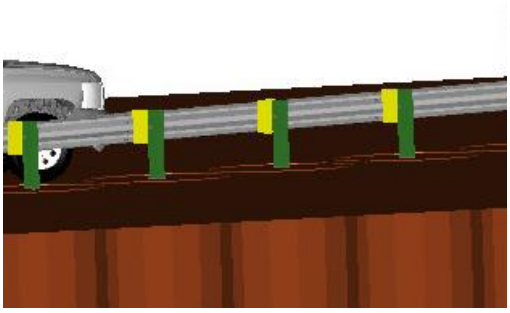
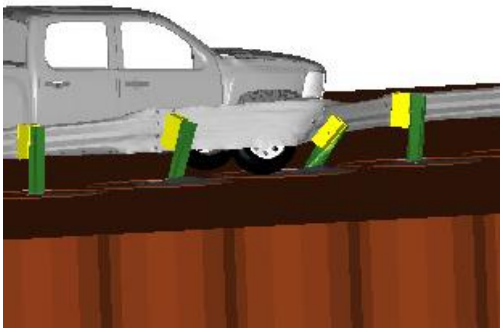
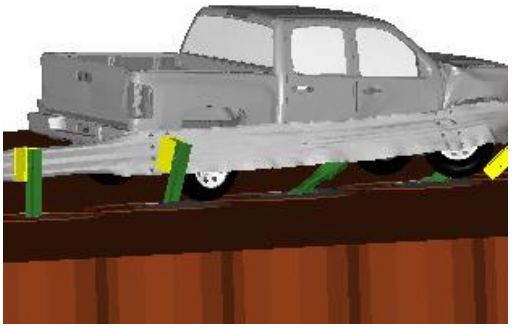


Figure 6a: Sequential Comparisons – Front View





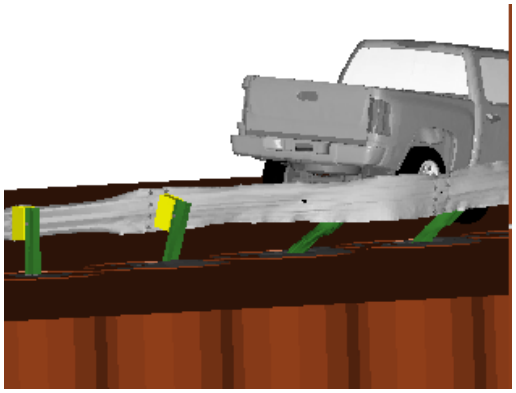


Figure 6b: Sequential Comparisons – Rear View

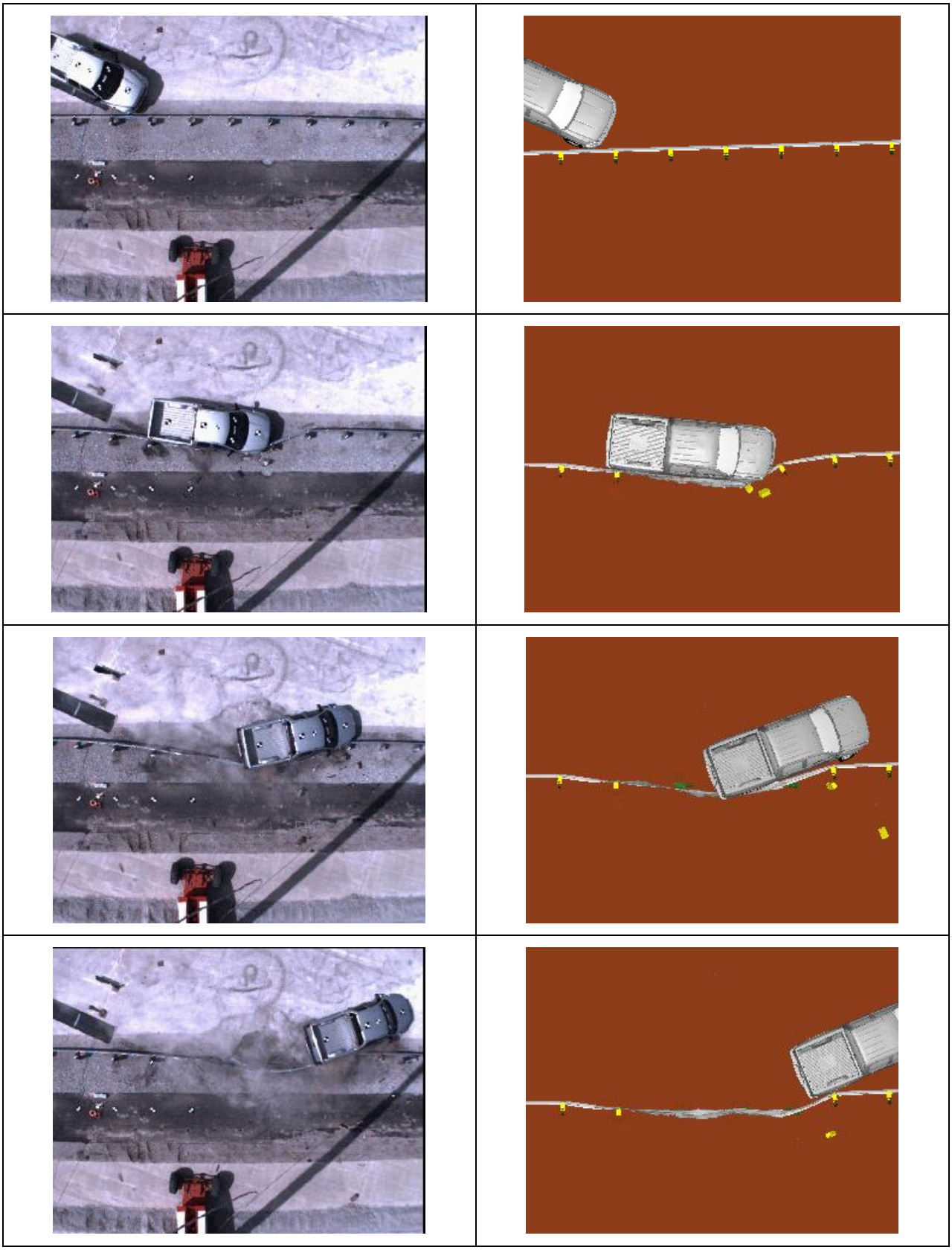


Figure 6c: Sequential Comparisons – Top View

CCSA VALIDATION/VERIFICATION REPORT

Project: CCSA Longitudinal Barriers on Curved, Superelevated Roadway Sections
Comparison Case: 2270P (Pickup Truck) with G41S Barrier

Table F - Composite Verification and Validation Summary:

List the Report MASH08 Test Number		
Table C – Analysis Solution Verification	Did all solution verification criteria in table pass?	**YES**
Table D - RSVVP Results	Do all the time history evaluation scores from the single channel factors result in a satisfactory comparison (i.e., the comparison passes the criterion)?	**NO**
	If all the values for Single Channel comparison did not pass, did the weighted procedure result in an acceptable	**YES**
Table E - Roadside Safety Phenomena Importance Ranking Table	Did all the critical criteria in the PIRT Table pass? Note: Tire deflation was observed in the test but not in the simulation. This due to the fact that tire deflation in not incorporated in the model. This is considered not to have a critical effect on the outcome of the test	**YES**
Overall	Are the results of Steps I through III all affirmative (i.e., YES)? If all three steps result in a "YES" answer, the comparison can be considered validated or verified. If one of the steps results in a negative response, the result cannot be considered	**YES**

NOTES:
(none)

Appendix J-3: MGS Barrier Impact with 2270P Vehicle

CCSA VALIDATION/VERIFICATION REPORT

Project: **CCSA Longitudinal Barriers on Curved, Superelevated Roadway Sections**
Comparison Case: **2270P (Pickup Truck) with MGS Barrier**
Impact Description: **25.5 degree impact into barrier at 101.1 km/h (62.82 mph)**
Governing Criteria: **MASH TL-3**
Report Date: **March 2013**

Table A – Information Sources:

General Information	Known Solution	Analysis Solution
Performing Organization	MwRSF	CCSA-GWU
Test/Run Number	TRP-03-171-06	s130411a
Vehicle	Dodge Ram 1500 Quad Cab	Silverado C
Vehicle Mass (lb/kg)	5000 / 2268	4918 / 2231
Impact Speed (mph/kph)	62.82 / 101.1	62.82 / 101.1
Impact Angle (degrees)	25.5	25.5

Table B - Evaluation Parameters Summary:

Category	Subset	Values
Evaluation Method	MASH (V1, 2009)	
Hardware Type	Longitudinal	
Test Number	3-11	
Test Vehicle	2270C	
Criterion to be Applied	**Structural Adequacy**	**A -** Test article should contain and redirect the vehicle; the vehicle should not penetrate, under-ride, or override the installation although controlled lateral deflection of the test article is acceptable.
	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.
		F - The vehicle should remain upright during and after the collision although moderate roll, pitching and yawing are
		H - The occupant impact velocity in the longitudinal direction should not exceed 40 ft/sec and the occupant ride-down acceleration in the longitudinal direction should not exceed 20 G¨s.
		I - Longitudinal & lateral occupant ridedown accelerations (ORA) should fall below the preferred value of 15.0 g, or at least below the maximum allowed value of 20.49 g.
	Vehicle Trajectory	For redirective devices the vehicle shall exit within the prescribed box.

Project: CCSA Longitudinal Barriers on Curved, Superelevated Roadway Sections
Comparison Case: 2270P (Pickup Truck) with MGS Barr

Table C – Analysis Solution Verification Summary

Verification Evaluation Criteria	Change (%)	Pass?
Total energy of the analysis solution (i.e., kinetic, potential, contact, etc.) must not vary more than 10 percent from the beginning of the run to the end of the run.	1.07%	YES
Hourglass Energy of the analysis solution at the end of the run is less than 5 % of the total initial energy at the beginning of the run	< 1%	YES
The part/material with the highest amount of hourglass energy at any time during the run is less than 5 % of the total initial energy at the beginning of the run.	< 1%	YES
Mass added to the total model is less than 5 % the total model mass at the start of the run.	< 1%	YES
The part/material with the most mass added had less than 10 % of its initial mass added.	< 1%	YES
The moving parts/materials in the model have less than 5 % of mass added to the initial moving mass of the model.	< 1%	YES
There are no shooting nodes in the solution?	NA	YES
There are no solid elements with negative volumes?	NA	YES

Table D - RSVVP Results

Single Channel Time History Comparison Results			**Time interval [0 sec - 0.67**		
O	***Sprauge-Geer Metrics***		**M**	**P**	**Pass?**
	X acceleration		45	40	NO
	Y acceleration		13.2	27.6	YES
	Z acceleration		146.8	45.4	NO
	Yaw rate		13.4	11.7	NO
	Roll rate		9.6	52.7	NO
	Pitch rate		251.3	48	YES
P	***ANOVA Metrics***		**Mean**	**SD**	**Pass?**
	X acceleration/Peak		-1.92	39.08	NO
	Y acceleration/Peak		5.81	35.92	NO
	Z acceleration/Peak		1.09	65.76	NO
	Yaw rate		0.79	20.97	NO
	Roll rate		10.04	51.73	NO
	Pitch rate		1.45	119.09	YES
Multi-Channel Weighting Factors			**Time interval [0 sec; 0.67**		
Multi-Channel Weighting Method		**X Channel**	0.206777873		
Peaks Area I		**Y Channel**	0.275396472		
Area II Inertial		**Z Channel**	0.017825655		
		Yaw Channel	0.441018937		
		Roll Channel	0.032383125		
		Pitch Channel	0.026597937		
Sprauge-Geer Metrics			**M**	**P**	**Pass?**
	All Channels (weighted)		28.5	24.8	YES
ANOVA Metrics			**Mean**	**SD**	**Pass?**
	All Channels (weighted)		1.9	33.2	YES

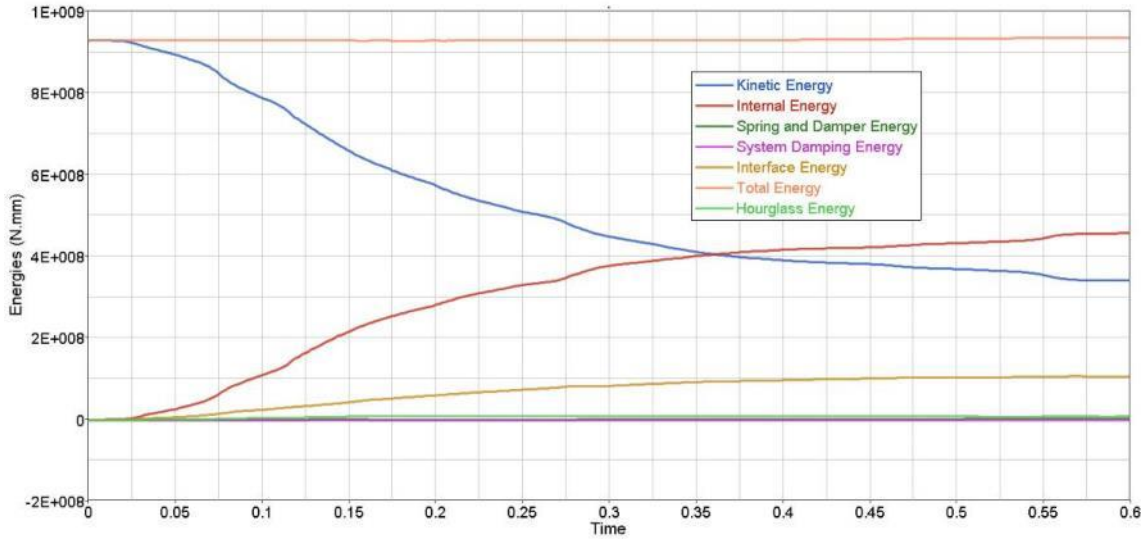


Figure 1: Simulations Energies

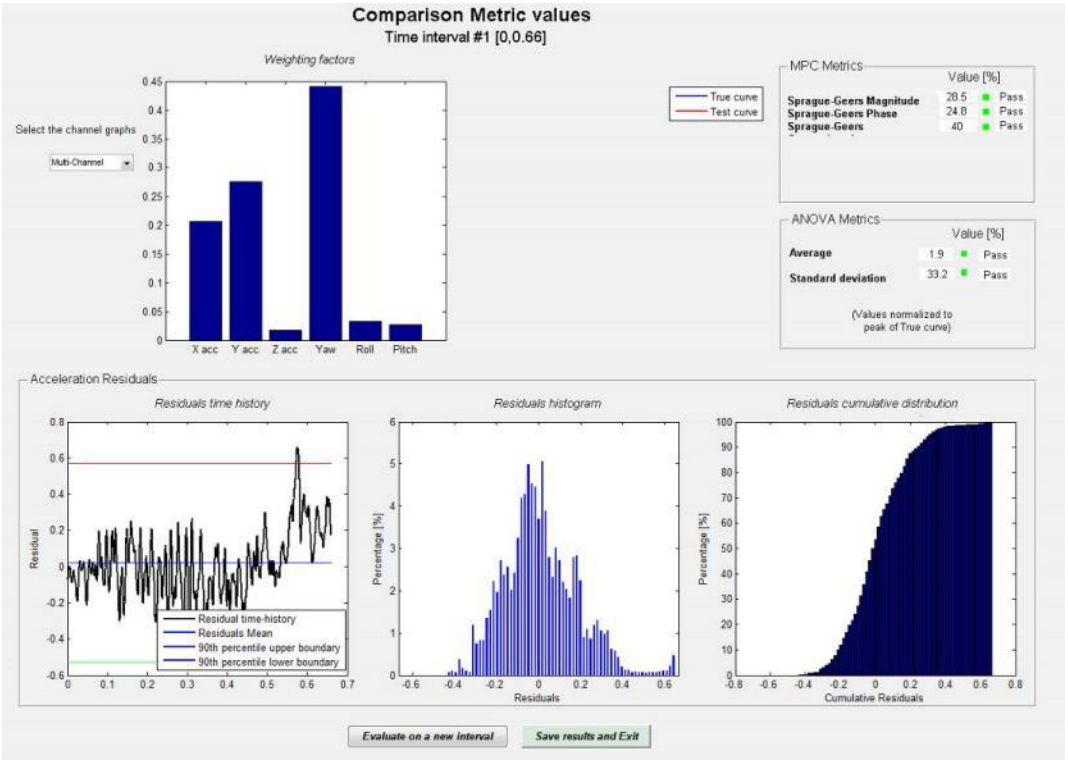


Figure 2a: RSVVP Results – All Channels

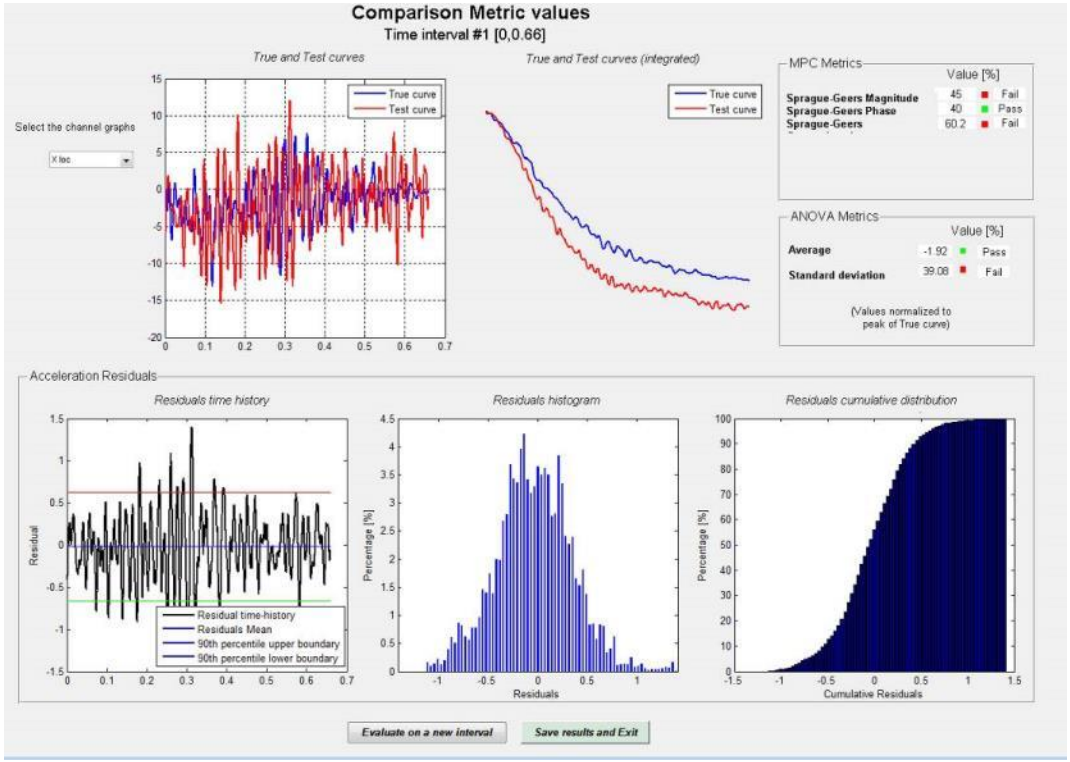


Figure 2b: RSVVP Results – Longitudinal Acceleration

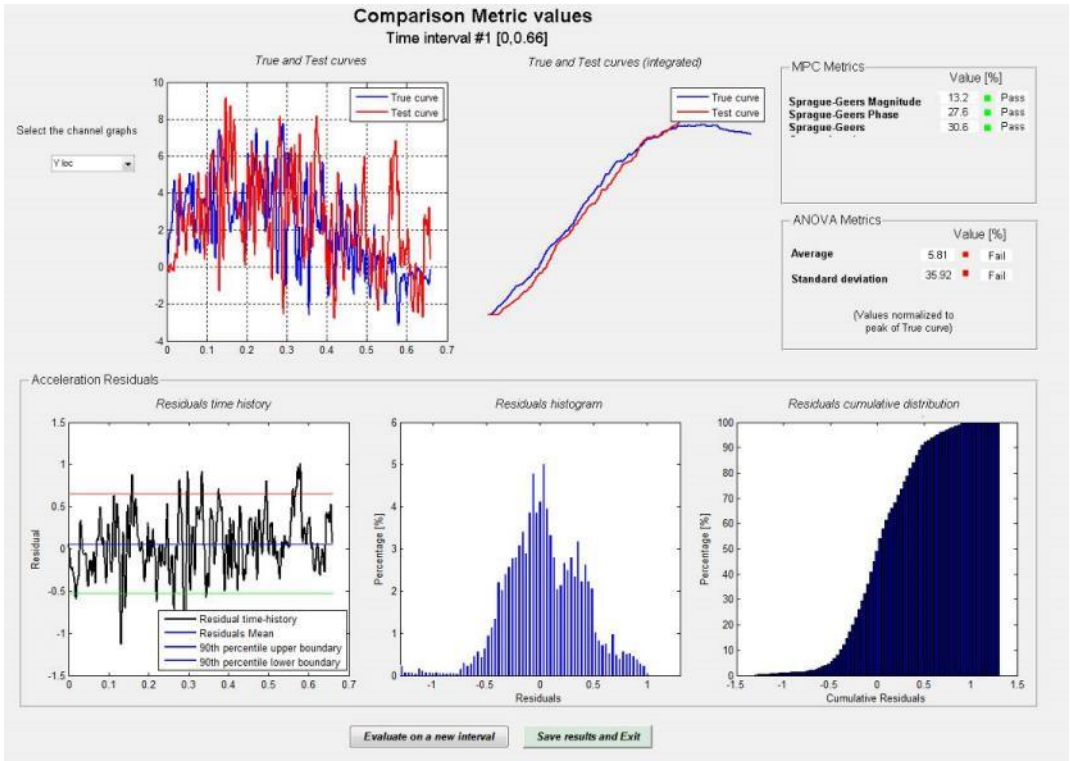


Figure 2c: RSVVP Results – Lateral Acceleration

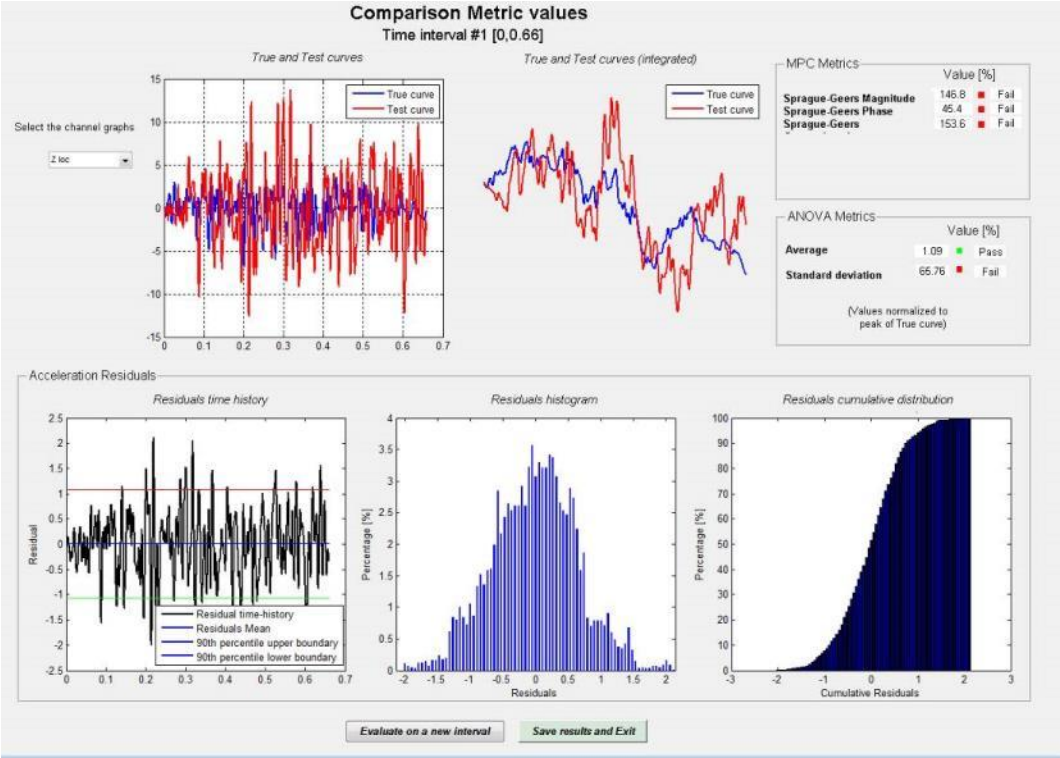


Figure 2d: RSVVP Results – Vertical Acceleration

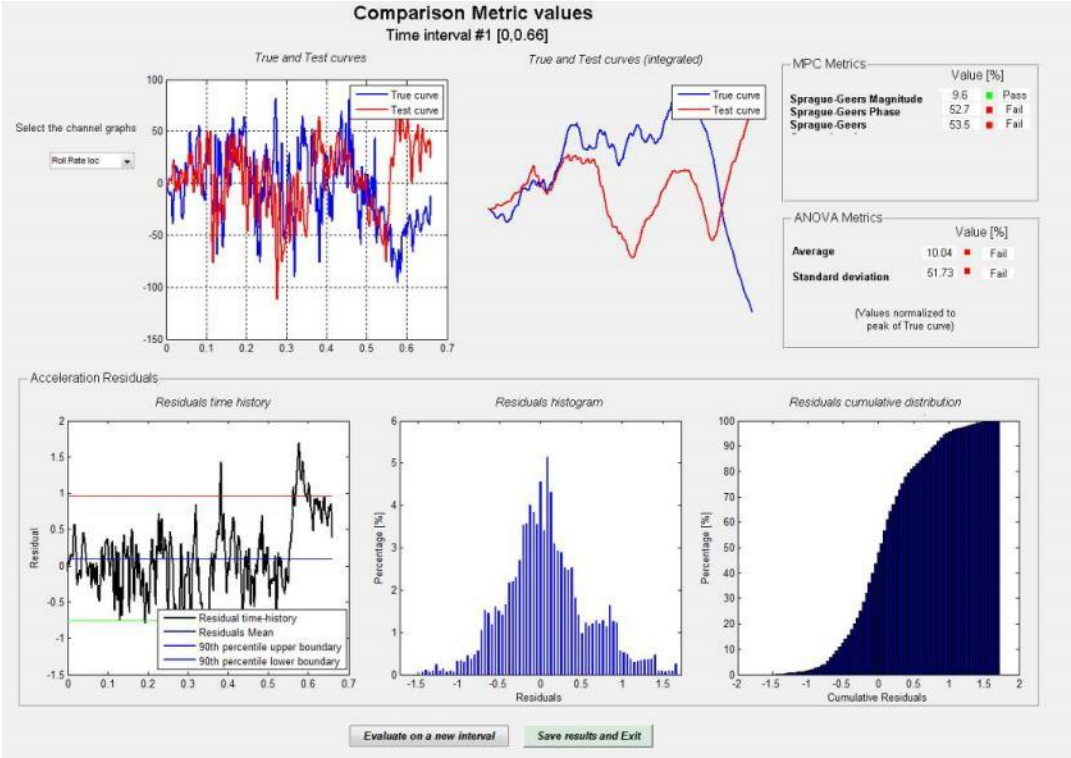


Figure 2e: RSVVP Results – Roll Angle

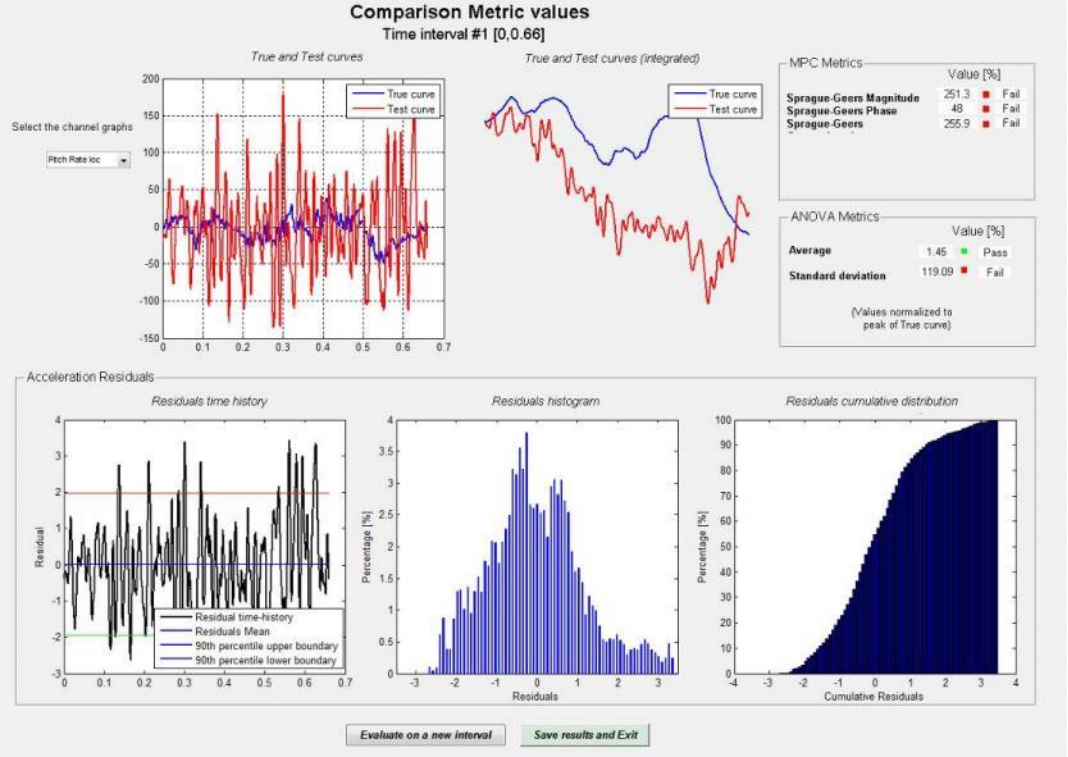


Figure 2f: RSVVP Results – Pitch Angle

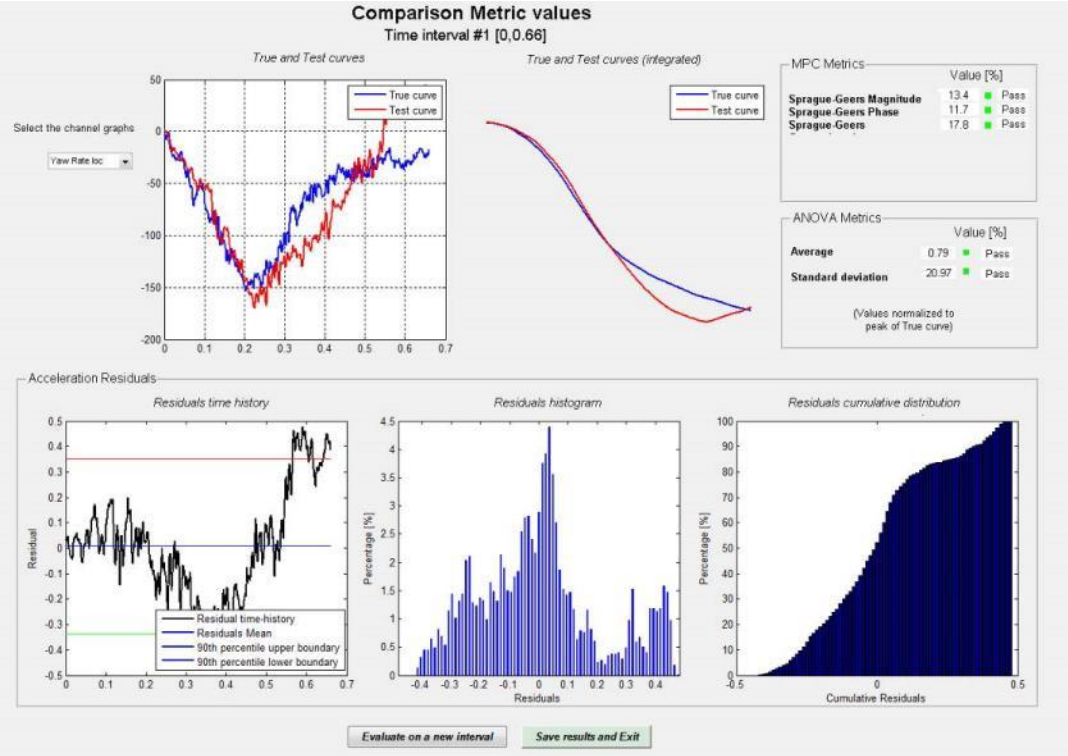


Figure 2g: RSVVP Results – Yaw Angle

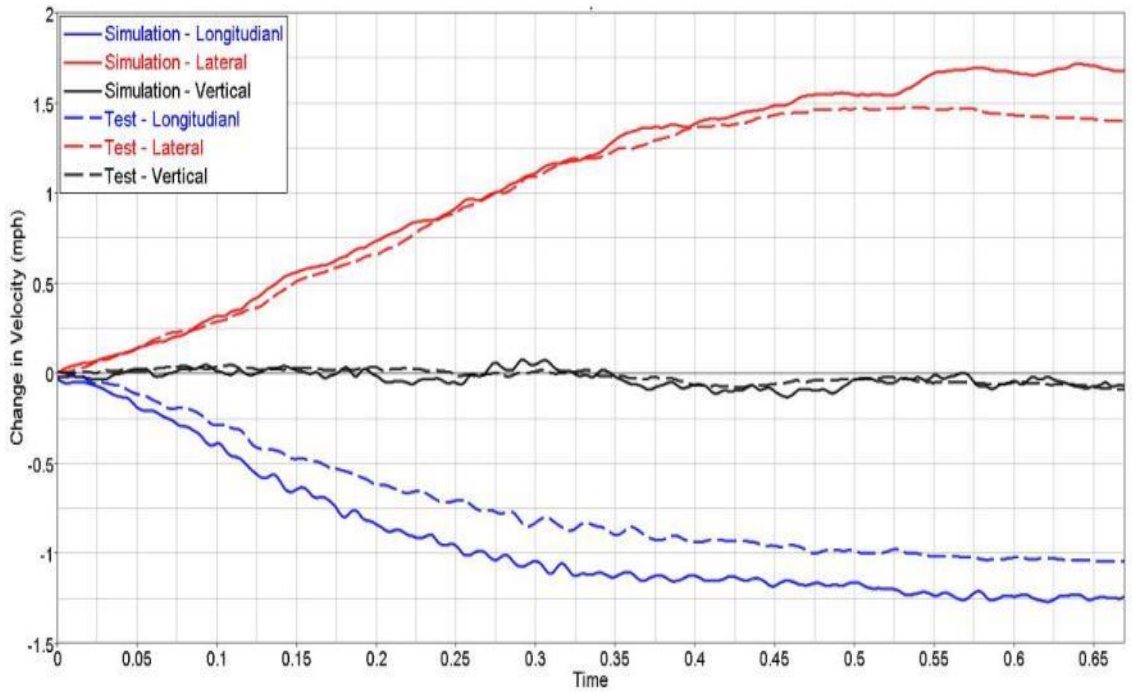


Figure 3: Change in Vehicle Velocities

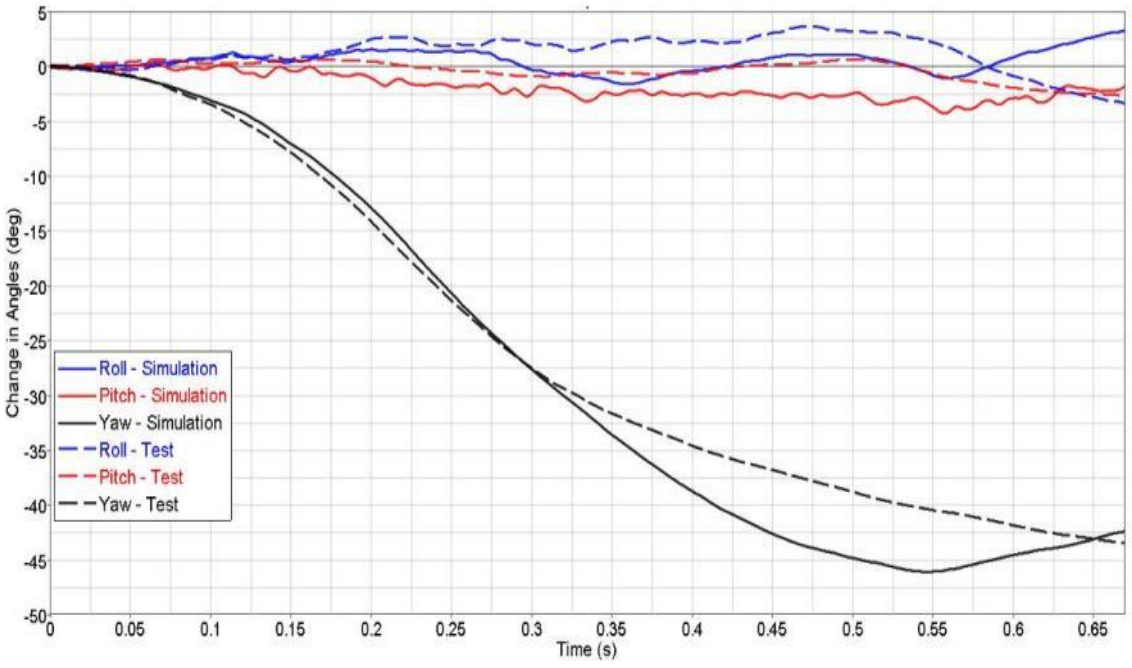


Figure 4: Change in Vehicle Angle

Project: CCSA Longitudinal Barriers on Curved, Superelevated Roadway Sections
Comparison Case: 2270P (Pickup Truck) with MGS Barrier

Table E - Roadside Safety Phenomena Importance Ranking Table (MASH Evaluation)

Evaluation Criteria				Known Result	Analysis Result	Relative Diff. (%)	Agree?
Structural Adequacy	A	A1	Test article should contain and redirect the vehicle; the vehicle should not penetrate, under-ride, or override the installation although controlled lateral deflection of the test article is acceptable.	Yes	Yes		YES
		A2	The relative difference in the maximum dynamic deflection is less than 20 percent.	1.11 m	1.03 m	7%	YES
		A3	The relative difference in the time of vehicle-barrier contact is less than 20 percent.	0.72 s	0.63 s	12%	
		A4	The relative difference in the number of broken or significantly bent posts is less than 20 percent.	3	3		YES
		A5	Barrier did not fail (Answer Yes or No).	Yes	Yes		YES
		A6	There were no failures of connector elements (Answer Yes or No).	Yes	Yes		YES
		A7	There was no significant snagging between the vehicle wheels and barrier elements (Answer Yes or No).	Yes	Yes		YES
		A8	There was no significant snagging between vehicle body components and barrier elements (Answer Yes or No).	Yes	Yes		YES
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 (Answer Yes or No).	Yes	Yes		YES
	F	F1	The vehicle should remain upright during and after the collision. The maximum pitch & roll angles are not to exceed 75 degrees.	Yes	Yes		YES
		F2	Maximum vehicle roll – relative difference is less than 20% or absolute difference is less than 5 degrees.	3.58 (.68s)	3.49 (.68s)	3% 0.09 deg	YES
		F3	Maximum vehicle pitch – relative difference is less than 20% or absolute difference is less than 5 deg.	2.86 (.68s)	4.17 (.68s)	31.4% 1.31 deg	YES
		F4	Maximum vehicle yaw – relative difference is less than 20% or absolute difference is less than 5 deg.	43.74 (.68s)	46.01 (.68s)	4.9% 2.27 deg	YES
	H	H1	Longitudinal & lateral occupant impact velocities (OIV) should fall below the preferred value of 30 ft/s (9.1 m/s), or at least below the maximum allowed value of 40 ft/s (12.2 m/s)	Yes	Yes		YES
		H2	Longitudinal OIV (m/s) - Relative difference is less than 20%t or absolute difference is less than 2 m/s	4.67	5.59	16.4% 0.92 m/s	YES
		H3	Lateral OIV (m/s) - Relative difference is less than 20% or absolute difference is less than 2 m/s	4.76	5.09	6.5% 0.33 m/s	YES
	I	I1	Longitudinal & lateral occupant ridedown accelerations (ORA) should fall below the preferred value of 15.0 g, or at least below the maximum allowed value of 20.49 g.	Yes	Yes		YES
		I2	Longitudinal ORA (g) - Relative difference is less than 20% or absolute difference is less than 4 g's	8.23	12.10	31.9% 3.87 g	YES
		I3	Lateral ORA (g) - Relative difference is less than 20% or absolute difference is less than 4 g's	6.93	9.68	28.4% 2.75 g	YES
Vehicle Trajectory			The vehicle rebounded within the exit box. (Answer Yes or No)	Yes	Yes		YES

Figure 5: Full-Scale Test Summary

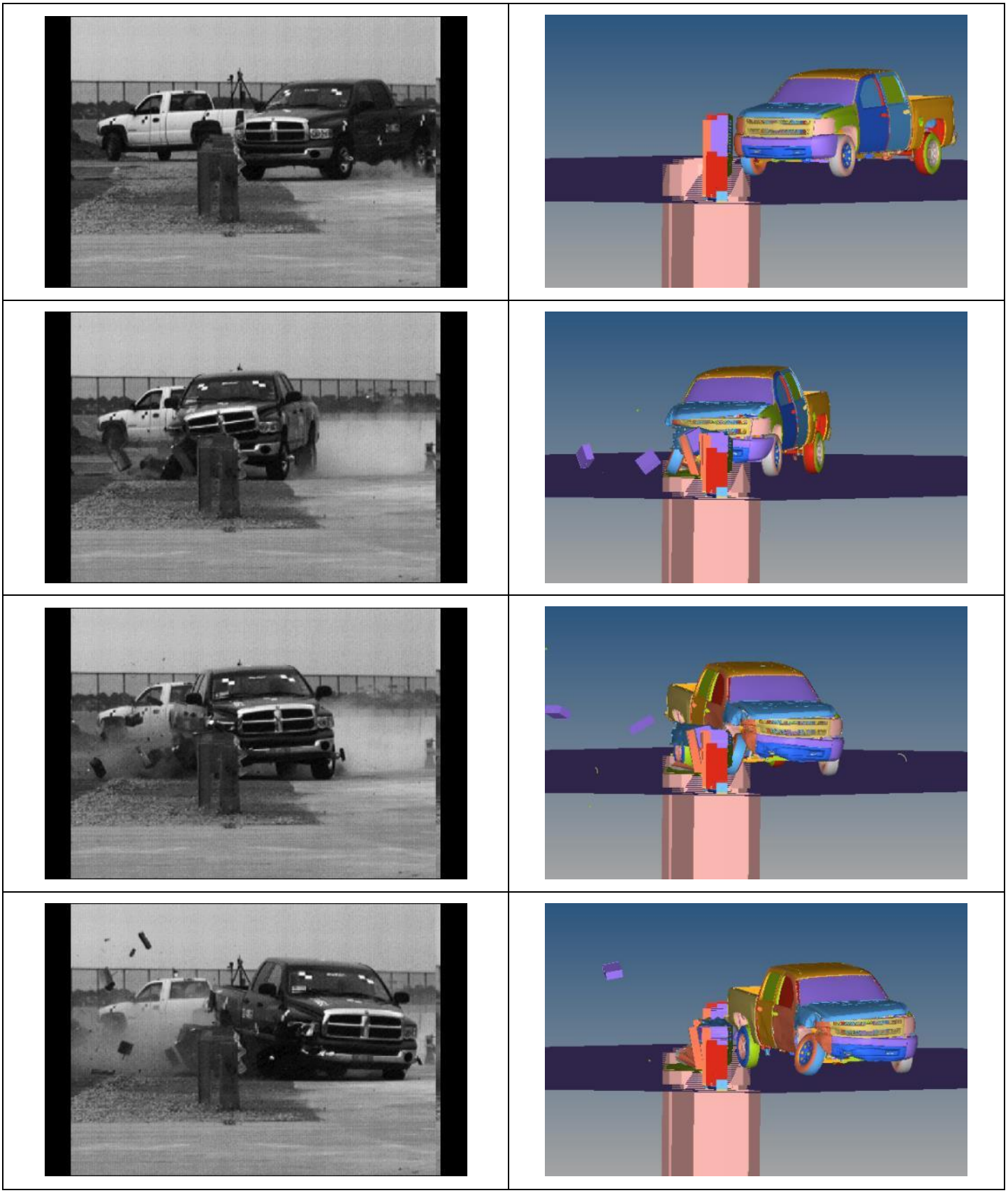


Figure 6a: Sequential Comparisons – Front View

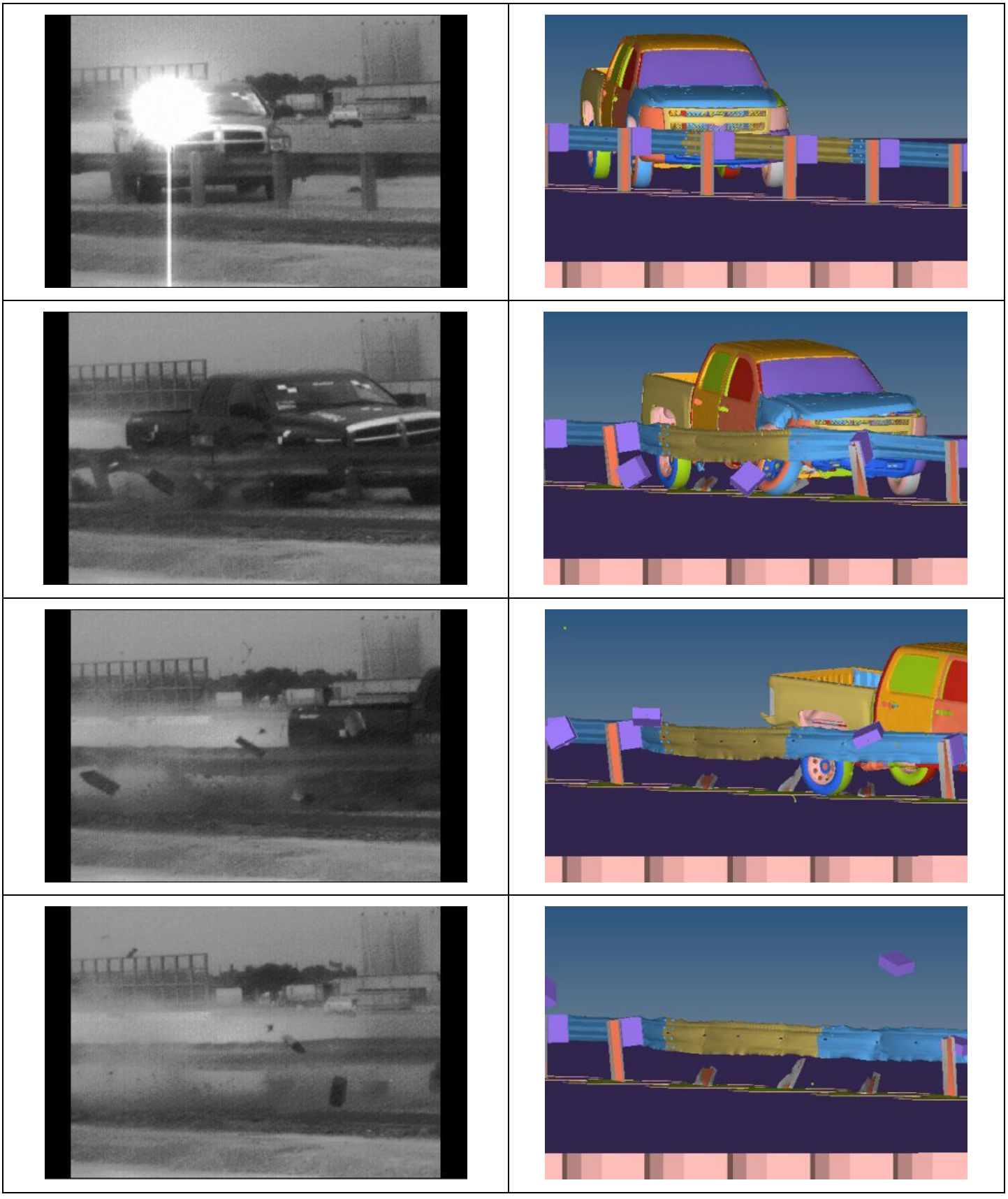


Figure 6b: Sequential Comparisons – Rear View

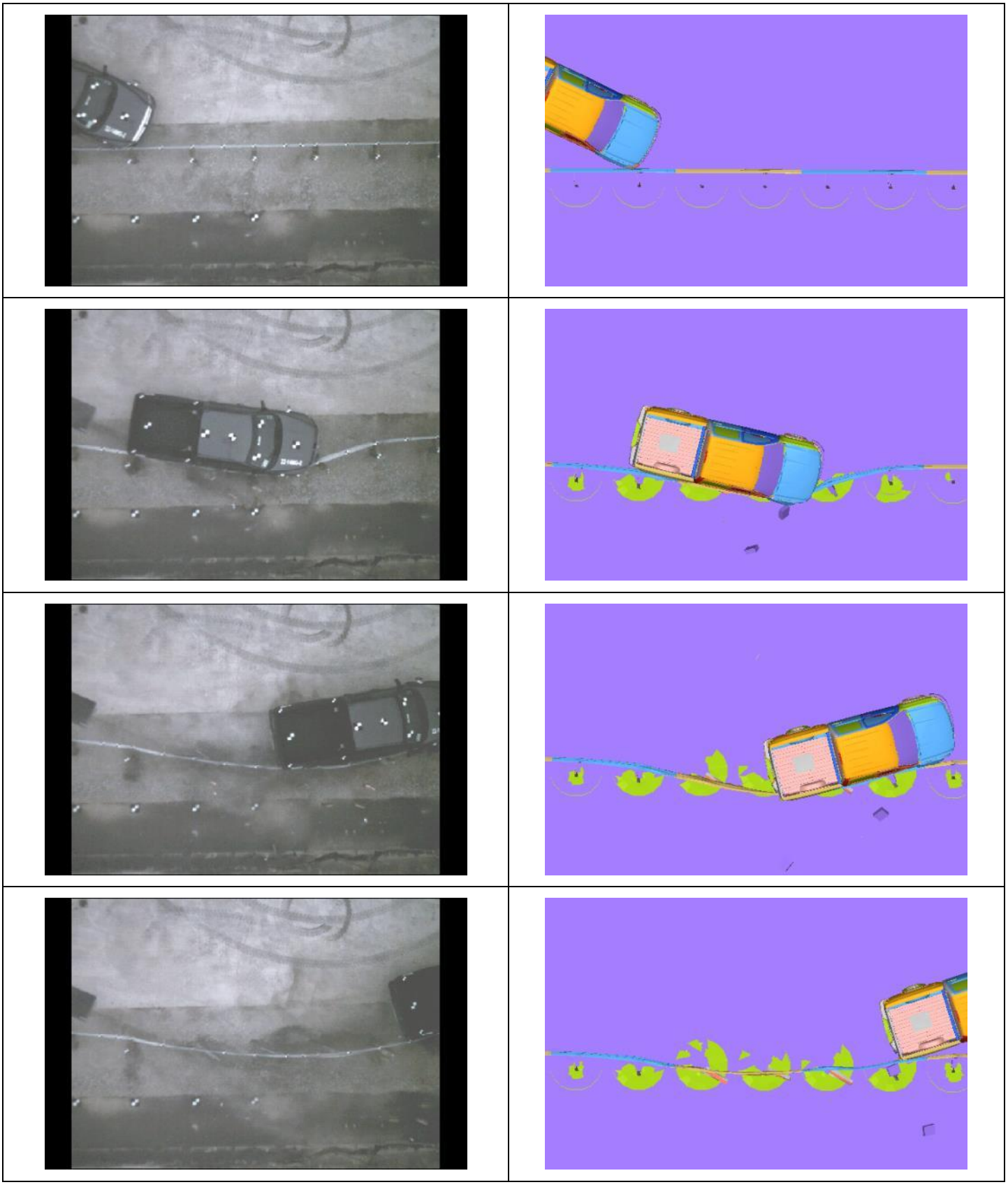


Figure 6c: Sequential Comparisons – Top View

CCSA VALIDATION/VERIFICATION REPORT

Project: CCSA Longitudinal Barriers on Curved, Superelevated Roadway Sections

Comparison Case: 2270P (Pickup Truck) with MGS Barrier

Table F - Composite Verification and Validation Summary:

List the Report MASH08 Test Number		
Table C – Analysis Solution Verification Summary	Did all solution verification criteria in table pass?	**YES**
Table D - RSVVP Results	Do all the time history evaluation scores from the single channel factors result in a satisfactory comparison (i.e., the comparison passes the criterion)?	**NO**
	If all the values for Single Channel comparison did not pass, did the weighted procedure result in an acceptable comparison.	**YES**
Table E - Roadside Safety Phenomena Importance Ranking Table	Did all the critical criteria in the PIRT Table pass? Note: Tire deflation was observed in the test but not in the simulation. This due to the fact that tire deflation in not incorporated in the model. This is considered not to have a critical effect on the outcome of the test	**YES**
Overall	Are the results of Steps I through III all affirmative (i.e., YES)? If all three steps result in a "YES" answer, the comparison can be considered validated or verified. If one of the steps results in a negative response, the result cannot be considered validated or verified.	**YES**

NOTES:
(none)