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SYNTHESIS OF SYSTEM/VEHICLE INTERACTION SIMILARITIES/DISSIMILARITIES WITH 12-INCH VS 8-INCH BLOCKOUTS WITH 31-INCH MOUNTING HEIGHT, MID-SPAN SPLICES

by

Chiara Silvestri Dobrovolny, Ph.D.
Associate Research Scientist

Kierstyn M. White
Graduate Research Assistant

and

Roger P. Bligh, Ph.D., P.E.
Research Engineer

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TEXAS A&M TRANSPORTATION INSTITUTE PROVING GROUND

Mailing Address:
Roadside Safety & Physical Security
Texas A&M University System
3135 TAMU
College Station, TX 77843-3135

Located at:
Texas A&M Riverside Campus
Building 7091
3100 State Highway 47
Bryan, TX 77807

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Chiara Silvestri Dobrovolny,
Associate Research Scientist

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16. Abstract

Full scale crash tests have been performed with use of a 31-inch guardrail with 12-inch blockouts and mid-span splices under a variety of impact conditions. Thus, the behavior of this test article has been fairly well documented. Certain DOTs prefer continued use of standard 8-inch blockouts to reduce inventory and simplify guardrail repair. A desire was raised from some States to receive eligibility for use on the NHS for configurations of 31-inch guardrail with 8-inch blockouts for configurations initially tested with 12-inch blockouts.

The purpose of this research was to review and compare system performance and vehicle interaction in full-scale crash tests of 31-inch guardrail with 12-inch and 8-inch blockouts. The information compiled from this research will enable the Federal Highway Administration and State Departments of Transportation to decide whether use of 8-inch deep blockouts can be considered a crashworthy alternative for configurations initially tested with a 31-inch guardrail with 12-inch blockouts.

To identify similarities and dissimilarities from use of 12-inch and 8-inch blockout depth, data collected through the crash events was then compared with respect to vehicle angular displacements (i.e., yaw, pitch, and roll angles), occupant risks (impact velocities and ridedown accelerations), rail system deflections (dynamic and permanent), and working width, and vehicle interaction with guardrail system through the impact event. Chapter 4 reports findings related to the comparison of vehicle angular displacements, and Chapter 5 compares longitudinal and lateral occupant impact velocities and ridedown accelerations. Information regarding rail system dynamic, permanent deflections, and working width is collected in Chapter 6. Chapter 7 includes an analytical study of after-impact lateral rail trajectory with respect to blockout depth use, and presents an evaluation of vehicle interaction with the rail system during the impact event. Summary and research conclusions are reported in Chapter 8.

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SI* (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

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

APPROXIMATE CONVERSIONS FROM SI UNITS

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

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

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Roadside Safety Research Pooled Fund Committee
CONTACTS
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ALASKA
Jeff C. Jeffers, P.E.
Statewide Traffic & Safety Engineering
Alaska Department of Transportation and Public Facilities
3132 Channel Drive
P.O. Box 112500
Juneau, AK 99811-2500
(907) 465-8962
jeff.jeffers@alaska.gov

CALIFORNIA
John Jewell, P.E.
Caltrans
Office of Materials and Infrastructure
Division of Research and Innovation
5900 Folsom Blvd
Sacramento, CA 95819
(916) 227-5824
john_jewell@dot.ca.gov

FLORIDA
John Mauthner, P.E.
Roadway Design Office
Florida Department of Transportation
605 Suwannee Street
Tallahassee, FL 32399-0450
(850) 414-4334
John.Mauthner@dot.state.fl.us

LOUISIANA
Paul Fossier, P.E.
Assistant Bridge Design Administrator
Bridge and Structural Design Section
Louisiana Transportation Center
1201 Capitol Road
P.O. Box 94245
Baton Rouge, LA 79084-9245
(225) 379-1323
Paul.Fossier@la.gov

Kurt Brauner, P.E.
Bridge Engineer Manager
(225) 379-1933
Kurt.Brauner@la.gov

MINNESOTA
Michael Elle, P.E.
Design Standards Engineer
Minnesota Department of Transportation
395 John Ireland Blvd, MS 696
St. Paul, MN 55155-1899
(651) 366-4622
michael.elle@state.mn.us

PENNSYLVANIA
Mark R. Burkhead, P.E.
Standards & Criteria Engineer
Pennsylvania Department of Transportation
Bureau of Project Delivery
400 North Street
Harrisburg, PA 17105
(717) 783-5110
mburkhead@pa.gov

TENNESSEE
Jeff Jones
Assistant Chief Engineer
Tennessee Department of Transportation
Suite 1300
James K. Polk State Office Building
Nashville, TN 37243-0348
(615) 741-2221
Jeff.C.Jones@tn.gov

Ali Hangul, P.E.
Civil Engineering Manager
(615) 741-0840
(615) 532-7745 (fax)
Ali.Hangul@tn.gov

TEXAS
Aurora (Rory) Meza, P.E.
Roadway Design Section Director
Texas Department of Transportation
Design Division
125 East 11th Street
Austin, TX 78701-2483
(512) 416-2678
Rory.Meza@txdot.gov

WASHINGTON
John P. Donahue, P.E.
Design Policy & Strategic Analysis Estimating Manager
Washington State
Department of Transportation
310 Maple Park Avenue SE
Olympia, WA 98504-7329
(360)705-7952
DonahJo@wsdot.wa.gov

Jeffery K. Petterson, P.E.
Roadside Safety Engineer
(360) 705-7278
PetterJ@wsdot.wa.gov

Rhonda Brooks
Research Manager
(360) 705-7945
Brookrh@wsdot.wa.gov

WEST VIRGINIA
Donna J. Hardy, P.E.
Mobility and Safety Engineer
West Virginia Department of Transportation – Traffic Engineering
Building 5, Room A-550
1900 Kanawha Blvd E.
Charleston, WV 25305-0430
(304) 558-9576
Donna.J.Hardy@wv.gov

FEDERAL HIGHWAY ADMINISTRATION
Richard B. (Dick) Albin, P.E.
Safety Engineer
FHWA Resource Center Safety & Design Technical Services Team
711 South Capitol Blvd.
Olympia, WA 98504
(303) 550-8804
Dick.Albin@dot.gov

William Longstreet
Highway Engineer
FHWA Office of Safety Design
Room E71-107
1200 New Jersey Avenue, S.E.
Washington, DC 20590
(202) 366-0087
Will.Longstreet@dot.gov

TEXAS A&M TRANSPORTATION INSTITUTE
D. Lance Bullard, Jr., P.E.
Research Engineer
Roadside Safety & Physical Security Div.
Texas A&M Transportation Institute
3135 TAMU
College Station, TX 77843-3135
(979) 845-6153
L-Bullard@tamu.edu

Roger P. Bligh, Ph.D., P.E.
Research Engineer
(979) 845-4377
RBligh@tamu.edu

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Chapter 1 Introduction

1.1 Problem Statement

Full scale crash tests have been performed with use of a 31-inch guardrail height with 12-inch blockouts depth and mid-span splices under a variety of impact conditions. Thus, the behavior of this test article has been fairly well documented. Certain Departments of Transportation (DOTs) prefer continued use of standard 8-inch blockouts to reduce inventory and simplify guardrail repair.   Although the 31-inch guardrail system with use of 8-inch blockouts has been tested in certain configurations,   its impact performance has not been evaluated in all configuration variety as for the 12-inch blockouts one. Some States have asked if the 31-inch guardrail with 8-inch blockouts can receive eligibility for use on the National Highway System (NHS) for the configurations that were previously tested with use of 12-inch blockouts. In order to evaluate this request and propose guidance for use of 8-inch blockouts on 31-inch guardrail, a review and comparison of impact performance of full-scale crash tests performed on 31-inch guardrail with 12-inch and 8-inch blockouts is needed.

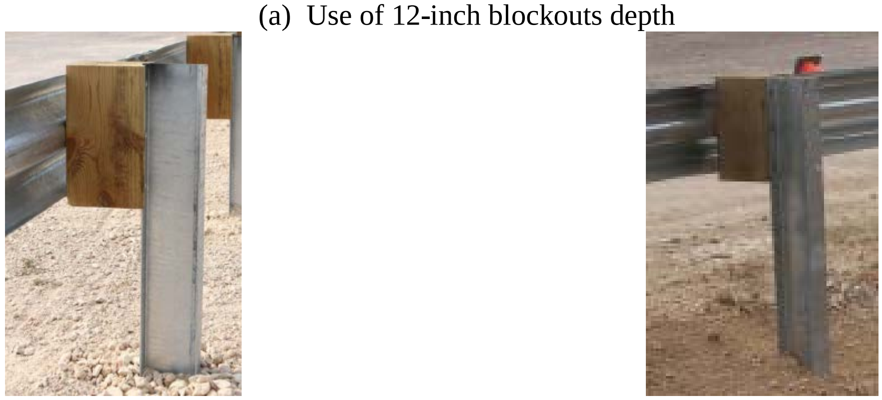
1.2 Research Objective

The purpose of this research is to review and compare system performance and vehicle interaction observed in full-scale crash tests of a 31-inch guardrail system with use of 12-inch and 8-inch blockouts. The information compiled from this research will enable the Federal Highway Administration (FHWA) and DOTs to decide whether use of 8-inch deep blockouts can be considered a crashworthy alternative for configurations initially tested with a 31-inch guardrail with 12-inch blockouts.

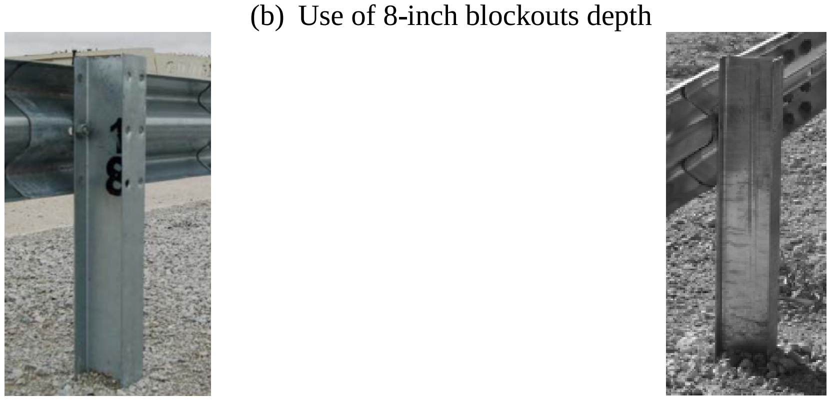
Chapter 2 Literature Review

On May 17, 2010, FHWA issued a technical memorandum to provide guidance to State DOTs on height of guardrail for new installations on NHS (*1*). In regard to *MASH*, the memorandum recognized performance issues with modified G4 (1S) guardrail and recommended adoption of 31-inch high guardrail designs for new installations (*2*). Blockouts are used in guardrail systems to offset the rail from the posts, in order to limit the possibility of vehicle wheel's snagging on the post and, thus, maintaining acceptable occupant risks and vehicle angular displacements. Examples of 31-inch w-beam guardrail systems with use of different blockouts depth and without use of blockouts are reported in Figure 2.1.

(a) Use of 12-inch blockouts depth



(b) Use of 8-inch blockouts depth



(c) No use of blockouts

Figure 2.1. Examples of systems with 12-inch, 8-inch, and no blockouts.

Use of 12-inch blockouts on a 31-inch guardrail mounting height has been crash tested in a variety of test article and field conditions. Crash tests were evaluated under the National Cooperative Highway Research Program (NCHRP) *Report 350* criteria for the Modified Midwest Guardrail System (MMGS) (*3, 4*). The same system was also evaluated with 6 inches tall concrete curb and with reduced post spacing under *NCHRP Report 350* criteria (4). The Midwest Guardrail System MGS) with use of 12-inch blockouts was also tested adjacent to an 8H:1V approach slope and on 13H:1V, 7H:1V, and 5H:1V flare rate, under *NCHRP Report 350* criteria (*5, 6*). The MMGS was crash tested also under Manual for Assessing Safety Hardware (*MASH*) requirements with use of 12-inch timber blockouts (*7, 8*). *MASH* 3-11 test was run for a Midwest Guardrail System (MGS) system adjacent to a 2H:1V foreslope and for MGS long-span with culvert both impacting into culvert area and into regular spacing area (*9, 10*).

However, concerns were expressed by certain DOTs regarding the size of the blockouts used in the MGS and the practical aspects of using it on new guardrail installations. Consequently, the Texas Department of Transportation (TxDOT) requested an evaluation of a 31-inch tall guardrail system that would incorporate 8-inch deep offset block. The 32-inch W-beam guardrail with standard offset blocks and on flat terrain was tested under *MASH* requirements: test TL 3-10 met all required *MASH* performance criteria (*11*). The same 31-inch tall guardrail system with use of 8-inch deep offset blocks was crash tested according to *MASH* criteria with the face of the rail aligned with the break point of a 2H:1V slope: with this configuration, both tests TL 3-10 and TL 3-11 were performed and evaluated. Also, a pooled fund program funded a project aimed at evaluating a 31-inch tall guardrail with 8-inch blockouts across a low-fill culvert according to *MASH* criteria (*12*).

This research aims at evaluating system and vehicle interaction similarities and dissimilarities for a 31-inch guardrail mounting height with 12-inch vs. 8-inch blockouts and mid-span splices. The information compiled from this research will enable the DOTs to decide whether use of 8-inch deep blockouts would be a crashworthy possible and/or preferable option for use with a 31-inch guardrail mounting height and mid-span splices according to different roadway conditions and/or test level certifications.

Table 2.1 lists full-scale crash tests that were reviewed during the development of this research study. Tests involve 31-inch guardrail height with use of 12-inch or 8-inch blockouts, or without use of blockouts. The list includes a variety of testing configurations for the 31-inch guardrail system such as guardrail on slopes, with curb, with reduced post spacing, at a culvert, with a flare, or as a median barrier. Also, the researchers decided to include recent testing developed at the Midwest Roadside Safety Facility on 34 and 36-inch MGS height.

Table 2.1. List of Reviewed Full-Scale Crash Tests.

					Impact	
Reference	Test	Blockout (in)	Article Description	Vehicle	Speed (mph)	Angle (deg)
(4)	NPG-4	12	MGS	2000P	61	25.6
	NPG-5	12	MGS with curb	2000P	60.1	25.8
	NPG-6	12	MGS with reduced post spacing	2000P	60.2	25.6
(7)	2214MG -1	12	MGS	2270P	62.6	25.2
(8)	2214MG -2	12	MGS	2270P	62.8	25.5
(13)	2214MG-3-1	12	MGS	1100C	60.8	25.4
(9)	MGS221-2	12	MGS on a 2:1 fill slope	2270P	63.1	25.5
(5)	MGSAS-1	12	MGS down from a 8:1 slope break	2000P	62.4	25.9
	MGSAS-2	12	MGS down from a 8:1 slope break	820C	61.7	21.6
(10)	LSC-1	12	MGS at a culvert	2270P	62.5	24.8
	LSC-2	12	MGS at a culvert	2270P	61.9	24.9
(6)	FR-1	12	MGS with 13:1 flare	2000P	63.9	30.6
	FR-2	12	MGS with 7:1 flare	2000P	63.1	34
	FR-3	12	MGS with 7:1 flare	820C	63.5	28.7
	FR-4	12	MGS with 5:1 flare	2000P	65	36.8
	FR-5	12	MGS with 5:1 flare	820C	59.3	31.8
(14)	MGSMRH-1	12	MGS at 34"	1100C	63.6	25
	MGSMRH-2	12	MGS at 36"	1100C	64.1	21.9
(11)	420020-5	8	W-beam guardrail	1100C	60.4	25.6
(15)	405160-20-1	8	W-beam on 2:1 slope	2270P	63.9	25
	405160-20-2	8	W-beam on 2:1 slope	1100C	60.3	25.9
(12)	405160-23-2	8	W-beam on low fill culvert	2270P	62.9	26.1
(16)	490023-3	8	W-beam median barrier	1100C	62.2	25
	490023-4	8	W-beam median barrier	2270P	63	25.4
(17)	220570-4	0	T31 W-beam guardrail	820C	63.4	20.3
(18)	220570-11	0	T31 guardrail on curb	2270P	62.3	24.4
(19)	400001-TGS1	0	TGS	2270P	63.3	23.8
	400001-TGS2	0	TGS	820C	61.1	19.7
(20)	MGSNB-1	0	MGS w/o blockouts	2270P	62.7	24.7
	MGSNB-2	0	MGS w/o blockouts	1100C	63	25.5

Chapter 3 Methodology

The researchers identified available data from full-scale crash tests performed on 31-inch guardrail mounting height with use of 12-inch, 8-inch blockouts and no use of blockouts, and mid-span splices. To identify similarities and dissimilarities from use of 12-inch and 8-inch blockout depth, data collected through the crash events was then compared with respect to:

1) Vehicle angular displacements (i.e., yaw, pitch, and roll angles);

2) Occupant risks (impact velocities and ridedown accelerations);

3) Rail system deflections (dynamic and permanent), and working width;

4) Vehicle interaction with guardrail system through the impact event.

When needed, film analysis of the full scale crash tests was reviewed to acquire a full understanding of the interaction between the vehicle and the guardrail posts. Also, statistical analysis was performed on collected data, when applicable, to objectively verify existence of similarities or dissimilarities among use of 12-inch or 8-inch blockout depth with a 31-inch guardrail system.

Chapter 4 reports findings related to the comparison of vehicle angular displacements, and Chapter 5 compares longitudinal and lateral occupant impact velocities and ridedown accelerations. Chapter 6 collects information regarding rail system dynamic, permanent deflections, and working width. Chapter 7 includes an analytical study of after-impact lateral rail trajectory with respect to blockout depth use, and presents an evaluation of vehicle interaction with the rail system during the impact event. Summary and research conclusions are reported in Chapter 9.

Chapter 4 Analysis of Angular Displacements

In this Chapter, data collected through crash events was reviewed and compared with respect to vehicle angular displacements (i.e., yaw, pitch, and roll angles). The researchers used the concept of ANalysis Of VAriance (ANOVA), to statistically evaluate angular displacement results obtained from the tests. In statistics, ANOVA provides a statistical test of whether or not the means of several groups are all equal, and therefore generalizes t-test to more than two groups.

4.1 Yaw

Vehicle yaw behavior is an indication of the vehicle stability and redirection after impacting the barrier system, as well as of possible vehicle's wheel snagging behavior during the test. Yaw angular displacements from tests included in Table 2.1 were collected and compared. Figure 4.1 shows yaw angles from all tests, including use of 12-inch, 8-inch, and no (0) blockouts. Two main observations were derived from Figure 4.1, in terms of similarities/dissimilarities from use of different blockout depths. First, vehicle yaw angular displacements can vary significantly among tests with use of same blockout depth. This is not a surprise, since as it was already stated, the yaw angular displacement is an indication of vehicle stability and system redirection capacity, and thus it might be influenced by the particular test installation configuration and the actual impact conditions. Also, the yaw displacement behavior recorded in some tests with use of 8-inch blockouts seems to compare favorably to the yaw displacement obtained with tests with use of 12-inch blockouts, and even with no blockouts (Figure 4.2).

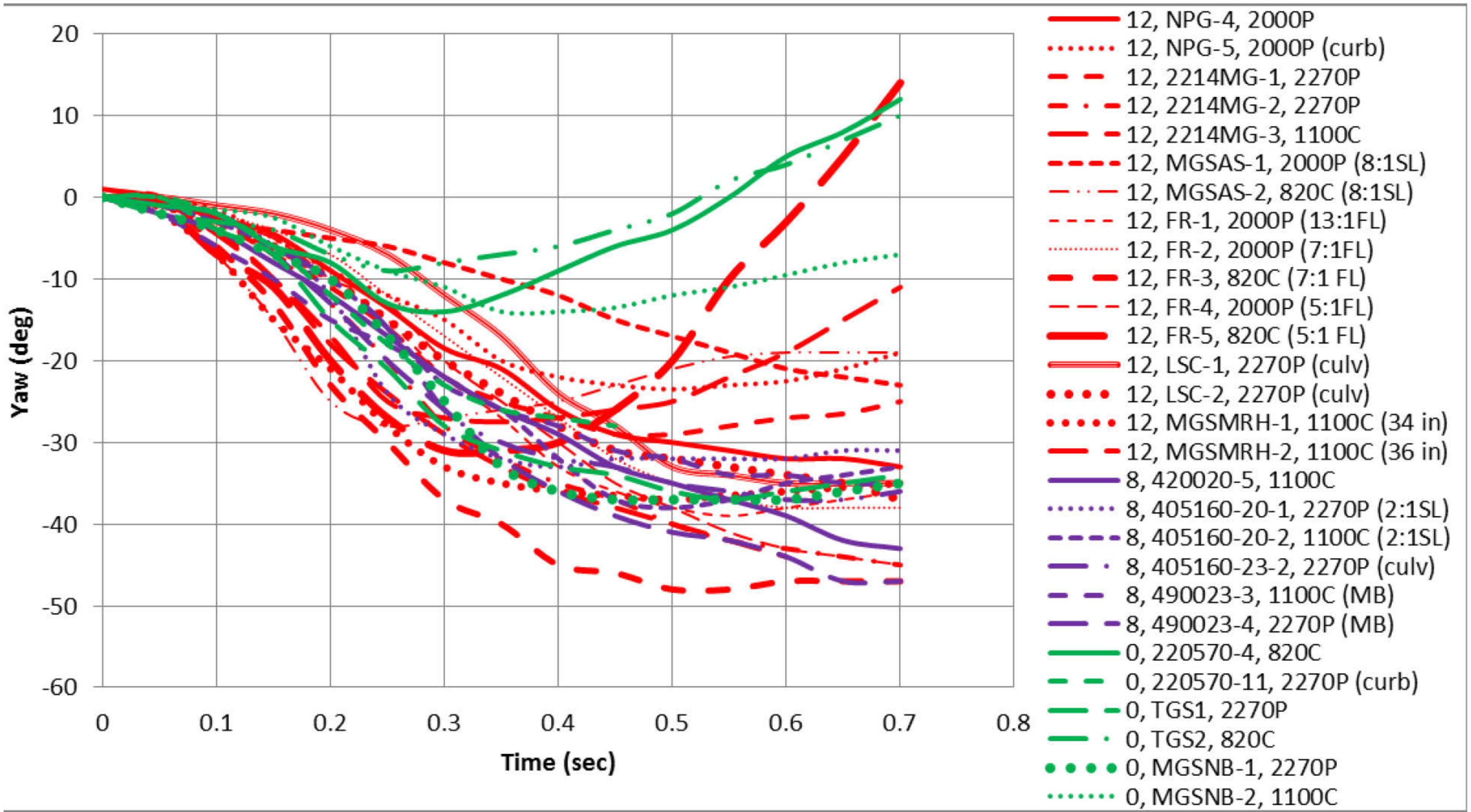


Figure 4.1. Recorded yaw angles from all considered tests.

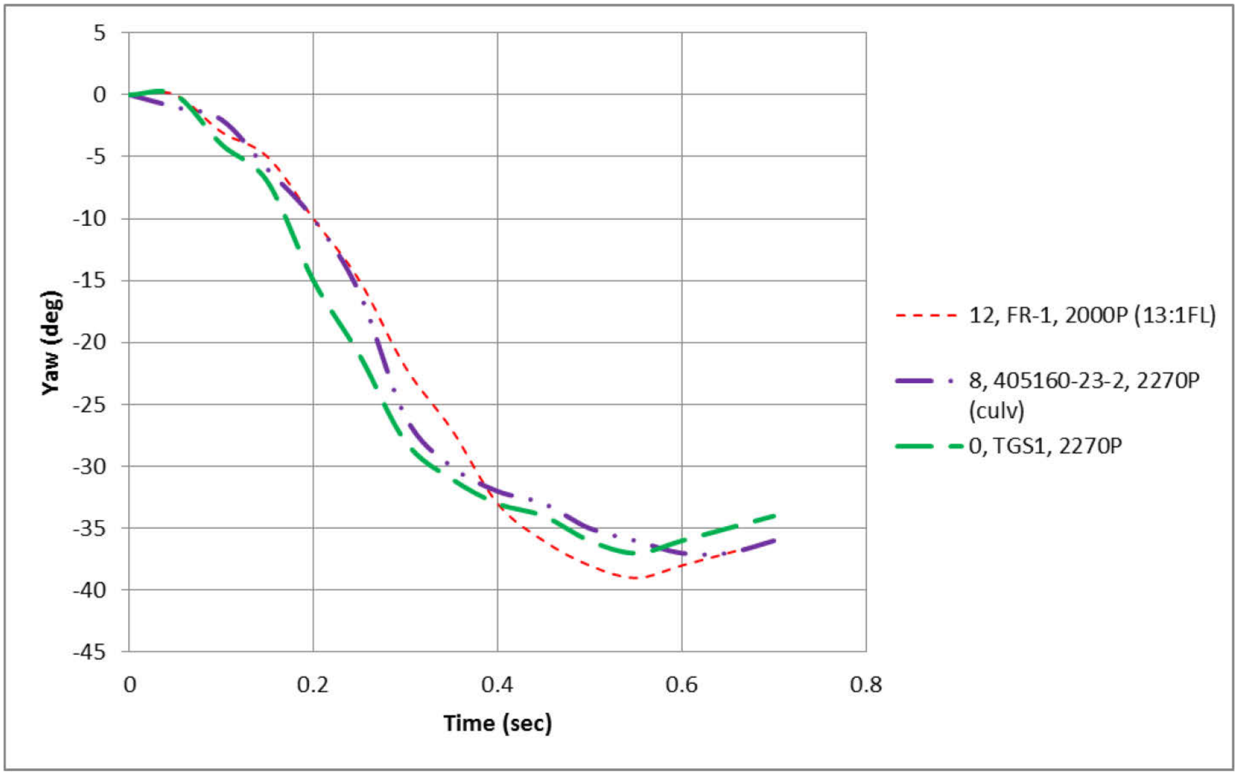
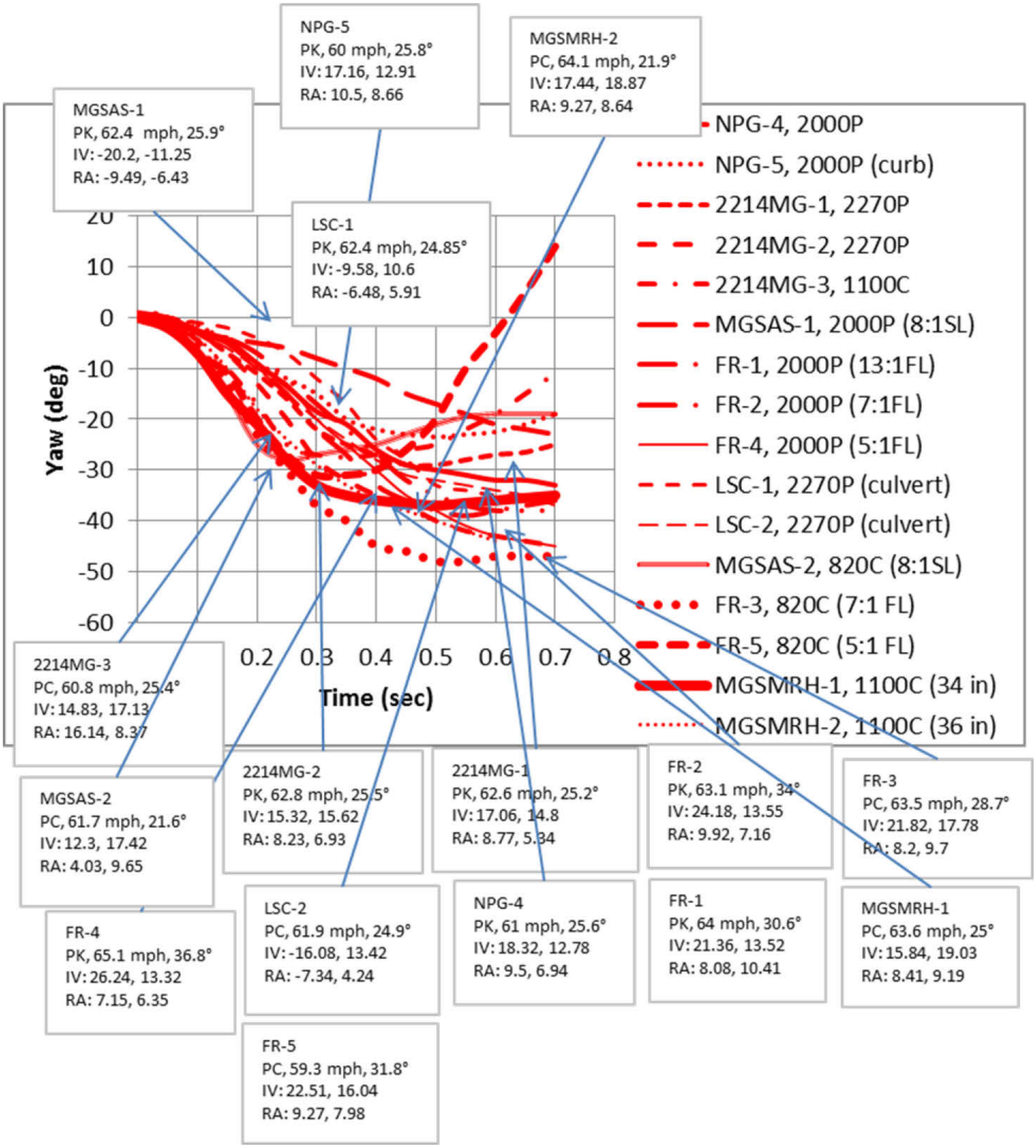


Figure 4.2. Yaw angular displacement comparison for selected tests with use of 12-inch, 8-inch, and no blockouts.

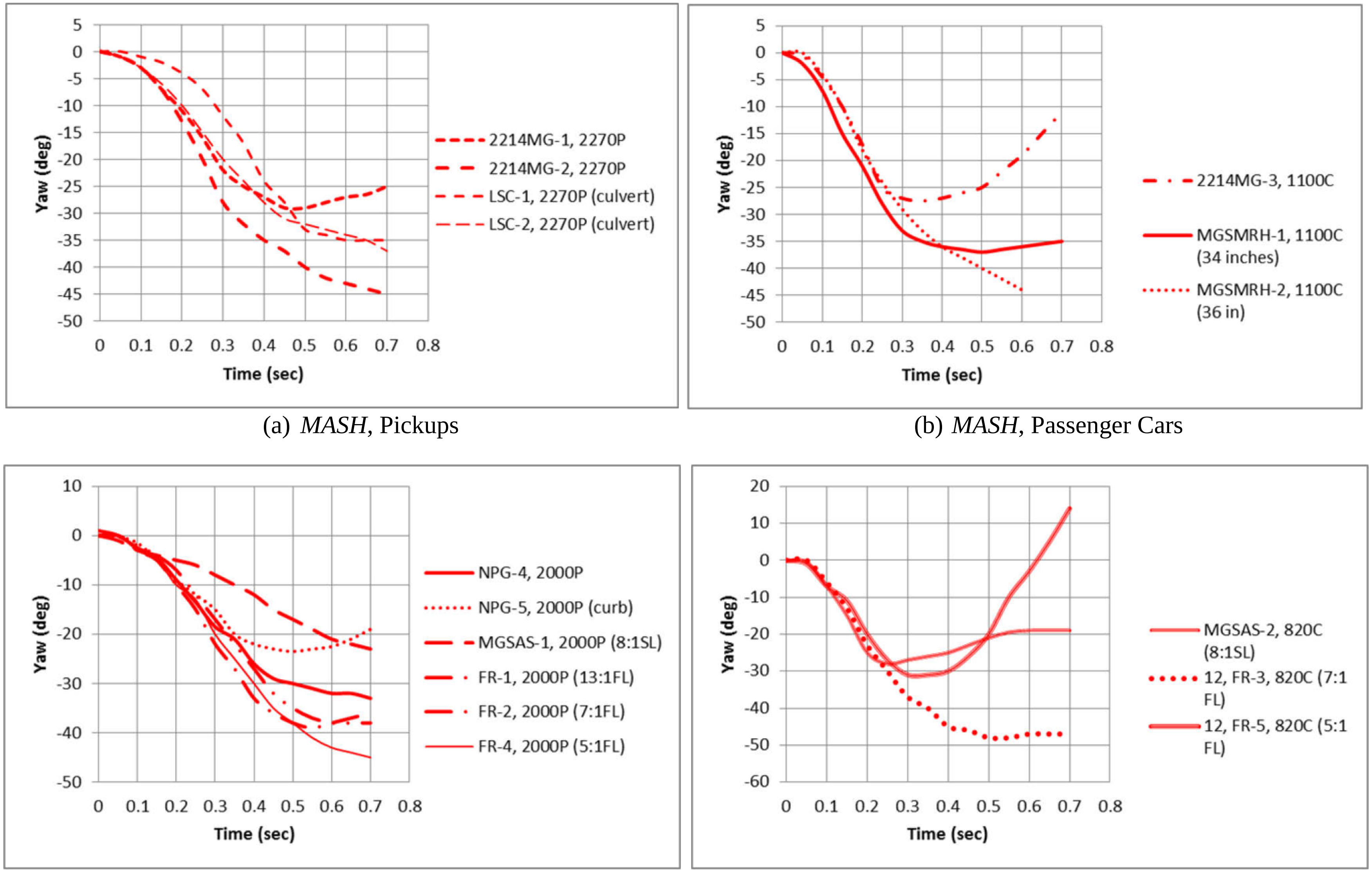
4.1.1 Yaw Comparison According to Blockout Depth

Yaw angular displacements were plotted for comparison according to blockout depths (12-inch, 8-inch, and no blockouts). Figure 4.3 collects yaw angular displacement recorded from tests with use of 12-inch blockout depth. Please refer to Table 2.1 for a brief description of tests. Yaw displacements for these systems with use of 12-inch blockout depth were then categorized in Figure 4.4 according to the testing criteria used. For example, Figure 4.4(a) collects yaw angular displacements recorded only from tests with 1) use of 12-inch blockouts, 2) 2270P (*MASH* pickup truck), and 3) *MASH* nominal impact conditions (62 mph and 25 degrees). Similarly, Figure 4.4(d) collects yaw angular displacements recorded only from tests with 1) use of 12-inch blockouts, 2) 820C (*NCHRP Report 350* Passenger Car), and 3) *NCHRP Report 350* nominal impact conditions (62 mph and 20 degrees). Please note that the actual impact conditions might have varied depending on the test article configuration tested (as an example, a test of a flared system will result in a higher impact angle).



PC: Passenger Car
PK: Pickup
IV: Impact Velocities (Longitudinal, Lateral) (ft/sec)
RA: Ridedown Accelerations (Longitudinal, Lateral) (g's)

Figure 4.3. Recorded yaw angles with use of 12-inch blockout depth.



(a) *MASH*, Pickups

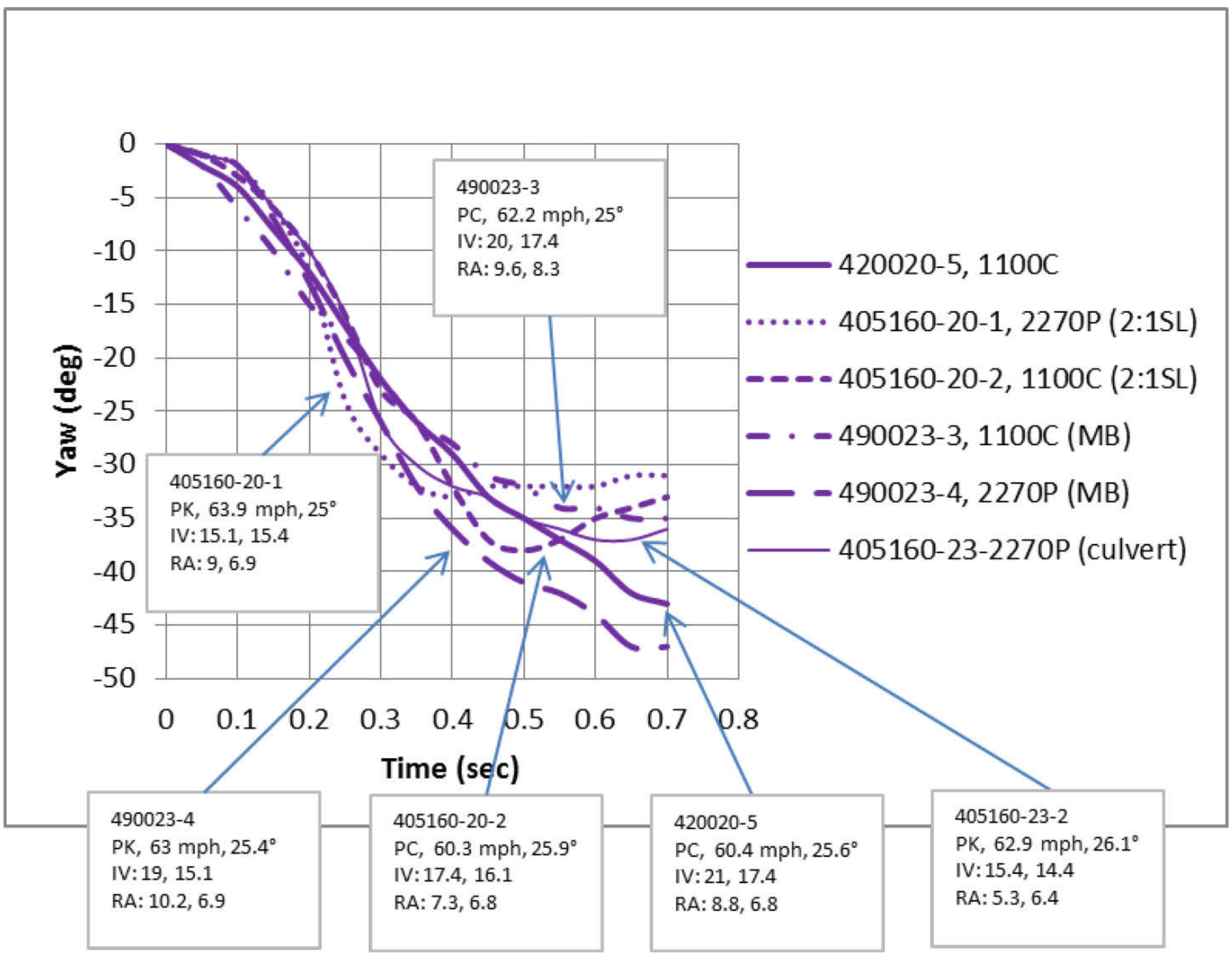
(b) *MASH*, Passenger Cars

(c) *NCHRP Report 350*, Pickups

(d) *NCHRP Report 350*, Passenger Cars

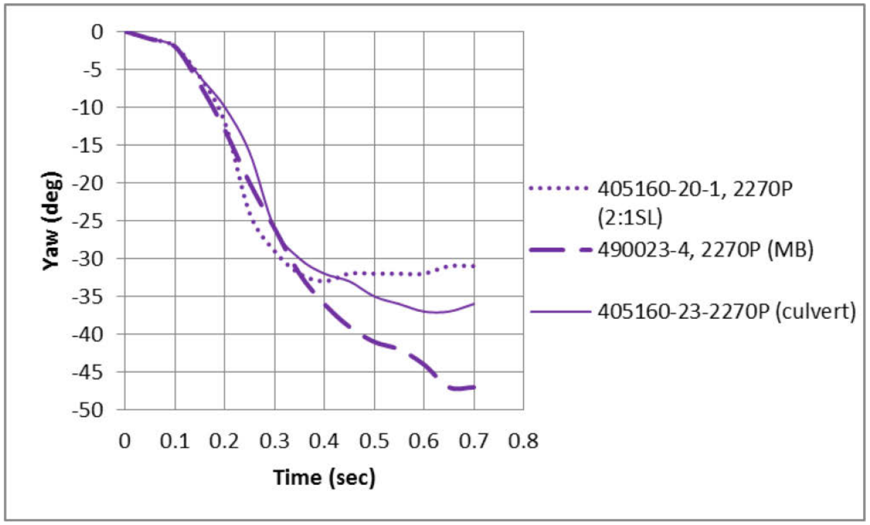
Figure 4.4. Recorded **y**aw angles with use of 12-inch blockout depth, differentiated by test type criteria used.

Figure 4.5 collects yaw angular displacement recorded from tests with use of 8-inch blockout depth. Please refer to Table 2.1 for a brief description of tests. Yaw displacements for these systems with use of 8-inch blockout depth were then categorized in Figure 4.6 according to the testing criteria followed. For example, Figure 4.6(a) collects yaw angular displacements recorded only from 1) tests with use of 8-inch blockouts, with 2) 2270P (*MASH* pickup truck), and with 3) *MASH* nominal impact conditions (62 mph and 25 degrees). As it can be noted, only *MASH* tests were performed on a 31-inch guardrail, with mid-span splices, and with use of 8-inch blockout depth.

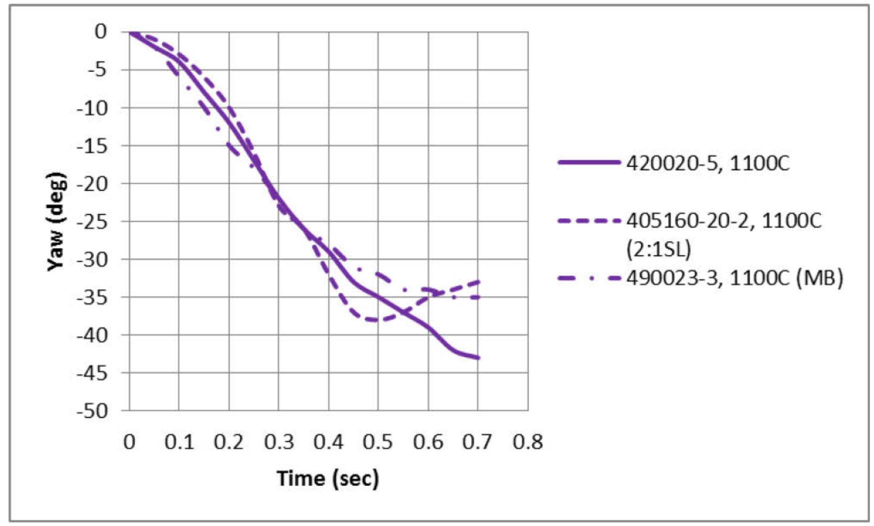


PC: Passenger Car
PK: Pickup
IV: Impact Velocities (Longitudinal, Lateral) (ft/sec)
RA: Ridedown Accelerations (Longitudinal, Lateral) (g's)

Figure 4.5. Recorded **y**aw angles with use of 8-inch blockout depth.



(a) *MASH*, Pickups



(b) *MASH*, Passenger Car

N/A

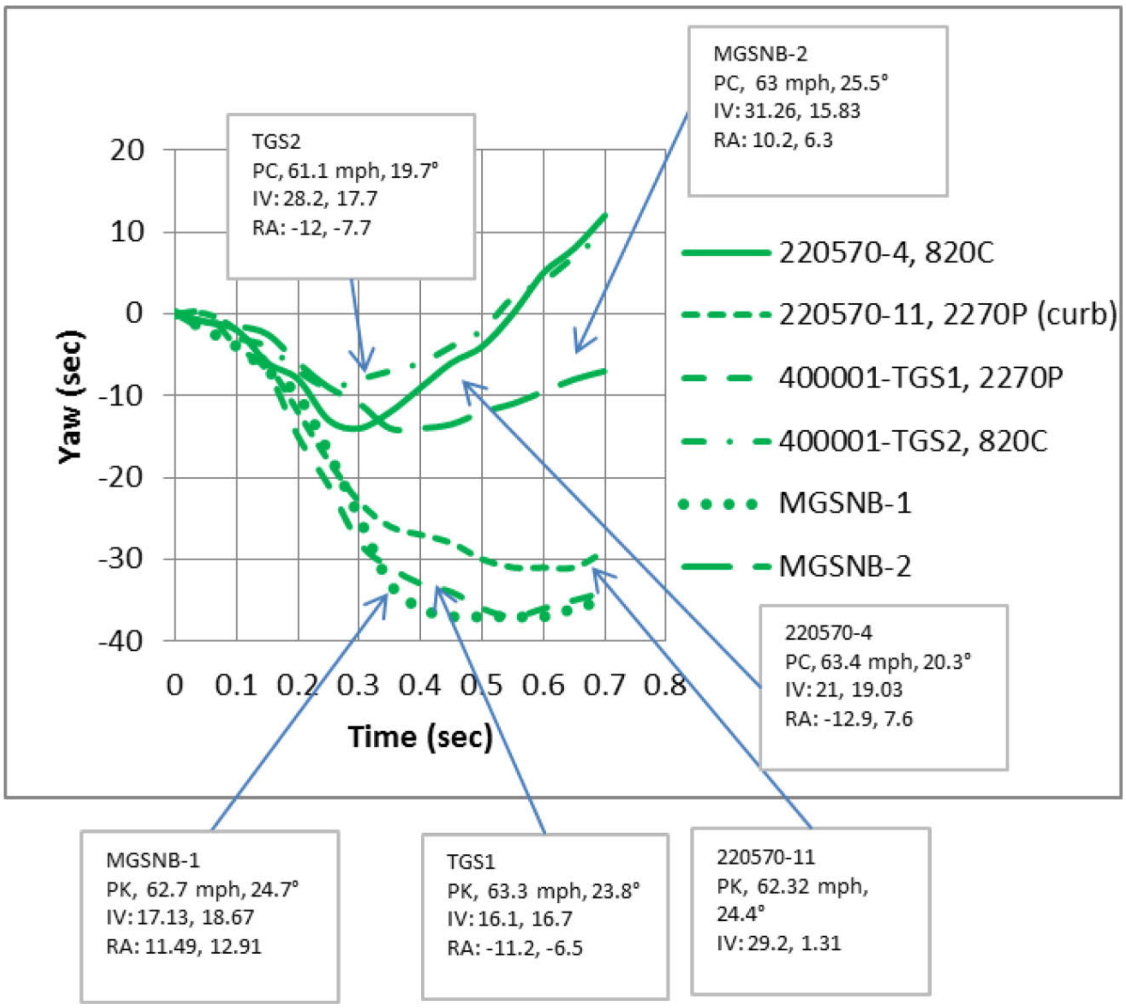
N/A

(c) *NCHRP Report 350*, Pickups

(d) *NCHRP Report 350*, Passenger Cars

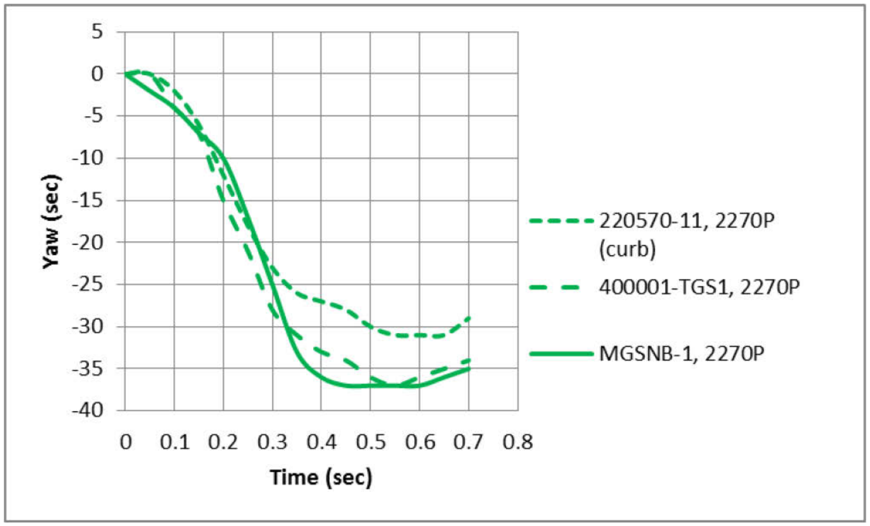
Figure 4.6. Recorded **y**aw angles with use of 8-inch blockout depth, differentiated by test type criteria used.

Figure 4.7 collects yaw angular displacement recorded from tests with no use of blockouts. Please refer to Table 2.1 for a brief description of tests. Yaw displacements for these systems with no use of blockouts were then categorized in Figure 4.8 according to the testing criteria followed. For example, Figure 4.8(a) collects yaw angular displacements recorded only from 1) tests with no use of blockouts, with 2) 2270P (*MASH* pickup truck), and with 3) *MASH* nominal impact conditions (62 mph and 25 degrees). Similarly, Figure 4.8(c) collects yaw angular displacements recorded only from 1) tests with no use of blockouts, with 2) 820C (*NCHRP Report* 350 Passenger Car), and with 3) *NCHRP Report 350* nominal impact conditions (62 mph and 20 degrees).



PC: Passenger Car
PK: Pickup
IV: Impact Velocities (Longitudinal, Lateral) (ft/sec)
RA: Ridedown Accelerations (Longitudinal, Lateral) (g's)

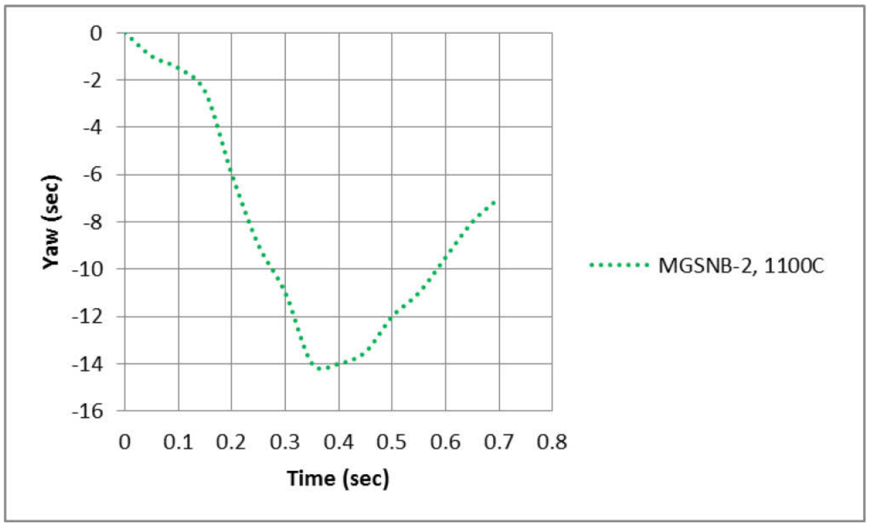
Figure 4.7. Recorded **y**aw angles with no use of blockouts.



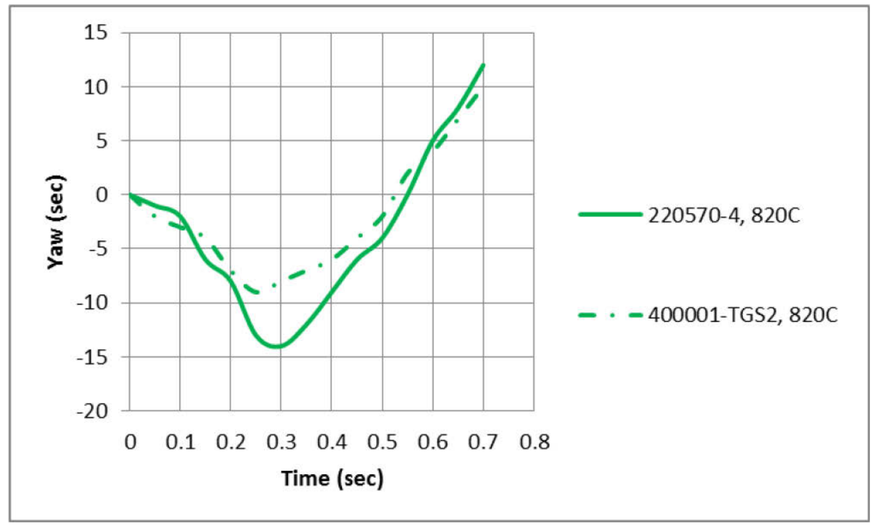
(a) *MASH*, Pickups

N/A

(b) *MASH*, Passenger Cars



(c) *NCHRP Report 350*, Pickups

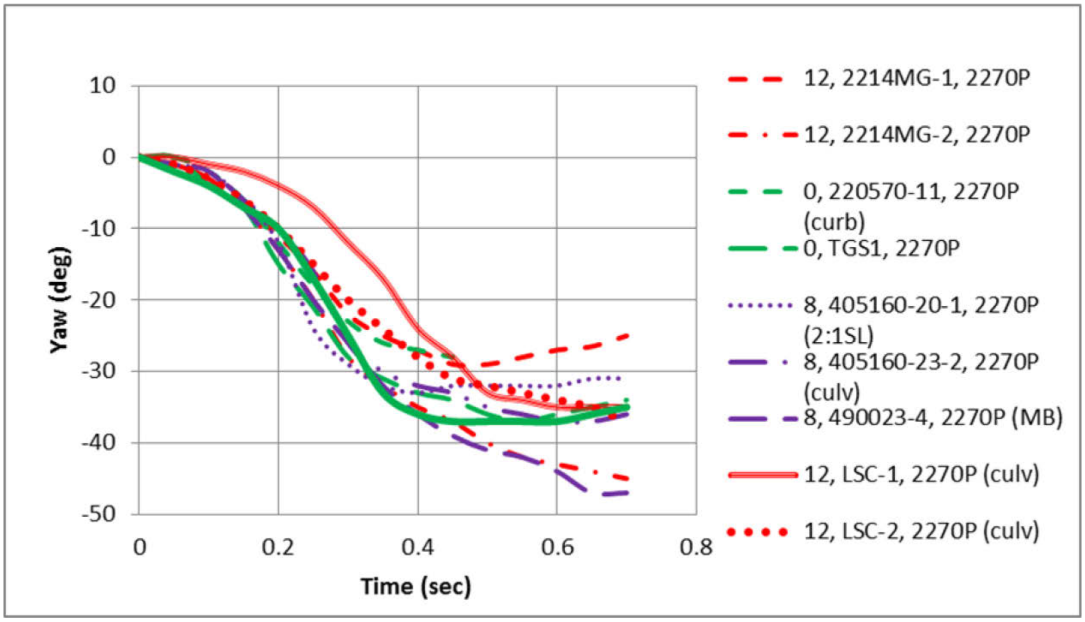


(d) *NCHRP Report 350*, Passenger Cars

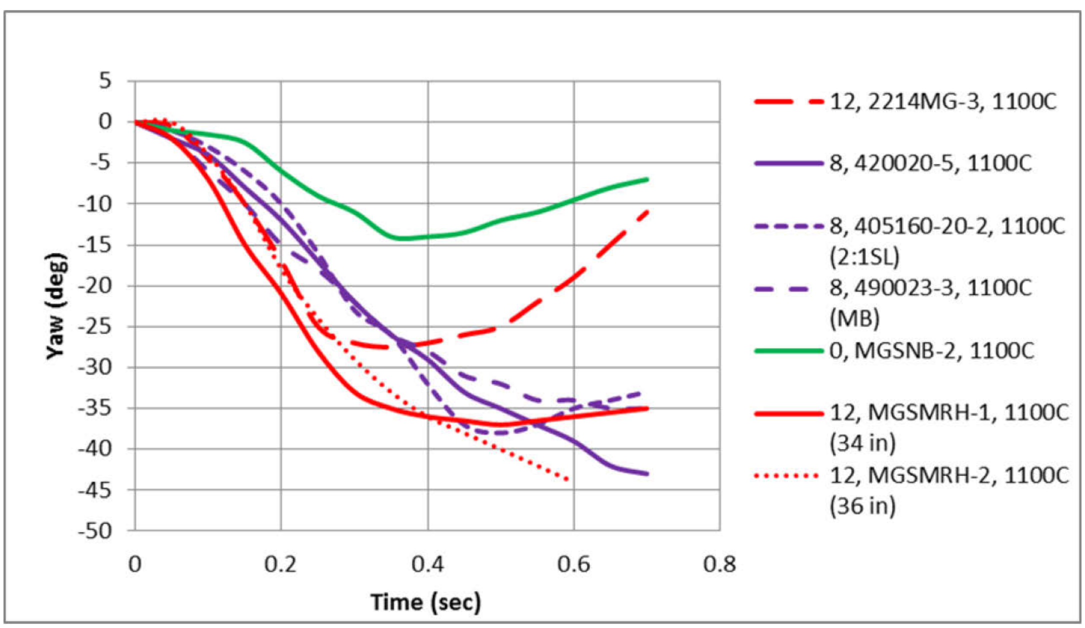
Figure 4.8. Recorded **y**aw angles with no use of blockouts, differentiated by test type criteria used.

4.1.2 Yaw Comparison According to Testing Criteria

Yaw angular displacements were plotted for comparison according to testing criteria (*NCHRP Report 350*, *MASH*). Figure 4.9 collects yaw angular displacement recorded from tests performed according to *MASH* criteria on systems with use of different blockout depths. Please refer to Table 2.1 for a brief description of tests.



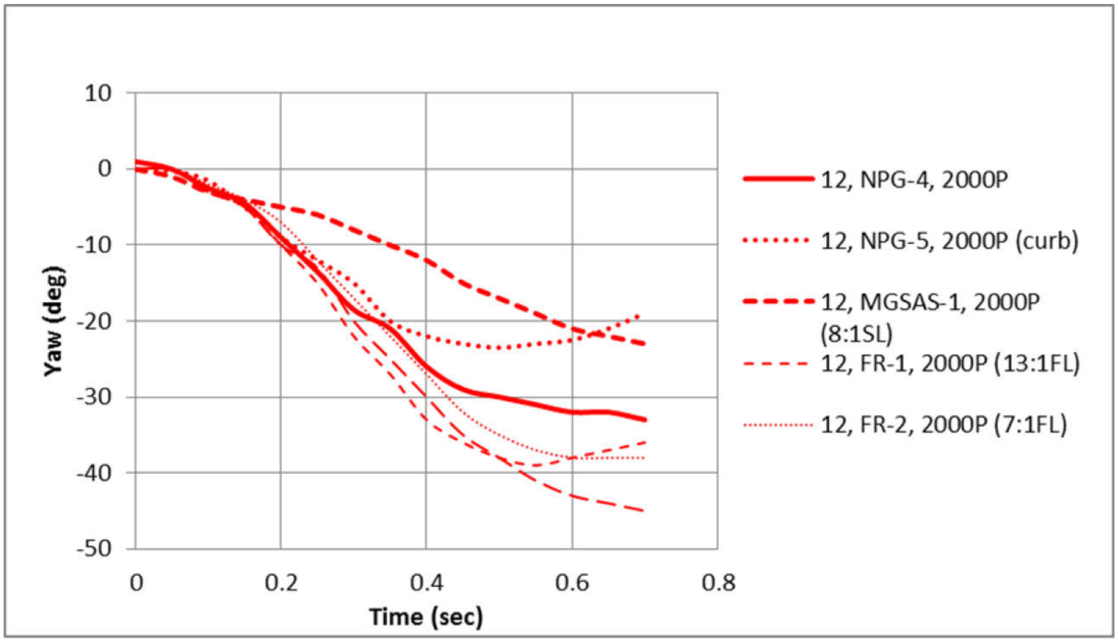
(a) *MASH*, Pickups



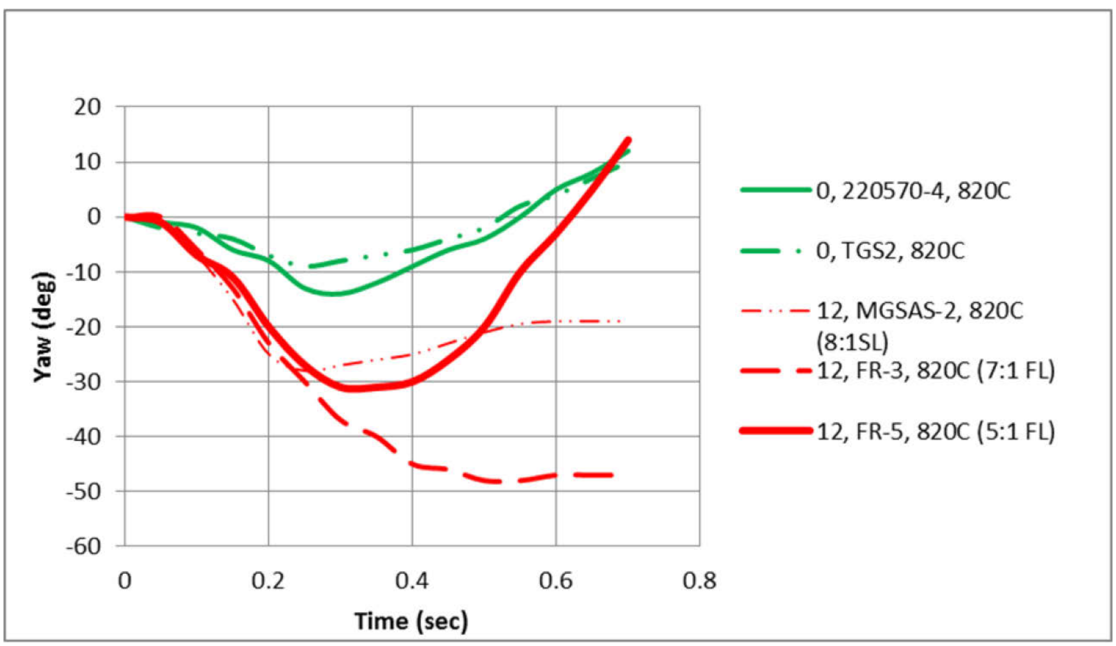
(b) *MASH*, Passenger Cars

Figure 4.9. Yaw angles for tests performed according to *MASH* criteria.

Figure 4.10 collects yaw angular displacement recorded from tests performed according to *NCHRP Report 350* criteria on systems with use of different blockout depths. Please refer to Table 2.1 for a brief description of tests.



(a) *NCHRP Report 350*, Pickups



(b) *NCHRP Report 350*, Passenger Cars

Figure 4.10. Yaw angles for tests performed according to *NCHRP Report 350* criteria.

4.1.3 Yaw Comparison According to ANOVA

ANOVA can be used to compare multiple groups, but can also be used to evaluate only two groups at a time. ANOVA evaluates and returns different variable, and one of them is the p-value. The p-value is defined as the probability of obtaining a test statistic at least as extreme as the one that was actually observed. When the p-value is less than a predetermined significance value n, usually chosen as 0.05, one often rejects the null hypothesis, indicating that the observed result would be highly unlikely under the null hypothesis. In other words, for the application on this particular chapter, if the calculated p-value results <0.05, then the groups that were formed can be considered significantly statistically different in terms of the angular displacement evaluated.

Table 4.2 lists the p-values calculated when applied ANOVA analysis for comparison of yaw angular displacements obtained from tests with different blockouts depths. The ANOVA analysis was evaluated taking into consideration the absolute maximum values of each yaw curve. As it can be noted, in all cases the ANOVA analysis returned p-values that were greater than 0.05. This means that for each analysis, the yaw angular displacements values of one group were not considered significantly different from the yaw angles belonging to the other group(s) compared. In other words, the yaw angular displacements measured from a test that belongs to a group of blockout depths could have been obtained from a test belonging to a different group of blockout depth.

Table 4.1. P-values for yaw angles.

Blockout Comparison	Yaw
All Blockouts	0.299358248
12" vs. 8"	0.658258515
12" vs. 0"	0.215227219
8" vs. 0"	0.177788783

4.2 Roll

Vehicle roll behavior is an indication of the vehicle stability and redirection after impacting the barrier system, as well as of possible vehicle's wheel snagging behavior during the test. Roll angular displacements from tests included in Table 2.1 were collected and compared. Figure 4.11 shows roll angles from all tests, including use of 12-inch, 8-inch, and no (0) blockouts. Also for the yaw angle, two main observations were derived from Figure 4.11, in terms of similarities/dissimilarities from use of different blockout depths. First, vehicle roll angular displacements can vary significantly among tests with use of same blockout depth. As stated already for yaw angles, roll angular displacement is also an indication of vehicle stability and system redirection capacity, and thus it might be influenced by the particular test installation configuration and the actual impact conditions. Also, the roll displacement behavior recorded in some tests with use of 8-inch blockouts seems to compare favorably to the roll displacement obtained with tests with use of 12-inch blockouts, and even with no blockouts (Figure 4.12).

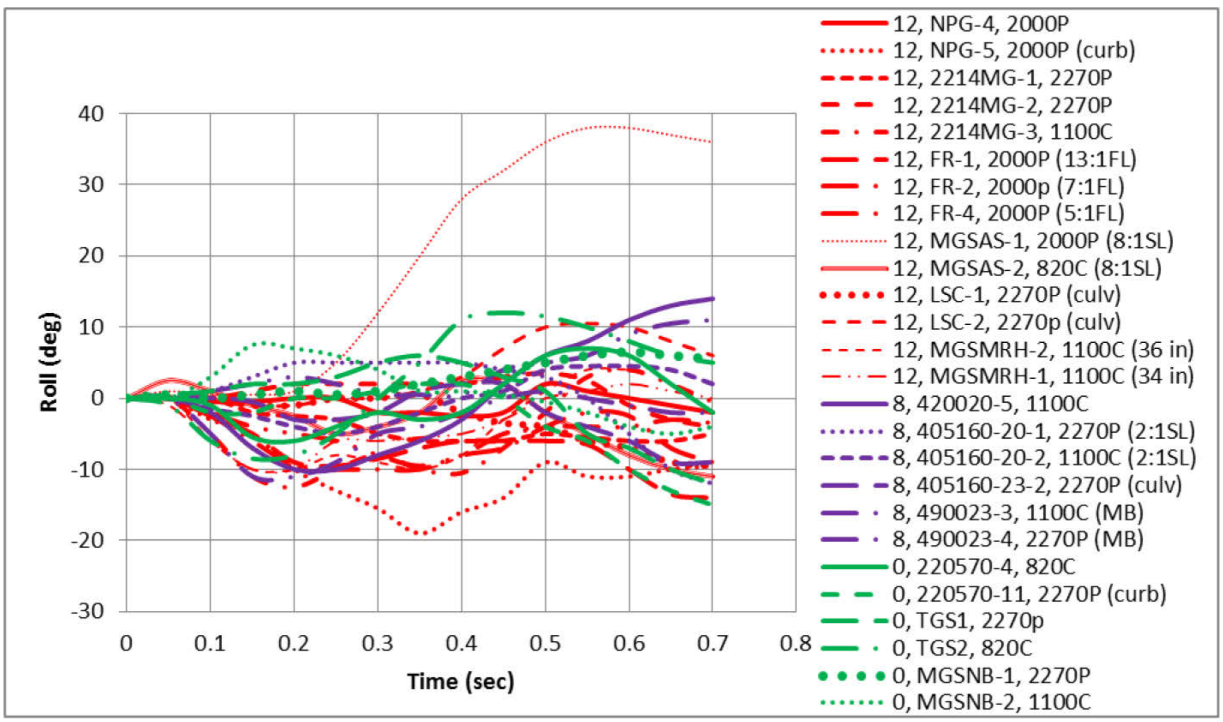


Figure 4.11. Recorded roll angles from all considered tests.

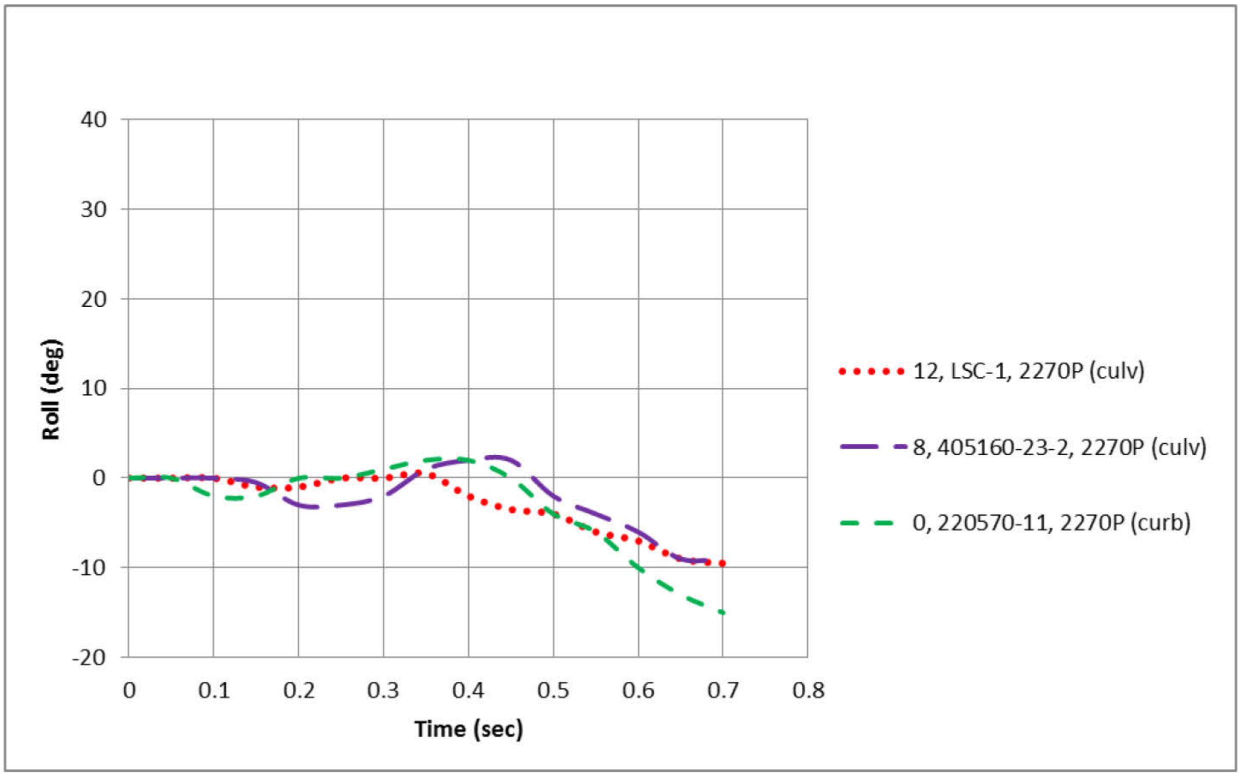
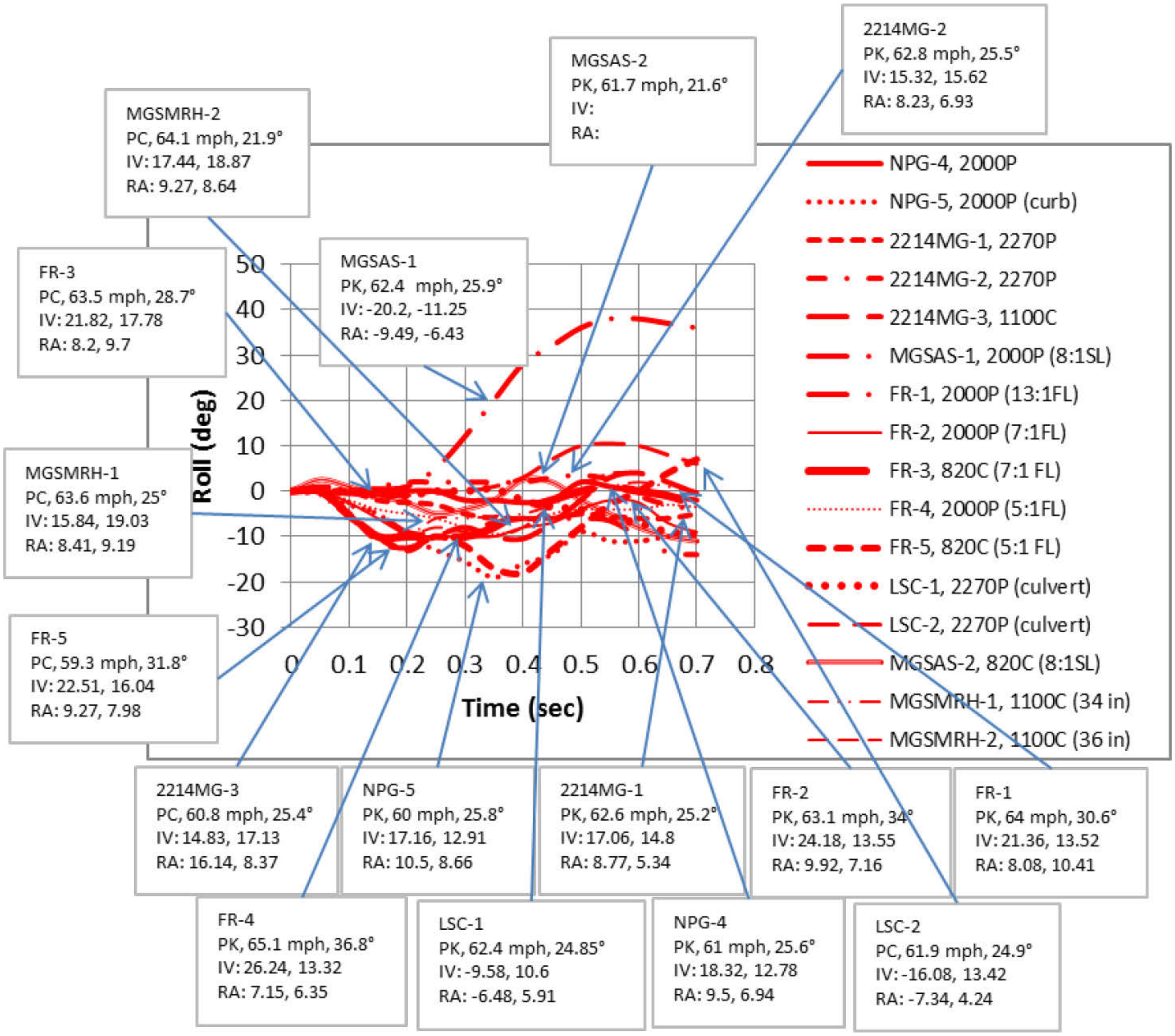


Figure 4.12. Roll angular displacement comparison for selected tests with use of 12-inch, 8-inch, and no blockouts.

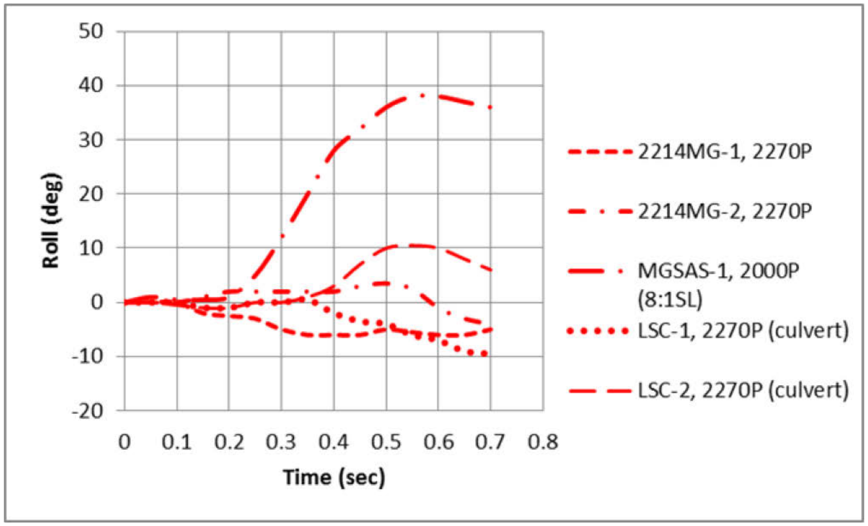
4.2.1 Roll Comparison According to Blockout Depth

Roll angular displacements were plotted for comparison according to blockout depths (12-inch, 8-inch, and no blockouts). Figure 4.13 collects roll angular displacement recorded from tests with use of 12-inch blockout depth. Please refer to Table 2.1 for a brief description of tests. Roll displacements for these systems with use of 12-inch blockout depth were then categorized in Figure 4.14 according to the testing criteria used. For example, Figure 4.14(a) collects roll angular displacements recorded only from tests with 1) use of 12-inch blockouts, 2) 2270P (*MASH* pickup truck), and 3) *MASH* nominal impact conditions (62 mph and 25 degrees). Similarly, Figure 4.14(d) collects roll angular displacements recorded only from tests with 1) use of 12-inch blockouts, 2) 820C (*NCHRP Report 350* Passenger Car), and 3) *NCHRP Report 350* nominal impact conditions (62 mph and 20 degrees). Again, please note that the actual impact conditions might have varied depending on the test article configuration tested (as an example, a test of a flared system will result in a higher impact angle).

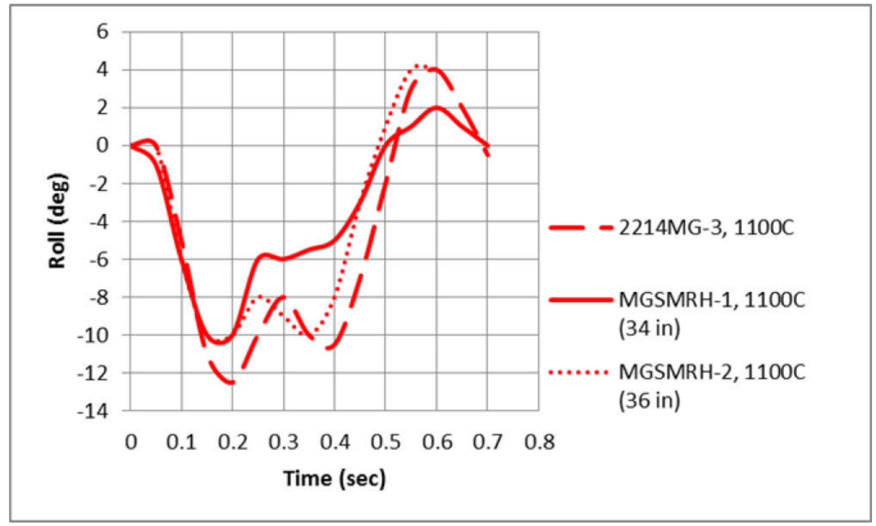


PC: Passenger Car
PK: Pickup
IV: Impact Velocities (Longitudinal, Lateral) (ft/sec)
RA: Ridedown Accelerations (Longitudinal, Lateral) (g's)

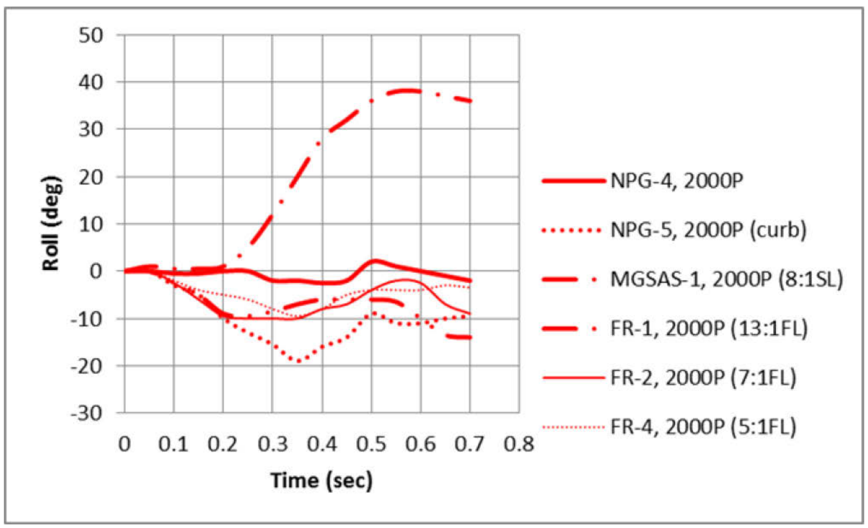
Figure 4.13. Recorded roll angles with use of 12-inch blockout depth.



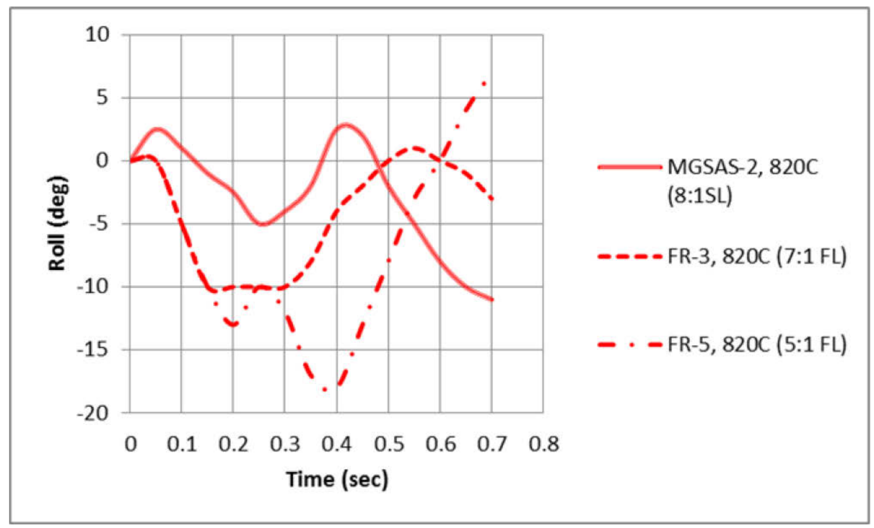
(a) *MASH*, Pickups



(b) *MASH*, Passenger Cars



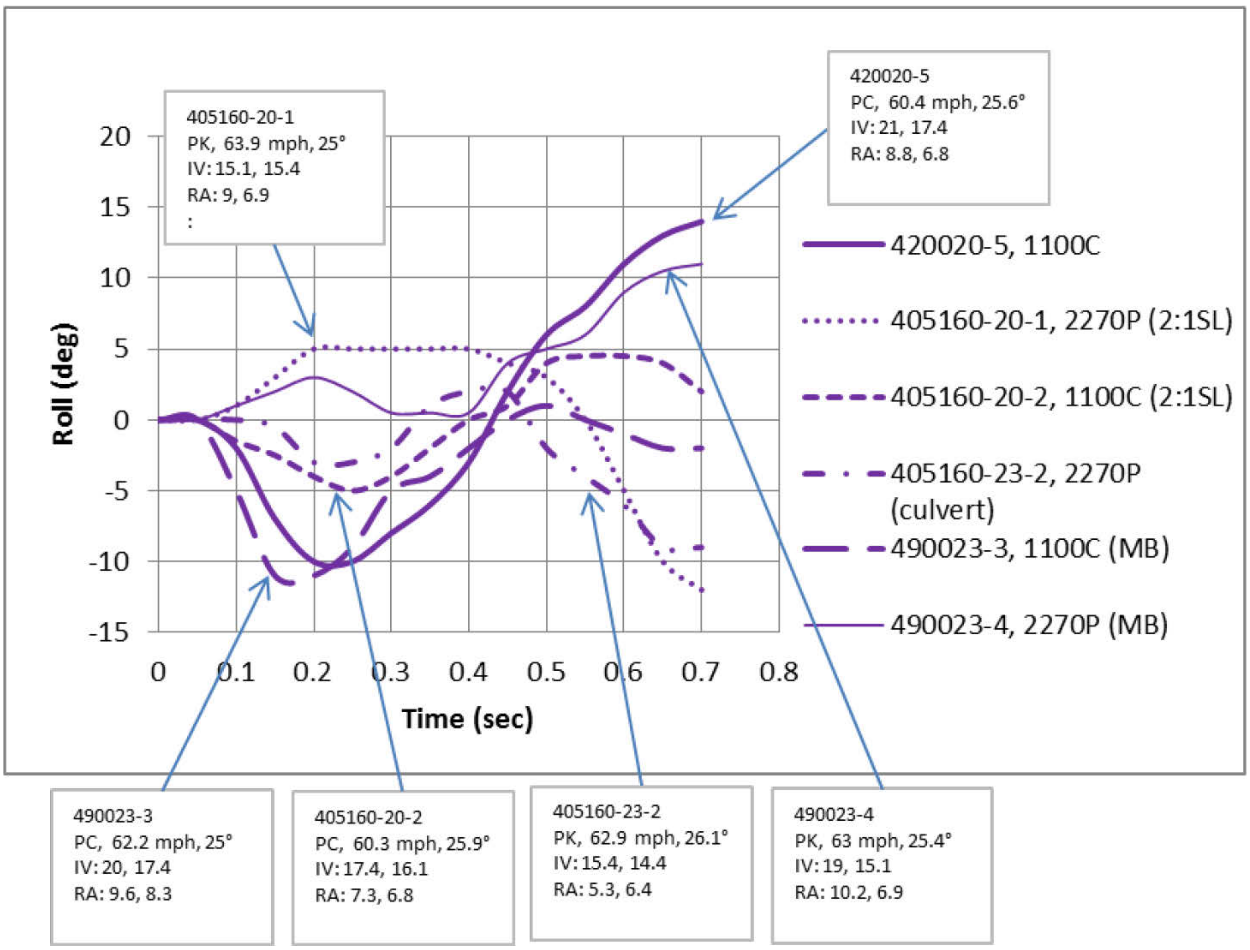
(c) *NCHRP Report 350*, Pickups



(d) *NCHRP Report 350*, Passenger Cars

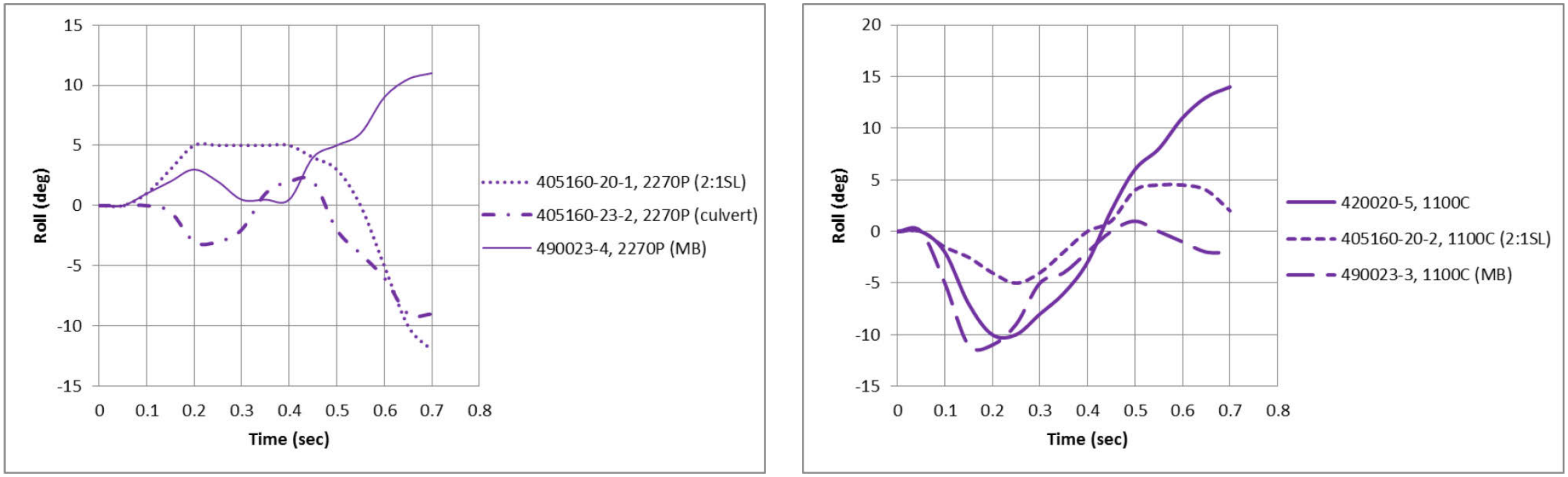
Figure 4.14. Recorded roll angles with use of 12-inch blockout depth, differentiated by test type criteria used.

Figure 4.15 collects roll angular displacement recorded from tests with use of 8-inch blockout depth. Please refer to Table 2.1 for a brief description of tests. Roll displacements for these systems with use of 8-inch blockout depth were then categorized in Figure 4.16 according to the testing criteria followed. For example, Figure 4.16(a) collects yaw angular displacements recorded only from 1) tests with use of 8-inch blockouts, with 2) 2270P (*MASH* pickup truck), and with 3) *MASH* nominal impact conditions (62 mph and 25 degrees). As it can be noted, only *MASH* tests were performed on a 31-inch guardrail, with mid-span splices, and with use of 8-inch blockout depth.



PC: Passenger Car
PK: Pickup
IV: Impact Velocities (Longitudinal, Lateral) (ft/sec)
RA: Ridedown Accelerations (Longitudinal, Lateral) (g's)

Figure 4.15. Recorded roll angles with use of 8-inch blockout depth.



(a) *MASH*, Pickups

(b) *MASH*, Passenger Cars

N/A

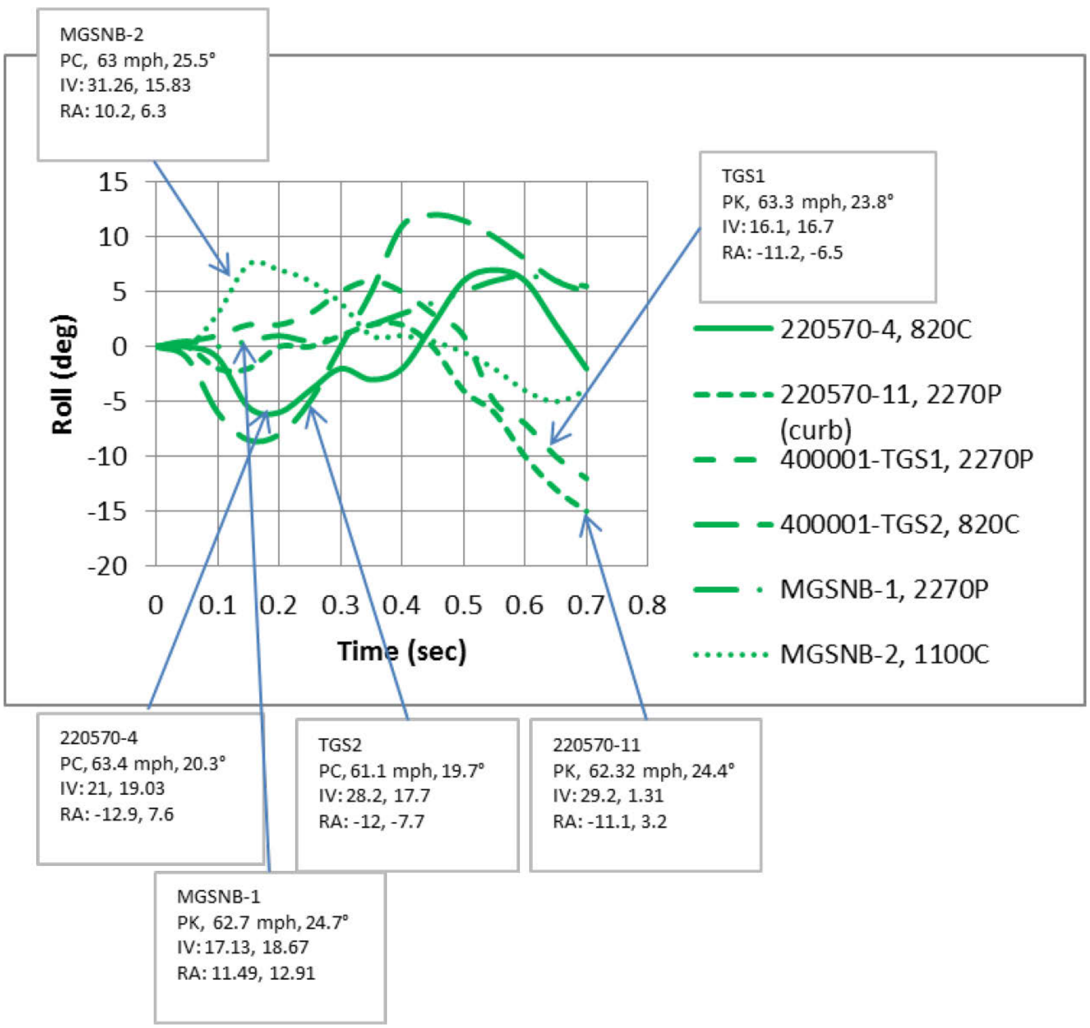
N/A

(c) *NCHRP Report 350*, Pickups

(d) *NCHRP Report 350*, Passenger Cars

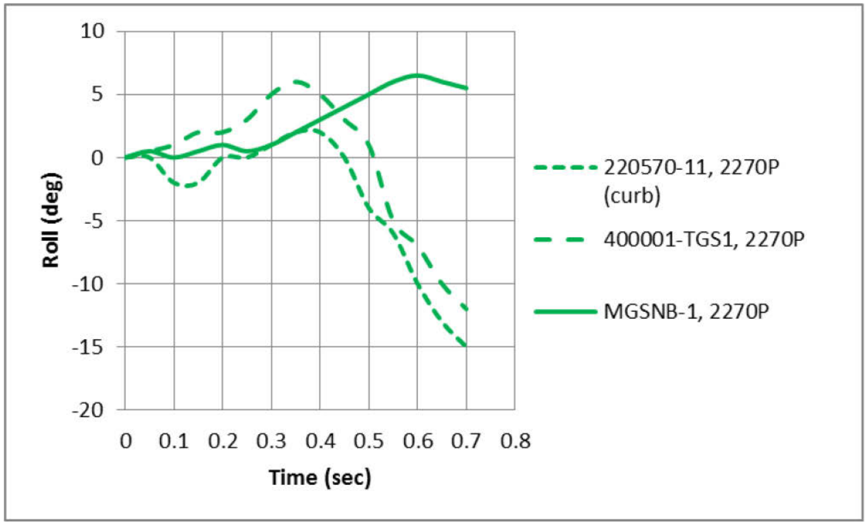
Figure 4.16. Recorded roll angles with use of 8-inch blockout depth, differentiated by test type criteria used.

Figure 4.17 collects roll angular displacement recorded from tests with no use of blockouts. Please refer to Table 2.1 for a brief description of tests. Roll displacements for these systems with no use of blockouts were then categorized in Figure 4.18 according to the testing criteria followed. For example, Figure 4.18(a) collects roll angular displacements recorded only from 1) tests with no use of blockouts, with 2) 2270P (*MASH* pickup truck), and with 3) *MASH* nominal impact conditions (62 mph and 25 degrees). Similarly, Figure 4.18(d) collects roll angular displacements recorded only from 1) tests with no use of blockouts, with 2) 820C (*NCHRP Report 350* Passenger Car), and with 3) *NCHRP Report 350* nominal impact conditions (62 mph and 20 degrees).

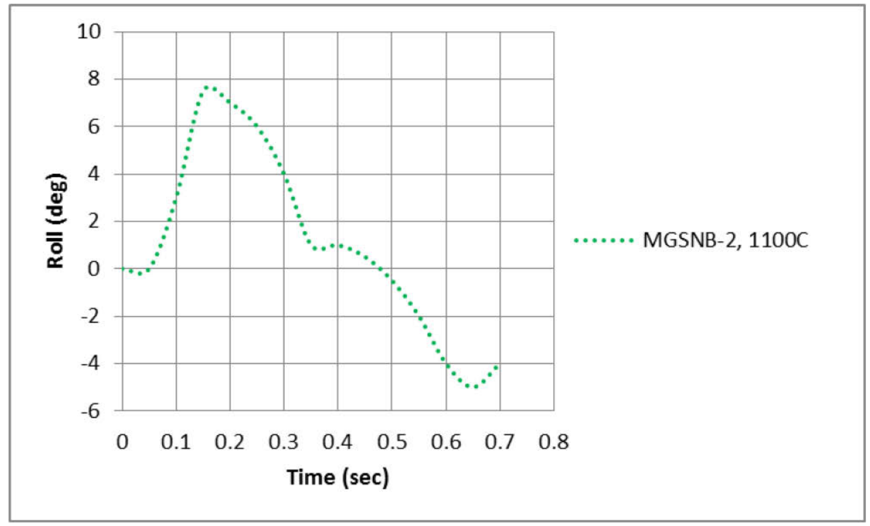


PC: Passenger Car
PK: Pickup
IV: Impact Velocities (Longitudinal, Lateral) (ft/sec)
RA: Ridedown Accelerations (Longitudinal, Lateral) (g's)

Figure 4.17. Recorded roll angles with no use of blockouts.



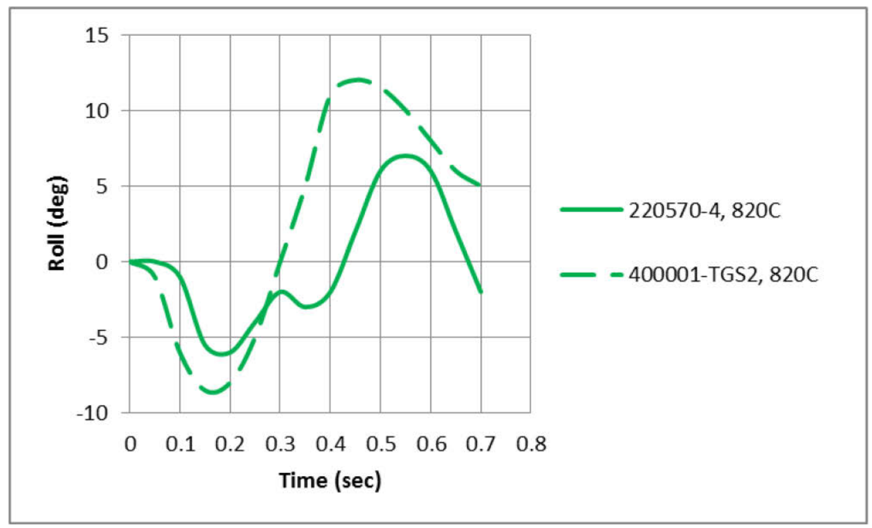
(a) *MASH*, Pickups



(b) *MASH*, Passenger Cars

N/A

(c) *NCHRP Report 350*, Pickups

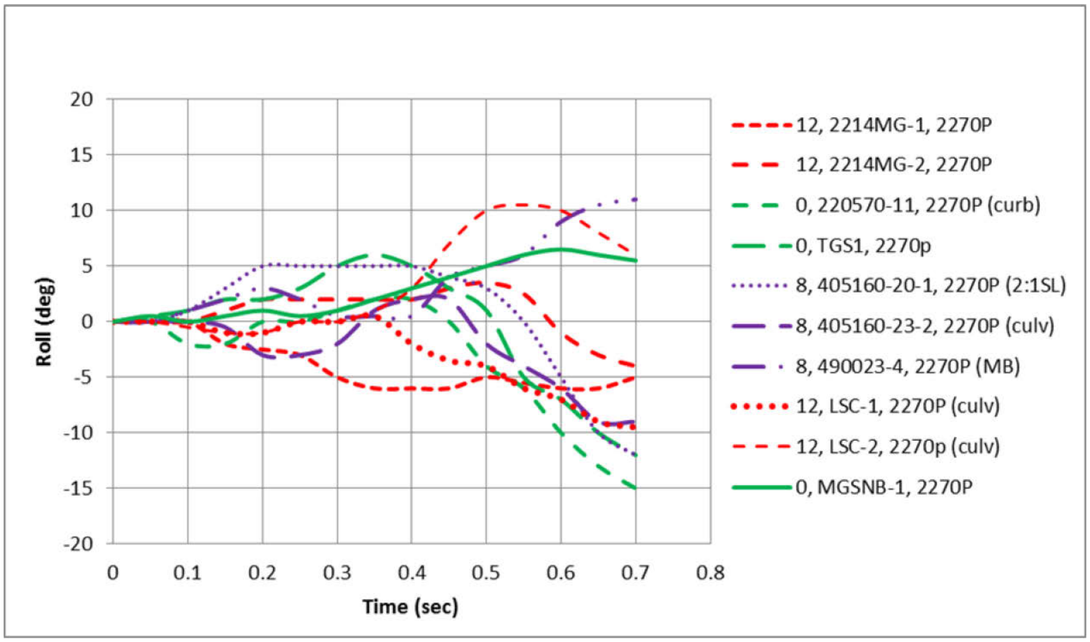


(d) *NCHRP Report 350*, Passenger Cars

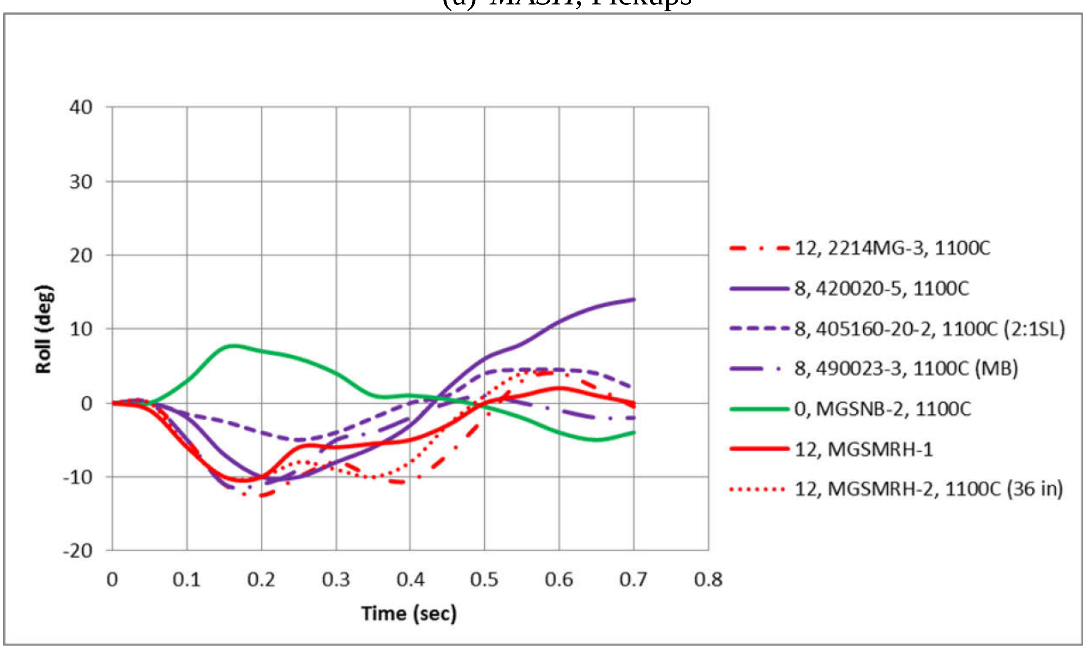
Figure 4.18. Recorded roll angles with no use of blockouts, differentiated by test type criteria used.

4.2.2 Roll Comparison According to Testing Criteria

Roll angular displacements were plotted for comparison according to testing criteria (*NCHRP Report 350*, *MASH*). Figure 4.19 collects roll angular displacement recorded from tests performed according to *MASH* criteria on systems with use of different blockout depths. Please refer to Table 2.1 for a brief description of tests.



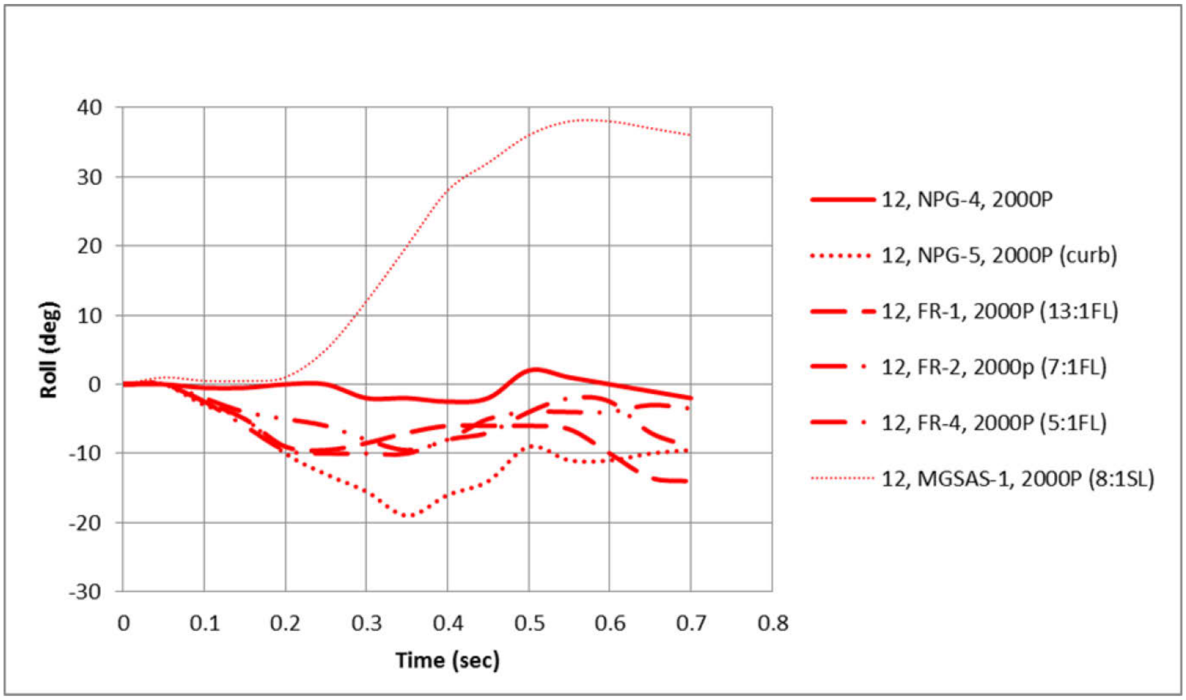
(a) *MASH*, Pickups



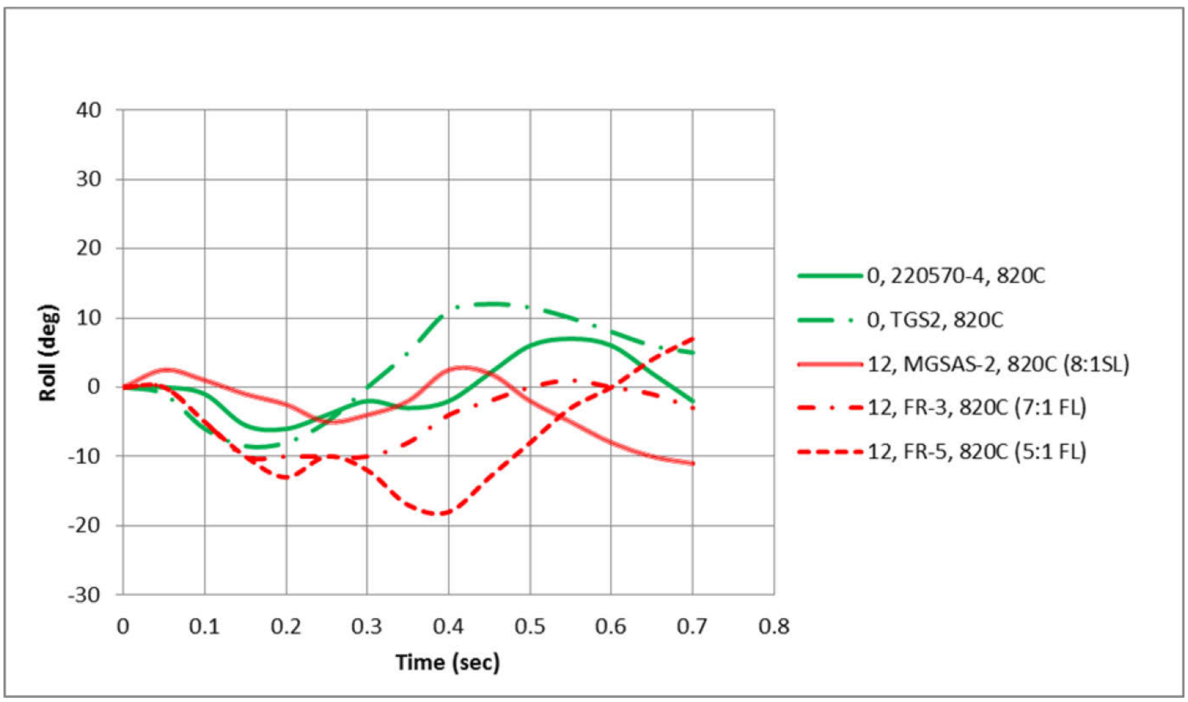
(b) *MASH*, Passenger Cars

Figure 4.19. Roll angles for tests performed according to *MASH* criteria.

Figure 4.20 collects roll angular displacement recorded from tests performed according to *NCHRP Report 350* criteria on systems with use of different blockout depths. Please refer to Table 2.1 for a brief description of tests.



(a) *NCHRP Report 350*, Pickups



(b) *NCHRP Report 350*, Passenger Cars

Figure 4.20. Roll angles for tests performed according to *NCHRP Report 350* criteria.

4.2.3 Roll Comparison According to ANOVA

Table 4.3 lists the p-values calculated when applied ANOVA analysis for comparison of roll angular displacements obtained from tests with different blockouts depths. The ANOVA analysis was evaluated taking into consideration the absolute maximum values of each roll curve. As it can be noted, in all cases the ANOVA analysis returned p-values that were greater than 0.05. This means that for each analysis, the roll angular displacements values of one group were not considered significantly different from the roll angles belonging to the other group(s) compared. In other words, the roll angular displacements measured from a test that belongs to a group of blockout depths could have been obtained from a test belonging to a different group of blockout depth.

Table 4.3. P-values for roll angles.

Blockout Comparison	Roll
All Blockouts	0.671971373
12" vs. 8"	0.461063278
12" vs. 0"	0.745530103
8" vs. 0"	0.36791915

4.3 Pitch

Pitch angular displacements from tests included in Table 2.1 were collected and compared. Figure 4.21 shows pitch angles from all tests, including use of 12-inch, 8-inch, and no (0) blockouts. Vehicle pitch angular displacements can vary significantly among tests with use of same blockout depth. As stated already for yaw angles, pitch angular displacement is also an indication of vehicle stability and system redirection capacity, and thus it might be influenced by the particular test installation configuration and the actual impact conditions. Also, Figure 4.21 shows how the recorded pitch angles from all tests were approximately contained between −12 and 6 degrees during the impact event.

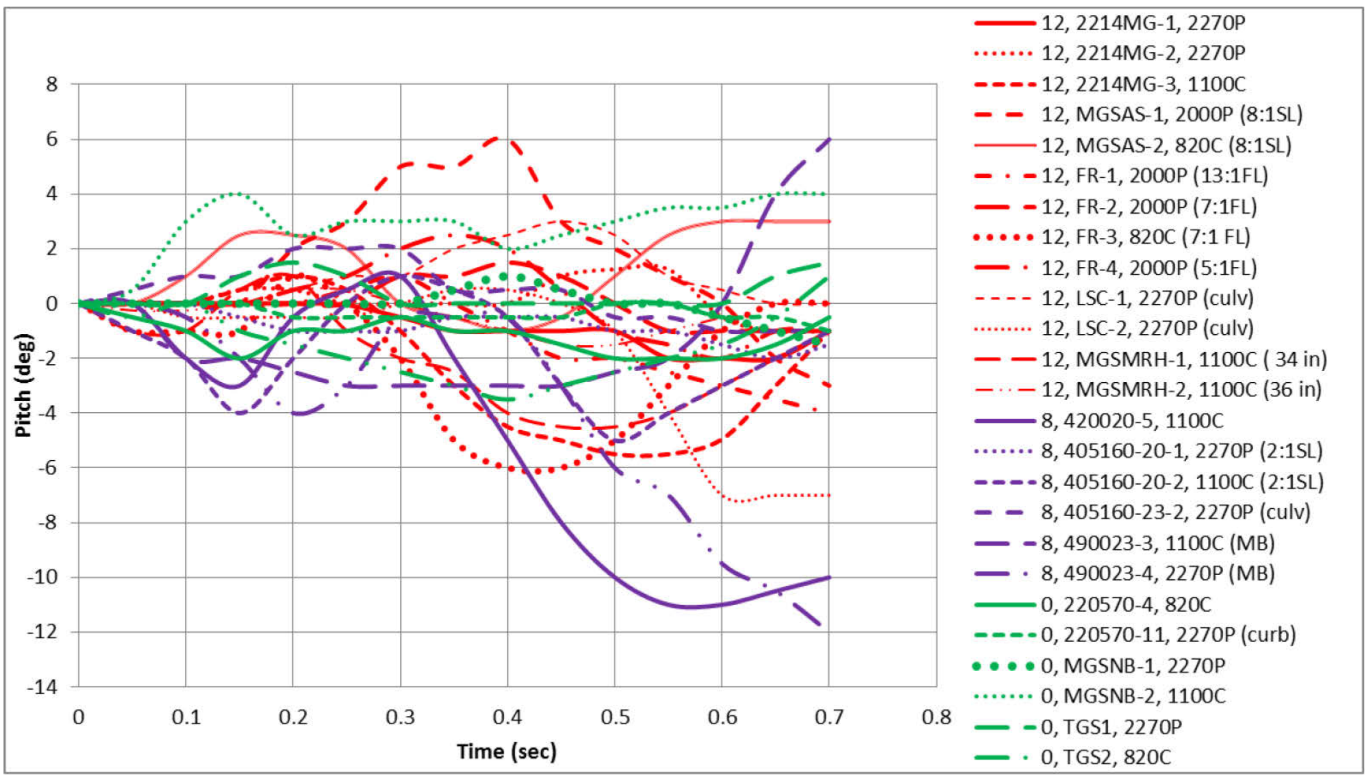
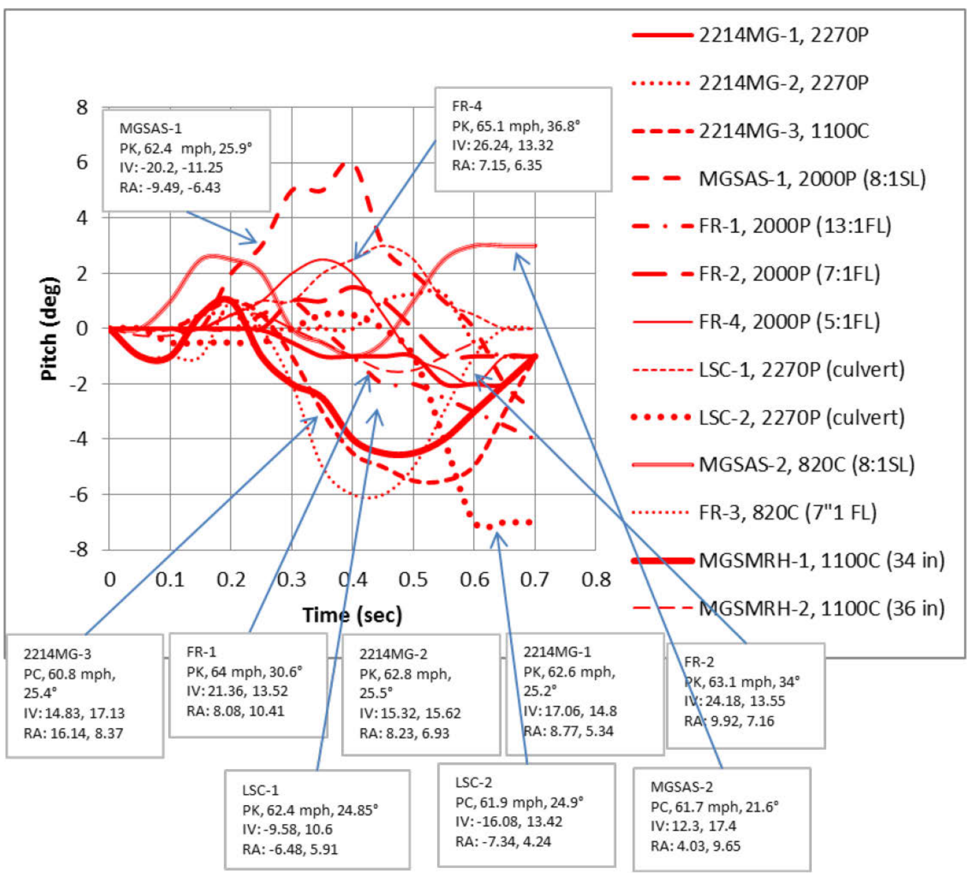


Figure 4.20. Recorded pitch angles from all considered tests.

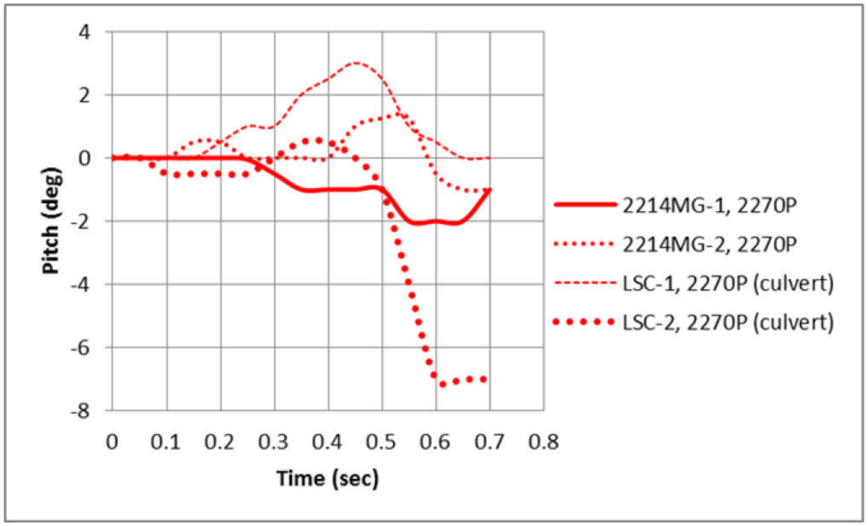
4.3.1 Pitch Comparison According to Blockout Depth

Pitch angular displacements were plotted for comparison according to blockout depths (12-inch, 8-inch, and no blockouts). Figure 4.22 collects pitch angular displacement recorded from tests with use of 12-inch blockout depth. Please refer to Table 2.1 for a brief description of tests. Pitch displacements for these systems with use of 12-inch blockout depth were then categorized in Figure 4.23 according to the testing criteria used. For example, Figure 4.23(a) collects pitch angular displacements recorded only from tests with 1) use of 12-inch blockouts, 2) 2270P (*MASH* pickup truck), and 3) *MASH* nominal impact conditions (62 mph and 25 degrees). Similarly, Figure 4.23(d) collects pitch angular displacements recorded only from tests with 1) use of 12-inch blockouts, 2) 820C (*NCHRP Report 350* Passenger Car), and 3) *NCHRP Report 350* nominal impact conditions (62 mph and 20 degrees). Again, please note that the actual impact conditions might have varied depending on the test article configuration tested (as an example, a test of a flared system will result in a higher impact angle

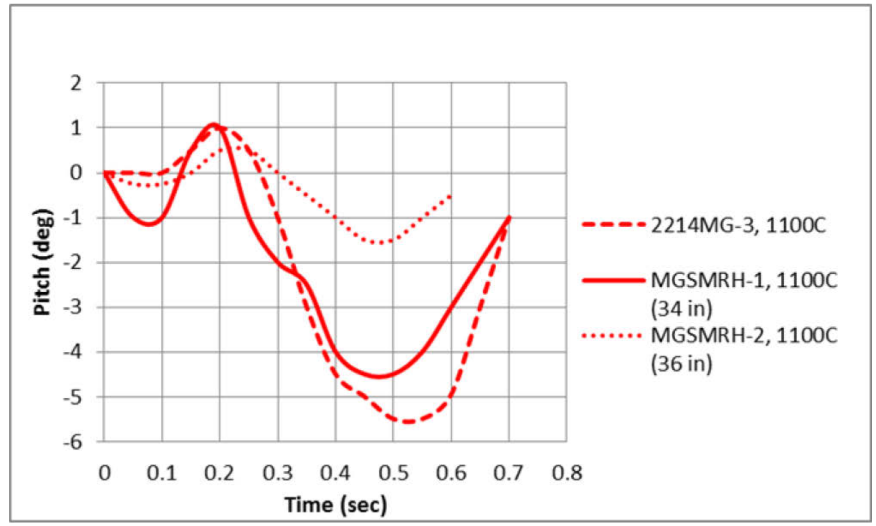


PC: Passenger Car
PK: Pickup
IV: Impact Velocities (Longitudinal, Lateral) (ft/sec)
RA: Ridedown Accelerations (Longitudinal, Lateral) (g's)

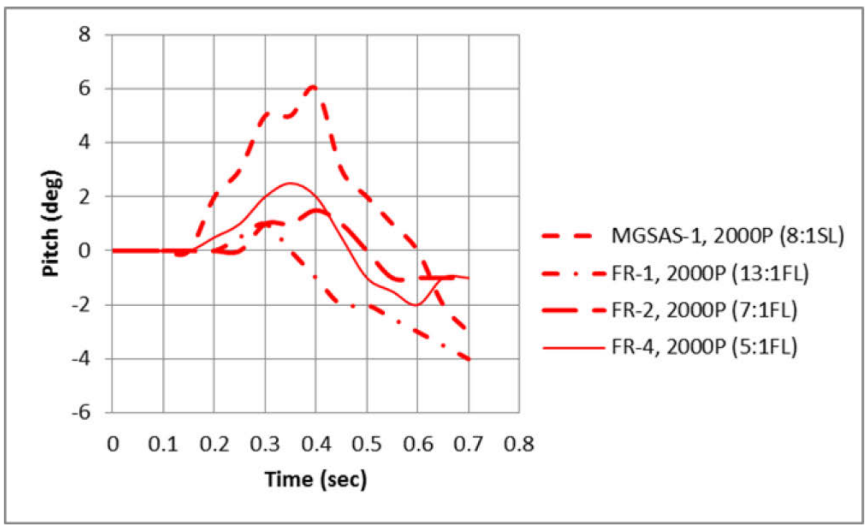
Figure 4.21. Recorded pitch angles with use of 12-inch blockout depth.



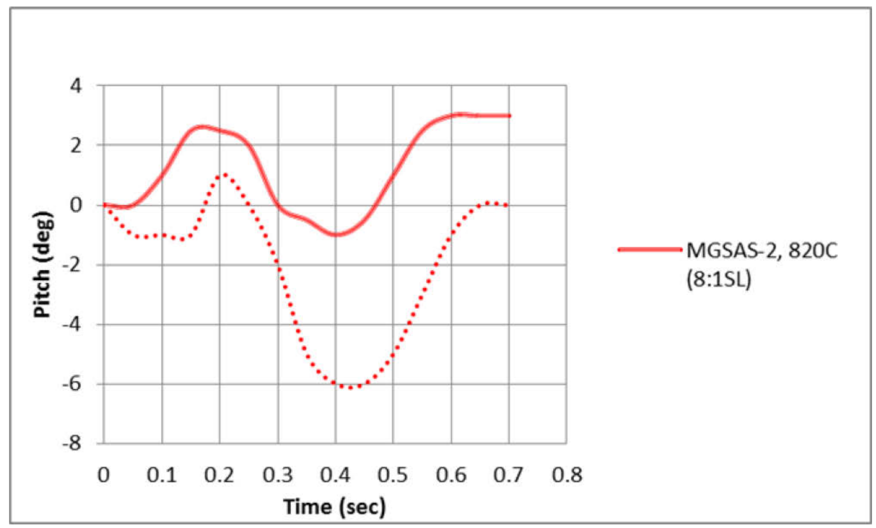
(a) *MASH*, Pickups



(b) *MASH*, Passenger Cars



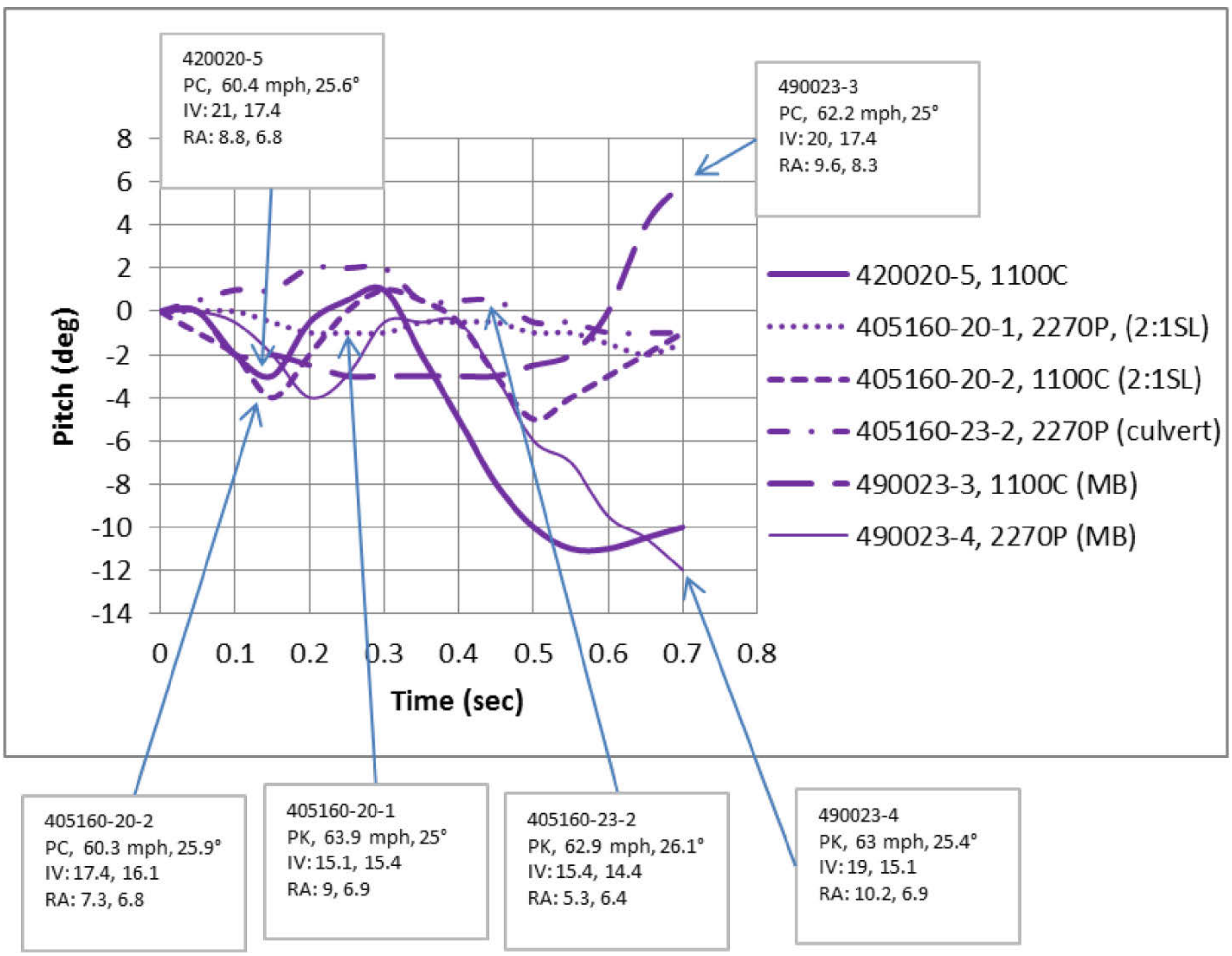
(c) *NCHRP Report 350*, Pickups



(d) *NCHRP Report 350*, Passenger Cars

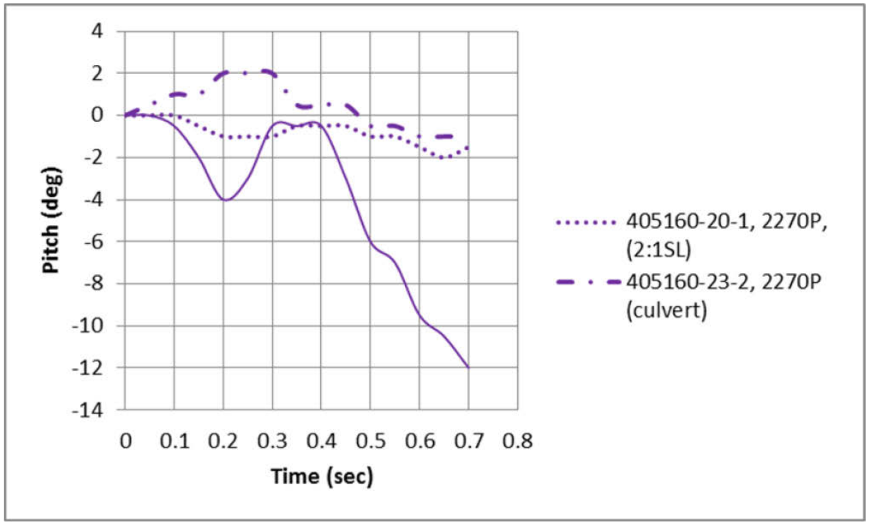
Figure 4.22. Recorded pitch angles with use of 12-inch blockout depth, differentiated by test type criteria used.

Figure 4.24 collects pitch angular displacement recorded from tests with use of 8-inch blockout depth. Please refer to Table 2.1 for a brief description of tests. Pitch displacements for these systems with use of 8-inch blockout depth were then categorized in Figure 4.25 according to the testing criteria followed. For example, Figure 4.25(a) collects yaw angular displacements recorded only from 1) tests with use of 8-inch blockouts, with 2) 2270P (*MASH* pickup truck), and with 3) *MASH* nominal impact conditions (62 mph and 25 degrees). As it can be noted, only *MASH* tests were performed on a 31-inch guardrail, with mid-span splices, and with use of 8-inch blockout depth.

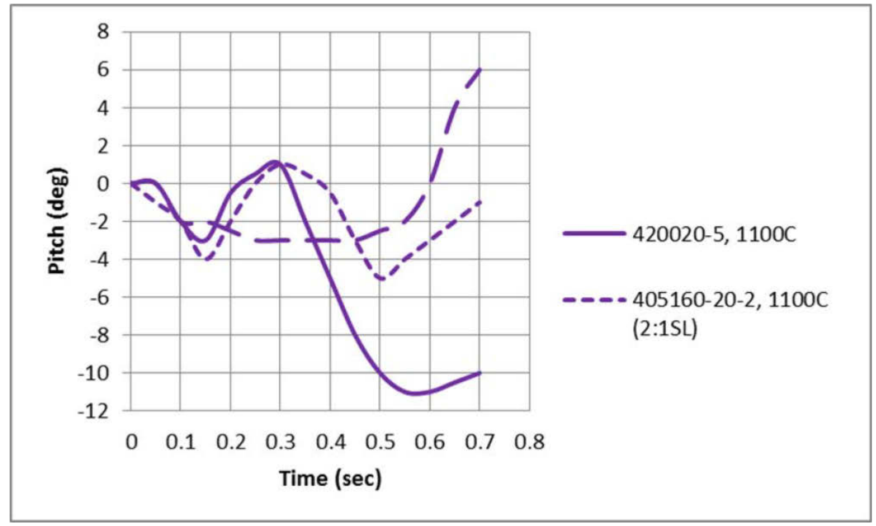


PC: Passenger Car
PK: Pickup
IV: Impact Velocities (Longitudinal, Lateral) (ft/sec)
RA: Ridedown Accelerations (Longitudinal, Lateral) (g's)

Figure 4.23. Recorded pitch angles with use of 8-inch blockout depth.



(a) *MASH*, Pickups



(b) *MASH*, Passenger Cars

N/A

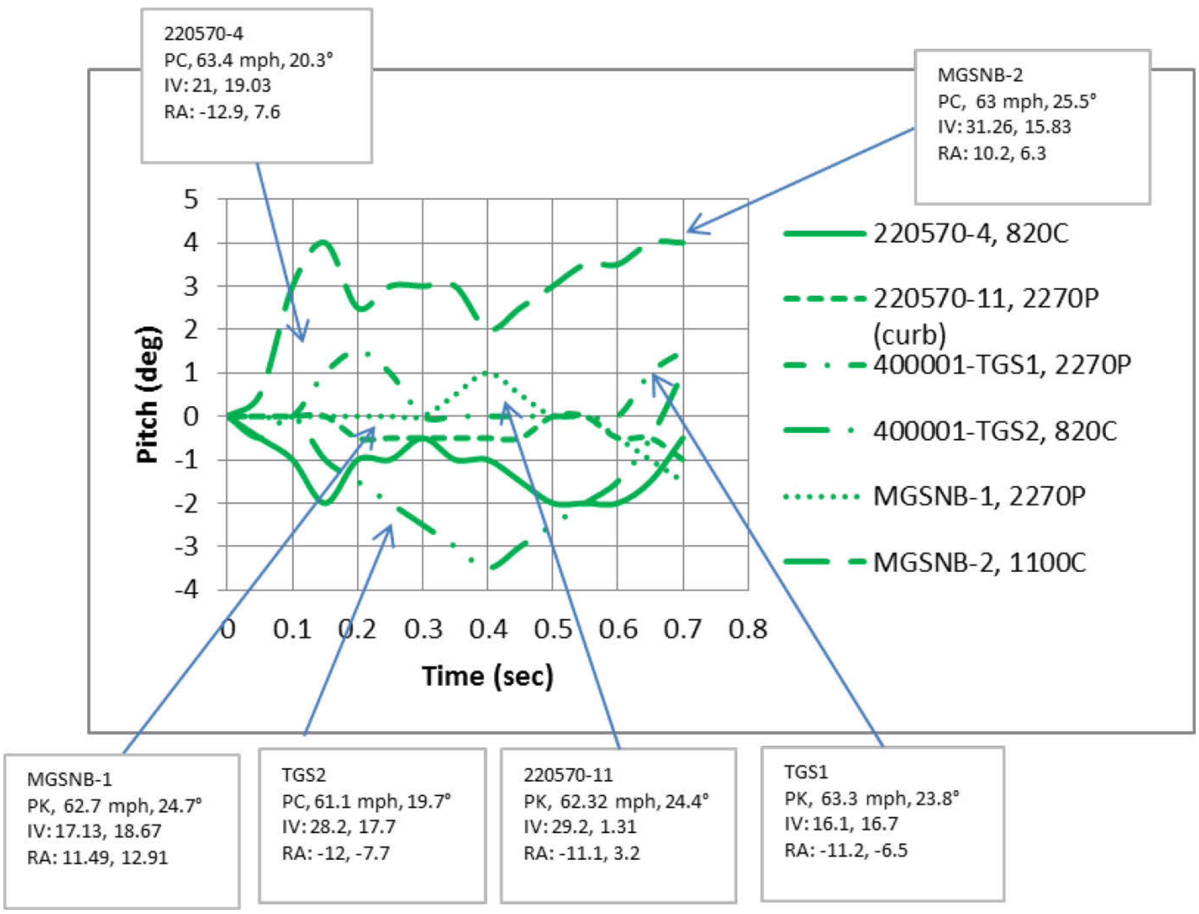
(c) *NCHRP Report 350*, Pickups

N/A

(d) *NCHRP Report 350*, Passenger Cars

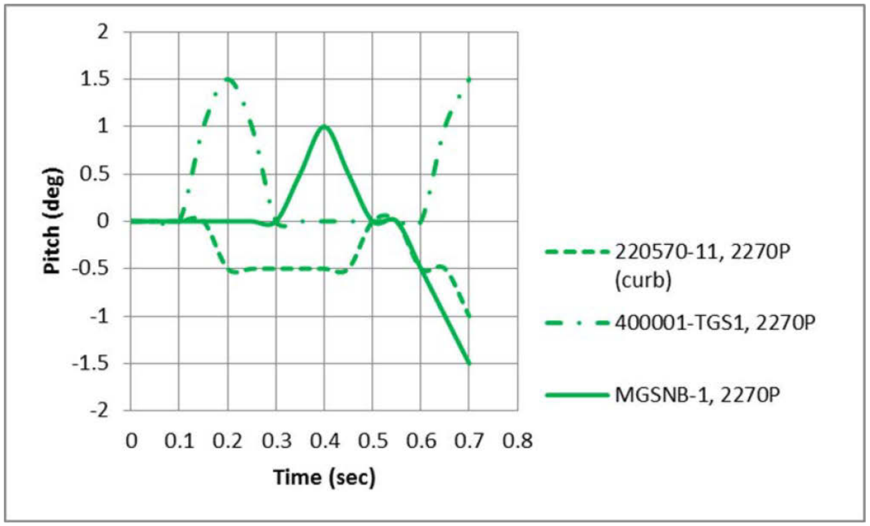
Figure 4.24. Recorded pitch angles with use of 8-inch blockout depth, differentiated by test type criteria used.

Figure 4.26 collects pitch angular displacement recorded from tests with no use of blockouts. Please refer to Table 2.1 for a brief description of tests. Pitch displacements for these systems with no use of blockouts were then categorized in Figure 4.27 according to the testing criteria followed. For example, Figure 4.27(a) collects roll angular displacements recorded only from 1) tests with no use of blockouts, with 2) 2270P (*MASH* pickup truck), and with 3) *MASH* nominal impact conditions (62 mph and 25 degrees). Similarly, Figure 4.27(d) collects roll angular displacements recorded only from 1) tests with no use of blockouts, with 2) 820C (*NCHRP Report 350* Passenger Car), and with 3) *NCHRP Report 350* nominal impact conditions (62 mph and 20 degrees).

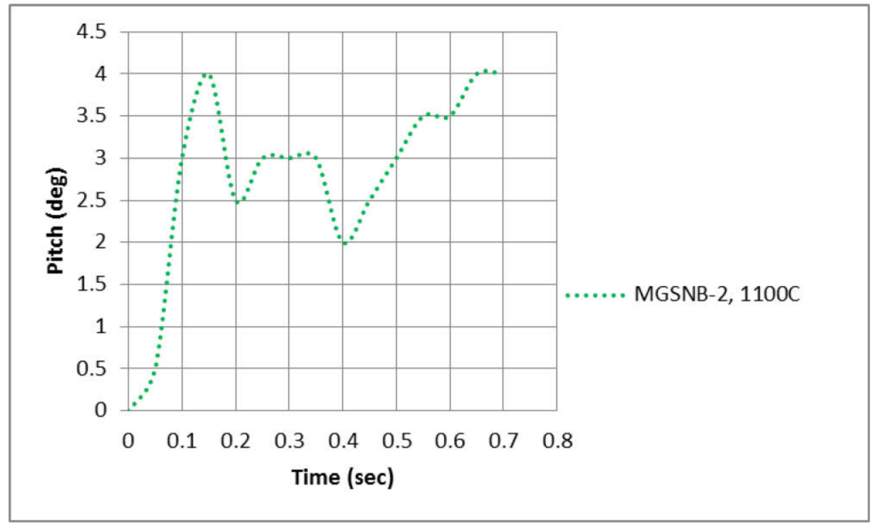


PC: Passenger Car
PK: Pickup
IV: Impact Velocities (Longitudinal, Lateral) (ft/sec)
RA: Ridedown Accelerations (Longitudinal, Lateral) (g's)

Figure 4.25. Recorded pitch angles with no use of blockouts.



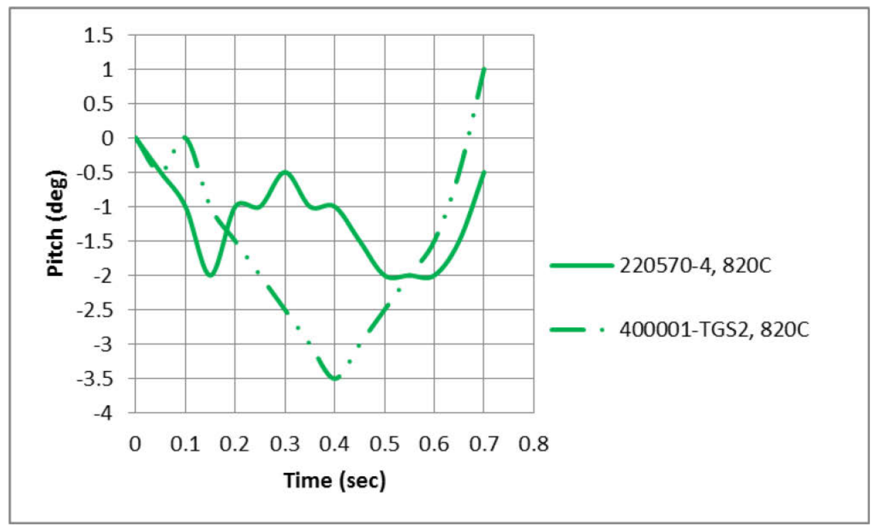
(a) *MASH*, Pickups



(b) *MASH*, Passenger Cars

N/A

(c) *NCHRP Report 350*, Pickups

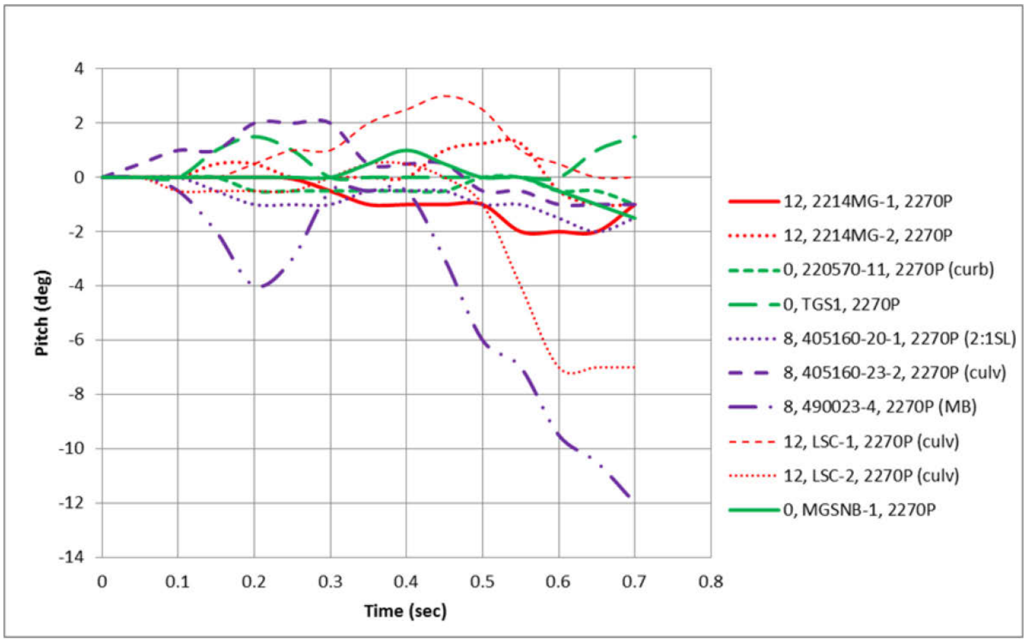


(d) *NCHRP Report 350*, Passenger Cars

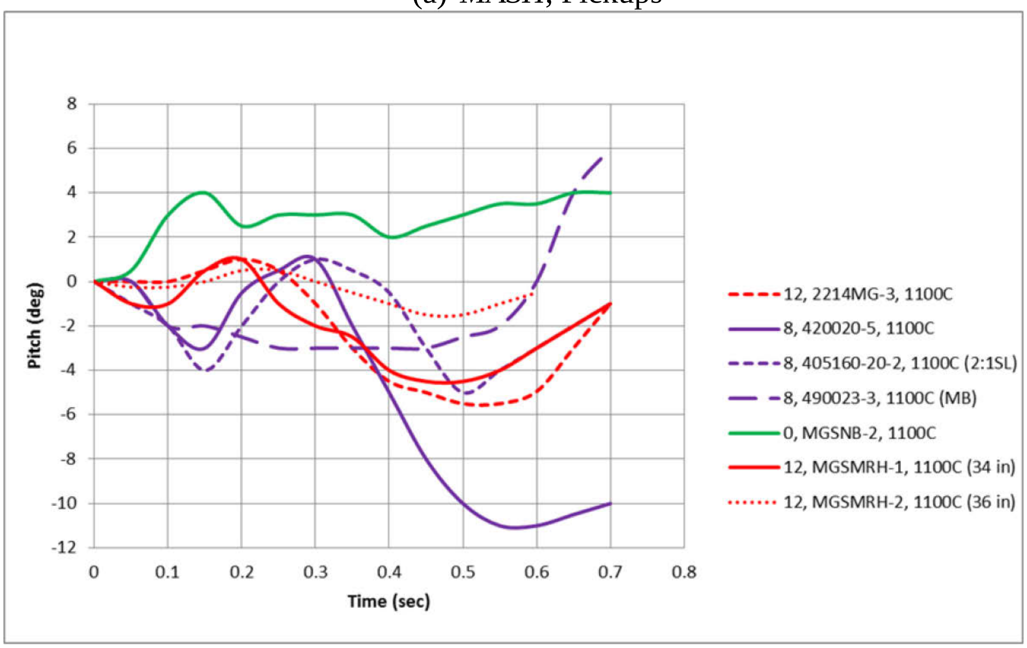
Figure 4.26. Recorded pitch angles with no use of blockouts, differentiated by test type criteria used.

4.3.2 Pitch Comparison According to Testing Criteria

Pitch angular displacements were plotted for comparison according to testing criteria (*NCHRP Report 350*, *MASH*). Figure 4.28 collects roll angular displacement recorded from tests performed according to *MASH* criteria on systems with use of different blockout depths. Please refer to Table 2.1 for a brief description of tests.



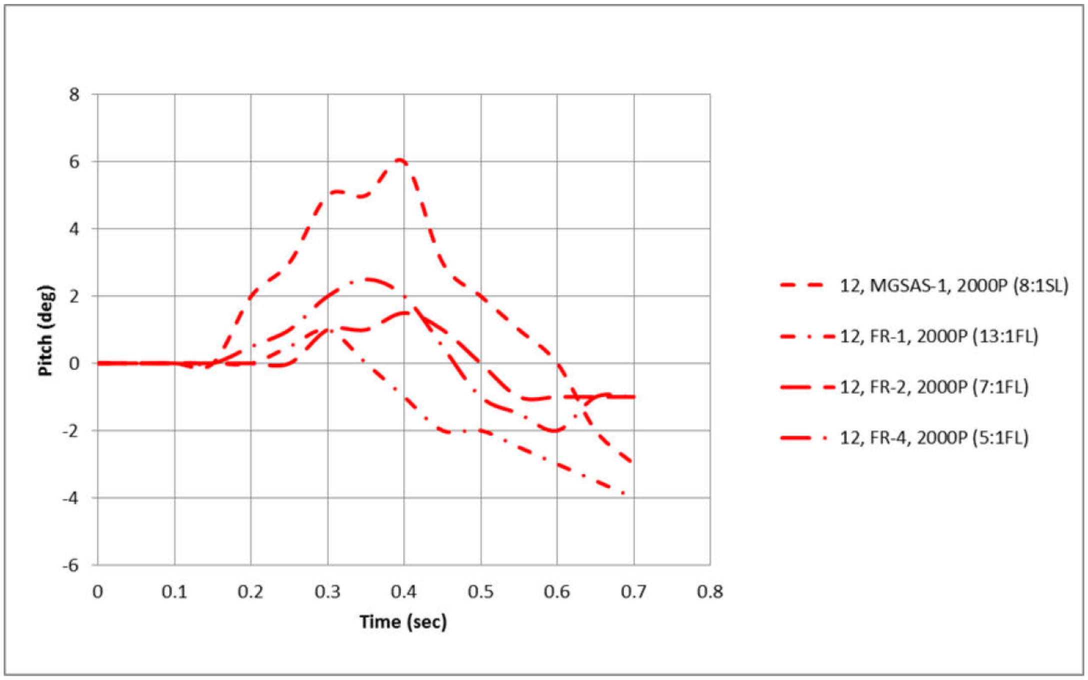
(a) *MASH*, Pickups



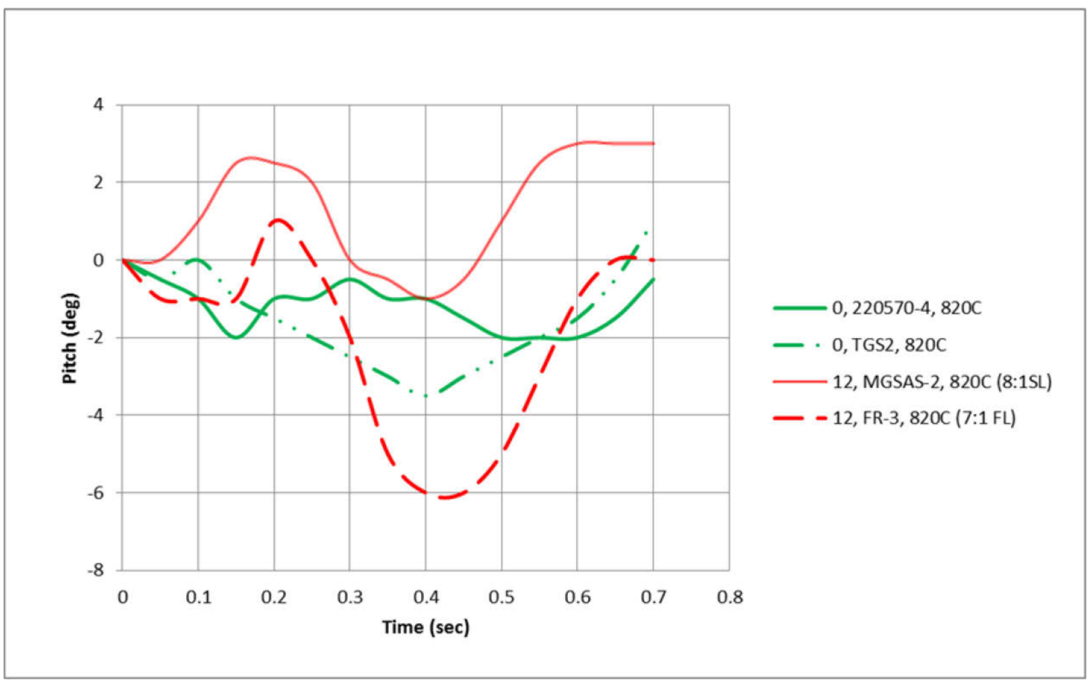
(b) *MASH*, Passenger Cars

Figure 4.27. Pitch angles for tests performed according to *MASH* criteria.

Figure 4.29 collects pitch angular displacement recorded from tests performed according to *NCHRP Report 350* criteria on systems with use of different blockout depths. Please refer to Table 2.1 for a brief description of tests.



(a) *NCHRP Report 350*, Pickups



(b) *NCHRP Report 350*, Passenger Cars

Figure 4.28. Pitch angles for tests performed according to *NCHRP Report 350* criteria.

4.3.3 Pitch Comparison According to ANOVA

Table 4.4 lists the p-values calculated when applied ANOVA analysis for comparison of pitch angular displacements obtained from tests with different blockouts depths. The ANOVA analysis was evaluated taking into consideration the absolute maximum values of each pitch curve. As it can be noted, only in one case the ANOVA analysis returned a p-value smaller than 0.05. When compared the values from the 12-inch and the 8-inch blockout groups, the obtained p-value was circa 0.0083, which would suggest that is a statistically significant difference between use of 12-inch and 8-inch blockouts in terms of pitch angular displacement. It is very interesting, though, that when comparing the groups of 12-inch and no blockouts, the p-value increased to 0.313, which would suggest there is no significant difference between use of 12-inch blockout or no blockouts as for pitch angle results. Moreover, no significant statistically difference was suggested when comparing all three groups.

Table 4.4. P-values for pitch angles.

Blockout Comparison	Pitch
All Blockouts	0.135534298
12" vs. 8"	0.008261962
12" vs. 0"	0.313345236
8" vs. 0"	0.546500615

4.4 Conclusions

Within this chapter, researchers have compared vehicle stability recorded during full-scale crash tests with use of 12-inch, 8-inch and no blockouts. Vehicle angular displacements (roll, pitch, and yaw) were also compared by considering the impact criteria used for performing the full-scale crash tests (*MASH* or *NCHRP Report 350*). Researchers noticed that vehicle stability outcomes can vary significantly among tests with use of same blockout depth. Researchers explained this observation as an indication of vehicle stability and system redirection capacity, which can be influenced by the particular test installation configuration and by the actual impact conditions. In addition, researchers noticed that recorded results in some tests with use of 8-inch blockouts compared favorably to tests results obtained with use of 12-inch blockouts, and even with no blockouts.

ANOVA analysis was performed for comparison of angular displacements obtained from tests with different blockouts depths. ANOVA analysis returned p-values that were greater than 0.05 for all comparisons investigated on angular displacements, except for two cases during the pitch angles evaluation. When compared the pitch values from the 12-inch and the 8-inch blockout groups, the obtained p-value was circa 0.0083, which would suggest that is a statistically significant difference between use of 12-inch and 8-inch blockouts in terms of pitch angular displacement. It was also noticed, though, that when comparing the groups of 12-inch and no blockouts, the p-value increased to 0.313, which would suggest there is no significant difference between use of 12-inch blockout or no blockouts as for pitch angle results.

After reviewing tests results and performing statistical analysis, it is opinion of the researchers that there is no statistically significant difference in terms of vehicle stability from use of 12-inch and 8-inch blockout depths.

Chapter 5 Analysis of Occupant Risks

In this Chapter, data collected through crash events (Table 5.1) was reviewed and compared with respect to occupant risks (i.e., impact velocity and ridedown acceleration). Occupant risk is also assessed by the response of a "hypothetical, unrestrained front seat occupant whose motion relative to the occupant compartment is dependent on vehicular accelerations" (*2*). Two performance factors need to be reviewed according to *MASH* criteria: the occupant impact velocities (OIV) (longitudinal and lateral) at impact with the associated interior surface and the ridedown accelerations (RA) (longitudinal and lateral) which is averaged over any 10-ms interval for the collision pulse subsequent to occupant impact with the associated interior surface. Lower values of these factors indicate that the safety features are more forgiving to the occupants of the impacting vehicles. Both OIV and RA are calculated from vehicular accelerations.

The impact velocity is defined as the longitudinal and Figures 5.1 through 5.4 report longitudinal and lateral impact velocities and ridedown accelerations with inclusion of a brief description of tests specification. Researchers also used the concept of ANOVA to statistically evaluate occupant risks results obtained from the tests.

Table 5.1. Occupant risk values for all tests.

			Impact Velocites (ft/s)		Ridedown Accelerations (g's)	
Report	Test No.	Blockout Depth (in)	Longitudinal	Lateral	Longitudinal	Lateral
TRP-03-139-04	NPG-4	12	18.32	12.78	9.5	6.94
TRP-03-139-04	NPG-5	12	17.16	12.91	10.5	8.66
TRP-03-139-04	NPG-6	12	25	18.42	10.67	8.97
TRP-03-170-06	2214MG -1	12	17.06	14.8	8.77	5.34
TRP-03-171-06	2214MG -2	12	15.32	15.62	8.23	6.93
TRP-03-172-06	2214MG-3-1	12	14.83	17.13	16.14	8.37
TRP-03-185-10	MGS221-2	12	13.9	13.61	5.36	5.28
TRP-03-188-08	MGSAS-1	12	20.2	11.25	9.49	6.43
TRP-03-188-08	MGSAS-2	12	12.3	17.42	4.03	9.65
TRP-03-191-08	FR-1	12	21.36	13.52	8.08	10.41
TRP-03-191-08	FR-2	12	24.18	13.55	9.92	7.16
TRP-03-191-08	FR-3	12	21.82	17.78	8.2	9.7
TRP-03-191-08	FR-4	12	26.24	13.32	7.15	6.35
TRP-03-191-08	FR-5	12	22.51	16.04	9.27	7.98
TRP-03-187-07	LSC-1	12	9.58	10.6	6.48	5.91
TRP-03-187-07	LSC-2	12	16.08	13.42	7.34	4.24
TRP-03-255-12	MGSMRH-1	12	15.84	19.03	8.41	9.19
TRP-03-255-12	MGSMRH-2	12	17.44	18.87	9.27	8.64
420020	420020-5	8	21	17.4	8.8	6.8
405160-20	405160-20-1	8	15.1	15.4	9	6.9
405160-20	405160-20-2	8	17.4	16.1	7.3	6.8
405160-23	405160-23-2	8	15.4	14.4	5.3	6.4
490023	490023-3	8	20	17.4	9.6	8.3
490023	490023-4	8	19	15.1	10.2	6.9
220570	220570-4	0	21	19.03	12.9	7.6
220570	220570-11	0	29.2	1.31	11.1	3.2
400001	400001-TGS1	0	16.1	16.7	11.2	6.5
400001	400001-TGS2	0	28.2	17.7	12	7.7
TRP-03-262-12	MGSNB-1	0	17.13	18.67	11.49	12.91
TRP-03-262-12	MGSNB-2	0	31.26	15.83	10.2	6.3

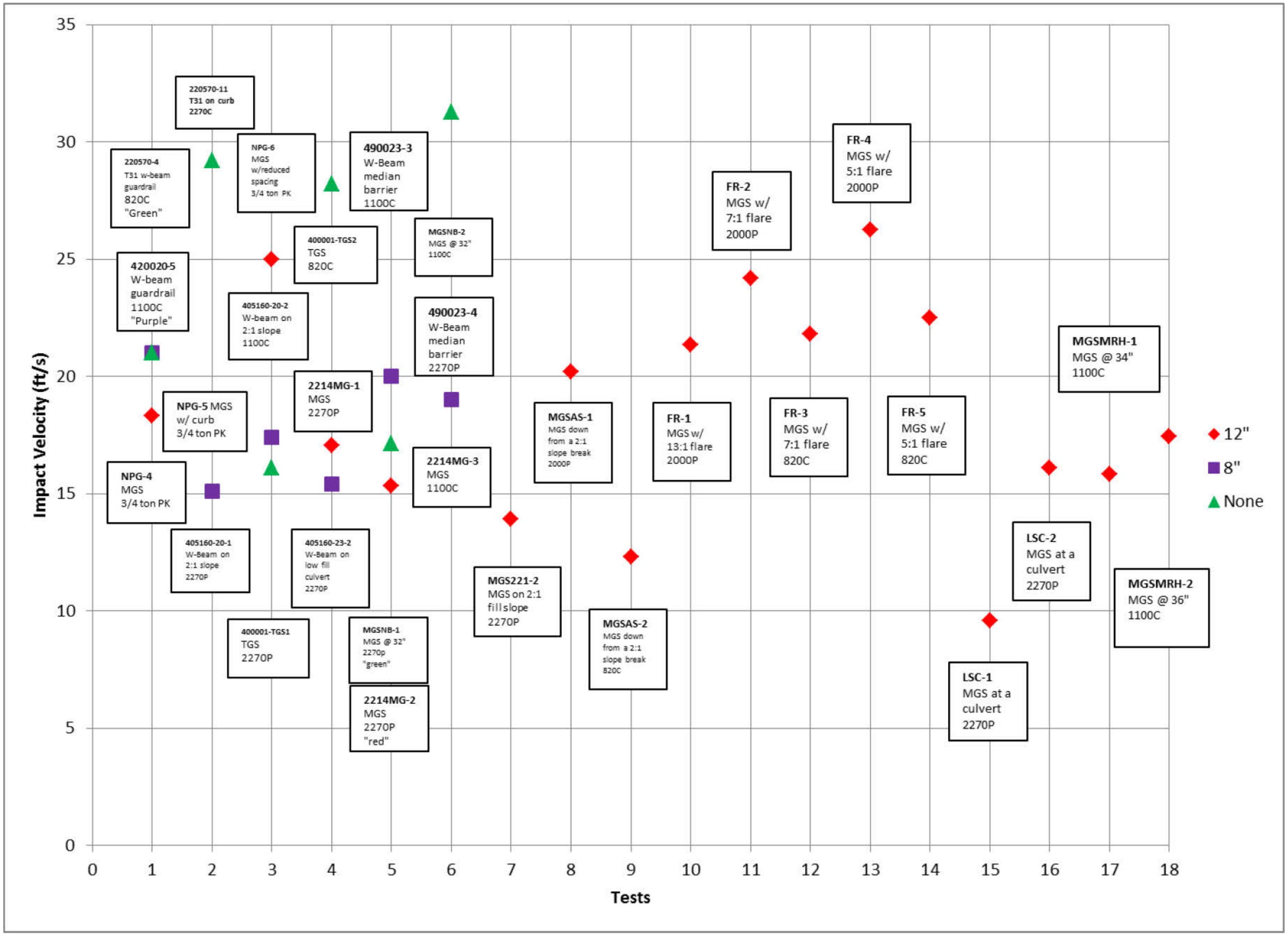


Figure 5.1. Longitudinal impact velocity with test specifications.

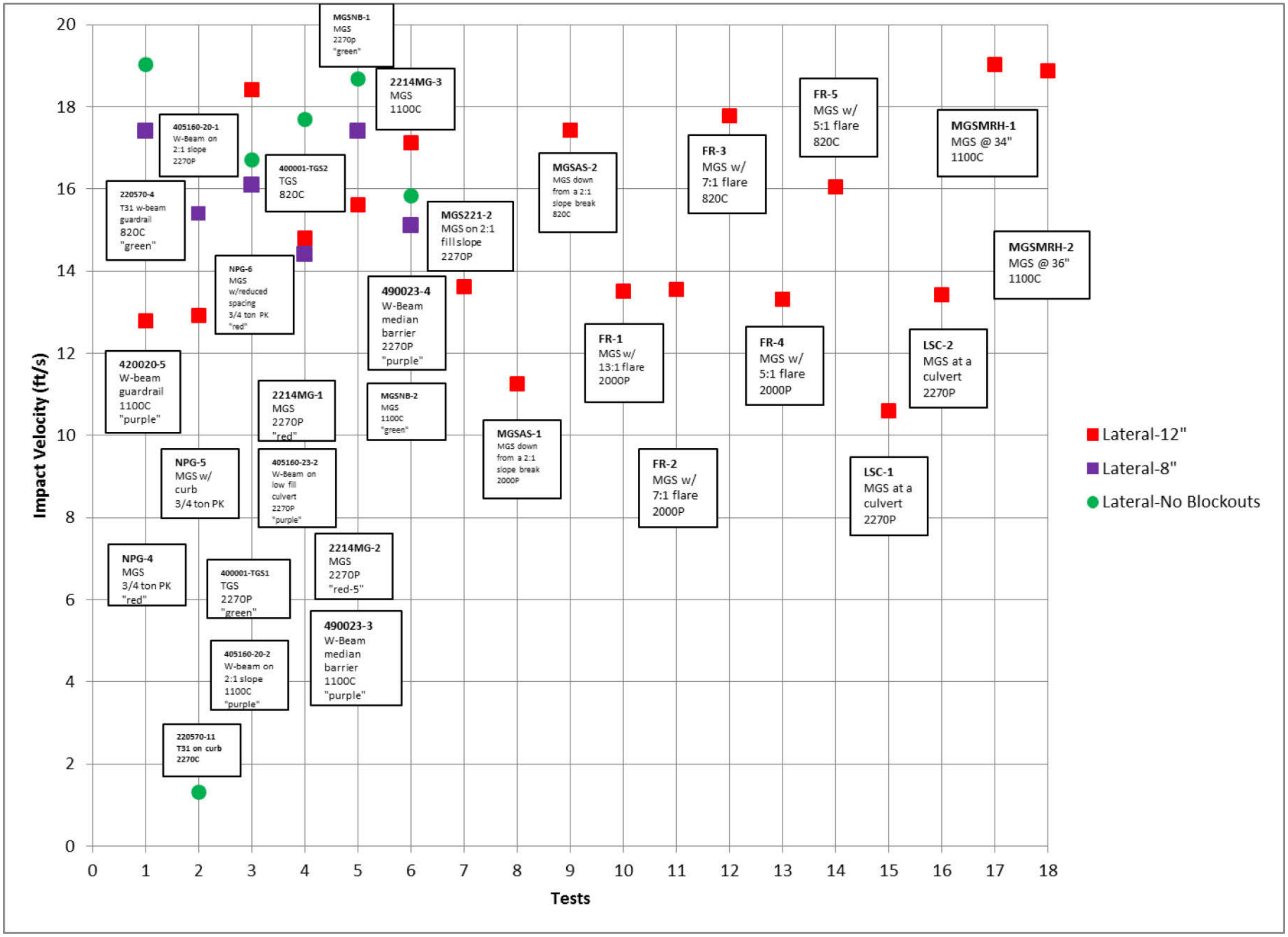


Figure 5.2. Lateral impact velocity with test specifications.

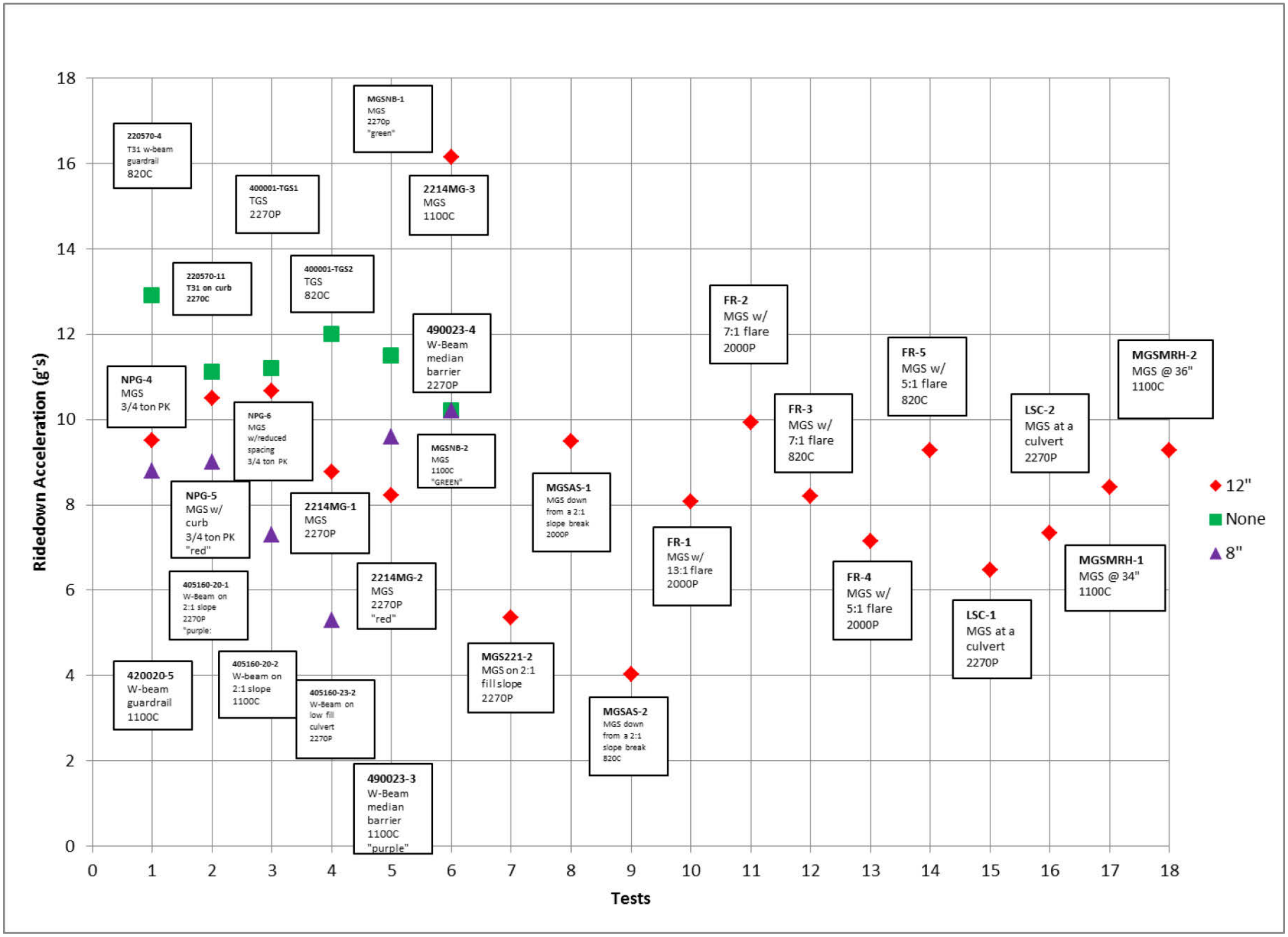


Figure 5.3. Longitudinal ridedown acceleration with test specifications.

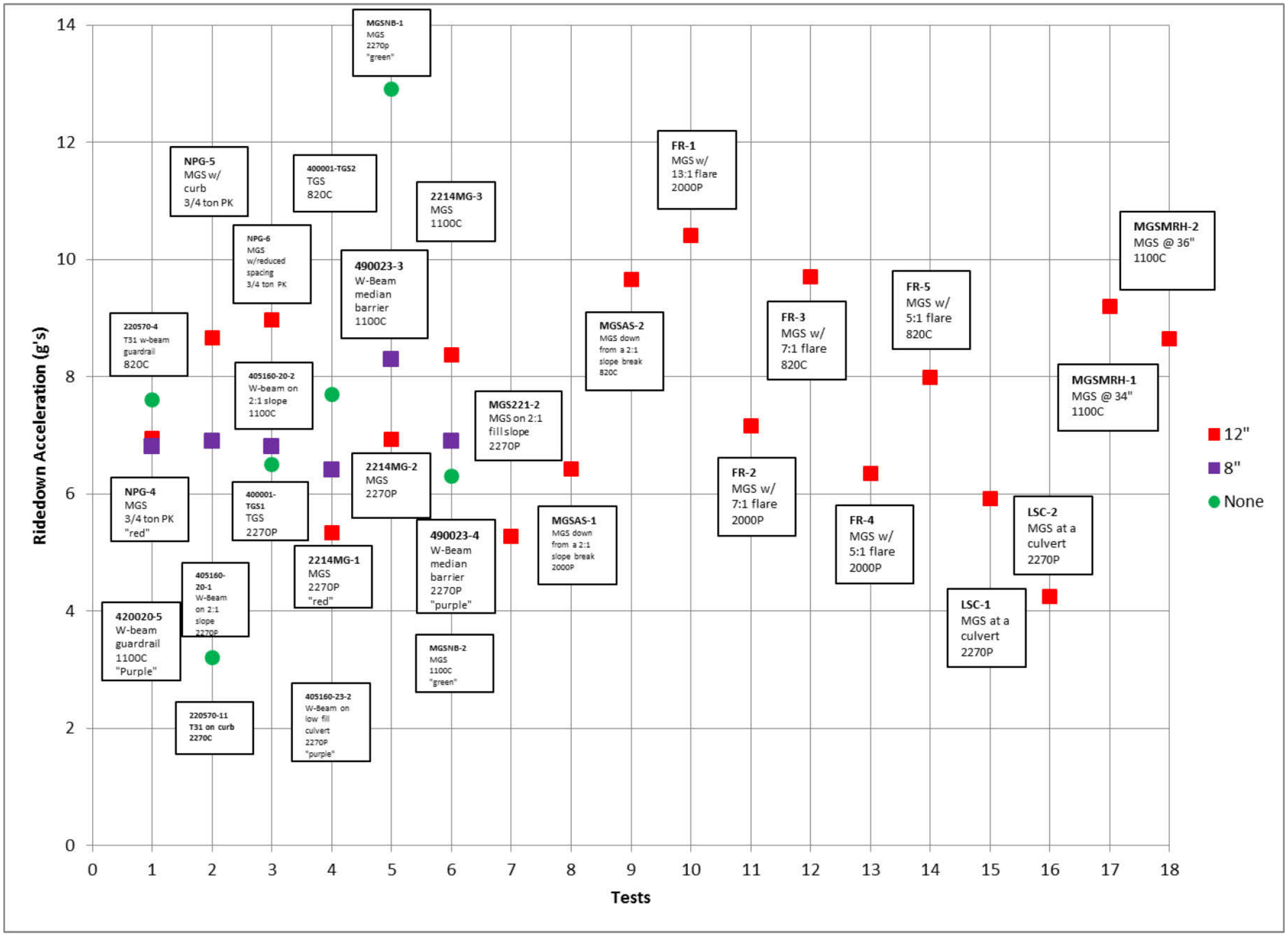


Figure 5.4. Lateral ridedown acceleration with test specifications.

5.1 Occupant Risk Comparison According to Blockout Depth

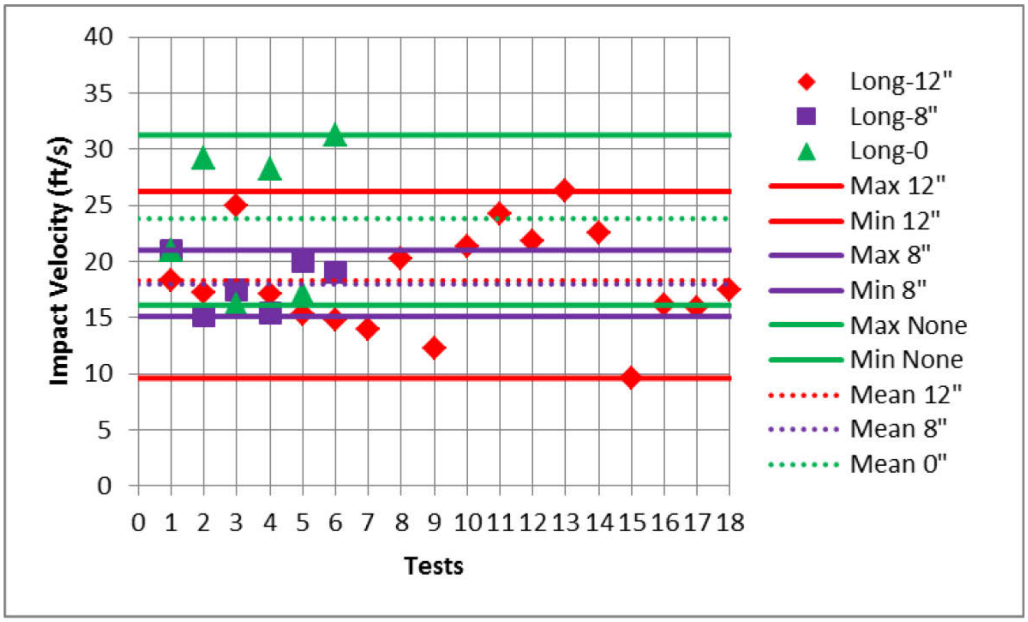
Impact velocities recorded from system tested with different types of blockout depths are reported in Figure 5.5. Within the same graph, the researchers plotted the maximum, minimum, and mean longitudinal (Figure 5.5(a)) and lateral (Figure 5.5(b)) impact velocity values for each blockout depth category. Similarly, longitudinal and lateral ridedown acceleration are reported together with their maximum, minimum, and mean values in Figures 5.3 and 5.4, respectively.

Longitudinal impact velocities recorded from full-scale crash tests on systems with 12-inch blockout depths range from 9.58 ft/sec to 26.24 ft/sec, with a calculated mean value of 18.29 ft/sec. The difference between the maximum and minimum values of the longitudinal impact velocity for 12-inch blockout is 16.66 ft/sec. Longitudinal impact velocities recorded from full-scale crash tests on systems with 8-inch blockout depths range from 15.1 ft/sec to 21 ft/sec, with a calculated mean value of 17.98 ft/sec. The difference between the maximum and minimum values of the longitudinal impact velocity for 8-inch blockout is 5.9 ft/sec. The mean value for the longitudinal impact velocity from 12-inch blockout is 1.69% bigger than the mean value from 8-inch blockout tests.

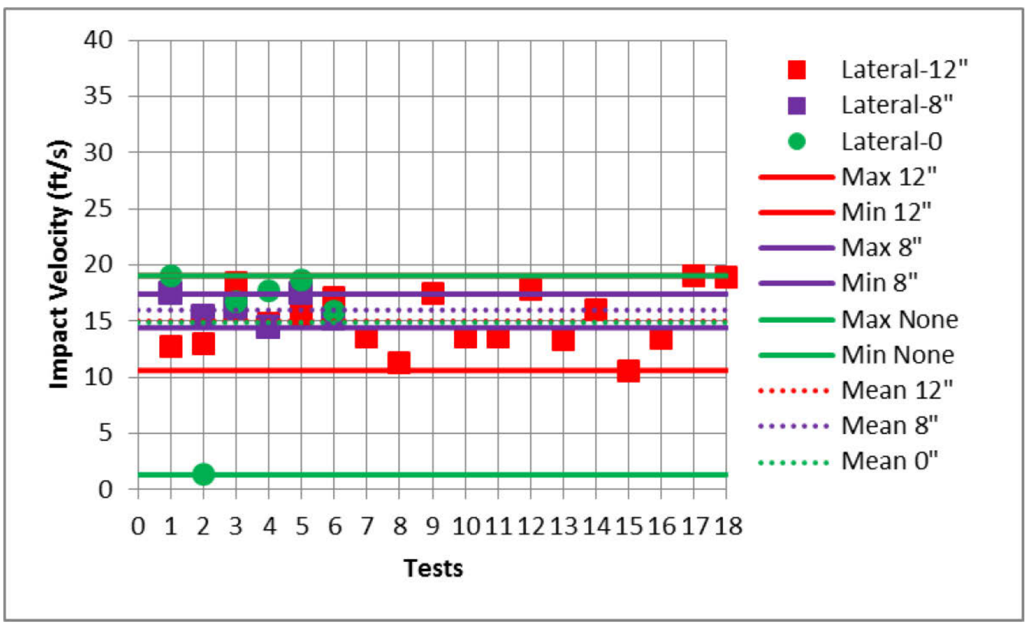
Lateral impact velocities recorded from full-scale crash tests on systems with 12-inch blockout depths range from 10.6 ft/sec to 19.03 ft/sec, with a calculated mean value of 15 ft/sec. The difference between the maximum and minimum values of the longitudinal impact velocity for 12-inch blockout is 8.43 ft/sec. Longitudinal impact velocities recorded from full-scale crash tests on systems with 8-inch blockout depths range from 14.4 ft/sec to 17.4 ft/sec, with a calculated mean value of 15.97 ft/sec. The difference between the maximum and minimum values of the longitudinal impact velocity for 8-inch blockout is 3 ft/sec. The mean value for the longitudinal impact velocity from 12-inch blockout is 6.07% smaller than the mean value from 8-inch blockout tests.

It is interesting also to note that the longitudinal impact velocities recorded from full-scale crash tests on systems with no use of blockouts range from 16.1 ft/sec to 31.26 ft/sec, with a calculated mean value of 23.82 ft/sec, which represents an increase of 30.24% from the mean value with 12-inch blockout tests. The lateral impact velocities recorded from full-scale crash tests on systems with no use of blockouts range from 1.31 ft/sec to 19.03 ft/sec, with a calculated mean value of 14.87 ft/sec, which represents a decrement of 0.87% from the mean value with 12-inch blockout tests.

Standard deviation values with respect to impact velocity data are reported in Table 5.2 and are used to define a corridor for each blockout depth category (Table 5.3). It can be noted that the corridor for longitudinal impact velocity for 8-inch blockout tests was calculated to be 15.55 to 20.41, which is completely contained by the corridor obtained with 12-inch blockout tests (13.68 to 22.78). Similarly, the corridor for lateral impact velocity for 8-inch blockout tests was calculated to be 14.73 to 17.21, and is completely contained by the corridor obtained with 12-inch blockout tests (12.38 to 17.62).



(a) Longitudinal



(b) Lateral

Figure 5.5. Evaluated maximum, minimum and mean impact velocity values from all considered tests.

Table 5.2. Calculated standard deviation values for impact velocity.

Standard Deviation		
	Impact Velocity	
Blockout Depth (in)	Longitudinal	Lateral
12	4.55	2.62
8	2.43	1.24
0	6.57	6.75

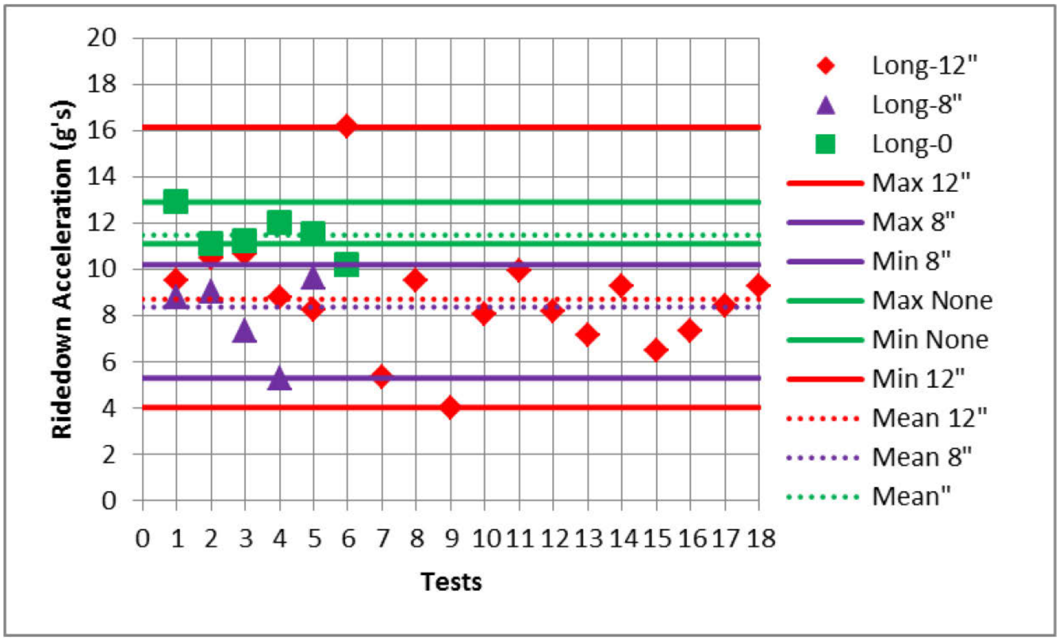
Table 5.3. Calculated corridor values for impact velocity.

Corridor		
	Impact Velocity	
Blockout Depth (in)	Longitudinal	Lateral
12	18.23 $\pm$ 4.55 (13.68, 22.78)	15 $\pm$ 2.62 (12.38, 17.62)
8	17.98 $\pm$ 2.43 (15.55, 20.41)	15.97 $\pm$ 1.24 (14.73, 17.21)
0	23.82 $\pm$ 6.57 (17.25, 30.39)	14.87 $\pm$ 6.75 (8.12, 21.62)

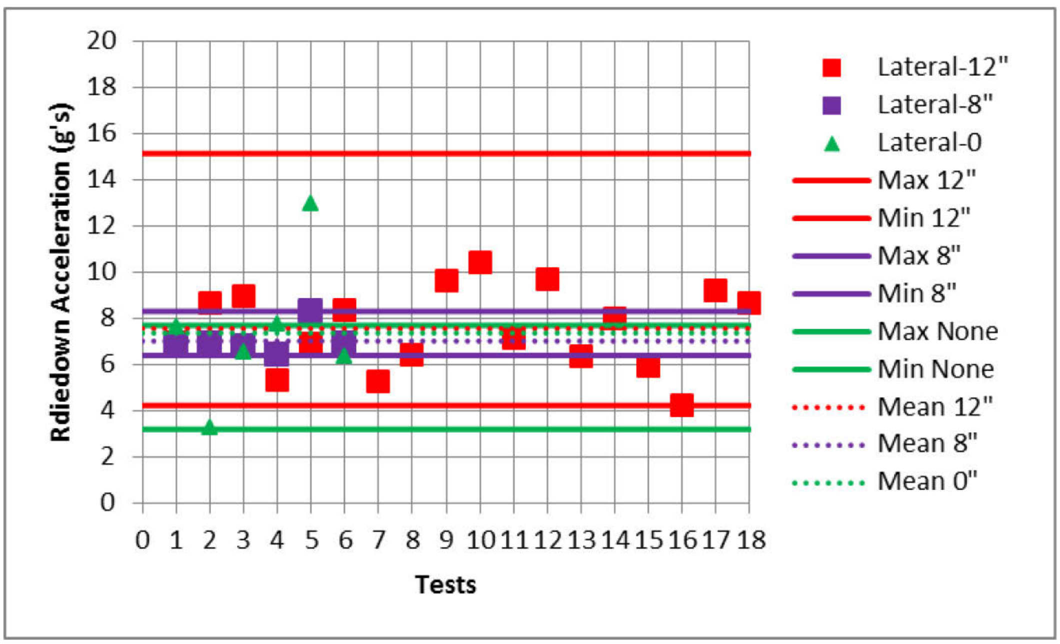
Longitudinal ridedown accelerations recorded from full-scale crash tests on systems with 12-inch blockout depths range from 4.03 ft/sec to 16.14 ft/sec, with a calculated mean value of 8.71 ft/sec. The difference between the maximum and minimum values of the longitudinal ridedown acceleration for 12-inch blockout is 12.11 ft/sec. Longitudinal ridedown accelerations recorded from full-scale crash tests on systems with 8-inch blockout depths range from 5.3 ft/sec to 10.2 ft/sec, with a calculated mean value of 8.37 ft/sec. The difference between the maximum and minimum values of the longitudinal ridedown acceleration for 8-inch blockout is 4.9 ft/sec. The mean value for the longitudinal ridedown acceleration from 12-inch blockout is 4.06% bigger than the mean value from 8-inch blockout tests.

Lateral ridedown accelerations recorded from full-scale crash tests on systems with 12-inch blockout depths range from 4.24 ft/sec to 10.41 ft/sec, with a calculated mean value of 7.56 ft/sec. The difference between the maximum and minimum values of the longitudinal ridedown acceleration for 12-inch blockout is 6.17 ft/sec. Longitudinal ridedown accelerations recorded from full-scale crash tests on systems with 8-inch blockout depths range from 6.4 ft/sec to 8.3 ft/sec, with a calculated mean value of 7.02 ft/sec. The difference between the maximum and minimum values of the longitudinal ridedown acceleration for 8-inch blockout is 1.9 ft/sec.

The mean value for the longitudinal ridedown acceleration from 12-inch blockout is 7.69% bigger than the mean value from 8-inch blockout tests.



(a) Longitudinal



(b) Lateral

Figure 5.6. Evaluated maximum, minimum and mean ridedown acceleration values from all considered tests.

In addition, the longitudinal ridedown accelerations recorded from full-scale crash tests on systems with no use of blockouts range from 10.2 ft/sec to 12.9 ft/sec, with a calculated mean value of 11.48 ft/sec, which represents an increase of 31.80% from the mean value with 12-inch blockout tests. The lateral ridedown accelerations recorded from full-scale crash tests on systems with no use of blockouts range from 3.2 ft/sec to 12.91 ft/sec, with a calculated mean value of 7.37 ft/sec, which represents a decrement of 2.51% from the mean value with 12-inch blockout tests.

Standard deviation values with respect to impact velocity data are reported in Table 5.4 and are used to define a corridor for each blockout depth category (Table 5.5). It can be noted that the corridor for longitudinal ridedown acceleration for 8-inch blockout tests was calculated to be 6.58 to 10.16, which is completely contained by the corridor obtained with 12-inch blockout tests (6.18 to 11.24). Similarly, the corridor for lateral ridedown acceleration for 8-inch blockout tests was calculated to be 6.36 to 7.68, and is completely contained by the corridor obtained with 12-inch blockout tests (5.8 to 9.88).

Table 5.4. Calculated standard deviation values for ridedown acceleration.

Standard Deviation		
	Ridedown Acceleration	
Blockout Depth (in)	Longitudinal	Lateral
12	2.53	1.76
8	1.79	0.66
0	0.91	3.17

Table 5.5. Calculated corridor values for ridedown acceleration.

Corridor		
	Ridedown Acceleration	
Blockout Depth (in)	Longitudinal	Lateral
12	8.71 ± 2.53 (6.18, 11.24)	7.56 ± 1.76 (5.8, 9.88)
8	8.37 ± 1.79 (6.58, 10.16)	7.02 ± 0.66 (6.36, 7.68)
0	11.48 ± 0.91 (10.57, 12.39)	7.37 ± 3.17 (4.2, 10.54)

5.2 Occupant Risk Comparison According to Test Criteria

Occupant risks recorded from systems tested with different types of blockout depths and differentiated by test impact criteria are reported in Tables 5.6 through 5.9. Researchers plotted the mean longitudinal (Figure 5.7-5.10(a)) and lateral (Figure 5.7-5.10(b)) impact velocity values for each blockout depth and test criteria. Similarly, longitudinal and lateral ridedown acceleration are reported together with their mean values in Figures 5.7-5.10(c) and 5.7-5.10(d), respectively.

Table 5.6. Occupant risk values for systems tested with 2270P vehicles (*MASH*).

MASH Pickups						
			Impact Velocities (ft/s)		Ridedown Acceleration (g's)	
Report	**Test**	**Blockout Depth (in)**	**Longitudinal**	**Lateral**	**Longitudinal**	**Lateral**
TRP-03-170-06	2214MG -1	12	17.06	14.8	8.77	5.34
TRP-03-171-06	2214MG -2	12	15.32	15.62	8.23	6.93
TRP-03-185-10	MGS221-2	12	13.9	13.61	5.36	5.28
TRP-03-187-07	LSC-1	12	9.58	10.6	6.48	5.91
TRP-03-187-07	LSC-2	12	16.08	13.42	7.34	4.24
405160-20	405160-20-1	8	15.1	15.4	9	6.9
405160-23	405160-23-2	8	15.4	14.4	5.3	6.4
490023	490023-3	8	20	17.4	9.6	8.3
400001	400001-TGS1	none	16.1	16.7	11.2	6.5
220570	220570-11	none	29.2	1.31	11.1	3.2
TRP-03-262-12	MGSNB-1	none	17.13	18.67	11.49	12.91

Longitudinal impact velocities recorded from full-scale crash tests on systems with 12-inch blockout depths with *MASH* pickup test criteria have a calculated mean value of 14.39 ft/sec. Longitudinal impact velocities recorded from full-scale crash tests on systems with 8-inch blockout depths have a calculated mean value of 16.83 ft/sec. The mean value for the longitudinal impact velocity from 12-inch blockout is 14.50% smaller than the mean value from 8-inch blockout tests.

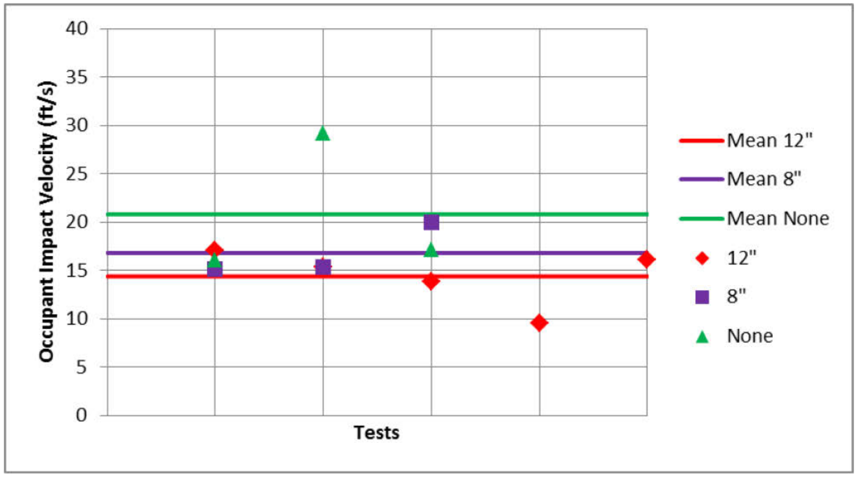
Lateral impact velocities recorded from full-scale crash tests on systems with 12-inch blockout depths with *MASH* pickup test criteria have a calculated mean value of 13.61 ft/sec. Longitudinal impact velocities recorded from full-scale crash tests on systems with 8-inch blockout depths have a calculated mean value of 15.73 ft/sec. The mean value for the longitudinal impact velocity from 12-inch blockout is 13.48% smaller than the mean value from 8-inch blockout tests.

It is interesting also to note that the longitudinal impact velocities recorded from full-scale crash tests on systems with no use of blockouts with *MASH* pickup test criteria have a calculated mean value of 20.81 ft/sec, which represents an increase of 44.61% from the mean value with 12-inch blockout tests. The lateral impact velocities recorded from full-scale crash tests on systems with no use of blockouts with *MASH* pickup test criteria have a calculated mean value of 12.23 ft/sec, which represents a decrement of 10.14% from the mean value with 12-inch blockout tests.

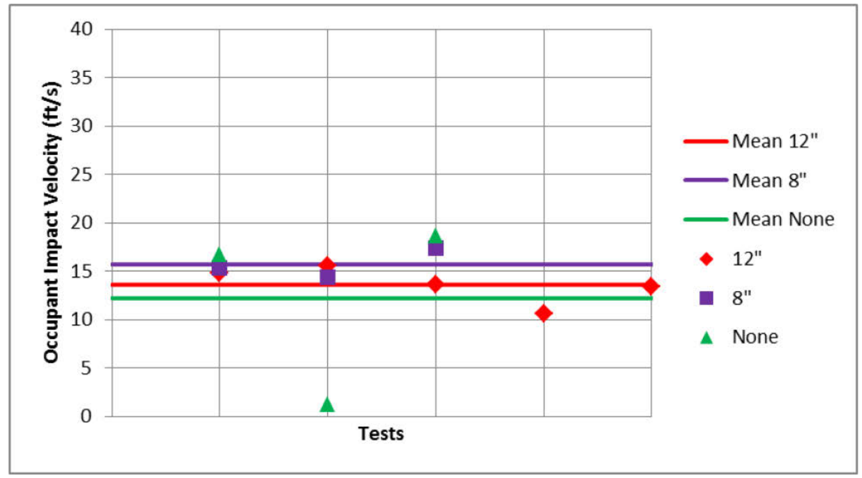
Longitudinal ridedown accelerations recorded from full-scale crash tests on systems with 12-inch blockout depths with *MASH* pickup test criteria have a calculated mean value of 7.24 ft/sec. Longitudinal impact velocities recorded from full-scale crash tests on systems with 8-inch blockout depths have a calculated mean value of 7.97 ft/sec. The mean value for the longitudinal impact velocity from 12-inch blockout is 9.16% smaller than the mean value from 8-inch blockout tests.

Lateral ridedown accelerations recorded from full-scale crash tests on systems with 12-inch blockout depths with *MASH* pickup test criteria have a calculated mean value of 5.54 ft/sec. Longitudinal impact velocities recorded from full-scale crash tests on systems with 8-inch blockout depths have a calculated mean value of 7.2 ft/sec. The mean value for the longitudinal impact velocity from 12-inch blockout is 23.05% smaller than the mean value from 8-inch blockout tests.

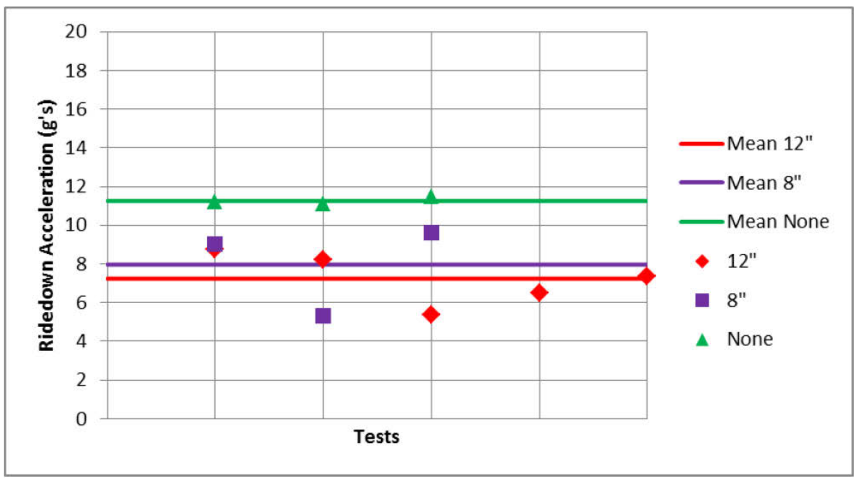
It is interesting also to note that the longitudinal ridedown accelerations recorded from full-scale crash tests on systems with no use of blockouts with *MASH* pickup test criteria have a calculated mean value of 11.26 ft/sec, which represents an increase of 55.52% from the mean value with 12-inch blockout tests. The lateral ridedown accelerations recorded from full-scale crash tests on systems with no use of blockouts with *MASH* pickup test criteria have a calculated mean value of 7.54 ft/sec, which represents an increase of 36.1% from the mean value with 12-inch blockout tests.



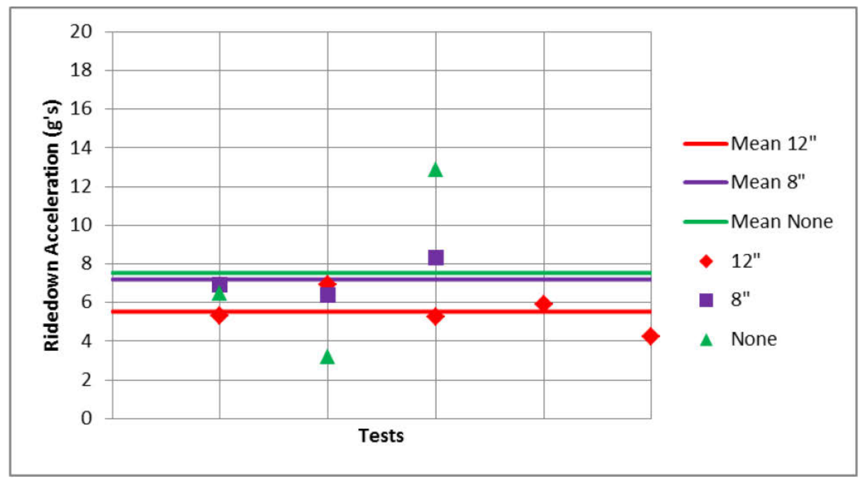
(a) Longitudinal impact velocity



(b) Lateral impact velocity



(c) Longitudinal ridedown acceleration



(d) Lateral ridedown acceleration

Figure 5.7. Occupant risk values with means for systems tested with 2270P vehicles (*MASH*)

Longitudinal impact velocities recorded from full-scale crash tests on systems with 12-inch blockout depths with *MASH* passenger car test criteria have a calculated mean value of 16.04 ft/sec. Longitudinal impact velocities recorded from full-scale crash tests on systems with 8-inch blockout depths have a calculated mean value of 19.47 ft/sec. The mean value for the longitudinal impact velocity from 12-inch blockout is 17.62% smaller than the mean value from 8-inch blockout tests.

Lateral impact velocities recorded from full-scale crash tests on systems with 12-inch blockout depths with *MASH* passenger car test criteria have a calculated mean value of 18.34 ft/sec. Longitudinal impact velocities recorded from full-scale crash tests on systems with 8-inch blockout depths have a calculated mean value of 16.97 ft/sec. The mean value for the longitudinal impact velocity from 12-inch blockout is 8.07% bigger than the mean value from 8-inch blockout tests.

Longitudinal ridedown accelerations recorded from full-scale crash tests on systems with 12-inch blockout depths with *MASH* passenger car test criteria have a calculated mean value of 11.27 ft/sec. Longitudinal impact velocities recorded from full-scale crash tests on systems with 8-inch blockout depths have a calculated mean value of 8.57ft/sec. The mean value for the longitudinal impact velocity from 12-inch blockout is 31.51% greater than the mean value from 8-inch blockout tests.

Lateral ridedown accelerations recorded from full-scale crash tests on systems with 12-inch blockout depths with *MASH* passenger car test criteria have a calculated mean value of 8.73 ft/sec. Longitudinal impact velocities recorded from full-scale crash tests on systems with 8-inch blockout depths have a calculated mean value of 7.3 ft/sec. The mean value for the longitudinal impact velocity from 12-inch blockout is 19.59% greater than the mean value from 8-inch blockout tests.

Table 5.7. Occupant risk values for systems tested with 1100C vehicles (*MASH*).

MASH Passenger Cars						
			Impact Velocities (ft/s)		Ridedown Acceleration (g's)	
Report	**Test**	**Blockout Depth (in)**	**Longitudinal**	**Lateral**	**Longitudinal**	**Lateral**
TRP-03-172-06	2214MG-3-1	12	14.83	17.13	16.14	8.37
TRP-03-255-12	MGSMRH-1	12	15.84	19.03	8.41	9.19
TRP-03-255-12	MGSMRH-2	12	17.44	18.87	9.27	8.64
420020	420020-5	8	21	17.4	8.8	6.8
405160-20	405160-20-2	8	17.4	16.1	7.3	6.8
490023	490023-3	8	20	17.4	9.6	8.3
TRP-03-262-12	MGSNB-2	none	31.26	15.83	10.2	6.3

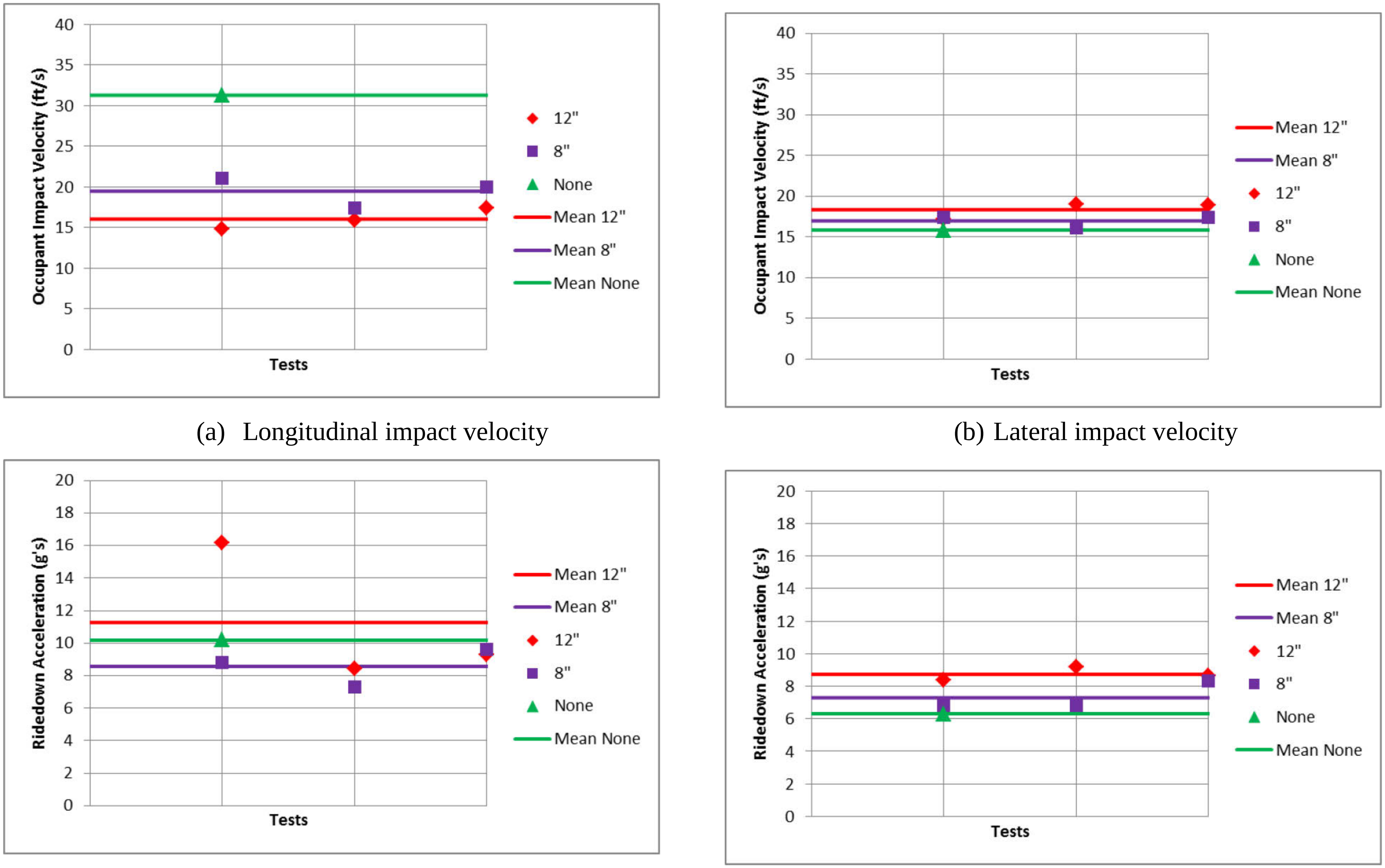
Longitudinal and lateral impact velocities recorded from full-scale crash tests on systems with 12-inch blockout depths with *NCHRP Report 350* pickup test criteria have a calculated mean value of 21.78 ft/sec and 13.68 ft/sec, respectively.

Longitudinal and lateral ridedown accelerations recorded from full-scale crash tests on systems with 12-inch blockout depths with *NCHRP Report 350* pickup test criteria have a calculated mean value of 9.33ft/sec and 7.85ft/sec, respectively.

No comparison with other blockout depths categories are possible since there are no available full-scale crash tests conducted with 2000P vehicles on a 31-inch guardrail with 8-inch blockout or with no use of blockouts.

Table 5.8. Occupant risk values for systems tested with 2000P vehicles (*NCHRP Report 350*).

NCHRP Report 350 Pickups						
			Impact Velocities (ft/s)		Ridedown Acceleration (g's)	
Report	Test	Blockout Depth (in)	Longitudinal	Lateral	Longitudinal	Lateral
TRP-03-139-04	NPG-4	12	18.32	12.78	9.5	6.94
TRP-03-139-04	NPG-5	12	17.16	12.91	10.5	8.66
TRP-03-139-04	NPG-6	12	25	18.42	10.67	8.97
TRP-03-188-08	MGSAS-1	12	20.2	11.25	9.49	6.43
TRP-03-191-08	FR-1	12	21.36	13.52	8.08	10.41
TRP-03-191-08	FR-2	12	24.18	13.55	9.92	7.16
TRP-03-191-08	FR-4	12	26.24	13.32	7.15	6.35



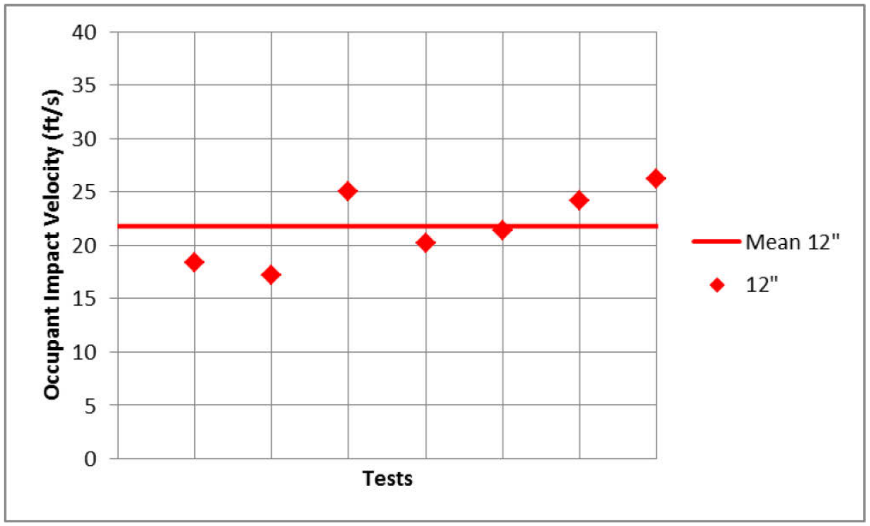
(a) Longitudinal impact velocity

(b) Lateral impact velocity

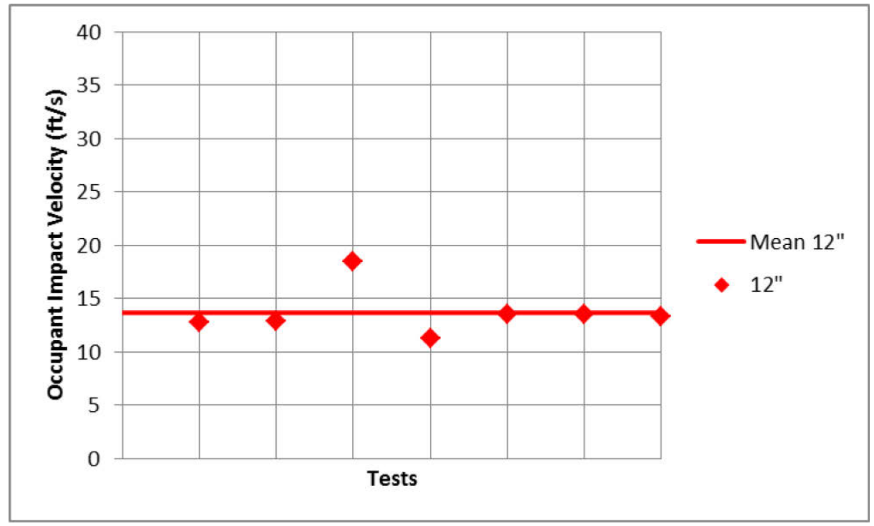
(c) Longitudinal ridedown acceleration

(d) Lateral ridedown acceleration

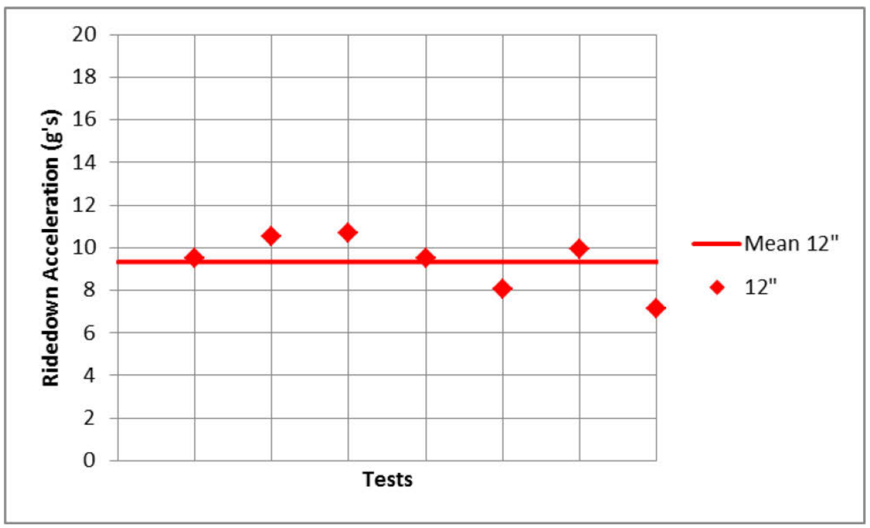
Figure 5.8. Occupant risk values with means for systems tested with 1100C vehicles (*MASH*).



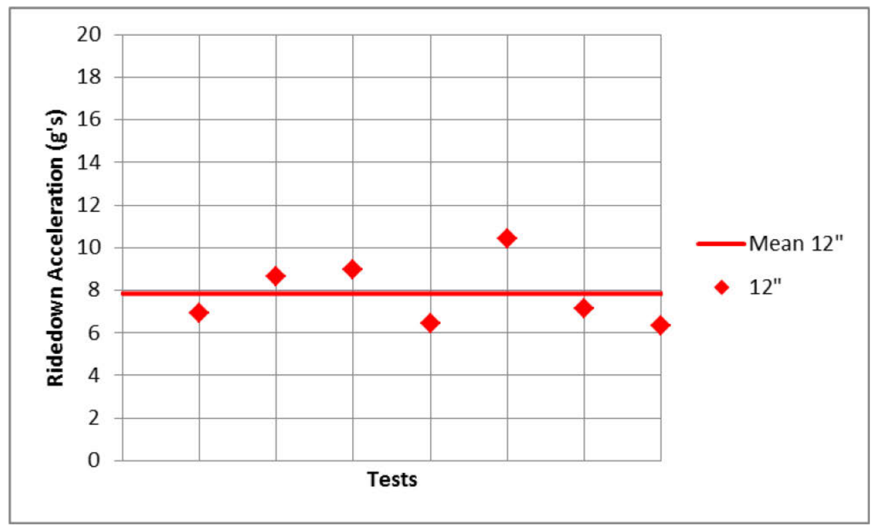
(a) Longitudinal impact velocity



(b) Lateral impact velocity



(c) Longitudinal ridedown acceleration



(d) Lateral ridedown acceleration

Figure 5.9. Occupant risk values with means for systems tested with 2000P vehicles (*NCHRP Report 350*).

Longitudinal impact velocities recorded from full-scale crash tests on systems with 12-inch blockout depths with *NCHRP Report 350* passenger car test criteria have a calculated mean value of 18.88 ft/sec

Lateral impact velocities recorded from full-scale crash tests on systems with 12-inch blockout depths with *NCHRP Report 350* passenger car test criteria have a calculated mean value of 17.08 ft/sec

The longitudinal impact velocities recorded from full-scale crash tests on systems with no use of blockouts with *NCHRP Report 350* passenger car test criteria have a calculated mean value of 24.6 ft/sec, which represents an increase of 30.3% from the mean value with 12-inch blockout tests. The lateral impact velocities recorded from full-scale crash tests on systems with no use of blockouts with *NCHRP Report 350* passenger car test criteria have a calculated mean value of 18.37 ft/sec, which represents an increment of 7.55% from the mean value with 12-inch blockout tests.

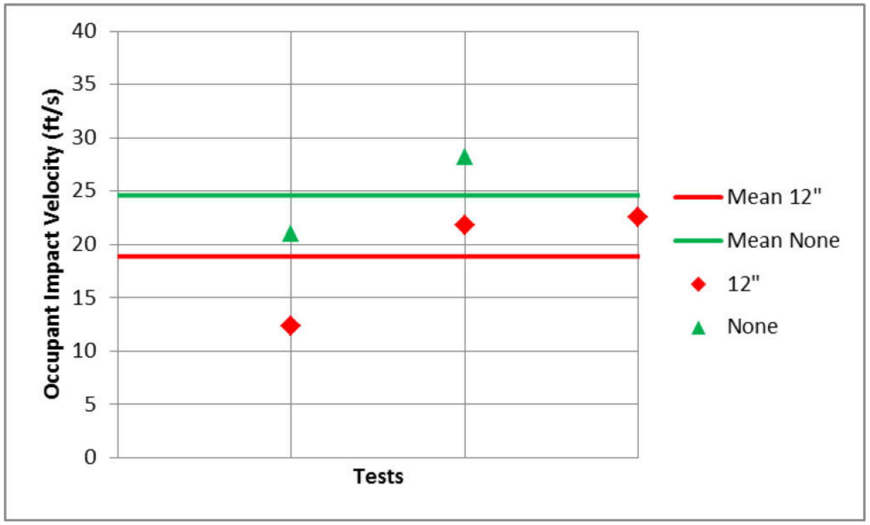
Longitudinal ridedown accelerations recorded from full-scale crash tests on systems with 12-inch blockout depths with *NCHRP Report 350* passenger car test criteria have a calculated mean value 7.17 ft/sec

Lateral ridedown accelerations recorded from full-scale crash tests on systems with 12-inch blockout depths with *NCHRP Report 350* passenger car test criteria have a calculated mean value of 9.11 ft/sec.

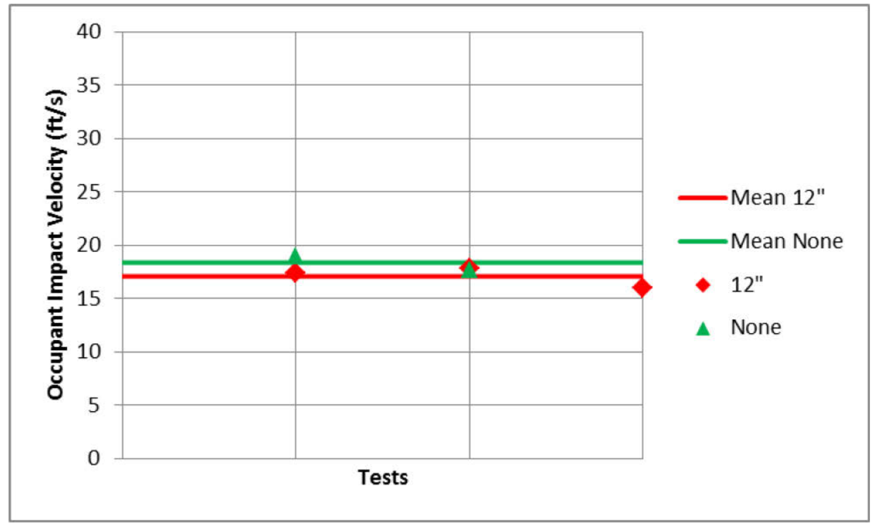
The longitudinal ridedown accelerations recorded from full-scale crash tests on systems with no use of blockouts with *NCHRP Report 350* passenger car test criteria have a calculated mean value of 12.45 ft/sec, which represents an increase of 73.64% from the mean value with 12-inch blockout tests. The lateral ridedown accelerations recorded from full-scale crash tests on systems with no use of blockouts with *NCHRP Report 350* passenger car test criteria have a calculated mean value of 7.65 ft/sec, which represents a decrement of 16.03% from the mean value with 12-inch blockout tests.

Table 5.9. Occupant risk values for systems tested with 820 vehicles (*NCHRP Report 350*).

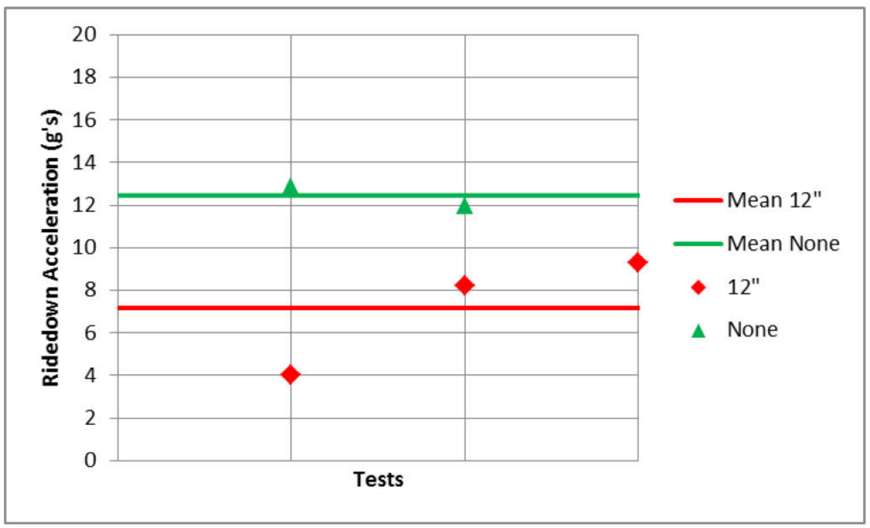
NCHRP Report 350 Passenger Cars						
			Impact Velocities (ft/s)		**Ridedown Acceleration (g's)**	
Report	**Test**	**Blockout Depth (in)**	**Longitudinal**	**Lateral**	**Longitudinal**	**Lateral**
TRP-03-188-08	MGSAS-2	12	12.3	17.42	4.03	9.65
TRP-03-191-08	FR-3	12	21.82	17.78	8.2	9.7
TRP-03-191-08	FR-5	12	22.51	16.04	9.27	7.98
220570	220570-4	none	21	19.03	12.9	7.6
400001	400001-TGS2	none	28.2	17.7	12	7.7



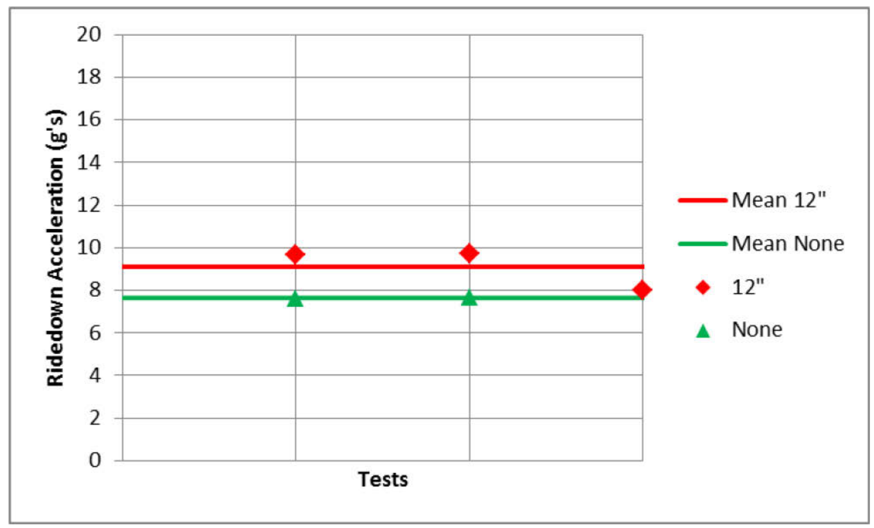
(a) Longitudinal impact velocity



(b) Lateral impact velocity



(c) Longitudinal ridedown acceleration



(d) Lateral ridedown acceleration

Figure 5.10. Occupant risk values with means for systems tested with 820 vehicles (*NCHRP Report 350*).

5.3 Occupant Risk Comparison According to ANOVA

Tables 5.10 through 5.13 list the p-values calculated when applied ANOVA analysis for comparison of occupant risk values obtained from tests with different blockouts depths. The ANOVA analysis was evaluated taking into consideration the absolute maximum values of each occupant risk category. As it can be noted, only in a couple of cases the ANOVA analysis returned a p-value smaller than 0.05. These two cases were lateral ridedown accelerations for 12-inch vs 8 inch for passenger cars and longitudinal ridedown accelerations for 8-inch vs no blockouts for passenger cars (Table 5.11).

When compared the values from the 12-inch and the 8-inch blockout groups, the obtained p-value was circa 0.0188, which would suggest that is a statistically significant difference between use of 12-inch and 8-inch blockouts in terms of lateral ridedown acceleration for passenger cars. It is very interesting, though, that when comparing the groups of 12-inch and no blockouts, the p-value increased to 0.7053, which would suggest there is no significant difference between use of 12-inch blockout or no blockouts as for lateral ridedown acceleration for passenger car results. Moreover, no significant statistically difference was suggested when comparing all three groups.

Table 5.10. P-values for all pickups.

Blockout Comparison	Long IV (ft/s)	Lat IV (ft/s)	Long RA (g's)	Lat RA (g's)
All Blockouts	0.4502	0.1200	0.2584	0.4294
12" vs. 8"	0.6004	0.0950	0.5329	0.8534
12" vs. 0"	0.3108	0.1164	0.1585	0.2309
8" vs. 0"	0.3522	0.3333	0.1641	0.1994

Table 5.11. P-values for all passenger cars.

Blockout Comparison	Long IV (ft/s)	Lat IV (ft/s)	Long RA (g's)	Lat RA (g's)
All Blockouts	0.3174	0.2179	0.3237	0.2685
12" vs. 8"	0.4480	0.3405	0.7916	0.0188
12" vs. 0"	0.8696	0.3289	0.2562	0.7053
8" vs. 0"	0.4823	0.0632	0.0107	0.3129

Table 5.12. P-values for *MASH* passenger cars.

Blockout Comparison	Long IV (ft/s)	Lat IV (ft/s)	Long RA (g's)	Lat RA (g's)
All Blockouts				
12" vs. 8"	0.0595	0.1391	0.3462	0.0612
12" vs. 0"				
8" vs. 0"				

Table 5.13. P-values for *MASH* pickups.

Blockout Comparison	Long IV (ft/s)	Lat IV (ft/s)	Long RA (g's)	Lat RA (g's)
All Blockouts	0.1532	0.6602	0.2031	0.9888
12" vs. 8"	0.2495	0.0954	0.8748	0.9804
12" vs. 0"	0.0856	0.7633	0.1212	0.8994
8" vs. 0"	0.4263	0.5624	0.0710	0.9134

5.4 Conclusions

Within this chapter, researchers have compared occupant risks recorded during full-scale crash tests with use of 12-inch, 8-inch and no blockouts. Impact velocities and ridedown accelerations were also compared by considering the impact criteria used for performing the full-scale crash tests (*MASH* or *NCHRP Report 350*).

Researchers noticed that occupant risks outcomes can vary significantly among tests with use of same blockout depth and explained this observation as an indication of vehicle stability and system redirection capacity, which can be influenced by the particular test installation configuration and by the actual impact conditions. In addition, researchers evaluated corridors (defined as mean value ± standard deviation) for each of the evaluated variables and each of the blockout depth groups: results showed that corridors developed for 8-inch blockout group results were always contained within corridors developed for 12-inch blockout group.

When comparing the tests values from the 12-inch and the 8-inch blockout groups, ANOVA results suggest that there is a statistically significant difference between use of 12-inch and 8-inch blockouts in terms of lateral ridedown acceleration for passenger cars. It is very interesting, though, that when comparing the groups of 12-inch and no blockouts, the p-value increased to 0.7053, which would suggest there is no significant difference between use of 12-inch blockout or no blockouts as for lateral ridedown acceleration for passenger car results. Moreover, no significant statistically difference was suggested when comparing all three groups.

After reviewing tests results and performing statistical analysis, it is opinion of the researchers that there is no statistically significant difference in terms of occupant risks from use of 12-inch and 8-inch blockout depths.

Chapter 6 Analysis of Deflection

In this Chapter, data collected through crash events was reviewed and compared with respect to maximum deflections (i.e., permanent and dynamic deflection and working width) (Tables 6.1through 6.3).

Table 6.1. Maximum deflections and working width with use of 12-inch blockout depth.

Report	Test	Year	Vehicle	Vehicle Mass (kg)	Rail Height (in)	Post		Maximum Deflection		Working Width (in)
						Material	Spacing (in)	Permanent (in)	Dynamic (in)	
TRP-03-139-04	NPG-4	2002	Pickup	1986	31	steel	75	25.67	43.07	49.61
TRP-03-139-04	NPG-5	2002	Pickup	1991	31	steel	75	24.06	40.31	57.2
TRP-03-139-04	NPG-6	2002	Pickup	2001	31	steel	reduced	12	17.6	36.65
TRP-03-170-06	2214MG-1	2004	2270P	2268	31	steel	75	42.87	57	57.32
TRP-03-171-06	2214MG-2	2004	2270P	2268	31	steel	75	31.61	43.86	48.58
TRP-03-172-06	2214MG-3-1	2004	1100C	1099	31	steel	75	19.88	35.94	48.31
TRP-03-185-10	MGS221-2	2006	2270P	2274	31	steel	75	42	57.6	64.21
TRP-03-188-08	MGSAS-1	2006	2000P	2036	31	steel	75	34.25	57.64	82.83
TRP-03-188-08	MGSAS-2	2006	820C	912	31	steel	75	14.65	25	46.34
TRP-03-191-08	FR-1	2005	2000P	2026	31	steel	75	44.88	66.3	70.63
TRP-03-191-08	FR-2	2005	2000P	2023	31	steel	75	45.51	75.79	87.87
TRP-03-191-08	FR-3	2005	820C	894	31	steel	75	20.75	36.42	43.58
TRP-03-191-08	FR-4	2006	2000P	2014	31	steel	75	69.02	75.55	97.44
TRP-03-191-08	FR-5	2006	820C	908	31	steel	75	25.98	35.75	50
TRP-03-187-07	LSC-1	2006	2270P	2264	31	steel and wood	75	28.5	92.24	93.43
TRP-03-187-07	LSC-2	2006	2270P	2261	31	steel and wood	75	54.01	77.48	83.98
TRP-03-255-12	MGSMRH-1	2010	1100C	1179	34	steel	75	18.25	29	49.4
TRP-03-255-12	MGSMRH-2	2010	1100C	1172	36	steel	75	16.25	23.5	40.5

Table 6.2. Maximum deflections and working width with use of 8-inch blockout depth.

Report	Test	Year	Vehicle	Vehicle Mass (kg)	Rail Height (in)	Post		Maximum		Working Width (in)
						Material	Spacing (in)	Permanent (in)	Dynamic (in)	
420020	420020-5	2010	1100C	1104	31	steel	75	18.96	28.56	28.56
405160-20	405160-20-1	2012	2270P	2288	31	steel	75	37.2	51.6	55.2
405160-20	405160-20-2	2012	1100C	1102	31	steel	75	22.8	32.4	37.2
490023	490023-3	2013	1100C	1109	31	steel	75	20.25	25.4	33.6
490023	490023-4	2013	2270P	2276	31	steel	75	29.5	39	55
405160-23	405160-23-2	2011	2270P	2270	31	steel	75	terminal detached	45.6	49.2

Table 6.3. Maximum deflections and working width with no use of blockouts.

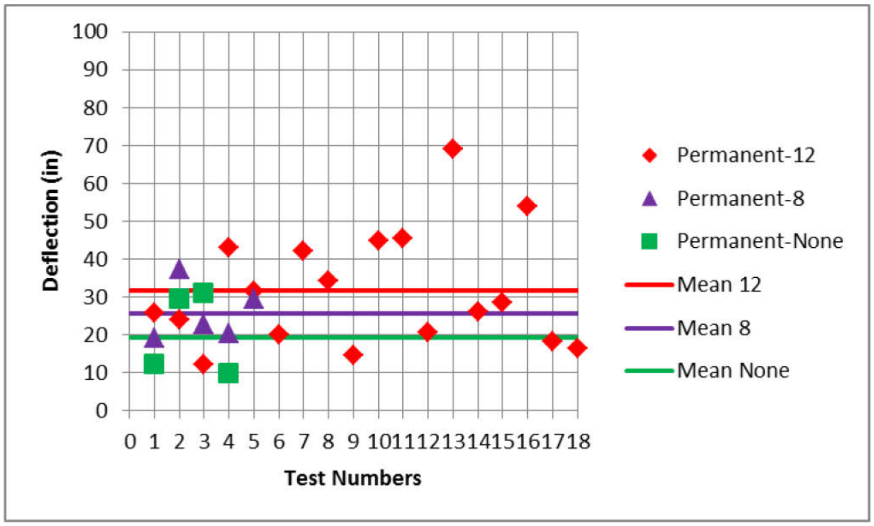
Test No.	Test	Year	Vehicle	Vehicle Mass (kg)	Rail Height (in)	Post		Maximum		Working Width (in)
						Material	Spacing (in)	Permanent (in)	Dynamic (in)	
220570	220570-4	2005	820C	825	31	steel	75	12.2	19.29	52.76
220570	220570-11	2006	2270P	2293	31	steel	75	29.53	48.82	48.82
400001	400001-TGS1	2007	2270P	2254	31	steel	75	31	38.4	40.9
400001	400001-TGS2	2007	820C	1830	31	steel	75	9.6	19.4	22.2
TRP-03-262-12	MGSNB-2	2011	2270P	2350	32	steel	75	13.88	29.1	34.5
TRP-03-262-12	MGSNB-1	2011	1100C	1169	32	steel	75	19.38	34.1	43.2

6.1 Deflections and Working Width

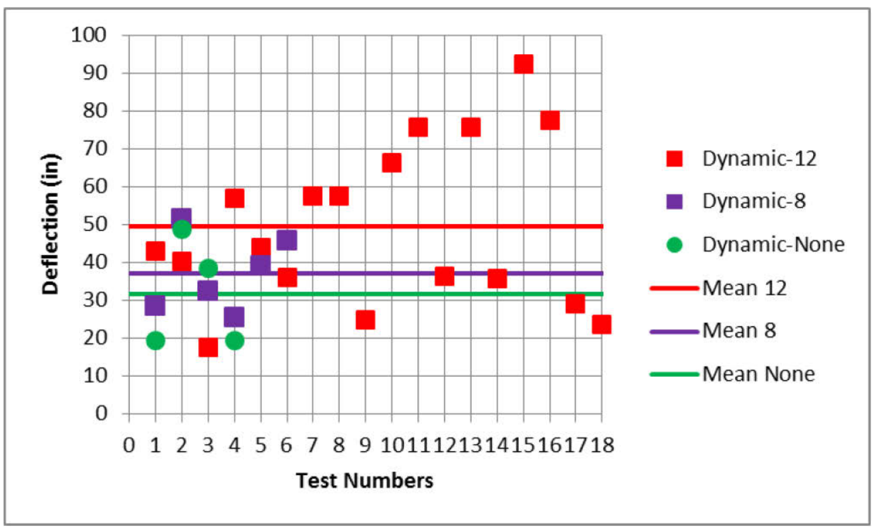
Figure 6.1 shows permanent, dynamic deflections and means for each blockout depth category. Figure 6.2 reports working width and means for each blockout depth category. Permanent deflections recorded from full-scale crash tests on systems with 12-inch blockout depths have a calculated mean value of 31.67 in. Permanent deflections recorded from full-scale crash tests on systems with 8-inch blockout depths have a calculated mean value of 25.74 inches. The mean value for the permanent deflection from 12-inch blockout is 23.04% bigger than the mean value from 8-inch blockout tests.

Dynamic deflections recorded from full-scale crash tests on systems with 12-inch blockout depths have a calculated mean value of 49.45 in. Dynamic deflections recorded from full-scale crash tests on systems with 8-inch blockout depths have a calculated mean value of 37.09 in. The mean value for the dynamic deflection from 12-inch blockout is 33.32% bigger than the mean value from 8-inch blockout tests.

It is interesting also to note that permanent deflections recorded from full-scale crash tests on systems with no use of blockouts have a calculated mean value of 19.27 in, which represents a decrement of 39.15% from the mean value with 12-inch blockout tests. The dynamic deflections recorded from full-scale crash tests on systems with no use of blockouts have a calculated mean value of 31.52 in, which represents a decrement of 36.26% from the mean value with 12-inch blockout tests.



(a) Permanent deflections with means.



(b) Dynamic deflections with means.

Figure 6.1. Maximum deflections and means for all tests.

Working width deflections and their means recorded from system tested with different types of blockout depths are reported in Figure 6.3.   Working width deflections recorded from full-scale crash tests on systems with 12-inch blockout depths have a calculated mean value of 61.55 in. Working width deflections recorded from full-scale crash tests on systems with 8-inch blockout depths have a calculated mean value of 43.13 in.   The mean value for the working width deflection from 12-inch blockout is 42.71% bigger than the mean value from 8-inch blockout tests.

It is interesting also to note that working width deflections recorded from full-scale crash tests on systems with no use of blockouts have a calculated mean value of 40.40 in, which represents a decrement of 34.36% from the mean value with 12-inch blockout tests.

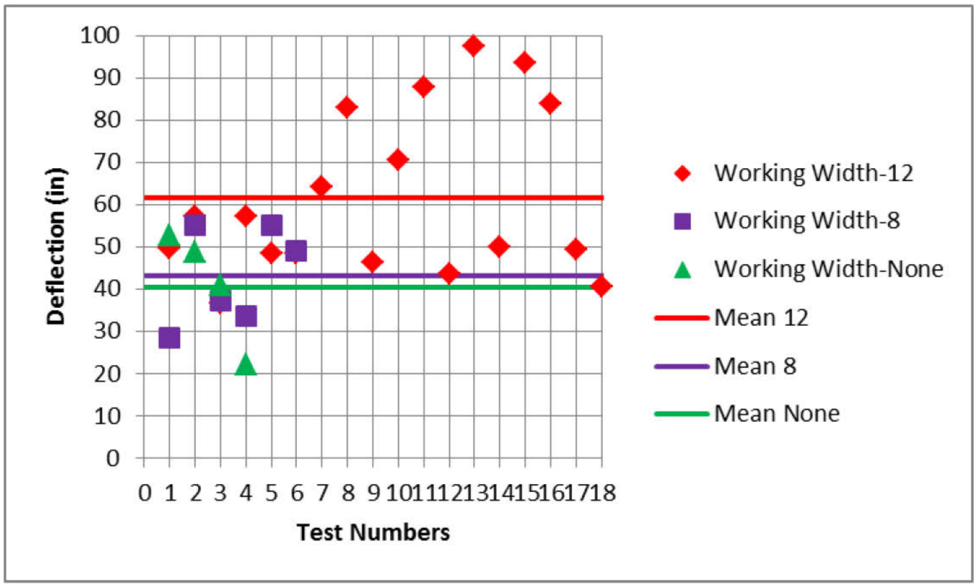


Figure 6.2. Working width and means for all tests.

6.2 Conclusions

Within this chapter, researchers have compared systems deflections (permanent and dynamic) and working widths recorded during full-scale crash tests with use of 12-inch, 8-inch and no blockouts. Researchers noticed that deflections and working width values can vary significantly among tests with use of same blockout depth due to the particular test installation configuration and by the actual impact conditions.

Although it was calculated that the mean values for permanent, dynamic deflections and working width from 12-inch blockout is approximately 23%, 33% and 43% bigger than the values from 8-inch blockout tests, it is opinion of the researchers that this difference does not depend on the type of blockouts used, but rather on the test installation configuration and the actual impact conditions.

Chapter 7 Analysis of Vehicle Interaction

Within this Chapter, results of a numerical evaluation of rail height variation during post rotation due to impact event is presented and compared to realistic rail behavior observed through film review of full-scale crash testing.

7.1 Rail Height Investigation

A numerical investigation of the rail height variation with respect to horizontal rail deflection due to post rotation during impact event is reported in Figure 7.1. This numerical evaluation was conducted for 31-inch guardrail height with use of both 8-inch and 12-inch blockout depths.

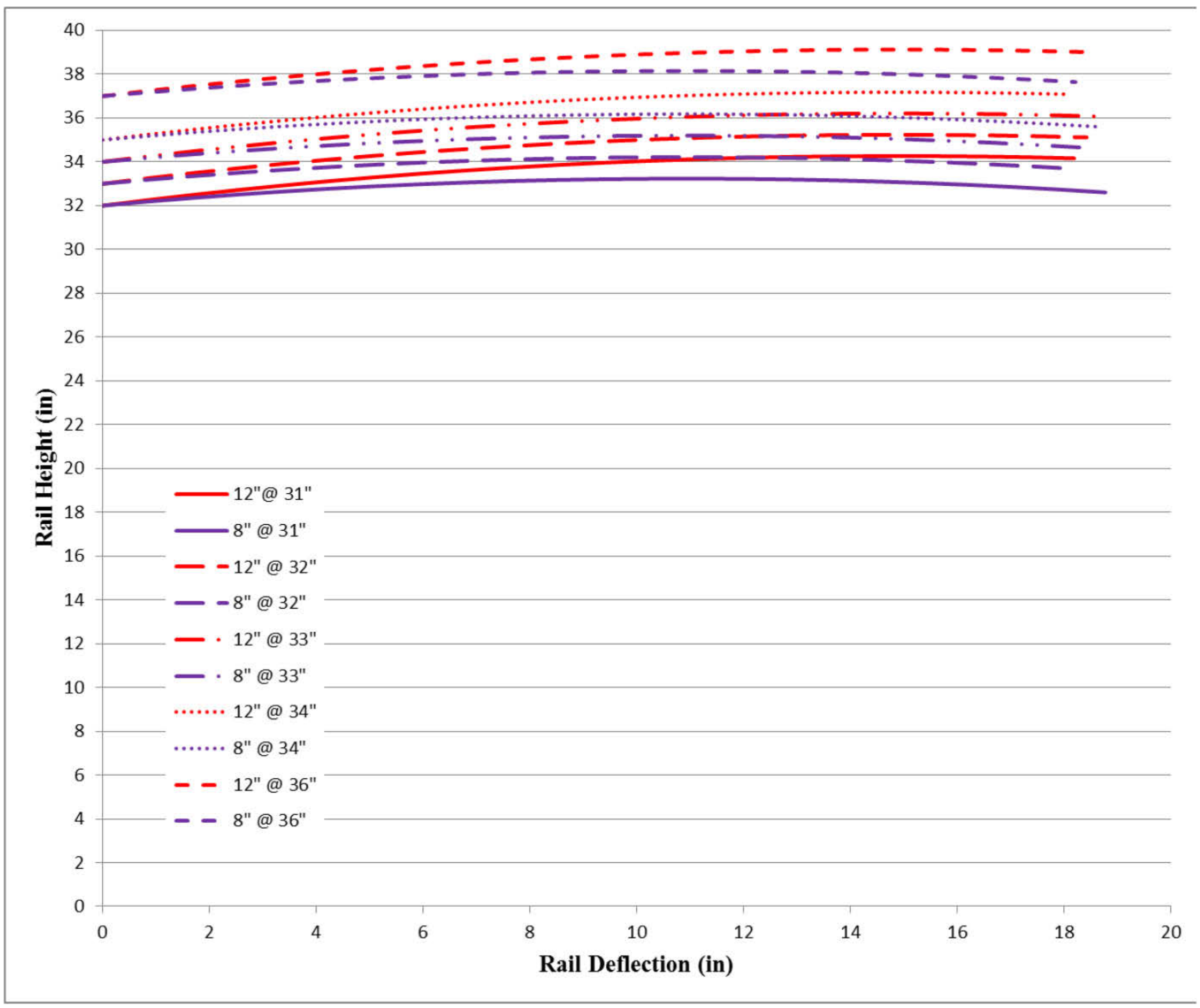


Figure 7.1. Analytical rail height variation with respect to horizontal rail deflection during post rotation.

Curves were terminated at18 inches of horizontal rail deflection, since it was observed that during full-scale crash tests the rail generally disengages from the blockout when a horizontal deflection of approximately 14 to18 inches is reached. Therefore, after this moment, rail displacement is independent from the post-blockout system behavior. The calculated geometrical maximum difference between the two curves representing rail height-deflection when using 8-inch and 12-inch blockouts is approximately 1 inch. In fact, the maximum height of the rail for a system with use of 8-inch and 12-inch blockouts resulted being 33.2 inches and 34.2 inches, respectively.

While these results were obtained through a theoretical analysis, rail behavior during real life impact scenarios can differ for various reasons. Researchers have reviewed multiple videos of full-scale crash tests against 31-inch guardrail with 8-inch and 12-inch blockouts to verify similarity or dissimilarity from the theoretical behavior reported above. In real life scenario, the rail remains attached and constrained to the posts until approximately the posts have reached a horizontal deflection of 14 to 18 inches during their rotation in soil. After that, the rail is released from the posts, so vertical displacement of the rail is not dictated by blockout size. Instead, it appears to be depending on the vehicle interaction with the rail system.

Researchers focused on reviewing rail behavior at locations downstream the impact event, at various instants. Figures 7.2 through 7.4 report pictures of examples of full-scale testing frames of 31-inch guardrail with use of 12-inch blockouts. Researchers came to the conclusion that during the post-blockout system rotation at location downstream the impact event, the rail did not undergo a significant vertical displacement in the first instant of the rotation. In other words, researchers did not observe the rail being “lifted up” by the blockout during the first phase of post rotation.

(a) Passenger car test. 2214MG-3-1

(b) Pickup truck test FR-4

Figure 7.2. Real-world rail behavior examples.

Researchers observed that the rail behavior and height change appear to depend on the vehicle-system interaction, instead.

FR-1 test FR-4 test

Figure 7.3. Commonly observed pickup truck-rail interaction.

2214MG-3-1 test 420020-5 test

Figure 7.4. Commonly observed passenger car-rail interaction.

7.2 Post-Blockout System and Vehicle Interaction

Researchers investigated post-blockout system and vehicle interaction for systems with use of 12-inch and 8-inch blockouts and compared the likelihood of snagging. Blockouts are used in guardrail systems to offset the rail from the posts, in order to limit the possibility of vehicle wheel's snagging on the post and, thus, maintaining acceptable occupant risks and vehicle angular displacements. Researchers decided to investigate whether an additional 4-inch offset allowed by 12-inch blockouts with respect to the use of 8-inch ones does, in fact, make a difference in terms of occupant safety and vehicle stability.

Angular displacements and occupant risks comparisons have been already presented in previous chapters of this report and researchers came up to the conclusion that there was no statistical significant difference between outcomes derived from full-scale crash tests with use of different blockout depth groups. Researchers, however, decided to carefully review video frames of previously performed crash test on 31-inch guardrail with use of 12-inch and 8-inch blockouts to investigate the interaction between the impacting front tire and the post-blockout system.

While it is important to include in this analysis also impacts with pickup trucks, generally the evaluation of roadside safety systems includes consideration of full-scale crash test involving a passenger car impacting the system. This is primarily a severity test that assesses risk of injury to the vehicle occupants. The test evaluates if a small passenger car can be successfully contained and redirected without excessive deceleration or unacceptable occupant compartment deformation. TTI performed a full-scale crash test to evaluate the performance of a 31-inch tall w-beam guardrail with standard 8-inch offset blocks according to *MASH* Test Level 3 impact conditions (11). The impact location was at a 38.0 inches upstream of a post. The test met all applicable evaluation criteria and the guardrail system was judged to comply with *MASH* guidelines. As a consequence of the impact event and the vehicle interaction with the post-blockout system, the impacting front tire and wheel rim were damaged and completely ripped off the vehicle (see Figure 7.5).

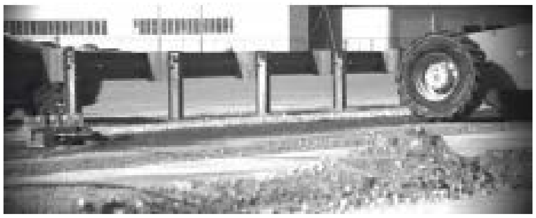
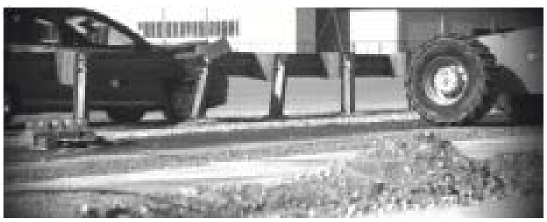
(a) Position of vehicle after test No. 420020-5

(b) Vehicle damage after test No. 420020-5

Figure 7.5. Small passenger car (a) position and (b) damage after test No. 420020-5 against 31-inch guardrail with standard offset blockouts (ref).

Researchers then compared vehicle-system interaction (Table 7.3), vehicle damage and test results of full scale crash test 420020-5 with outcomes from test 2214MG-3, which involved a passenger car impacting the MGS system (31-inch guardrail, mid-span splices, and 12-inch blockout depth).

Table 7.1. Post-Blockout System and Vehicle Interaction Examples for 12 and 8-inch blockouts.

2214MG-3 (12-inch blockout) (*13*)	**420020-5 Test (8-inch blockout) (*11*)**
 0.000 sec	 0.000 sec
 0.064 sec	 0.106 sec
 0.110 sec	 0.211 sec
 0.164 sec	 0.317 sec
 0.376 sec	 0.420 sec

For 2214MG-3, the actual impact location was 6-ft 11-in upstream from the center of the splice at the midspan between posts. Vehicle damage was concentrated on the impacting front corner of the vehicle. The impacting front wheel assembly deformed and crushed inward toward the engine compartment. Although the impacting front tire was pulled off the rim and deflated, the wheel rim, however, was not completely ripped off the vehicle. Table 7.1 compares impact velocities and ridedown accelerations derived from both tests. It can be noted that ridedown accelerations, lateral impact velocity and PHD obtained from test No. 420020-5 (MGS with use of 8-inch blockout) were all below or very similar to the values obtained from test no. 2214MG-3 (MGS with use of 12-inch blockout). Only the longitudinal impact velocity from test 420020-5 was higher than the recorded value from test 2214MG-3, although still very well below the preferred *MASH* limits.

Table 7.2. Comparison of occupant risk factors for tests 2214MG-3, 420020-5.

Test No.	**Impact Velocity (ft/s)**		**Ridedown Accelerations (g's)**		**THIV (ft/s)**	**PHD (g's)**
2214MG-3	Longit.	14.8	Longit.	16.14	23.8	16.20
	Lateral	17.1	Lateral	8.37		
420020-5	Longit.	21.0	Longit.	8.8	26.6	10.1
	Lateral	17.4	Lateral	6.8		
***MASH* Limits**	Longit.	< 29.5 (pref.)	Longit.	< 15 (pref.)		
	Lateral	< 29.5 (pref.)	Lateral	< 15 (pref.)		

Also, Table 7.2 reports comparison of maximum angular displacements roll and yaw for tests 2214MG-3 and 420040-5. It can be noted that roll angle obtained from test 420020-5 is very similar to the roll recorded from test 2214MG-3, and very well below *MASH* limit.

Table 7.3. Comparison of angular displacements for tests 2214MG-3, 420020-5, and *MASH* limits (*13*,*11*).

Test No.	Max Roll (degrees)	Max Yaw (degrees)
2214MG-3	~ -13	~ -28
420020-5	−16	49
***MASH* Limits**	< 75	N/A

Researchers believe that during a full-scale crash test, the failure of various components in the vehicle's suspensions limits the snagging force that the impacting vehicle experiences. Once these force limits are reached, front tire and wheel rim are generally damaged and completely ripped off the vehicle, but still maintaining occupant risk factors and the angular displacements well within the preferred limits (*11*).

7.3 Conclusions

Researchers came to the conclusion that during the post-blockout system rotation at location downstream the impact event, the rail did not undergo a significant vertical displacement in the first instant of the rotation. Researchers observed that the rail behavior and height change appear to depend on the vehicle-system interaction, instead. Moreover, the researchers believe that during a full-scale crash test, the failure of various components in the vehicle's suspensions limits the snagging force that the impacting vehicle experiences. Once these force limits are reached, front tire and wheel rim are generally damaged and completely ripped off the vehicle, but still maintaining occupant risk factors and the angular displacements well within the preferred limits (*11*).

Chapter 8 Summary and Conclusions

8.1 Summary and Conclusions

Full scale crash tests have been performed with use of a 31-inch guardrail with 12-inch blockouts and mid-span splices under a variety of impact conditions. Thus, the behavior of this test article has been fairly well documented. Certain DOTs prefer continued use of standard 8-inch blockouts to reduce inventory and simplify guardrail repair. It is the desire of some States to receive eligibility for use on the NHS for configurations of 31-inch guardrail with 8-inch blockouts for configurations initially tested with 12-inch blockouts.

The purpose of this research was to review and compare system performance and vehicle interaction in full-scale crash tests of 31-inch guardrail with 12-inch and 8-inch blockouts. The information compiled from this research will enable the Federal Highway Administration and State Departments of Transportation to decide whether use of 8-inch deep blockouts can be considered a crashworthy alternative for configurations initially tested with a 31-inch guardrail with 12-inch blockouts.

To compare performance of guardrail with 12-inch and 8-inch blockout depth, the researchers collected and analyzed data derived from full-scale crash tests and compared them with respect to vehicle angular displacements, occupant risk criteria, rail system deflection, working width, and vehicle interaction with the guardrail system through the impact event. Engineering analysis and judgment, detailed film analysis review, and statistical analysis was employed to adequately compare results derived from groups of 31-inch guardrail tests utilizing 12-inch and 8-inch blockout depths. Tests of 31-inch guardrail without blockouts were also included in the engineering analysis and comparison for a full and complete evaluation of the rail behavior under design impacts according to different offsets from posts.

Vehicle angular displacements (roll, pitch, and yaw) and occupant risk criteria (occupant impact velocity and ridedown acceleration) from groups of guardrail tests using 12-inch, 8-inch and no blockouts were compared by considering the relevant evaluation criteria used for performing the full-scale crash tests (*MASH* or *NCHRP Report 350*). First, researchers noticed that tests outcomes can vary among tests with the same blockout depth. Researchers explained this observation as an indication of vehicle stability and system redirection capacity, which can be influenced by the particular test installation configuration and by the actual impact conditions. In addition, researchers noticed that recorded tests results in some tests of 8-inch blockouts compared favorably to tests results obtained using 12-inch blockouts, and even with no blockouts. As for barrier deflection and working width, it is opinion of the researchers that any difference observed between tests is not related to the type of blockouts used, but rather on the test installation configuration and the actual impact conditions of the tests.

Moreover, researchers came to the conclusion that the rail behavior and height change does not depend on the blockout depth used in the system. Instead, it seems to be a function of the vehicle-system interaction. When the system is impacted by a pickup-truck, the rail tends to generate vehicle deformation between the impacting tire and fender. When the system is impacted by a passenger car, the rail tends to be pushed up, because of the engagement of the vehicle with the bottom of the rail.

Based on the research reported herein, it is opinion of the researchers that there is no significant difference between use of 12-inch and 8-inch blockouts in terms of vehicle stability, occupant risk, rail system deflection, and interaction between vehicle and guardrail system. Moreover, the researchers believe that during a full-scale crash test, the failure of the post and various components in the vehicle's suspension limit the snagging force that the impacting vehicle experiences. Once these force limits are reached, front tire and wheel rim are generally damaged and completely ripped off the vehicle, but still maintaining occupant risk factors and the angular displacements well within the preferred limits (*11*).

8.2 Implementation

Based on the research results reported herein, it is opinion of the researchers that there is no significant difference in the performance between MGS with 12-inch and 8-inch blockouts when impacted under the design impact conditions of *NCHRP Report 350* and *MASH*. Therefore, the researchers recommend that 8-inch deep blockouts be considered a crashworthy alternative for configurations initially tested with a 31-inch guardra.il with 12-inch blockouts and mid-span splices.

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APPENDIX A

Vehicle Interactions for Systems with 12-inch Blockouts

	Impact Configurations			Occupant Risk				Stability (°)			Pictures		
Test No.	Vehicle	Impact Speed (mph)	Impact Angle (mph)	Long Impact Velocity (ft/s)	Lat Impact Velocity (ft/s)	Long Ridedown Acceleration (g's)	Lat Ridedown Acceleration (g's)	Roll	Pitch	Yaw	Impact	Vehicle/System Interaction	Vehicle Damage
NPG-4	2000P	61	25.6	18.32	12.78	9.5	6.94	5	N/A	32			
NPG-5 (curb)	2000P	60	25.8	17.16	12.91	10.5	8.66	18	N/A	24			
NPG-6	2000P	60.1	25.6	25	18.42	10.67	8.97	5	N/A	45			
2214MG -1	2270P	62.6	25.2	17.06	14.8	8.77	5.34	38	8	26			

Figure A.1. Vehicle interaction for systems with 12-inch blockouts.

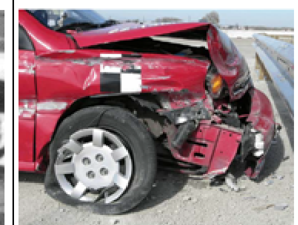
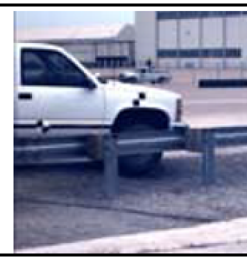
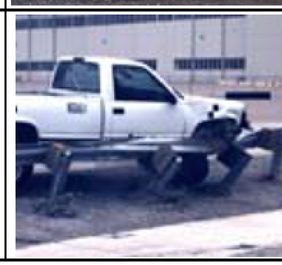
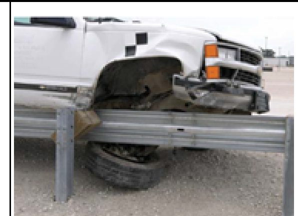
	Impact Configurations			Occupant Risk				Stability (°)			Pictures		
Test No.	Vehicle	Impact Speed (mph)	Impact Angle (mph)	Long Impact Velocity (ft/s)	Lat Impact Velocity (ft/s)	Long Ridedown Acceleration (g's)	Lat Ridedown Acceleration (g's)	Roll	Pitch	Yaw	Impact	Vehicle/System Interaction	Vehicle Damage
2214MG -2	2270P	62.8	25.5	15.32	15.62	8.23	6.93	5	2	45			
2214MG-3-1	1100C	60.8	25.4	14.83	17.13	16.14	8.37	Satisfactory					
MGS221-2 (2:1 Slope)	2270P	63.1	25.5	-13.9	13.61	-5.36	5.28	6	5	45			
MGSAS-1 (8:1 Slope)	2000P	62.4	25.9	-20.2	-11.25	-9.49	-6.43	38	8	26			

Figure A.1. Vehicle interaction for systems with 12-inch blockouts (continued).

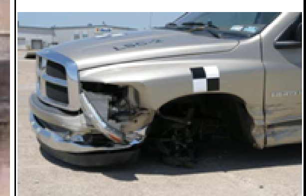
	Impact Configurations			Occupant Risk				Stability (°)			Pictures		
Test No.	Vehicle	Impact Speed (mph)	Impact Angle (mph)	Long Impact Velocity (ft/s)	Lat Impact Velocity (ft/s)	Long Ridedown Acceleration (g's)	Lat Ridedown Acceleration (g's)	Roll	Pitch	Yaw	Impact	Vehicle/System Interaction	Vehicle Damage
MGSAS-2 (8:1 Slope)	820C	61.69	21.6	-12.3	-17.42	-4.03	-9.65	11	3	29			
LSC-1 (Culvert)	2270P	62.5	24.8	-9.58	10.6	-6.48	5.91	10	3	35			
LSC-2 (Culvert)	2270P	61.9	24.9	-16.08	13.42	-7.34	4.24	11	7	57			
FR-1 (Flare)	2000P	64	30.6	21.36	13.52	8.08	10.41	14	4	39			

Figure A.1. Vehicle interaction for systems with 12-inch blockouts (continued).

	Impact Configurations			Occupant Risk				Stability (°)			Pictures		
Test No.	Vehicle	Impact Speed (mph)	Impact Angle (mph)	Long Impact Velocity (ft/s)	Lat Impact Velocity (ft/s)	Long Ridedown Acceleration (g's)	Lat Ridedown Acceleration (g's)	Roll	Pitch	Yaw	Impact	Vehicle/System Interaction	Vehicle Damage
FR-2 (Flare)	**2000P**	**63.1**	**34**	**24.18**	**13.55**	**9.92**	**7.16**	**15**	**2**	**37**			
FR-3 (Flare)	**820C**	**63.5**	**28.7**	21.82	17.78	8.2	9.7	**10**	**6**	**48**			
FR-4 (Flare)	**2000P**	**65.1**	**36.8**	**26.24**	**13.32**	**7.15**	**6.35**	**10**	**4**	**45**			
FR-5 (Flare)	**820C**	**59.3**	**31.8**	22.51	16.04	9.27	7.98	**20**	**N/A**	**30**			

Figure A.1. Vehicle interaction for systems with 12-inch blockouts (continued).

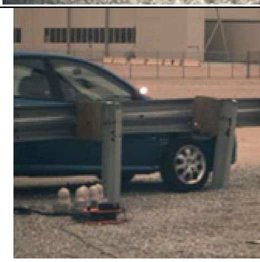
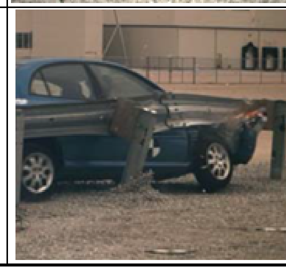
	Impact Configurations			Occupant Risk				Stability (°)			Pictures		
Test No.	Vehicle	Impact Speed (mph)	Impact Angle (mph)	Long Impact Velocity (ft/s)	Lat Impact Velocity (ft/s)	Long Ridedown Acceleration (g's)	Lat Ridedown Acceleration (g's)	Roll	Pitch	Yaw	Impact	Vehicle/System Interaction	Vehicle Damage
MGSMRH-1	1100C	63.6	25	15.84	19.03	8.41	9.19	11	5	37			
MGSMRH-2	1100C	64.1	21.9	17.44	18.87	9.27	8.64	11	2	45			

Figure A.1. Vehicle interaction for systems with 12-inch blockouts (continued).

APPENDIX B

Vehicle Interactions for Systems with 8-inch Blockouts

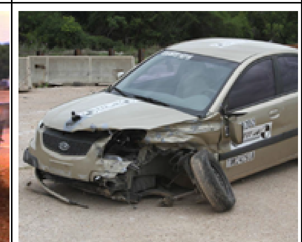
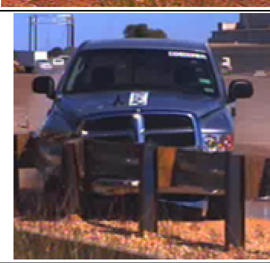
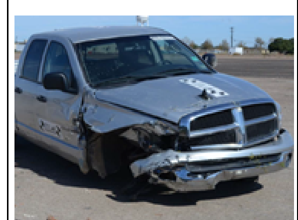
	Impact Configurations			Occupant Risk				Stability (°)			Pictures		
Test No.	Vehicle	Impact Speed (mph)	Impact Angle (mph)	Long Impact Velocity (ft/s)	Lat Impact Velocity (ft/s)	Long Ridedown Acceleration (g's)	Lat Ridedown Acceleration (g's)	Roll	Pitch	Yaw	Impact	Vehicle/System Interaction	Vehicle Damage
420020-5	1100C	60.4	25.6	21	17.4	8.8	6.8	16	11	49			
405160-20-1	2270P	63.9	25	15.1	15.4	9	6.9	13	3	34			
405160-20-2	1100C	60.3	25.9	17.4	16.1	7.3	6.8	7	5	38			
405160-23-2	2270P	62.9	26.1	15.4	14.4	5.3	6.4	9	11	37			

Figure B.1. Vehicle interaction for systems with 8-inch blockouts.

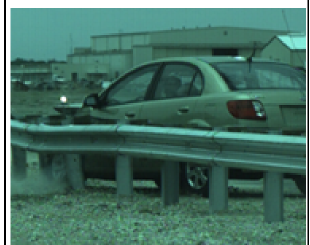
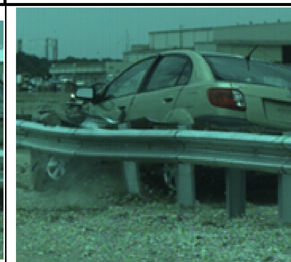
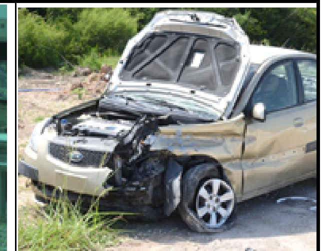
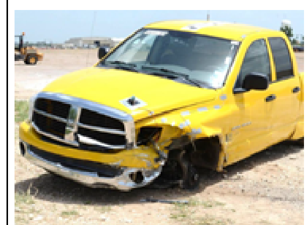
	Impact Configurations			Occupant Risk				Stability (°)			Pictures		
Test No.	Vehicle	Impact Speed (mph)	Impact Angle (mph)	Long Impact Velocity (ft/s)	Lat Impact Velocity (ft/s)	Long Ridedown Acceleration (g's)	Lat Ridedown Acceleration (g's)	Roll	Pitch	Yaw	Impact	Vehicle/System Interaction	Vehicle Damage
490023-3	1100C	62.2	25	20	17.4	9.6	8.3	11	9	36			
490023-4	2270P	63	25.4	19	15.1	10.2	6.9	12	11	47			

Figure B.1. Vehicle interaction for systems with 8-inch blockouts (continued).

APPENDIX C

Vehicle Interactions for Systems with No Blockouts

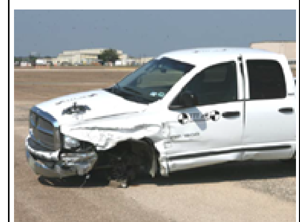
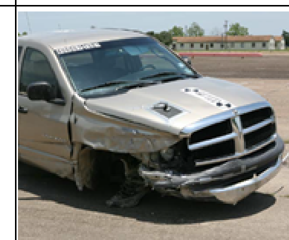
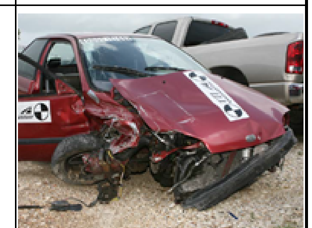
	Impact Configurations			Occupant Risk				Stability (°)			Pictures		
Test No.	Vehicle	Impact Speed (mph)	Impact Angle (mph)	Long Impact Velocity (ft/s)	Lat Impact Velocity (ft/s)	Long Ridedown Acceleration (g's)	Lat Ridedown Acceleration (g's)	Roll	Pitch	Yaw	Impact	Vehicle/System Interaction	Vehicle Damage
220570-4		63.4	20.3	21	19.03	12.9	7.6	7	3	35			
220570-11		62.3	24.4	29.2	1.31	11.1	3.2	40	19	31			
400001-TGS1		63.3	23.8	16.1	16.7	11.2	6.5	13	2	37			
400001-TGS2		61.1	19.7	28.2	17.7	12	7.7	13	6	26			

Figure C.1. Vehicle interaction for systems with no blockouts.

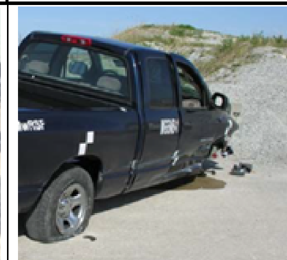
	Impact Configurations			Occupant Risk				Stability (°)			Pictures		
Test No.	Vehicle	Impact Speed (mph)	Impact Angle (mph)	Long Impact Velocity (ft/s)	Lat Impact Velocity (ft/s)	Long Ridedown Acceleration (g's)	Lat Ridedown Acceleration (g's)	Roll	Pitch	Yaw	Impact	Vehicle/System Interaction	Vehicle Damage
MGSNB-1		62.7	24.7	17.13	18.67	11.49	12.91	16	5.3	50.3			
MGSNB-2		63	25.5	31.26	15.83	10.2	6.3	8.3	3.98	14.2			

Figure C.1. Vehicle interaction for systems with no blockouts (continued).

APPENDIX D

ANOVA Values for Pickups, Passenger Cars, *MASH* Pickups, and *MASH* Passenger Cars

ANOVA Pickups:

Pickup					
Test	Blockout (in)	Long IV (ft/s)	Lat IV (ft/s)	Long RA (g's)	Lat RA (g's)
NPG-4	12	18.32	12.78	9.5	6.94
NPG-5	12	17.16	12.91	10.5	8.66
NPG-6	12	25	18.42	10.67	8.97
2214MG -1	12	17.06	14.8	8.77	5.34
2214MG -2	12	15.32	15.62	8.23	6.93
MGS221-2	12	13.9	13.61	5.36	5.28
MGSAS-1	12	20.2	11.25	9.49	6.43
FR-1	12	21.36	13.52	8.08	10.41
FR-2	12	24.18	13.55	9.92	7.16
FR-4	12	26.24	13.32	7.15	6.35
LSC-1	12	9.58	10.6	6.48	5.91
LSC-2	12	16.08	13.42	7.34	4.24
405160-20-1	8	15.1	15.4	9	6.9
405160-23-2	8	15.4	14.4	5.3	6.4
490023-3	8	20	17.4	9.6	8.3
400001-TGS1	none	16.1	16.7	11.2	6.5
220570-11	none	29.2	1.31	11.1	3.2
MGSNB-1	none	17.13	18.67	11.49	12.91

Longitudinal Impact Velocity (all):

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Column 1	13	239.29	18.40692	23.25049
Column 2	3	50.5	16.83333	7.543333
Column 3	2	45.3	22.65	85.805

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	42.64828	2	21.32414	0.841969	0.450241	3.68232
Within Groups	379.8975	15	25.3265			
Total	422.5458	17				

Longitudinal Impact Velocity (12" vs. 8"):

Anova: Single Factor

SUMMARY

Groups	Count	Sum	Average	Variance
Column 1	13	239.29	18.40692	23.25049
Column 2	3	50.5	16.83333	7.543333

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	6.0357	1	6.0357	0.287324	0.600354	4.60011
Within Groups	294.0925	14	21.00661			
Total	300.1282	15				

Longitudinal Impact Velocity (12" vs. 0"):

Anova: Single Factor

SUMMARY

Groups	Count	Sum	Average	Variance
Column 1	13	239.29	18.40692	23.25049
Column 2	2	45.3	22.65	85.805

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	31.20642	1	31.20642	1.112038	0.310845	4.667193
Within Groups	364.8109	13	28.06238			
Total	396.0173	14				

Longitudinal Impact Velocity (8" vs. 0"):

Anova: Single Factor

SUMMARY

Groups	Count	Sum	Average	Variance
Column 1	3	50.5	16.83333	7.543333
Column 2	2	45.3	22.65	85.805

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	40.60033	1	40.60033	1.207245	0.352151	10.12796
Within Groups	100.8917	3	33.63056			
Total	141.492	4				

Lateral Impact Velocity (all):

Anova: Single Factor

SUMMARY

Groups	Count	Sum	Average	Variance
Column 1	13	176.15	13.55	3.839467
Column 2	3	47.2	15.73333	2.333333
Column 3	2	18.01	9.005	118.4261

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	55.25646	2	27.62823	2.449799	0.120047	3.68232
Within Groups	169.1663	15	11.27775			
Total	224.4228	17				

Lateral Impact Velocity (12" vs. 8"):

Anova: Single Factor

SUMMARY

Groups	Count	Sum	Average	Variance
Column 1	13	176.15	13.55	3.839467
Column 2	3	47.2	15.73333	2.333333

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	11.61943	1	11.61943	3.205974	0.095011	4.60011
Within Groups	50.74027	14	3.624305			
Total	62.35969	15				

Lateral Impact Velocity (12" vs. 0"):

Anova: Single Factor

SUMMARY

Groups	Count	Sum	Average	Variance
Column 1	13	176.15	13.55	3.839467
Column 2	2	18.01	9.005	118.4261

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	35.80551	1	35.80551	2.829621	0.11639	4.667193
Within Groups	164.4997	13	12.65382			
Total	200.3052	14				

Lateral Impact Velocity (8" vs. 0"):

Anova: Single
Factor

SUMMARY

Groups	Count	Sum	Average	Variance
Column 1	3	47.2	15.73333	2.333333
Column 2	2	18.01	9.005	118.4261

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	54.32456	1	54.32456	1.323991	0.333272	10.12796
Within Groups	123.0927	3	41.03091			
Total	177.4173	4				

Longitudinal Ridedown Acceleration (all):

Anova: Single
Factor

SUMMARY

Groups	Count	Sum	Average	Variance
Column 1	13	114.98	8.844615	4.45766
Column 2	3	23.9	7.966667	5.423333
Column 3	2	22.3	11.15	0.005

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	12.72485	2	6.362427	1.483231	0.258354	3.68232
Within Groups	64.34359	15	4.289573			
Total	77.06844	17				

Longitudinal Ridedown Acceleration (12" vs. 8"):

Anova: Single
Factor

SUMMARY

Groups	Count	Sum	Average	Variance
Column 1	13	114.98	8.844615	4.45766
Column 2	3	23.9	7.966667	5.423333

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	1.87881	1	1.87881	0.408827	0.532889	4.60011
Within Groups	64.33859	14	4.595614			
Total	66.2174	15				

Longitudinal Ridedown Acceleration (12" vs. 0"):

Anova: Single
Factor

SUMMARY

Groups	Count	Sum	Average	Variance
Column 1	13	114.98	8.844615	4.45766
Column 2	2	22.3	11.15	0.005

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	9.212317	1	9.212317	2.238636	0.158478	4.667193
Within Groups	53.49692	13	4.115148			
Total	62.70924	14				

Longitudinal Ridedown Acceleration (8" vs. 0"):

Anova: Single Factor

SUMMARY

Groups	Count	Sum	Average	Variance
Column 1	3	23.9	7.966667	5.423333
Column 2	2	22.3	11.15	0.005

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	12.16033	1	12.16033	3.361788	0.164094	10.12796
Within Groups	10.85167	3	3.617222			
Total	23.012	4				

Lateral Ridedown Acceleration (all):

Anova: Single Factor

SUMMARY

Groups	Count	Sum	Average	Variance
Column 1	13	97.75	7.519231	8.013158
Column 2	3	21.6	7.2	0.97
Column 3	2	9.7	4.85	5.445

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	12.353	2	6.176501	0.894774	0.429429	3.68232
Within Groups	103.5429	15	6.902859			
Total	115.8959	17				

Lateral Ridedown Acceleration (12" vs. 8"):

Anova: Single Factor

SUMMARY

Groups	Count	Sum	Average	Variance
Column 1	13	97.75	7.519231	8.013158
Column 2	3	21.6	7.2	0.97

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	0.248401	1	0.248401	0.035451	0.853357	4.60011
Within Groups	98.09789	14	7.006992			
Total	98.34629	15				

Lateral Ridedown Acceleration (12" vs. 0"):

Anova: Single Factor

SUMMARY

Groups	Count	Sum	Average	Variance
Column 1	13	97.75	7.519231	8.013158
Column 2	2	9.7	4.85	5.445

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	12.34964	1	12.34964	1.580126	0.230858	4.667193
Within Groups	101.6029	13	7.815607			
Total	113.9525	14				

Lateral Ridedown Acceleration (8" vs. 0"):

Anova: Single Factor

SUMMARY

Groups	Count	Sum	Average	Variance
Column 1	3	21.6	7.2	0.97
Column 2	2	9.7	4.85	5.445

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	6.627	1	6.627	2.692079	0.199384	10.12796
Within Groups	7.385	3	2.461667			
Total	14.012	4				

ANOVA *MASH* Pickup:

MASH Pickup					
Test	Blockout (in)	Long IV (ft/s)	Lat IV (ft/s)	Long RA (g's)	Lat RA (g's)
2214MG -1	12	17.06	14.8	8.77	5.34
2214MG -2	12	15.32	15.62	8.23	6.93
MGS221-2	12	13.9	13.61	5.36	5.28
LSC-1	12	9.58	10.6	6.48	5.91
LSC-2	12	16.08	13.42	7.34	4.24
405160-20-1	8	15.1	15.4	9	6.9
405160-23-2	8	15.4	14.4	5.3	6.4
490023-3	8	20	17.4	9.6	8.3
400001-TGS1	none	16.1	16.7	11.2	6.5
220570-11	none	29.2	1.31	11.1	3.2
MGSNB-1	none	17.13	18.67	11.49	12.91

Longitudinal Impact Velocity (all):

Anova: Single Factor

SUMMARY

Groups	Count	Sum	Average	Variance
Column 1	6	86.83	14.47167	6.887217
Column 2	3	50.5	16.83333	7.543333
Column 3	3	62.43	20.81	53.0593

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	80.48832	2	40.24416	2.327129	0.153245	4.256495
Within Groups	155.6414	9	17.29348			
Total	236.1297	11				

Longitudinal Impact Velocity (12" vs. 8"):

Anova: Single Factor

SUMMARY

Groups	Count	Sum	Average	Variance
Column 1	6	86.83	14.47167	6.887217
Column 2	3	50.5	16.83333	7.543333

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	11.15494	1	11.15494	1.576741	0.24952	5.591448
Within Groups	49.52275	7	7.074679			
Total	60.67769	8				

Longitudinal Impact Velocity (12" vs. 0"):

Anova: Single Factor

SUMMARY

Groups	Count	Sum	Average	Variance
Column 1	6	86.83	14.47167	6.887217
Column 2	3	62.43	20.81	53.0593

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	80.34894	1	80.34894	4.001593	0.085569	5.591448
Within Groups	140.5547	7	20.07924			
Total	220.9036	8				

Longitudinal Impact Velocity (8" vs. 0"):

Anova: Single Factor

SUMMARY

Groups	Count	Sum	Average	Variance
Column 1	3	50.5	16.83333	7.543333
Column 2	3	62.43	20.81	53.0593

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	23.72082	1	23.72082	0.782831	0.426257	7.708647
Within Groups	121.2053	4	30.30132			
Total	144.9261	5				

Lateral Impact Velocity (all):

Anova: Single Factor

SUMMARY

Groups	Count	Sum	Average	Variance
Column 1	6	80.4	13.4	3.17508
Column 2	3	47.2	15.73333	2.333333
Column 3	3	36.68	12.22667	90.35043

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	19.45427	2	9.727133	0.435018	0.660172	4.256495
Within Groups	201.2429	9	22.36033			
Total	220.6972	11				

Lateral Impact Velocity (12" vs. 8"):

Anova: Single Factor

SUMMARY

Groups	Count	Sum	Average	Variance
Column 1	6	80.4	13.4	3.17508
Column 2	3	47.2	15.73333	2.333333

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	10.88889	1	10.88889	3.710543	0.095444	5.591448
Within Groups	20.54207	7	2.934581			
Total	31.43096	8				

Lateral Impact Velocity (12" vs. 0"):

Anova: Single Factor

SUMMARY

Groups	Count	Sum	Average	Variance
Column 1	6	80.4	13.4	3.17508
Column 2	3	36.68	12.22667	90.35043

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	2.753422	1	2.753422	0.098048	0.763308	5.591448
Within Groups	196.5763	7	28.08232			
Total	199.3297	8				

Lateral Impact Velocity (8" vs. 0"):

Anova: Single Factor

SUMMARY

Groups	Count	Sum	Average	Variance
Column 1	3	47.2	15.73333	2.333333
Column 2	3	36.68	12.22667	90.35043

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	18.44507	1	18.44507	0.398022	0.562364	7.708647
Within Groups	185.3675	4	46.34188			
Total	203.8126	5				

Longitudinal Ridedown Acceleration (all):

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Column 1	6	49.67	8.278333	8.007337
Column 2	3	23.9	7.966667	5.423333
Column 3	3	33.79	11.26333	0.041033

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	21.66205	2	10.83103	1.912654	0.203136	4.256495
Within Groups	50.96542	9	5.662824			
Total	72.62747	11				

Longitudinal Ridedown Acceleration (12" vs. 8"):

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Column 1	6	49.67	8.278333	8.007337
Column 2	3	23.9	7.966667	5.423333

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.194272	1	0.194272	0.026726	0.87476	5.591448
Within Groups	50.88335	7	7.26905			
Total	51.07762	8				

Longitudinal Ridedown Acceleration (12" vs. 0"):

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Column 1	6	49.67	8.278333	8.007337
Column 2	3	33.79	11.26333	0.041033

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	17.82045	1	17.82045	3.109348	0.121211	5.591448
Within Groups	40.11875	7	5.73125			
Total	57.9392	8				

Longitudinal Ridedown Acceleration (8" vs. 0"):

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Column 1	3	23.9	7.966667	5.423333
Column 2	3	33.79	11.26333	0.041033

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	16.30202	1	16.30202	5.966663	0.071003	7.708647
Within Groups	10.92873	4	2.732183			
Total	27.23075	5				

Lateral Ridedown Acceleration (all):

Anova: Single Factor

SUMMARY

Groups	Count	Sum	Average	Variance
Column 1	6	42.83	7.138333	16.10134
Column 2	3	21.6	7.2	0.97
Column 3	3	22.61	7.536667	24.37703

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	0.328717	2	0.164358	0.011275	0.988803	4.256495
Within Groups	131.2008	9	14.57786			
Total	131.5295	11				

Lateral Ridedown Acceleration (12" vs. 8"):

Anova: Single Factor

SUMMARY

Groups	Count	Sum	Average	Variance
Column 1	6	42.83	7.138333	16.10134
Column 2	3	21.6	7.2	0.97

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	0.007606	1	0.007606	0.000646	0.980436	5.591448
Within Groups	82.44668	7	11.7781			
Total	82.45429	8				

Lateral Ridedown Acceleration (12" vs. 0"):

Anova: Single Factor

SUMMARY

Groups	Count	Sum	Average	Variance
Column 1	6	42.83	7.138333	16.10134
Column 2	3	22.61	7.536667	24.37703

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	0.317339	1	0.317339	0.017185	0.89939	5.591448
Within Groups	129.2608	7	18.46582			
Total	129.5781	8				

Lateral Ridedown Acceleration (8" vs. 0"):

Anova: Single Factor

SUMMARY

Groups	Count	Sum	Average	Variance
Column 1	3	21.6	7.2	0.97
Column 2	3	22.61	7.536667	24.37703

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	0.170017	1	0.170017	0.013415	0.913374	7.708647
Within Groups	50.69407	4	12.67352			
Total	50.86408	5				

ANOVA Passenger Car:

Passenger Car					
Test	Blockout (in)	Long IV (ft/s)	Lat IV (ft/s)	Long RA (g's)	Lat RA (g's)
2214MG-3-1	12	14.83	17.13	16.14	8.37
MGSAS-2	12	12.3	17.42	4.03	9.65
FR-3	12	21.82	17.78	8.2	9.7
FR-5	12	22.51	16.04	9.27	7.98
MGSMRH-1	12	15.84	19.03	8.41	9.19
MGSMRH-2	12	17.44	18.87	9.27	8.64
420020-5	8	21	17.4	8.8	6.8
405160-20-2	8	17.4	16.1	7.3	6.8
490023-3	8	20	17.4	9.6	8.3
220570-4	none	21	19.03	12.9	7.6
400001-TGS2	none	28.2	17.7	12	7.7
MGSNB-2	none	17.13	18.67	11.49	12.91

Longitudinal Impact Velocity (all):

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Column 1	6	104.74	17.45667	16.13587
Column 2	3	58.4	19.46667	3.453333
Column 3	3	66.33	22.11	31.5603

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	43.78083	2	21.89041	1.307267	0.317383	4.256495
Within Groups	150.7066	9	16.74518			
Total	194.4874	11				

Longitudinal Impact Velocity (12" vs. 8"):

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Column 1	6	104.74	17.45667	16.13587
Column 2	3	58.4	19.46667	3.453333

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	8.0802	1	8.0802	0.645781	0.448049	5.591448
Within Groups	87.586	7	12.51229			
Total	95.6662	8				

Longitudinal Impact Velocity (12" vs. 0"):

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Column 1	6	104.74	17.45667	16.13587
Column 2	4	66.33	16.5825	143.2532

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	1.834002	1	1.834002	0.028744	0.86958	5.317655
Within Groups	510.439	8	63.80488			
Total	512.273	9				

Longitudinal Impact Velocity (8" vs. 0"):

Anova: Single Factor

SUMMARY

Groups	Count	Sum	Average	Variance
Column 1	3	58.4	19.46667	3.453333
Column 2	3	66.33	22.11	31.5603

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	10.48082	1	10.48082	0.598671	0.482272	7.708647
Within Groups	70.02727	4	17.50682			
Total	80.50808	5				

Lateral Impact Velocity (all):

Anova: Single Factor

SUMMARY

Groups	Count	Sum	Average	Variance
Column 1	6	106.27	17.71167	1.260457
Column 2	3	50.9	16.96667	0.563333
Column 3	3	55.4	18.46667	0.473233

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	3.375075	2	1.687538	1.813383	0.21791	4.256495
Within Groups	8.375417	9	0.930602			
Total	11.75049	11				

Lateral Impact Velocity (12" vs. 8"):

Anova: Single Factor

SUMMARY

Groups	Count	Sum	Average	Variance
Column 1	6	106.27	17.71167	1.260457
Column 2	3	50.9	16.96667	0.563333

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	1.11005	1	1.11005	1.045955	0.340478	5.591448
Within Groups	7.42895	7	1.061279			
Total	8.539	8				

Lateral Impact Velocity (12" vs. 0"):

Anova: Single Factor

SUMMARY

Groups	Count	Sum	Average	Variance
Column 1	6	106.27	17.71167	1.260457
Column 2	3	55.4	18.46667	0.473233

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	1.14005	1	1.14005	1.100928	0.328932	5.591448
Within Groups	7.24875	7	1.035536			
Total	8.3888	8				

Lateral Impact Velocity (8" vs. 0"):

Anova: Single Factor

SUMMARY

Groups	Count	Sum	Average	Variance
Column 1	3	50.9	16.96667	0.563333
Column 2	3	55.4	18.46667	0.473233

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	3.375	1	3.375	6.511882	0.063182	7.708647
Within Groups	2.073133	4	0.518283			
Total	5.448133	5				

Longitudinal Ridedown Acceleration (all):

Anova: Single Factor

SUMMARY

Groups	Count	Sum	Average	Variance
Column 1	6	55.32	9.22	15.3048
Column 2	3	25.7	8.566667	1.363333
Column 3	3	36.39	12.13	0.5097

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	22.86543	2	11.43271	1.281853	0.323709	4.256495
Within Groups	80.27007	9	8.918896			
Total	103.1355	11				

Longitudinal Ridedown Acceleration (12" vs. 8"):

Anova: Single Factor

SUMMARY

Groups	Count	Sum	Average	Variance
Column 1	6	55.32	9.22	15.3048
Column 2	3	25.7	8.566667	1.363333

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	0.853689	1	0.853689	0.075404	0.791553	5.591448
Within Groups	79.25067	7	11.32152			
Total	80.10436	8				

Longitudinal Ridedown Acceleration (12" vs. 0"):

Anova: Single Factor

SUMMARY

Groups	Count	Sum	Average	Variance
Column 1	6	55.32	9.22	15.3048
Column 2	3	36.39	12.13	0.5097

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	16.9362	1	16.9362	1.528865	0.256157	5.591448
Within Groups	77.5434	7	11.07763			
Total	94.4796	8				

Longitudinal Ridedown Acceleration (8" vs. 0"):

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Column 1	3	25.7	8.566667	1.363333
Column 2	3	36.39	12.13	0.5097

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	19.04602	1	19.04602	20.33708	0.010743	7.708647
Within Groups	3.746067	4	0.936517			
Total	22.79208	5				

Lateral Ridedown Acceleration (all):

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Column 1	6	53.53	8.921667	0.495737
Column 2	3	21.9	7.3	0.75
Column 3	3	28.21	9.403333	9.225033

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	7.610717	2	3.805358	1.526979	0.268539	4.256495
Within Groups	22.42875	9	2.492083			
Total	30.03947	11				

Lateral Ridedown Acceleration (12" vs. 8"):

Anova: Single Factor

SUMMARY

Groups	Count	Sum	Average	Variance
Column 1	6	53.53	8.921667	0.495737
Column 2	3	21.9	7.3	0.75

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	5.259606	1	5.259606	9.253624	0.018794	5.591448
Within Groups	3.978683	7	0.568383			
Total	9.238289	8				

Lateral Ridedown Acceleration (12" vs. 0"):

Anova: Single Factor

SUMMARY

Groups	Count	Sum	Average	Variance
Column 1	6	53.53	8.921667	0.495737
Column 2	3	28.21	9.403333	9.225033

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	0.464006	1	0.464006	0.155195	0.705345	5.591448
Within Groups	20.92875	7	2.989821			
Total	21.39276	8				

Lateral Ridedown Acceleration (8" vs. 0"):

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Column 1	3	21.9	7.3	0.75
Column 2	3	28.21	9.403333	9.225033

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	6.636017	1	6.636017	1.330525	0.312945	7.708647
Within Groups	19.95007	4	4.987517			
Total	26.58608	5				

ANOVA *MASH* Passenger Car:

MASH Passenger Car					
Test	Blockout (in)	Long IV (ft/s)	Lat IV (ft/s)	Long RA (g's)	Lat RA (g's)
2214MG-3-1	12	14.83	17.13	16.14	8.37
MGSMRH-1	12	15.84	19.03	8.41	9.19
MGSMRH-2	12	17.44	18.87	9.27	8.64
420020-5	8	21	17.4	8.8	6.8
405160-20-2	8	17.4	16.1	7.3	6.8
490023-3	8	20	17.4	9.6	8.3
MGSNB-2	none	31.26	15.83	10.2	6.3

Longitudinal Impact Velocity (all):

Anova: Single Factor

SUMMARY

Groups	Count	Sum	Average	Variance
Column 1	3	48.11	16.03667	1.732033
Column 2	3	58.4	19.46667	3.453333
Column 3	1	31.26	31.26	#DIV/0!

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	174.0546	2	87.02728	33.56649	0.003162	6.944272
Within Groups	10.37073	4	2.592683			
Total	184.4253	6				

Longitudinal Impact Velocity (12" vs. 8"):

Anova: Single Factor

SUMMARY

Groups	Count	Sum	Average	Variance
Column 1	3	48.11	16.03667	1.732033
Column 2	3	58.4	19.46667	3.453333

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	17.64735	1	17.64735	6.806597	0.059486	7.708647
Within Groups	10.37073	4	2.592683			
Total	28.01808	5				

Longitudinal Impact Velocity (12" vs. 0"):

Anova: Single Factor

SUMMARY

Groups	Count	Sum	Average	Variance
Column 1	3	48.11	16.03667	1.732033
Column 2	1	31.26	31.26	#DIV/0!

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	173.8124	1	173.8124	100.3517	0.009818	18.51282
Within Groups	3.464067	2	1.732033			
Total	177.2765	3				

Longitudinal Impact Velocity (8" vs. 0"):

Anova: Single Factor

SUMMARY

Groups	Count	Sum	Average	Variance
Column 1	3	58.4	19.46667	3.453333
Column 2	1	31.26	31.26	#DIV/0!

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	104.312	1	104.312	30.20619	0.031548	18.51282
Within Groups	6.906667	2	3.453333			
Total	111.2187	3				

Lateral Impact Velocity (all):

Anova: Single Factor

SUMMARY

Groups	Count	Sum	Average	Variance
Column 1	3	55.03	18.34333	1.110533
Column 2	3	50.9	16.96667	0.563333
Column 3	1	15.83	15.83	#DIV/0!

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	5.697638	2	2.848819	3.403878	0.136977	6.944272
Within Groups	3.347733	4	0.836933			
Total	9.045371	6				

Lateral Impact Velocity (12" vs. 8"):

Anova: Single Factor

SUMMARY

Groups	Count	Sum	Average	Variance
Column 1	3	55.03	18.34333	1.110533
Column 2	3	50.9	16.96667	0.563333

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	2.842817	1	2.842817	3.396706	0.139111	7.708647
Within Groups	3.347733	4	0.836933			
Total	6.19055	5				

Lateral Impact Velocity (12" vs. 0"):

Anova: Single Factor

SUMMARY

Groups	Count	Sum	Average	Variance
Column 1	3	55.03	18.34333	1.110533
Column 2	1	15.83	15.83	#DIV/0!

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	4.737633	1	4.737633	4.266088	0.174881	18.51282
Within Groups	2.221067	2	1.110533			
Total	6.9587	3				

Lateral Impact Velocity (8" vs. 0"):

Anova: Single Factor

SUMMARY

Groups	Count	Sum	Average	Variance
Column 1	3	50.9	16.96667	0.563333
Column 2	1	15.83	15.83	#DIV/0!

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	0.969008	1	0.969008	1.720133	0.320011	18.51282
Within Groups	1.126667	2	0.563333			
Total	2.095675	3				

Longitudinal Ridedown Acceleration (all):

Anova: Single Factor

SUMMARY

Groups	Count	Sum	Average	Variance
Column 1	3	33.82	11.27333	17.94823
Column 2	3	25.7	8.566667	1.363333
Column 3	1	10.2	10.2	#DIV/0!

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	11.05627	2	5.528133	0.57252	0.604425	6.944272
Within Groups	38.62313	4	9.655783			
Total	49.6794	6				

Longitudinal Ridedown Acceleration (12" vs. 8"):

Anova: Single Factor

SUMMARY

Groups	Count	Sum	Average	Variance
Column 1	3	33.82	11.27333	17.94823
Column 2	3	25.7	8.566667	1.363333

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	10.98907	1	10.98907	1.138081	0.346167	7.708647
Within Groups	38.62313	4	9.655783			
Total	49.6122	5				

Longitudinal Ridedown Acceleration (12" vs. 0"):

Anova: Single Factor

SUMMARY

Groups	Count	Sum	Average	Variance
Column 1	3	33.82	11.27333	17.94823
Column 2	1	10.2	10.2	#DIV/0!

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	0.864033	1	0.864033	0.04814	0.846689	18.51282
Within Groups	35.89647	2	17.94823			
Total	36.7605	3				

Longitudinal Ridedown Acceleration (8" vs. 0"):

Anova: Single Factor

SUMMARY

Groups	Count	Sum	Average	Variance
Column 1	3	25.7	8.566667	1.363333
Column 2	1	10.2	10.2	#DIV/0!

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	2.000833	1	2.000833	1.467604	0.349437	18.51282
Within Groups	2.726667	2	1.363333			
Total	4.7275	3				

Lateral Ridedown Acceleration (all):

Anova: Single Factor

SUMMARY

Groups	Count	Sum	Average	Variance
Column 1	3	26.2	8.733333	0.174633
Column 2	3	21.9	7.3	0.75
Column 3	1	6.3	6.3	#DIV/0!

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	5.607619	2	2.80381	6.064695	0.061501	6.944272
Within Groups	1.849267	4	0.462317			
Total	7.456886	6				

Lateral Ridedown Acceleration (12" vs. 8"):

Anova: Single Factor

SUMMARY

Groups	Count	Sum	Average	Variance
Column 1	3	26.2	8.733333	0.174633
Column 2	3	21.9	7.3	0.75

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	3.081667	1	3.081667	6.665705	0.061211	7.708647
Within Groups	1.849267	4	0.462317			
Total	4.930933	5				

Lateral Ridedown Acceleration (12" vs. 0"):

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Column 1	3	26.2	8.733333	0.174633
Column 2	1	6.3	6.3	#DIV/0!

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	4.440833	1	4.440833	25.42947	0.037147	18.51282
Within Groups	0.349267	2	0.174633			
Total	4.7901	3				

Lateral Ridedown Acceleration (8" vs. 0"):

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Column 1	3	21.9	7.3	0.75
Column 2	1	6.3	6.3	#DIV/0!

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.75	1	0.75	1	0.42265	18.51282
Within Groups	1.5	2	0.75			
Total	2.25	3				