

Safety Belt Buckle Environment in Vehicle Rollover Crash Tests

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ABSTRACT

A study was conducted by General Motors (GM) to further expand upon the currently available research regarding the safety belt buckle environment during full scale vehicle crash tests. A previous study by GM [1] focused on the environment experienced by safety belt buckles in planar, non-rollover, vehicle crash conditions. This study expands upon that work by measuring buckle acceleration and webbing tension in a variety of full scale vehicle rollover crash tests. A variety of test vehicles, rollover crash types, seating positions, roll directions, test speeds, and safety belt systems were included in the study. Emphasis was placed on examination of the buckle response data during vehicle-to-ground impacts (roof, body, and wheel).

This study reports on data recorded from 20 full scale rollover crash tests with 40 instrumented end release safety belt buckles. Crash tests in this study were limited to rollover tests involving un-tethered vehicles where at least one-quarter turn or more occurred. Acceleration measurements were made using tri-axial accelerometers mounted onto the buckles. The accelerations were recorded in the axial, lateral, and perpendicular axes relative to the buckle. Belt webbing tension was also measured with load cells mounted on the lap and shoulder webbing.

The data summarized in this study characterizes the environment for safety belt buckles during a variety of full scale vehicle rollover crash test conditions. In the 20 vehicle rollover crash tests included in this study, there were no buckle to latch plate separations.

INTRODUCTION

The potential for safety belt buckles to release due to inertial forces has been studied since the 1960's. Numerous studies have examined the inertial characteristics of both side and end release safety belt buckles and have concluded that inertial release in the field if it ever occurs, is very rare. These studies consistently recognized the need for additional understanding of a wider variety of vehicle level crash environments and buckle responses.

A comprehensive study of the environment experienced by buckles in full scale vehicle testing was reported in 2008 by Haldenwanger et al [1]. That study reported buckle response data that characterized the environment for safety belt buckles during a variety of standardized full scale vehicle planar crash test conditions. One hundred vehicle crash tests were included, and there were no buckle to latch plate separations. The authors concluded that the conditions that may result in an inertial unlatch have been, and continue to be, well understood (acceleration magnitude, acceleration direction, acceleration duration, and webbing tension) and that automotive safety belt buckles are effectively designed to be resistant to inertial release. Automotive safety belt buckles are designed to operate properly in the intended vehicle environment without an unreasonable real-world risk of buckle release due to inertial forces.

Despite the findings of Haldenwanger et al and other studies, litigation based allegations of buckle inertial releases in the field continue, especially when associated with rollover crashes where limited published data exists regarding measured buckle responses. Some notable published studies that provide insight into buckle responses during rollover crashes are discussed below.

In 1990 Bahling et al [2] published the results a series of dolly rollover tests of Chevrolet Malibu vehicles utilizing side release buckles. Although buckle acceleration was not recorded, no buckle to latch plate separations occurred during these rollover tests.

In 1995 Moffatt et al [3] published the results of a series of six dolly rollover tests of a Chevrolet Blazer vehicle equipped with side release buckles. Buckle acceleration and webbing tension were measured during the rollover tests. The authors discovered that for the test conditions studied, the combination of highest buckle accelerations and lowest webbing tension occurred when the leading wheels struck the ground. They also noted that the Hybrid III dummy hip area tends to be significantly stiffer than the average human hip under the tested conditions, potentially producing unrealistically high buckle acceleration due to direct dummy lateral contact with the buckle. Despite these higher accelerations from contact with the ATD hip, no buckle to latch plate separations occurred in these rollover tests. They concluded that significant differences exist between the conditions necessary for release in the field compared with those measured in the crash tests. They further opined that it was extremely unlikely that the side release buckle studied in this test series would inertially unlatch in similar vehicle collisions.

In 2002 Hare et al [4] published the results of a series of 8 dolly rollover tests involving 8 instrumented driver buckles. All of the tested buckles remained latched during the testing. The paper reported the maximum acceleration in the negative axial direction for the driver buckle in each test never exceeded -48.8 g's.

In 2004 Davee et al [5] published the results of a series of shock table tests using seats, safety belt buckle assemblies, and an ATD pelvis. The study was conducted to investigate the theory that vehicle accelerations due to impacts could be amplified at the buckle by a factor of 10 or more. The authors reported that acceleration amplifications measured at the buckle were quite small (less than a factor of 1.3), and only for very short acceleration pulse durations. No buckle to latch plate separations occurred during these tests. The authors concluded the amplified buckle accelerations were far below the level required to cause the buckles to inertially release at low webbing tensions.

In 2005 Klima et al [6] published the results of a series of catastrophic drop tests of full vehicles in order to simulate severe wheel to ground impacts that may occur in severe rollover crashes. The authors drop tested the vehicles and measured, among other things, the resulting buckle and floor anchor responses. The authors reported that the ratio between peak acceleration measured at the buckle and anchor was consistent with the findings of Davee [5], and that the magnitudes and durations of the accelerations were well below those necessary for inertial release. No buckle to latch plate separations occurred during the testing.

In 2006 Cooper et al [7] published the results of a series of impact tests that generated impulses into the vehicle body structure at or near the buckle stalk floor anchors such as might occur during a rollover crash. Several buckle assembly attachment methods were evaluated. There were no buckle to latch plate separations in these impact tests and the authors concluded that sufficient damping existed in the tested systems to filter any amplified shock induced loading that might transfer back to the buckle.

The literature recognizes that further investigation of buckle responses in a variety of full scale vehicle rollover crash testing is desirable. This study examines selected full scale vehicle rollover crash tests. These tests further define buckle responses in full scale crash environments beyond planar crashes. This study reports the acceleration magnitudes, directions, durations, and safety belt webbing tension experienced by safety belt buckles during testing in a variety of vehicles and rollover crash configurations.

The buckle responses that occur during laboratory rollover crashes were examined in this study. Each rollover crash was examined for any measured buckle acceleration that exceeded 150 g in any of the three primary axes at any time during the rollover (except as a result of pretensioner deployment or vehicle arrest at the end of the test), as well as the highest measured negative axial direction acceleration regardless of magnitude. A 150 g threshold allowed focus on acceleration magnitudes that have resulted in inertial releases of other buckles tested outside the vehicle under laboratory conditions.

TEST PARAMETERS

This study focuses on rollover crash tests involving untethered vehicles where at least a ¼ turn or more was observed. The following GM test types fit into this description:

- Soil Trip
- Ditch Fall-Over
- Corkscrew
- SAE J2114 Dolly

The vehicles tested in this study included those used to develop the rollover test procedures needed for development of rollover sensors for future production applications. This rollover crash testing was reported in the 2007 O'Brien-Mitchell et al [8] technical paper. The vehicle content and crash type varied from test to test as dictated by development requirements. The distribution of tested vehicles by market segment is shown in Figure 1.

During this testing, some vehicles impacted facility protection barriers and the buckle accelerations due to these impacts were not included in this study. These impacts only occurred on the corkscrew type tests when post rollover, a vehicle continued to slide and was arrested by contact with a concrete barrier and/or netting. No buckles released due to any of these impacts.

VEHICLES TESTED

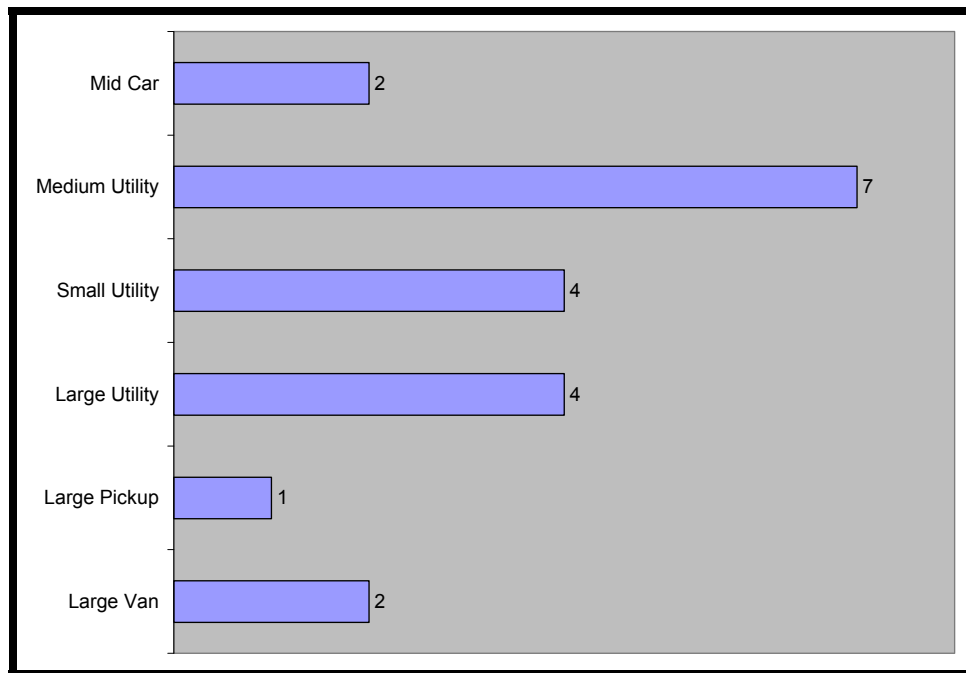


FIGURE 1 - DISTRIBUTION OF TESTED VEHICLES BY MARKET SEGMENT

Crash Test Types

The rollover test configurations for the 20 tests included in this study are shown in Figure 2.

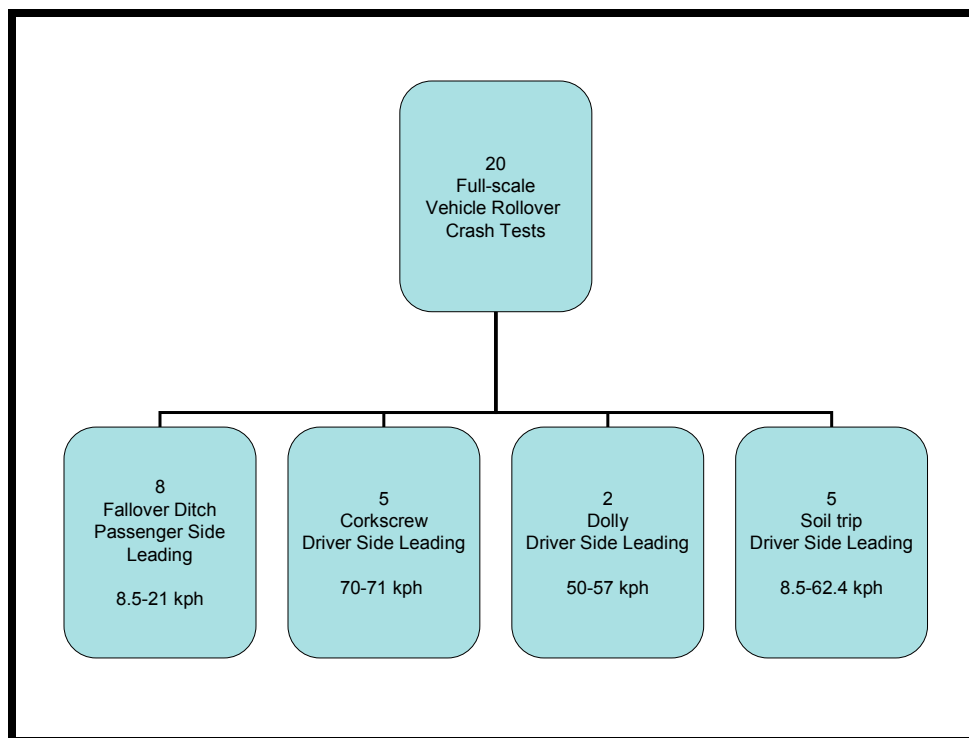


FIGURE 2 - DISTRIBUTION OF TESTS BY TEST TYPE

Anthropomorphic Test Devices (ATD)

The ATDs in this study were all safety belt restrained Hybrid III 50th percentile adult males.

ATD Seating and Buckle Positions

The seating positions evaluated in this study are evenly divided between driver and right front passenger. No rear or center seating positions were tested. In the 20 tests, there were 40 seating positions with instrumented buckles consisting of 20 driver buckles and 20 right front passenger buckles. All ATDs were restrained by the provided safety belts. Twelve tests were driver side leading rolls, and 8 were passenger side leading rolls. When the roll is initiated on the passenger side, the right front passenger is the “leading-side” ATD, and the driver is the “trailing-side” ATD. Conversely, for a driver side initiated roll the right front passenger is the “trailing-side” ATD, and the driver is the “leading-side” ATD.

Safety Belt Restraint Systems

The safety belt restraint systems tested were production representative. All were manual lap/shoulder belts with end release buckles supplied by various manufacturers. None of the tests in this study included deployment of air bag systems.

Safety belt buckle assembly design variations included buckles attached by cables or webbing. All buckle assemblies were attached to the seat structure. Safety belt buckle assembly overall geometry was based upon the overall vehicle and occupant protection requirements.

The testing included both deployed and non-deployed pretensioners as dictated by the requirements for each test. The pretensioners were either buckle or retractor type. Of the 40 buckles, 18 were exposed to pretensioner deployments which generated acceleration peaks over 150 g. Additional study of the peaks associated with the deployment of a pretensioner was not undertaken for this paper since it was observed that the buckle responses to these events in the rollover testing were similar to those reported in planar type crash tests previously reported by Haldenwanger et al [1].

Test Procedures

The rollover crash tests were performed using GM rollover sensor development test procedures as described by O'Brien-Mitchell et al [9]. The instrumentation and sign convention utilized in this study are defined in Appendix A.

DATA MANAGEMENT

In order to evaluate the measured data, a plot was created for each of the 40 instrumented buckles. The plot included the axial, lateral, and perpendicular components of buckle acceleration, safety belt lap and shoulder webbing tension, and time. Each plot also contained vertical datum lines representing each vehicle to ground impact. Vehicle rotational velocity and roll angle were also plotted.

For each acceleration peak of 150 g or greater magnitude (regardless of axes or direction) the following information was recorded:

- direction of acceleration peak
- duration of acceleration peak above 150g
- magnitude of the peak acceleration
- time of the acceleration peak
- at the time of the peak acceleration, the following information was also recorded:
 - magnitudes of acceleration in the other two axes
 - lap belt webbing tension
 - shoulder belt webbing tension

The highest negative axial direction acceleration peak during each test even if less than 150 g is shown in Table 2.

Anomalous Data

Anomalous channels were excluded from this analysis. Data anomalies occurred due to a variety of reasons such as loose, separated, or damaged accelerometers, severed wiring and instrumentation malfunctions.

DISCUSSION

- I. Vehicle Kinematics
- II. Vehicle-to-Ground Impacts
- III. Wheel-to-Ground Impacts
 - A. Leading-side Impacts
 1. Leading-side ATD Kinematics
 2. Trailing-side ATD Kinematics
 - B. Trailing-side Impacts
 1. Leading-side ATD Kinematics
 2. Trailing-side ATD Kinematics
 - C. Buckle Responses
- IV. Body-to-Ground Impacts
- V. Roof-to-Ground Impacts

I. VEHICLE KINEMATICS

The types of rollover tests and the subsequent vehicle kinematics are generally categorized as being tripped or un-tripped. Most rollovers involve vehicle rotational velocity about its longitudinal axis. However, large differences in longitudinal and lateral velocity were inherent in the types of rollover tests conducted. These differences influenced the ATD's kinematics during the rollover crash.

The soil and dolly type tests were those where the pre-roll motion of the vehicle was predominately lateral. It was observed that these tests generally resulted in higher longitudinal axis rotational velocity, multiple rolls, and more leading-side wheel-to-ground impacts than observed in the ditch fall-over and corkscrew tests where the pre-roll motion of the vehicle was predominately longitudinal.

Vehicle kinematics have been previously described in the literature by what portion of the vehicle hits the ground [2]:

1. Wheel – primary impact occurs on the tire or wheel.
2. Body - primary impact occurs anywhere on the vehicle below the door window belt line.
3. Roof – primary impact occurs anywhere on the vehicle above the door window belt line.

A description of the vehicle-to-ground impact types is shown in Figure 3. The description of vehicle-to-ground impacts was further refined to include whether the impacts were leading-side or trailing-side relative to the seating position and roll direction about the vehicles longitudinal axis.

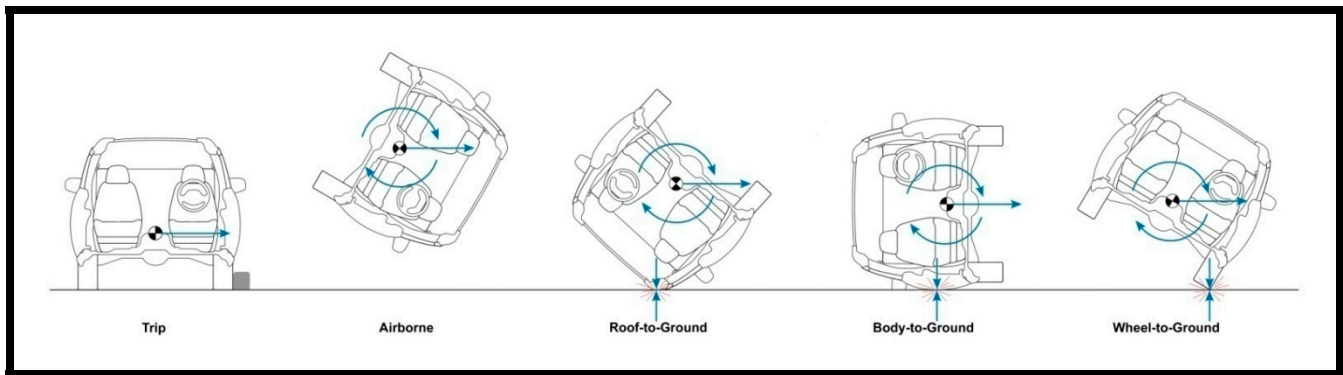


FIGURE 3 - DESCRIPTION OF VEHICLE-TO-GROUND IMPACT TYPES

II. VEHICLE-TO-GROUND IMPACTS

The vehicle-to-ground impacts were examined in part to address the contention that automotive buckles are susceptible to inertial unlatching in the field due to the buckle environment generated by vehicle-to-ground impacts, especially during wheel-to-ground impacts. It is difficult to precisely identify the type and timing of each individual vehicle-to-ground impact. However, by focusing on the impacts severe enough to cause a significant change in the vehicle's rotational velocity, reasonable judgments were made by analyzing vehicle rotational velocity together with vehicle roll angle, and the off-board and on-board high speed video. The timing of the vehicle-to-ground impacts was identified in this way and indicated by a vertical datum line on the plots.

Vehicle-to-ground impacts caused changes in the vehicle's rotational velocity. Although unpredictable, vehicle-to-ground impacts are often characterized by rapid changes in the vehicle rotational velocity followed by chaotic periods during which the vehicle continues to roll while in contact with the ground. Post-trip airborne phases were typically characterized by relatively constant rotational velocity.

Changes in rotational velocity resulted in relative movement between the ATDs and the vehicle interior. This presented opportunities for the ATDs to load the safety belts. The extent of belt loading depended on the kinematics of the vehicle and ATD during the particular impact. Once the vehicle-to-ground impacts were identified, the buckle acceleration data was examined for instances where it exceeded the 150 g threshold, and at each negative axial direction peak. Each peak was then associated with the vehicle-to-ground impact that most likely resulted in the acceleration peak.

DATA SUMMARY

Each test was examined for all vehicle-to-ground impacts. A total of 62 vehicle-to-ground impacts were identified. Table 1 categorizes the impacts as wheel, body, or roof impacts, lists the test conditions, and reports the number of vehicle rolls. Table 2 reports the highest negative direction axial acceleration and associated data measured during each test. Acceleration duration data is reported only for acceleration peaks > 20 g. Webbing tension values reported as zero were originally recorded as negative values, and are thought to be an inherent anomaly with the load cell design.

TABLE 1: SUMMARY OF VEHICLE-TO-GROUND IMPACT

TEST TYPE	TEST NUMBER	SPEED (KPH)	¼ TURNS	LEADING-SIDE VEHICLE TO GROUND IMPACTS			TRAILING-SIDE VEHICLE TO GROUND IMPACTS		
				WHEEL (LW)	BODY (LB)	ROOF (LR)	WHEEL (TW)	BODY (TB)	ROOF (TR)
DITCH	030328	12.1	1	1	1	-	-	-	-
DITCH	040385	19.3	1	-	1	-	-	-	-
DITCH	050091	20.9	1	1	1	-	-	-	-
DITCH	050089	19.8	1	1	1	-	-	-	-
DITCH	050118	15.3	1	-	1	-	-	-	-
SOIL	020245	62.4	4	2	-	-	2	-	1
DITCH	050116	15.0	1	-	2	-	-	-	-
SOIL	020257	52.6	6	1	-	1	-	1	2
SOIL	020222	57.6	8	2	-	1	-	2	2
SOIL	020223	57.8	4	3	-	-	2	-	1
DOLLY	040223	57.0	9	3	1	3	1	-	2
DITCH	040419	19.3	1	-	1	-	-	-	-
CORKSCREW	040420	70.5	1	-	1	-	-	-	-
DITCH	030329	16.9	1	-	-	1	-	-	-
DOLLY	040344	50.8	4	2	-	1	1	2	1
CORKSCREW	030337	71.3	1	-	1	-	-	-	-
CORKSCREW	020115	71.4	2	-	-	1	-	-	-
CORKSCREW	040230	70.0	1	-	1	-	-	-	-
CORKSCREW	040342	70.3	2	-	-	2	-	-	-
SOIL	040242	52.1	6	1	-	1	-	-	2