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Repeatability of a Small Overlap and an Oblique Moving Deformable Barrier Test Procedure

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ABSTRACT

NHTSA has developed two different moving deformable barrier-to-vehicle test procedures to assess the vehicle and occupant response in narrow overlap motor vehicle crashes. An assessment of test repeatability is one of the requirements necessary to accept the test procedure as viable. Previous methodologies, coefficient of variation (CV) and similarity analysis were developed to assess the repeatability of vehicle and occupant response in motor vehicle crash tests for full frontal and 40% overlap tests procedures. These will be used for this assessment.

Three repeat tests were performed in each test procedure, with all other factors held constant: vehicles of the same make, model, and model year; moving deformable barriers of the same mass, velocity, and barrier face properties; and the same occupant - a THOR 50th percentile adult male in the driver's seat. In general, for this one vehicle make and model the repeatability of both vehicle and occupant response metrics were good for both test modes. In isolated cases, differences in occupant response resulted from the timing of side curtain air bag deployment.

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INTRODUCTION

Saunders et al, 2012 [1] performed paired vehicle test in both “Small Overlap Impact” (SOI) and “Offset Oblique” (Oblique) test procedures with vehicles that were redesigned or introduced in 2010 and 2011. Most of these vehicles received highest ratings in current US consumer rating systems. Saunders et al, 2012 [1] demonstrated that even though these vehicles had good ratings in consumer information crash tests and were newly designed, there still exists potential for vehicle design improvements that could mitigate real-world injuries and fatalities in the both of these crash types.

A next step is to make sure these test procedures are repeatable. Meyerson et al, 1996 [2] reported on repeat tests of five vehicles in the 64 kph, 40 percent offset deformable fixed barrier test. Meyerson deemed this test procedure repeatable because the ratings of the vehicles did not change between the paired tests.

This paper presents the analysis of repeated 2011 Chevrolet Cruze tests, three each in the SOI and Oblique test modes, to assess the repeatability of these procedures. The paper uses established criteria for evaluating repeatability in comparing these two test procedures to repeatability in 56 kph full frontal and the 40 percent offset deformable barrier (ODB) test procedures with model year vehicles greater than 1999.

METHODOLOGY

Test Setup

This section describes the SOI and Oblique test procedures, as well as the methodology for presentation and analysis of the vehicle and occupant response. Figure 1 shows the general test setup for both test modes. The general procedure is to mark the overlap on the target vehicle (width excludes mirrors and door handle) and then position the stationary target at the desired angle. Once this is achieved, the outer edge of research moving deformable barrier (RMDB) is aligned with the overlap mark on the target vehicle. Table 1 shows the test parameters for both the SOI and Oblique test procedures.

Saunders et al, 2012 [1] described the reasoning for the design of the RMDB. It should be noted that the design characteristics (i.e. frontal stiffness) of the RMDB were not developed to match a specific or even an average passenger car, but were developed to address the issues observed when using the FMVSS No. 214 MDB for this testing. Figure 2 shows the basic dimensions and properties of the RMDB. The total weight of the barrier is 2486 kg (5481 lbs).

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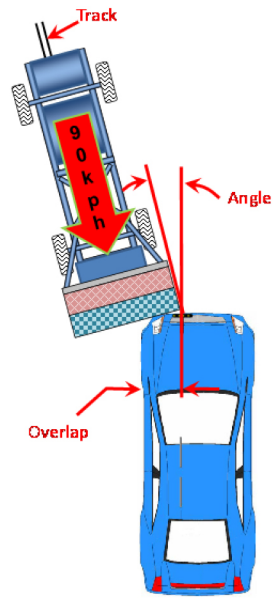

Figure 1. Test configuration

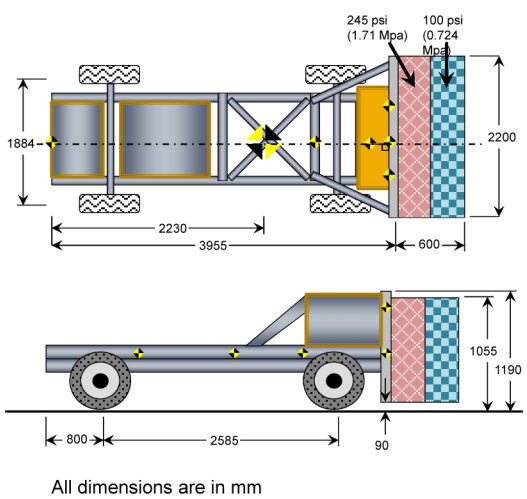

Figure 2. Dimensions of the RMDB

Table 1. Setup parameters for SOI and Oblique test procedure

Test Type	Overlap (%)	Angle (degrees)	RMDB Closing Speed (kph/mph)
SOI	20	7	90/56
Oblique	35	15	90/56

Vehicle Parameters

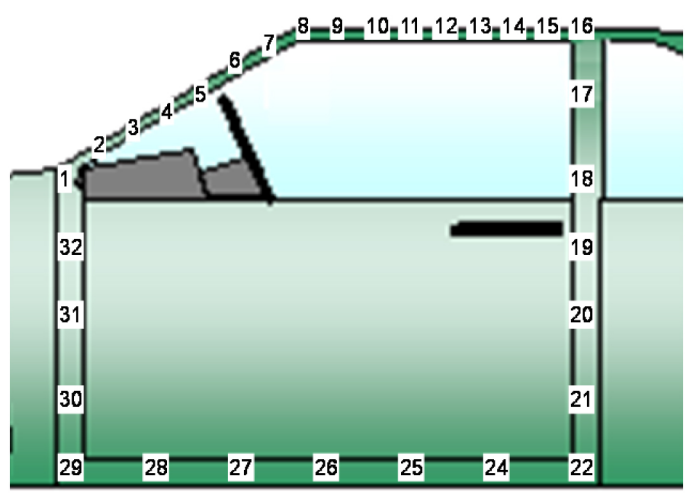

Figure 3. Door profile measurement points

This section describes the vehicle parameters and responses used for repeatability analysis:

1. The y and z distance from the target point. If y is positive it means the actual overlap was less than the calculated overlap.

2. 6 points on the bumper beam were recorded pre and post-test (see Appendix A for procedure to locate these points)

3. Door profile (DP) points (Figure 3) (see Appendix B for procedure to locate these points)

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4. Interior intrusions points (Figure 4) (see Appendix C for procedure to locate these points):

a. Toepan points: points A2, B2, C2, D2 are used for this analysis

b. Left and right instrument panel (IP)

c. Steering wheel

5. Vehicle accelerations and velocities

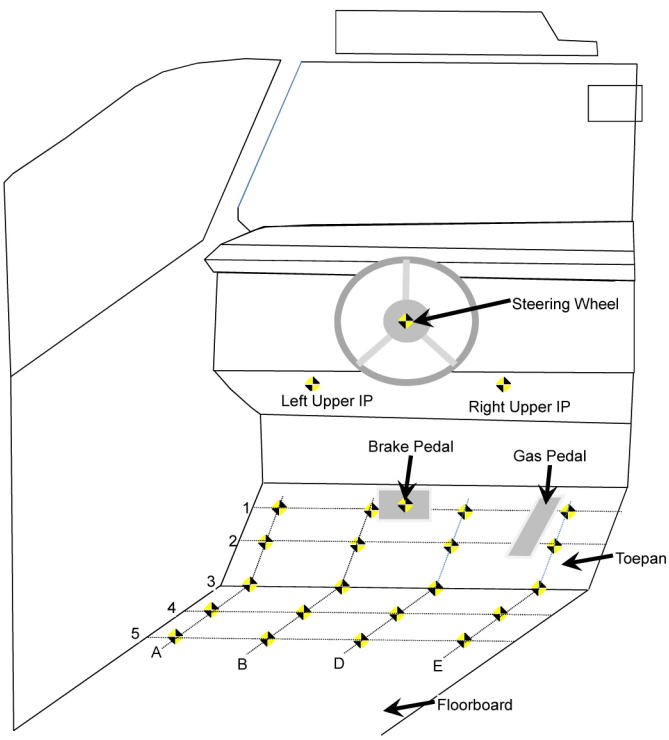

Figure 4. Interior intrusion points

Occupant Response Assessment

In the SOI and Oblique RMDB tests, a Test Device for Human Occupant Restraint (THOR) 50th percentile male anthropomorphic test device (ATD) was positioned in the driver's seat. The THOR ATD used in the RMDB tests represents the Mod Kit build level [1].

While injury risk functions specific to the THOR hardware have not yet been developed [1], provisional injury assessment reference values have been developed for several body regions. To assess head injury risk, the head injury criterion (HIC_{15} and HIC_{36} results are both presented) is assumed to be applicable to THOR, since the design requirements for the mass, moment of inertia, and biomechanical response characteristics mirror that of the Hybrid III for which HIC is traditionally applied. The Injury Assessment Reference Values (IARVs) for HIC_{15} and HIC_{36} are 700 and 1000 [4]. The rotational brain injury criterion (BRIC) is implemented with critical values of 63.5 rad/s and 19,501 rad/s^2 [1], and the BRIC IARV is 0.89 [5]. For the neck, cervical spine axial load tolerance values of 2520 Newtons (N) in tension and 3640 N in compression [6]. Injury assessment reference values have not yet been determined for THOR chest deflection or 3-millisecond clip acceleration, so the Hybrid III IARVs of 63 millimeters and 60 g [4] are used for the purposes of this analysis. The fracture tolerance of a human hip under neutral loading through the knee was determined to be 4560 N [7]; adjusting for the difference in load transfer between the THOR dummy and human subjects, the associated load measured at the THOR acetabulum would be 3,316 N [8]. The IARV for the human femur in axial compressive load is 9,040 N [9]. Since the THOR femur was designed to meet the human response in axial compression, this IARV can be applied directly [3]. Lower extremity injury risk was assessed using the Revised Tibia Index, for which the IARV of 1.16 [9].

Repeatability

To determine repeatability of these two test procedures, three tests of 2011 Chevrolet Cruze were performed in each procedure. Table 2 shows the NHTSA test numbers and the naming convention used throughout the paper.

Table 2. Name of each test throughout the paper and NHTSA test number

Test Type	Name	NHTSA Test
SOI	SOI_1	7432*
	SOI_2	7773
	SOI_3	7867
Oblique	Oblique_1	7431*
	Oblique_2	7852
	Oblique_3	7851

* Vehicle purchased with automatic transmission

Coefficient of Variation

Coefficient of Variation (CV) is calculated (Eqn. 1) by dividing the standard deviation (Eqn. 2) of the test measurements, either a peak value or an injury assessment value (IAV), by the mean (Eqn. 3) of the given measurement values for each test in the group. The population standard deviation is used here since only the values in each group are being considered, not a projection on a greater population.

$$CV = \frac{\sigma}{\mu} \times 100\% \qquad \textit{Eq. 1}$$

$$\sigma = \sqrt{\frac{\sum (x-\mu)^2}{n}} \qquad \textit{Eq. 2}$$

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$$\mu = \frac{1}{n}\sum x$$

Eq. 3

RESULTS: VEHICLE RESPONSE

The section describes the vehicle response parameters and vehicle responses that are compared to determine the repeatability of the SOI and Oblique test procedures. The vehicle parameters include the actual overlap of the test (target point location), how the vehicle crushes and/or intrudes, and the acceleration/velocity of the vehicle.

Figure 5 shows that the RMDB impacted the desired target within 25 mm for the 6 tests performed. Figure 6 (a) and Figure 6 (b) shows the bumper beam crush for SOI and Oblique test procedure, respectively. It can be seen from Figure 6 (a) that SOI_1 had 129 mm difference in the x-direction when compared to SOI_2 and SOI_3. SOI_2 and SOI_3 had similar x-direction crush. Figure 6 (b) shows the oblique bumper crush was similar for each test. The max x-direction difference was only 58 mm.

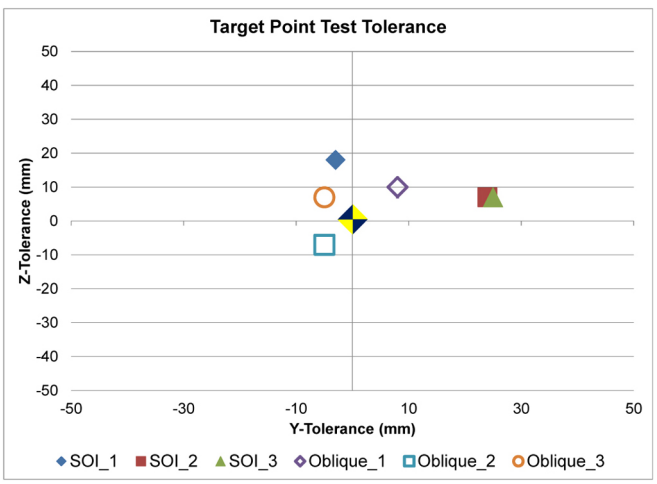
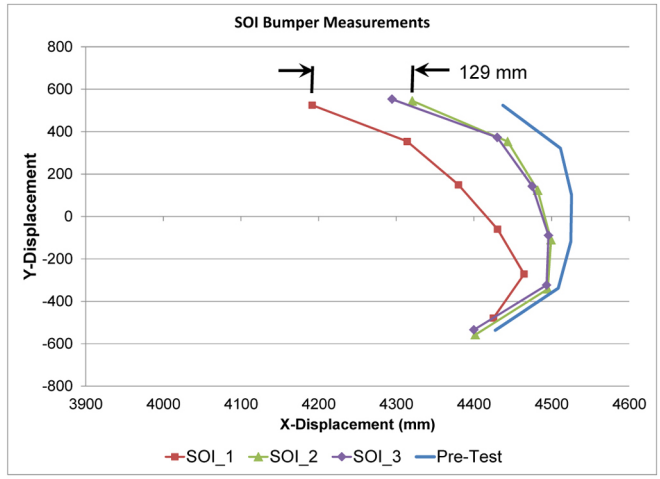


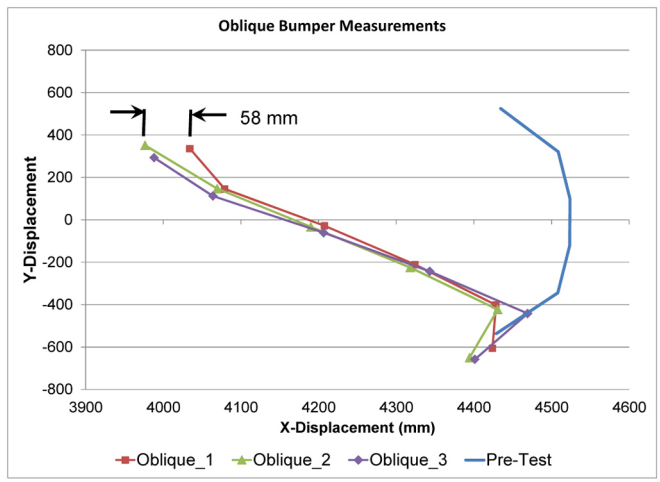
Figure 5. Distance from target point

Figure 7 (a) and Figure 7 (b) shows that the door profile was similar for both the SOI and Oblique test procedure. When looking at the lower rocker panel the max difference in the x-direction for the SOI tests was 52 mm and 59 mm for the oblique tests.

Figure 8 (a) and Figure 8 (b) show row 2 of the toepan x, y, and z intrusions for SOI and Oblique, respectively. Figure 8 (a) shows that SOI_3 had the highest intrusion in the X-direction and SOI_1 had the highest intrusion in the Z-direction. Figure 8 (b) shows Obique_1 had the highest intrusion in x, y, and z direction. The max difference for the SOI procedure occurred at A2Z and was 97 mm, whereas the max difference was 14 mm for the Oblique procedure.

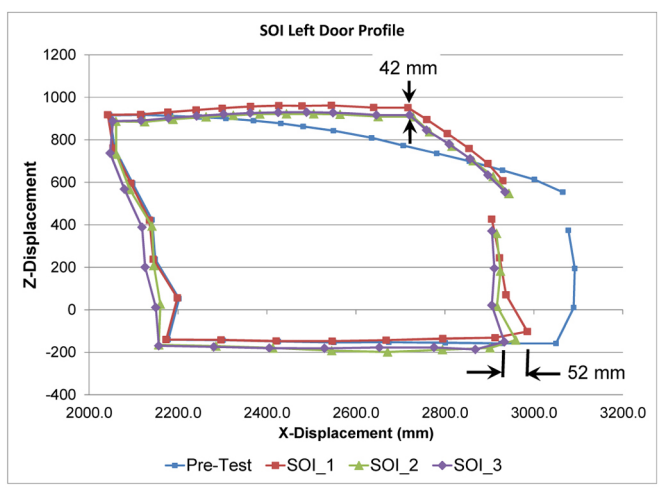


(a)



(b)

Figure 6. Bumper crush



(a)

Figure 7. Left door profile

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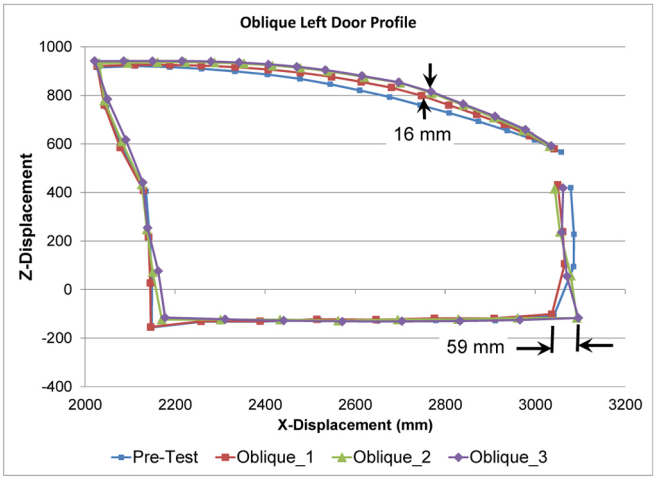
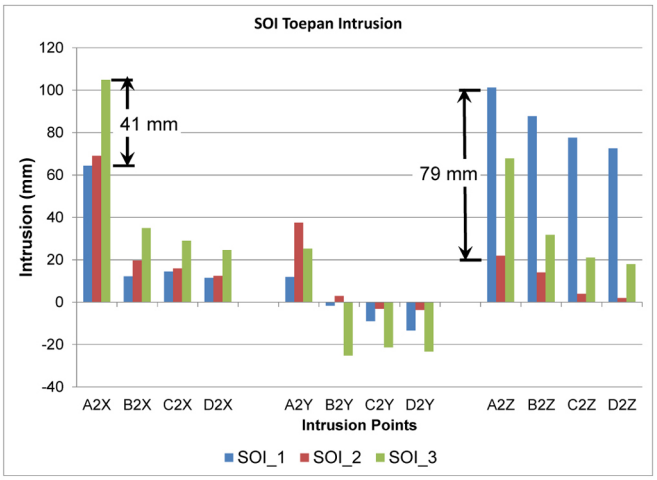
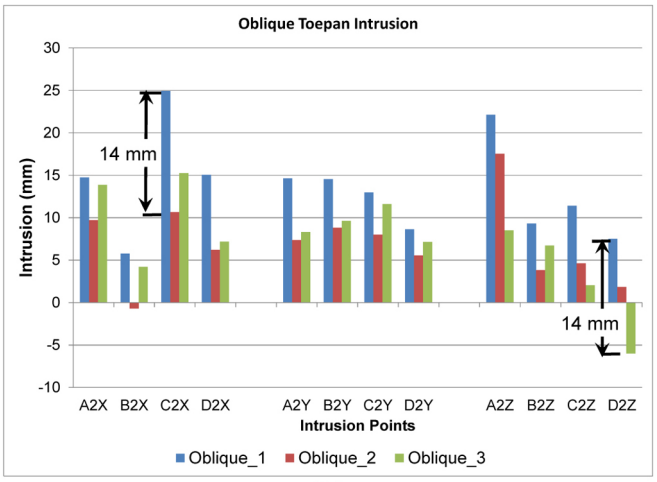


(b)

Figure 7. (cont.) Left door profile



(a)

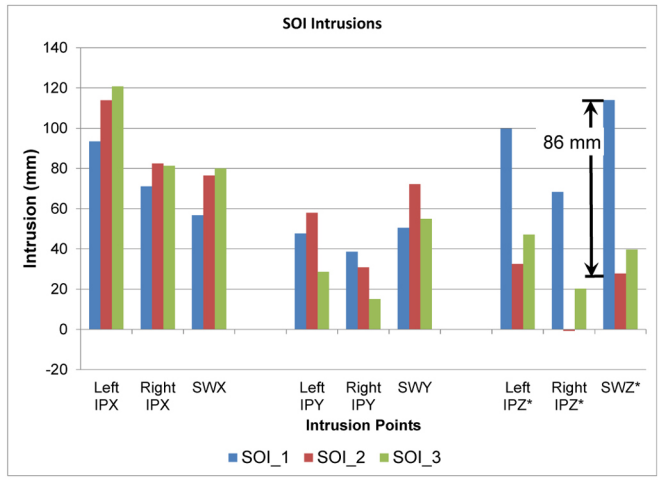


(b)

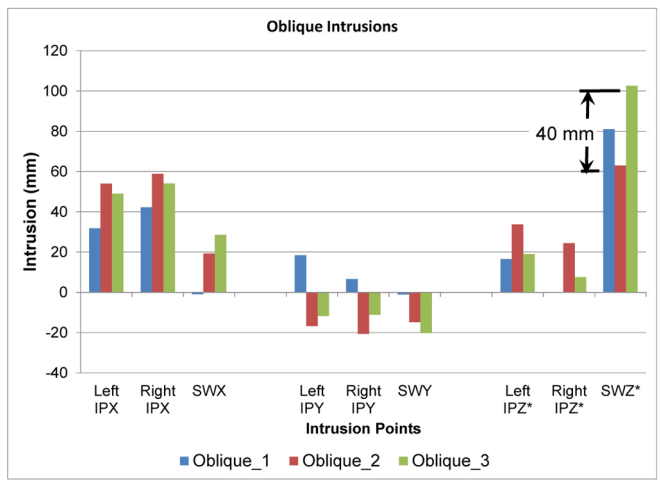
Figure 8. Toepan row 2 x, y, and z difference in intrusion pre and post-test

Figure 9 shows the x, y, and z intrusions for the left and right IP and the SW. It should be noted that the Z intrusion for the SW was flipped for graphical purposes. The X-direction intrusions were similar for both the left and right IP and the SW for both SOI and Oblique procedures (Figure 9 (a) and Figure 9(b)). The Z-direction intrusion for the left and right IP and SW showed the most variability for the SOI procedure.

Figure 10(a) shows that the left rear sill X-direction acceleration had similar shape and timing of peak Gs. Figure 10(b) shows that the Oblique test procedure had similar shape, but different timing of peak Gs. The difference between the Peak Gs and the CV for SOI was 6.6 Gs and 7.8 percent and 4.8 Gs and 7.3 percent for Oblique.



(a)



(b)

Figure 9. IP and SW x, y, and z difference in intrusion pre and post-test

Figure 11 (a) and Figure 11 (b) shows that both SOI and Oblique have similar velocity traces. The range in peak change in velocity (delta-V or DV) was approximately 2 kph

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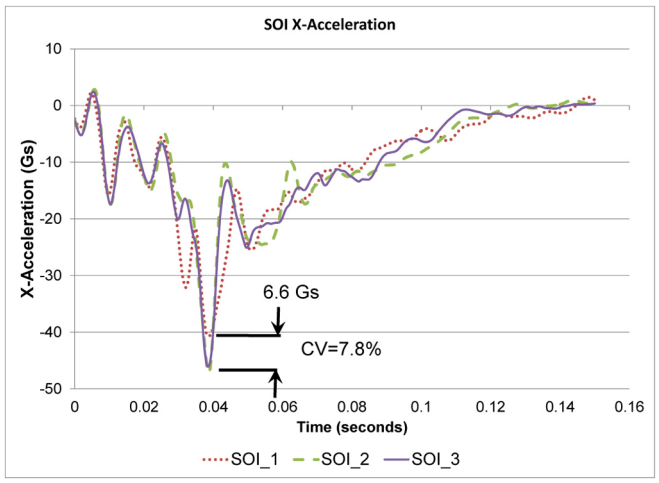
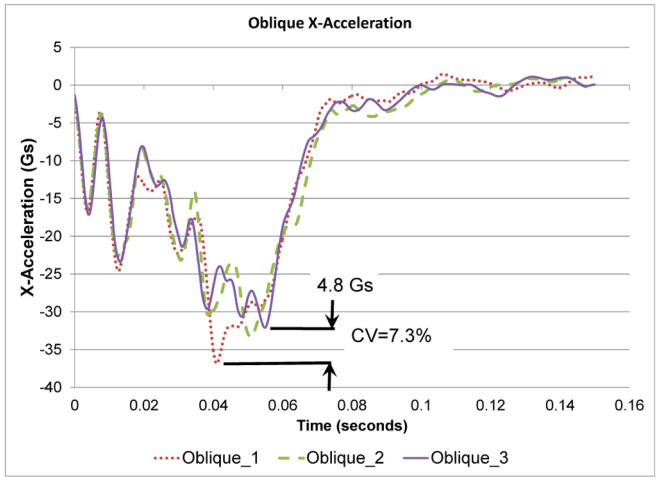
at 150 ms for both procedures and the CV was approximately 2 percent for both procedures.

Figure 12(a) and Figure 12 (b) show the left rear sill Y-direction acceleration. For both procedures the shape of the curves are similar. The difference in the Peak Gs for the SOI procedure was 2.7 Gs and the CV was 8.7 percent. The Oblique procedure difference in Peak Gs was 5.7 Gs and the CV was 13.8 percent.



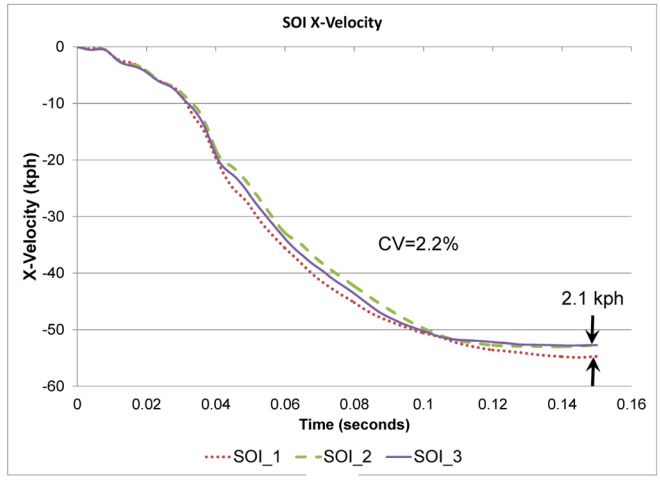
(a)



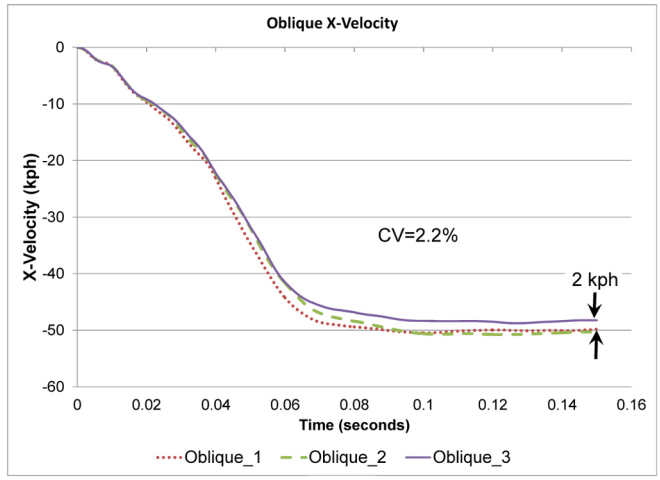
(b)

Figure 10. Left rear sill x-acceleration

Figure 13 (a) shows similar Y-direction velocity traces for the SOI procedure except from 60 to 80 ms. At 150 ms, the range DV was 3 kph and the CV was 8.1 percent. Figure 13 (b) shows that the Y-direction velocity in Oblique_3 was similar to the other tests up to 50 ms and then continued to go higher. At 150 ms, the range in DV and the CV were 4 kph and 14.3 percent, respectively.

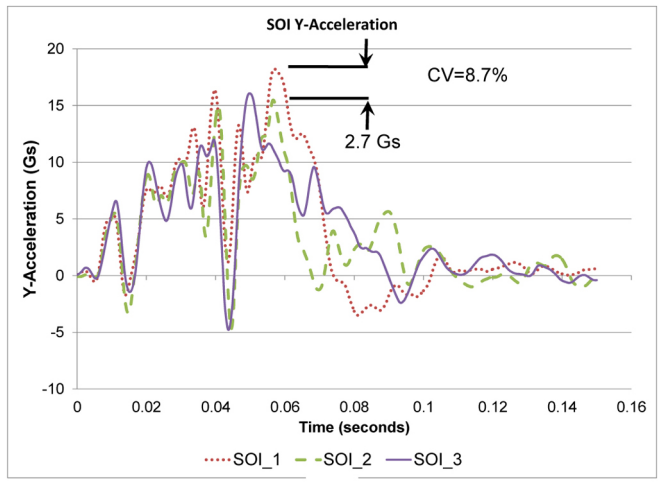


(a)



(b)

Figure 11. Left rear sill x-velocity



(a)

Figure 12. Left rear sill y-acceleration

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