CHANGE OF VELOCITY AND PULSE CHARACTERISTICS IN REAR IMPACTS: REAL WORLD AND VEHICLE TESTS DATA

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ABSTRACT

Impact severity in collisions that can cause soft tissue neck injuries are most commonly specified in terms of change of velocity. However, it has been shown from real-world collisions that mean acceleration influences the risk of these injuries. For a given change of velocity this means an increased risk for shorter duration of the crash pulse. Furthermore, dummy response in crash tests has shown to vary depending on the duration of the crash pulse for a given change of velocity. The range of duration for change of velocities suggested for sled tests that evaluate the protection of the seat from soft tissue neck injuries are still to be established. The aim of this study was to quantify the variation of duration of the crash pulse for vehicles impacted from the rear at change of velocities suggested in test methods that evaluate the protection from soft tissue neck injuries. Crash pulses from the same vehicle models from different generations in real-world collisions producing a similar change of velocity were also analysed.

The results from the crash tests show that similar changes of velocity can be generated with various durations of crash pulses for a given change of velocity in rear impacts. The results from real-world collisions showed that a similar change of velocity was generated with various durations and shapes of crash pulses for the same vehicle model.

INTRODUCTION

Rear impacts causing AIS 1 (AAAM 1990) neck injuries most frequently occur at delta-Vs (changes of velocity) below 30 km/h in the struck vehicle (Parkin et al., 1995, Hell et al., 1999, Temming and Zobel, 2000). Furthermore, it has been shown that mean acceleration (i.e. the duration of the crash pulse for a given delta-V) influences the risk of AIS 1 neck injuries (Krafft et al., 2002). It has also been shown that the shape of the crash pulse influences. risk of AIS 1 neck injuries in frontal impacts (Kullgren et al., 1999). Acceleration pulses from rear impacts shows that the same delta-V can cause a large variation in acceleration pulse shapes in the struck vehicle (Krafft, 1998, Zuby et al., 1999, Heitplatz et al., 2002). From real-world collisions it has been shown that the acceleration pulse also can vary in shape (i.e. duration of crash pulse, maximum magnitude of acceleration, onset rate etc) in impacts of similar delta-Vs (Krafft, 1998).

Dummy response in crash tests has been shown to vary depending not only on the delta-V but also on the duration of the crash pulse for a given delta-V (Linder et al., 2001a). The range of the duration of the crash pulse that corresponds to a specific delta-V in rear impacts has been shown to cover a wide range for vehicles impacted at the rear at a delta-V of up to 11 km/h (Linder et al., 2001b). The range of the duration of the crash pulse that corresponds to a specific delta-V in rear impacts that can cause AIS 1 neck injuries remains to be established. The range of the duration of the crash pulse for a specific delta-V is necessary to establish when designing impact severities for sled test methods that evaluate the safety performance of a seat in rear impacts, particularly in respect of AIS 1 neck injuries. Such test methods are at the moment under development Cappon et al. (2001), Muser et al. (2001), Langwieder and Hell (2002) and Linder (2002) and under discussion in groups like IIWPG (International Insurance Whiplash Prevention Group), EuroNCAP (European New Car Assessment Program), EEVC (European Enhanced Vehicle Safety Committee) Working group 12 and ISO (International Organization for Standardization) TC22/SC10/WG1. The delta-V suggested in sled test in these methods that represent the delta-V where the majority of rear impacts are reported is 15 or 16 km/h (Cappon et al., 2001, Muser et al., 2001 and Langwieder and Hell, 2002).

The first aim of this study was from laboratory crash tests to quantify the variety of mean acceleration monitored in different vehicles impacted in the same way. The second aim was to demonstrate the variety of the duration and shape of the crash pulse in the same vehicle model from real-world crashes producing similar delta-V.

MATERIALS AND METHODS

Laboratory Crash Tests

Sixteen vehicles (Table 1) were impacted at the rear either with a barrier or with a vehicle of the same make and model as the impacted vehicle. The barrier used in the OW test had a weight of 1000 kg (Figure 1). The barrier used in the CR tests had a weight of 1800 kg. The vehicles were impacted at the rear with 100 % overlap. The test where a vehicle was impacted by another vehicle (test OW3739, CR01001 and CR01002), the same make and model of vehicle was used as the bullet vehicle. The mass of the cars used were from 1010 kg - 1966 kg. The OW9999 vehicle was from 1983 series car (the actual vehicle was a used vehicle new in 1993 and with no structural corrosion) and the other vehicles were from the mid 1999.

Table 1.
The weight of the impacted vehicles and the impact velocity of the barrier or the impacting vehicle in the rear impacts.

Impact No.	Vehicle mass (kg)	Impact velocity (km/h)
OW9999	1190	18.3
OW3660	1450	30.0
OW3737	1965	52.4
OW3749	1445	36.9
OW3763	1347	35.7
OW3759	1493	32.1
OW3760	1493	43.8
OW3718	1010	40.0
OW3539	1384	24.9
OW3594	1405	35.2
OW3500	1339	18.5
CR98001	1450	24.0
CR98002	1800	24.0
CR98006	1750	24.0
CR01001	1439	32.0
CR01002	1461	32.0

Figure 1.

A rigid barrier impacting the rear of the vehicle.

One vehicle model was impacted both with a barrier and with another vehicle in order to compare the crash pulse from a rigid barrier to that generated by an impacting vehicle. The crash pulses from the laboratory tests were from previously performed tests at the Motor Insurance Repair Research Centre in the UK and at the Insurance Institute for Highway Safety in the US. The accelerometer was mounted at the base of the B-pillar on the left hand side in the vehicles in the OW tests. The vehicles in the OW tests were right-hand drive vehicles for the UK market. The vehicles in the CR tests were left-hand drive vehicles. The accelerometer was mounted on a steel bar pinned between the front door hinge-pillar and the b-pillar on the left hand side in the vehicles in the CR98001 and CR98002 tests. The accelerometer was mounted to the floor in the vehicle centreline just behind the front row of the seats in the vehicles in the CR98006 and the CR01 tests. The CR01 tests were performed with vehicles of the same make and model for the US and European market. These vehicles were structurally identical except from the bumper system. All vehicles were a conventional monocoque construction.

Real-World Rear Impacts

Since 1995, Folksam in Sweden have been equipping various new car models with one-dimensional crash-pulse recorders, mounted under the driver or passenger seat to record the crash pulse obtained during real-world impacts. The crash-pulse recorder is based on a spring mass system where the movement of the mass is registered on photographic film. When a vehicle equipped with a crash recorder has been involved in a collision the crash pulse is analysed by Folksam and the outcome for the occupants in terms of injuries is analysed by Folksam. In this study, crash pulse from rear impacts with two generation of the same vehicle model, T1 and T2 from 1993 and 1998, were presented.

Data Acquisition and Analysis

The crash pulse measured as the acceleration signals of the vehicle were filtered in accordance with SAE CFC 60 and the velocity was calculated by integrating the acceleration. The duration of the crash pulse (T_p) and the delta-V were identified from the filtered acceleration curves and the velocity curves.

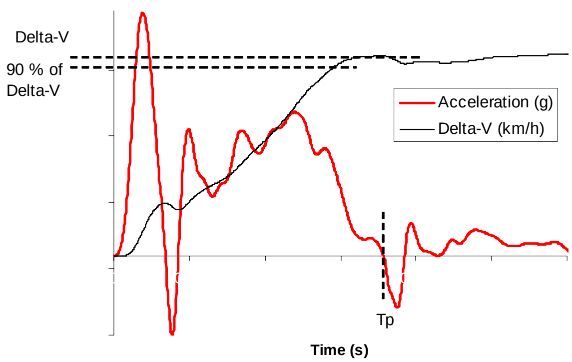

Figure 2.

Schematic drawing showing how the duration of the crash pulse T_p were identified from the graphs.

The T_p was defined as the time when the acceleration changed from positive to negative after 90 % of delta-V had occurred. Mean acceleration was calculated, defined as delta-V(at Tp)/Tp. For a given change of velocity a higher mean acceleration thus correspond to this a shorter duration of the crash pulse. For the graphic presentation of the crash pulses in this study the pulses were all adjusted so that the acceleration of 1 g occurred at time zero. Furthermore the crash pulses were filtered with CFC 36 (corresponding to a cut of frequency of 60 Hz) since oscillations in the crash pulses were found (Figure 3).

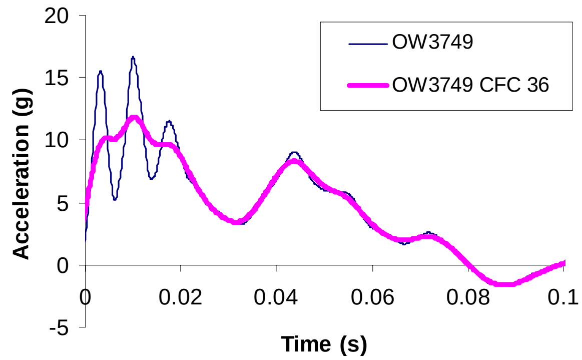

Figure 3.

Example of the oscillations filtered out by the CFC 36 filtering compared to the SAE standard filtering (CFC 60).

RESULTS

The results showed a considerable variation of the duration of the crash pulse for a similar delta-V both for different vehicles impacted the same way and for the same vehicle model impacted in various ways in real-world collisions. Furthermore, various pulse shapes were registered in the same vehicle from impacts which generated a similar delta-V.

Laboratory Crash Tests

The crash pulses from sixteen vehicles rear impacted with delta-Vs from 10.2 km/h to 19.4 km/h were examined. The duration of the crash pulse were between 65 ms and 130 ms. This resulted in mean accelerations between 3 g and 7.9 g (Figure 4 and 5 and Table 2).

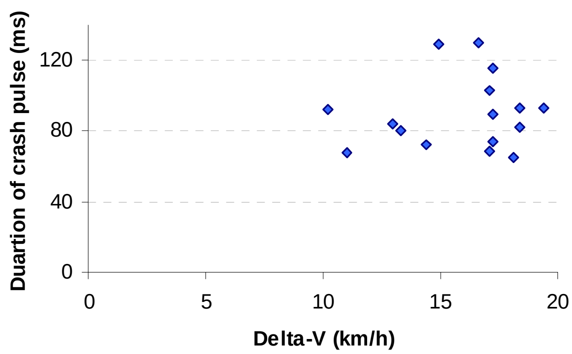

Figure 4.

The duration of the crash pulse versus delta-V from vehicles impacted at the rear with a rigid barrier or with another vehicle.

Table 2.
The delta-V, mean acceleration and duration of the crash pulse, T_p, from the vehicles impacted at the rear with a rigid barrier or another vehicle.

Impact No.	Delta-V (km/h)	T_p (ms)	a_{mean} (g)
OW9999	10.2	92	3.0
OW3660	17.1	69	7.0
OW3737	17.1	103	4.7
OW3749	18.4	82	6.4
OW3763	17.2	89	5.5
OW3759	18.4	93	5.6
OW3760	17.2	74	6.6
OW3718	18.1	65	7.9
OW3539	13.3	80	4.9
OW3594	13.0	84	4.4
OW3500	11.0	68	4.4
CR98001	16.6	130	3.6
CR98002	14.4	72	5.7
CR98006	14.9	129	3.3
CR01001	19.4	93	5.6
CR01002	17.2	116	4.1

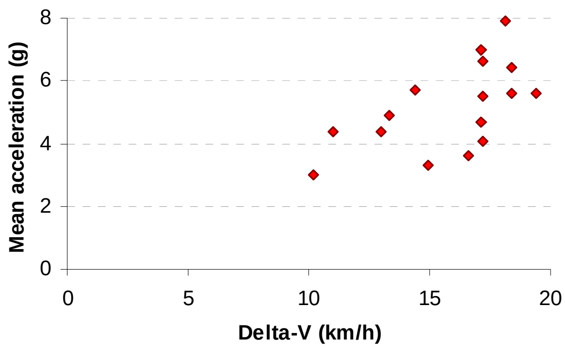

Figure 5.

The mean acceleration versus delta-V from vehicles impacted at the rear with a rigid barrier or with another vehicle.

The crash pulses from thirteen vehicles impacted with a rigid barrier (all OW tests except OW3759 and the CR98 tests) showed a range of mean acceleration from 3 g to 7.9 g. The crash pulses from the three vehicles impacted with another vehicle (OW3759 and CR01 tests) showed a range of mean acceleration from 4.1 g to 5.6 g.

The crash pulses recorded in the laboratorial tests are displayed in Figures 6-12.

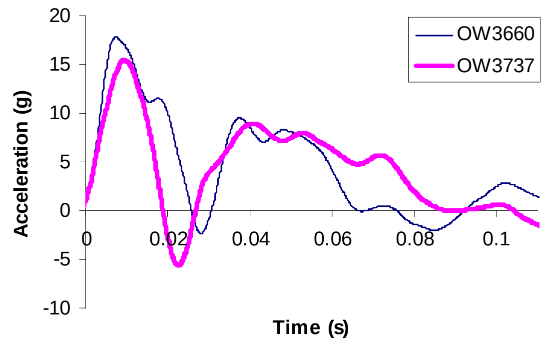

Figure 6.

The crash pulses from the OW3660 and OW3737, in tests at 100 % overlap with an impacting barrier generating a delta-V of 17.1 km/h.

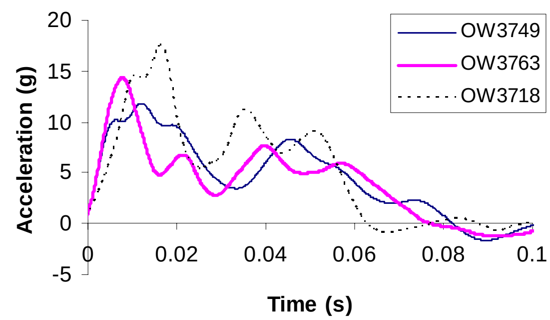

Figure 7.

The crash pulses from the OW3749, OW3763 and OW3718, in tests at 100 % overlap with an impacting barrier generating a delta-V of 17.2 km/h to 18.4 km/h.

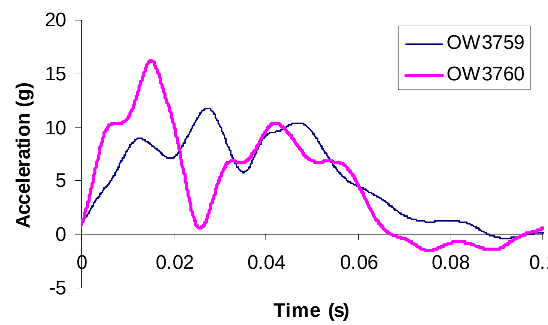

Figure 8.

The crash pulses from the OW3759 (car-to-car), and OW3760 (barrier to car), in tests at 100 % overlap with a delta-V of 17.2 km/h and 18.4 km/h.

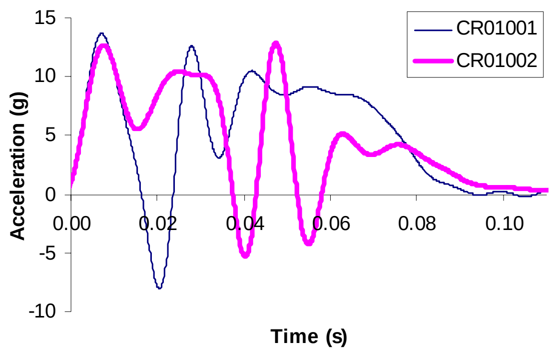

Figure 9.

The crash pulses from the car-to-car test with the same vehicle model for the US and European market, in tests at 100 % overlap with a delta-V of 17.2 km/h and 19.4 km/h.

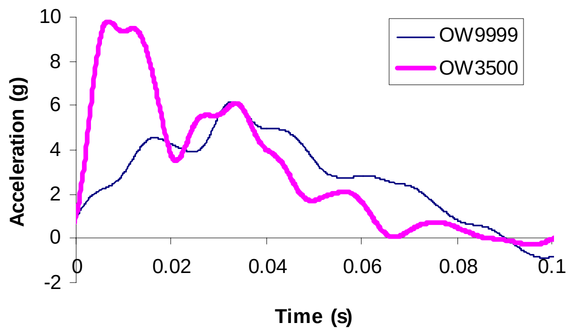

Figure 10.

The crash pulses from the OW3500 and OW9999, in tests at 100 % overlap with an impacting barrier generating a delta-V of 10.2 km/h to 11 km/h.

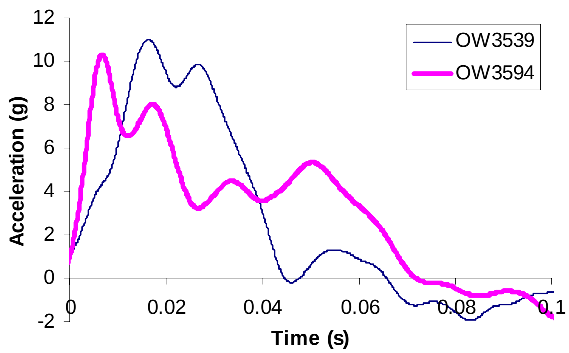

Figure 11.

The crash pulses from the OW3539 and OW3594, in tests at 100 % overlap with an impacting barrier generating a delta-V of 13 km/h to 13.3 km/h.

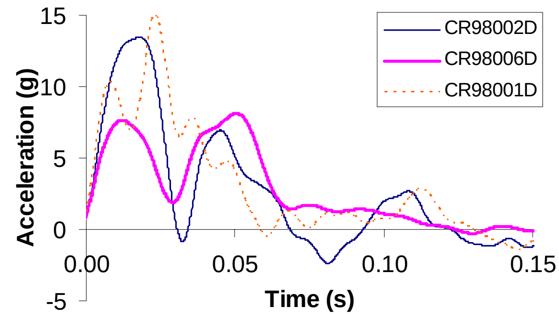

Figure 12.

The crash pulses from theCR98001, CR98002, and CR98006, in tests at 100 % overlap with an impacting rigid barrier generating a delta-V of 14.4 km/h to 16.9 km/h.

Real-World Rear Impacts

A large range of durations of crash pulses were found in the same type of vehicle where a similar delta-V was generated. Figure 13 and 14 and Table 3 shows the duration of the crash pulse, the mean acceleration and the delta-V from the real-world impacts from the vehicles T1 and T2. Furthermore, a considerable difference in shape of the crash pulse was registered in these cases (Figure 15 and 16). The duration of the pulses ranged from 77 ms - 134 ms. For vehicle T1, a change of velocity between 12.0 - 14.7 km/h and duration of the crash pulse from 77 ms to 109 ms was registered. For vehicle T2, a change of velocity between 17.1 - 20.4 km/h and duration of the crash pulse from 100 ms to 134 ms was registered.

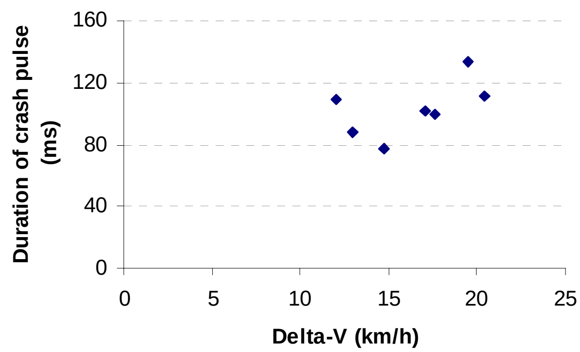

Figure 13.

The duration of the crash pulse and the delta-V from the crash recorder data from two different vehicle models of the same make.

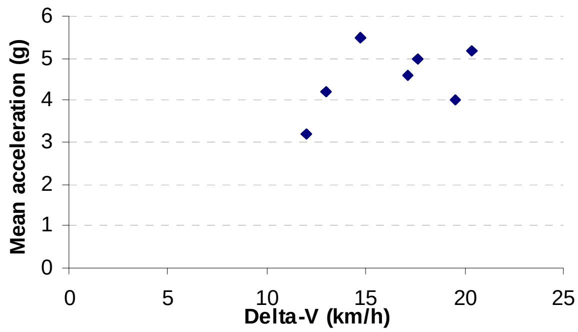

Figure 14.

The mean acceleration and the delta-V from the crash recorder data from two different year models of the same make and model of vehicle.

Table 3.
The duration of the crash pulse and the delta-V from the crash recorder data from two different year models of the same make and model of vehicle.

Car	CPR Number	Delta-V (km/h)	T_p (ms)	a_{mean} (g)
T1	C29521	14.7	77	5.5
T1	C30044	13.0	88	4.2
T1	C29614	12.0	109	3.2
T2	C30032	20.4	111	5.2
T2	C29732	19.5	134	4.0
T2	C29876	17.6	100	5.0
T2	C29739	17.1	102	4.6

Figures 15 and 16 shows the acceleration pulses from the real-world impacts from the vehicles T1 and T2.

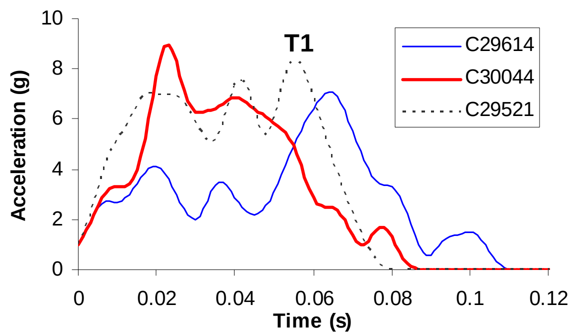

Figure 15.

The crash pulse measured in vehicle T1 in collisions with a change of velocity between 12.0 - 14.7 km/h.

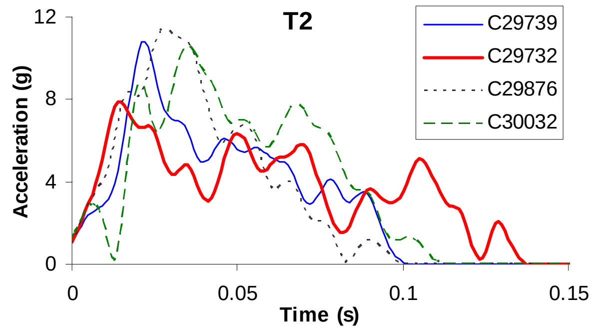

Figure 16.

The crash pulse measured in vehicle T2 in collisions with a change of velocity between 17.1 - 20.4 km/h.

DISCUSSION

A large variation in duration of crash pulse for a given delta-V and pulse shape can be produced in vehicles manufactured in the mid 1990s in rear impacts (Figure 6-12). Both delta-V and mean acceleration (i.e. duration of the crash pulse for a given delta-V) have been shown to influence the risk of AIS 1 neck injuries (Krafft et al., 2002). For a given delta-V a longer pulse will result in a lower mean acceleration and a lower risk of neck injuries (Krafft et al., 2002). The variation in durations of crash pulse for a given delta-V revealed in this study implies that vehicle seats aimed at reducing the risk of an AIS 1 neck injury should be designed in such a way that they provide the optimum protection in rear impacts in crashes where a great variation in duration of the crash pulse for a given delta-V might occur. These findings emphasise the importance of mean acceleration or the duration of crash pulse for a specific delta-V to be specified, in addition to delta-V, for sled tests that evaluate the protection from AIS 1 neck injuries of the seat, as suggested by Linder (2002).

A large variety of durations of crash pulse for a specific delta-V will be produced in the same car model, as exemplified by the real-world crash pulses collected from two year models of the same vehicle make and model (Figure 15 and 16). Therefore it can be expected that any vehicle will in real-world collisions be exposed for a large variety of durations of crash pulses for a specific delta-V. This might indicate that the design of the seat would have the largest potential to reduce the risk of AIS 1 neck injury in a rear impact since a huge variety of pulse shapes will be generated in the same vehicle model due to the various configurations of the collisions.

In this study the duration of the crash pulse (T_p) was defined as the time when the acceleration changed from positive to negative after 90 % of delta-V had occurred. This definition was used to ensure that the main part of the energy was transferred into the impacted vehicle at T_p. From the crash pulses analysed for this study it was found to be a robust definition of the duration of the crash pulse.

The crash pulses were filtered with CFC 36 due to oscillations found in the crash pulses. It has been surmised that these oscillations may be due to the mounting methods used to attach the accelerometers to the vehicles. For the real-world data the oscillations could be due to the design of the crash recorder. The filtering of CFC 36 was chosen instead of the CFC 60 and did not influence the delta-V from any of the pulses (as exemplified in Figure 3). The benefit of the CFC 36 filtering was that it highlighted the main characteristics of the crash pulses and was thus the rational of the choice.

The two vehicles of the same make and model for the US and European market which were tested in this study had different bumper systems. The European bumper system (crush cans, bottom, Figure 17) was designed for the NCAR damageability test and required replacement after a test. The US bumper system (hydraulic shock absorbers, top Figure 17) resulted in no damages in both rear-into-flat barrier and rear-into-pole impact test at five mile per hour.

Figure 17.

The US bumper (upper) and the European bumper (lower) from the vehicle tested in test SL01001 and SL01002.

The US and European bumper systems resulted in similar shape of the crash pulse for the first 10 ms (Figure 9). After that the first peak acceleration was reach the shape of the two pulses developed somewhat differently in terms of when maximum and minimum magnitude of the pulses was reached.

The range of delta-V explored in this study cover the range where rear impacts causing AIS 1 neck injuries most frequently occur (Parkin et al., 1995, Hell et al., 1999, Temming and Zobel, 2000). The main part of the crash tests and real-world data were from delta-Vs at or close to those suggested as delta-Vs for sled tests that evaluate the protection from neck injuries in rear impacts. The delta-V for these sled tests has been proposed to 15 km/h or 16 km/h (Cappon et al., 2001, Muser et al., 2001 and Langwieder and Hell, 2002). For each vehicle in the crash tests a range of durations of the crash pulse for a specific delta-V according to various crash configurations as for the real-world data can be expected. The range of durations of crash pulses for delta-Vs at 14.9 km/h or 17.1 km/h would, according to the results shown in Figure 4 and 13, be at least 69 ms to 130 ms which correspond to a range of mean acceleration of 3.3 g to 7 g. The range of duration of the crash pulses published by Heitplatz et al. (2002) were for the delta-V of 15.7 km/h to 16.9 reported to be approximately 90 ms to 110 ms. These findings are within the range of what has been found in this study. And not surprisingly, with a larger number of vehicle tested the range of duration for a specific delta-V widens, as show in this study.

Mean acceleration has for frontal collisions been shown to influence the risk of injuries (Ydenius, 2002). In that study it was shown that increased mean acceleration increased the risk of MAIS 1 injuries. Of the MAIS 1 injuries in Ydenius (2002) neck injuries are approximately 30 % of these. As a consequence, Ydenius findings emphasises the findings in this study of the importance of mean acceleration with respect to neck injuries.

Recently, attention has been focused on the need to define an acceleration pulse for standardised rear impact testing to evaluate the risk of AIS 1 neck injuries. In sled test proposals (Cappon et al., 2001, Muser et al., 2001 and Langwieder and Hell, 2002) corridors for the crash pulses with a wide range of durations of the crash pulse for a specific delta-V has been suggested to be used. From the results of this study it is not possible to identify a typical mean acceleration (which correspond to a duration of the crash pulse) for a specific delta-V either in the laboratory crash tests or from the real-world data. It might be the case that in rear impacts with a risk of AIS 1 neck injuries there is not one typical pulse or impact severity to be found. Rather a range of duration of crash pulses and delta-Vs that influence the risk of injury. Therefore it is suggested that duration of the crash pulse or mean acceleration, in addition to delta-V, should be specified for impact severity of sled test that evaluate the protection from the seat in rear impacts. This should be taken into consideration in such tests to minimizing the risk of sub optimization of seat protective performances.

CONCLUSIONS

From laboratorial tests with various vehicles impacted at the rear, a range of crash pulse durations between 65 ms to 130 ms was found for delta-Vs from 10.2 km/h to 19.4 km/h. Furthermore, from real-world rear collisions of the same vehicle make, a range of duration of crash pulse between 77 ms to 134 ms was found for delta-Vs from 12 km/h to 20.4 km/h.

This study shows that a similar delta-V can be generated by a variety of mean accelerations. Since mean acceleration have been found to be the main factor influencing the risk of AIS1 neck injuries, both delta-V and the duration of the crash pulse for a specific delta-V (i.e. mean acceleration) should be taken into consideration when defining impact severities in sled test procedure for vehicle seat safety performance assessment. In a sled test procedure a specification of a delta-V is therefore suggested to be accompanied with a specification of the mean acceleration or the duration of the crash pulse and the range of duration for a given delta-V of crash pulses that the seat could be exposed to, be taken into consideration in such tests.

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