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Crashworthiness Analysis of Real Small Overlap Impact (SOI) Accidents in Spain and Comparison to SOI Tests

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Abstract:

Background: Recent studies identified new trends in frontal accident configurations, i.e. small overlap.

Objective: This emerging type of crash represent a higher injury risk for the occupants compared to other frontal crashes due to the small interaction of the structural energy absorption elements.

Method and Material: In response to this new accident reality, IIHS introduced a new type of crash test to evaluate crashworthiness: the Small Overlap Impact (SOI) test.

Results: The purpose of this study is to analyze the accident trend in Spain to study the changes in the overlap in frontal crashes and identify crashworthiness similarities between an SOI crash test and a real crash.

Keywords: Accident Analysis, IIHS, Crashworthiness, Small Overlap Impact (SOI).

1 Introduction

Over the last 30 years, the consumer test programs enhanced the development of crashworthiness in cars and, with lower impact, light trucks. These initiatives caused a positive response in the automakers which developed several innovative countermeasures significantly increasing the safety level of their vehicles [1].

Although, frontal impacts is the most common crash test configuration, these type of accidents still represent the largest proportion of crashes with serious and fatal outcomes in terms of occupant injury [2] and several factors were identified that are thought to contribute to fatalities of restraint occupants in newer vehicles [3,4]. For this reason IIHS performed a study on frontal crashes of good rated vehicles resulting in serious or fatal injuries[4] as despite that consumer programs are a significant contributing factor of the increase in vehicle safety, a lack of further progress incentives was identified in 2009[5].

Additionally, accident studies indicate that Small Overlap Impacts (SOI) account for a significant percentage of frontal crashes [6, 7]. SOI are frontal crashes in which the impact forces do not engage the interaction of the rails in charge of energy absorption (Figure 1).

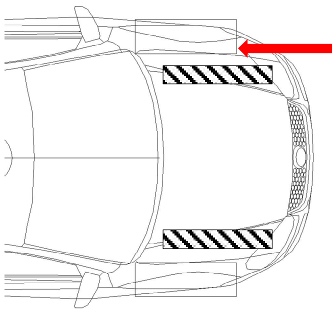

Figure 1. Example of force intrusion outside the long members

This type of crash is at least as severe as other frontal crashes. Some authors consider that the countermeasures designed for frontal crashes with more overlap may not be effective for SOI [2] as this impact configuration is not only frequent but also pose greater injury risk [7]. However, other studies observed that the injury risk is similar for other frontal crashes [1].

2 Test configurations

As a result, the Small Overlap Impact test was introduced in 2012 by the IIHS as a consumer assessment test aiming to increase the crashworthiness of vehicles in this new impact situation that was not tested previously.

In the SOI test, a vehicle is propelled at 64.4 km/h towards a rigid barrier. The test vehicle is aligned with the rigid barrier with a 25 ± 1 percent overlap between the vehicle's frontend width and the right edge of the barrier's surface. The test configuration is shown in Figure 2.

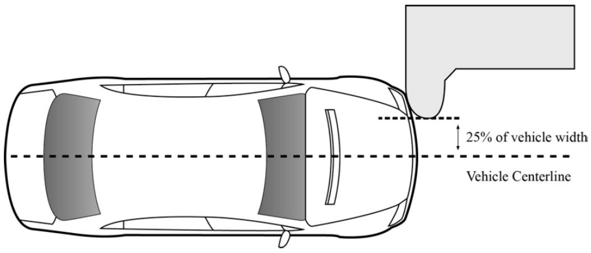

Figure 2. Small Overlap Impact Test configuration. Source:9

The side of the barrier is set back from the radius to prevent secondary contacts with the vehicle.

3 Implications of SOI test to vehicle design

Crush zones of newer vehicles manage crash energy to reduce forces on the occupant compartment but main structures are concentrated in the middle 50 percent of the front end. Small overlap frontal crashes primarily affect a vehicle's outer edges, which are not well protected by the crush zone structures.

Real accident analysis enables to determine the most common injuries occurred in these types of crashes and the main structural parts involved. The injuries can be divided in upper (head and chest) and lower (pelvis and legs) body regions [7].

3.1 Upper body region

The upper body region is the second area with the highest percentage in AIS 3+ injuries (42% for chest and 20% for head) in small overlap crashes [10]. This crash configuration frequently produce lateral motion increasing injury risk from contacts with outboard components such as A-Pillar and door [4]. This is due to the fact that this lateral motion causes oblique kinematics to the occupant influencing to the interaction with the restraint systems significantly reducing its performance.

However, there are other identified factors related to the restraint systems interaction such as steering wheel intrusion, seat belt characteristics and the airbags design [7]. The interaction of these factors is shown in Figure 4.

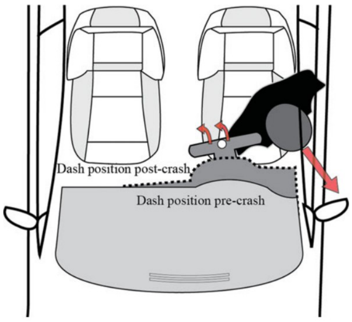

Figure 3. Interaction between the dummy lateral displacement and the dashboard intrusion. Source (7)

The oblique motion is also identified in SOI tests. As the occupant in real crashes, this crash configuration causes the Hybrid III dummy to move laterally and therefore increase the risk of head impact against the A-Pillar and steering column. In fact, in testing environment is frequent that, the most critical aspect in head and chest injury prevention is the poor interaction with the restraint systems.

However, it is know that the forward head excursion of the Hybrid III dummy it is usually undervalued due to dummy kinematics [11] for this reason, it is possible that in test cases the head contacts is being underestimated.

Additionally, the impact with the stiffest vehicle structures leave to a severe acceleration pulse and the restraint system must dissipate a lot of energy. This energy causes an increase of upper body region injury risk.

New restraint systems improvements are needed to prevent the abovementioned occupant excursion and lateral movements.

3.2 Lower body region

The most injured body region in SOI crash conditions is the knee-thigh-hip (KTH) (including pelvis). In fact, the percentage of AIS 3+ injuries in KTH is more than 70% [10] making the lower body region the most critical area in SOI.

The lateral motion of the dummy not only affects the overall performance in the upper body region but also has a negative influence in the lower part of the dummy. The dummy lateral displacement causes that the knee impact zone is not the expected in other frontal impacts. Therefore, the knee impacts in a stiffer zone increase the KTH injury risk.

Additionally, tibia and foot injuries account for AIS 2+ injuries in 36% of cases [10]. These injuries are commonly caused by the lower Instrument Panel (IP), footrest and brake pedal. In this lower area the barrier hits the wheel impacting against the wheel house and firewall. The crashworthiness of this area is very important to prevent intrusions in the lower structures. It is necessary to reduce the intrusion to prevent injuries by creating load paths to the long members, floor, subframe, door, roof and rocker panel.

3.3 Countermeasures

As previously mentioned, SOI tend to show high levels of intrusion and there is strong relationship between intrusion and injury severity [5]. The challenges posed by the SOI in terms of energy dissipation and structural intrusion suggest that improvements have to be made in order to prevent these intrusions when the vehicles is loaded outboard of the longitudinal members [2].

In the EC FIMCAR project [12] the need for improvement was also identified. It is suggested that spreading the loads in the horizontal direction is also an important factor for addressing small overlap cases.

Literature identifies two main countermeasures to increase crashworthiness in this crash configuration. One is based on a design that enables to deflect the vehicle and avoid the full engagement [1]. The second consist in modifying the structural elements to increase energy absorption [14].

3.4 Sliding collision strategy

The main differences between sideswipe and no sideswipe crashes rely on the initial impact location and the overall performance of the deformation structures. This countermeasure aims to cause a sliding motion of the car against the barrier by increasing the stiffness of the impacted structural elements to prevent the vehicle engaging.

The interaction between the crash barrier and the wheel is highly important in the general motion of the vehicle in a SOI. Depending on the stiffness of the wheel rim and the wheel supporting elements, the vehicle can deflect the trajectory causing a sliding collision. This design avoids high intrusion values but causes a high lateral motion which is very demanding for the restraint systems. Additionally, the lateral motion can also increase the risk of knee impacts in stiffer areas increasing injury risk.

3.5 Energy absorption strategy

In contrast to the previous strategy, in this case the vehicle structure is designed to absorb the crash. As mentioned previously, the wheel crashworthiness can determine the intrusion in the lower area. For this reason an efficient design of the load paths is of high importance to prevent intrusions in the occupant compartment. Developing new structural elements to use the traditional load paths and the increase of the stiffness of the most affected areas can be useful solutions to increase the crashworthiness of new vehicles.

Additionally, to provide effective protection in SOI, the occupant compartment needs to resist crash forces that are not tempered by new designed crush-zone structures and the restraint systems must dissipate the high acceleration due the stiffness structure.

4 SOI in Europe

Currently the SOI test is only implemented in IIHS consumer tests and therefore is only applicable to vehicles sold in the US market. However, Lindquist et al. [6] identified that 34% of fatal frontal crashes occurred in Sweden were SOI. Additionally, accident data from the PENDANT EC-project [16] showed that nearly 20% of the analyzed frontal crashed corresponded to an overlap lower than 25% (Figure 5).

Additionally, results from the FIMCAR project [16] using GIDAS accident data show a higher rate of fatal outcome for lower overlap rates (Figure 6).

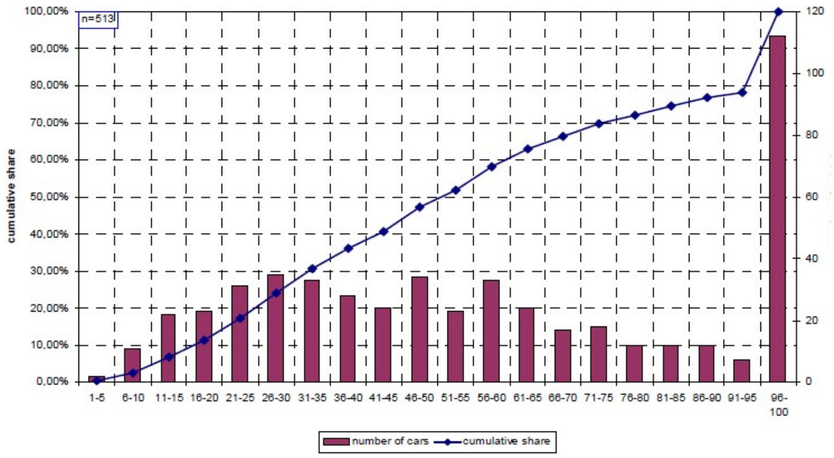

Figure 4. Level of overlap in the PENDANT cases. Source (15)

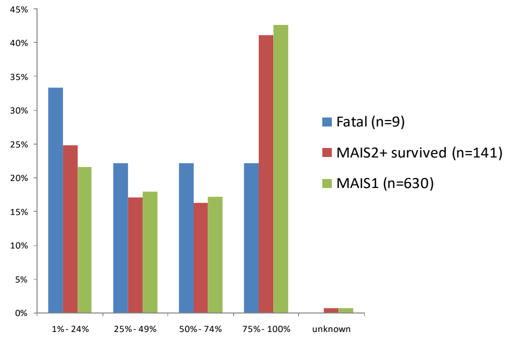

Figure 5. Outcome severity depending on the impact overlap. Source (16)

4.1 Spanish data

From publicly available Spanish accident data it is not possible to determine the frequency or risk of SOI due to the lack of injury and overlap information. However, analyzing accident records from the Spanish Traffic Administration [17] it can be observed that frontal crashes account for only 12% of total accidents but for the 38% of accidents with fatal outcome (Figure 7).

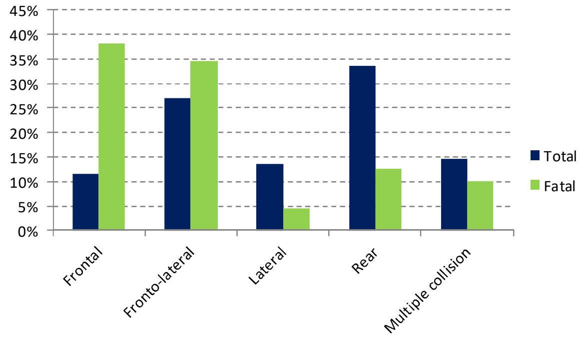

Figure 6. Crash configuration of the Spanish accidents. Source (17)

This overrepresentation indicates that further research is needed in frontal crashes in Spain and more detailed information needs to be collected to enable this research.

5 Analysis of real SOI accidents

In response of the lack of research in frontal accidents and SOI in Spain, this paper shows the result of the study of 19 frontal impacts corresponding to SOI.

5.1 Data sources and selection criteria

The Accident Investigation Team at Applus+ IDIADA gathered in-depth accident data since 1999. A total of 110 cases were made available for analysis.

The selection criterion was based on the Collision Deformation Classification (CDC) as it is a good indicator of the type of crash and extent of the deformation. However each case was individually examined through picture reports as limiting the selection to the CDC can significantly reduce the number of SOI cases[5] because when the frontal longitudinal structure is engaged it is easier to classify the crash[18] and therefore SOI can be underrepresented in CDC.

Only crashes on the left side of the vehicle were selected as all vehicles are left handled drive (LHD) and therefore the CDC codes shown in Figure 8 were selected:

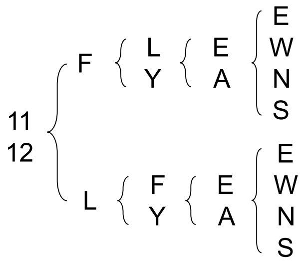

Figure 7. CDC options used for the sampling criteria

22 cases were obtained complying with the abovementioned selection criterion. However, after exhaustive analysis of the accident graphic material, 5 accidents were identified as SOI that can be well compared with the current SOI test configuration.

6 Results

The selected cases were analyzed in detail through the investigation reports and pictures. The results of this analysis are shown in this section.

First of all the different types of vehicles involved are analyzed as in laboratory crash tests, there is only one car involved and therefore there is no interaction with other structural elements from the oncoming vehicle. In the sample selected, the 70% of the vehicles are Passenger Cars (PC) which are the most testes vehicles in the IIHS SOI tests. However, there is also a 10% of Sport Utility Vehicles (SUV), Utility Vehicles (UV) and trucks (Figure 9). Although the work reflected here does not correspond to a full impaired analysis, the differences between the two involved vehicles are taken into account when analyzing the consequences of the impact.

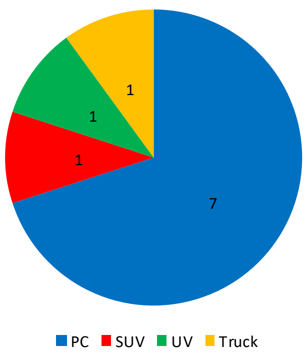

Figure 8. Distribution of the type of vehicles involved in the studied accidents

One of the most important differences between the two vehicles is the different mass. For this reason, the mass ratio was taken into account as shown in Figure 10. In four out of five cases, the mass ratio is 1±0.2 which is significantly adequate for direct comparison.

However, in the second case a mass ratio lower than 0.2 can be observed. This is due to the fact that one of the involved vehicles is the truck that was mentioned previously. The truck collided against a passenger car and therefore the difference in the mass of both vehicles is very high.

Despite this limitation, the second case was still considered for analysis as the deformation patterns that can be observed in the accident pictures show good correlation with the common patterns in crash tests. The deformation of the vehicle can be observed in Figure 11.

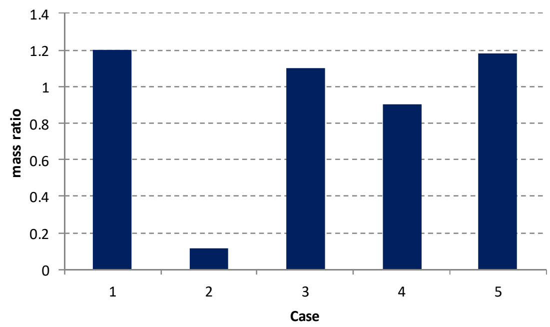

Figure 9. Mass ratio between the involved vehicles in each of the studied cases

Figure 10. Final position of a vehicle involved in a SOI crash

As mentioned in the deformation patterns that are commonly observed in SOI tests, in Figure 11 it can be observed that the incoming force did not involve longitudinal structural elements causing high levels of intrusion in the driver compartment.

In all of the analyzed cases, the estimated impact speed is considerably higher than the speed in SOI tests. The calculated delta V which is commonly used to express impact severity in accident investigation are highly variable but this variability is mainly due to the second case with a very low delta V for the truck that was involved. This can be observed in Figure 12.

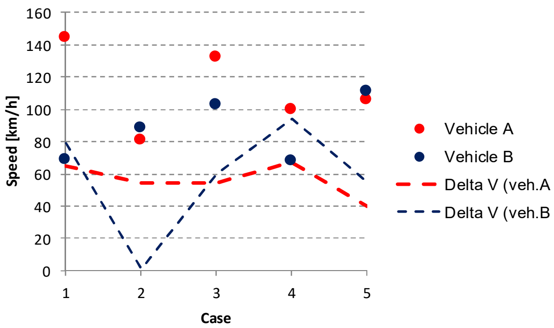

Figure 11. Impact speeds and delta V of the studied cases

Finally, concerning the injuries, all the investigated accidents had severe outcome. This is mainly due to the fact that the sampling criterion of the source database is based on fatal outcome or severe outcome for several passengers. This bias the database and therefore most of the injured passengers suffered severe injuries.

This fact can be observed in Figure 12 in which the number of MAIS 3+ injuries for the upper and lower extremities is shown. In the analyzed cases, these injuries are usually caused by the high intrusions in the vehicle due to the impact. Additionally, lower extremities injuries is more closely related to that fact and it is also reflected in the graph of Figure 12 with an 80% of lower extremities injuries with injury severity of MAIS 3 or more.

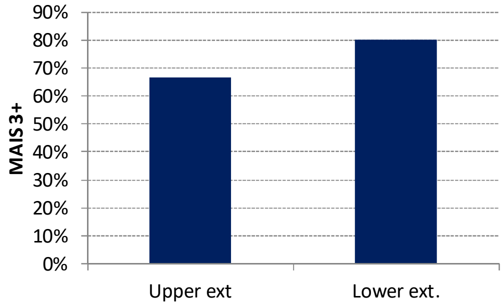

Figure 12. Level of severe injuries in the upper and lower extremities

7 Conclusions

The introduction of Small Overlap Impact tests responded to a reality observed in the United States. Some studies also show that this type of accident also occur in Europe. Additionally, these accidents are significantly frequent and pose at least the same risk than other type of frontal crashes.

The passive safety improvements achieved in the last years led to a significant reduction of fatalities in the roads. Consumer tests have been one of the main drivers for these improvements and still are by improving the current crash procedures and assessments and introducing new ones. These improvements are always connected to the accident reality or technological improvement of vehicles. This is reflected in the introduction of the SOI test in the IIHS assessment.

As abovementioned, in Europe there is also evidence of the existence of this type of accident and the extensive work carried out in the EC-funded FIMCAR project concerning frontal impact reflected that several improvements in frontal impact compatibility should be made.

However, further research must be conducted in this field to assess the suitability of the introduction of this type of crash in the European consumer assessment as the priorities must be based on cost benefit assessment and, to the knowledge of the authors; there is no research in this direction for this type of countermeasures.

Finally, with the current accident data in Spain the incidence of this type of accident nor the injury risk to the occupants cannot be assessed. Additionally, the database used for analysis is biased as it only includes a small number of cases and only with severe outcome. However, some trends such as injuries related to SOI intrusion in the occupant compartment were identified.

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