VEHICLE DEFORMATION IN REAL-WORLD SIDE IMPACT CRASHES AND REGULATORY CRASH TESTS

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ABSTRACT

Side impact crashes with fatal or serious injuries were selected from the National Automotive Sampling System/ Crashworthiness Data System files. Deformation patterns for the sample of crashes were compared with the damage seen in regulatory tests. In particular, the rate of involvement of the sill and pillar structures was considered. The study suggests these structures are less involved in real crashes than in the current regulatory Federal Motor Vehicle Safety Standard 214 test. Suggestions for altering the test conditions are made.

INTRODUCTION

In the United States, the minimum side impact protection is now governed by Federal Motor Vehicle Safety Standard (FMVSS) 214. The standard specifies a minimum requirement for the quasi-static side structure strength (phase-in requirement since 1993), assessed by measuring the force required to deform the structure at a low rate of loading (13 mm/s). The standard also includes a dynamic test (applicable to all new passenger vehicles since 1997), where the vehicle is subjected to a 54 km/h impact from a moving deformable barrier. In Europe, new vehicle designs are required to meet ECE R95, or the equivalent EC Directive 96/27/EC since October 1, 1998.

Although both U.S. and European regulations use a mobile deformable barrier to assess side impact protection in vehicle-to-vehicle crashes, the regulations vary in detail.

FMVSS 214 uses a 1,361 kg mobile barrier with a deformable element striking a vehicle at 53.9 km/h. The face of the deformable element is made from two sections of aluminium honeycomb. The main section has uniform crush characteristics, with an additional section representing a bumper. The vehicle under test is stationary. In order to simulate two moving vehicles, the mobile barrier is crabbed at an angle of 27 degrees to the perpendicular. The front face of the barrier is 1,676 mm wide and 559 mm high, with the bottom edge set at a height of 279 mm from the ground. The bumper element is 203 mm high and mounted 51 mm above the lower edge of the main element.

The European test uses a lighter deformable barrier with a mass of 950 ±20 kg. The barrier has smaller physical dimensions—1,500 mm wide and 500 mm high. The barrier consists of 6 equal-area crush elements (3 across the top and bottom), each with varying stiffness. A bumper is represented by extending the bottom row of elements 60 mm further than the top row. The elements are stiffer at the bottom and in the middle and softer on the sides, to represent a real vehicle stiffness distribution. The bottom edge of the barrier is 300 mm from the ground. There is no attempt to simulate two moving vehicles in the European regulations. The mobile barrier impacts the target vehicle perpendicularly at an impact speed of 50 km/h.

To learn more about the real-world relevance of these different regulatory test conditions, a study was initiated of side impact injury crashes in the United States. In this paper, the extent to which the side impact test procedures appear to reproduce real-world side impact vehicle damage is discussed. Further analysis of occupants' injury experience in the crashes studied will be presented in a later paper.

With the limited regulatory side impact testing, there is always the risk that design will be optimised for that condition, with energy management features virtually bottoming out to achieve the best results. Good safety design requires energy management over a wide range of crash scenarios. This study is intended to provide information on how the test specification could be altered to improve the quality of the simulation, and perhaps provide a (further) test that discourages tuning of the side impact performance to meet one specific set of criteria.

METHOD

The source of data was the National Automotive Sampling System/ Crashworthiness Data System (NASS/CDS) database. The selection criteria for extracting the serious injury cases from the NASS/CDS 1992-99 database were:

- side impacts with a principal direction of force (PDOF) between 2 and 4 o'clock, or 8 and 10 o'clock;
- damage involving the passenger compartment; VDI specific horizontal area codes P, D, Y, or Z;
- occupants with at least one injury rated at AIS 3+ but not killed;
- passenger vehicles of model year 1992 or later;

- age of ‘case’ occupant(s) was restricted to between 13 and 64 years old;
- restrained occupants only; and
- contained or partially ejected occupants only.

The same criteria were used to extract fatal cases for study, with the exception that the case occupants died.

The vehicle occupants selected for study were thus chosen to be as closely relevant to the type of situation mimicked by legislative testing as possible. The intention was to understand if the test could be further refined, both in terms of vehicle loading and injury prediction, though the injury analysis will be presented in a later paper.

Details of the serious injury cases were obtained in hard copy form with slides for cases from 1992-96. Since 1997, NASS/CDS cases have been available electronically. Thus serious injury cases (AIS 3+) for 1997 and 1998 were printed out from the electronic files. It was not possible to obtain hard copies of fatal cases from 1992-96 in a timely manner, so cases from these years were not examined. Fatal cases from 1997-99 were included in the study and were printed out from the NASS/CDS electronic files.

Each case was reviewed in detail by the investigators to confirm whether the coded variables used for selection were correct. If the investigators judged that any of the variables had been incorrectly assessed, the data were recoded, and the cases eliminated from the sample if the recoded versions did not meet the above selection criteria.

In the case of multiple impacts to the case vehicle, the case was eliminated unless it was clear that the serious or fatal injuries were sustained in a side impact meeting the criteria above.

Several additional assessments of the damage profile were made in each case. In particular, an assessment was made of whether either the A- or C-pillars were significantly involved in the direct crush damage. Vertically, the amount of involvement of the sill relative to the rest of the side structure above it was also assessed. The general vertical profile was also characterised by assessing whether there was more crush at pelvic level (bottom-in), waist level (top-in), or uniform (vertical) adjacent to the case occupant.

RESULTS

The selection criteria produced 147 crashes with seriously injured occupants (MAIS 3+) for study from the 1992-98 period. There were no crashes with more than one vehicle containing a ‘case’ occupant, so there were also 147 vehicles in cases that appeared to meet the selection criteria.

Following the case-by-case review, 20 of the original 147 serious injury cases were excluded from further analysis for the following reasons:

- direction of force incorrect (6 cases);
- AIS 3+ injury not sustained in side impact (4 cases);
- no occupant with AIS 3+ injury (5 cases);
- relevant occupant not restrained (2 cases);
- no significant damage to passenger compartment (2 cases); and
- more than one of above (1 case).

In 2 of the 127 remaining serious injury cases, photographs of the case vehicle were not available, but these were retained in the analysis despite some loss of data. Thus there were a total of 127 crashes and 127 case vehicles available for study.

Forty-six case vehicles containing 47 fatally injured occupants apparently met the selection criteria, according to the NASS coding. When these cases were studied in detail, 8 were eliminated from further consideration for the following reasons:

- direction of force incorrectly assessed (3 cases);
- fatal injuries not clearly sustained in relevant side impact (2 cases);
- occupant unlikely to be restrained (1 case);
- lack of photographs prevents analysis (1 case); and
- total structural failure giving effective total ejection (1 case).

That left 38 vehicles with 39 fatally injured occupants available for study.

Because the serious and fatal cases selected for study came from different time periods, albeit with the same selection criteria, results were tabulated separately in this analysis.

The type of object striking (or struck by) the case vehicle in the whole sample is shown in Table 1. Tables 1-4 include cases with both struck and non-struck side ‘case’ occupants, though each vehicle is counted only once where there were two or more ‘case’ occupants.

Passenger cars were less often the striking vehicle in the fatal group, with pickups and trucks in particular being more common. In total, 108 (85 percent) of the serious sample and 31 (82 percent) of the fatal sample involved another vehicle as the striking object. The PDOF in these vehicle-to-vehicle crashes is shown in Table 2. Note that more than two vehicles may have been involved in any particular crash, but the description ‘vehicle-to-vehicle crash’ applies to the critical side impact.

Table 1.
Striking Object by Number of Crashes

Striking Object	Serious N	Serious %	Fatal N	Fatal %
Motorcycle	1	1	—	—
Car	56	44	6	16
Pickup	20	16	10	26
Passenger van	3	2	2	5
SUV	9	7	4	11
Light-goods van	6	5	2	5
Coach/bus	3	2	—	—
Truck	10	8	7	18
End of barrier	2	2	1	3
Pole	9	7	1	2
Tree	4	3	3	8
Other fixed objects	2	2	—	—
Multiple off road	2	2	2	5
Totals	127		38	

Sixty-four of the total 139 vehicle-to-vehicle crashes (46 percent) had a PDOF of 3 or 9 o'clock, i.e., close to perpendicular impacts. Sixty-six (47 percent) had a PDOF of 2 or 10 o'clock. It should be noted, however, that the PDOF has only been coded to the nearest 30 degrees, and therefore even crashes with PDOF assessed as being closer to 9 o'clock than 10 o'clock may still have some small longitudinal component. In other words, the figures in Table 2 should not be interpreted as implying that nearly half the impacted vehicles were stationary. The majority of these crashes occurred at intersections (79 percent of the serious crashes and 77 percent of the fatal crashes) where both vehicles were likely to be moving.

Table 2.
Principal Direction of Force in Two-Vehicle Crashes

PDOF	Serious N	Serious %	Fatal N	Fatal %
2	12	11	4	13
3	12	11	6	19
4	3	3	1	3
8	4	4	1	3
9	36	33	10	32
10	41	38	9	29
Totals	108		31	

Table 3 shows the mass distribution of the striking vehicles in all vehicle-to-vehicle side crashes.

Table 3.
Striking Vehicle Mass in Two-Vehicle Side-Crashes

Mass (kg)	Serious N	Serious %	Fatal N	Fatal %
<1001	4	4	2	6
1001-1500	42	43	8	26
1501-2000	32	33	10	32
2001-2500	8	8	4	13
Truck/bus	11	11	7	23
Other NK	11		—	
Totals	108		31	

The fatal cases tended to involve heavier vehicles as the striking object. The masses of trucks and buses are not normally stated in the NASS files because these vehicles are rarely inspected, but such vehicles are inevitably considerably heavier than the case vehicles.

Delta V estimates are available in most of the files. Note that delta V figures have not been recalculated when any of the damage data or PDOF were changed. The authors cannot attest to the accuracy of these delta V estimates.

Table 4.
Struck Vehicle Total Delta V by Number of Vehicles in Two-Vehicle Crashes

Delta V (km/h)	Serious N	Serious %	Fatal N	Fatal %
<10	1	1	—	—
10-19	1	1	—	—
20-29	22	25	1	5
30-39	37	42	5	24
40-49	19	21	7	33
50-59	7	8	4	19
60-69	1	1	4	19
70-79	1	1	—	—
NK	19		10	
Totals	108		31	

It can be seen that the fatal cases tended to have higher delta Vs as would be expected.

All the analysis so far presented was based on the whole sample of cases studied. In order to comment more directly on the relevance of the regulatory tests, cases involving vehicle-to-vehicle crashes with a passenger vehicle (car, pickup, SUV, and passenger van) as both the struck and striking vehicle were selected. Further, cases were considered only if there was at least one 'case' occupant on the struck side in each crash, for direct comparison with the regulatory test situation. Cases with two seriously injured occupants on the struck side were counted only once in the following analysis. There were no vehicles with two fatally injured case occupants on the struck side, nor any with one fatally and one seriously injured case occupant on the struck side, so each vehicle was counted only once in the following analysis.

With these further restrictions, the sample was reduced to 68 serious injury crashes and 21 fatal crashes. This represents less than half the cases meeting the original selection criteria, which themselves did not cover all side impacts. One should be aware that although this subgroup is particularly relevant when commenting on the type of crash the regulatory tests try to reproduce, it represents something less than half of all side impacts with serious or fatal injuries.

The type of passenger vehicle involved as both the struck and striking vehicle is shown in Tables 5 and 6.

Table 5.
Struck Vehicle Type in Crashes Similar to Regulatory Tests

	Serious		Fatal	
Vehicle type	**N**	**%**	**N**	**%**
Car	62	91	18	86
Pickup	1	1	—	—
Passenger van	4	6	2	10
SUV	1	1	1	5
Totals	68		21	

Only a small proportion of the struck vehicles, almost certainly less than the proportion in the fleet, are larger passenger vehicles (vans, pickups, and SUVs). This suggests the typical higher seating position in such vehicles affords some measure of protection in side impacts. A similar conclusion about the benefits of higher seating positions and of higher sills in light trucks was suggested by Kahane (2000). He found that seat belt effectiveness was much higher for struck side occupants in light trucks than in passenger cars, probably due to less intrusion adjacent to the occupant's thorax with higher seating positions and sill structures.

Table 6.
Striking Vehicle Type in Crashes Similar to Regulatory Tests

	Serious		Fatal	
Vehicle type	**N**	**%**	**N**	**%**
Car	43	63	5	24
Pickup	17	25	10	48
Passenger van	6	9	4	19
SUV	2	3	2	10
Totals	68		21	

Nearly two-thirds of the serious injury cases involved a passenger car as the impacting vehicle, but only a quarter of the fatal cases involved a striking passenger car. This suggests that the generally larger, higher, and heavier pickups, passenger vans and SUVs are more aggressive than conventional cars as striking objects in side impacts. This result is consistent with other research indicating that these vehicles are more aggressive in side impact crashes than cars of comparable mass (Gabler and Hollowell, 1998; Lund and Chapline, 1999; Nolan et al., 1999; Sommers et al., 1999). The reasons for the greater aggressivity of the larger passenger vehicles as the striking object in this study will be examined further in a later paper.

Table 7 shows the PDOF in this subgroup of crashes most closely represented by regulatory tests.

Table 7.
Principal Direction of Force in Crashes Similar to Regulatory Tests

	Serious		Fatal	
PDOF	**N**	**%**	**N**	**%**
2	4	6	3	14
3	3	4	2	10
4	—		1	5
8	2	3	1	4
9	26	38	7	33
10	33	49	7	33
Totals	68		21	

Forty-three percent of both the serious and fatal groups had a PDOF close to 3 or 9 o'clock. Fifty-four percent of the serious sample and 48 percent of the fatal sample had a PDOF closer to 2 or 10 o'clock. As noted above, even those cases assessed as being closer to 9 or 3 o'clock are likely to have had at least a small longitudinal force component.

The striking vehicle mass in this restricted sample is shown in Table 8.

Table 8.
Striking Vehicle Mass in Crashes Similar to Regulatory Tests

	Serious		Fatal	
Mass (kg)	**N**	**%**	**N**	**%**
<1001	2	3	2	10
1001-1500	32	50	7	33
1501-2000	27	42	9	43
2001-2500	3	5	3	14
NK	4		—	
Totals	68		21	

Surprisingly perhaps, there is relatively little difference in the mass distribution of striking vehicles between the fatal and serious groups. The average mass of the striking vehicles in the serious sample was 1,485 kg, and in the fatal sample it was only a little higher at 1,560 kg. As the difference in the mass distribution of striking vehicles in the fatal and serious samples is small, this suggests that other factors, such as the height and structure of the striking vehicle's front structure, are more critical in the injury outcome than the mass. This result matches the findings of a previous Insurance Institute for Highway Safety study to assess the effects of mass, stiffness, and geometry in side impact crashes (Nolan et al., 1999). In this study, striking vehicle mass was found to have a relatively small effect on struck vehicle occupant injury measures when compared with striking vehicle ride height.

Although the analysis has now been restricted to crashes 'similar' to the regulatory tests, how similar are real crashes to the tests?

Horizontal Deformation Patterns

When the FMVSS 214 side impact barrier is used as the striking test object, there is typically loading by the barrier across or near to the A- and C-pillars of the struck vehicle. The alignment of the barrier in the FMVSS 214 test typically results in the left edge of the barrier engaging the A-pillar. As the crabbed barrier crushes the struck vehicle, it also moves toward the C-pillar, usually generating maximum deformation near the C-pillar. In a survey of 20 vehicles currently available at the Institute's Vehicle Research Centre, two-thirds have A-to-C-pillar distances less than or equal to the FMVSS 214 barrier width, suggesting the barrier would span the pillars on these vehicles.

Is this involvement of both pillars evident in real-world crashes? Table 9 shows the rate of involvement of the A- and C-pillars in this subgroup of crashes selected to be similar to the regulatory test. Cosmetic damage to the sheet metal panels around the pillars was not regarded as significant pillar involvement. Only when the basic structure of the pillars was deformed were the pillars judged to be significantly involved.

Table 9.
Pillar Involvement in Crashes Similar to Regulatory Tests

Pillars involved	**Serious**		**Fatal**	
	N	**%**	**N**	**%**
A & C	4	6	3	14
A only	36	53	13	62
C only	15	22	4	19
Neither	13	19	1	5
Totals	68		21	

The A- and C-pillar loading seen in the regulatory test may be attributable to the FMVSS 214 design. The FMVSS 214 barrier is flat across the front and is 168 cm wide. The front-end widths (measured according to SAE J1100) of 122 late model vehicles tested by the Institute since 1995 range from 117 to 171 cm, with an average of 144 cm. The average vehicle width is 24 cm narrower than the FMVSS 214 barrier. The width of the barrier more closely approximates the maximum vehicle width in this 122-vehicle sample. The maximum width ranges from 168 to 197 cm, with an average of 179 cm. The mismatch in width of the FMVSS 214 barrier and the late model vehicles reflects the evolution in vehicle design since the inception of the barrier in the late 1970s. Most modern vehicles have aerodynamic designs with front ends much narrower than the maximum vehicle width.

The ECE R95 barrier minimises the loading of the A- and C-pillars with a narrow width barrier with softer elements on the barrier edges. Typically, the A-pillar is not involved at all except sometimes late in the impact, with contact on the backplate of the deformable barrier. On all but the smallest cars, the face of the barrier does not reach back to the C-pillar.

It can be seen from Table 9 that significant involvement of both A- and C-pillars is unusual. The C-pillar is involved in only about one-third of the cases, while the A-pillar is involved in about 60-75 percent. In a U.K. study, Thomas and Bradford (1989) found involvement rates of 68 percent for the A-pillar and 26 percent for the C-pillar. Their selection criteria included a wider range of side impacts, but nevertheless, the involvement rates of A- and C-pillars are similar to those found in this study.

This suggests that the typical A- and C-pillar involvement seen in the FMVSS 214 regulatory test is unrealistic and should be reduced. One way to do this would be to move the centre of the impact further forward on the side of the struck vehicle.

Another way of reducing the involvement of the pillars would be to shape the front of the deformable element so that it represents the shape of real vehicles more closely. Such a design would delay the involvement of the pillars in a way that is likely to produce more realistic crush to the doors and B-pillar early in the impact.

The numbers in the sample were too small to justify any further breakdown of pillar involvement to see if the type of striking vehicle had any effect.

Another way of looking at the horizontal location of the damage is to consider the specific horizontal area of damage in the VDI classification. This is shown in Table 10. In the coarse VDI classification, both the FMVSS 214 and ECE R95 test deformation would typically be classified with the VDI code P, whereas the majority of the serious and fatal sample are coded Y. The code Z might be used for some of the smallest European cars.

Table 10.
Specific Horizontal Area of Damage in Crashes Similar to Regulatory Tests

VDI4 code	Serious N	Serious %	Fatal N	Fatal %
Distributed	2	3	—	0
Y (front fender and passenger compartment)	35	51	13	62
Z (rear fender and passenger compartment)	13	19	3	14
P (passenger compartment only)	18	26	5	24
Totals	68		21	

Tables 9 and 10 give broadly similar results, although there are minor differences as the pillar involvement variables included a judgement as to whether the involvement was significant or not. Crashes where one or both pillars were just involved would be coded as D, Y, or Z in the VDI variable but would not necessarily have significant pillar involvement as classified in Table 9.

Both tables consistently suggest that the horizontal distribution of damage is more likely to involve the front fender (wing) area and passenger compartment than the rear fender (wing) and passenger compartment. This may be due to the fact that the occupancy of the rear seat is low, so crashes involving the rear part of the passenger compartment and the rear fender (VDI code Z) are less likely to cause serious or fatal injury to an occupant, as the relevant seating position is usually vacant.

While one could consider moving the impact forward on the side structure of the target vehicle to better simulate the 'typical' crash, this would reduce the ability to assess side impact protection for rear occupants when they are present. As FMVSS 214 does currently attempt to assess side impact protection for both front and rear occupants on the struck side, the option of moving the impact forward could be regarded as less attractive than modifying the shape of the barrier to reduce early pillar involvement and bridging across the A- and C-pillars.

Vehicle Deformation Patterns

In order to study the vertical loading, the involvement of the sill was assessed. Those cases where the sill showed essentially no evidence of direct loading were classified as 'none' in terms of the degree of involvement. Cases where there was some limited direct contact damage, either just to the very top of the sill, or localised loading from the wheel of the striking vehicle, were categorised as 'minor.' Cases where the sill was significantly deformed by direct loading, but not to the same extent as the side structure above, were categorised as 'partial.' Finally, cases where the deformation of the sill was substantial, and similar in extent to the deformation of the rest of the side structure, were categorised as 'full.' The results are shown in Table 11.

Table 11.
Sill Involvement in Crashes Similar to Regulatory Tests

Degree of involvement	Serious N	Serious %	Fatal N	Fatal %
None	3	4	2	10
Minor	25	37	10	48
Partial	25	37	5	24
Full	15	22	4	19
Totals	68		21	

Only about one-fifth of the cases involved substantial deformation of the sill. In most cases, there was only minor involvement, or at least considerably less involvement of the sill compared with the rest of the side structure. In the fatal cases, the sill was not involved to any significant extent in more than half the cases. When only pickups and SUVs were considered as the striking object, 65 percent put little or no load into the sill of the impacted car.

Both the FMVSS 214 barrier and the ECE R95 barrier produce 'partial' door sill loading of passenger cars. The bottom edge of the FMVSS 214 barrier is 28 cm from the ground, and the bottom of the ECE R95 barrier is 30 cm from the ground. The typical passenger car door sill spans between 20 and 29 cm from the ground (Lund et al., 2000).

This suggests the height of the lower edge of the barrier needs to be reconsidered, especially in view of the increasing popularity of passenger vehicles other than conventional cars. Raising the lower edge of the barrier and shaping it to reduce pillar involvement would probably produce more realistic early crush in the critical regions of the door and B-pillar adjacent to the struck side occupant.

The shape of the intrusion of the side structure vertically was also assessed. The categorisation is shown schematically in Figures 1-3. In deciding whether the intrusion was 'top-in' or 'bottom-in,' the deciding factor was whether the intrusion was greater at chest level or pelvic level. The tabulated results are shown in Table 12.

The most common vertical profile in the serious cases is bottom-in, occurring in two-thirds of the sample. In the fatal sample, there tends to be more intrusion higher up, perhaps reflecting the increased incidence of larger passenger vehicles as the striking object. When the striking vehicle was a conventionally styled passenger car, only 27 percent of cases had a vertical or top-in intrusion profile. When the striking object was a larger passenger vehicle, 51 percent of the struck vehicles had a top-in or vertical intrusion profile.

In the European test situation, the vertical intrusion profile is typically bottom-in, though sometimes near vertical. Top-in is rarely seen if at all. The vertical intrusion in the FMVSS 214 tests is also typically bottom-in because of the bumper element.

Dalmotas compared the vertical intrusion patterns for three models subjected to both the FMVSS 214 barrier test and the ECE R95 test. For all three passenger cars tested, the 214 barrier produced more deformation at the driver's pelvis level than higher up on the door. In the ECE R95 test, the deformation of the middle of the door was slightly greater than the pelvic level for all tests (Dalmotas et al., 1991).

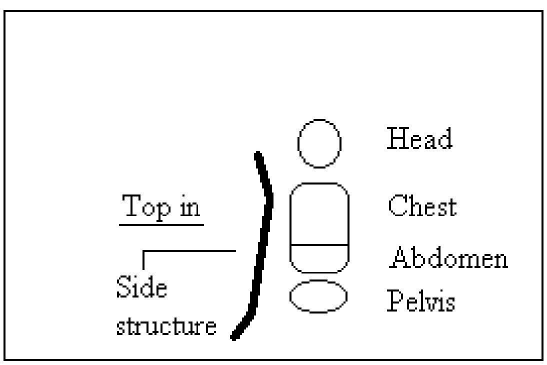

Figure 1. Top-in intrusion profile

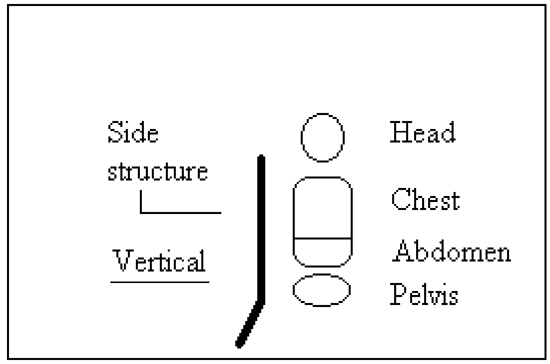

Figure 2. Vertical intrusion profile

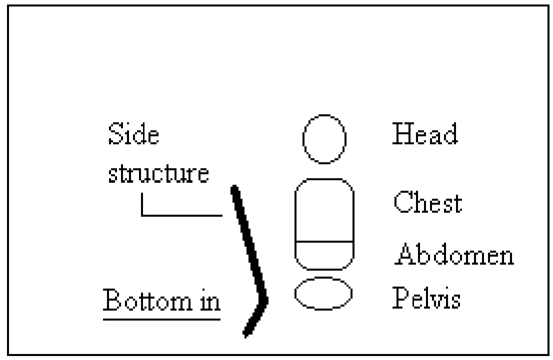

Figure 3. Bottom-in intrusion profile

Since the crashes in the fatal sample tend to be more severe than those in the serious sample, one possibility is that the vertical profile could be related to crash severity measured in terms of intrusion extent or delta V. This was investigated. In the serious sample, 80 percent of the bottom-in profiles were at estimated delta Vs of less than 40 km/h. Only 69 percent of the vertical and 40 percent of the top-in profiles were at delta Vs of less than 40 km/h. In the fatal sample, 6 out of 7 (86 percent) of the bottom-in profiles occurred in crashes with estimated delta Vs less than 50 km/h, but only 50 percent of the vertical and top-in profiles occurred at delta Vs less than 50 km/h.

With the relatively small numbers in this study, it is not possible to determine whether there is some causal link between the vertical intrusion profile and crash severity, or whether there is some other explanation for these observations. Since the crush profile (in the horizontal plane) is used to estimate the delta V, the two variables are not independent. Alternatively, other research suggests the vertical crush profile is a more important factor than the extent of deformation in injury causation in side impact crashes (Hobbs, 1995; Nolan et al., 1999). Consequently, the crush profiles may influence the risk of AIS 3+ injury being sustained, so that the case was included in the study.

Table 12.
Vertical Intrusion Profile in Crashes Similar to Regulatory Tests

Vertical profile	Serious N	Serious %	Fatal N	Fatal %
Top-in	7	11	6	32
Vertical	14	22	6	32
Bottom-in	43	66	7	37
Below occupant	1	2	—	—
Not known	3		2	
Totals	68		21	

CONCLUSIONS

Trucks and larger passenger vehicles were more frequent as the striking object in the fatally injured group than in the seriously injured group.

When the sample was restricted to passenger vehicles only as both struck and striking vehicle, and struck side occupants only, the involvement of larger vehicles as the striking object was much higher in the fatal group than the serious group (77 vs. 37 percent). This suggests that larger passenger vehicles are more aggressive as striking objects than conventionally styled passenger cars, consistent with the findings of prior Institute research (Lund and Chapline, 1999; Nolan et al., 1999).

Larger passenger vehicles accounted for only about 10 percent of the struck vehicles in total in two-passenger vehicle crashes. This suggests larger passenger vehicles afford some measure of protection in side crashes, probably due in part at least to the increased occupant sitting height.

In crashes involving two passenger vehicles, the distribution of striking vehicle mass was not very different between the serious and fatal groups. This, combined with the observations made above, suggests that it is not the increased mass of larger passenger vehicles that is principally responsible for their increased aggressivity as striking vehicles in side crashes. Other factors such as the height and stiffness of their front structures may be responsible.

Analysis of the involvement rates of A- and C-pillars in two-passenger vehicle crashes suggests significant loading of both pillars is uncommon. The A-pillar is typically involved in about two-thirds of the crashes studied, and the C-pillar only in about one third. Reduction of the C-pillar loading seen with the flat barrier used in FMVSS 214 regulatory testing would be likely to produce more realistic loading conditions on the side structure of the target vehicle.

The results suggest that one way of achieving this would be to move the centre of the impact forward on the side structure of the target vehicle, to reduce the involvement of the C-pillar. This would not necessarily allow proper assessment of the injury risk to rear seat occupants in a single test, which is at present an objective in FMVSS 214.

An alternative approach would be to shape the front face of the deformable element of the barrier so that it is more representative of the typically curved front structure of vehicles. This would delay the involvement of the A- and C-pillars, probably producing more realistic crush immediately adjacent to the dummies in the early stages of the impact when the highest injury parameters occur.

The degree of sill involvement also needs to be considered. Particularly in the fatal crashes, and in crashes with larger passenger vehicles as the striking object, the sill was not involved to any major extent in 60-65 percent of the cases. Adjusting the height of the deformable barrier element to be more representative of the current fleet would probably produce more realistic crush profiles in terms of the involvement of the sill.

The ‘bottom-in’ vertical profile of the side structure intrusion normally seen in regulatory style crash tests appears to be more closely representative of serious injury cases than of fatal cases. Further analysis of the effect of vertical intrusion profile on the pattern of injuries will be presented in a later paper.

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