ACCIDENT ANALYSES OF VEHICLE SIDE COLLISIONS

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1. INTRODUCTION

Due to the improvements of frontal crashworthiness and due to the mandatory belt wearing in more and more countries the problems of side impact gain in priority in the field of occupant protection. The fundament for technical improvements are statistical data. Therefore, recent accident analyses, especially those of In-Depth-Studies, shall be evaluated with regard to the following nowadays interesting aspects:

- types and configurations of side collisions
- impact speeds
- injury patterns
- injuries correlated with car and accident parameters
- compatibility
- biomechanics
- occupant protection
- test procedures

It will be shown that the side impact is not clarified up to now. Some results are confirmed by several authors, but many questions are unsolved, beginning with the definition of side impacts and of impact speeds.

2. RELEVANCE AND TYPES OF SIDE COLLISIONS AND SIDE IMPACTS

Side collisions, defined as collisions of cars with cars, trucks or obstacles - whereby the struck car is impacted in the side - account for a share of nearly 40% compared to frontal and rear end collisions [1], in rural areas for a share of nearly 60%, see Fig. 1. Side collisions are responsible for most of the occupant injuries. Evaluating the social costs by taking the fifth potency of the AIS, side collisions take with nearly 60% the first rank, see Fig. 1. Within the side collisions more than 70% are car to car collisions, about 20% are car to obstacle collisions and in about 10% the cars are struck by trucks [1 to 3] see Fig. 2. The distribution depends on the regarded accident severity. For example, collisions with fixed obstacles are not so often, but mostly result in severe injuries.

The impact type refers to the direction and area of the impact on the case car only. Within the four impact types - frontal, side, rear, and rollover - the side or lateral impact takes the second position with a share of 13 to 28% [3 to 7], depending on the definition of side impact (see chapter 3) and depending on the severeness of the accidents in the sample, see

Fig. 3. As several authors state, there is no doubt that the side impact is the most dangerous impact type. In the sample of Cesari [3] the average overall severity index OSI is 2.9 for the side impact and only 2.3 for the frontal impact. The frequency of severe injuries in vehicles with side impact is twice as high as for occupants in vehicles with frontal impact [8]. As a consequence, 28% of all fatally injured occupants in car/vehicle accidents are to be found in cars with side impact.

3. DEFINITION OF SIDE IMPACTS

One of the main problems in evaluating and comparing accidents, especially side impacts, is the lack of standarized definitions. The internationally used "Vehicle Deformation Index (VDI)" [9] gives the elements for an uniform description of impacts, but there is no comprising definition of frontal, side, and rear impacts.

Today, two definitions for side impacts do exist. The more common definition [1, 3, 10] considers two aspects, see Fig. 4a:

a) impact area on the side
b) impact direction 02, 03, 04 or 08, 09, 10

Thereby, the impact direction is given by the vector describing the change of momentum or the resulting impact force, see Fig. 5. Formerly, as an approach, also the direction of the relative collision speed vector was used.

The other definition [2] states an impact to be a side impact if the trajectory of the occupants relative to the car is inside the directions mentioned before, see Fig. 4b. Both definitions are the more equal as the impact for the case car is a central impact, see Fig. 5.

A third proposal - discussed in the FAKRA (member of DIN and ISO) at present - defines an impact as side impact if the impact area lies between the front and rear axle, independent from the impact direction, see Fig. 4c.

Due to the fact of two cars colliding under an angle the determination of a collision or impact speed is more difficult for side collisions than for frontal or rear end collisions. The determination of the

absolute collision speed and
relative collision speed

presumes the reconstruction of the accident, see Fig. 6. These velocities contain no information on the important speed variation of the case car. They describe the pre-crash situation which can result in very different impact severities, depending on other parameters. A better measure for the impact severity of the case car are the

equivalent test speed and the
speed variation.

Especially the speed variation is advantageous for describing loading conditions for the occupants of the case car. The mass ratio of the colliding cars is in Δv included. Necessary is the knowledge of the absorbed energies or of the equivalent test speeds of both cars. These values are difficult to estimate for the side impacted car. Necessary for the application of the Δv -method is the assumption that the impact is central, that means in practice that the case car is stationary [2, 3].

4. EXTERIOR COLLISION PARAMETERS

4.1 Impact Areas and Impact Directions

For the description of the impact area three different methods can be applied (Fig. 7):

- impact areas according to VDI [1, 9]
- impact areas according to ONSER [3, 10]
- impact points according to Renault/Peugeot [2]

The results evaluated with these methods are shown in Fig. 8. It can be seen that they can not be directly compared but it can be stated that the compartment is the more concerned as the injury severity rises up and as rigid obstacles are regarded. Hartemann et al [2] localizes the most probable impact point for both types of side collisions, car to car as well as car to obstacle, in the region shortly before the R-point of the front occupant.

There is also only to some extent agreement in the frequency distribution of impact directions, Fig. 9. In [1] and [6] the most frequent impact direction is 02 and 10 o'clock corresponding to 60°, in [7] and [10] vertical to the car. The most frequent occupant trajectory angle in [2] is some 65°.

4.2 Impact Speeds

For collision and impact speeds several results shall be given. Fig. 10 shows the frequency distributions of absolute speeds of the striking cars, at different levels of the absolute speed of the struck car [1]; there exists a dependency. The faster the struck car the faster the striking car. 83% of the striking vehicles and 77% of the struck cars have a collision speed lower than 45 km/h.

The relative collision speeds of side collisions compared to frontal and rear end collisions are shown in Fig. 11 [8]. The 50% value is 36 km/h. This describes a lower level than the 50 percentile speed variation in [2, 3] which is 23 km/h (33 km for severe accidents). Car to obstacle collisions reveal a 50% value of 32 (34 respectively) km/h [2], see Fig. 12. The 50 percentile value of the acceleration of the case car was found to be 12.5 g [7] in accidents with fatal consequences.

4.3 Mass Ratio in Car-to-Car Side Collisions

With respect to the compatibility problem - especially in side collisions - the mass ratio of the striking and the struck car is of essential interest. In Table 1 the 50% point and 90% point of the mass ratio for different injury levels are given [1]:

	all cases	OSI ≥ 3
50%	1,05	1,15
90%	1,75	2,40

Table 1: Mass ratios in side collisions for cumulative frequencies 50% and 90%

The risk for suffering severe injuries in light cars is twice compared to heavy cars (internal severity rate), the risk for causing severe injuries for light cars is half than for heavy cars (external severity rate) [2]. In about 90% of fatal side collisions the mass ratio was greater than 1 [7].

With respect to setting up representative test conditions it is useful to know that the mass of the striking vehicle is below 1100 kg in 65%, below 1800 kg in 88% of all serious car/vehicle collisions [1].

5. OCCUPANT INJURIES

Dealing with the occupant injuries one has to distinguish between injury frequency and injury severity for the occupants sitting on the "struck side" and occupants sitting on the "non struck side".

The injury frequency for the main body regions gives in several investigations nearly the same sequence [1, 2, 3, 10, 11]:

- head 46 - 62%
- upper extremities 33 - 52%
- lower extremities 24 - 40%
- chest 18 - 46%
- abdomen 6 - 22%
- spine 15 - 20%

Regarding only severe injuries (AIS ≥ 4) the sequence changes to [1, 2]:

- head 69 - 78%
- chest 39 - 60%
- abdomen 31 - 33%
- spine 8%

Nearly the same sequence reveals if the "degree of traumatisation" is calculated by multiplying the frequency with the AIS [11] or with the cube of AIS for each particular body region.

Extremely frequent for the occupant on the struck side are fractures of ribs, pelvis and hip-joint. Severe and fatal injuries occure twice to three times more frequently on the impact side than on the opposite side [1].

5.1 Injuries and Their Sources

Formerly, ejection was the leading cause of severe injuries in automobile accidents [12]. Due to the strengthening of doors, hinges and latches ejection is reduced today and has a share of 20% in side collisions with front- and rearward impact area [2].

Taking into account only severe injuries AIS $\geq$ 4, Hartemann et al [2] found the following priority of injury sources:

- door panel
- parts outside the case car
- roof frame
- A-pillar
- steering wheel

Griffith et al [7] found internal and external sources (incl. ejection) being about equally involved in fatal side impacts. The most severe internal injuries are caused by the intruding door in the chest and abdominal area, external injuries are caused by the intruding object or car on the head.

The share of severe injuries produced by interaction (overload) of nearside and offside occupants has not been analysed until yet. Hartemann et al [2] suppose that overload is only a problem in impacts without intrusion, in impacts with intrusion the injury severity is high anyway. In their sample of 269 collisions there were only two abdominal injuries caused by interaction. Cesari et al [10] suspect an increase of the injury severity for the nearside occupant and a decrease for the offside occupant.

The side window is nearly never source for injuries [6], very probably because it breaks before the head impact occurs.

5.2 Injuries and Intrusions

According to the nowadays discussed problems of side structure design the question of correlation between injuries and exterior as well as interior deformations of side impacted cars arises.

Danner/Langwieder [1] state that intrusion is not a measure of accident severity and does not correlate directly with injury severity. They found two shapes of intrusion, the rectangular shape and the triangular shape, see Fig. 13. The rocker panels - seldom deformed - do not contribute to the energy absorption, the doors get the deepest intrusion in their medium hight.

On the other hand, accident analyses of Cesari et al [3, 10] and Suren et al [11] give a nearly linear correlation between injury severity and the relative side deformation , expressed as VDI [9] or VIDI [13], see Fig. 14. These results do not allow a valuation of the door design because the side deformation depend furthermore on the impact speed and other specific accident parameters.

Hartemann et al [2] seperated the influences of speed variation and intrusion, see Fig. 15, and found the injury severity essentially increased by intrusion for the nearside occupants. The injuries of the offside occupants are not influenced by intrusions. This result gives the clear recommendation for the design of struck and striking cars to reduce intrusions by strengthening the side and soften the front structure.

The increase of the injury severity with intrusions is caused by two reasons:

1. The nearside occupant is struck with an impact velocity equal (fixed obstacle) or even greater than the speed variation of the car
2. The deformed inner door is more aggressive than the undamaged door.

The possibility to reduce the injuries of nearside occupants by intrusions using the so-called "ride down effect" is indicated in Fig. 14. There is a reduction of the OAIS with increasing exterior deformations from VDI = 1 to VDI = 2.

5.3 Effects of Belt Wearing

Safety belts protect the occupant of a side impacted car in two ways:

- the occupants are prevented from ejection
- the offside occupant is restraint to some extent.

In 1966 Huelke, Gikas [12] found ejection with 27% to be the leading cause of death in all types of automobile accidents. Ten years later Hartemann et al [2] found - for side impacted cars only - the following facts:

- the share of ejected occupants is 18% for frontward and rearward impacted cars and 8% for cars impacted in the compartment area respectively
- ejection, totally or partially, accounts for more than 40% of the fatal injuries.

Griffiths et al [7] attained to an ejection rate of some

10% in their investigations of fatally injured occupants. The majority of the totally ejected occupants were ejected through the doors.

The effect of seat belt use in side impacts is judged by Griffiths et al [7]. Very probably 4 out of 55 nearside occupants (7%) and 21 out of 34 offside occupants (62%) would have survived if they would have been belted. Hartemann et al [2] assume the reduction of risk for fatal injuries by wearing seat belts by 5 out of 59 (8%). The injured body areas of belted and non-belted occupants do not differ.

6. TEST RESULTS CONCERNING INTRUSIONS

Cesari et al [10] conducted 90° car-to-car side impact tests in order to study the influence of side intrusions by direct comparison. In half of the tests the struck car was fitted with an additional side shield preventing intrusions absolutely, in half of the tests not. This device was the only parameter variation in the three test series conducted with standard model cars in the range of 39 to 54 km/h.

The test conditions and the results are shown in Fig. 16. The results belong to the struck cars and are ratios of the figures with and without shield.

The high speed films showed in all cases without shield that the door-interior impacts the nearside dummy before he moves relatively to the car, thereby possibly causing penetration. For the integral results in head, chest and pelvis Fig. 16 furthermore demonstrates the positive influence of preventing intrusions. The injury criteria are mostly less than half. These test results are in accordance with the accident analysis results of Hartemann, see Fig. 15.

7. TEST CONDITIONS FOR SIDE IMPACTS AND REAL WORLD ACCIDENTS

For standard model cars today in USA the static intrusion test according FMVSS 214 and, if a passive restraint system is installed, the moving barrier test according FMVSS 208 and SAE J 972a is mandatory (see Fig. 17 and 18). For Europe, the lighter bended moving barrier of Fig. 18 is provided for. The ECE draft takes into consideration the lower mass of European passenger cars. Because of standardization the ISO draft took over the ECE draft for the light version. The ESV specifications provide pole tests as well as car-to-car impacts. Nowadays, within CCMC and other organisations, the test conditions of side impacts on the basis of available and new test methods are discussed. The following problems arise:

- is the car-to-car impact necessary or is the moving barrier-to-car impact sufficient
- is an additional pole impact necessary
- has the moving barrier to be deformable

- is the speed level of the moving barrier impact 65 or 35 km/h
- should the impact angle be 75° or 90°?

The French proposal, based on the investigations of Hartemann et al [2] is shown in Fig. 19. The impact speed of 65 km/h in car-to-car collisions, covering 50% [2] of killed occupants and 80% [2, 3] or 90% [1] of the injured occupants, has to be regarded as too high compared to other test conditions and their cost/benefit figures [14].

Under the aspects of representativeness, reproducibility, and low costs it is likely to have - as a first step - beside the static intrusion test only the following dynamic side impact test:

- ECE moving barrier
- 90°
- 40 km/h
- car stationary

The problem of compatibility, involved in side impacts, has to be proved for the front ends in frontal crash conditions.

8. UNSOLVED PROBLEMS IN SIDE IMPACTS

Many questions involved in side impacts have been answered in recent investigations. For example, the following facts can be stated:

- side collisions take the first and side impacts the second place in severe and fatal car impacts and produce injuries more severe than all other impact types
- the most frequent impact point lies some 10 cm before the R-Point
- the most frequent impact direction is frontal/lateral with 60 - 70°
- in impacts with high impact speed, weak door structure and aggressive front structure the intruding door hits the nearside occupant faster than Δv , producing severe injuries
- some 80% of side collisions occure up to a speed variation of 40 km/h
- the nearside occupant is more than twice endangered compared to the offside occupant
- head and chest are the most endangered body parts in side impacted cars
- in side impacts with fatal consequences internal and external impact points are nearly equally causative
- intrusions increase the injury severity of nearside occupants
- ejection accounts for 10 to 40% of all fatal injuries in side impacts
- belt wearing decreases the risk for severe injuries for the offside occupant by approx. 50%

Besides these relatively well established results many problems and questions of accident analyses have still to be solved, e.g.:

- standardized definition of side impacts
- ratio of the energies absorbed in the struck car and the striking car
- behaviour of belts in side impacts
- effect of interior padding
- optimal frontal and side structure stiffness

For the practical design the following recommendations, based on the existing results, can be given:

- to make the rocker panel participating in energy absorption by lowering the bumper or raising up the rocker panel
- to make the side structure stiff and the front structure soft
- to increase the interior padding in the head and body level for three reasons, see Fig. 20:
  1. to reduce the distance between occupant and door
  2. to absorb internal energies and to lower the accelerations
  3. to lower the internal shape-aggressivity of the deformed side structure
  4. to prevent the head impact on the striking car or obstacle.

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Collision Type (acc. Langwieder)	Criterion: Damage Area [%]	Criterion: AIS (medium)	Criterion: Cost Ratio [%]	Criterion: Cost Ratio	Rank: Damage Area	Rank: AIS (medium)	Rank: Cost Ratio	Rank: Cost Ratio
	0.7		-		11			
	6.2	1.7	11.3	38.9	7	2		2
	11.7	2.2	23.3		4	1	1	
	9.7	1.1	4.3		5	6	5	
	12.4	1.5	8.8		3	4	4	
	26.9	1.2	22.6	56.5	1	5	2	1
	15.2	1.6	22.1		2	3	3	
	2.1	-	3.0		10	-	7	
	7.6	1.0	1.4		6	7	8	
	2.8		-	4.6	8	-	-	3
	0.7		3.2		12	-	6	
	2.8	-			9	-	-	

Fig. 1: The relevance of impact types
In-Depth-Study
Hannover, Berlin
1977
150 cases

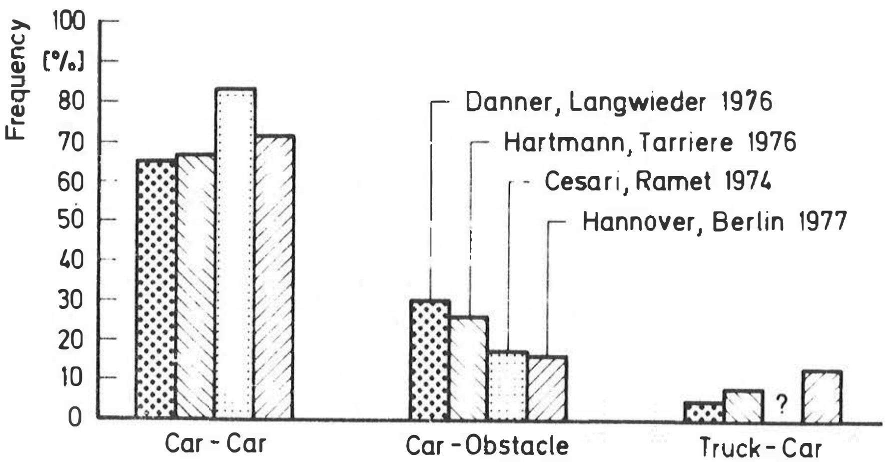


Fig. 2: Frequency of different types of side collisions

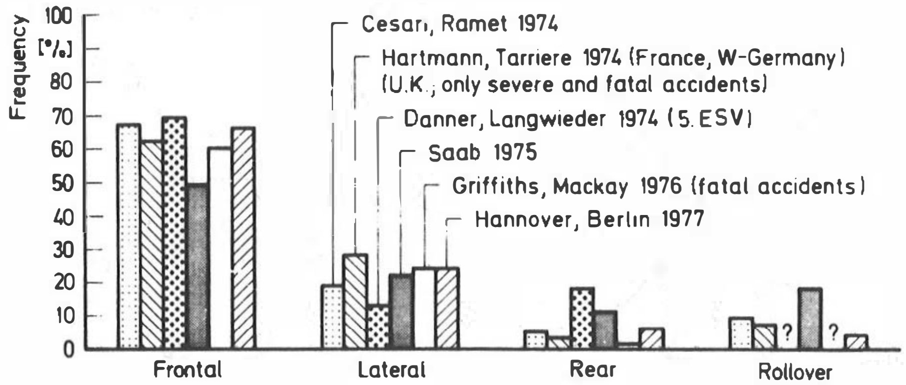


Fig. 3: The relevance of side impacts compared with other impact types

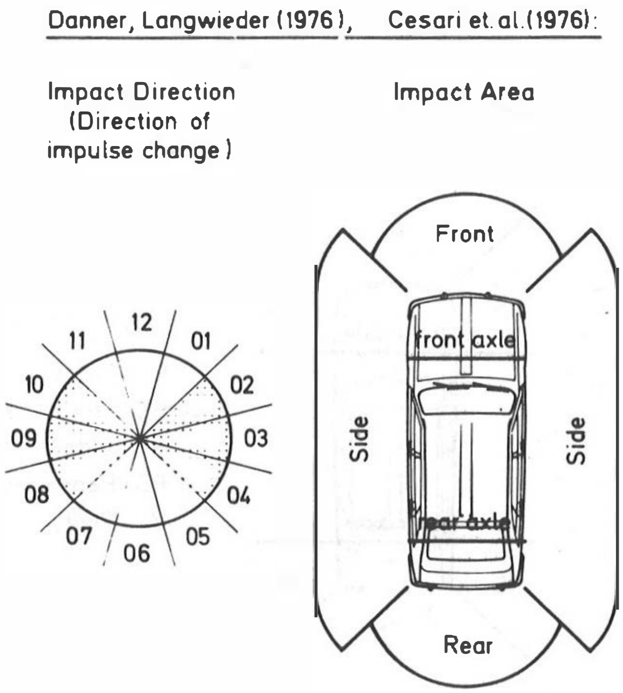


Fig. 4 a: Definitions of side impacts

Hartmann et. al. (1976):

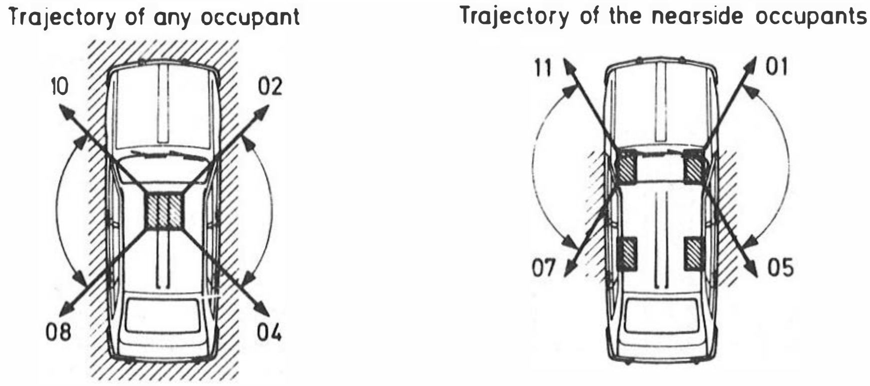


Fig. 4 b: Definitions of side impacts

FAKRA-Proposal 1977 (criterion is impact area)

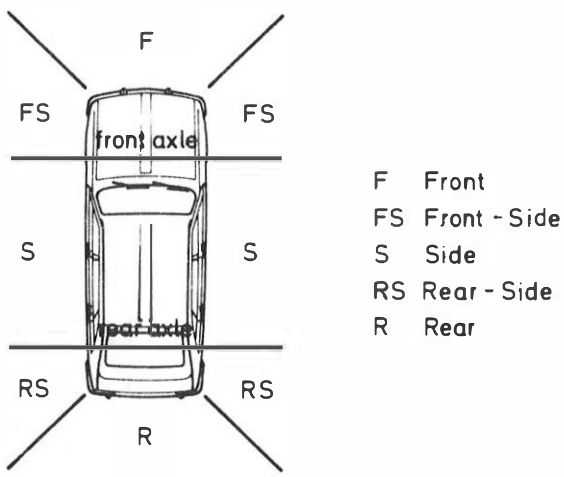


Fig. 4 c: Definitions of side impacts

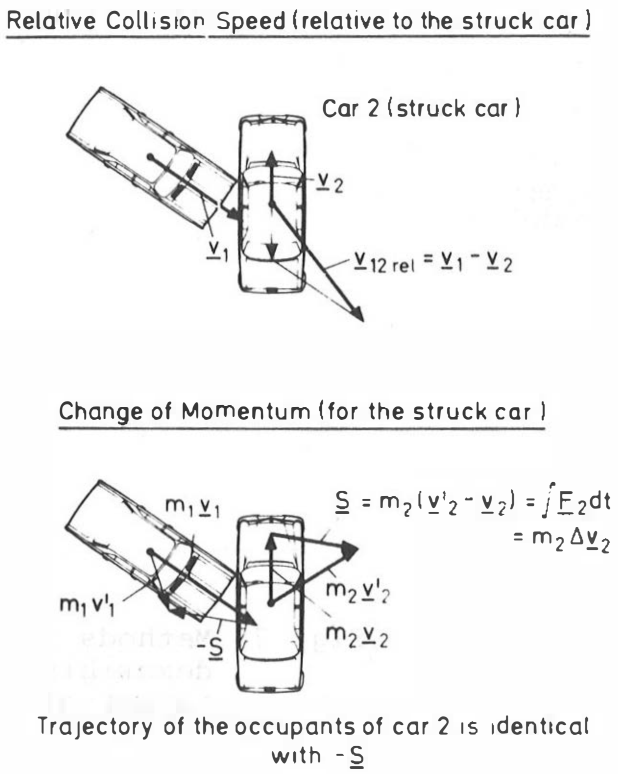


Fig. 5: Definitions of the impact direction in side collisions

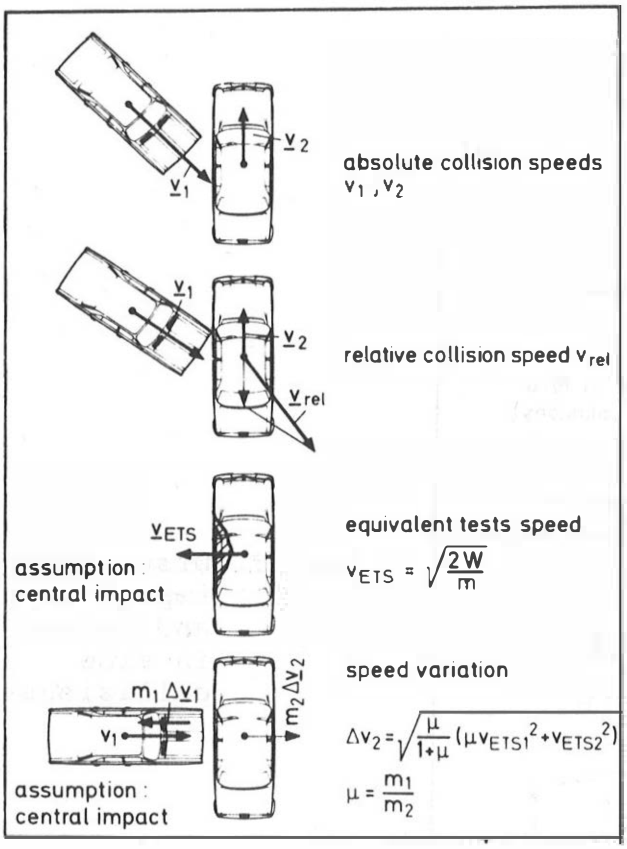


Fig. 6: Definition of impact speed

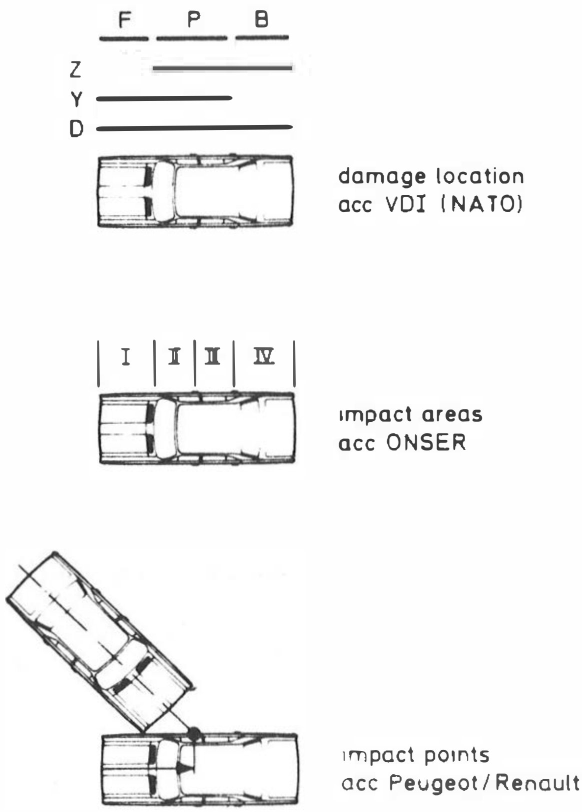


Fig. 7: Methods for describing the impact areas

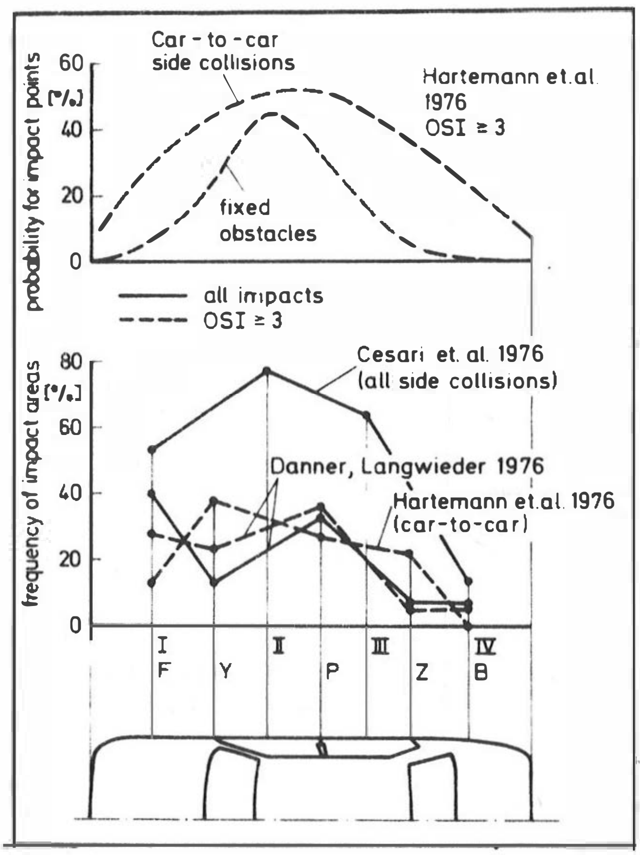
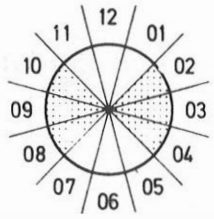


Fig. 8: Distribution of impact points and impact areas in side collisions



direction	Danner, Langwieder 1976	Bäckström, Anderssen 1976	Cesari et. al. 1976	Griffith et.al. 1976
10,02	60	33	66	17
09,03	30	57	27	79
08,04	10	10	7	4
	100	100	100	100

Fig. 9: Frequency of impact directions in side collisions

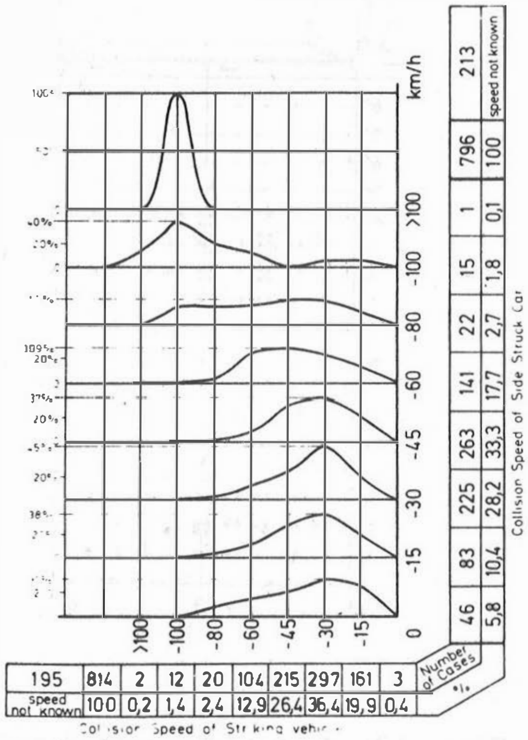


Fig. 10: Absolute collision speeds of striking and struck cars in side collisions (Danner, Langwieder 1976)

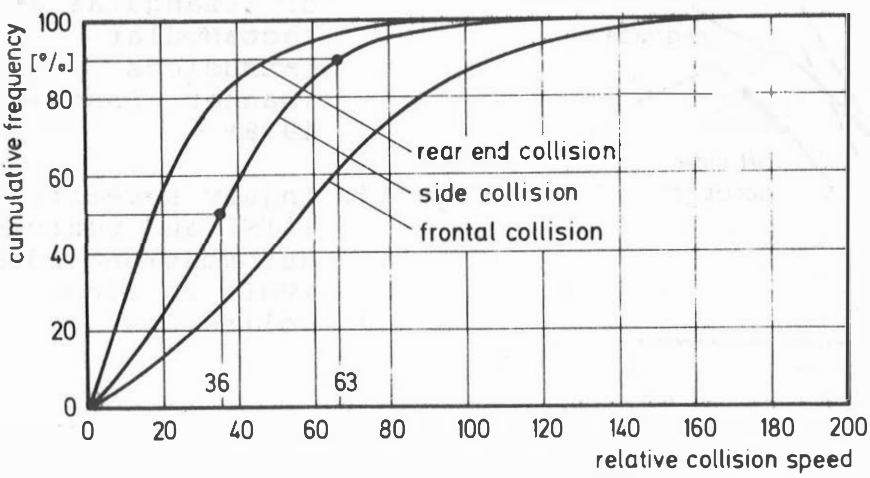


Fig. 11: Relative collision speeds in different car/ vehicle collision types (Langwieder Diss. 1975)

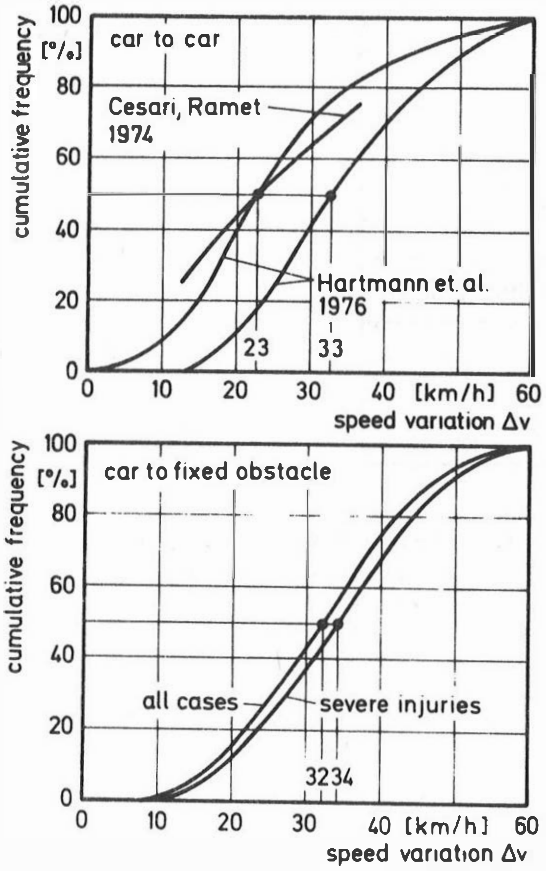


Fig. 12: Speed variation in side impacts

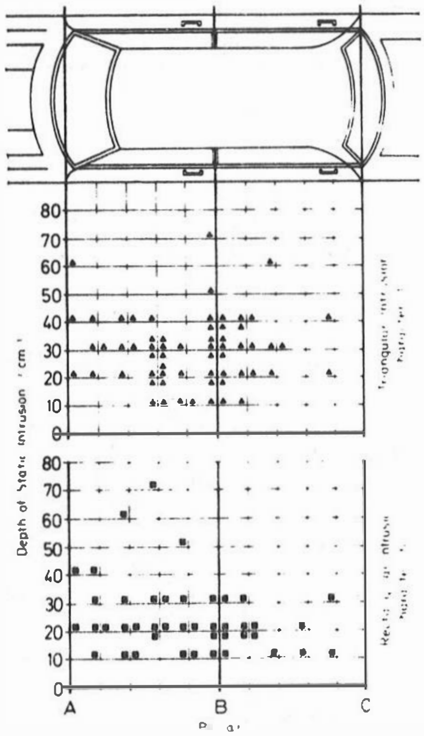


Fig. 13: Location and depth of triangular and rectangular intrusions (Danner, Langwieder 1976)

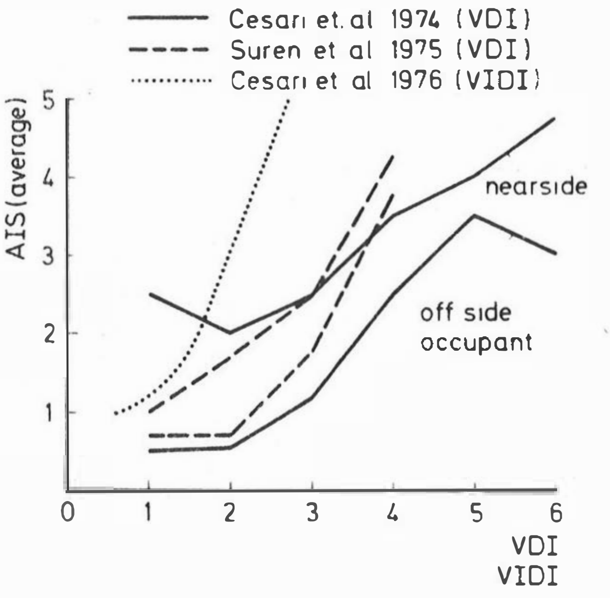


Fig. 14: Injury severity (AIS) and vehicle deformation index (VDI) in side collisions)

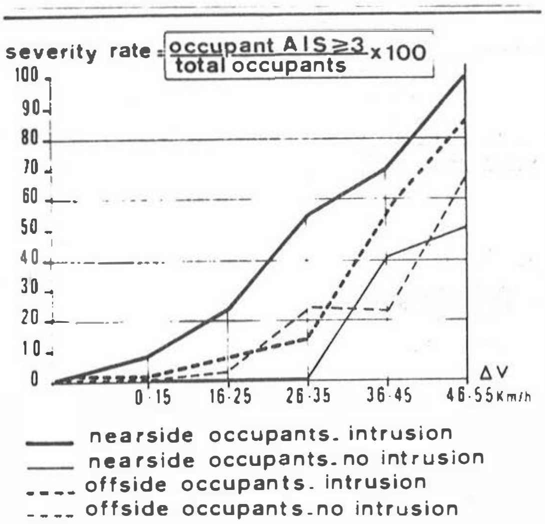


Fig. 15: Severity rate versus speed variation and intrusion in side impacts

abs. collision speeds [km/h]		impact duration	a_{res} car	HIC head	SI chest	a_y pelvis
striking car	struck car					
52	0	0.91	1.08	3.12	0.32	0.54
40	40	1.40	1.08	0.29	0.31	-
51	51	1.08	1.38	0.20	0.68	0.52

Fig. 16: Side impact test results without and with intrusion (ratios of the figures in the struck car) (acc. to Cesari et al 1976)

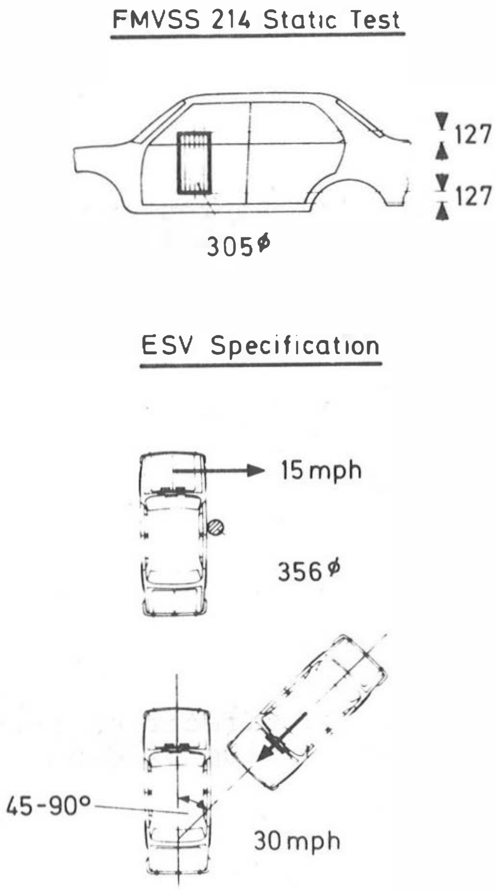


Fig. 17: Test conditions for side impacts

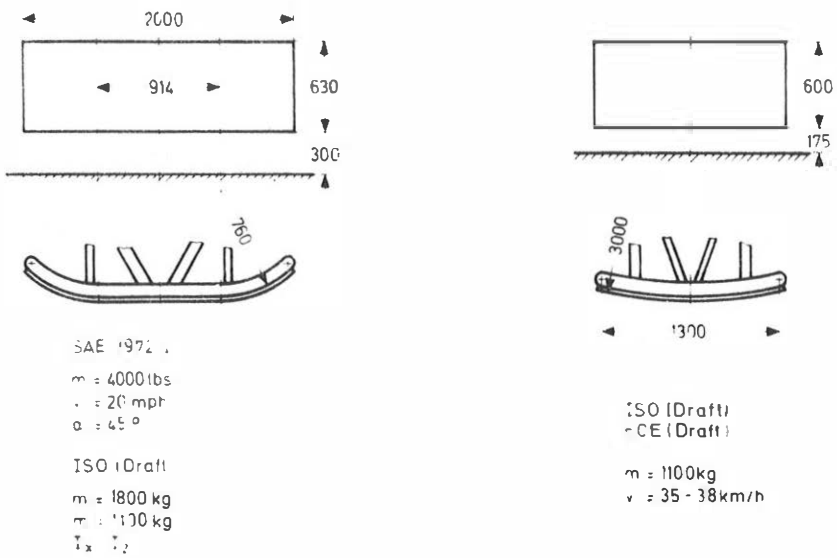


Fig. 18: Moving barriers for side impacts

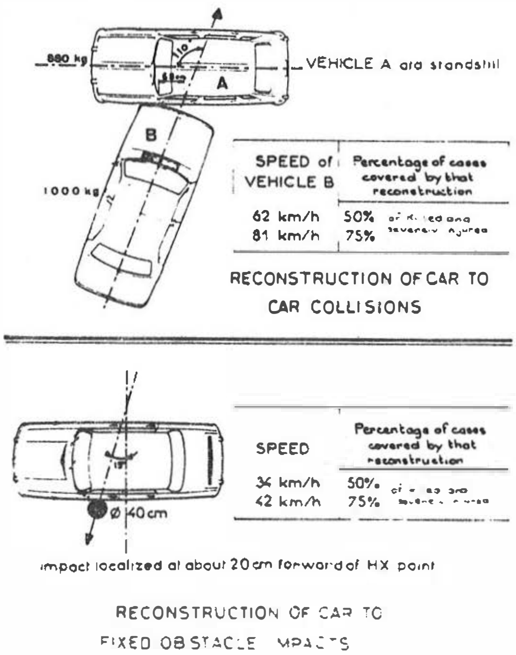


Fig. 19: Representative lateral impacts (Hartemann et al 1976)

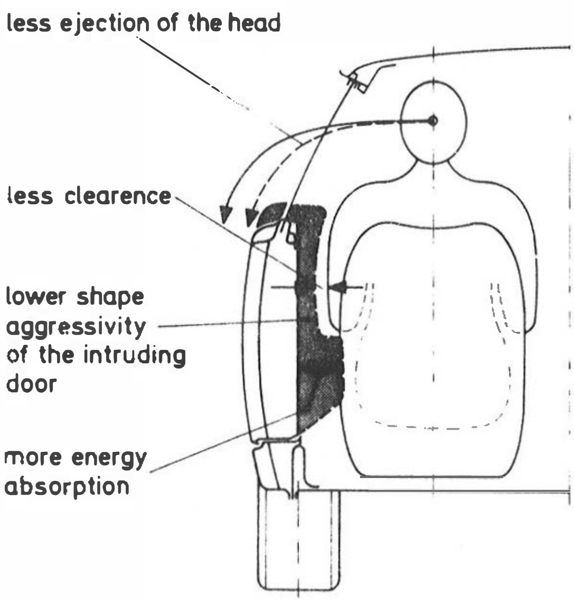


Fig. 20: Effects of interior side padding