The Deformable Barrier, a Realistic Extension of Offset Testing

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Abstract

The passive safety of passenger cars in frontal collisions is usually assessed by means of crash tests against a flat or offset rigid barrier. In addition some institutes perform car-to-car tests; however, the effort involved is very high and the reproducibility is not as good.
Accident analyses show that in most of the frontal car-to-car collisions the stiffer zones such as the engine and the front-end structures do not overlap, thus affecting the softer zones of the impacting cars. Therefore, the amount of energy absorbed in both longitudinal members is relatively low.
For this reason and in order to increase the effort spent on a realistic frontal test procedure, Mercedes-Benz is extending its offset test program by a test against a deformable barrier.
Since the deformable element according to FMVSS 214 is well known and validated, this Honeycomb element was chosen for this purpose.
The force/deflection characteristics of this element represent the stiffness of the front end of a medium to full-size car.
First results show that the vehicle deformation patterns are very similar to those found in the course of real-world accidents. Another also very important result is that the degree of overlap does not greatly influence the load on the occupants, in contrast to the tests against a rigid offset barrier which are very sensitive to different degrees of overlap.

1 Introduction

To further reduce the injury risk of car occupants in accidents, appropriate test procedures must be derived from the findings of real-world accident investigations.
General statistical information on accidents such as the accident configuration and the status of injuries can be obtained from the National Statistics. However, to design safe cars, details on the type of impact, accident severity and the nature of injuries are necessary. Therefore the results of in-depth accident investigations, for example those of the Medical University of Hanover /1/, Germany or those coming from investigations of automobile manufacturers /2/ are meaningful.
Based on Mercedes-Benz safety research, an advanced frontal impact test procedure is described.

2 The frontal impact

Most important for the definition of a frontal impact test procedure is the knowledge about the frequency of collision configurations, namely single vehicle or car-to-car accidents. Fig. 1 shows the frequency in the German National Accident Statistics. The frequency of car-to-car accidents is about 2.5 times higher than the frequency of single vehicle accidents, with an increasing tendency in the last few years. However, the number of injured occupants in single vehicle accidents is higher than in car-to-car accidents (Fig. 2).

These conclusions cannot be drawn from the Mercedes-Benz accident sample (fig. 3-4), since only accidents with injured occupants are to be investigated. In comparison to the national sample therefore a higher frequency of single accidents was observed in the Mercedes-Benz sample (see fig. 1 and 3). In contrast to the national sample the relative number of injured car occupants in the Mercedes-Benz sample in single accidents is lower, which can be explained by the different age groups and risks in the respective samples (see fig. 2 and 4).

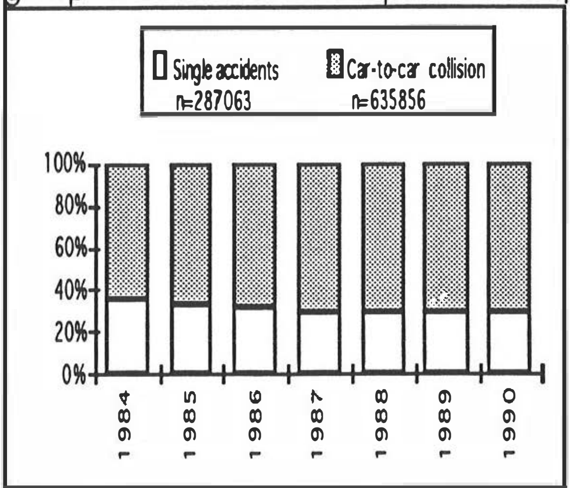

Fig. 1 - Relation of single accidents to car-to-car collisions (car-to-truck accidents not included). National Sample /3/.

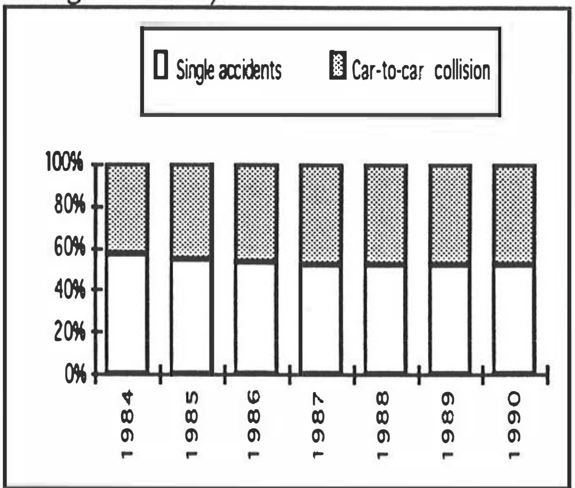

Fig 2 - Relation of injured occupants (AIS 1+) and fatalities in real-world accidents (car-to-truck accidents not included). National Sample /3/.

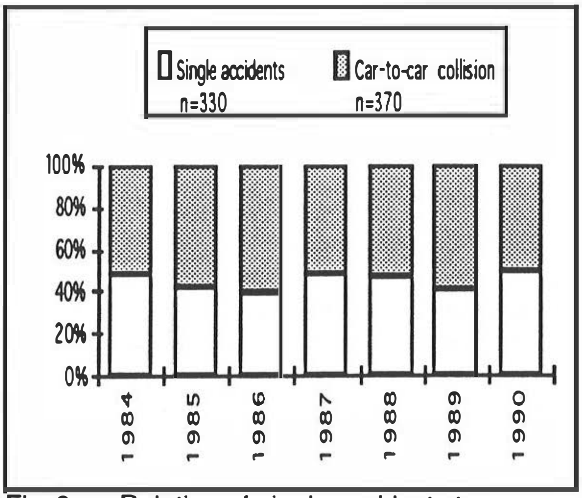

Fig. 3 - Relation of single accidents to car-to-car-collisions (car-to-truck accidents not included). Mercedes-Benz Sample.

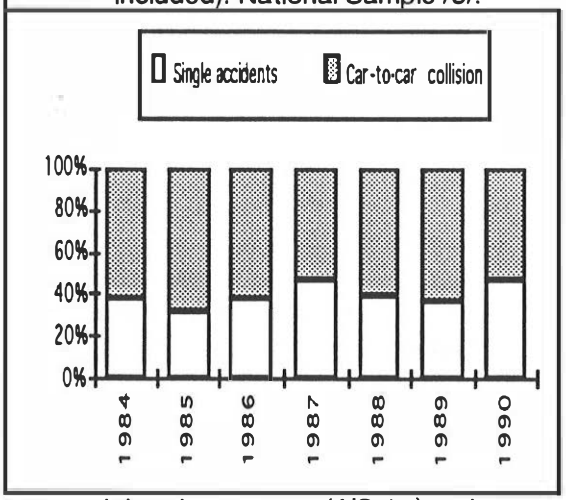

Fig. 4 - Injured occupants (AIS 1+) and fatalities in real-world accidents (car-to-truck accidents not included). Mercedes-Benz Sample.

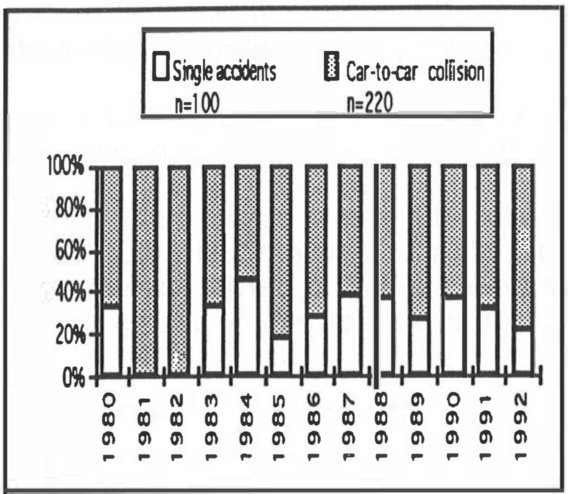

Fig. 5 - Relation of single accidents to frontal car-to-car collisions

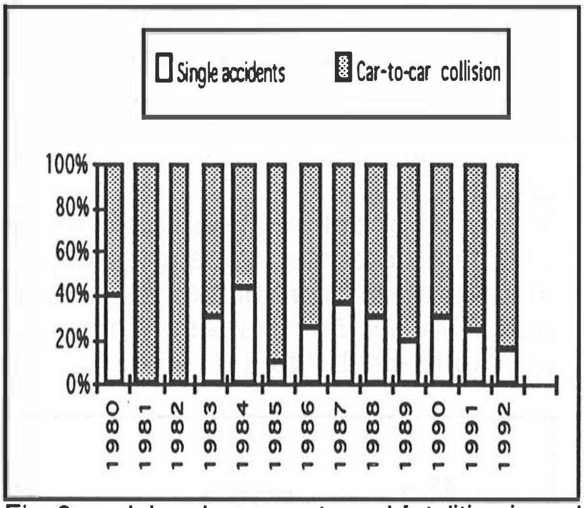

Fig. 6 - Injured occupants and fatalities in real-world frontal accidents in relation to the accident type

A more detailed analysis of single accidents based on the national data is not feasible and therefore the Mercedes-Benz data are analysed in detail, especially in regard to frontal collisions. This is all the more appropriate because it is the protection of car occupants we are aiming at by the definition of a realistic frontal test procedure (fig. 5-6).

Over the last ten years, the car-to-car collisions are the most important frontal impacts regarding both frequency and injury risk. Therefore, in a first and realistic approach a test procedure with 40% of frontal overlap and a test speed of 55 km/h was derived and presented in /4/. The choice of a rigid barrier was governed by the need for repeatability and the lack of a deformable element, simulating the force/deflection characteristics of a representative car front-end structure. Having this deficiency in mind, some additional car-to-car crash tests have been carried out. As a result of these car-to-car crashes the following conclusions were be drawn:

- the offset test in general is appropriate to simulate the most frequent and injurious car-to-car frontal collisions
- the overlap degree in rigid barrier tests has a great influence on both frontal deformation and acceleration of the passenger compartment
- to monitor the different stiffness/deformation characteristics of the various elements of the front-end structure, a deformable element is appropriate.

2.1 The realistic type of deformation

In real-world collisions the different stiffness properties of front-end structures are of importance resulting in higher deformations of the weaker zones. This is mainly true in offset collisions with initially small overlap degrees of about 1/3, occuring most frequently (fig. 7) in frontal collisions. Table 1 summarizes the deformation pattern of the frontal longitudinal members according to different overlap degrees as analysed in real-world accidents:

- In about 25% of the 81 investigated accidents the longitudinal members were not directly hit by the impacting car and remained undeformed.

- In collisions with greater overlap degrees (≥ 1/3) the longitudinal members are impacted but very frequently bent up or down without longitudinal deformation and major energy absorption.

As a result, the upper zones of the front end, not capable of absorbing great amounts of energy, are heavily loaded with the risk of intrusion into the passenger compartment.

This type of deformation would be best reproduced by a car-to-car test procedure. However, to come to a standardized, reproducible and efficient test procedure this method must be rejected. As an alternative the deformable barrier, defined in the new FMVSS 214, representing a median car front-end structure seems to be an appropriate substitute.

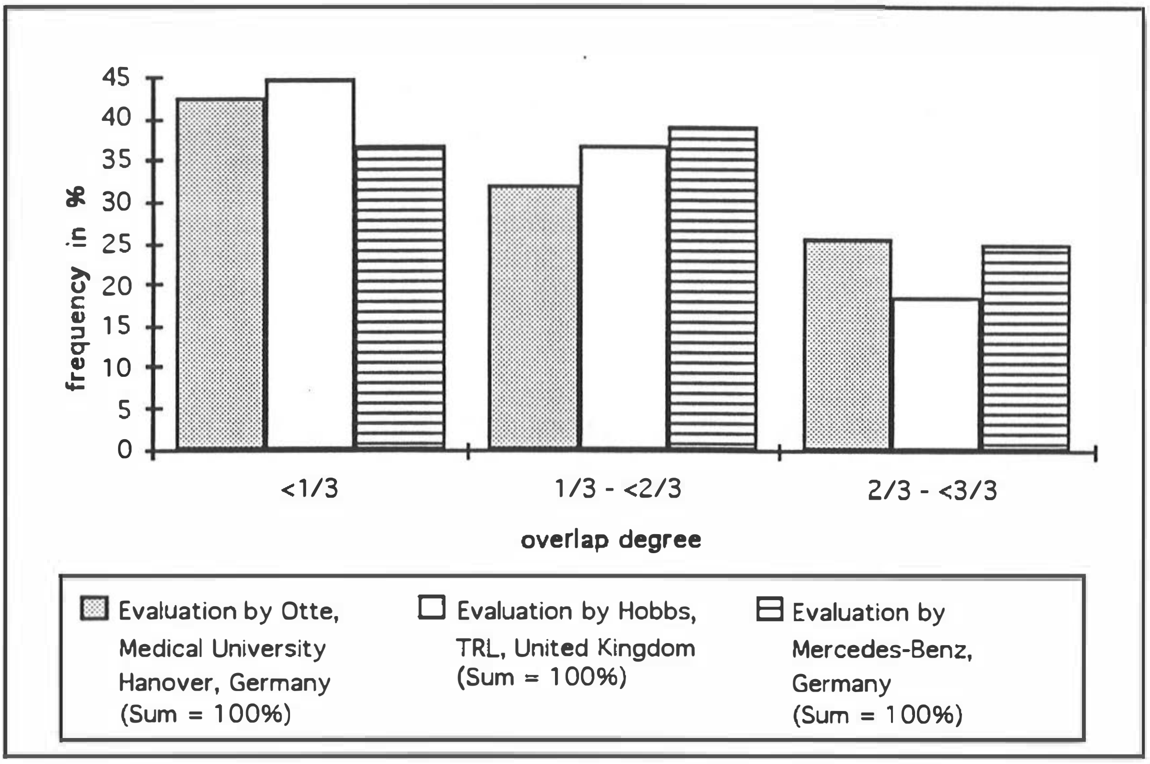

Fig. 7 - Comparison of overlap degrees of different evaluations (single accidents, car-to-car accidents)

Deformation pattern assigned to overlap degree	Cases	No deformation and movement	deformed without bending		bent without deformation		deformed and bent (up or down)	
			Both	One	Both	One	Both	One
≤ 25%	18	8	0	1	1	7	0	1
26%-50%	27	5	3	1	4	7	0	7
51%-100%	23	7	1	0	6	2	3	4
30°	13	0	0	1	6	4	0	2
Σ	81	20	4	3	17	20	3	14
	100%	25%	5%	4%	21%	25%	4%	17%

Table 1 - Deformation patterns of the front longitudinal members in frontal collisions (124, 126, 129, 140, 201 car series).

3 The offset crash against a deformable barrier

Fig. 8 shows the geometry of the FMVSS 214 barrier whereas fig. 9 focuses on the supporting members and the engine location in the front end of an actual typical Mercedes-Benz passenger car. As it can be seen from the geometrical relations, the depth of the FMVSS 214 barrier is not sufficient for frontal impact testing and may be discussed.
However, a barrier with different force/deflection characteristics in its horizontal and vertical plane (inhomogeneous stiffness) , as proposed with the CCMC foam barrier, is not appropriate. This barrier would make the test too sensitive to overlap degrees or engine configurations as opposed to impacts against a rigid barrier. A further discussion on the need of a bumper or the definition of its ground clearance is necessary.

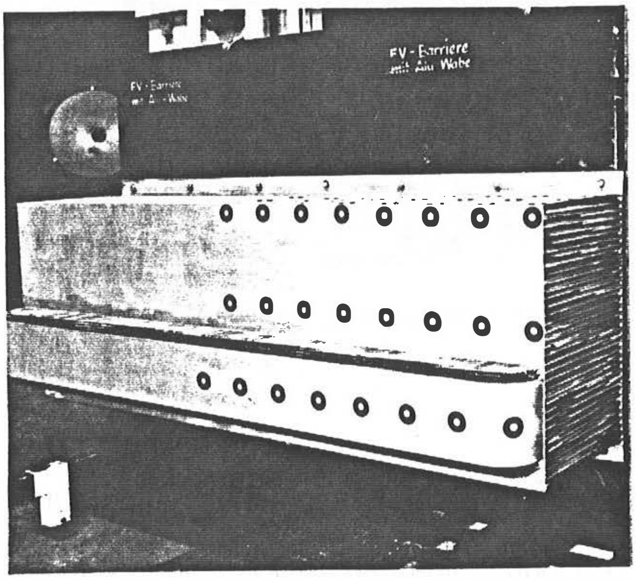

Fig. 8 - Deformable barrier

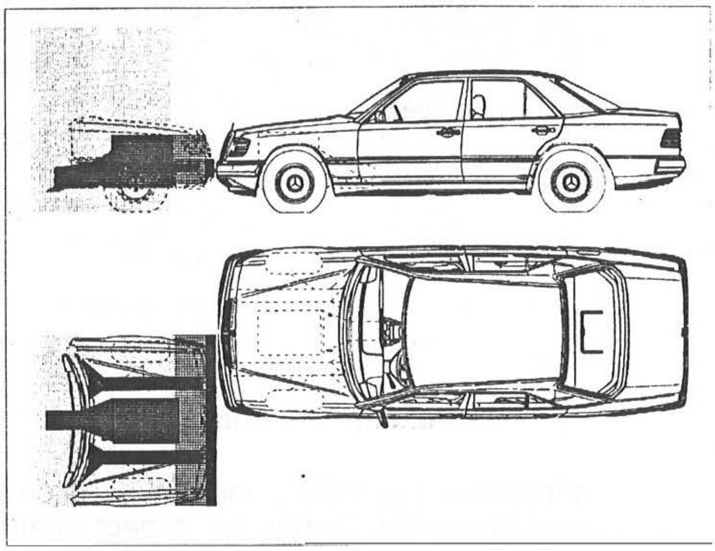

Fig. 9 - Comparison of barrier and car front

4 Test results

Independent of the specific stiffness/deformation characteristics of an individual car front-end the rigid barrier will lead to equal crush distances of both stiffer and weaker zones, thus representing only the impact of two identical cars with the same stiffness properties and 100% overlap degree.
To further analyse the stiffer and weaker zones of the front end of an individual car a deformable barrier is better suited, due to the influence of the engine, the longitudinal members and the wheel suspensions .
Fig. 10 shows a car after an impact against the deformable barrier with an overlap degree of 50% and a test speed of 55 km/h. Initially the engine and the frontal

longitudinal members remain undeformed, while the wheel housing, for instance, sustains substantial deformation.

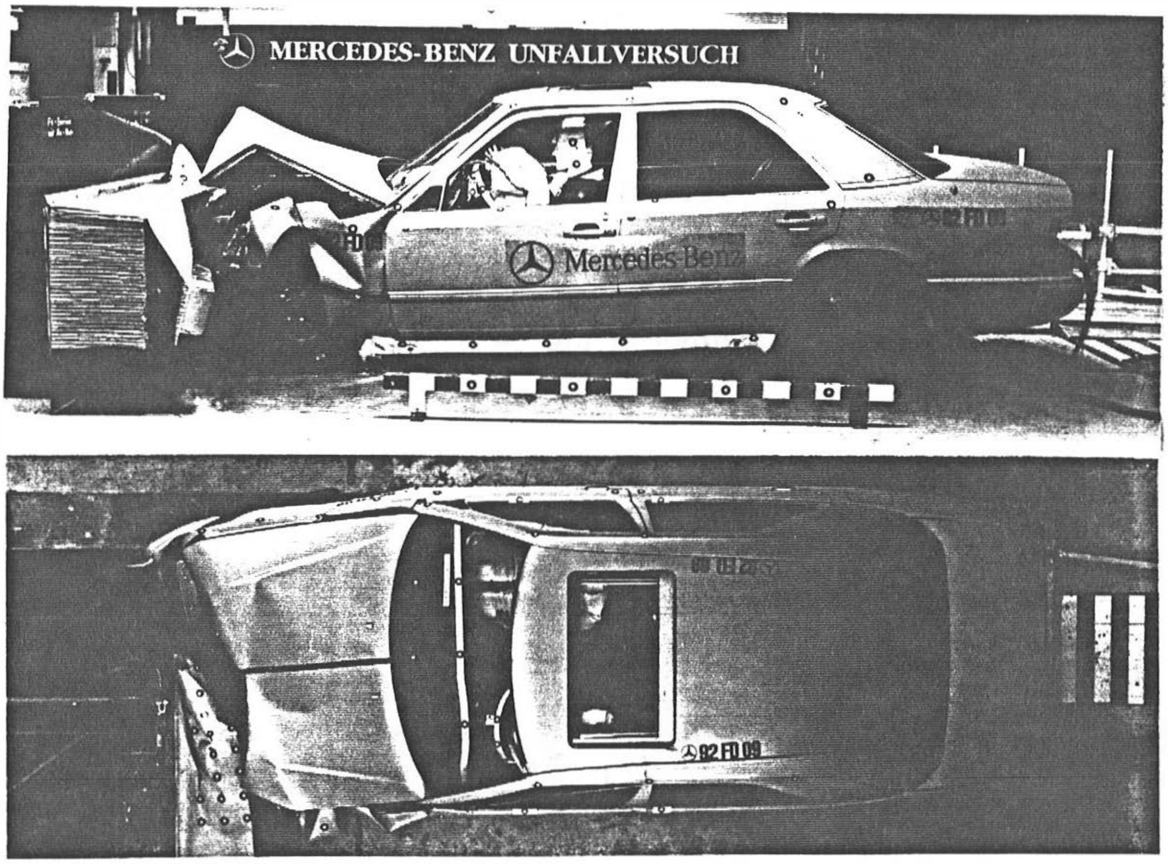

Fig. 10 - Mercedes-Benz 124 series car after 50% offset impact against a deformable barrier at 55 km/h

4.1 Vehicle accelerations

In frontal impacts the energy absorption capabilities of the longitudinal members are most important. During an impact against the flat barrier these energy absorption capabilities are activated in the best way. The longitudinal member is loaded with an equivalent force, acting exclusively in longitudinal direction.
During a test with the deformable barrier, the stiffer structures will penetrate into the barrier, until reactional forces - necessary to crumple, for instance, the longitudinal member - are built up.

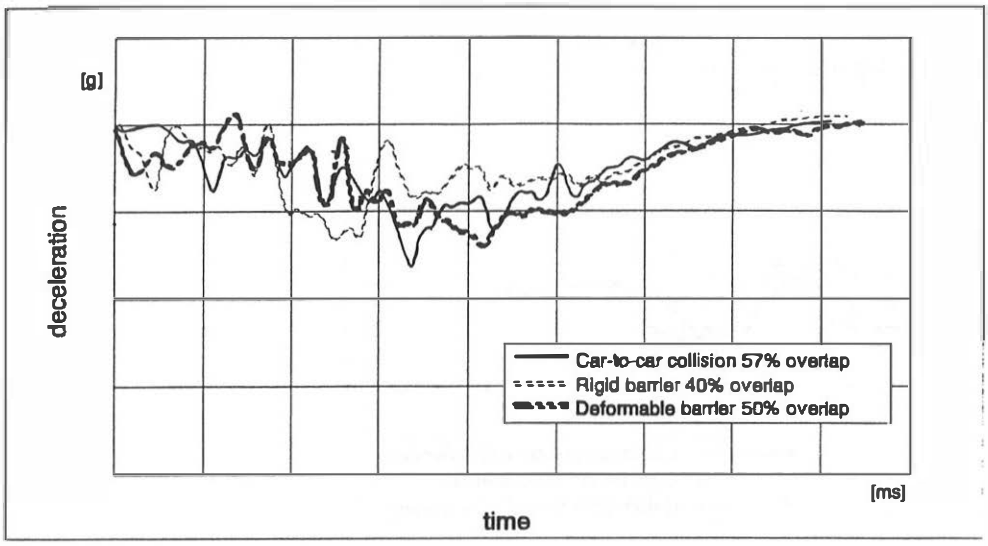

Fig. 11 - Car deceleration characteristics

Fig. 11 shows the acceleration/time histories resulting from different crash configurations. In the first phase (up to 60ms), accelerations are lower in the deformable barrier test and car-to-car impact tests compared to those found in the rigid barrier test. Later in the impact phase the results are reversed.
Therefore, the velocity/time history (fig. 12) derived from the deformable barrier test corresponds most closely to the car-to-car test curve.
One of the major disadvantages of the rigid barrier is the high reaction force when the engine hits the barrier. Over a relatively short crush distance a high amount of energy is absorbed. This results in a:

- short ride-down distance of the engine
- rearward displacement of the engine, leading to high forces into the firewall.

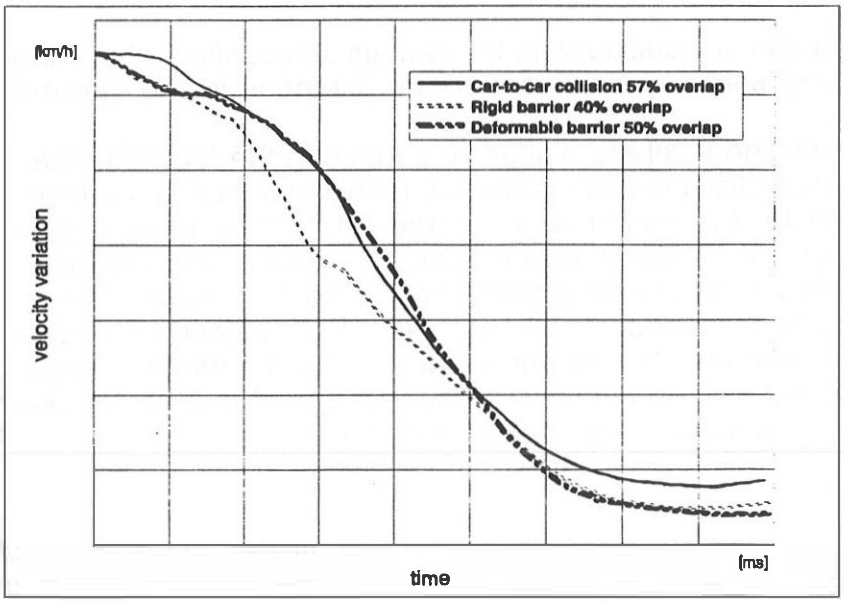

Fig. 12 - Change of velocity under different impact configurations

In the most frequent car-to-car collisions, such a heavy loading on the engine cannot be seen. Overlap degrees of greater than 70% would be necessary to directly load the engines of both impacting cars.

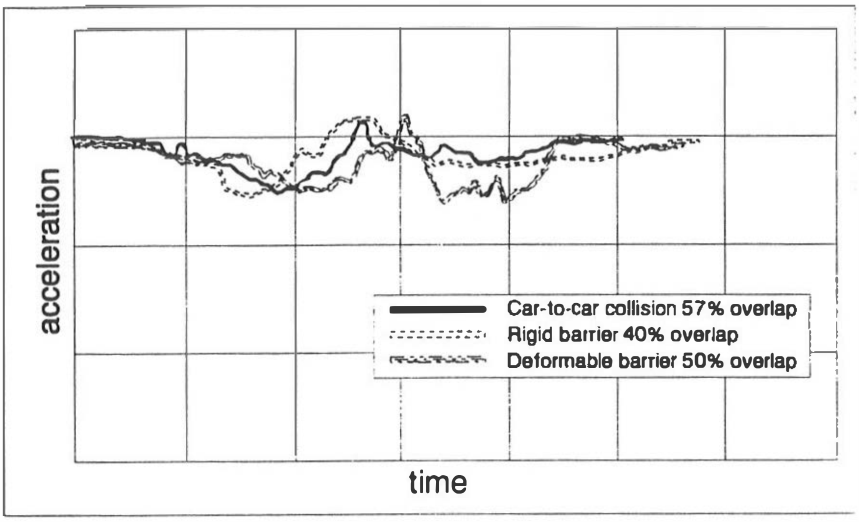

Fig. 13 - Engine and gearbox acceleration in different offset-test configurations

The ride-down of the engine under different impact configurations is shown in fig. 13. Even with an overlap degree of 50% the engine block deeply penetrates into the deformable barrier. Displacement of the engine can only be seen after significant crush of the other front-structure elements has taken place. Due to the increasing force generated by the deformable barrier, the engine is displaced into the firewall in later stages of the impact.

4.2 Vehicle deformations

A comparison of car deformations resulting from the various test configurations under similar test speeds (fig. 14) shows the highest crush distances in the car-to-car configuration.
The deformations at the belt-line level are higher than those in the footwell area. In the rigid barrier test, the crush distances are reversed, resulting in higher loadings of the footwell area induced by the higher loading and force transmission of the longitudinal members. Car deformations and intrusions found in the deformable barrier test are principally lower than those produced in the rigid barrier or car-to-car configuration under the same test speed of 55 km/h. This is explained by a certain energy absorption of the deformable barrier, thus reducing the amount of energy to be absorbed by the impacting car. An increase of the test speed to 60 km/h would lead to more realistic, i.e. higher loadings on the car structure.

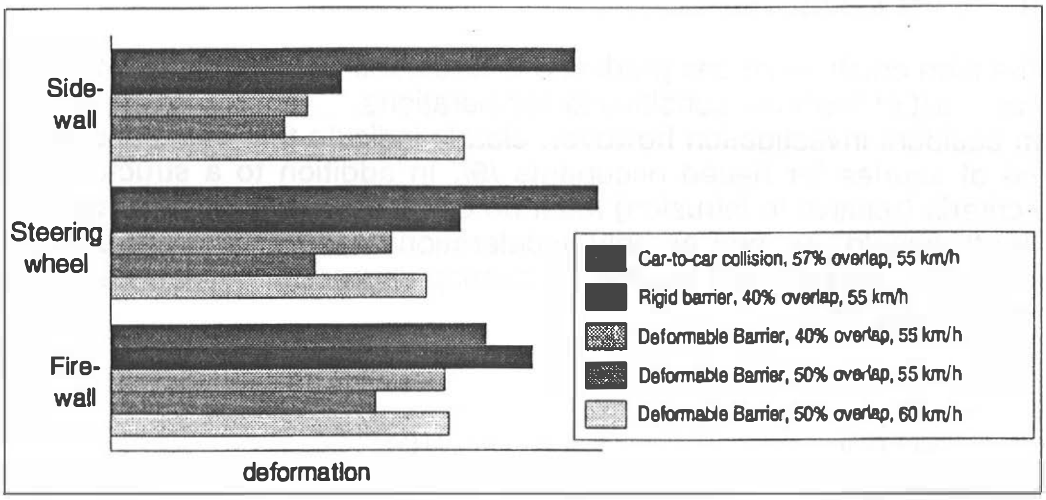

Fig. 14 - Vehicle deformations after different offset impacts

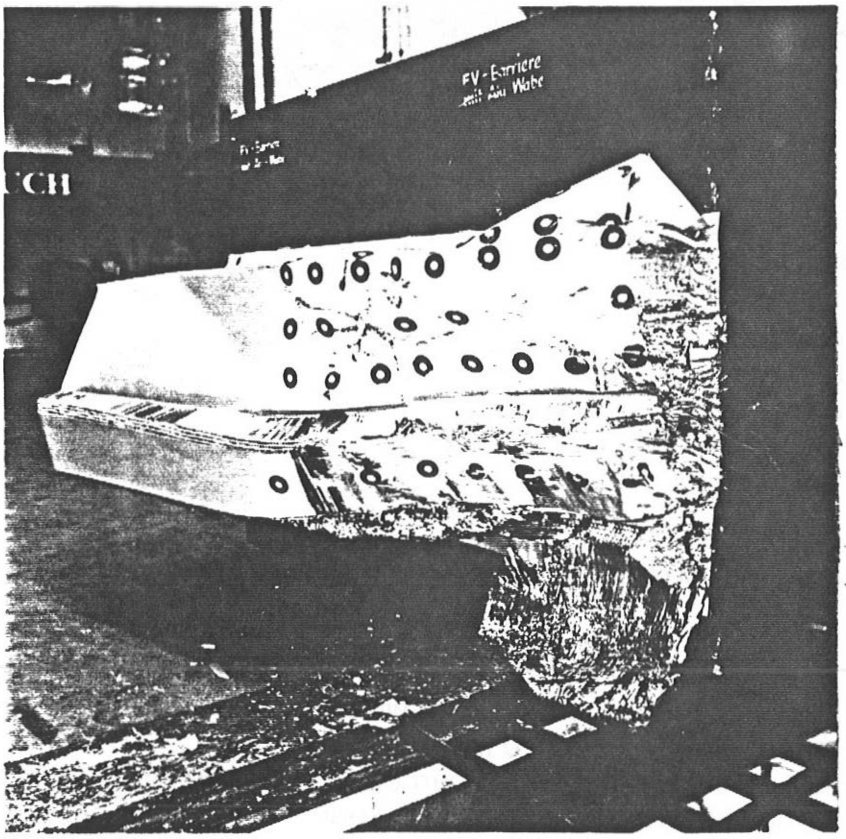

Fig. 15 - Deformable barrier after a frontal impact with 50% overlap at 55 km/h

Despite the different overlap degree the respective deformation patterns of the "Honeycomb" element are quite similar. Stiff structures of the impacting car, such as the engine, frames etc., cause extreme crush, while the peripheral zones are moderately deformed. This pattern reflects the deformation seen on colliding cars (fig. 15).

4.3 Loadings on the occupants

In general, the high crush distances produced in structural tests result in low dummy readings since most of them are sensitive to accelerations.
Results from accident investigation however, clearly indicate that intrusions are the major source of injuries for belted occupants /5/. In addition to a structural test, appropriate criteria (relative to intrusion) must be defined, to give an estimate of the realistic injury threshold. As long as only acceleration-based criteria are used, the dummy readings are not sensitive to different overlap degrees in offset tests with the deformable barrier (fig. 16).

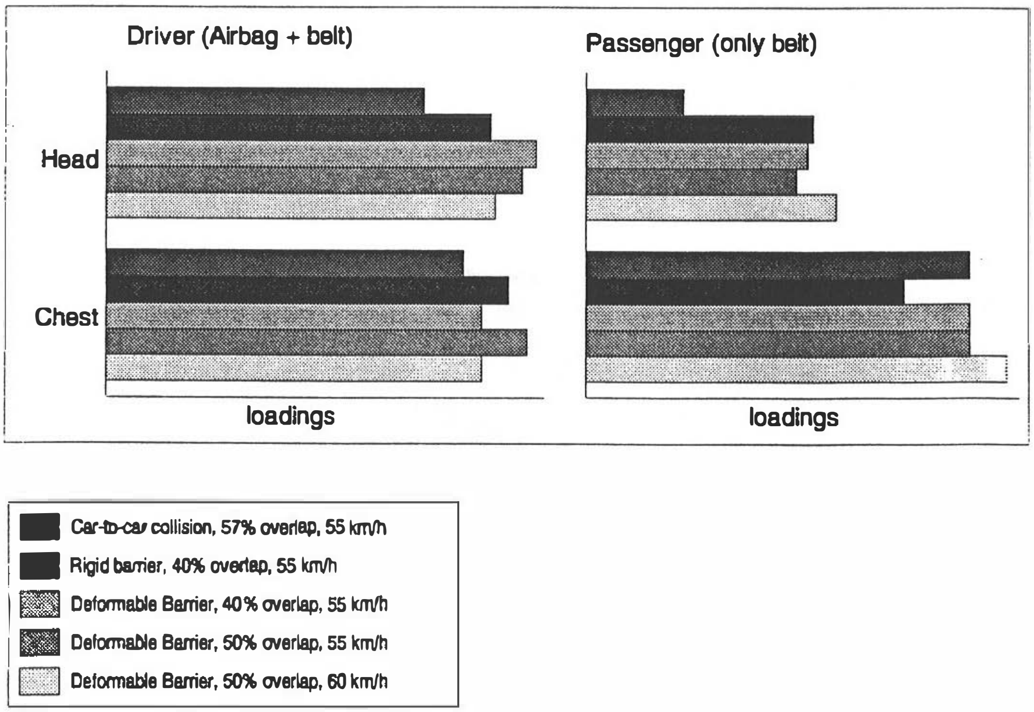

Fig. 16 - Occupant loadings during different offset impacts

5 Consequences

Frontal offset collisions are most frequent in real-world accidents, resulting in significant intrusions which can greatly influence the injury outcome.
With the Mercedes-Benz offset test against a rigid barrier with 40% overlap and at 55 km/h, the major front deformation and injury threshold, seen in real-world accidents was simulated.

A more sophisticated approach, providing a better insight into the design of the front-end structures, can be achieved by using a deformable barrier.
In addition, the test with a deformable barrier is less sensitive to the degree of overlap, taking into account the different engine and drive concepts of different cars.
Some components of the front end, not of great influence in rigid barrier tests, are of increasing importance in tests using the deformable barrier.
To simulate the crush characteristics of car-to-car accidents by only one test, the offset test with a deformable barrier (based on the FMVSS 214 barrier) is very promising.
Further discussions concerning the overlap degree, the need of a bumper and its ground clearance, as well as the appropriate test speed are necessary. Mercedes-Benz is continuing test series with the respective modifications.

6 Literature

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