

COMPARATIVE ANALYSIS OF FRONTAL ZONE OF DEFORMATION IN VEHICLES WITH SELF-SUPPORTING AND FRAMED BODIES

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Abstract

The work considers changes occurred in the features of the supporting structure in three categories of cars, namely: with the self-supporting body, framed body and intermediate structures between these two solutions. The area of analysis includes the length of deformation (crush) of the front part of the car after collision with a rigid obstacle (barrier). The range of deformation is a significant factor of the passive car safety and indicates the efficiency of fulfilling the protective function for the passengers.

The work shows absolute and relative (percentage and unit) variations of the car deformation, depending on the year of manufacture, including the period of 1980 – 2010. Marked trend lines indicated general nature of the deformation range variations together with the improvement of the car supporting system structures. The course of the trend line has been calculated on the basis of average deformation length values, calculated in defined periods of vehicle manufacture. Selected sections of time result from the division of the period of analysis 1980 – 2010 into six parts.

The analysis of the deformation length of the frontal part of passenger cars, SUVs and pickups has been combined with simultaneous evaluation of total car length variations and their weight values. The car weight directly affects the kinetic energy of the impact so it has a significant influence on the range of deformation of the car front during collision with an obstacle.

Keywords: transport, road safety, vehicle safety, crash tests, body deformation range

1. Introduction

The passenger car body is a developed spatial structure which consists of the supporting structure (framework), elements integrated with the supporting structure or removable ones (bonnet and plating) and equipment items. Apart from significant differentiation of structure of individual components and the whole bodies, they can be divided not only according to their form (shape) but first of all in respect of the supporting structure type. In that aspect, there are usually two types of the structures: framed and self-supporting ones. Self-supporting bodies make a dominant solution but the framed structured can still be found in the SUV and sport vehicles.

The shell bodies make an example of the self-supporting structure (fig.1a), made of properly shaped spatial elements, pressed from thin sheets and with numerous reinforcements (thresholds, pillars, frames etc.).

Off-road vehicles are usually equipped with durable framed chassis (fig.1b). The most often solutions include stiff longitudinal frames where longitudinal ones are parallel or almost parallel to the vehicle symmetry axis. Sometimes, the semi self-supporting bodies are used – supporting frame welded with the body. The floor plate and its reinforcements make the basic supporting structure in the self-supporting bodies.

The increasing popularity of off-road vehicles affects their increasing share in the road traffic, resulting in higher share in the road accidents. In that type of accidents, the results of significant structural incompatibility with the passenger cars can be observed [1, 5].

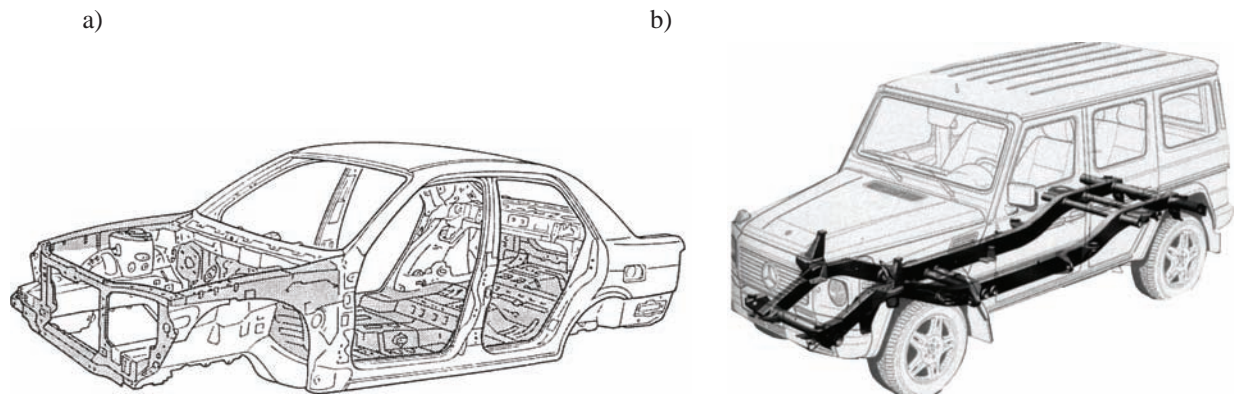


Fig.1. Shell structure of the self-supporting body (a) and the frame of the off-road vehicle Mercedes – Benz G (b)

2. Objective and scope of the work

The objective of this work is to analyze the influence of changes that have been made to the structures of the self-supporting systems in recent years on the vehicle crashworthiness. The analysis included the range of deformation of the frontal part of cars with framed structure of the supporting system and the self-supporting body. The analysis included the cars with the following body types:

- self-supporting (sedan, hatchback, coupe),
- semi self-supporting and framed (SUV);
- framed (pickup).

The objective of the work is to show general trends of deformation range variations in those bodies during frontal collision with a rigid obstacle and to evaluate the safety of the car passengers on that basis.

The work made use of results of many frontal car collisions with a rigid obstacle [6]. A global nature of car manufacture and automotive market results in the same car structure on all continents. The following points of the work consider the car models popular in Europe, USA and Poland.

3. Characteristics of cars selected for analysis

Car design decides about its structure and equipment and it affects the car weight and dimensions. The work pays attention to the cars of weight between 1500kg and 3000 kg. The weight term refers to a car prepared for a crash test and results from a sum of the complete car kerb weight and the weight of 1-3 test dummies. Figure 2 presents the points that show considered weight values of over 650 cars in three aforementioned categories:

- S1 - passenger with self-supporting body, n=347 (number of considered vehicles);
- S2 - SUV (semi self-supporting and framed bodies), n=213;
- S3 - pickup (framed bodies), n=109.

Collected data was systematized and divided into groups, according to the year of manufacture. Periods of time and their marking is as follows: 2 – years of 1980-1985; 3 – years of 1986-1990; 4 – years of 1991-1995; 5 – years of 1996-1999; 6 – years of 2000-2004; 7- years of 2005-2010; 8 – years after 2010. That division makes further calculations easier.

Using the data compared on figure 2, collected on the basis of [6], the course of the lines characterizing the weight variation trend in the considered period of time was marked. The course of the trend line indicates the increasing kerb weight if the pickup type vehicles, when the passenger car weight undergoes only minor changes. The weight of considered passenger cars with the self-supporting bodies (sedan, hatchback, coupe) usually does not exceed 2200 kg and no significant change was observed during last 30 years.

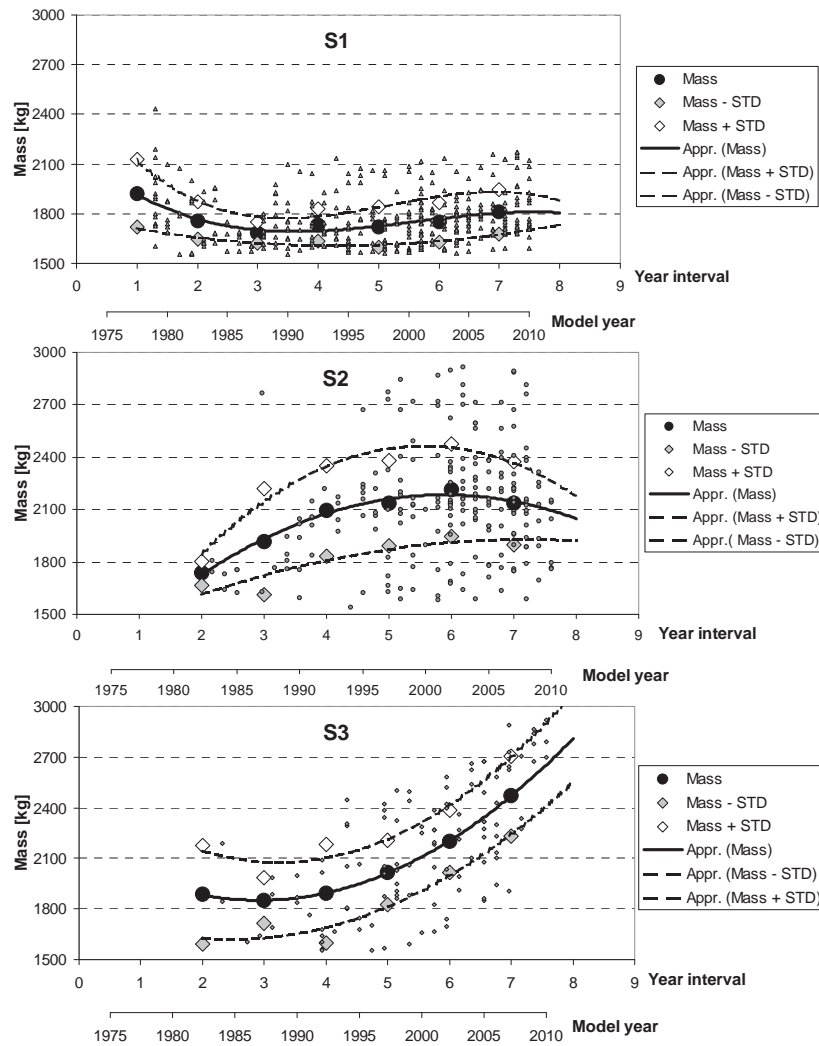


Fig.2. Variations of the average value and standard deviation of the car weight for three vehicle categories (S1, S2 and S3)

The weight increase trend in the SUV group does not have unambiguous nature. However, the pickups are manufactured as the more heavy vehicles, from 1800 kg during the 90's to 2800 kg nowadays. Such condition probably results from constant improvement of the vehicle standard. They were often transformed from the “operating” vehicles into luxury SUVs. Analyzed weight value variations have a significant influence on the impact energy during the car collision with an obstacle and in that way they affect the range of deformation.

4. Car body deformation

4.1. Range of car body deformation in three car categories

Protective role of the car body is fulfilled by a proper association of a rigid supporting structure of the cabin and special shaped energy-consuming zones (that undergo significant deformations), that surround the cabin from each side. It should be underlined that the supporting structure of the car body consists of basic energy-consuming elements and provides high dispersion of impact energy or transfers them to the supporting structure areas outside the vehicle crash zone.

The authors have already indicated [2, 3, 4, 7], that the course of car deformation during the frontal collision depends on the arrangement of drive units, their fittings and the volume of the space in the engine chamber.

In the considered tests, the car hit a rigid barrier at the speed of about 56 km/h, placed at the angle of 90° against the direction of the motion. Obtained results were used in the calculations their results are shown on figure 3.

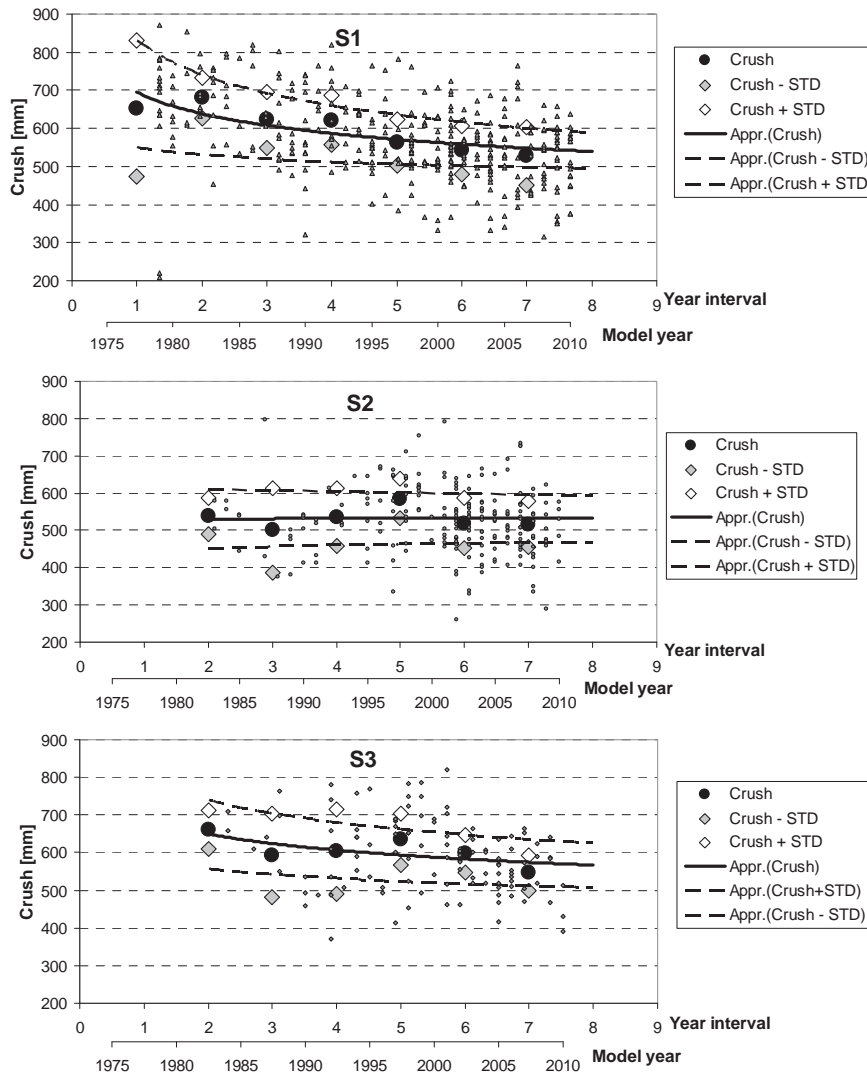


Fig.3. Variations of average car deformation value and standard deviation (STD) in the following year intervals

The lines on figure 3 show the course of variations of the average deformation value and the standard deviation from the average value in particular periods of car manufacture. Compared results refer to three car body categories S1, S2 and S3, and it has a direct influence on shaping the supporting structure of their front part. The course of the trend line indicates that deformation decreases in each analyzed car category as the car structure was improved in the following years of manufacture. That improvement is proven by increasing energy dissipation capacities at decreasing deformation. However, the pace of deformation decline, obtained in the following year intervals is getting lower. It indicates that the car structure improvement process within that scope is getting more and more difficult.

Table 1 shows an approximate analytical description of the function approximating the dependence of the average car front deformation on the period of years of manufacture, namely:

$$D_{SR} = a x^b, \tag{1}$$

where D_{SR} is an average car deformation value in [mm], manufactured in x year interval and a and b make the approximation coefficients.

Table 1. Approximation of deformation dependence on the years of car manufacture during the period of 1980 – 2010 (x is a number indicating the year interval of car manufacture)

| Deformation | Approximation of average car deformation dependence on the interval of years of manufacture |
|-------------|---|
| S1 | $D_{SR} = 694.81x^{-0,122}$ |
| S2 | $D_{SR} = 528.84x^{0,005}$ |
| S3 | $D_{SR} = 695.4x^{-0,098}$ |

Table 2. Characteristics of the car structure improvement on the basis of the crash test results.

| Car group | Years: 1980-1990 | | | Years: 2000-2010 | | |
|-----------|---------------------|---------------------------------|----------|---------------------|---------------------------------|----------|
| | Average weight [kg] | Range of deformation depth [mm] | HIC36 | Average weight [kg] | Range of deformation depth [mm] | HIC36 |
| S1 | 1700 | 550-800 | 400-2000 | 1800 | 500-600 | 150-800 |
| S2 | 1800 | 500-600 | 800-1600 | 2200 | 450-600 | 200-1000 |
| S3 | 1800 | 550-750 | 600-1400 | 2500 | 500-650 | 300-1000 |

The courses of approximating function (given in table 1) confirm the values of dominating range of deformation variations shown in table 2. Crash zone structure improvement is proven by the reduction of the HIC (*Head Performance Criterion*) index value in the following years of car manufacture with simultaneous decrease of the deformation range apart from the increasing impact energy (car weight increase). The HIC index values refer to a 50-centile male dummy (driver).

4.2. Percentage deformation variations

Using the data from figure 3, the following figure 4 shows relative (percentage) variations that refer to average values from the period of 1980-1985 in all car categories. Courses of relative deformation variations make the progress evaluation easier. In order to do that, figure 4 shows, apart from a line characterizing the course of deformation (dC), the course of car length variations (dL) and kinetic impact energy (dE), which was changing (maintaining almost constant barrier impact velocity) as the tested car weight was changed. The deformation approximation function shown in table 3.

Table 3. Functions approximating the car deformation length variations D_{SR} in %, as a dependence on the year interval of the car manufacture; x as in table 1

| Deformation | Deformation approximation function |
|-------------|--------------------------------------|
| S1 | $D_{SR} = 0.346x^2 - 7.57x + 113.25$ |
| S2 | $D_{SR} = -0.855x^2 + 7.69x + 84.38$ |
| S3 | $D_{SR} = -0.311x^2 + 0.52x + 96.60$ |

During 1980- 2010, over 20% reduction of front car body deformation at little decrease of car body length and weight was obtained in the S1 car category. It indicates the increase of the passenger safety zone length by app. 100mm in front of the car. In the S2 car category, i.e. SUV, the reduction of deformation by app. 5% was obtained at the increase of general car length by over 10% and the car weight by over 20% (fig. 4). So in that category the front passenger safety zone was increased by app. 60 mm.

The S3 category cars increased their length by app. 8% and their weight by 30%, obtaining a significant improvement of usable features at the same time during the analyzed period.

Reduction of deformation by 15% indicates significant structural modifications in the supporting elements in the front of the car body. In total, those modifications allowed for the increase of the passenger safe zone length by almost 150 mm.

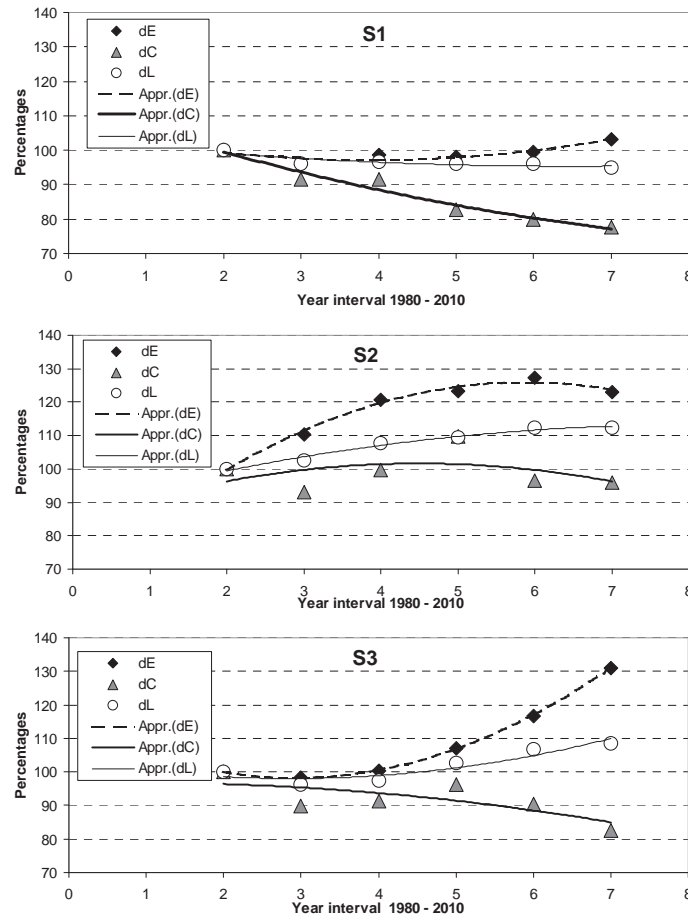


Fig.4. Percentage variations of deformation (dC), length (dL) and impact energy (dE) in three car categories (S1, S2, S3)

4.3. Unit deformation

Synthetic specification of calculation results presented on figure 4 refers to the average values in individual periods of years of manufacture. At present, the results of individual car measurements were used for calculation of the unit deformation of the front part of the car body (fig.5), namely:

$$W1(i) = \frac{WDD_i}{WDD_2} \cdot 100\% , \quad (2)$$

where WDD_i is an average unit deformation of the of the front part of the car body, calculated in each "i" year interval of car manufacture, that is:

$$WDD_i = \frac{1}{n_i} \sum_{k=1}^{k=n_i} \frac{D_k^i}{L_{Nk}^i} , \quad (3)$$

n_i is a data quantity in "i" interval, and $(D^i \ i \ L_N^i)_k$ are the car body deformation and length values of "k" car in that interval.

The WDD_i index values of the cars manufactured during 1980 – 2010 fall between 0,10- 0,13 (table 4).

Table 4. Index value of relative car deformation and weight variation

| Car category | WDD_i index | WMD_i index |
|--------------|---------------|---------------|
| S1 | 0.11- 0.13 | 0.35- 0.38 |
| S2 | 0.11- 0.13 | 0.41- 0.47 |
| S3 | 0.10- 0.13 | 0.37- 0.44 |

The WMD_i index values given in table 4 were calculated in the following way

$$WMD_i = \frac{1}{n_i} \sum_{k=1}^{k=n_i} \frac{M_k^i}{L_{Nk}^i}, \quad [\text{kg/mm}], \quad (4)$$

where M_k^i is the "k" car weight value in "i" year interval of car manufacture.

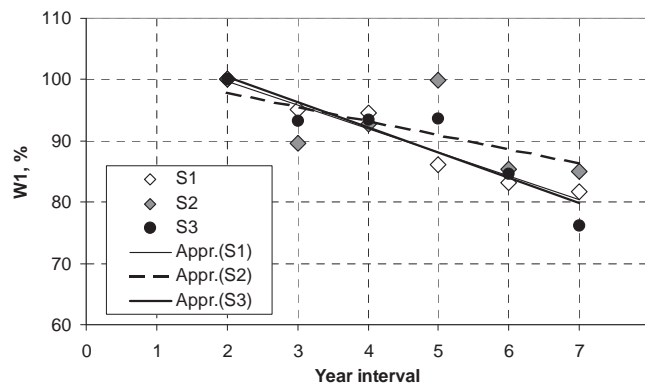


Fig.5. Percentage variations of the W1 unit deformation in three car categories (S1, S2, S3)

Trend lines on figure 6 show the average course of unit deformation dependence $W1(i)$ on the weight unit index, i.e. $W2(i)$

$$W2(i) = \frac{WMD_i}{WMD_2} 100\% , \quad (5)$$

Calculation results presented on figure 6 allow for the following conclusions:

- a significant decrease of deformation of the front part of the car body was obtained at a little car weight increase in the S1 category cars;
- a significant dispersion of values of the analyzed indexes in the whole set of the SUV cars can be observed, so it is difficult to define a stable trend of deformation variations;
- a significant decrease of the unit deformation was also obtained at a distinct car weight increase in the S3 category.

5. Summary

Dependences given in this work have been obtained on the basis of the analysis of the test results including 650 cars. They show different car body features in the aspect of transferring the dynamic loads in the cars with framed and self-supporting bodies during collision with a rigid barrier.

The trends of the car structure modifications in the analyzed car categories observed in recent years can be defined in the following way:

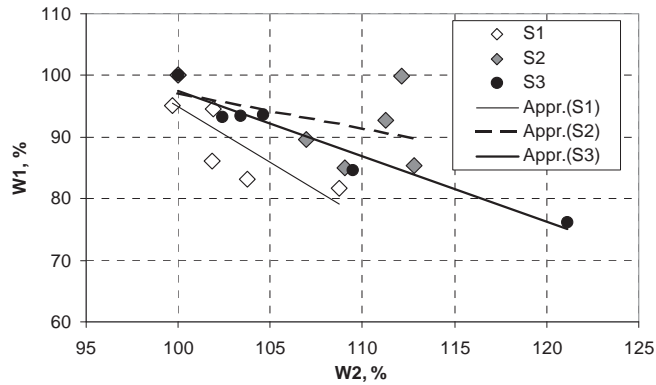


Fig.6. Trend lines of the unit deformation variation depending on the car weight modifications

- range of deformation, tested in comparable crash test conditions, does not increase in any considered category;
- unit car body deformation in the S1 and S3 car categories is getting lower and lower and it was reduced by app. 20% in the analyzed period.

During the period of 30 years, the increase of the passenger safe zone length by app. 60mm in S2 category to almost 150mm in S3 category were obtained in all cars of the analyzed categories (by reducing the range of deformation).

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