DEFORMATION CHARACTERISTICS OF AUTOMOBILE IN A FRONTAL IMPACT INTO RIGID BARRIER

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DOI: 10.17973/MMSJ.2020_11_2020020

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Current simulation programmes for analyzing car accidents uses impact velocity, mass, user-defined overlay and a coefficient of restitution for defining the value of EES (Energy Equivalent Speed). However, the impact velocity must be entered manually through the expert´s own calculation of EES parameter depending on the level of car damage. To do this, experts can choose from several available methods. Latest programmes allow us to calculate the EES parameter from the user-given deformation of the certain part of a vehicle. The main aim of this paper is to show the significance of deformation characteristics in the impact into rigid barrier as well as the significance of deviation determined by EES calculation between the real and linear deformation characteristics.

KEYWORDS

Deformation characteristics, Deformation work, EES.

1 INTRODUCTION

Most car accidents require a complex analysis of a car crash. Apart from other things, it can also include a frontal impact of the vehicle on a solid barrier. When solving this problem, a very important parameter is to determine the vehicle´s energy loss when crashing the barrier. This energy loss is caused by the transformation of kinetic energy set by immediate speed of the vehicle, into the deformation energy absorbed by its deformation zones [Vlk 2003, Evin 2016]. This deformation energy is important for the calculating the speed of the vehicle just before the impact. Precise determining of deformation energy from the extension of existing deformation requires the knowledge of deformation characteristics of a particular distorted part of the vehicle [Jurko 2012, Murcinkova 2013, Hlavac 2018]. The value of EES parameter reflects such a velocity (kph) of which corresponding vehicle´s kinetic energy is equivalent to deformation work used for reaching a certain level of vehicle´s deformation. Latest programmes allow us to calculate the EES parameter from the user-given deformation of the certain part of a vehicle. They are based on the assumption that there is a linear dependence between the acting force and deformation range of the vehicle. This assumption can be a source of some inaccuracy. The aim of this paper is to show a deviation score for the EES parameter calculated by the use of real deformation characteristics in comparison to using linear deformation characteristics.

2 DEFORMATION CHARACTERISTICS OF THE FRONTAL PART OF THE VEHICLE

Specialist literature states that deformation characteristics of the vehicle can be either real or linear. The linear deformation characteristics (Fig.1) are determined by the only known parameter, meaning stiffness coefficient k. If the outer damage range of the frontal part of vehicle´s bodywork is known, it is possible to calculate deformation energy during the impact. Deformation energy E_D is determined by deformation work done by the impact force $\vec{F}$ acting on a deformation path $\vec{x}$. It can be calculated from the following formula:

$$E_D = W_D = \int \vec{F}.d\vec{x} \qquad (1)$$

Assuming the linear dependence between the force $\vec{F}$ and the deformation displacement $\vec{x}$, including constant value of stiffness coefficient k, the following equation can be applied:

$$\vec{F} = k\vec{x} \qquad (2)$$

After the substitution of force in formula (1) with force from formula (2) and assuming that impact force acts in the direction the path, deformation work can be calculated from:

$$E_D = W_D = \int k\vec{x}.d\vec{x} \qquad (3)$$

Then, the EES parameter of a particular vehicle is determined by the calculated deformation work:

$$EES = \sqrt{\frac{2W_D}{m}} \qquad (4)$$

Where E_D stands for deformation energy consumed during the impact, W_D – deformation work for a particular level of deformation, $\vec{F}$ – impact force, m – mass of the vehicle, $\vec{x}$ – deformation displacement, on which the impact force is active, EES - Energy Equivalent Speed of the vehicle. Real deformation characteristics are the relations between the force acting on deformed frontal part of the vehicle and the deformation itself. It is shown on the Fig.2, in which the ochre curve shows the real development of the force in relation to the progress of deformation. It is clear that the linear fit of deformation characteristics by the only known stiffness coefficient is limited because of the fact that in deeper deformation the curve is shifted from the real course. Afterwards, it can cause the inaccuracy in counting deformation energy and therefore also in counting the EES parameter.

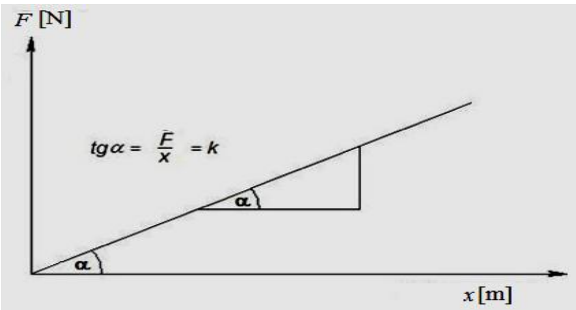

Figure 1. Linear dependence between the impact force F and the depth of deformation x

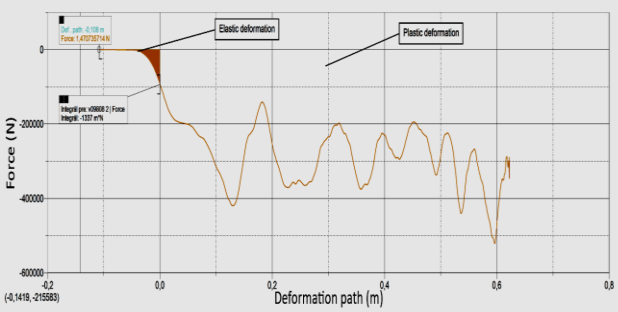

Figure 2. Real deformation characteristics

3 DATA ACQUISITION FOR REAL DEFORMATION CHARACTERISTICS GAINED FROM THE IMPACT TEST

Real deformation characteristics are processed for personal automobile Honda Civic LX Coupe (year of production 2016). Data were gained from the frontal impact test into rigid barrier with the full overlap within the speed of 56.17 kph from the source [NCAP 2017] according to NCAP (New Car Assessment Program) (Fig. 3). Moreover, a solid barrier contains also force sensors (the left side of Fig. 3).

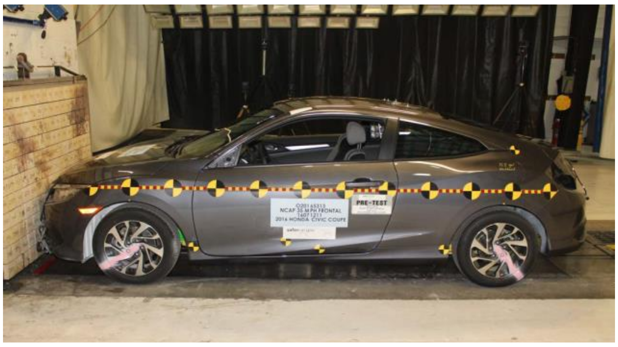

Figure 3. Left-sided view of the tested vehicle during the frontal impact into rigid barrier according to NCAP [NCAP 2017]

The recording of vehicle deceleration during its impact on a solid barrier was gained from accelerometer, which was firmly attached to the vehicle´s floor in the back of the bodywork. Accelerometer is the sensor of non-electric physical quantities. It changes detected physical quantity into electrical signal which is subsequently processed and interpreted [Krenicky 2010]. As a result of strong signal oscillations during the impact tests, the accelerometer recording must be filtered by the CFC 60 filter (Channel Frequency Class) [Cichos 2006]. Table 1 summarizes the most common types of filters. A very important filter parameter is the slope of decreasing line, which is a function of a filter order. In order to provide valid impact test measurements, signal processing must be done in special predetermined conditions. These rules are given by the SAE J211 Standard called Instrumentation for Impact Test, Part 1, Electronic Instrumentation. This standard specifies all physical quantities necessary for the impact test. SAE J211 Standard requires only filtered signals from the impact tests: They should be filtered by one of the four possible filters having a low pass filter. Furthermore, it also specifies acceptable frequencies, which are classified as CFC 60, 180, 600 and 1000. The edge of the low pass filter of Butterworth filter is defined as a frequency which causes the signal to lose one half of its power. This means that signal attenuation equals 3 decibels (dB).

Fig. 4 shows a data signal coming from the accelerometer situated in the back left part of the vehicle´s floor.

Table 1. Types of filters

Types of filters	Parameters of filters		Usage of filters
CFC 60	3 dB limit frequency	100 Hz	Acceleration on a structure
	Stop damping	–30 dB	
	Sampling frequency	At least 600 Hz	
CFC 180	3 dB limit frequency	300 Hz	Acceleration for integrated speeds and trajectories
	Stop damping	–30 dB	
	Sampling frequency	At least 1800 Hz	
CFC 600	3 dB limit frequency	1000 Hz	Component analysis
	Stop damping	–40 dB	
	Sampling frequency	At least 6 kHz	
CFC 1000	3 dB limit frequency	1650 Hz	Acceleration on the figurine head
	Stop damping	–40 dB	
	Sampling frequency	At least 10 kHz	

This data signal is already filtered by a particular filter (CFC 60), see Fig. 5. Knowing the position (distance) in time, it is possible to calculate instantaneous speed as well as instantaneous acceleration of the object. On the contrary, knowing the value of instantaneous speed, it is possible to calculate distance parameter by applying mathematical operation called integration:

$$\vec{s}(t) = \int_{t_1}^{t_2} \vec{v}(t)dt \qquad (5)$$

or

$$\vec{v}(t) = \int_{t_1}^{t_2} \vec{a}(t)\, dt \qquad (6)$$

See Fig.6 or eventually, by double integration of instantaneous acceleration in time:

$$\vec{s}(t) = \iint_{t_1}^{t_2} \vec{a}(t)dt \qquad (7)$$

See Fig.7 , where $t_2 - t_1$ represents the time parameter in seconds, during which the deceleration is being measured, $\vec{v}(t)$ is instantaneous speed and $\vec{a}(t)$ is instantaneous acceleration in [ms^{-2}] [Coufal 2012, Mathworks 2020, Vernier 2020, Ljung 1994].

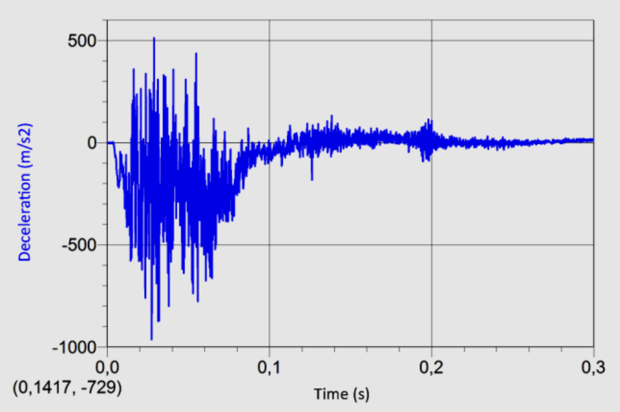

Figure 4 . Deceleration of Honda Civic vehicle LX 2016 during the frontal impact

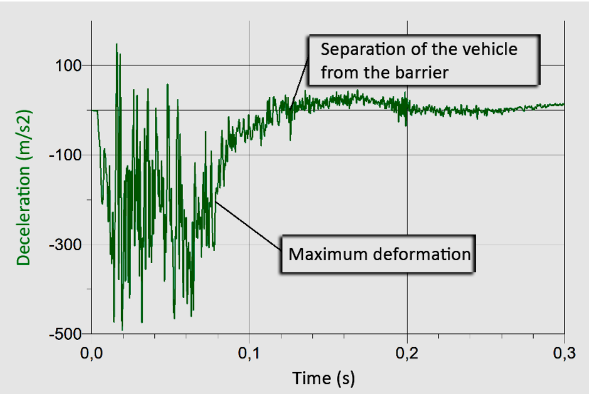

Figure 5. Deceleration curve (filtered signal by CFC filter 60) of Honda Civic vehicle LX 2016 during the frontal impact

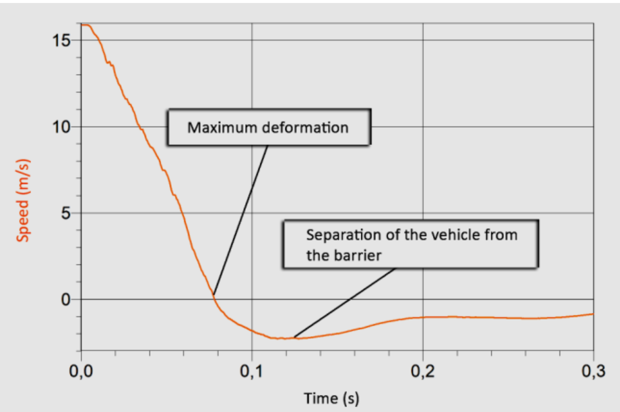

Figure 6. Speed curve of Honda Civic vehicle LX 2016 during the frontal impact

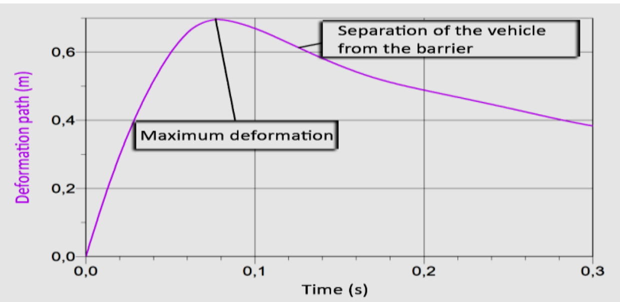

Figure 7. Deformation path of Honda Civic vehicle LX 2016 during the frontal impact

4 ACHIEVED RESULTS FROM THE DEFORMATION CHARACTERISTICS OF THE FRONT OF THE VEHICLE AND THEIR DISCUSSION

Force recording was processed from each individual force sensor situated in a solid barrier (left part of Fig. 3). Final force affecting the vehicle during the impact was counted from all force sensors. Due to source [NCAP 2017], this force recording was being filtered by CFC 60 filter. Figure 8 shows time development of such a filtered force.

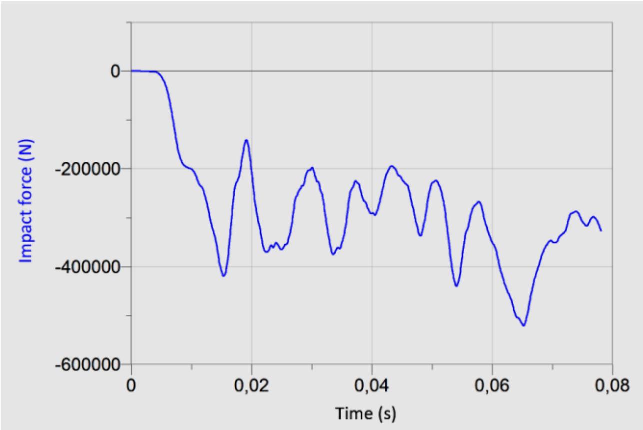

Figure 8. Time development of Impact force filtered by CFC 60 filter

In Figure 9, it is possible to see the dependence of the real impact force (blue color) and the linear impact force (black color) on the deformation of the vehicle, which is actually the deformation characteristic of the front of the vehicle. The area above the particular curve represents a deformation energy, which is being consumed by deformation zones of the vehicle during the impact. Linear impact force substitutes real one – gained from the accelerometer in such a way that areas above both curves are of the same size (therefore same deformation energies eventually same deformation works).

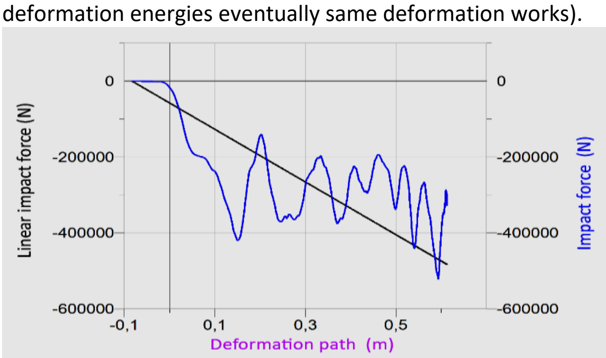

Figure 9. Modified real (blue colour) and linear (black colour) deformation characteristics (shifted left in comparison to the beginning of coordinate system) of the frontal part of Honda Civic vehicle LX 2016

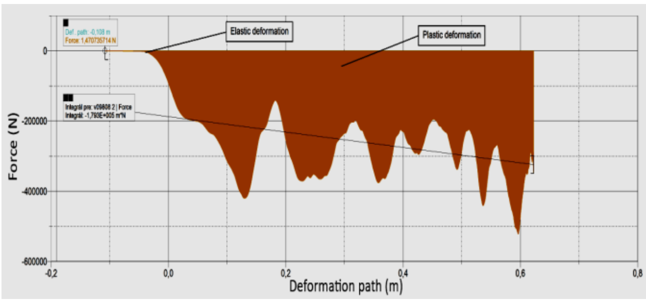

Figure 10. Total deformation work including both types - elastic and plastic (ochre colour) of the frontal part of Honda Civic vehicle LX 2016

4.1 *EES calculation with the use of real deformation characteristics of the frontal part oh the vehicle*

Calculation is being done from the real deformation characteristics of the vehicle in order to make it possible to use it also for calculating the deformation work, see Fig. 1. Figure 10 shows the total deformation work W_D – including both, elastic and plastic work – reaching the value of $1.793x10^5$ Nm. Y-axis represents force given in Newton unit. This force was measured by force metres situated in the impact barrier. X-axis represents deformation distance. It is shifted left by the value equalling to one half of deformation elastic distance. Therefore, Figure 10 shows so called modified deformation work. What is considered a former (non-modified) deformation work, is the dependence of deformation force on deformation distance since the beginning of coordinate system [0,0] until the separation of the vehicle from the solid barrier, see Fig. 7 and Fig. 9. Former deformation characteristics are; therefore, shifted left by a distance corresponding to the amount of elastic deformation energy eventually to the extent of elastic deformation. The reason is the fact that after the impact, the frontal part of the vehicle returns back to its position using the same amount of elastic deformation energy (see Fig. 2). It means that after the impact, the frontal part of the vehicle remains deformed at about the extent of plastic deformation, which can be measured on the vehicle. Knowing the extent of vehicle´s deformation, it is possible to count deformation energy consumed by deformation zones of the vehicle during the impact on a barrier. This deformation energy is determined by deformation work done by impact force on a distance .

For setting deformation energy of the vehicle, specialists usually use their professional estimation of energy equivalent speed (EES). It expresses the kinetic energy of the vehicle which is in relation to deformation work needed for reaching a certain level of deformation, see (4).

Based on the formulas (2), (3) and (4) as well as the use of modified deformation characteristics, the computing program called Logger Pro 3.12 can be used for calculating the EES of the Honda Civic vehicle LX 2016 from the given parameter of average deformation of its frontal part (Fig.10). Figure 11 shows the relation between the EES and EESlin parameters and the extent of vehicle deformation.

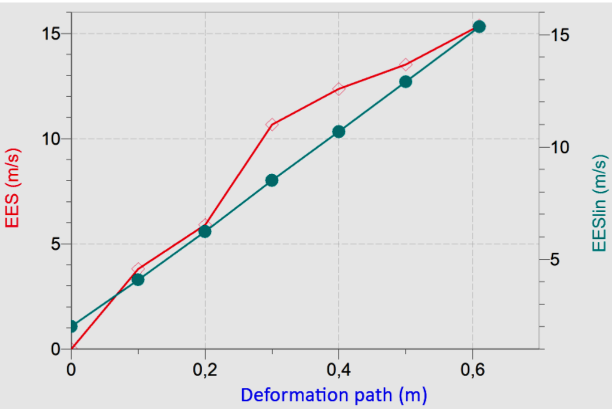

Figure 11 . Comparison of EES parameter calculated from the real (red curve) and the EESlin parameter calculated from the linear (green line) deformation characteristic and their relation to vehicle deformation

Based on the great amount of acquired data, it is possible to use Logger Pro 3.12 in order to calculate the absolute deviation as well percentage deviation of EES linear deformation characteristics from the real one concerning the frontal part of the Honda Civic vehicle LX 2016 (Fig.12, Fig. 13).

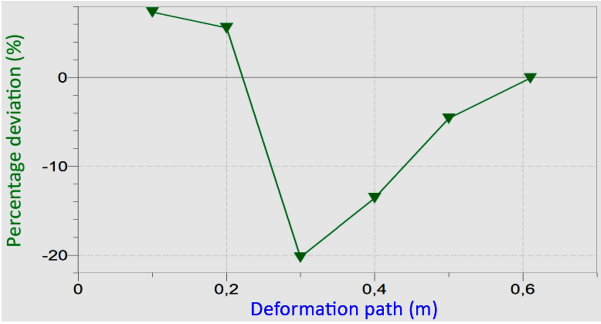

Figure 12. Percentage deviation of EES parameter calculated from real deformation characteristics from EESlin parameter calculated from linear deformation characteristics concerning the frontal part of the vehicle

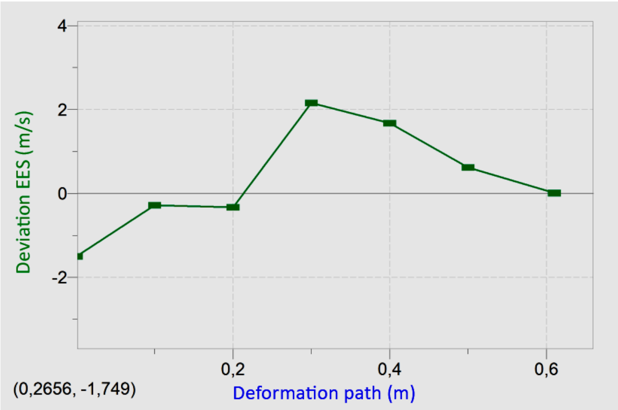

Figure 13. Deviation of EES real deformation characteristics from linear deformation characteristics EESlin concerning the frontal part of the vehicle

5 CONCLUSION

This paper deals with the topic of frontal impact test provided with the Honda Civic vehicle LX 2016. In order to gain the real deformation characteristics of this vehicle, it was necessary to process and interpret the recordings from the accelerometer (situated inside of the vehicle) as well as from the force sensors (situated on a solid barrier). The calculation of EES parameter for Honda Civic LX 2016 was done by the Logger Pro 3.12 computing program [Vernier 2020]. Subsequently, comparisons of real and linear deformation characteristics (used by PC Crash program when calculating the EES parameter) were being done. Resulting from Fig.11, Fig.12 and Fig. 13 as well as the results of calculations, we found out that maximum percentage deviation of EES-parameter calculated from real deformation characteristic from EESlin-parameter calculated from linear deformation characteristic concerning the frontal part of the vehicle reaches the value of 20.2 % .The maximum deviation during the whole deformation process is about 5 kph. The only exception is the point from the deformation distance, which is slightly above this value. A finite element method (FEM) is a very good way to gain detailed strength characteristics of vehicles. On the contrary, there are several problems connected to this method, such as high financial requirements on FEM software, longer time duration of simulations and last but not least, the so called Know-How of car factories. This is the reason why FEM simulation

[Munyazikwiye 2013, Cacko 2014] did not became very popular in professional sector and it is important to look for easier solutions. This paper is focused on presenting one possible solution for this problematic situation. It is the way of determining the EES parameter (EESlin parameter) from the crash test data . This seems to be better for experts´ everyday work than dealing with the FEM simulations.

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