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Aspects of Side Impact with Vertical Cylindrical Obstacles

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Abstract

This paperwork, written by the authors, has proven to be the introduction regarding far-reaching study of the side-impact collision. In this purpose a methodological system has been set for the design and realization of the simulated test procedure platform and measurement chain. A series of test structures has been created, for the realization of a tehnical system that interfere with an IT system of measurement. Vehicle and occupant behaviors identified in this step are: the damage occurring mechanism and injuries that are representative of different applications and actual road events investigations practices.

Keywords: investigating procedures, side impact; crush energy; lateral stiffness

1. Introduction

Every year, road events produce victims with fatal injuries, 25% of deaths occur in side impact events. This mod of collision subdue the occupants to violent forces and accelerations because the space between the victim and vehicle components (non-lethal space) is limited. Serious injury result from the side impact collisions because the side structure is less rigid than the front part [2].

Modelling and simulation of traffic events require laborious technical procedures. In practice, engineers and experts investigators, estimate the severity of road event and initial condition movement using data such as braking distance, the coefficient of adherence and energy consumption. Sometimes braking tracks are not preserved and collected, or the vehicle is moving on surfaces (wet, snowy or high traffic areas) which do not retain traces of tire.

A lot of models have been developed that allow investigators to match the damage geometry with the energy consumed in collision. Some of these analytical models emphasize the link between crush and vehicle speed before

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the collision. All these models primary target is the victims and the vehicle behavior simulation during the event, and the accuracy is validated by comparing simulation data of interes from the experimental tests obtained from tests in laboratory or field conditions [1].

Many programs were conducted to help the engineers to accurately estimate vehicle speeds and their behavior before the collision. This research is conducted using a program called Virtual Crash22, which is used by most engineers and expert investigators for reconstruction of road events and provides information that leads investigators to a better understanding of side impact application tasks and how they are transformed into deformation energy of the vehicle structure. This paperwork provides valuable reference material for the investigators to reconstitute road events [3].

Crash tests from the front, side and rear, were performed. Crush energy determined by using data from experimental tests provide researchers a better understanding in terms of stiffness variation of the vehicle side [5]. The techniques used, data collected and the obtained results from the experimental tests are presented in this paper with the conclusions and recommendations for the future. Methodical investigation of collisions include measuring and comparing data collected, from the site of the road event with the data obtained from experimental tests [4]. This study contributes to the evaluation and comparison of lateral stiffness of the vehicle structure at various points. As the criterion for comparing the results of different tests is the size of deformation energy absorbed by the vehicle elements [9].

2. Side impact energy

In the side impact collision the driver and occupants are subjected to high solicitation loads in comparison with other types of collision with the same level of crush energy absorbed [7].

The procedures for investigating road events suppose that the determined strain energy with the measured deformations of the vehicle to contribute in determining the vehicle speed at that moment. So the amount of deformation energy for two vehicles can be checked by providing energy losses with the help of dynamic timing analysis (PC-, Virtual- Crash). Using hand calculation methods we can obtain reasonable estimations, instead they are extensive, laborious and requires deep knowledge in the field [6]. The kinetic energy of a colliding vehicle with a massive and rigid structure (pole, tree, and bridgehead) has the following form:

$$E_c = 0.5 \cdot mV_i^2 = 0.5 \cdot \frac{G}{g} V_i^2 \tag{1}$$

where m is mass, G - weight of the vehicle in motion, g - acceleration of gravity and V_i - initial speed of the vehicle. The analysis will consider true the assumption according to which before the impact the car has only translational kinetic energy, and at the moments of the collision, the law of conservation impulse is applied respectively the kinetic moment.

Part of the vehicle's kinetic energy before the collision is converted to strain energy and another part in energy consumed thru the movement of translation and/or rotation. From energy considerations based on energy conservation law the energy balance will be established:

$$E_t = E_{def} + E_{dc} + E_r \tag{2}$$

where E_t is total energy

$$E_t = 0.5 \cdot mv_i^2 \tag{3}$$

E_{def} - crush energy
E_{dc} - translational kinetic energy after collision

$$E_{dc} = 0.5 \cdot m v_f^2 \tag{4}$$

E_r - rotational kinetic energy

$$E_r = 0.5 \cdot I\Omega_f^2 \tag{5}$$

During vehicle collision, they suffer both elastic and plastic deformations. Structural behavior of the vehicle during the collision can be modeled in different ways. An energy measurement uses the concept of compensation to identify the elastic properties of the collision by defining rejection speed (recoil) as a percentage of the vehicles speed before impact [7].

This method is presented below. The behavior of the side of a vehicle during the collision is generally defined as a function of the deformation form [8]. The simplest mathematical model considers the deformation forces as constant throughout the collision, C_i. Under these circumstances the medium force during impact is F_i = constant where i represent the number of collisions with impact in the same place, and the average constant force is calculated using the total energy of the collisions structure, the strain energy is given by:

$$E_{defi} = \bar{F}_i \times C_i \tag{6}$$

$$E_{deft} = \sum_i E_{defi} \tag{7}$$

Presentation of the simplified model of deformation is expressed as a linear function of the impact $F = kx$, is:

$$E_{def} = \int_c F dx = 0.5 \cdot kc^2 \tag{8}$$

These conditions are applicable at the stage preceding the appearance of the deformation in ideal conditions of transmission of force.

To correlate the impact with a fixed cylindrical vertical obstacle, in this study, simple linear models were used.

3. Coefficient of restitution

The mechanism of the collision can be represented with a high degree of accuracy realized in speed-time coordinates, where the initial moment will be considered when the collision is initiating. In the moments before impact initiation it is considered that the velocity (V_i) is stabilized at the desired clash value at least one second before. Starting with the t_0 origin of time the vehicle changes its velocity (ΔV), the obtained characteristic presents the general function of speed-time, being useful to study the vehicle behavior at impact. Its allure presents the shape of a simple harmonic oscillations with a period of 0.075 s, has the form:

$$m\left(\frac{d^2x}{dt^2}\right) + kx = 0 \tag{9}$$

During centric collisions the speed varies continuously changing its sense and direction (velocity becomes negative) moment which the vehicle changes its geometric configuration by deforming, Figure 1 curve 1. Positive surface represents the consumed energy thru plastic deformation, and the negative, the energy gained due to elastic deformation and which is decreased from the total residual kinetic energy by this obtaining total kinetic energy.

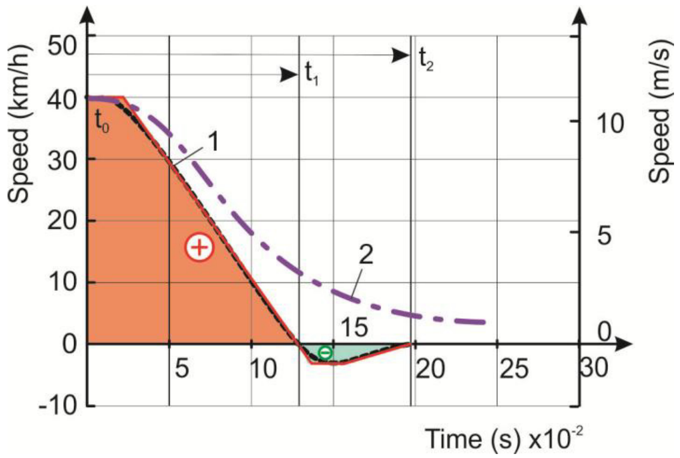

Fig. 1. Speed/Time diagram for centric and non-centric impact.

Restitution (ε) is defined as the ratio of the speed of rejection (V_r) and initial velocity (Vi) as follows:

$$\varepsilon = \frac{V_r}{V_i} = \frac{P_R}{P_C} = \frac{v_2 - v_1}{v_{01} - v_{02}} \tag{10}$$

The coefficient of restitution is the ratio of the relative velocity of the centers of mass of the vehicle at the end of the collision phase and their relative speed at the beginning of the collision phase. The velocities at the end of the impact being known, one can determine the kinetic energy consumed during the collision as the shape of deformation energy:

$$E_{def} = \frac{m_1 \cdot m_2}{2 \cdot (m_1 + m_2)} \cdot (1 - \varepsilon^2) \cdot (v_{01} - v_{02})^2 \tag{11}$$

For $\varepsilon = 0$, the maximum value of ΔE is specific to elastic collisions, while for $\varepsilon = 1$, the energy consumed during the collision is zero ($\Delta E = 0$, elastic collision).

From a tehnical point of view the restitution for centric collisions is defined although the concept can be used in non-central collisions with small derivations. The application of restitution in off-center collisions must be made with caution, because applying the concept becomes very complex when the gyration effects are involved. Note that the refund in case of vehicle collision is usually quite low, being between 5-15%, so its effect on the total kinetic energy is often ignored in the calculations of the road event reconstruction.

The speed of rejection (V_r) can be determined by analyzing the optical information offered by high-speed video camera 1500 fps on center mass position change within an interval of 1500 successive frames. Using rotation post impact factor used in most experimental tests, the center of mass of the vehicle does not always move in the opposite direction of the initial velocity (V_i), as expected in case of the impact in the central area:

$$\varepsilon = \frac{V_r}{V_i} \approx \frac{x_r}{x_i} \tag{12}$$

where

V_r is rejection speed;

V_i - initial speed;
x_i - mass center position before initiating collision;
x_r - successive positions of the center of mass in the range of 1500 fps from the start collision.

This technique proved to be superior to the measurement of variation in time of the equivalent distance. Taking in consideration the positioning of the camera objective and the markers from the fare side plain we can retain the parallax error can be out of it for all areas covered by working angle lens. In this context the distance between the center of the maximum deformation and the bumped obstacle it will be measured continuously and at the end a sketch of shadows will be created from the surface of the road and the state of the obstacle in case of the wood trunk.

4. Yaw movement

During lateral collision with a vertical cylindrical obstacle of unique radius, the central forces induce to the vehicle a particular rotating angular velocity. This induced angular velocity (ω) will continue to grow, with the deformation of the vehicle body elements, until it reaches the maximum level. For calculating the energy absorbed by deformation of the vehicle structure resulting rotational energy must be subtracted from the total energy of the impact. The rotation induced as a result of vehicle impact is composed of:

- rotating phase of the vehicle around the obstacle collided;
- rotation phase of the vehicle after separation from the obstacle collided. At this stage, the rotational speed decreases thanks to interaction between tire and road surface area. In general the angular velocity reaches the maximum value at the end of the collision phase.

The moment of inertia during the rotation of the vehicle take into account the two components of inertia:

$$I_0 = m \cdot k_\omega^2 \tag{13}$$

$$I_p = m\left(k_\omega^2 + \xi^2\right) = \frac{G}{g}\left[k_\omega^2 + \xi^2\right] \tag{14}$$

where m is mass of the vehicle, G - vehicle weight, k_ω - radius of gyration, ξ - distance from the point of impact to the center of mass (C_g), I_0 - moment of gyration and I_p - moment of inertia of vehicle that rotates around the point of impact, Figure 2.

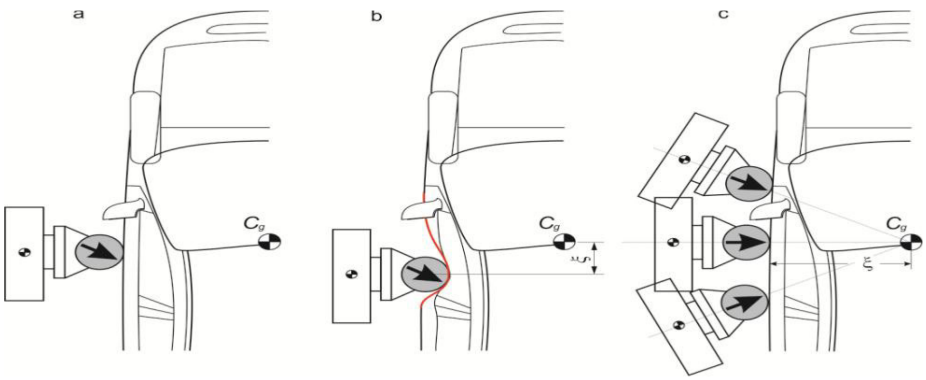

Fig. 2. (a) collision direction; (b) severity of impact; (c) collision trajectory through center of mass.

Rotation, after separation, is supposed to be around the center of mass (C_g), since contact with vertical cylindrical obstacle to the end position.

Energy angular velocity is calculated using the inertia moment I_0 from the center of mass of the vehicle. Center of mass was determined by weighing the individual vehicle measurements without load. Were not taken into account changes in the position of the center of mass or I_0 yaw moment during the collision. When collision occurs in a direction perpendicular to the side of the vehicle and passing through the center of mass, distance from the point of impact at the center of mass is quite common who connecting the mass center with side of the vehicle, Figure 2 c. Since the angular velocity is small, rotational energy of the collision can be neglected.

So, to determine the vehicle deformation energy consumption, it reduces the rotational energy of the kinetic energy of translation resulting in the equation:

$$E_{def} = \left(E_t - E_{dc}\right) - E_{rot} \tag{15}$$

Curve 2 on Figure 1 represents the variation of the center of mass velocity for a *non-centric* impact with an vertical cylindrical obstacle. Velocity of the center of mass does not vanish, but change its position by gyration movement.

5. Experimental analysis and electronics

Subject vehicles undertaken to experimental side impact testing were foreseen with acceleration measurement devices, Figure 3 a, and yaw sensors, Figure 3 b, in the center of the mass or as close as possible to it applying after correction formula for the measured data, Figure 3 a. The sensors were applied on the opposite side to the impact, directly on the structure elements of the body and in case of front axle measurement the sensor was positioned in the area of the inner wing. In the same way the measurement sensors are mounted on the A and B poles but mirror on the opposed A and B poles.

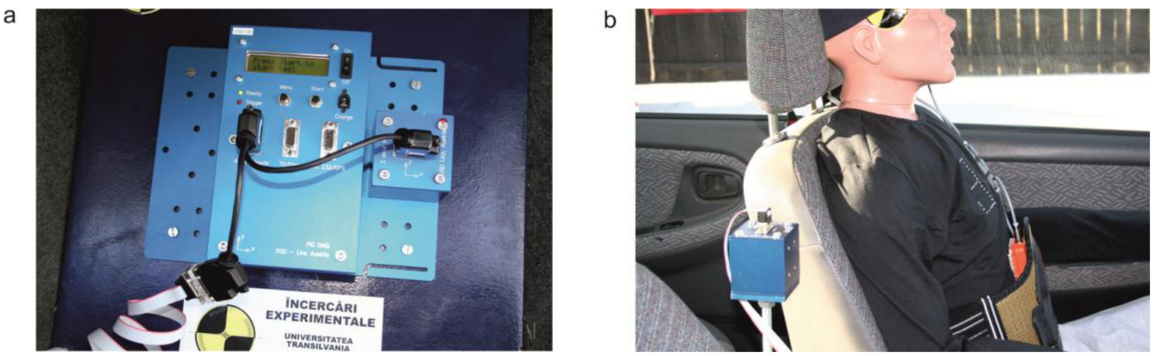

Fig. 3. (a) Accelerometers sensors; (b) Yaw sensor and Xsenz.

6. Conclusion

The results of this study allow generalization of the characteristics of energy dissipation in the lateral side of the vehicle.

During collision of a fixed vertical cylindrical obstacles the energy turns in strain energy of the side of the vehicle, and the information regarding the deformation can be used in reconstructing road events. Only data obtained from tests vehicle collisions are compared with similar technical characteristics.

The paper presented a test procedure where is performed a reversibly collision, namely the obstacle collides the vehicle which otherwise is in rest. Although this working mode is not always met in practice, the test procedure may be considered valid to study the energy absorbed during road event.

Modern vehicles must meet consumer requirements regarding performance and safety features. One should remember that the results of experimental tests could be erroneously interpreted and conclusion could be erroneously placed that the lateral limits of the cabin are not capable to provide non-lethal space to the passengers.

Test procedures used in the present are expensive and requires time in relation to the proposed solution.

The proposed solutions come to support road events research and implicitly determine the causes of their occurrence.

In the future this experimental test procedure is intended to be extended to the rear side behavior and rollover during road events research.

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