

## Some components of safety and comfort of a car

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**Abstract:** The questions of minimizing of vibration levels of unsprung weight of elements of vehicles suspension are considered. Some methods of parametric optimization with dynamic vibration absorbers (DVA) in elements of a nonlinear suspension with dynamic mechanical properties have been applied. To determine the low frequency components of vibration of laminated composite plates with the DVA system numerical estimates of the vibration of the equivalent plate of Timoshenko used. One structural version for ensuring the preservation of the residual space of the passenger cabin of the bus during the rollover according to norms 66 is considered. The energy-absorbing structure of the roof of the bus is made in the form of tubular space-frame made of composite materials.

**Keywords:** suspension, unsprung masses, damping, dynamic vibration absorber, bus rollover, passenger residual space, European regulation ECE R66.

### 1. Introduction

One of the important problems of designing modern vehicles, in particular wheeled vehicles, is the safety and comfort of the driver and passengers while maintaining the optimal technical and economic performance, such as functionality, efficiency, energy and material consumption, maintenance costs, repair costs, and so on. The primary task in this direction is the need to improve the analytical method for calculating the effect of dynamic loads in order to approximate theoretical results to experimental data and achieve rational and efficient design of safety and comfort elements.

An important issue for the development of modern vehicles is the reduction of vibration. DVA are widely used to reduce vibration and noise levels in vehicle cabs, rotating parts machines, unsprung weight of wheeled vehicles. So it is expedient to consider the suspension of a car with DVA. This devices should also be used in shock absorber safety devices by accident's. They distinguish from traditional energy absorbing elements and can serve as vibration and noise protection elements also.

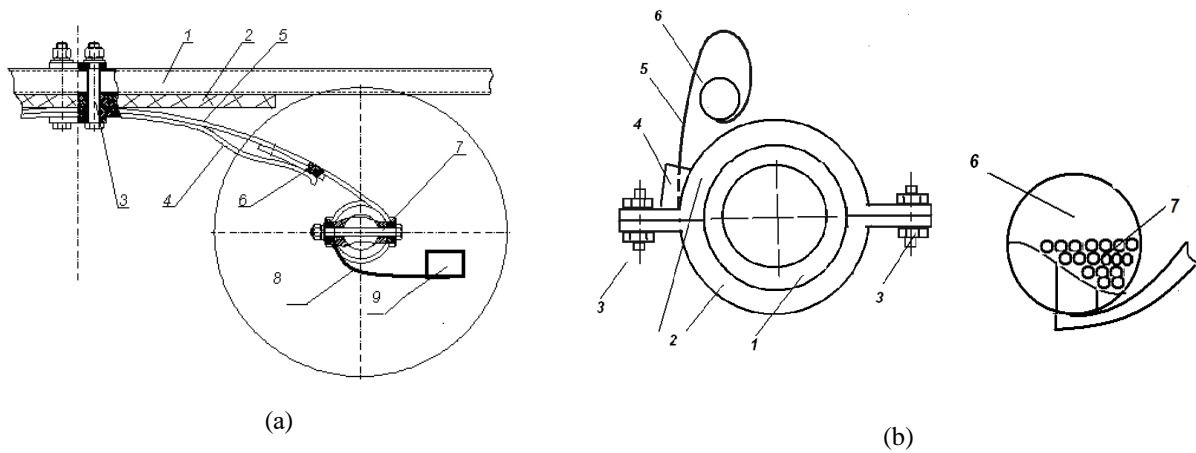
The traditional suspension system of vehicle consists springs and dampers and be classified as passive suspension. It does not require external control, but only dissipates energy. This system has weak adaptability due to the fixed characteristics of springs and shock absorbers. A good designed passive suspension can, to some extent, optimize the quality of ride comfort and stability, but cannot completely eliminate the consistency between characteristics of suspension [1].



An important characteristic of the suspension is its smooth ride, which is usually characterized by displacements of unsprung masses. This is due to ensuring the contact of the wheels with the road. This criterion differs from the more general criterion of controllability of the system on some programmatic moves [2]. Although the criterion for the movement of unsprung masses can be improved by the suspension, however, the most effective way is to join of DVA to the unsprung masses. This is especially true for the newest designs of cars with electric motors on the axle of the wheels. For such structures, the traditional reduction in the weight of unsprung masses can not be achieved to improve handling. DVA is widely used to reduce vibrations [3-8]. An example of the use of DVA in a suspension of boom-sprayer is given in [9].

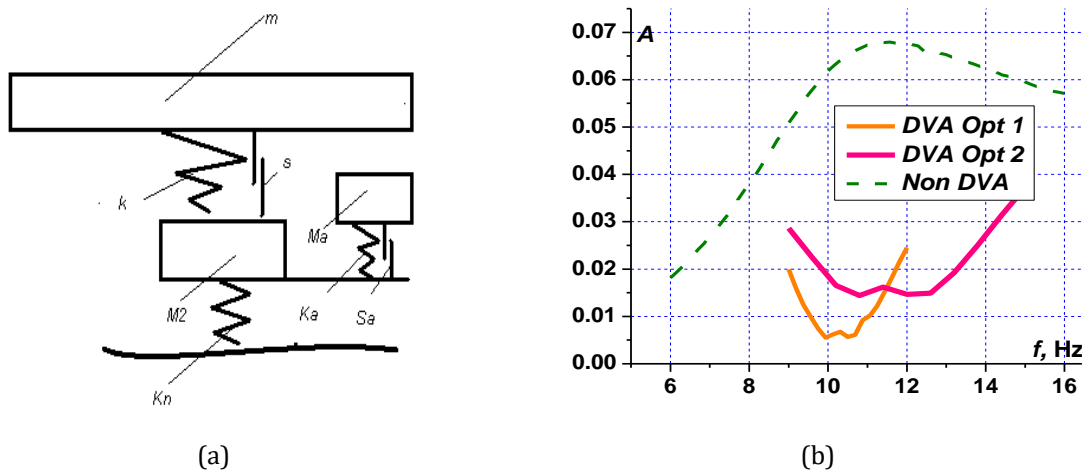
**2. Materials and methods**

For vehicles many DVA have been developed. They differ in weight and dimensions, design features, ranges of regulation. One of the variants of non-linear suspension with DHA and container with vibration absorbing parts is in Figure 1 shown.



**Figure 1.** Constructive variants of the suspension from the DVA: (a) - nonlinear suspension; (b) - suspension container with particles.

On the basis of the discrete-continual approach, a three-mass calculation scheme, taking into account the unsprung masses and the DVA attached to them, is obtained (Figure 2a) [10]. Optimization of parameters is carried out.



**Figure 2.** (a) - calculation scheme of the suspension; (b) - the results of optimization in different frequency ranges: -amplitude of unpowered masses.

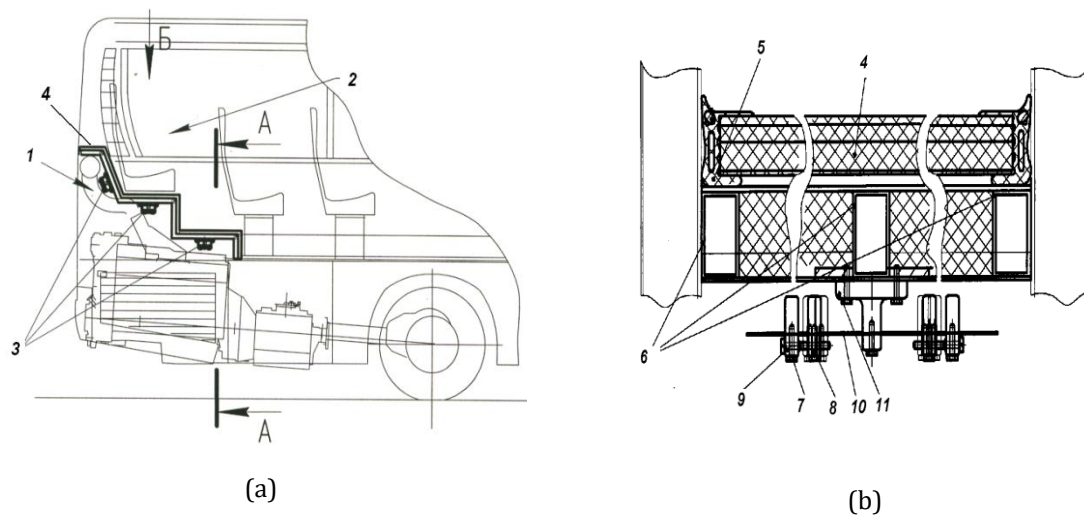
To obtain optimal projects in a plurality of constructive parameters, algorithms of genetic optimization were used in conjunction with condensed non-parametric circuits. The results of optimization are shown in Figure 2b for different frequency ranges.

### 3. Results

Noise-absorbing partition shown of a thin-walled element - the base of the partition and the attached DVA's which serve for noise protection against interference acting on the partition. Such a partition can be applied to the floor of the bus, in the elements of the body of the engine compartment of vehicles, and at a wall of the cabin, which are in conditions of high acoustic loads, as well as cabins of mining machinery, in schemes of sound insulation of premises, salon of airplanes, etc. However, thin-walled laminar noise-absorbing partitions that are used today are effective only in the higher frequency range and inefficient in the low-frequency range typical of many machines. Their noise-absorbing properties can be greatly improved in the low-frequency range with the help of DVA. At Figure 3 schematically shown the general view of the soundproof partition of the bus motor. The cross-section view shown the bus septum where: 1 - engine compartment, 2 - passenger compartment, 3 - DVA, 4 - internal part of the partition, 5 - elastic fastening of the partition, 6 - external part of the sound absorber of reinforcing elements, 7 - fixed mass DVA, 8 - moving mass DVA, 9 - adjusting screw, 10 - elastic plate member, 11 - DVA mounting node.

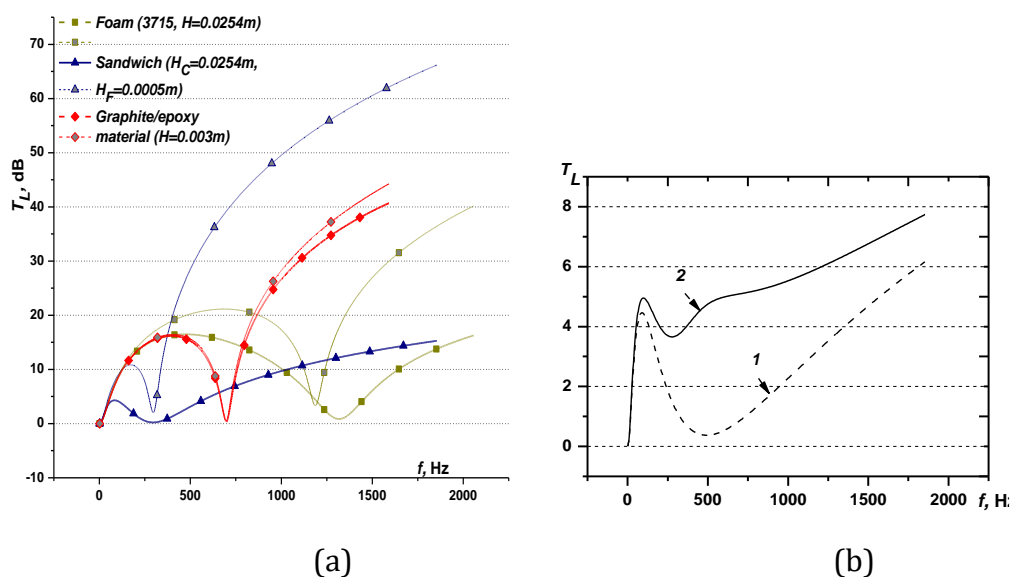
Between the engine 1 and the passenger compartment 2, a sound absorbing partition is installed to the outer part of which the DVA-11 unit with a stationary mass DVA 7 and a moving mass DVA 8 are mounted on the elastic plate member 10 with an adjusting screw 9 attached.

To study the soundproof properties of panels in the low-frequency range, the layered elements of partitions are drawn to the equivalent of them Timoshenko beams [11]. The algorithms of the reduction to the Timoshenko beam are considered in [12]. In works [13-24] the damping and sound protection properties of layered plates with additional elements are considered. Consider the three-layer beam. Its parameters: length  $L=0.6$  m, thickness of the filler  $H = 0.0254$  m, thickness of the facial layers  $h=0.003$ m; filler modules  $C_{xx} = C_{zz} = 180$  MPa,  $G = 35$  MPa,  $C_{xz} = 40$  MPa, density  $\rho=240$  kg/m<sup>3</sup>); modules of rigid facial layers -  $C_{xx}=43$  GPa;  $C_{xz}=6$  GPa;  $G=0.6$  GPa,  $\rho=2000$  kg/m<sup>3</sup>).



**Figure 3.** (a) - general appearance of the soundproofing of the bus; (b) - the cross-section of partition-wall.

Figure 4 shows the sound loss coefficient for various materials as a function of the dimensionless frequency  $f/fr$ . Figure 4a shows the coefficient of sound loss for different ratios of Young's modulus  $E$  to the coefficient of displacement  $G$  of the equivalent beam of Timoshenko, in Figure 4b - partition with DVA.



**Figure 4.** (a) - coefficient of sound loss for different materials, (b) - sound losses for the partition with DVA.

#### 4. Discussion

Noise-insulating material can also serve other purposes, namely to reduce the traumaticity of passengers in accidents. Layers of this material will improve the frames ability to absorb kinetic energy, while maintaining the residual space of passenger compartment. In order to ensure the structural integrity of the vehicle and its ability to absorb the impact of energy, it is important to examine the nature of the fracture to reduce peak loads and improve the power absorption of impact.

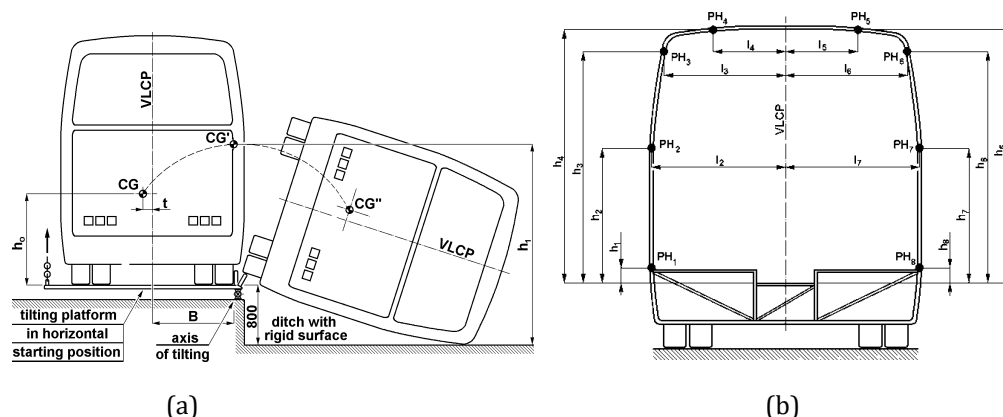
These factors can be reduced by using special energy-absorbing devices also. A rollover of a bus is one of the most dangerous accidents. The risk of fatal consequence is greater than other cases. It is determined that at least the amount of accidents involving buses is smaller, but fatal consequences (31%) and serious injuries (21%) more than in other accidents. The UNECE Regulation 66 requires that the large vehicles superstructure strength need be sufficient to provide residual space during and after a rollover.

Superstructure contribute to the strength and energy absorbing capability of the bodywork, and preserve the residual space, which preserved in the passengers', crew and driver's compartment(s) better survival possibility for passengers, driver and crew in case of a rollover accident. Side superstructure is formed from cantrail and waistrail. Cantrail means the longitudinal structural part of the bodywork above the side windows including the curved transition to the roof structures. Waistrail means the longitudinal structural part of the bodywork below the side windows. In the rollover test the waistrail may be the second area to contact the ground after initial deformation of the vehicle cross-section. In the rollover test the cantrail hits the ground first. a structural part or element which does not have significant deformation and energy absorption during the rollover test means a "Rigid part".

The superstructure of the vehicle shall have the sufficient strength to ensure that the residual space during and after the rollover test on complete vehicle is unharmed. The residual space is continuous in the passenger, crew and driver compartment(s) between its rearmost and foremost plane and is defined by moving the defined vertical transverse plane through the length of the vehicle along straight lines through some points on both sides of the vehicle.

Passive safety European Regulation ECE R66 preferred real high cost roll-over test. The application for approval of a vehicle type with regard to the strength of its superstructure shall be submitted by the vehicle manufacturer and identify main data and parameters of the vehicle type, an overview of the main verification methods of bus rollover test precised analysis of virtual procedure of rollover test, detailed initial condition-system for rollover simulation and possible virtual method of reference energy. There "reference energy" is the potential energy of the vehicle type to be approved,

measured in relation to the horizontal lower level of the ditch, at the starting, unstable position of the rollover process. In this paper a new type of energy absorbing devices is investigated.



**Figure 5.** Rollover test (a) and geometrical parameters of plastic hinges on a bay (b) defined by UNECE Regulation 66.

Various designs of anti strike devices are known. They are widely used for wheeled cars. Their principle of work is plastic deformation of materials. During impact, energy absorption occurs due to crumple of construction.

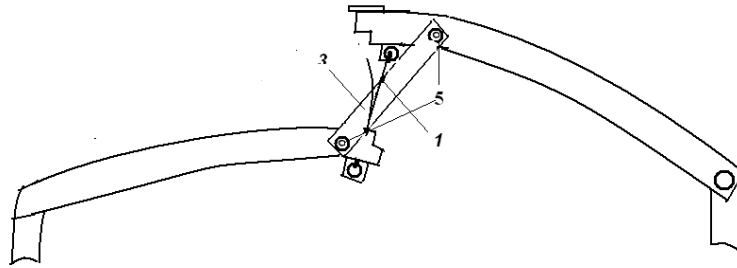
During an accident at the moment of a collision of a car with an obstacle, the impact energy is absorbed by plastic deformation of the body parts. Such items are specifically provided in the design. To a certain level of loading they act as elements of body frame. When the load exceeds the threshold value, the energy-absorbing elements begin work as shock-resistant devices. Descri "Plastic zone"(PZ) and "Plastic hinge"(PH). PZ means a special geometrically limited part of the superstructure in which, as the result of dynamic, impact forces:

- large scale plastic deformations are concentrated;
- essential distortion of the original shape (cross section, length, or other geometry) occurs;
- loss of stability occurs, as a result of local buckling;
- kinetic energy is absorbed due to deformation.

PH means a simple plastic zone formed on a rod-like element (single tube, window column, etc). However, most of devices work due to flattening various beams. This does not allow uniformly absorb the shock energy. They do not give them the opportunity to absorb the impact energy in the lateral reversal of the bus, which is often accompanied by injury of passengers.

In Figure 6 crash resistance bus roof is presented [19]. It contains of energy absorbing composite rod connected with horizontal beams of the roof, breaking rod and side racks of the bus. Energy absorption coupling installed in the places of attachment of bearing rods, hinged fixing of one half of the horizontal beam roof to the side rack. At Figure 6 the structure is depicted in a post-impacted state. The crash resistance roof of the bus contains energy-absorbing elements that are made in the form of a carrier spatial rod symmetric system, consisting of bearing rods 2, interconnected by a breaking rod 3 and connected to one absorbing composite rod 4 and energy absorbing couplings 5. The shock absorbing roof of the bus joins at plastic hinges on a bay.

The shock absorber roof of the bus works in such a way that the principle of its operation involves the presence of a mechanism for multi-point absorption of impact energy. During the rollover of the bus 1 during the impact load, for example, the left wall 1 (Figure 6), the membrane of the left side or right side rack 4 and the subsequent movement of the left or right bearing rod 2, causing the displacement of the composite rod 3, occurs in turn causes strain of the tensile strength of the composite rod 4 (detachment of one layer from the other) and the scroll of the absorbing clutch 5, crushing their internal construction, and emitting the entire structure of the roof when rotating against the hinge 6 upwards, which is substantially enhances the energy absorption efficiency, provides the minimum spatial deformation of the body of the vehicle (in the direction of the passenger compartment) and increases the level of safety in emergencies.



**Figure 6.** The shock absorber roof of the bus (after reaching the critical force value): 1 - energy absorbing composite rod; 2 - horizontal beams of the roof; 3 - breaking rod; 4 - side racks of the bus; 5 - shock absorbing coupling

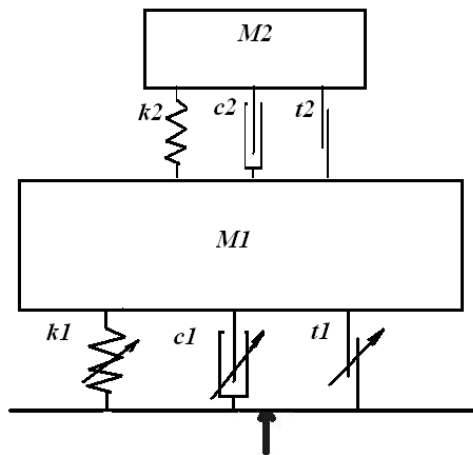
The minimum energy required to be absorbed by the body section ( $E_{min}$ ) is the sum of the energy of the bays comprising the body section. The body section passes the loading test in case, when all the bays which form that body section are considered to have passed the quasi-static loading test and these results can be quoted in future requests for approval provided that the component bays are not expected to carry a greater mass in the subsequent superstructure. The body section fails the loading test if one of the bays go into the residual space.

The total energy ( $E_T$ ) shall be distributed among the bays of the superstructure in the proportions of their masses. The total energy to be absorbed by the superstructure is:

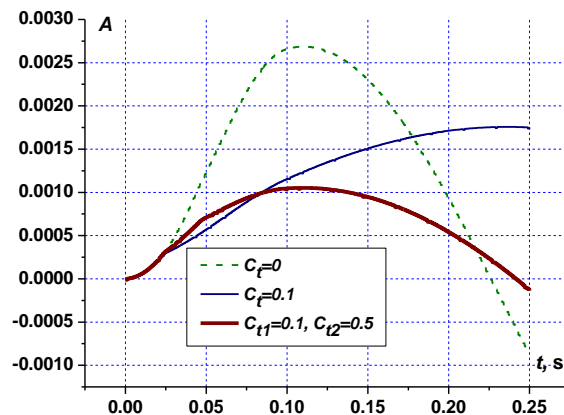
$$E_T = 0.75 M g \Delta h$$

where:  $M = M_k$  - unladen kerb mass of the vehicle if there are no occupant restraints; or,  $M_t$ , total effective vehicle mass when occupant restraints are fitted;  $g$  - gravitational constant;  $\Delta h$  - vertical movement of the vehicle centre of gravity during a rollover test.

A number of methods have been developed to investigate the mechanics of hinges demolition. Some models are simple, mostly single mass. To study the dynamics of the system: the basic design - the passengers will use a relatively simple two-axle model (Figure 7,a) with variable parameters. In Figure 7b shows optimization results with constant damping and controlled friction. Friction, and especially, controlled friction, reduces the acceleration of passengers, and grade of injuries.



(a)



(b)

**Figure 7.** (a) - two mass model; (b) - optimization results with stable damping and controlling traction.

## 5. Conclusions

An important issue for the development of modern vehicles is the reduction of vibration. DVA are widely used to reduce vibration and noise levels in vehicle cabs, rotating parts machines, unsprung weight of wheeled vehicles. So it is expedient to consider the suspension of a car with DVA. This devices should also be used in safety devices by accident's. They distinguish from traditional energy absorbing elements and can serve as vibration and noise protection elements also.

The traditional suspension system of vehicle consists springs and dampers and be classified as passive suspension. It does not require external control, but only dissipates energy. This system has weak adaptability due to the fixed characteristics of springs and shock absorbers. A good designed passive suspension can, to some extent, optimize the quality of ride comfort and stability, but cannot completely eliminate the consistency between characteristics of suspension.

A series of vibration, noise and absorbing elements for vehicles are considered. In order to improve the smooth ride of the suspension, the use of DVA in unsprung masses is considered. Laminated partitions with DVA system are considered for noise reduction in car salons. Impact absorbing elements of the new type are considered in order to prevent injuries to passengers during rollover of buses. The resulting calculation schemes and optimal projects confirm the effectiveness of this kind of elements.

To obtain optimal projects in a plurality of constructive parameters, algorithms of genetic optimization were used in conjunction with condensed non-parametric circuits.

Noise-absorbing partition shown of a thin-walled element - the base of the partition and the attached DVA's which serve for noise protection against interference acting on the partition. Such a partition can be applied to the floor of the bus, in the elements of the body of the engine compartment of vehicles, and at a wall of the cabin, which are in conditions of high acoustic loads, as well as cabins of mining machinery, in schemes of sound insulation of premises, salon of airplanes.

Noise-insulating material can also serve other purposes, namely to reduce the traumaticity of passengers in accidents. Layers of this material will improve the frames ability to absorb kinetic energy, while maintaining the residual space of passenger compartment. In order to ensure the structural integrity of the vehicle and its ability to absorb the impact of energy, it is important to examine the nature of the fracture to reduce peak loads and improve the power absorption of impact.

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