Study on setting the structural components of the front compartment of the car body

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Abstract. During a frontal impact at speeds exceeding 50 km/h, the deformation of the front compartment structure of the car body must absorb a large amount of the impact energy so that the passengers’ compartment remains as undeformed as possible. At low speeds, the structure of this compartment must be deformed so that the body structure and subassemblies in the engine compartment are less affected and the cost of repair is reduced. The paper presents a study on how to set the structural compartments of the front compartment to achieve the best impact at low speed impact. In this analysis is used a simplified model with finite elements of the front compartment structure, made with Ansys software. In order to study the behavior at the front impact and to set the stiffness of the characteristic areas, a series of tests at different low speeds were performed.

1. Introduction

According to the basic concept used to make the car body, the front compartment is a very important part of the body with an essential role in impact behavior. The front compartment structure must also be capable of absorbing large amounts of energy, by deformation. In this way, the passengers’ compartment remains undeformed. These requirements are particularly necessary in the case of an impact occurs only on half of the structure. Depending on the architecture of the front compartment, during a frontal impact with a barrier, at a speed of approximately 50 km/h, it must record a deformation of 400-700 mm and the deformation of the safety cell is limited [1]. At very low speed, up to 4 km/h, the impact energy is absorbed by the bumpers. Typically, the bumper structure is reversible deformation so that after an impact, the bar returns to its original shape without any repairs [2, 3].

Some studies show that during a frontal impact at 50 km/h, the front compartment absorbs 79% of the impact energy, 12% goes to the engine and the remaining 9% is absorbed by the firewall. The energy absorbed by the front compartment structure is distributed as follows: 72% to the front side member, 22% to the wheel houses and 6% to the fenders, (figure 1) [3].

The front side member is the most important primary member in the front compartment structure [2]. A straight front side member with continuously increasing cross section and moment of resistance from bumper to firewall in best able to convert the kinetic energy into controlled work of deformation during a collision. Also a very rigid underframe is attached to the front side member on which the
engine is mounted and the suspensions arms. Considering the stiffness characteristics of the front compartment structure, it can be divided into four characteristic areas (figure 2), [3, 4]:

![Figure 1. Impact absorption capacity.](image)

![Figure 2. The stiffness characteristics of the front compartment structure.](image)

A - reversibility area, (very low speeds, less than 10-15 km / h). The impact energy is absorbed by the bumper or crash box and the front side members are protected. The deformation is reversible, returning to the original shape and no expense for repair.

B - deformable area, (speeds below 25 km / h). Dissipation of all impact energy through plastic deformation of bumpers, crash boxes up to in the area of the motor mount and strut, (150-250mm). In order to obtain an acceptable cost of repair, deformation should not extend further.

C - rigid area (speeds between 25-50 km / h). The plastic deformation it is extends to the bulkhead. Repair requires use of a bench at a high cost.

D - very rigid area (speeds over 50 km / h). The deformation affects the bulkhead and other safety cell elements. The cost of the repair is very high.

2. Front compartment behavior during front impact with rigid barrier

2.1 Model geometry and finite element network

In order to study the front compartment structure behavior in front impact on 40% of the front surface, a simplified 3D model was developed in the ANSYS program (figure 3). This model consists of the
the main elements of the structure of the front compartment (front cross member, front side members, wheel house, upper side member). Because has been followed the behavior of the front compartment structure at impact with lower speeds, up to 50 km/h, the model was simplified. In this case the rest of the car body is not affected, so, it was modeled only the front compartment.

![Figure 3. 3D model geometry and finite element network.](image)

The finite element model is obtained by meshing the geometric model of the structure made from surfaces. The main parameters used for the structure, thickness and material were determined after several attempts. Table 1 lists the parameters from the last test.

| Parameter         | automobile frame rails | crash box | cross member | the other elements | obstacle               |
|-------------------|-------------------------|-----------|--------------|--------------------|------------------------|
| Thickness [mm]    | solid-flexible behavior | 2.8       | 2            | 1.5                | 1.5                    |
| Material          | Steel                   | Steel NL3 (YS=420 MPa) | Steel NL2 (YS=380 MPa) | Steel NL3 (YS=420 MPa) | Steel NL2 (YS=380 MPa) |
| Mesh size [mm]    | 150                     | 10        | 10           | 150                | 150                    |

2.2 Test protocol and initial conditions
The geometric model used to analyze a front impact on 40% of the car body structure, attempts to simulate the impact test at low speeds according to the Research Council for Automobile Repairs protocol. The purpose of the RCAR protocol is to reduce the loss of human lives and to reduce as far as possible the cost of repair [5]. In figure 4 shows the barrier drawing and description at front impact, where \( U = 40\% \) overlap; \( B \) = vehicle width (front); \( R = 150 \) mm radius; \( F \) = test vehicle; \( A = 10 \) degree angle.

The initial conditions imposed on the model are set out in the Ansys program, (figure 5) for the entire structure as follows:
- The velocity vector is selected for the entire structure and the velocity value is between 4 km/h and 50 km/h;
- The 3D model will be propelled against the barrier;
- To provide the required kinetic energy, the body car was molded by a solid body so that the total weight of the structure was equal to the mass of the vehicle;
- Test structure weight = 1400 kg;
- The impact barrier is a rigid body and the height of the barrier shall exceed the height of the front of the test vehicle.
2.3 Results of the impact tests

Studies are to be conducted on the frontal impact behavior of the compartment structure at different speeds. These tests aim at highlight the impact resistance, the deformation and repair cost. Taking into account the characteristic stiffness areas of the front compartment structure, the following attempts are proposed:

- Front impact test on 40% of surface with V = 4 km/h

  ![Figure 6.](image)

  In this case, figure 6, the impact was achieved at a low speed of 4 km/h. It is noted that the deformation is very small, approximately 14 mm. The structure is affected, it doesn’t return to the original shape. This deformation occurs also because the front bumper is missing. The bumper during impact of low speeds absorbs the impact energy.

- Front impact test on 40% of surface with V=10 km/h

  Note that at the speed of 10 km/h only the front cross member is deformed, the other elements are not affected. Usually this deformation is reversible, returning to the initial form. But if this is not possible, only the front cross member is deformed, the front side member is protected. Repair costs are minimal.

- Front impact test on 40% of surface with V=20 km/h

  It can be seen in figure 8 that at 20 km/h the structure of the front compartment is more affected. Deformation extends to the front lonjeron. The impact energy is absorbed by the front cross member and the crash box.

- Front impact test on 40% of surface with V=23 km/h
Figure 7. Equivalent Stress and equivalent plastic strain of geometric model to 10 km/h.

Figure 8. Equivalent Stress and equivalent plastic strain of geometric model to 20 km/h.

Figure 9. Equivalent Stress and equivalent plastic strain of geometric model to 23 km/h.

The test at 23km/h made more sense to highlight the deformation of the front side member (figure 9). From the initial data, he did not have to deform. However, given the fact that the model is made only from the front structure, without the closing components, which play a role in the strength and stiffness of the body car (the front bumper), the deformation occurs earlier at speeds of less than 25 km/h.

- Front impact test on 40% of surface with viteza V=25 km/h

At the speed of 25 km/h it is noticed that the deformation of the front side member is more pronounced, (figure 10). Also, comparing the two figures 9 and 10, the line of deformation can be observed. Deformation of the front side member is controlled, so the model performs its role.

- Front impact test on 40% of surface with V=50 km/h

The deformation recorded at 50 km/h is approximately 500-600 mm according to the color grid in figure 11, [3]. During the simulation, the model gets more degrees of freedom because the model does not have any link elements with the road, the front wheels are missing from the model. The
deformation recorded before the model is spinning around the impact barrier is within the imposed limits.

![Figure 10. Equivalent Stress and equivalent plastic strain of geometric model to 25 km/h.](image)

![Figure 11. Total deformation and equivalent stress of geometric model to 50 km/h.](image)

3. Conclusions
At low speeds the deformation of the front area is very small. Beginning with the speed of 10 km/h the front cross member is plastic deformed. Some automotive manufacturers also provide an elastic deformation for this speed. The proposed model resolves only a deformation on the front cross member, the other elements are protected. At the speed of 20 km/h it has been observed that the deformation extends to the crash box. The front side member is protected. A test at 23 km/h was made to see the deformation evolution. There are tensions and deformations on the front side member. To observe the development of the deformation, an impact test is performed at 25 km/h. From these two tests we can say that the deformation of the front compartment is controlled. The controlled deformation of the front compartment is up to 50km/h.

The proposed model behaves according to the stiffness of the front compartment. A simplified model allows to analyse the behavior of the front compartment structure from the design stage, so that the optimal materials and thicknesses of structural elements can be chosen.

References
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