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Evaluation of the seat fastening in the frame of a road bus submitted to frontal impact

Abstract

The collective intercity transportation by bus is currently a mean of locomotion much sought after by people. Security in accidents is a very important factor that must be taken into account in design of bus body structure, being the evaluation of passenger safety of this type of vehicle is an important subject that should be checked, because in many accidents occur disconnection between seats and fastening members causing serious passengers injury, often fatal. This work aims at evaluation the behavior of frame fixing of seats of intercity bus bodies, submitted to the frontal impact situation in a rigid wall of 100% offset, through evaluation by finite element method (FEM). This study uses a numerical model corresponding to the body structure and chassis, developed through flexible beam elements, combining with shell elements for the structure of the seats and its fastening members, with the objective of not missing the essential aspects of the problem, allowing the solution with a reduced computational time. The numerical model of bus body and seat was impacted against a rigid wall at a speed of 8.89 m/s, being its validation according to the deceleration curve established by Regulation 80. Then it was gotten the Von Mises stress in fastening members of the seat structure in bus body. It is also presented a proposal to improve the fastening of the seat structure, comparing the results of the stress gotten in the two types fastening submitted to the frontal impact.

Keywords

bus body, impact, fastening members, seat, design

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1 INTRODUCTION

The collective intercity transportation in Brazil has been one of the most popular means of locomotion for people today, and the bus, specifically, is one of the most used transport options in this category.

According to data provided by the latest Statistical Yearbook, from National Agency for Land Transport (ANTT, 2007), in 2007 the number of companies that provide transport by bus in Brazil is 197 companies and bus-type vehicles that travel on the highways are 13907. The Statistical Yearbook also reports the number of passengers carried in the mode of long distance transportation, with distances up to 75 miles. In 2007 the number of passengers was 61.570,406, for a total of 2.299,898 trips in that year. Table 1 shows the evolution of accidents involving vehicles of collective transport on federal roads in Brazil, from 2007 to 2010.

Table 1 Evolution of accidents. (Statistical Yearbook of federal highways, 2010)

Year	Collective Transport
2007	8852
2008	10185
2009	9495
2010	9417

Figure 1 presents the average value per year of deaths, serious injuries and KSI (killed or seriously injuries) in accidents, head-on collisions of buses/cars by country (ES, DE, FR, NL and GB).

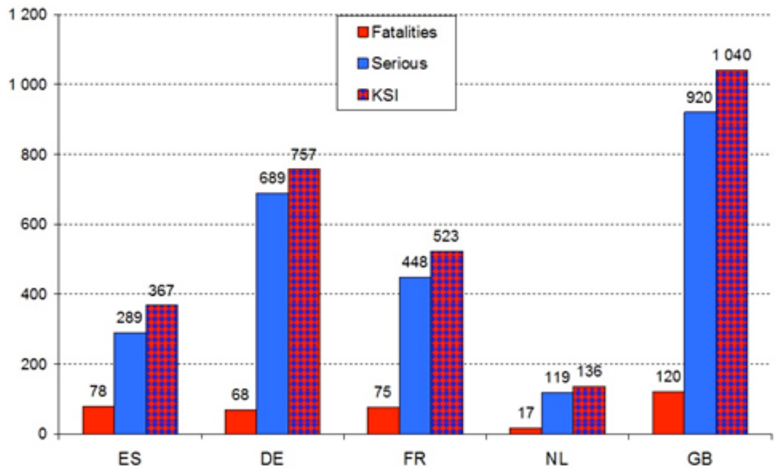


Figure 1 Bus crash/cars (frontal impact) Europe, EEVC WG21. (Bus & Coach Frontal Impact Analisys, 2010)

According to Páez et al. (2011) the security improvements in vehicles introduce in European regulations over the past few years are proving to be efficient, however, in case of collision, especially in frontal collisions not only the driver is susceptible to injury in an accident, but also the rest of the passengers, who often suffer serious or fatal injuries.

Figure 2 shows a statistical analysis based on the database of Spanish accidents, showing, in the period between 1993 and 2008, the number of frontal impact accidents occurred with large vehicles (LPV), heavy goods vehicles (HGV) cars and vehicles weighing up to 3500 kg (LGV), being that the bus type vehicles fall into the category LPV.

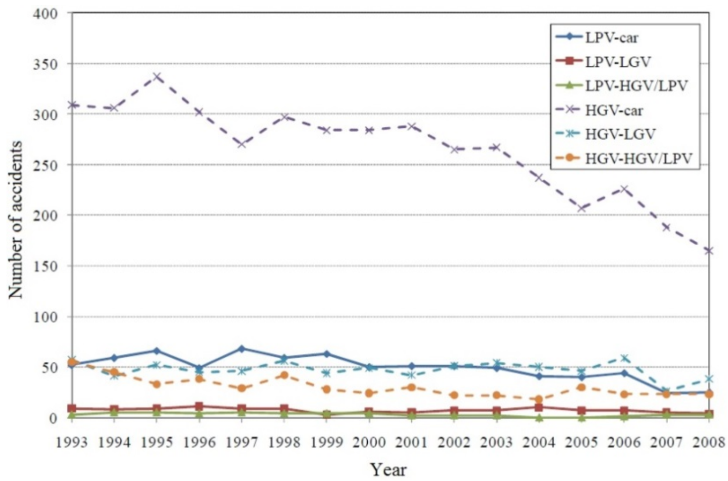


Figure 2 Number of bus accidents in Spain. (Páez et al., 2011)

Statistical analysis reveals that more than 50% of interurban accidents in Spain resulted in deaths and serious injuries. The study suggests, based on analysis of accidents, that new structural solutions in the design of the bus should be considered to improve the protection of passengers (Páez et al., 2011).

In this context, the manufacturers of buses must comply with current legislation to perform the project. One of the major problems that may occur during an accident is the so-called "domino effect" that occurs when the seats are disconnected from the bodywork due to inadequate anchoring of same, increasing the number of victims in the event of an accident. Figures 3a to 3c show the resulting damages in a bus due to a frontal impact in accidents in Brazil. Figure 3d show what may happen inside the body in that kind of situation, with the seats given off during the impact event.

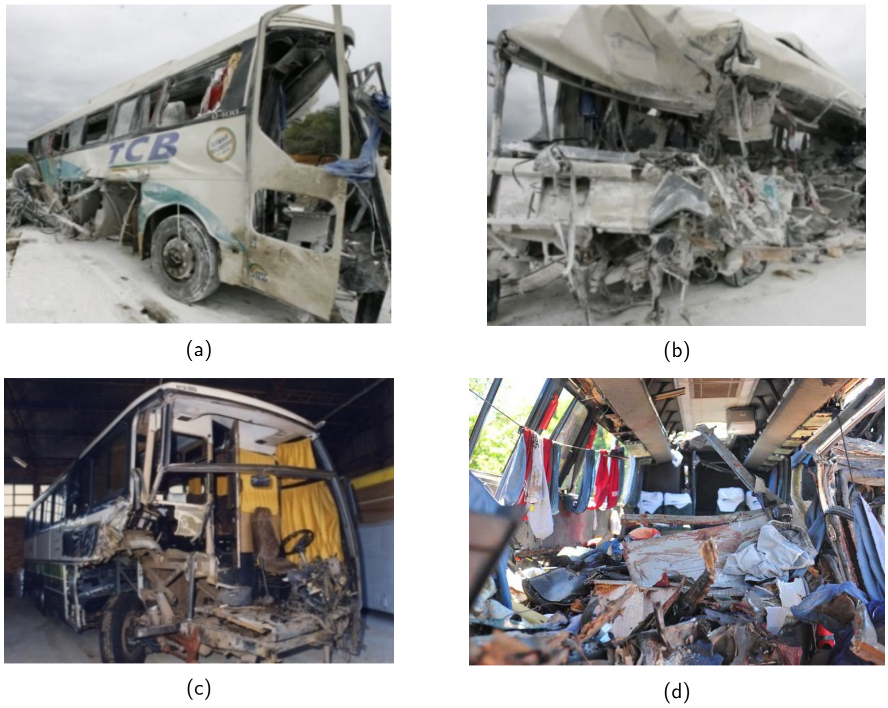


Figure 3 Bus crash (frontal impact). (Dias de Meira Junior, 2010)

According to Dias de Meira Junior (2010), the frontal area of the bus is responsible for the absorption of the impact energy, which is concluded by observing the result of frontal impact accidents with road buses. Among the several types of accidents involving buses, the most dangerous is the train collision, followed by tumbling; then, the collisions with hard obstacles and heavy vehicles. The risk of injury fatality depends on the type of the accident (ex. frontal, side and rear impact accidents). The reduction of damages and fatalities in the development and construction of a bus is proper for one type of accident, but it's not generally effective for all. For example, a design modification which is very effective in tumbling may be useless in a frontal impact situation and vice-versa. Therefore, the development of a structure that meets all requirements is a complex task.

The seat anchoring in Brazil follows the predicted norms established by the Resolution 445/2013 of National Traffic Council (CONTRAN, 2013). The seat anchoring in the European Community is established by Regulation 80 (1989), applied to all constructed for the transportation of 16 passengers or more (Categories M2 and M3).

2 BUS BODIES

2.1 Bus bodies geometry

The structure of a bus is composed of columns and thin-walled panels, steel plates, joints and other structural components, as shown in Figure 4. These structural components are those that absorb the largest amount of energy during the impact. The cocoon of the body is engaged in a chassis, then, the other bus accessories are assembled (Dias de Meira Junior, 2010).

Figure 4 Bodywork attached to the chassis. (Manual Guidelines bodybuilding Volksbus, 2007)

The bus body is covered on the sides below the window with thin sheets of aluminum. The front, rear and ceiling are covered with fiberglass. The doors and external small doors (trunk) are also composed of structure and siding of aluminum.

The cocoon of a bus body is basically divided into six parts: Base, ceiling, right side, left side, front and rear. Figure 5 shows an example of a cocoon structure.

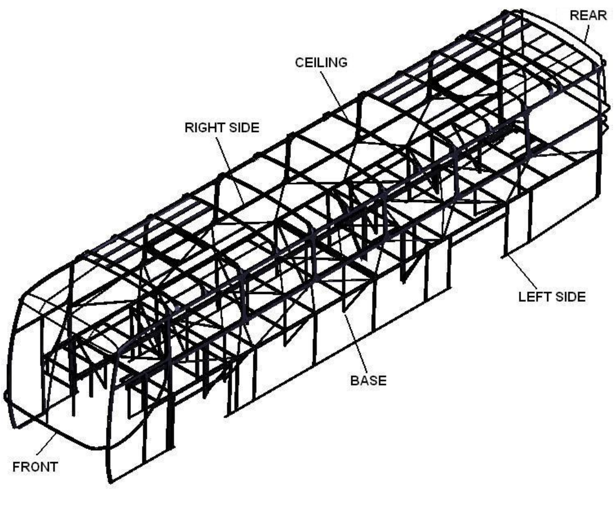


Figure 5 A bus body cocoon. (Walber, 2009)

2.2 Fastening structure of the seat

The fastening system of the seat structure used in this study is fixed by screws on a longitudinal rail welded along the structure of the base of the cocoon. The structure of the seat is also supported by a profiled plate that is welded structures along the sides of the cocoon. Figure 6 shows the cross section of a bus body, showing the fixing points and support of seats and also the main components that makes up the cocoon of a bus body.

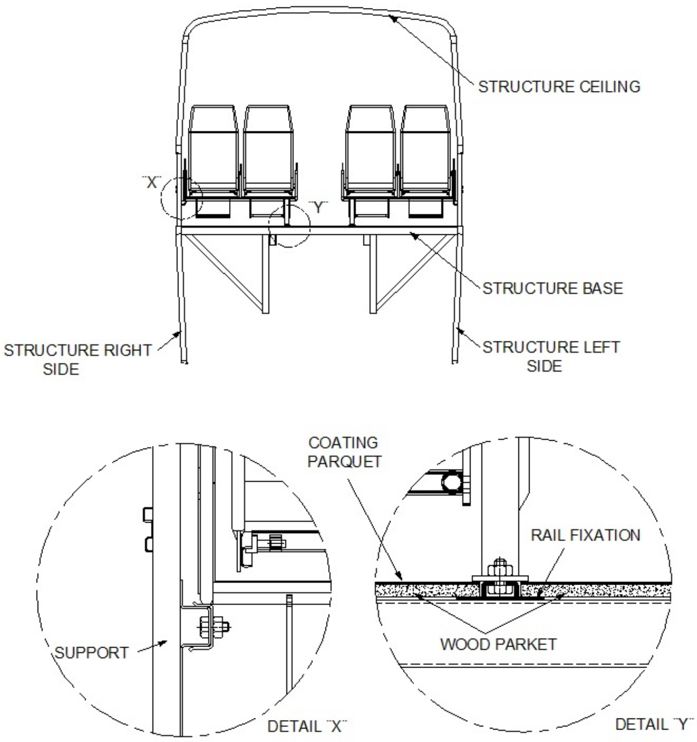


Figure 6 Cross-section of a bus body. (Walber, 2009)

Evaluating accidents on the roads of Brazil, it appears that the screws that hold the seat structure fail causing the detachment, consequently injuring the passengers. The seat can be approved by dynamic test or static test defined by Regulation 80 (1989) and Resolution CONTRAN (2013).

2.3 Numerical model of body

The numerical model of the body structure used in this study is composed of flexible beam elements, assigning sections for the different parts that make up the cocoon and the chassis. The model was discretized with 5502 nodes and 2566 elements of the type "BEAM161" with option formulation Hughes_Liu with integration of the cross section (Ls-Dyna, 2010). Each element has two nodes and six degrees of freedom at each node (displacements and rotations in directions x, y and z). This numerical model was developed and used in doctoral thesis by Dias de Meira Junior (2010) and Walber (2009).

The material used in the chassis and bus structure was a structural steel and has the following properties (Dias de Meira Junior, 2010):

- Elastic Modulus: $E_L = 210_x 10^9$ Pa
- Poisson's Ratio: $\nu = 0.3$

- Density: $\rho = 7850$ kg/m^3
- Yield Stress: $\sigma_{esc} = 240_x10^6$ Pa
- Tangent Modulus: $E_{TAN} = 431_x10^6$ Pa

The coefficients of Cowper-Symonds which take into account the strain rate are $D = 40.4\ s^{-1}$ and $q= 5$, thereby, the yield stress will act dynamically, varying continuously during the impact event. The constitutive equation defined by Cowper and Symonds (1957) apud Jones (2001) is expressed by:

$$\dot{\varepsilon} = D\left(\frac{\sigma_0'}{\sigma_0} - 1\right)^q, \sigma_0' \geq \sigma_0 \tag{1}$$

Where σ_0' is the dynamic flow stress to a rate of plastic deformation $\dot{\varepsilon}$, σ_0 is the static flow stress associated and D and q are constants for a particular material (Dias de Meira Junior, 2010).

According to Ls-Dyna (2010), strain rate can be taken into account using the model of Cowper and Symonds, which scale the yield stress with the factor:

$$1 + \left(\frac{\dot{\varepsilon}}{C}\right)^{\frac{1}{\rho}} \tag{2}$$

Where $\dot{\varepsilon}$ is the strain rate, $C = D$ and $\rho = q$. In this work will be used kinematic hardening, which can be obtained by the utilization of plastic kinematic material (*MAT_PLASTIC_KINEMATIC) from the materials library of software Ls-Dyna, with option to $\beta = 0.0$ (kinematic hardening) and with the formulation for rate effects $VP = 0.0$ (Dias de Meira Junior, 2010). The failure strain for eroding elements configured in the material was 25% ($FS = 0.25$) (Ls-Dyna, 2010).

The thickness used for the frame stringer is 6.3 mm. For the tubes that make up the ceiling structure was adopted to 2.6 mm thickness and, for the rest of the tubes and profiles of the cocoon, thickness of 2 mm.

With data provided by a manufacturer Brazilian bus company, it was adopted a weight of 5330 kg for a Scania chassis, being 1030 kg in front and 4300 kg on the rear. For the bound body was adopted a total weight of 13020 kg, considering the bus with 44 seats (12 m length), with air conditioning and toilet; the weights of the external fibers are also computed, doors, small doors and windows. This body considers the weight without passengers and baggage (unloaded), 4520 kg being located at the front axle and rear axle 8720 kg. Considering the vehicle with maximum load of 3080 kg, which is the weight of 44 passengers (with an average weight of 70 kg per person) plus 1000 kg, resulting a total weight loaded of 17100 kg. Figure 7 shows the numerical model of the body composed of beam elements.

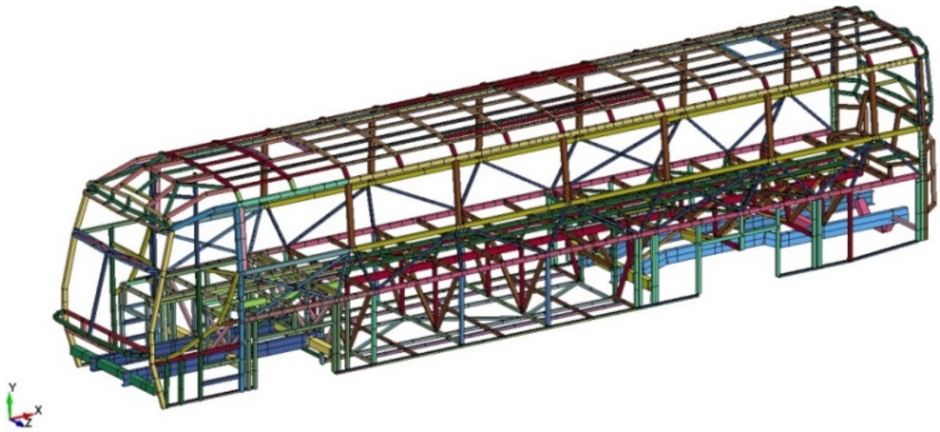


Figure 7 Numerical model cocoon/chassis.

2.4 Numerical model calibration

The method used to validate the model of beams consists in the measurement experimental of natural frequencies of the structure, by measuring the acceleration in the longitudinal direction (x), transverse (z) and vertical (y), and then perform the comparison with the frequencies of the numerical model, according with Walber (2009) and Dias de Meira (2010).

To perform the test it was installed micro accelerometers on the rear side of the bus structure. This point was chosen because the natural modes obtained numerically present greater tendency to move in this part. Figure 8 shows the location of accelerometers.

Figure 8 Location of accelerometers.

The digital signal transmitted by accelerometers is converted to analog through a board DA/USB 1208FS (Computerboards, USA) of four channels, three of which are linked to accelerometers. This board has two analog outputs, converting a 12-bit digital signal into a voltage of 0-4 Volts. The measurement of acceleration at the points of response of the structure (rear of the chassis) was performed using two biaxial accelerometers, model ADXL 321 and ADXL 311 Analog Devices, with full scale of 18 g and 10 g, respectively.

Table 2 presents the frequencies obtained in the tests for each direction. The frequencies were placed in ascending order, presented in the column with the title of "Ordination".

Table 2 Frequencies obtained experimentally.

Experimental			Ordination (Hz)
Longitudinal Direction (x) (Hz)	Transverse Direction (z) (Hz)	Vertical Direction (y) (Hz)	
6.84	5.86	5.86	5.86
7.8	7.82	6.84	6.84
10.7	8.79	8.79	7.82
12.7	10.75	11.73	8.79
15.64	11.73	14.66	10.75
17.59	14.66	17.59	11.73

Table 3 presents the frequency values for the top five modes of vibration, obtained numerically.

Table 3 Modal characteristic prevalent.

Mode	Frequency (cicles)	Characteristic of mode
1	6.17	Torsion
2	7.86	Flexion
3	8.40	Flexion torsion
4	9.30	Flexion torsion
5	10.47	Flexion torsion

Table 4 presents a comparison between the results obtained experimentally and those obtained by finite element method for the structure under study.

Table 4 Comparison frequencies results FEM x Experimental.

Mode	FEM	Experimental	Difference (%)
1	6.17	5.86	3.9
2	7.86	6.84	13.4
3	8.40	7.82	6.9
4	9.30	8.79	5.6
5	10.47	10.75	2.7

Figure 9 shows graphically the comparison of the experimental results with the natural modes of vibration of numerical model for the first five modes. The percentage differences between the results are small, which validates the numerical model used, of the viewpoint from modal assessment.

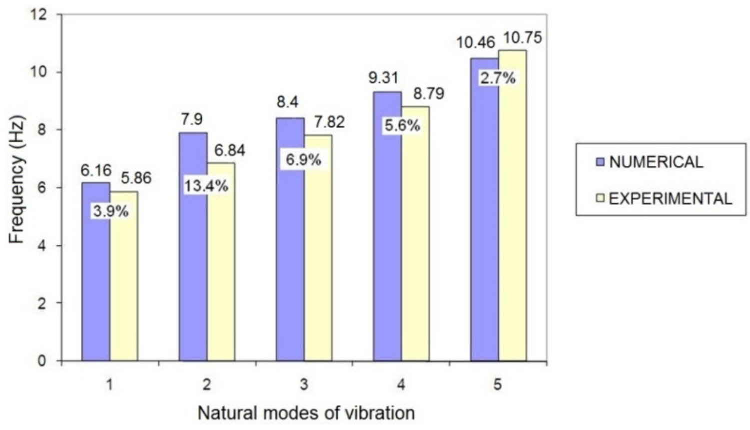


Figure 9 Comparison between numerical model x experimental frequencies.

2.5 Calibration of the numerical model using the Riera Method (1980)

Riera (1980) presents a simplified methodology that allows determining the reaction force $F_x(t)$ due to the impact of a one-dimensional projectile against a target disk. This validation was presented in Dias de Meira Junior (2010). In this method, the structure is discretized into masses and springs in series and obtained through energy methods. This methodology is about integrating the Equation (3):

$$F_x(t) = P_C[x(t)] + \mu_x(t)V^2(t) \tag{3}$$

where $u_x(t)$ is the mass of the projectile per length unit; $x(t)$ is the distance from the front of the projectile; $V(t)$ is the speed of the projectile that hits the rigid wall that behaves as a rigid body and $P_c[x(t)]$ is the force of the collapse portion of structure that is colliding (Figure 10).

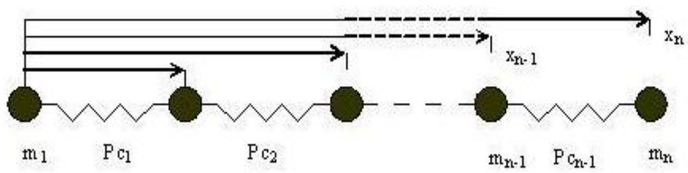


Figure 10 Riera Method. (Riera, 1980)

The strength of collapse P_C is the force required to compress until the collapse of the structure studied, which can be determined experimentally or numerically. This collapse force can be determined for structures as the cave of an intercity bus body, the fuselage of an airplane or a simple profile tablet. This collapse force is a result of the interaction among collapse forms, as the plastic and local buckling, distortional or global (Riera, 1980).

It's possible determine the force P_C using expressions provided by NBR 14762 (2010) of cold-formed steel structures and the Direct Strength Method (Schafer e Peköz, 1998 and Hancock, Kwon and Bernard, 1994). The equations that determine P_C are:

$$P_P = \sigma_1 A \tag{4}$$

$$\lambda_0 = \sqrt{P_P / P_{FG}} \tag{5}$$

$$P_{PFG} = \rho P_P \tag{6}$$

$$P_{CL}\left(\frac{P_{FL}}{P_{PFG}}\right)^{0.4}\left[1-0.15\left(\frac{P_{FL}}{P_{PFG}}\right)^{0.4}\right]P_{PFG} \tag{7}$$

$$P_{CD} = \left(\frac{P_{FD}}{P_P}\right)^{0.6}\left[1-0.25\left(\frac{P_{FD}}{P_P}\right)^{0.6}\right]P_P \tag{8}$$

$$P_C = Min\left(P_{PFG}, P_{CL}, P_{CD}\right) \tag{9}$$

where P_P is the plastic collapse force; σ_1 is the tension of material flow; A is the cross-sectional area profile; λ_0 is the slenderness ratio reduced to compressed bars; P_{FG} is the elastic buckling strength global; P_{PFG} is the force resulting from the interaction between the strength global elastic buckling strength and plastic collapse; ρ is the reduction factor associated with the global buckling (NBR 14762, 2010); P_{FL} and P_{FD} represent the strength local and distortional elastic buckling collapse forms, respectively; P_{CL} and P_{CD} are the forces due to the interaction among global and local buckling and distortional buckling and yielding, respectively, and P_C is the collapse force of the element analyzed which will be minimum of three loads found collapse. Using the Direct Strength Method it's necessary calculating previously the loads of elastic buckling of the element studied.

Next, it is presented a quantitative evaluation of the bus structure, applying the simplified method proposed by Riera (1980), enabling the determination of the reaction force due to impact against a rigid wall. The methodology proposed by Riera (1980) applies the one-dimensional projectile (missile), but has also been applied successfully for Tech and Iturrioz (2005) for bus structures. This is possible because of the nature of this structure, which presents itself in the form of a cave, forming a composite structure.

Figure 11 shows the distribution of masses used, as well as discretization of the used structure, distances and kneading forces.

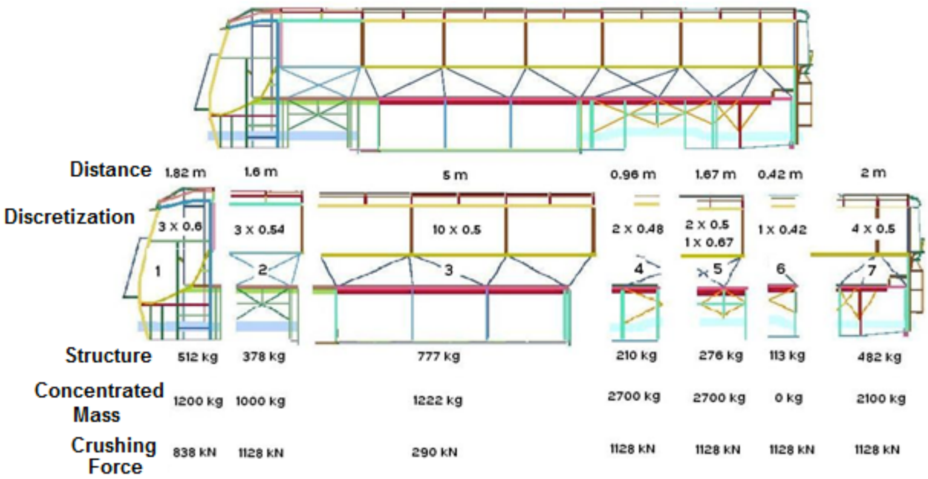


Figure 11 Mass Distribution and Discretization.

The modeling using the Riera Method (1980) used a discretization of 26 spring mass sets. Figure 12 presents the collapse forces obtained numerically, as well as the mode of deformation of the structure under study in each section.

It is possible to notice on Figure 13 that the failure on the front area of the bus structure occurs by buckling profile "C" of the chassis. After the failure of this profile, occurs the sudden collapse of the structure remainder. It can also be observed on Figure 13 the failure on the front area of the bus structure occurs on the longitudinal stringer of greater section (rectangular profile 60 x 100 x 2 mm) and also occurs by buckling. If this profile fails, the structure buckles globally in the central region.

It can be concluded that the behavior of the structure in the front of the bus is controlled by the "C" profile and in the central area the structural behavior is controlled by the rectangular profile (60 x 100 x 2 mm).

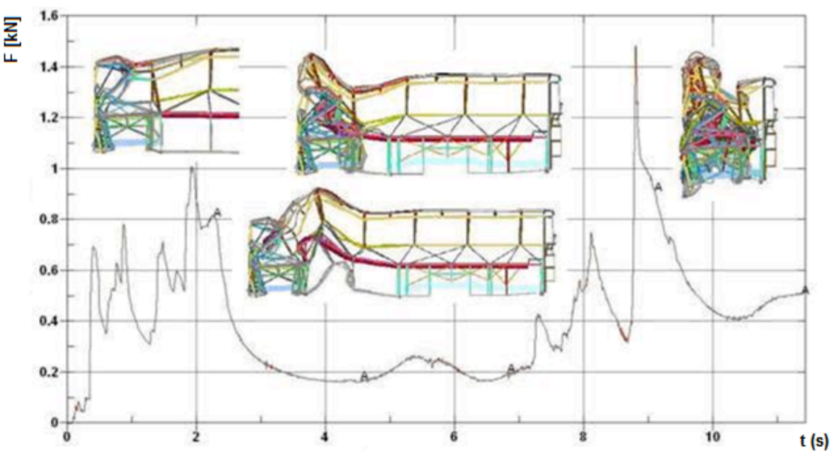


Figure 12 Collapse forces and deformation modes.

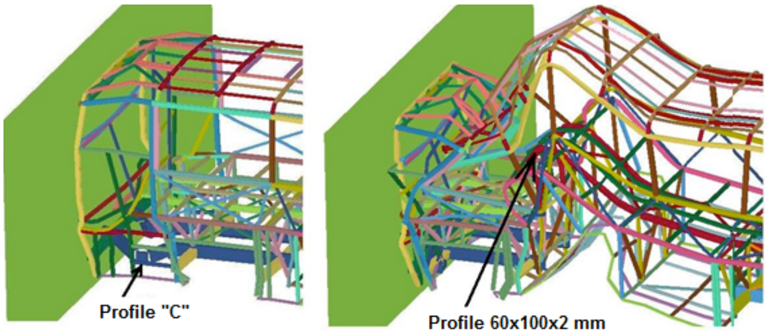


Figure 13 Failure modes.

Whereas in the front of the bus (region 1), seen in Figure 11, the resistance offered to the kneading is due mainly to two "C" profiles, the overall strength of kneading is F_C = 838 kN in this area. In the immediately following area (region 2), the resistance to kneading is F_C = 1128 kN, considering the presence of two profiles in “C” 80 x 200 x 6 and two rectangular profiles 60 x 100 x 2 mm. In the central area (region 3) the strength of kneading is 290 kN, considering the presence of two profiles 60 x 100 x 2 mm. In the back areas (4, 5, 6 e 7) It took F_C = 1128 kN (two profiles “C” 80 x 200 x 6 mm and two rectangular profiles 60 x 100 x 2 mm). The rigid wall reaction force obtained by finite element of beams model is compared with the one obtained through the methodology of Riera (1980) that is presented in Figure 14.

As a conclusion of this section, it can be affirmed that the comparison between the finite element numerical model and the model using the method of Riera showed consistent and very similar results.

2.6 Real accident simulation for calibration of the model

This section presents a numerical simulation of the accident that occurred in 1/22/2006 on the Raposo Tavares highway (SP-270), one of the biggest road tragedies that occurred in Brazil (Dias de Meira Junior, 2010). One of the buses with 13 passengers and the other with 38 passengers on board collided frontally, resulting 32 dead and 21 injured. The shock was so violent that one of the buses came up to half of the other vehicle.

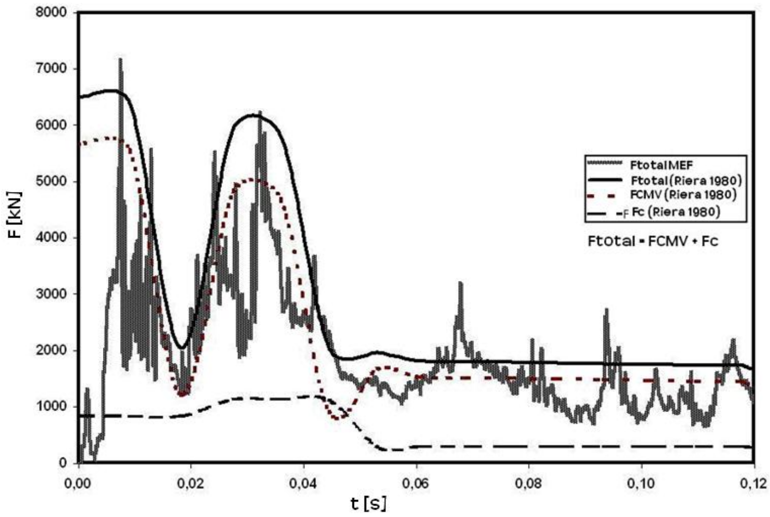


Figure 14 Reaction force on the rigid wall.

Next, it's is presented the frontal impact simulation using the model composed of bar elements in study, in order to demonstrate the ability of the bars to represent a model event of a similar nature. Initially, it will be performed the simulation with the two vehicles with the same speed. The material used for the bodywork/chassis of both buses is steel NBR 7008 ZAR-230 with yield strength of 230 MPa and failure stress of 310 MPa, with tangent module of 730 MPa, the coefficients of Cowper-Symonds are $D = 40.4$ and $q = 5$, a steel commonly used in the industry of building bus bodies. Figure 15 shows the results obtained for the same speeds between 22.22 m/s and 33.33 m/s for each bus. As the speeds add up because the vehicles are going against each other, the evaluation that is being done is of the order of impact speeds of 44.44 m/s up to 66.67 m/s.

Figure 16 presents another situation of frontal impact, with different speeds. One of the buses moves to 25 m/s and the other 36.11 m/s. In this situation, one of bus enters until half the other, around 6.95 m in a time of 0.5 s.

By the evaluation of the figures 15 and 16, It is concluded that the model composed by beam elements is fit to represent frontal impact similar to the events occurred on the Raposo Tavares highway in 2006. The beam model undergoes a displacement in your forward, approximately until half due to an impact.

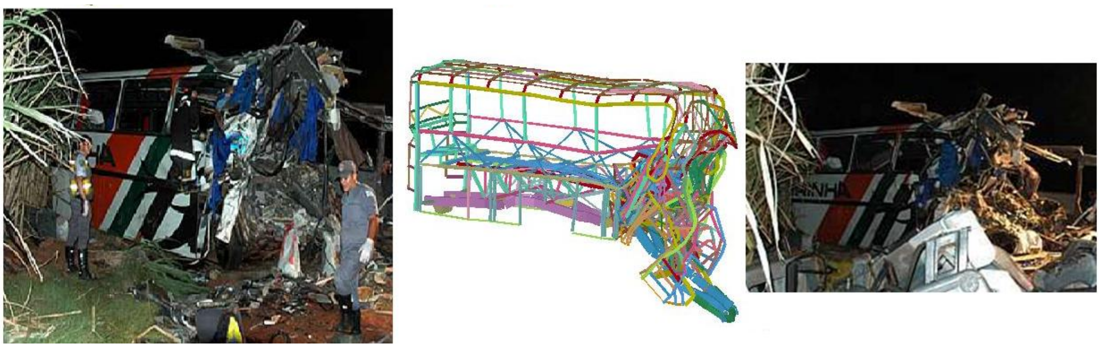


Figure 15 Frontal impact – Accident of Raposo Tavares in 2006. (Dias de Meira Junior, 2010)

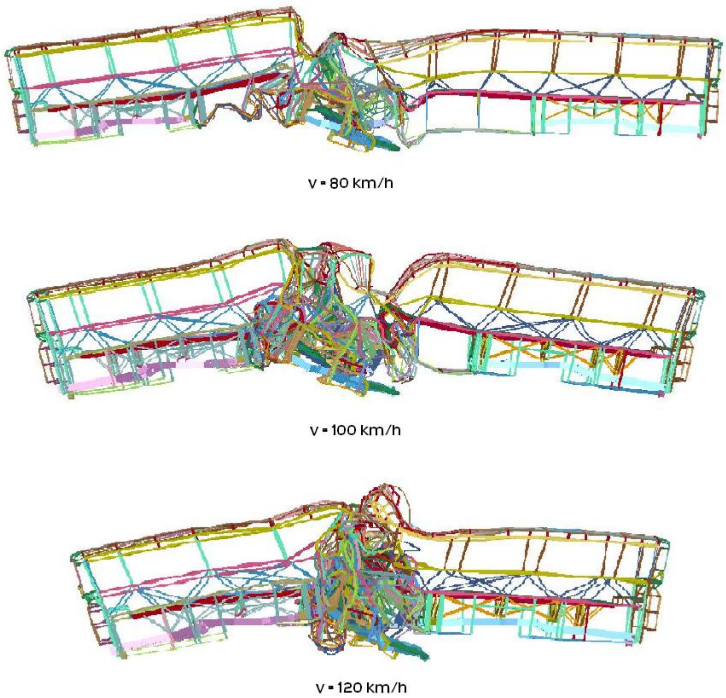


Figure 16 Simulation of impact at different speeds.

2.7 Numerical model of seats

The analysis methodology presented below was developed in the Technical University of Madrid in the University Institute of Automobile Research (INSIA) together with researchers from Brazil from University of Passo Fundo (UPF).

The numerical model of the seat structure used in this study is composed of elements of type "SHELL 163" (Ls-Dyna, 2010), element used in dynamic analyses with explicit formulation. This element type is thin shell, consisting of four nodes with six degrees of freedom at each node (displacements and rotations in the directions x, y e z). The model was discretized with 12430 elements formed by 14560 nodes, generating 87360 degrees of freedom.

The finite element mesh was generated with average size of 10 mm to the structure of the seat and 2 mm for the fastening screws.

The material property values of the seat are:

- Elastic Modulus: $E_L = 210_x10^9$ Pa
- Poisson's Ratio: $\nu = 0.3$
- Density: $\gamma = 7850$ kg/m^3
- Yield Stress: $\sigma_{esc} = 240_x10^6$ Pa
- Tangent Modulus: $E_{TAN} = 431_x10^6$ Pa

The material property values of the fastening screws of the seat are:

- Elastic Modulus: $E_L = 210_x10^9$ Pa
- Poisson's Ratio: $\nu = 0.3$
- Density: γ 7850 kg/m^3
- Yield Stress: $\sigma_{esc} = 640_x10^6$ Pa
- Tangent Modulus: $E_{TAN} = 431_x10^6$ Pa

It was considered for the seat structure tubes with 2 mm of thickness and for the seat base and mounting rail 3 mm of thickness. The seat is fixed on the fixing rail with M10x1.5 screws and in the side support with M8x1 screws, both 8.8 class. The coefficients of Cowper-Symonds which take into account the strain rate are $D = 40.4\ s^{-1}$ and $q = 5$.

Figure 17 shows the finite element mesh generated for the seat structure, with indication of the fixing screws, lateral support plate and rail fixation. Figure 18a shows the mesh of the side plate. Figure 18b shows the mesh generated in the longitudinal rail of fixation.

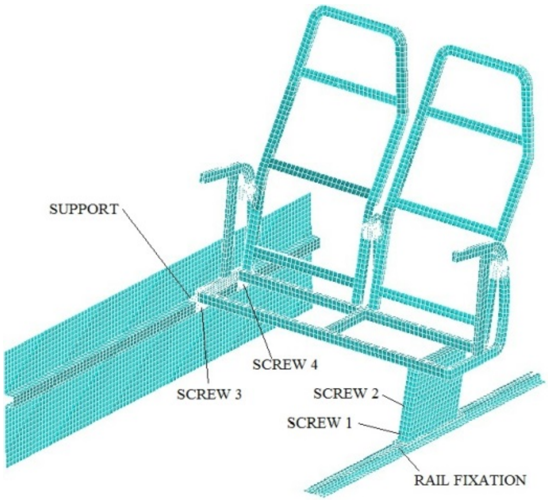
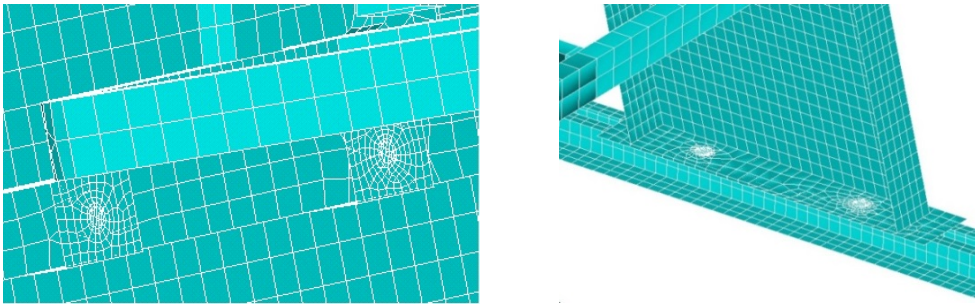


Figure 17 Finite element mesh structure of seat.



a) Mesh side plate b) Mesh rail fixation

Figure 18 Finite element mesh fixing screws.

2.8 Standards for verification of fasteners

The tests of anchors in seats of the buses in Brazil are regulated by Resolution N^{o} 445/2013 of CONTRAN (2013) that is based on Regulation 80 of the United Nations. The Regulation 80 (1989) establishes that, for dynamic tests should be positioned behind the seat rehearsing a dummy free of any restraint, holding a second force acting on the structure of the seat during the impact. The speed during the impact test shall be situated between 8.33 and 8.89 m/s. The deceleration during the impact test set by the Regulation shall be as shown in Figure 19. The deceleration shown should be between 6.5 and 8.5 g.

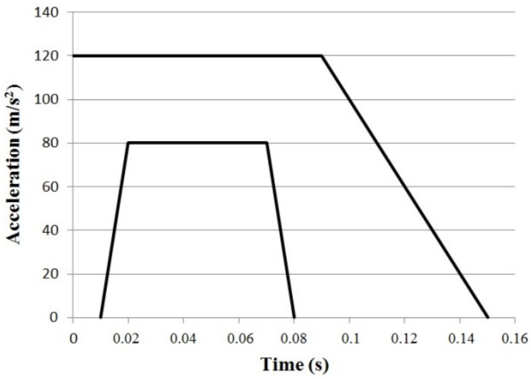


Figure 19 Deceleration window R80. (Regulation N° 80, 1989)

2.9 Frontal impact assessments

In this section will be presented a performance evaluation of bus structure subjected to frontal impact against a rigid wall with 100% offset, as shown in Figure 20.

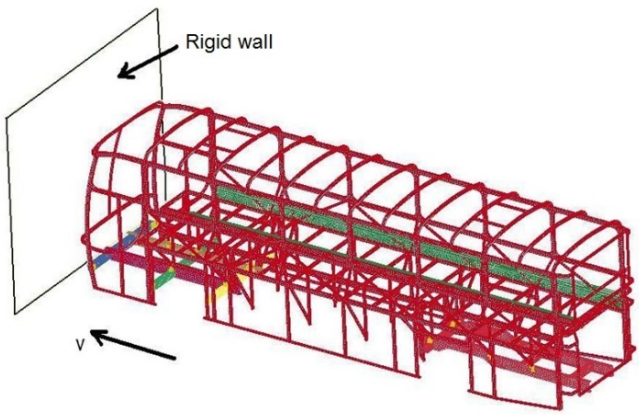


Figure 20 Impact conditions. (Dias de Meira Junior, 2010)

First, the numerical model will be impacted with a speed of 8.89 m/s (established by the Regulation 80) to verify that the levels of deceleration resulting from the impact on this speed are in accordance with the Regulation.

Figure 21 shows the deformed mode for the numeric model impacting against a rigid material wall at a speed of 8.89 m/s in a time of 0.5 s. Figure 22 shows the deceleration obtained numerically in the vehicle gravity center position, while the frontal impact simulation.

Figure 21 Deformed configuration for 8.89 m/s.

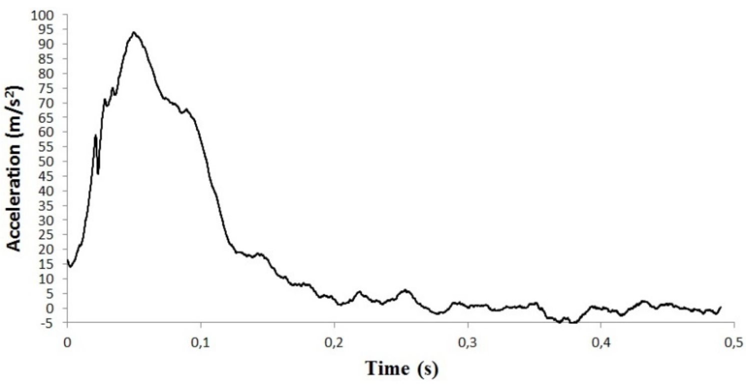


Figure 22 Deceleration curve in vehicle C.G.

Figure 23 shows the deceleration curve obtained numerically compared to the deceleration curve determined by Regulation 80 (1989). The deceleration numerically obtained in those conditions was 5.4 g.

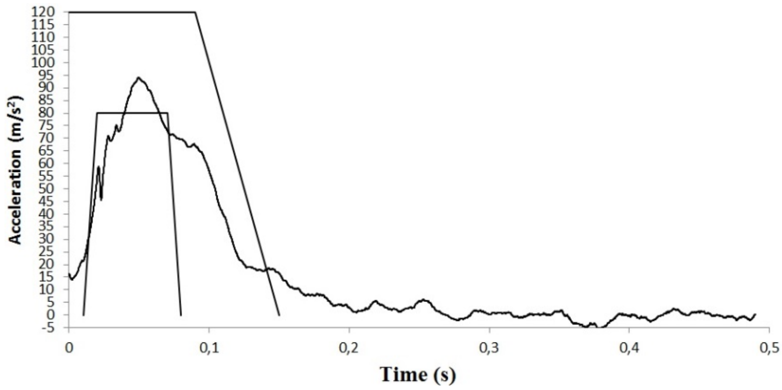


Figure 23 Comparison with R80.

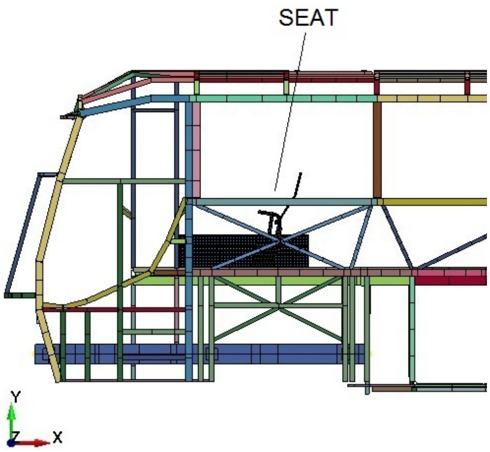
Note that the resulting deceleration curve presented by numerical model in virtual dynamic test condition prescribed by Regulation 80, comparing with the deceleration curve established by this, presents a good agreement, a fact that also makes the valid model to work with frontal impacts.

2.9.1 Numerical model with seat structure

The seat structure with shell element type was inserted in numerical model of the body beam type and elements linked to this via the command "Constrained_Generalized_ Weld_Spot", available in Ls-Dyna (2010).

The complete model is discretized with a total of 20062 nodes and 14996 elements, as described earlier.

Figures 24a and 24b show the numerical model complete with the seat inside. The mounting position of the seat structure in front of the vehicle was chosen to be closer to the impact region.



(a) Side view

(b) Perspective view

Figure 24 Seat installation.

2.9.2 Impact simulations with the seat structure

In this section the numerical model will be impacted with a speed of 8.89 m/s against a rigid wall. It will be evaluated the deceleration of the model and the Von Mises stress level in the elements that make up the screws that hold the seat structure in side bracket and mounting rail.

One force was applied on the back of the seat, for each seat, with the weight of 686 N, corresponding to the weight of one passenger, multiplied by the deceleration curve presented by the model (Figure 25), at the initial time of 0.005 s (that matches the contact time of the front part of the bus structure against the rigid wall), simulating a "loose" passenger in the seat back, as set out in Regulation 80. The height of force application is 0.75m from the floor of the bus, in the horizontal direction and the direction of travel of the vehicle, according establishment of Regulation 80 (1989).

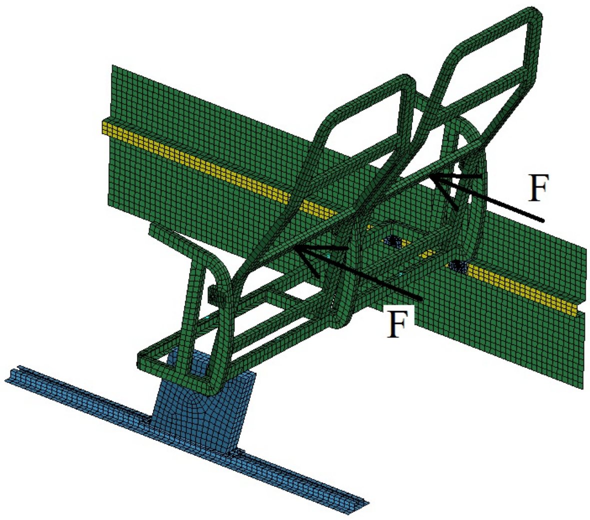


Figure 25 Application of force in seat structure.

The time used in the analysis was of 0.3 s, time required so the speed reaches zero and all the kinetic energy is absorbed by the structure. Figure 26 shows the numeric model deformation mode after the impact event.

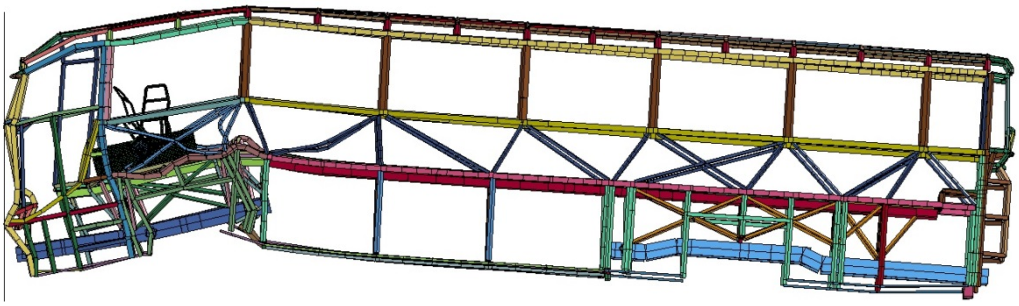


Figure 26 Deformation mode – speed 8.89 m/s.

Figure 27 shows the Von Mises stresses acting on the set, in the area of the screw fixing leg seat. Figure 28 shows the Von Mises stresses acting on the side fixing screws.

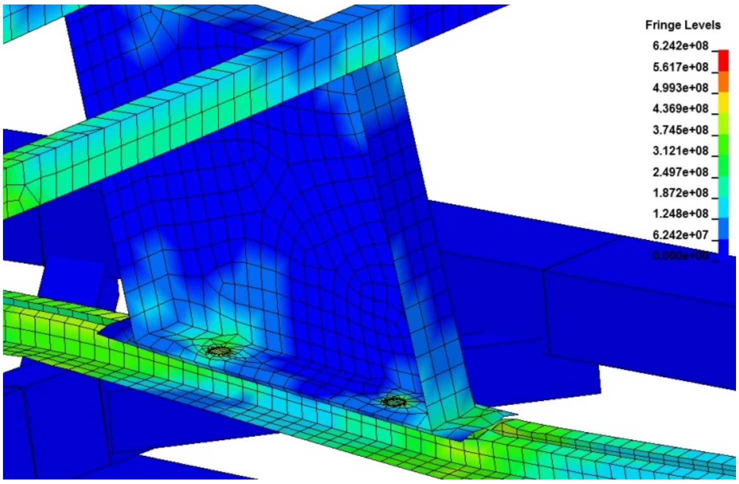


Figure 27 Von Mises stresses global - fixing rail.

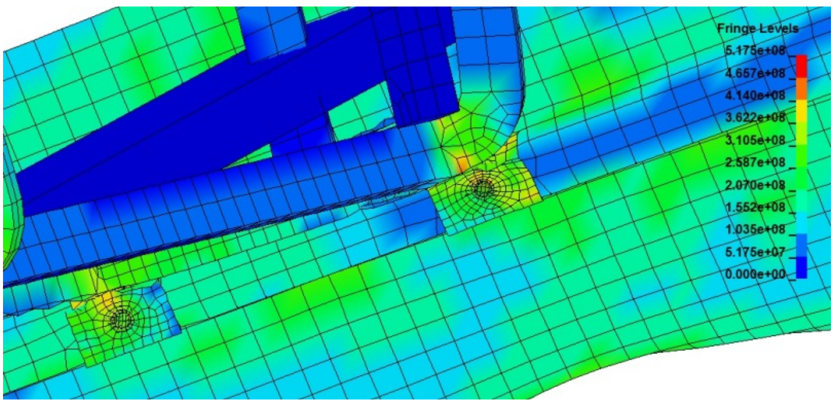
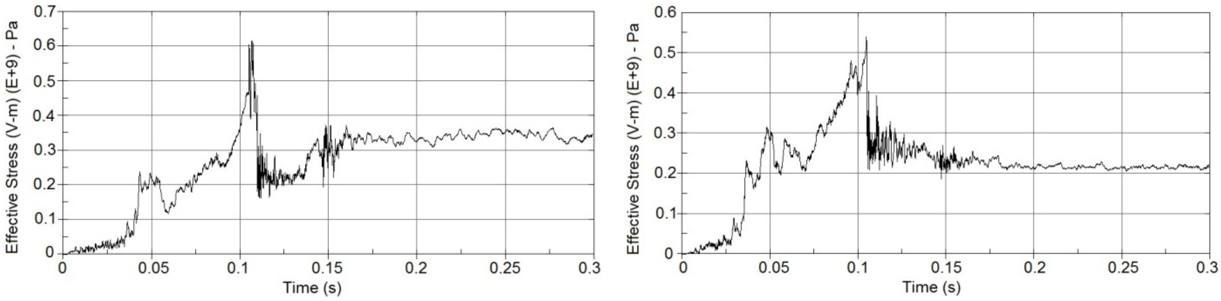


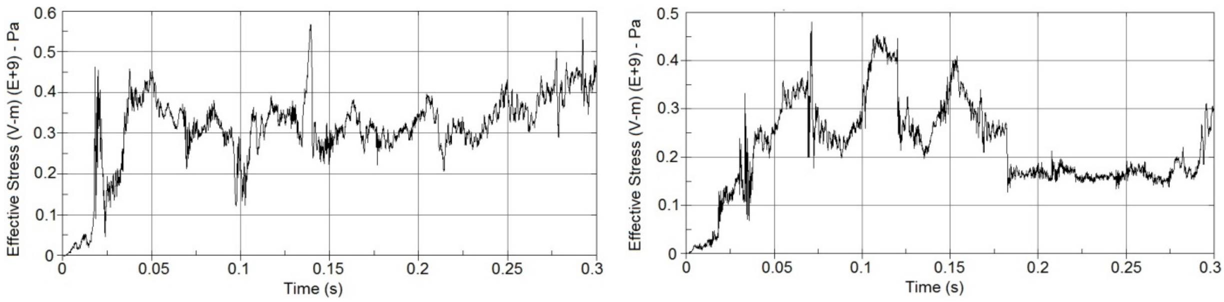
Figure 28 Von Mises stresses global - side grip.

The critical points of Von Mises stress that can be observed occurring in all 4 screws that hold the structure of the seat and also the rail and the mounting plates, near the region of fixing screws. It can also be seen in figure that the type of failure that occurs in the mounting plates is characterized as flexo-torsion. Figures 29 and 30 show the variation of Von Mises stress on the elements that make up the two screws holding the mounting rail in the seat and the two screws that fasten the side structure, as shown in Figure 17.



Screw 1 **Screw 2**

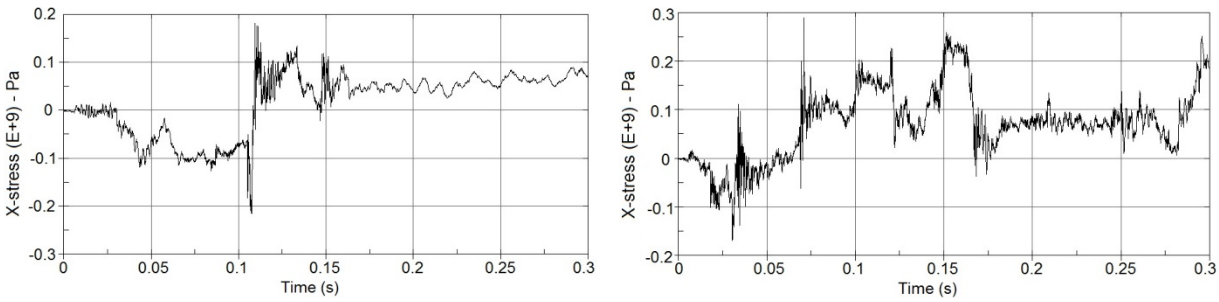
Figure 29 Von Mises stress - screws 1 and 2.



Screw 3 **Screw 4**

Figure 30 Von Mises stress - screws 3 and 4.

Figures 31 and 32 show shear stress acting on the same screws, following the same order.



Screw 1 **Screw 2**

Figure 31 Shear stress – screw 1 and 2.

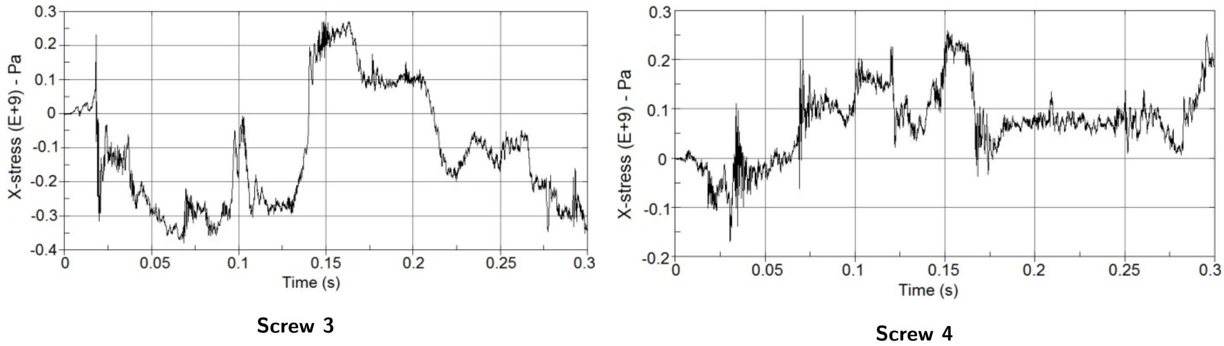


Figure 32 Shear stress – screw 3 and 4.

Table 5 shows the maximum Von Mises stress and shear stress found in each screw.

Table 5 Maximum stresses obtained on the screws – 8.89 m/s.

Screw	Von Mises Stress (MPa)	Shear Stress (MPa)
1	617.37	183.27
2	552.40	212.45
3	585.70	273.05
4	481.11	291.4

The stress value found, show that, for a speed of 8.89 m/s impacting on a rigid wall screws and clamping structure are subject to very high Von Mises Stress, close to yield stress of the screw, getting a safety factor very close to 1. The higher stress values were found in the screws 1 and 2, which secure the foot structure of the seat in the fixing rail.

An analysis by increasing the impact speed to 13.89 m/s was carried out in order to simulate an accident with a speed closer than actually occurs, because in a crash between two vehicles the speeds add up.

The results of this analysis are presented in table 6.

Table 6 Maximum stresses obtained on the screws – 13.89 m/s.

Screw	Von Mises Stress (MPa)	Shear Stress (MPa)
1	919.39	776.49
2	936.95	902.58
3	759.28	706.80
4	726.25	575.01

The stress values found are higher than yield stress of the screws and fixation structure, leading to fail of the anchorages in this condition of impact.

2.9.3 Impact simulations with change in the structure of the seat fixation

In order to reduce stress in the elements that compose the seat in the region between the foot of the structure and the mounting rail, it is presented a proposal for a new profile for the fixing rail, without changing the mounting system of the structure of the seat structure.

The Figure 33a shows the format of the current profile section, Figure 33b shows a suggestion for modification of the rail profile section, keeping the start of assembly, adding tabs of reinforcement and increase the thickness, to increase the resistance of the profile, and therefore seek a reduction in the tensions of the fixing screws.

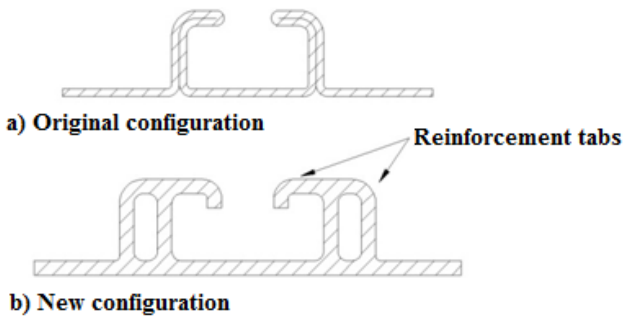


Figure 33 Proposal for a new configuration for mounting rail.

A new numerical model analysis with the new configuration of the rail mounted on the structure was held, impacting against a rigid wall at 8.89 m/s.

Figure 34 shows the Von Mises stresses acting on set, in the region of the fixing screws of the foot of the seat, the point considered more critical.

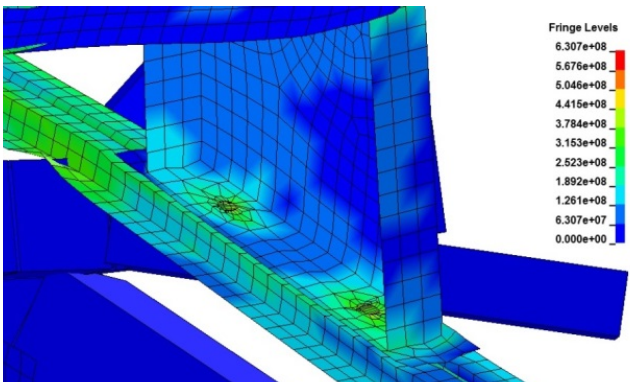


Figure 34 Von Mises stresses global - fixing rail.

Table 7 shows the maximum Von Mises stress and shear found on each screw in these conditions.

Table 7 Maximum stresses obtained on the screws – 8.89 m/s.

Screw	Von Mises Stress (MPa)	Shear Stress (MPa)
1	396.48	398.01
2	445.32	205.61
3	371.58	213.59
4	431.02	384.14

It can be seen from Figure 34 that there was a significant reduction in Von Mises stresses in the modified rail in the region near the fixation screws, influencing the reduction of stress found in all screws. In this situation the safety factor found is higher to 1, improving the conditions of the project of fixing the structure of the chair. Table 8 shows the results impacting at a velocity of 13.89 m/s.

Table 8 Maximum stresses obtained on the screws – 13.89 m/s.

Screw	Von Mises Stress (MPa)	Shear Stress (MPa)
1	721.56	348.91
2	594.02	362.75
3	423.38	142.15
4	513.02	269.76

It's observed that for impact with that speed, the stress found on the screw 1 is still higher than the yield stress of the material. Table 9 shows a comparison between the Von Mises Stress obtained in the analysis of frontal impact between the original configuration and new configuration of the rail, for an impact speed of 8.89 m/s.

Table 9 Comparison of Von Mises stress – 8.89 m/s.

Screw	Von Mises Stress (MPa) Original configuration	Von Mises Stress (MPa) New configuration	Reduction (%)
1	617.37	396.48	35.78
2	552.40	445.32	14.75
3	585.70	371.58	36.55
4	481.11	431.02	10.41

Table 10 shows the comparison between Von Mises Stress on profiles to an impact velocity of 13.89 m/s.

Table 10 Comparison of Von Mises stress – 13.89 m/s.

Screw	Von Mises Stress (MPa) Original configuration	Von Mises Stress (MPa) New configuration	Reduction (%)
1	919.39	721.56	21.51
2	936.95	594.02	36.60
3	759.28	423.38	44.23
4	726.25	513.02	29.36

For both speeds employed the design of new profile showed an increased resistance to torsion. This configuration allowed the reduction of tensions in the fastening screws to the structure of the seat.

3 CONCLUSIONS

Through the comparisons performed, the configuration proposed reduced the Von Mises stress, for both speeds of analysis used and in all the points of fastening of the seat structure in the bus structure. One of screws to the impact velocity of 13.89 m/s, even is solicited with high stress, but it must take into account that this is an extreme condition, speed up that recommends the Regulation 80 for dynamic impact tests. The new geometric configuration and also the increase of thickness of the seat base caused an increase in weight around 55% comparing with the original configuration, representing 0.19% the weight of a bus body with12m in length.

In this article was presented a methodology to evaluate the setting of seats of highway buses under condition of frontal impact, checking which attachment points were subject to greater efforts, using the finite element method.

The numerical model of body used was validated through the measurements of natural frequencies and also comparing with the deceleration curve established by Regulation 80.

It was performed analyses impacting the model against a wall of rigid material, with speeds of 8.89 m/s and 13.89 m/s, respectively, and that speed of 8.89 m/s is established by Regulation 80 dynamic impact testing.

The results obtained show that the stress levels supported by the elements that make up the screws are close to the yield stress of the material, to impact speed of 8.89 m/s and exceeded in impact speed of 13.89 m/s, causing breakage of fasteners.

In the present article a new configuration of the rail to fix seat to the bus structure was presented, where significant reduction was obtained in stress levels supported by screws. The predominant type of solicitation to the rail profile can be characterized as flexo-torsion.

The failure criterion used to evaluate the performance between the models was the equivalent Von Mises stress, as they consider it conservative. In continuation of this study other failure criteria can be evaluated, studying their influence on the results.

In this context, the main objective of the study was achieved. The method of analysis employed can be used to evaluate and test other design alternatives for fixing the structure of the seat, as a modification of the lateral fixation plate and also the modification of the screws to a higher class.

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