STRUCTURAL DYNAMICS OF THE CHASSIS OF A LIGHT TRAILER

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Abstract. *Normally, the project engineer uses generic formulations that hide critical situations and adopts high coefficients of safety. In this work numerical tools of simulation are applied to analyze the structural dynamic behavior of a light trailer passing through in a secondary highway. This work detects and evaluates the critical point of the chassis of a light trailer used for luggage transportation, up to 350 kg. In this way, first is constructed one mass-spring simplified model. This model is required for realizing the dynamic test that simulates cycles of work for one road profile type, and for obtaining the descriptions of the transmitted forces. Having on hands such results, then a model of the trailer is created where different profiles of beams and plates are used for application of loads obtained in the previous process. This model is called global and supplies enough information on critical points of the system. Once the most critical points are identified on the model, one global/local analysis is applied for studying such critical region in order to improve the confidence of proposed alterations. These results supply important information to the designer, making possible that modifications in the design can be best realized to improve the performance of the product.*

Keywords: *Structural dynamics, light trailer, finite element*

1. Introduction

Numerical methods for engineering work are becoming more extensively used also in small and medium companies. The correct use of these methods prevents the excess of empiric rules in the development of new products. This reality has allowed that the product development can be best technically, safer and more competitive.

This work makes use of numerical methods for detecting and evaluating the critical point of a light trailer chassis used for luggage transportation. In this way, first is developed a simplified dynamic model and a road profile function in order to simulate its traffic, obtaining the descriptions of the transmitted forces from the pavement to the chassis structure. Having in hands such results, a simplified structural model of the trailer for finite element analysis is created using beam and shell elements according to the real structure. This model is called global and supplies enough information about the structural behavior and the critical points of the system. Once the most critical points are identified on the model, a local model is developed to obtain more detailed information on critical region stresses in order to help engineering work.

The model of trailer focused in this study is projected for transporting light loads, up to 350 kg. The chassis is assembled with SAE 1020 steel "C" profiles joined by electrical weld, and receives reinforcements in critical points, as in suspension supports. The trailer studied is showed in Fig. 1.

Figure 1. Light trailer used for luggage transportation

2. Experimental measurements

Experimental measurements are realized at this stage in order to obtain some useful dynamic parameters, such as the damping coefficient and the natural frequency of the structure, which will be necessary to calibrate the numerical model in the next stage. To carry out the experiment an accelerometer Bruel & Kjaer type 4338 was used, calibrated for 878 mV/g, whose band of usage is extended from 0 to 5000 Hz, connected to an pre-amplifier of 10 times. An oscilloscope Yokogawa DL 1200A (1 GHz) was used to register the exit signals.

The damping coefficient determination test consists of the installation of the accelerometer in the axle of the trailer. As excitation, the trailer was raised until almost getting the separation of the tires from the ground and was freed suddenly. A sub-damped movement signal was obtained where the amplitude decreases exponentially through the time as it can be observed in Fig. 2.

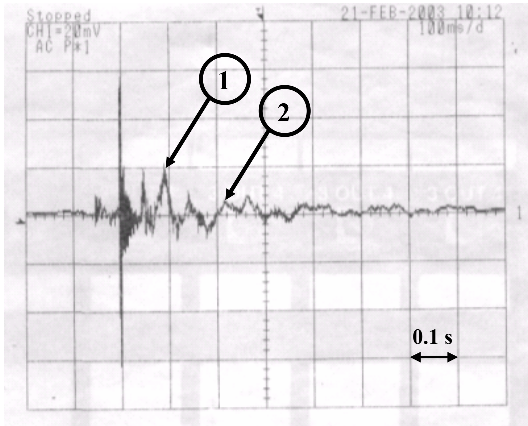

Figure 2. Oscillation signal obtained from the trailer excitation

The decay rate of the logarithmic decrement of the damped viscous movement can be calculated with Eq. (1), (Thompson, 1978).

$$\delta = \frac{1}{m} \ln\left(\frac{x_1}{x_{m+1}} \right) \tag{1}$$

where m is the number of cycles, x_1 is the amplitude of the signal in the first chosen cycle and x_{1+m} is the amplitude of the signal of the last chosen cycle. In the problem in question the indicated amplitudes 1 and 2 in Fig. 2 were used, obtaining a logarithmic decrement value δ equal to 0.75. Then the index of damping can be calculated using the Eq. (2).

$$\xi = \frac{\delta}{\sqrt{(2\pi)^2 + \delta^2}} \tag{2}$$

The obtained value of the damping index ξ was 0.09. The time (τ_d) between two consecutive peaks is inversely proportional to the damped natural frequency (ω_d), then this can be calculated with the Eq. (3).

$$\tau_d = \frac{2\pi}{\omega_d} \tag{3}$$

After that, the system natural frequency ω_n is calculated with the Eq. (4).

$$\omega_n = \frac{\omega_d}{\sqrt{1 - \xi^2}} \tag{4}$$

The first natural frequency calculated from the experimental data was of 126 Hz. The mass of the trailer (~115 kg) allowed the accomplishment of the damping coefficient value calculation through the Eq. (5), obtaining its value equal to 2.612 kg.s/mm.

$$c = 2\xi\omega_n m \quad (5)$$

It is possible now, to calculate the stiffness constant k in agreement with Eq. (6), obtaining the value of 1,831 kN/m.

$$k = \omega_n^2 m \quad (6)$$

3. Attainment of the road roughness profile

For the attainment of the roughness profiles to be used in the trailer dynamic analysis it is considered the Power Spectral Density (PSD) method. This method uses experimental curves of spectral density for the characterization of typical road roughness profiles. In this case, it was used the characteristic table of classification of roads and parameters as proposed by Dodds (1972) and Dodds and Robson (1973).

As the trailer in analysis is a model for camping, it was adopted the profile of secondary roads for using in the dynamic analysis because it must be probably the most common and severe conditions imposed to it. The characteristic values of the secondary roads used to calculate the profiles are shown in Tab. 1.

Table 1. Characteristic parameters of secondary roads

Road type	Quality	c (10^{-6} m³/cycle)	w_1	w_2
Secondary roads	Medium	128	2.28	1.428
	Low	512		
	Very low	2048		

where c is the roughness coefficient, n is the wave number and w_1 and w_2 are constants characteristics of the road which can usually assume a value equal to 2.5 and even get good results (Clough & Penzien, 1993).

For each profile of road it was determined three functions, where two were out of phase functions between themselves with an angle selected by a generating function of random numbers. These two functions will be used for the excitation of the suspension, wile the third function will be an average of them and will be used to excite the trailer coupling joint. Functions are calculated for a speed of 60 km/h and the power spectral density curve is discretized in 18 components. The roughness road profile for each secondary roads selected can be observed in Figs. 3, 4, 5.

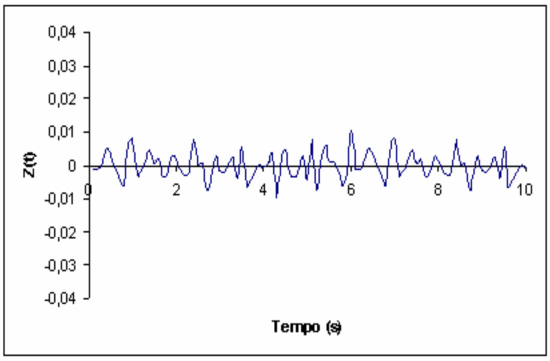

Figure 3. Roughness profile for an average quality secondary road

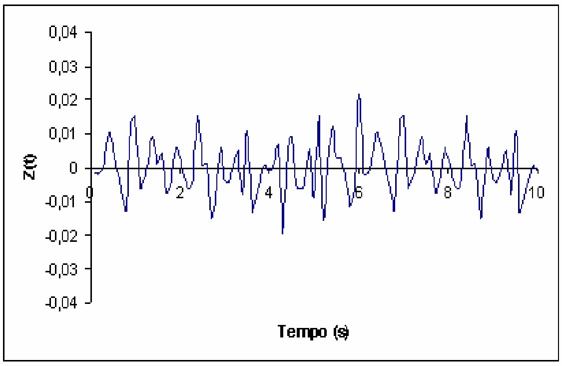

Figure 4. Roughness profile for a low quality secondary road

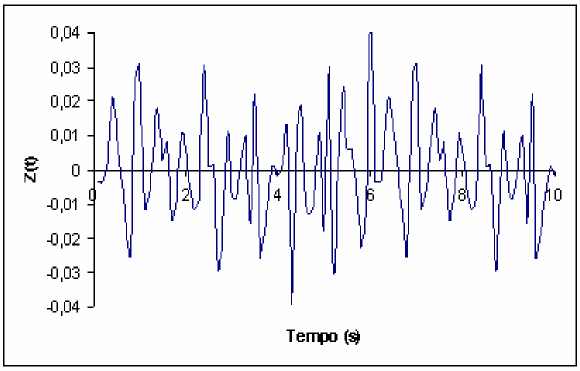

Figure 5. Roughness profile for a very low quality secondary road

Logically, highest amplitudes occurs at very low quality secondary roads, so this profile is selected to perform the dynamic simulation of the trailer model.

4. Dynamic analysis

In order to represent the trailer structure, first, a solid model was developed in 3D CAD software. Beams of "C" profile, structure reinforcements and other components were modeled in order to obtain a detailed model, but welded joints between these beams were not considered for simplification. The rigid model of the chassis is shown in Fig. 6.

Figure 6. Solid model of the chassis

For the dynamic simulation it was used MSC Visual Nastran Desktop software which allows the application of dynamic simulations returning, among others data, the description of forces, accelerations and displacements. In this simulation the focus are the forces on the joint between the chassis structure and the springs.

Hence, it was possible simplifying some elements in relation to the real model on trailer dynamic simulation. For example, the half-elliptical springs used in the trailer were simplified to linear springs mounted over a half-elliptical bar. This is necessary once the software does not have this kind of spring element in its libraries. Wheels and axle were simplified too, once they have not been the main focus of the work. The dynamic model is shown in Fig. 7.

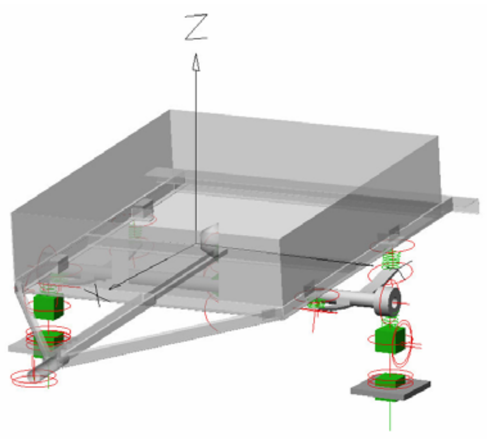

Figure 7.Simplified trailer dynamic model

The tires were represented in the model by linear springs with rigidity value chosen as sufficiently high to help on the system adjusting. Hence, it was possible to concentrate all flexibility of the system in the four equivalent springs. Three linear actuators (one on the frontal coupling and two on the tires) were used to simulate the road profile displacement. These actuators were programmed with the PSD functions, however right and left profiles present their excitation out of phase in order to promote angular displacement of the suspension axle (Morsch, 2001).

A special kind of excitation was applied in frontal coupling as the average of right and left profiles values. This is not the real situation, but guarantees different signal acting in the coupling (Reckziegel, 2002), which in fact is excited by the vehicle in which it is connected. In order to develop the model similar to the trailer movements it is considered a ballistic model for the trailer excitation. In other words, the tire actuators were created over a base that simulates the ground, which collide with the tire without any linking element between them, allowing the separation of tires from the ground, as shown in Fig. 8. This effect is typical in trailers when occurs a severe variation in the pavement displacement, as can be evidenced in some moments of the dynamic simulation. Some restrictions were included to the model stabilizing the dynamic movement’s response. For example, a spherical joint in chassis allows its free rotation but displacement only through the vertical plane. A rotation joint permits only rotation around longitudinal axis and translation through vertical plane of the trailer axle.

The simulation used data from the experimental measurements of the trailer. The structure rigidity constant was divided in four equal parts corresponding to the dynamic model spring constants. The model was upward displaced similar to the trailer experiments and released. It permits to obtain a graph of displacement of the trailer center of mass, as shown in Fig. 8, which was used in order to calibrate the dynamic model.

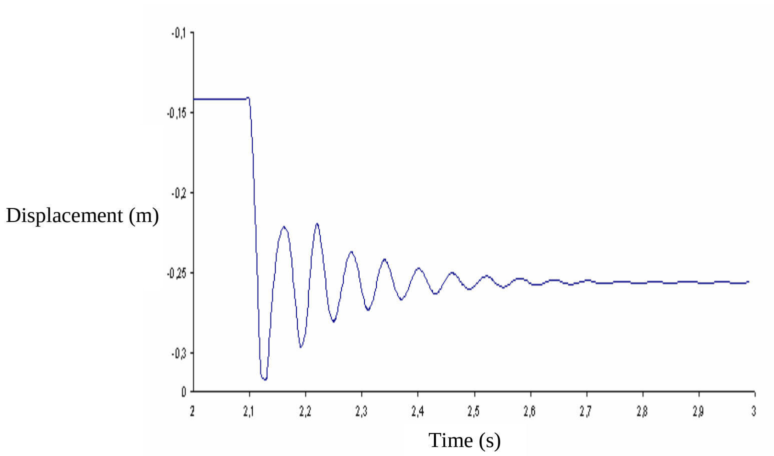

Figure 8. Trailer center of mass oscillation

The dynamic model natural frequency is equal to 107 Hz and the logarithmic decrement equal to 0.8, meaning a difference of 10% relative to the experimental measurements. Then this model represents a good first approximation of the trailer.

The dynamic model was excited during 20 seconds obtaining responses on forces acting over the trailer chassis, which will be useful in the finite element analysis (FEA) of the structural model. One of these results can be visualized in Fig. 9.

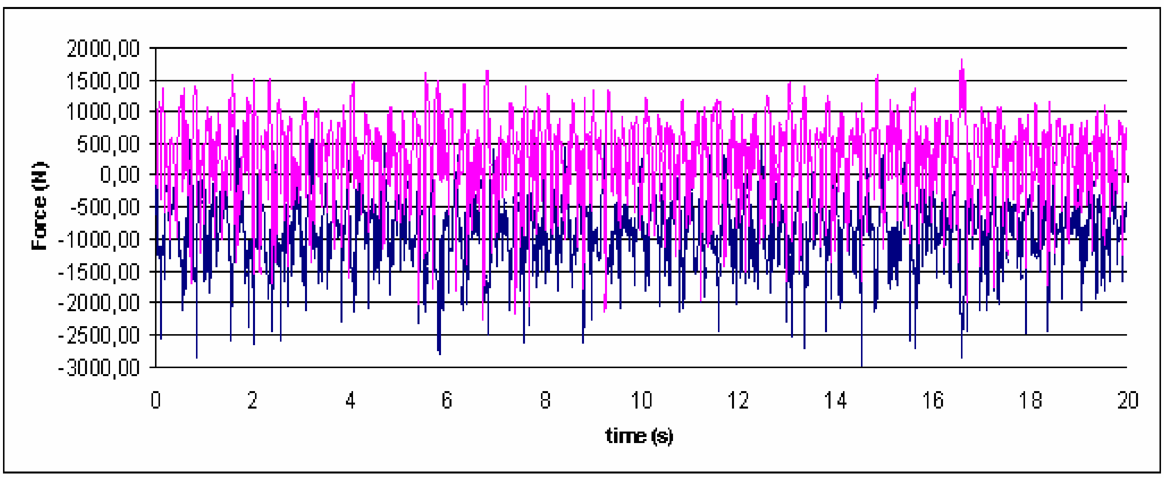

Figure 9. Force exerted on the right spring of the model

5. Structural analysis

The development of the global analysis of the trailer was made using the Ansys software. The model was designed in this software using simple elements for a previous determination of the critical points that later will be analyzed with more details in a local analysis. Thus, a set of one-dimensional lines, representing "C" beams, composes the chassis structure of the trailer and plates, its bodywork. Timoshenko theory based beams and Reissner-Mindlin theory based shells were used because these kinds of elements are based upon theories which accommodate transverse shear strains (Hughes, 1987), so they can be used for short and rough beams and shells. This model is shown in Fig. 10.

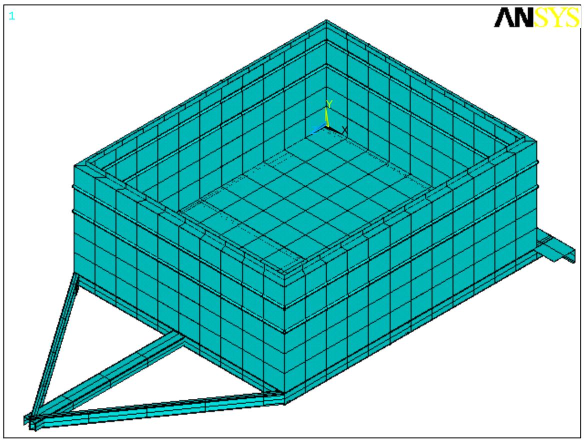

Figure 10. Structural model for finite element analysis

In order to find out the critical region of the structure one side of the model and the frontal coupling were fixed and the other side was released only under the action of its weight. It generated a torsion effect on the structure and permitted verify critical regions as shown in Fig. 11.

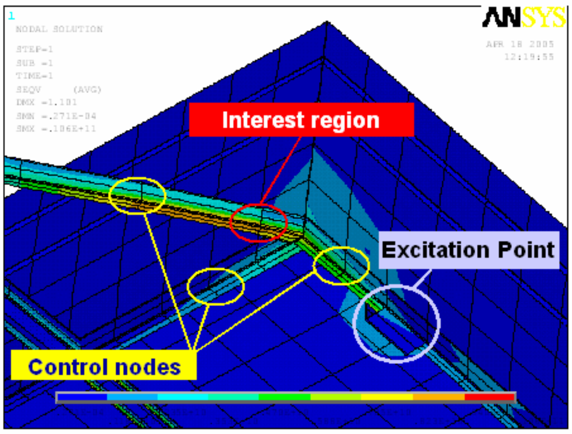

Figure 11. Critical region with stress concentrations

As presented in Fig. 12, it is necessary to identify in the global structural model a set of important points. In this case, there are four excitation points R, three control nodes M and one interest region J. Applying the global-local method, it is possible to obtain more detailed information about stress concentration in specific points of the structure. Thus, applying a vertical unitary force over one of the excitation points and fixing the others it is possible to obtain the control nodes displacement in agreement with Eq. (7).

$$\{\mathbf{u}_J\} = [\mathbf{C}_J] \cdot \{\mathbf{f}\} \tag{7}$$

The $\mathbf{C}_J$ matrix is called flexibility coefficients matrix and its size is $6M \times R$ for 3D structural analysis so, in this case it is compound of four columns and eighteen rows.

At this moment the global stage is completed, thus it is necessary to create a local model which has sufficient details to verify more stress information in critical points. A shell element model based on Reissner-Mindlin theory as explained before was created for local analysis. Figure 12 shows the local model of the chassis.

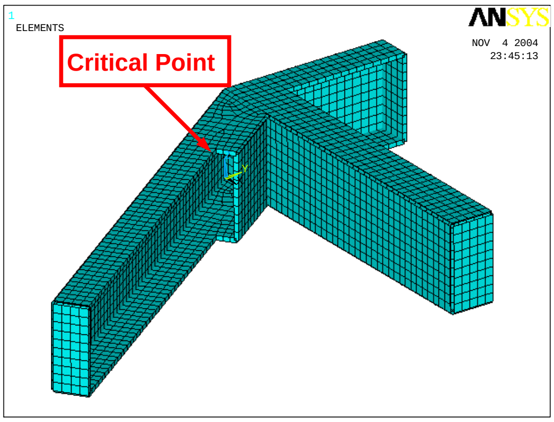

Figure 12. Local model and determined critical point

At this stage, it is possible to obtain $[\mathbf{B}_P]$ matrix that contain the relation between the critical point stress and control nodes displacement, which are represented in local model by areas. Hence, all degrees of freedom of the control nodes are fixed in all directions and rotations except one of them, numbering 17 fixed degrees of freedom. The free degree of freedom is displaced one value equal to the unitary positive displacement. This process must be realized for all of the 18 degrees of freedom of the three control points. Thus, solving Eq. (8) it is possible to identify and record the critical point stress and define $[\mathbf{B}_P]$ matrix which sizes 6 *x* 6*M* for this case.

$$\{\boldsymbol{\sigma}_P\} = [\mathbf{B}_P] \cdot \{\mathbf{u}_J\} \tag{8}$$

Substituting Eq. (8) in the Eq. (7) it is possible to obtain a matrix **[T]** that directly relates forces applied in the excitation points to the critical point stress, as shown in Eq. (9).

$$\{\sigma_P\} = [\mathbf{T}] \cdot \{\mathbf{f}\} \tag{9}$$

Thus, in this study, substituting the results of dynamic forces obtained in the previous analysis in the force vector of Eq. (9) it is possible to obtain the historic of stress components of the critical point, and operating on it, obtain Von Misses stress, as shown in Fig. 13.

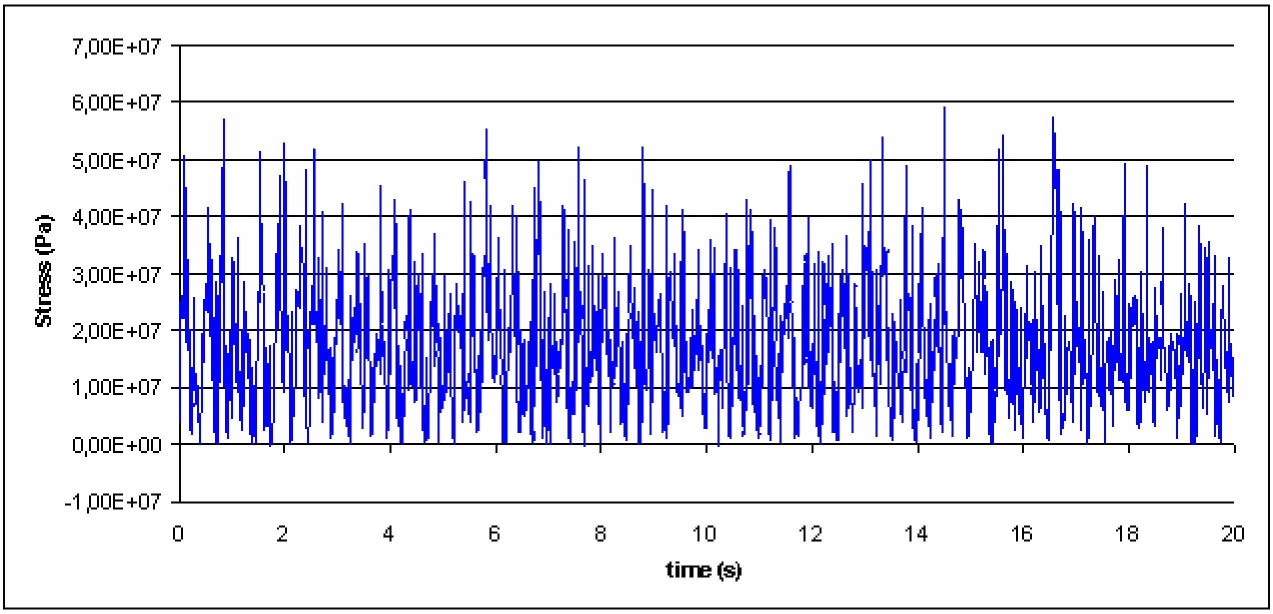

Figure 13. Von Misses Stress of the critical point

This method opened different possibilities for the development of innovative solution as for risk situations that previously were only dependent on empirical methods based in the logic an intuition of the designer.

Critical regions with stress concentrations on the structure were identified, which can be remodeled to guarantee better performance of the product. In future works these critical regions can be analyzed in more detail, and based on results of global-local technique it could be possible to realize fatigue analysis of the region and develops the reliability of the model. Certantly the model must be checked and refined in order to obtain more reliable results.

6. Conclusions

This method opened different possibilities for the development of innovative solution in trailer design that previously were only dependent on empirical methods based in the logic an intuition of the designer.

Furthermore, global-local analysis can enable the engineer to attain detailed information about stress distribution and values for determined critical points in the structure using a reduced number of elements. In terms of finite element analysis, it means that it is possible to analyze complex structures making use of less computer memory, obtaining results quickly.

Critical regions with stress concentrations on the structure were identified, which can be remodeled to guarantee better performance of the product. In future works these critical regions can be analyzed in more detail, and based on results of global-local technique it could be possible to realize fatigue and reliability analysis of the structure.

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