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Dynamic Analysis of Railroad Tank Car Under motion scenario Yaw and Sway

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ABSTRACT: *In this paper the dynamic analysis to a railroad tank car is performed using the Finite Element Method (FEM). The natural frequencies of vibration and the dynamic response of the structure subject to harmonic loads were obtained. A railway vehicle during his operation is subjected to various harmonic loads caused by irregularities in the track. These harmonic loads have a working frequency that varies with the displacement speed of the train. Therefore it is important determine the natural frequencies of vibration of the structure and the dynamics response to harmonic loads to determine the security with which operates the tank car and avoid structural problems.*

Keywords *– Dynamic Response, FEM, Harmonic Response, Tank Car, Yay and Sway.*

I. INTRODUCTION

The railway train running along a track is one of the most complex dynamical systems in engineering. It has a many degrees of freedom, the interaction between wheel and rail involves both complex geometry of wheel tread and rail head and non-conservative forces generated by relative motion in the contact area, and there are many non-linearities [1]. The dynamics of the railway vehicle represents a balance between the forces acting between the wheel and the rail, the inertia forces and the forces exerted by the suspension and articulation.

Most mechanical structures or elements of existing machines are under dynamic forces, some of these forces often can be neglected and simply by performing a static analysis to determine the mechanical behavior. But sometimes it is not possible to exclude variants forces in time of a structural analysis, and is necessary perform a dynamic analysis to better understand the mechanical behavior.

A dynamic load is one that applies when a movement of inertia is generated and can take various features. The vibration is a common type of dynamic loading and can be free or forced. Forced vibrations are caused by an external force that acts on the system. In this case, the exciting force continuously supplies energy to the system to compensate for that dissipated by damping [2].

The harmonic excitation is one of train system common excitation modes. Many reason can cause the periodic harmonic excitation for example, the local damage of train wheel created by the soldering, the deviation of the wheel gravity and geometric center and track irregularities [3].

Track irregularities can cause motions scenarios. During railroad vehicle operations, one or more of the following motion scenarios are encountered: hunting, twist and roll, pitch and bounce, yaw and sway, and dynamic curving [4]. The simulation scenarios are important in the design process of railroad vehicle. Track test are also often conducted for diagnostic performance problems, including derailment, caused by vehicle or track conditions, or a combination of both [5].

The Yaw and Sway is the response of the vehicle in the lateral and vertical directions due to track perturbation like shown in Figure 1. This type of motion leads to either high oscillations or high impact forces when the wheel flange comes into contact whit the rail.

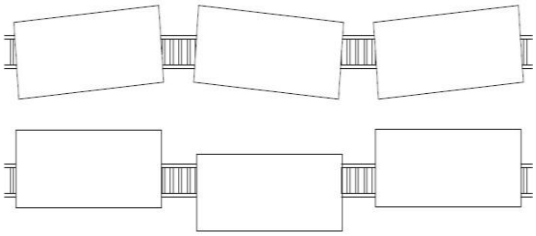

Figure 1. Motion scenario Yaw and Sway.

II. DYNAMIC ANALYSIS

This research is the continuation of the analysis previously conducted to DOT-111 tank car in others papers [6] [7]. The methodology used to carry out the research is presented in Figure 2, and the analysis were performed using ANSYS Workbench.

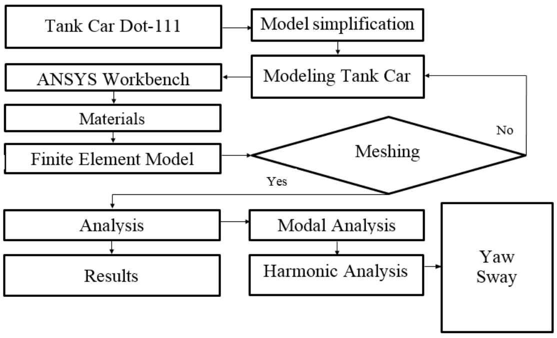

Figure 2. Proposed methodology.

The model selected of study is a DOT-111 tank car as illustrated in Figure 3, it is standardized by the Association of American Railroads (AAR) and the Department of Transportation of the United States. It is the common unpressurized tank car used in North America.

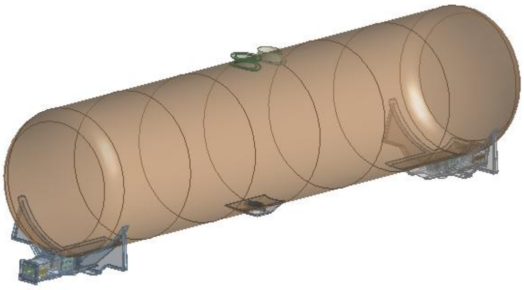

Figure 3. Isometric view of the tank car

The dimensions and capacities of the tank car model proposed are presented in Table I.

Table I. Dimensions and Characteristics of Tank Car

Characteristics	Magnitude
Full Length	17 m
Length	16.36 m
Diameter	3.04 m
Shell Thickness	12.7 mm
Maximum Capacity	115,000 l
Weight	20,453 Kg
Material	TC-128 B Steel

The material selected for the model is the TC-128 B steel carbon, which is special for the construction of railroad tank car normalized by the AAR. Some properties are listed below in Table II.

Table II. TC-128 B Properties [8]

Characteristics	Magnitude
Density	7916.5 kg/m^3
Young´s Modulus	206.85 GPa
Poisson´s Ratio	0.3
Tensile Yield Strength	344.74 MPa
Tensile Ultimate Strength	558.48 MPa

The discretization and the analysis were performed using ANSYS Workbench. The meshing model presented in Figure 4, is solid with the exception of the tank which was generated as a surface.

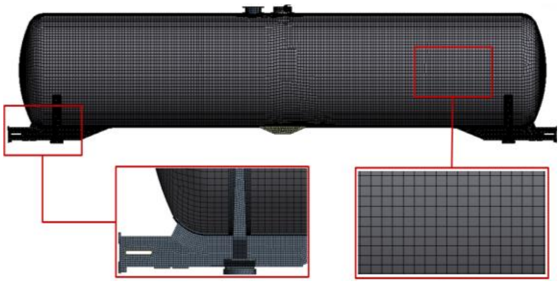

Figure 4. Detail of the mesh in the tank and stub sill.

According to the quality parameters of ANSYS Workbench, the values of skewness 0.38 and orthogonality 0.71, the mesh qualifies as very good.

Modal Analysis.

Modal analysis is a technique used to derive the modal model of a linear time-invariant vibratory system. The theoretical basis of the technique is secured upon establishing the relationship between the vibration response at one location and excitation at the same or another location as a function of excitation frequency [9].

The first 20 Natural frequencies were determined, the results are presented in Figure 5. The minimum natural frequency obtained is 10.481 Hz and the maximum is the 41.069.

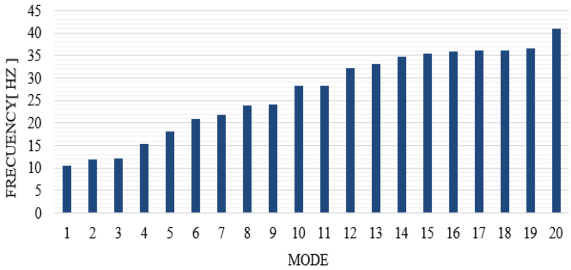

Figure 5. Modal frequencies derived from analysis.

Harmonic Analysis.

The Harmonic Response is a characteristic of a vibratory system, which is the result of a dynamic load applied with a known frequency. In the case of a mechanical structure is the frequency response spectrum of the vibration of the structure, divided by the spectrum of the input force to the system [10].

Using the results of modal analysis, harmonic response of the structure for motion scenario Yaw and Sway was determined. The yaw and sway has a graphic which is shown in Figure 6. This function determines the driving frequency of the applied dynamic loading with the traveling speed of the vehicle.

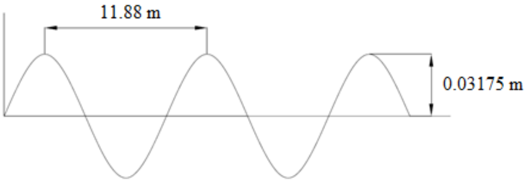

Figure 6. Graphical representation of yaw and sway.

To determine the excitation frequency is used Equation 1 where f is the frequency, v the speed of travel and the wavelength λ. To perform the analysis, three travel speeds, 60, 80 and 100 km/h were considered.

$$f = \frac{v}{\lambda} \qquad \textbf{Eq. 1}$$

The frequencies obtained at a certain speed are listed in the Table III.

Table III. Determined frequencies.

60 Km/h	80 Km/h	100 Km/h
1.232 m/s^2	2.190 m/s^2	3.422 m/s^2

The structure was subjected to an acceleration which is caused by yaw and sway. This acceleration has a bearing on the structure, so the objective of the analysis is to determine the frequency response in deformations and stresses generated. The acceleration was determined from the Equation 2.

$$A = 2\pi^2 f^2 D \qquad \text{Eq. 2}$$

The accelerations obtained at a certain speed are listed in the Table IV.

TableV. Determined accelerations.

v	*f*
60 Km/h	1.403 Hz
80 Km/h	1.870 Hz
100 Km/h	2.338 Hz

The direction of the acceleration was established as shown in Figure 7.

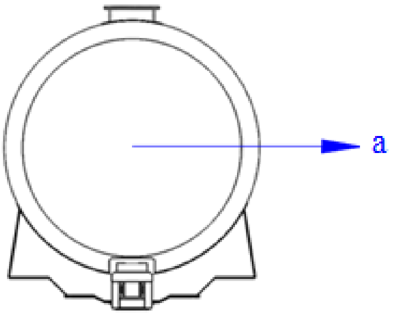

Figure 6. Boundary conditions of Yaw and Sway

In Figures 8 and 9 are presented results derived from harmonic analysis of the top of the tank.

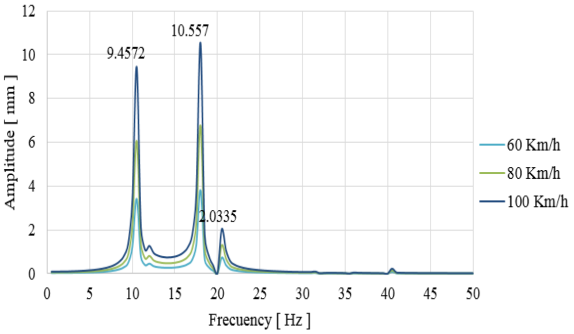

Figure 8. Deformation-frequency graph on the bottom of the tank

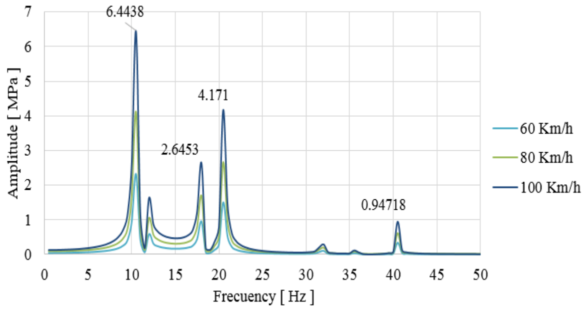

Figure 9. Stress-frequency graph on the bottom of the tank

In Figures 10 and 11 are presented results derived from harmonic analysis of the top of the tank.

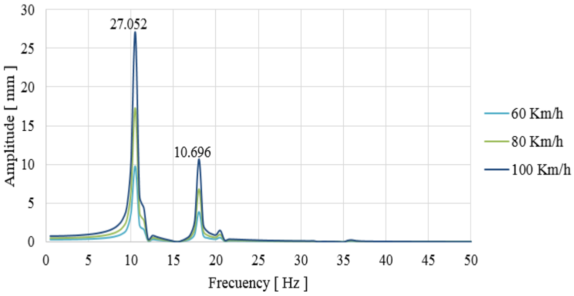

Figure 10. Deformation-frequency graph on the top of the tank

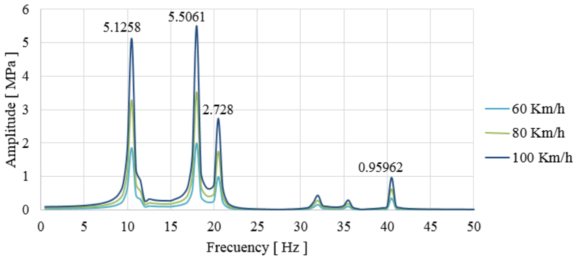

Figure 11. Stress-frequency graph on the top of the tank

In Figures 12 and 13 are presented results derived from harmonic analysis of stub sill.

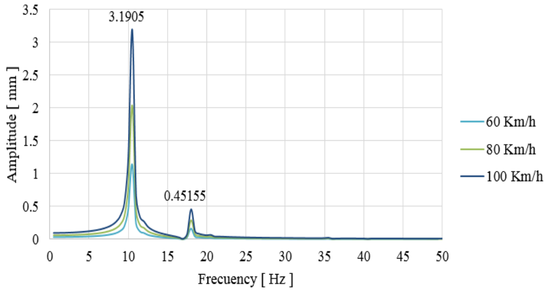

Figure 12. Deformation-frequency graph on the stub sill.

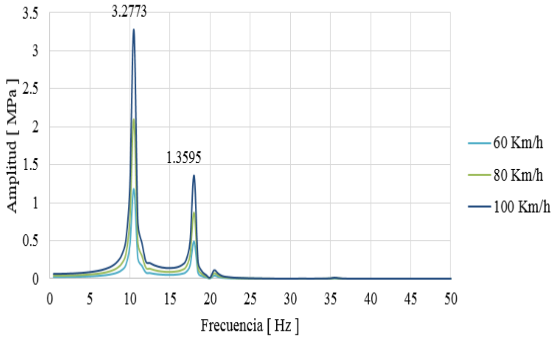

Figure 13. Stress-frequency graph on the stub sill.

Concluding the analysis high deformations were observed in the top of the tank, as recorded was 27.052 mm at a speed of 100 Km/h with a frequency of 5.10 Hz as shown in Figure 10. Minor deformations observed in the stub sill where most recorded was 3.19 mm at a speed of 100 Km/h with a frequency of 10.5 Hz, as shown in Figure 112.

The Figure 14 shown the deformation tendency having the structure, where the direction vector can be seen.

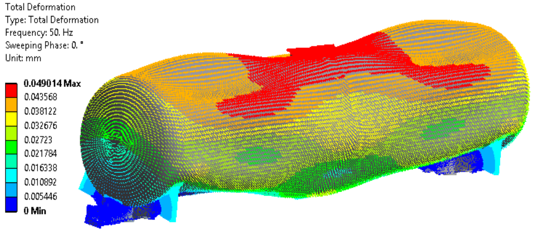

Figure 14. Stress-frequency graph on the stub sill.

As for the major stresses obtained were located in the top of the tank, the largest recorded is 5.12 MPa at a speed of 100 km/h with a frequency of 5.10 Hz as shown in Figure 11, however limit does not exceed the yield strength of steel minors efforts were located in the stub sill.

III. CONCLUSION

Results from the harmonic analysis presented deformations and high stresses at the top of the tank, so it can be concluded that is the most affected area because of these scenarios movement, however the frequency of this stage of motion is less than the critical frequency of 10.5 Hz.

IV. ACKNOWLEDGEMENTS

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