DEVELOPING A MULTIBODY MODEL OF AN ARTICULATED VEHICLE WITH A FLEXIBLE SEMI-TRAILER

Truong Dang Viet Thang[1,*], **Trinh Minh Hoang**[1],
Nguyen Trong Hoan[1], **Nguyen Minh Toan**[2]

DOI: http://doi.org/10.57001/huih5804.2024.156

ABSTRACT

This paper introduces an advanced multibody model of an articulated vehicle, including a multibody dynamics model of a tractor with a flexible semi-trailer. This study proposes a combination approach of Multibody Dynamics analyzing the rigid body motion and the Finite Element Analysis of the semi-trailer frame to estimate the displacement, stresses, deformation and dynamic loadings within a flexible body. The multibody dynamics model describes the physical relationship between the tractor and the flexible semi-trailer frame to extract the forces acting on joints and contacts between suspension components of the tractor and chassis frame at joints and the fifth wheel, which partially supports the semi-trailer payload. The methodology is applied to model the combination of a multibody tractor model and a flexible frame model simulated in typical driving scenarios using MotionView and HyperMesh within the HyperWorks environment. Finally, the graphical results of the simulations were generated, plotted as well as discussed in terms of modal analysis, static and dynamic stress, loading and force acting on the finite element model of a flexible semi-trailer frame. The analysis results from these simulations provide a comprehensive evaluation of the behavior of the vehicle frame, which can be used to assess the frame's durability and fatigue life under various driving scenarios.

Keywords: *FEA, MBD, flexible body, semi-trailer frame, articulated vehicle.*

[1] Hanoi University of Science and Technology, Vietnam
[2] Viettel Aerospace Institute, Vietnam
[*] Email: thang.truongdangviet@hust.edu.vn

Received: 05/8/2023
Revised: 20/10/2023
Accepted: 25/5/2024

1. INTRODUCTION

The semi-trailer frame is the main component supporting the entire cargo while maintaining it stable under all driving conditions. The vehicle frame is designed to ensure strength and rigidity to stand vibrations, and dynamic impacts which tems of torsional and bending stress within the frame component while traveling. When the vehicle moves on the road, the chassis is excited by the dynamic forces caused by the roughness of the road surface. Under dynamic loads, the chassis frame tends to vibrate. If any excitation frequency coincides with the natural frequency of the chassis, resonance occur and the chassis suffer dangerously large vibration, which can lead to excessive deformation and damage affecting chassis strength and fatigue. Therefore, studying the dynamic load acting on vehicle frame structure plays an extremely important role since the earlier phase in heavy-duty truck design, especially semi-trailer.

An important aspect of chassis design and analysis is the stress distribution and fatigue life of prediction process. In conventional vehicle development, the fatigue strength of the chassis, and its components, are evaluated through physical testing. Finite Element Analysis (FEA) is becoming increasingly popular in the automotive industry use to predict stress, strain, deformations, and failure of many different types of components [1, 2]. This study proposes a combination method to develop a full multibody (MBD) vehicle model. For this purpose, the programs used are HyperMesh, Optistruct, and MotionView modules in HyperWorks software.

To evaluate the strength and fatigue life of vehicle frame structures, [3] The study analyses the stress and deformation of the 4x2 truck frame using Pro/Mechanica software with a simple structural frame under the FEA model. [4] investigated the low beam semi-trailer frame stress with a trapezoidal shape using CATIA software to investigate the stress and strain considering the factor of safety according to the Australian Government's technical requirements. Madhu PS et al. in [5] studied the strength of the truck frame in a static condition, proposed improvements to reduce stress and displacement using HyperWorks software, and simulated in ANSYS to find out the natural frequency of the frame that can cause damage and resonance oscillation. [6] using the FEA method to investigate the frame strength in a static test with different types of steel to propose the proper material for the truck frame main members. In addition, [7] has meticulously synthesized various models of studies relating to chassis frame strength and fatigue strength using ANSYS software and synthesized survey and analysis conclusions about the frame structure to improve its fatigue life, showing that this issue is receiving more and more research attention.

Recently, many studies have used FEA and the MBD method in vehicle design. MBD and FEA method was utilized to analyze the fatigue life of a car body [8]. The analysis results showed that: compared with traditional fatigue methods, more acceptable prediction results could be obtained by the method combining MBD and FEA. The study [9] also shows that the use of MBS to extract loadings applied on the FEA model of suspension knuckles for fatigue analysis is an accurate technique to obtain very close to actual stress distributions, which is simple and results in an increase in confidence when selecting the damaging stress cases for fatigue life estimation.

This paper introduces a combined method using flexible bodies in MBD models. The semi-trailer chassis frame is considered a flexible component. Its deformations may occur due to static and cycling loads and forces extracted from mechanical systems, including suspension, steering systems, fifth-wheel interconnected at joints, and contact forces between bodies of multibody dynamic systems. This novel approach combining flexible bodies in Multibody Dynamics (MBD) models enhances the accuracy of mechanical components' strength and fatigue life predictions compared to conventional FEA.

2. MODEL DEVELOPMENT

HyperWorks® is an integrated solution to analyze and optimize the performance of multibody systems. It is a powerful CAE tool for modeling, analysis, and visualization in the vehicle dynamics field, including kinematics and dynamics, statics and quasi-statics, linear and vibration studies, stress and durability analysis, loads extraction, and co-simulation, which enables to estimate motion, stresses, and deformation within flexible bodies, vehicle component structure. The methodology in this study consists of the multibody tractor model, and a flexible frame model was developed and simulated MotionView and HyperMesh in HyperWorks. The research objective of the article is a semi-trailer frame 40 feet 2 axles with a total payload of about 27 tons driven by a tractor.

2.1. Finite element model

Firstly, 2 axles 40 ft flatbed container semi-trailer frame domestically produced was developed with its technical parameters and material properties shown in Table 1. Then, the 3D model of this frame was meshed by using HyperMesh.

Table 1. Dimension and weight of the semi-trailer

Specification	Parameter	Unit
Overall length	12500	mm
Overall width	2480	mm
Payload	27200	kg
Frame main members (HxBxL)	500x140x11986	mm
Material	Q345	-

In this study, to serve the calculation process more quickly and conveniently, the model has been simplified to develop geometrical structures that do not affect the accuracy of the actual structure as well as the results, for example, holes and studs. It's considered that the main beams and horizontal members are rigidly connected through the welds. Welds are described through specialized elements in HyperWorks to simulate them. The maximum payload is considered uniformly distributed on the entire semi-trailer model nodes. The FE model of the two axles 40 feet flatbed container semi-trailer frame is illustrated in Fig. 1.

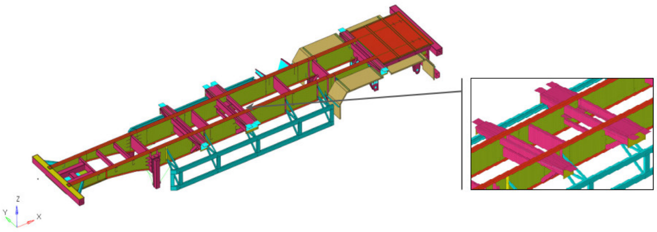


Fig. 1. Meshing model of the semi-trailer frame.

2.2. Multibody System

The multibody system of combination tractor and semi-trailer was built in the module MotionView. This MBS model was composed of bodies like a tractor, container, kingpin, fifth-wheel, tractor front/rear suspension systems, and semi-trailer rear tandem axle with their constraints (joints, linkages, springs, and dampers).

The structural compositions of the suspension system are simulated in the multibody system (MBS) model to describe the system characteristics to reflect the overall physical behaviors of the vehicle in the actual operating conditions. The tractor and semi-trailer combination is linked with a road by suspensions and wheels. In this research, the articulated vehicle model used in dynamic analysis and simulation parameters was referred to [10] by the same authors. The front/rear suspension system for the tractor and tandem axle trailer suspension of the semi-trailer was developed and shown in Fig. 2.

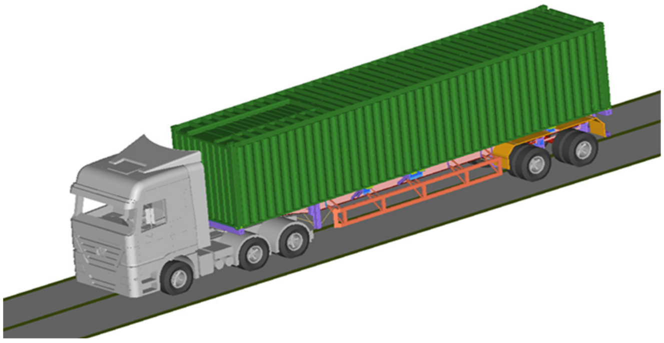


Fig. 2. The flexible multibody model of the full vehicle

2.3. Constraints and boundary conditions

The virtual simulation process has two phases: Finite element (FE) analysis and multibody dynamics simulation (MBD).

Simulation events were defined and added to closely physical tests performed in static and dynamic conditions. As shown in Fig. 3, the load extraction was achieved from the full articulated vehicle model enabling the resolution of stress and deformation responses in the flexible frame through plots.

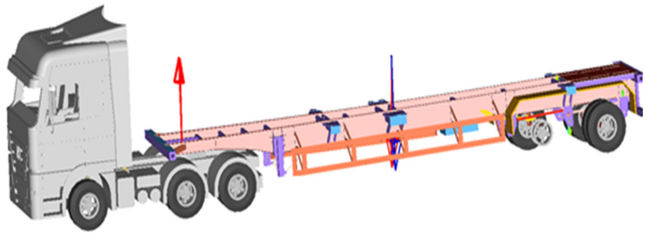


Fig. 3. Loadings and force outputs (MBD) applied on semi-trailer frame (FEA)

The kingpin of the semi-trailer frame is aligned on the tractor's fifth wheel. The frame's rear end is elastically coupled to the wheel via rear suspension and wheel. Wheel-to-ground contact is described by using a specific contact in MotionView. The force outputs acting on the frame at joints between frame members and suspension components, including the maximum allowable payload of the container, from the flexible model, as shown in Fig. 3, were imported into the finite element model of the frame as constraints and boundary conditions.

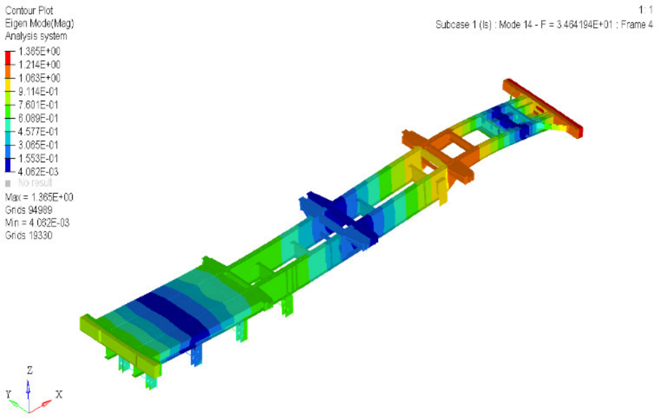
3. RESULTS AND DISCUSSION

The simulation cases in this study comprised both static states and dynamic characteristics, encompassing the following scenarios:

- Modal analysis of the chassis (case No. 1).
- Full payload on the frame, vehicle on the flat road surface (bending) (case No. 2).
- Full payload on the frame, vehicle on the flat road surface, the rear suspension of semi-trailer on a bump 20 cm height (torsional) (case No. 3).
- Traveling on a rough road profile (case No. 4).

3.1. Modal Analysis

Modal analysis was carried out firstly to examine the dynamic characteristics of a structure, including resonance frequencies, mode shapes, and natural frequencies. These factors are interconnected with the stiffness and mass distribution of the frame and serve to assess the overall viability of the body frame structure. The analysis results from the FEA will record many eigenstates, but the possible vibration for the semi-trailer was considered proper when the vehicle is on the road.



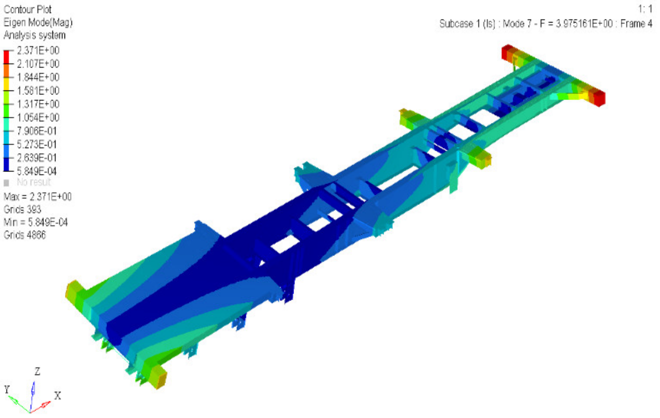


Fig. 4. Bending oscillation, flexible frame vibration frequency 34Hz (left) and 4Hz (right)

The natural frequency of the frame in the simulation had the frequency range from 0.004 to 40Hz. With the vibration frequency excitation of the road surface normally from 0.3 to 25.6Hz, resonance phenomena can occur on the frame. The member vibrates significantly at the front frame and the rear frame. Higher frequency vibration occurs in the middle and front members of the frame. Some typical results were plotted, shown in Fig. 4.

3.2. Static and dynamic loading procedures

The graphical results show the stress and deformation spectrum of the second case. Through the results, the largest deformation was 5.799mm located at the middle frame, the maximum von-Mises stress was 300.257MPa.

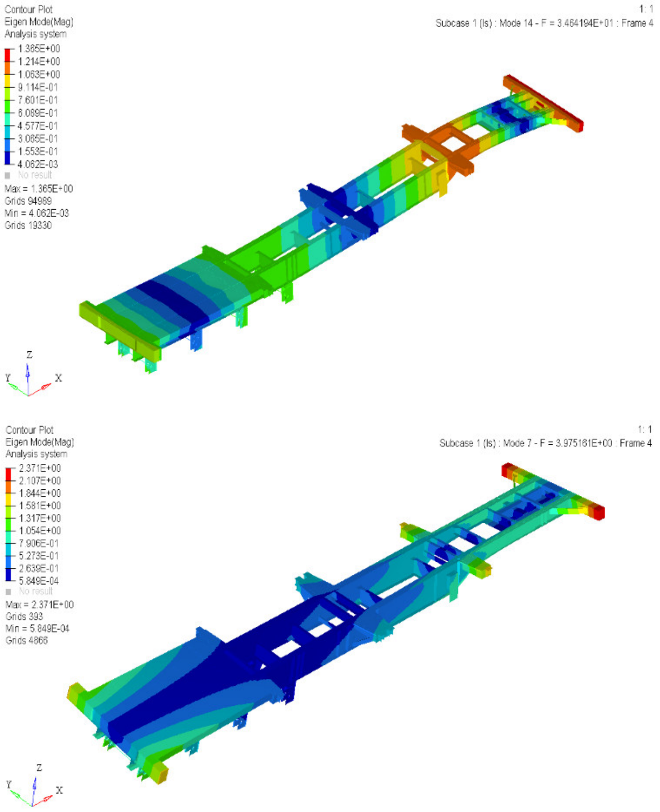


Fig. 5. Stress distribution on frame in case No. 2 (right) and No. 3 (left)

Fig. 5 shows the stress and displacement spectrum of the third case. The side member of the frame deformed significantly, 7.145mm, and the largest von-Mises stress about 344.945 MPa was concentrated at the flap area near the rear joints of leaf spring.

3.3. Traveling on a rough road profile

The road roughness profile according to ISO 8608 [11] can be used in finite element under cycling loading to simulate the dynamic loading of a vehicle or structure as vehicle travels over a rough road. the dynamic loads applied to the semi trailer frame at joint between frame and suspension fixed knuckles were plotted shown as in Fig. 6.

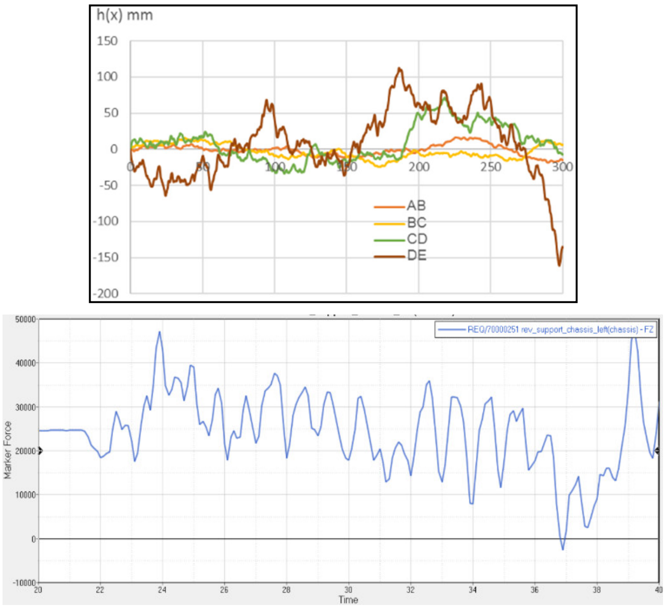


Fig. 6. Dynamic loading affecting to the semi-trailer frame at the joint between the frame and the suspension fixed knuckles on road roughness CD - ISO 8608

4. CONCLUSIONS

This research introduces a novel methodology for developing a comprehensive vehicle dynamic model to analyze flexible mechanical components. The approach leverages a combination of Multibody Dynamics (MBD) and Finite Element Analysis (FEA) frameworks within the widely used commercial CAE tool, HyperWorks which make it easier to accurately model and analyze complex mechanical systems, enabling them to gain valuable insights into the structural behavior and durability of components subjected to cyclic loading and stress.

Through this integration, numerous shape modes and frequencies are generated, facilitating the assessment of natural frequencies relative to excitation frequencies, along with the identification of deformation tendencies and regions of high stresses distributed throughout the mechanical body that enables designers to address structural weaknesses proactively. As a result, this methodology significantly enhances the accuracy of the FEA model, thereby contributing to more reliable fatigue life analysis of frame structures. The findings of this study have implications for advancing the understanding and design optimization of flexible mechanical systems. The integration of MBD and FEA frameworks offers a more holistic and reliable prediction of fatigue life, leading to enhanced design optimization and increased confidence in the durability and performance of flexible mechanical systems. However, the flexible model must be validated through experiments assessing its performance under characteristic static and dynamic loads, as well as on rough roads, to ensure the accuracy and precision of the proposed model in this study.

ACKNOWLEDGEMENT

This work was supported by Altair Engineering ASEAN Company in exploiting HyperWorks® Software.

REFERENCES

[1]. Mahvi Malik Shahzad, ShaikhRizwan, Tarique khan, "Finite Element Static Structural Analysis Of 4x2 Truck Chassis Frame," *International Journal of Modern Trends in Engineering and Research* (IJMTER), 2349-9745, 2015.

[2]. Ahmad O. Moaaz, Nouby M. Ghazaly, "Finite Element Stress Analysis Of Truck Chassis Using Ansys: Review," *International Journal of Advances in Engineering & Technology* (IJAET), 7, 5, 1386-1391, 2014.

[3]. Mohd Azizi Muhammad Nor, et.al, "Stress Analysis of a Low Loader Chassis," *International Symposium on Robotics and Intelligent Sensors 2012 (IRIS 2012), Procedia Engineering* 41, 995 - 1001, 2012.

[4]. Madhu PS, Venugopal TR, "Static Analysis, Design Modification and Modal Analysis of Structural Chassis Frame," *Int. Journal of Engineering Research and Applications*, I, 4, 5 (Version 3), 06-10, 2014.

[5]. Manca Adriano, Pappalardo Carmine, "Integration of CAD, MBD, and FEA Programs for the Topology Optimization of Aircraft Components," in *International Conference "New Technologies, Development and Applications", Lecture Notes in Networks and Systems* (LNNS, 128), 2020.

[6]. Ghazaly Nouby M.., "Applications of Finite Element Stress Analysis of Heavy Truck Chassis: Survey and Recent Development," *Journal of Mechanical Design and Vibration* 2, 3: 69-73, 2014.

[7]. Donglong Zhou, Jianlong Chang, "Fatigue Analysis of a Light Truck Rear Axle Based on Virtual Iteration Method," *Shock and Vibration*, 13 pages, 2022.

[8]. Meng Jin, Zhu Ping, Hu Zhi-gang, "Fatigue Life Prediction of Autobody Structure Based on Multibody Dynamics and Finite Element Method," *China Journal of Highway and Transport*, 23 (4): 113-120, 2010.

[9]. Kamal Masood, Md. Mustafizur Rahman, Sani Shahrir, "Applica-tion Of Multibody Simulation For Fatigue Life Estimation," *International Journal of Automotive and Mechanical Engineering*, 7, 912-923, 2013.

[10]. Truong Dang Viet Thang, Trinh Minh Hoang, Nguyen Trong Hoan, "A study to determine dynamic loadings affecting the semi-trailer frame," in *Proceeding of the 5th National Conference on Mechanical Science & Technology*, 950-957, 2019.

[11]. ISO 8608 (2016), Mechanical vibration - road surface profiles - reporting of measured data, ISO 8608:2016, International Organization for Standardization, ISO.

[12]. *Practical Aspect of Multibody Simulation with HyperWorks*. Altair University, Acedemic Program, 2019.