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Original Article

Dynamic Simulation of Multi-Wheel on Rail Using FEA: Analysis of Rolling Behavior with Gradual Deceleration

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Abstract - This paper presents a novel dynamic simulation of a multi-wheel system using Finite Element Analysis (FEA) in Abaqus, a finite element methods software, wherein the focus is on analyzing the rolling behavior of linked three-wheel configurations subjected to vertical loading and a turning moment. The simulation captures the movement of the leading wheel when the moment is applied and its subsequent reverse rolling after the moment is removed. The unique observation highlights the importance of applying parking brakes for the complete stability of the wheels of the rolling vehicles. The study demonstrates a practical approach to simulating dynamic wheel behavior and its potential for future work in multi-wheel system analysis.

Keywords - Dynamic, Simulation, Multi-wheel, FEA, Rolling, Stability, Vehicles, Parking brakes.

1. Introduction

The Finite Element Analysis (FEA) is a key tool in understanding the stresses in the physical world's various static and dynamic systems. The current study has been applied to the simulation of multi-wheel systems, focusing on the movements of the wheels after removal of the applied vertical loading and turning moment. This study simulates the rolling behavior of three wheels on a rail, focusing on the interaction between the applied turning moment and the resulting movement of the wheels. The objective is to get a feel of the interaction during the vehicle's deceleration and the importance of the vehicle's parking brakes application, demonstrating how dynamic simulations can be useful for practical applications in different analogous applications.

2. Literature Review

A very precise look at the application scenarios for Abaqus software is given here, with specific applications for wheel systems. A good beginning to work with Abaqus software is provided by Malik and Mishra [1], and deep understanding can be built with the help of references [2, 3]. The software is capable of analyzing stresses and simulating various phenomenons and the software has been used for analyzing stress distribution in wheel rims [4], non-linear dynamic analysis of impact tests on wheels [5], in vehicle tyres with antilock braking systems [6], in traction prediction of the smooth wheel on soil [7], in virtual validation and test correlation of vehicle wheel [8], tyre wear out behavior analysis [9] and steady-state rolling analysis of vehicular tyre during free-rolling, traction and braking [10].

3. Model Setup

The model consists of three wheels interacting with a rail. The setup involves defining contact surfaces between the wheels and the rail, applying boundary conditions between the wheels and the rail, and stabilizing the wheels with displacement boundary conditions for side supports. The material properties and their values are unimportant; hence, they are not provided here. The data sheet and the simulation video shall be available to the readers from the link. As applicable to physical systems, i.e. railway applications, the vertical loads are applied to all the wheels, and turning movement is applied to the leading wheels; considering the same, each wheel is subjected to vertical load and a turning moment is applied to the leading wheel to initiate rolling motion. The specific simulation loading and boundary conditions are provided in Table 1.

Table 1. Rail and wheel loading and boundary conditions

Part	Vertical Load in (N)	Moment (N-mm)	Boundary Condition	
			Static, Step-1	Dynamic, Step-2
Rail Bottom	0	0	Rail bottom surface, all DOF fixed	Rail bottom surface, all DOF fixed
Leading Wheel	Applied	Clockwise	Free only to move perpendicular to the rail surface	Free to roll along rail surface and move perpendicular to rail surface
Middle Wheel	Applied	0	Free only to move perpendicular to the rail surface	Free to roll along rail surface and move perpendicular to rail surface
Trailing Wheel	Applied	0	Free only to move perpendicular to the rail surface	Free to roll along rail surface and move perpendicular to rail surface

3.1. Material

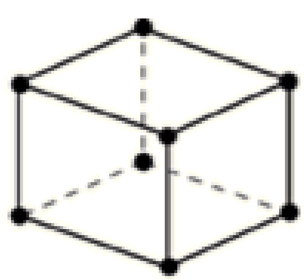
The material properties of the rail and wheel are presented in Table 2, as the focus of the study was to capture the movement of the wheels, and the material properties of the wheel and rail are not significantly different; hence, the same material properties were considered for both rail and wheel.

Table 2. Material properties

Part	Density (Tonnes/mm^3)	Young's Modulus (MPa)	Poisson's Ratio
Rail & Wheels	7.89E-09	200000	0.3

3.2. Meshing

The model has been meshed using the fully integrated, general-purpose linear brick element, C3D8, Figure 1.



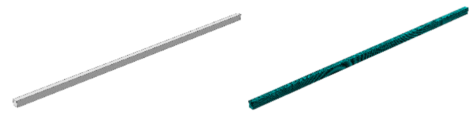
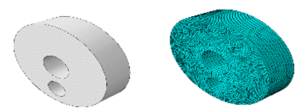
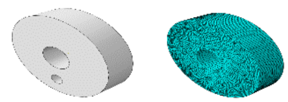
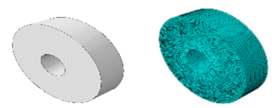
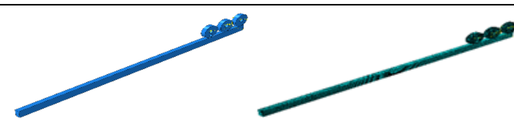
(a) Linear Element
(8-node brick, C3D8)

Fig. 1 Linear C3D8 element (Courtesy: Abaqus analysis manual)

3.3. Model Assembly

The leading, middle, and trailing parts are provided with larger holes, smaller holes, and no holes, respectively, to create a visual difference and make it easy to visualize the rolling movements. The meshed parts are also shown in the figures, along with their assembly is presented in Table 3.

Table 3. Rail and wheels, along with meshed

Part	Figure
Rail	
Leading Wheel	
Middle Wheel	
Trailing Wheel	
Model Assembly	

4. Simulation Setup

The assembled model was analyzed for rolling behavior when applied with the loading and moments applied gradually in two different steps per the conditions in Table 4. The load and moments are applied gradually to avoid errors during the analysis. The vertical load is applied at the centers of all the wheels gradually from 0. 0 seconds of analysis to 0.5 seconds and then maintained constant during the complete analysis. The moment is applied to the leading wheel gradually from 1 to 1.2 seconds, maintained until 1.5 seconds, and then gradually reduced to zero by 1.7 seconds. The wheel configuration is left free for rolling movement for the next 0.3 seconds.

Table 4. Step loadings

	Vertical Load in (N)		Moment (N-mm)	
Part/ Step	**Static, Step-1**	**Dynamic, Step-2**	**Static, Step-1**	**Dynamic, Step-2**
Leading Wheel	Applied	Applied	0	Applied
Middle Wheel	Applied	Applied	0	0
Trailing Wheel	Applied	Applied	0	0

5. Results and Discussion

The simulation set-up was run for two seconds. The wheel's three-wheel arrangement for simulation was executed, and the wheels moved along the rail as expected gradually and came to a stop as programmed. The results presented a unique observation after a gradual reduction of turning moment at 1.7 seconds; herein, the front wheel started to roll back in the opposite direction; however, the rolling of the middle wheel and trailing wheel continued in the initial direction, to reduced magnitude. The rotation of the middle wheel is more than that of the rear wheel. It will be necessary to watch the simulation to actually grasp the description of the simulation, with a zoomed significant portion.

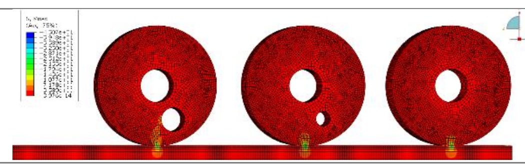
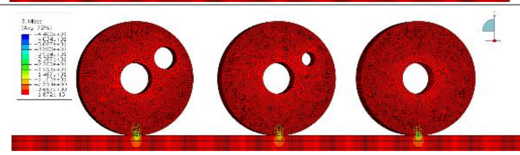
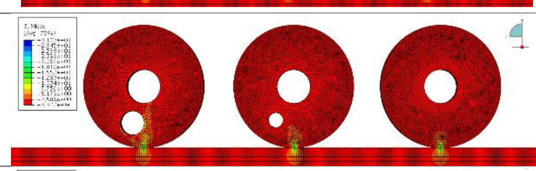
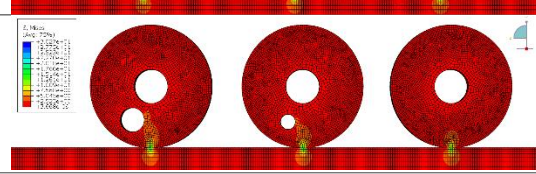
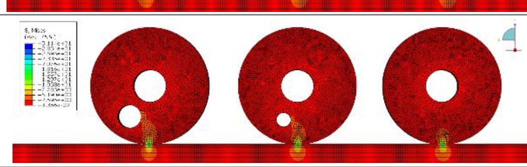
5.1. Rolling Behavior

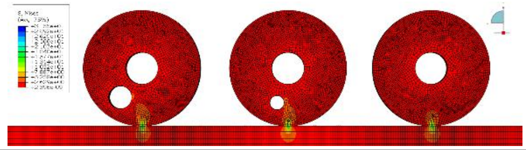
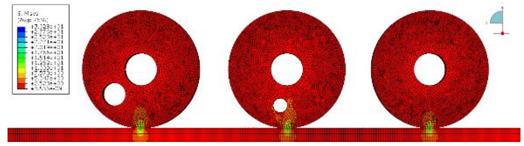
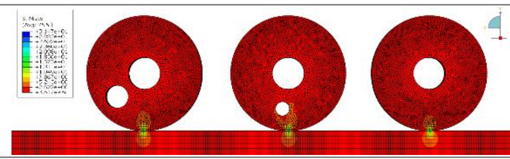
The rolling behaviour indicates the system's instability because of pulling and pushing forces between the wheel configurations due to previous rolling action, even though the driving force on the leading wheel is gradually brought to zero. This critical observation is a combined action and reaction of the inertial forces on the forward-moving trailing wheels and the decelerating leading wheel.

5.2. Real-Life Application

The practical application of this can be stated that whenever a running vehicle is stopped, the brakes shall continue for a little longer and be followed up by parking brakes. This behaviour of the simulated model is analogous to the observations by train passengers that sometimes the train moves forward or backwards after coming to a halt. One can visualize from the step time 0.74 and then from 0.8 to 1.0 from Table 5. Table 5 visually represents the observations at various increments.

Table 5. Observations

Rolling Step-2	Observation
Step Time 0.1 (Full Model)	
Step Time 0.1	
Step Time 0.2	
Step Time 0.74	
Step Time 0.82	
Step Time 0.84	

Step Time 0.90	
Step Time 0.90	
Step Time 1.0	

5.3. Future Work

A detailed, in-depth analysis is required to accurately describe the present observations.

6. Conclusion

It can be concluded that it is mandatory to apply parking brakes in the rolling vehicles, even if these have been brought to stand standstill, for the safety of man and machines.

Acknowledgments

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