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Ride Dynamics of a Tracked Vehicle with a Finite Element Vehicle Model

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ABSTRACT

Research on tracked vehicle dynamics is by and large limited to multi-rigid body simulation. For realistic prediction of vehicle dynamics, it is better to model the vehicle as multi-flexible body. In this paper, tracked vehicle is modelled as a mass-spring system with sprung and unsprung masses of the physical tracked vehicle by Finite element method. Using the equivalent vehicle model, dynamic studies are carried out by imparting vertical displacement inputs to the road wheels. Ride characteristics of the vehicle are captured by modelling the road wheel arms as flexible elements using Finite element method. In this work, a typical tracked vehicle test terrain viz., Trapezoidal blocks terrain (APG terrain) is considered. Through the simulations, the effect of the road wheel arm flexibility is monitored. Result of the analysis of equivalent vehicle model with flexible road wheel arms, is compared with the equivalent vehicle model with rigid road wheel arms and also with the experimental results of physical tracked vehicle. Though there is no major difference in the vertical bounce response between the flexible model and the rigid model, but there is a visible difference in the roll condition. Result of the flexible vehicle model is also reasonably matches with the experimental result.

Keywords: Tracked vehicle dynamics, flexible multibody dynamics, finite element method, road wheel arm, ride dynamics

1. INTRODUCTION

In general, the tracked vehicles are considered to be rigid during the vehicle dynamic analysis. But in the present day scenario of approach towards high speed tracked vehicles, which travels on severe terrain conditions, there is a necessity to approach the dynamic analysis of the tracked vehicles as a flexible system as far as possible.

Wong[1] quoted that computer simulation models for tracked vehicle mobility were gaining wide acceptance by industry in tracked vehicle development and most of the research work on tracked vehicle dynamics was done by using rigid bodies. Tong[2] observed that the high speed mechanical systems were generally modelled as multi-body systems. However, all mechanical systems are actually more or less flexible. In many situations, the rigid body dynamic modelling is not enough to predict more accurate system response due to the flexibility effect of the deformable bodies. Dhir and Sankar[3] presented the ride dynamic behaviour of a tracked vehicle negotiating rough terrains, studied through computer simulations and field tests. A comprehensive ride dynamic simulation model is developed, assuming constant forward vehicle speed and non-deformable terrain profile. Carlbom[4] dealt with a non-linear multi-body model of a rail vehicle combined with a finite element model of its car body. He reduced the finite element model by eigen mode representation and carried out the numerical solution of the equations of motion, using the combined flexible multi-body model. Ambrosio and Goncalves[5] presented a formulation to describe the linear elastodynamics of flexible multi-body systems in their paper. It is said that to deal with complex-shaped flexible body models it was essential to bring down the number of generalised coordinates. This is achieved with the component mode synthesis. Pennestrì[6], *et* al. developed numerical models to simulate the vibrational and postural comfort of car occupants. His approach was with multi-body dynamics model and also with finite element model. The authors focus on the advantages and disadvantages of each model. Sun[7], *et al.* attempted to predict and analyze the dynamic behavior of the full system of multi-rigid-body mechanisms mounted on flexible support structures via a rigid joint in three-dimensional cases. Ibrahim[8] dealt with the design of suspension controllers for a tractor semi-trailer system considering chassis elasticity and the controller time delay. Valembois[9], *et al.* extensively investigated various discretisation methodologies of flexible beams. Balamurugan[10] described the ride dynamic characteristics of a military tracked vehicle by using finite element method with beam and shell elements. Transient dynamic analysis is done and the dynamic response is obtained at some specific locations.

From the literatures, it is observed that research work on the dynamics of tracked vehicles considering flexibility of the components or the vehicle systems is less. Hence in this paper, the dynamic analysis of an equivalent tracked vehicle by defining the road wheel arms as flexible elements by finite element method is presented. Result of the analysis is compared with the equivalent vehicle model with road wheel arms as rigid elements. Moreover, the equivalent vehicle finite element

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model is validated by comparison with the experimental result of the physical tracked vehicle.

2. EQUIVALENT TRACKED VEHICLE MODEL

A tracked vehicle consists of chassis, turret, tracks and suspension system comprising of hydro-gas suspension, road wheel arms and road wheel assemblies on either side of the vehicle is as shown in Fig. 1. In this work, the tracked vehicle is modelled in simplified form using the finite element method as a mass-spring system with sprung and unsprung masses as an equivalent model to the tracked vehicle for carrying out the ride dynamic studies is as shown in the Fig. 2.

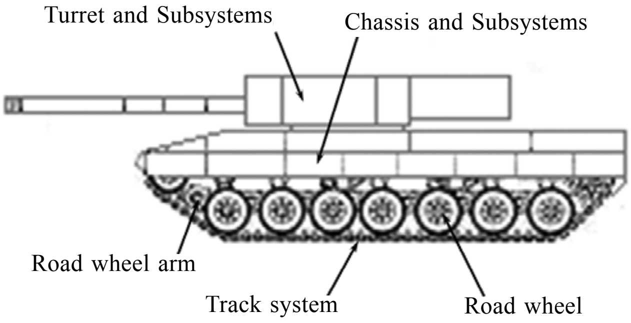

Figure 1. Schematic tracked vehicle configuration.

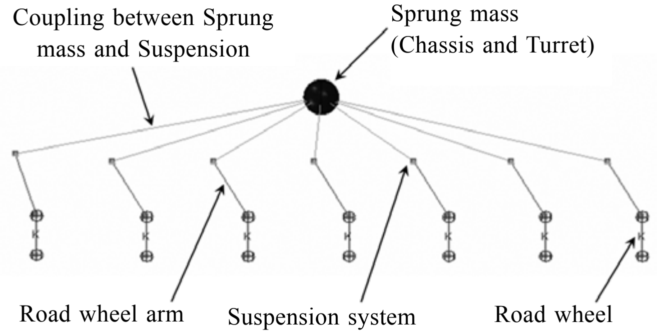

Figure 2. Equivalent tracked vehicle model.

The single assembly, consisting of chassis assembly, turret assembly, top roller assemblies, sprocket assemblies, idler assemblies and upper part of track chain system, is modelled as a sprung mass in this mass-spring system. It is represented in the finite element model as a single three dimensional mass element located at the centre of gravity of the combined chassis and turret system assembly along with its inertial properties. It is modelled as a sphere to represent it as a display body in the model. The suspension system is hydro-gas suspension system, and it is modelled as hinge connector element in this analysis with equivalent torsional stiffness derived from the kinematics of the suspension system. The assembly of road wheels, road wheel arms connecting the road wheel assembly with the chassis and the lower part of track chain system of the tracked vehicle is modelled as unsprung mass. The road wheel assembly is modelled as a translational spring with equivalent stiffness. Mass of track elements resting beneath the road wheels are appropriately distributed at the bottom node of the road wheel spring elements as three dimensional mass elements. Mass of the road wheel assemblies are distributed to the upper node of the spring element.

3. MODEL WITH RIGID ROAD WHEEL ARM

In this model, the main member of the unsprung mass is the road wheel arm which is connecting the road wheel assembly to the sprung mass through the suspension system. In this finite element mass-spring model, as shown in the Fig. 3, the road wheel arm is modelled as a rigid element. There are seven road wheel arms on either side in this tracked vehicle. The top node of these rigid road wheel arms are connected to the sprung mass through hinge connectors, representing the trailing arm suspension system, assigned with the non-linear suspension spring characteristics. The bottom nodes of these rigid road wheel arms are connected to the road wheel assembly through hinge connectors.

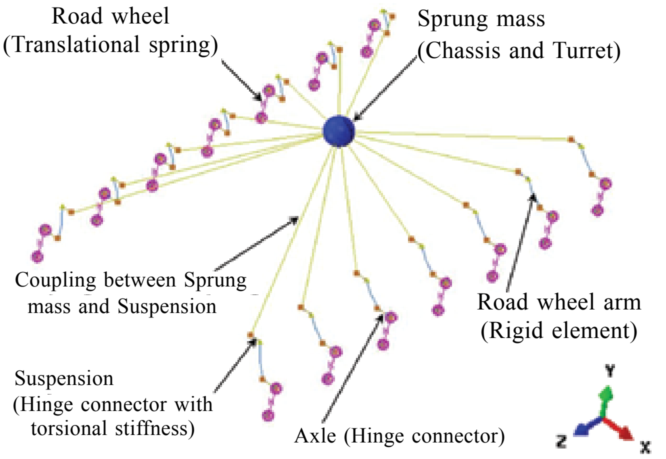

Figure 3. Equivalent model with rigid road wheel arm.

4. MODEL WITH FLEXIBLE ROAD WHEEL ARM

In the finite element model, as shown in the Fig. 4, the chassis assembly, turret assembly, road wheels, track chain system assembly etc. are modelled in the same way as that of the rigid body model mentioned above. But each road wheel arms are modelled using ten numbers of beam finite elements.

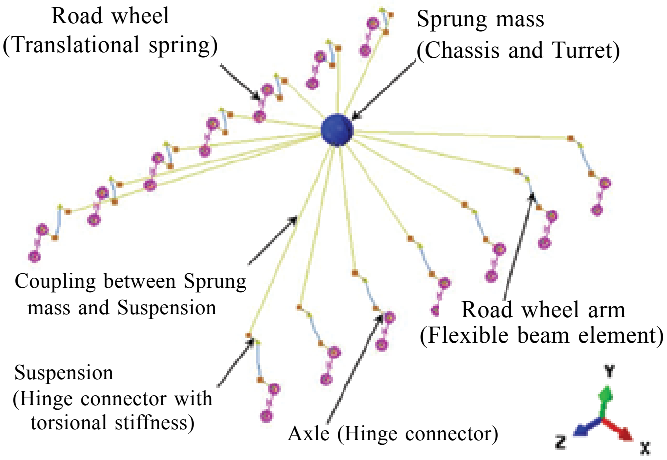

Figure 4. Equivalent model with flexible road wheel arm.

The beam finite elements are assigned with the steel material properties with appropriate density, modulus of elasticity, Poisson's ratio and the cross sectional properties. In this model, the flexible road wheel arm is modelled with a rectangular cross section of 140 mm width and 70 mm thickness. Hence, from the results of the investigation, the influence of modelling the road wheel arms as flexible elements in the dynamic behaviour of the tracked vehicle can be ascertained.

5. DYNAMIC SIMULATION

During the dynamic simulation of the tracked vehicle model, nodes of the 14 road wheels are allowed with linear degrees of freedom along x, y and z directions, and the suspension hinge connectors are provided with only rotational degree of freedom about x-direction along with torsional stiffness, so that the vehicle initially settles on the road for its self weight due to gravity. Then the vehicle is simulated on the Trapezoidal blocks terrain at a speed of 30 km/h, using dynamic implicit method in the Abaqus finite element analysis software. Standard Trapezoidal blocks terrain available for tracked vehicle testing is shown in the Fig. 5.

Figure 5. Trapezoidal blocks terrain.

Instead of giving the actual vertical profile dimension of the standard terrain profile as input, the vertical wheel displacements are captured at all the seven road wheel locations on the LH and RH sides of the vehicle, using ADAMS-ATV, a multi-body tracked vehicle dynamics software, which closely represent the wheel movement at different speeds. This vertical wheel displacements data for all the road wheels, is given as the vertical displacement input to the respective seven road wheel locations on the LH and RH sides of the above said finite element model. One such vertical displacement input data captured from the ADAMS-ATV software for the Trapezoidal blocks terrain at 30 km/h for the first road wheel location, is as shown in the Fig. 6. Response of the vehicle at the mass centre of sprung mass and other required locations is captured after the dynamic simulation.

6. RESULT OF THE SIMULATION

Dynamic simulation of the equivalent tracked vehicle model with Trapezoidal blocks terrain input as vertical wheel displacement data for a speed of 30 km/h is done using finite element method, for both the flexible road wheel arm model and rigid road wheel arm model, for a period of 17 seconds. Response of the vehicle is captured at the centre of gravity of the vehicle sprung mass for both the models which is shown in the following figures from Fig. 7 to Fig. 14. From the result of the analysis, it is evident that there is no appreciable difference between flexible body model and rigid body model in the vertical bounce displacement and vertical bounce acceleration, which is as shown in the Fig. 7 and Fig. 8. Moreover, there is no much influence on the pitch characteristics of the vehicle, as it is evident from the angular displacement and angular acceleration plots as shown in the Fig. 9 and Fig.10. But, the influence of flexibility is significant only in the lateral direction (along X-axis) and Roll characteristics of the tracked vehicle, which is observed from the lateral displacement, lateral acceleration, roll angular displacement and roll angular acceleration plots, as shown in the Figs. 11-14. Scale of Y-axis is different in the Figs. 11-14, for the flexible model and rigid model to exhibit clearly the difference in dynamic response.

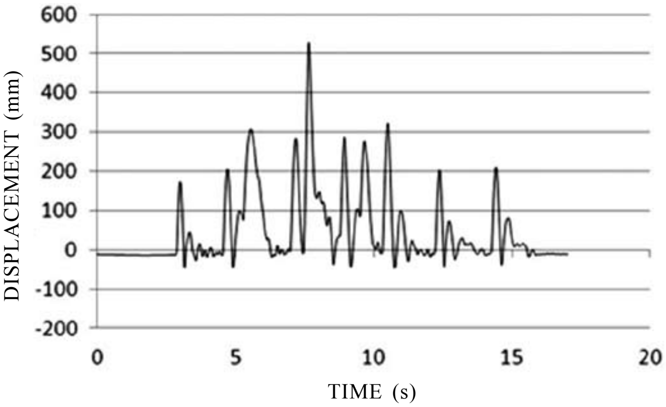

Figure 6. Vertical wheel displacement data.

7. EXPERIMENTAL VALIDATION

Dynamic vehicle response of the equivalent vehicle model at the sprung mass CG, on the Trapezoidal blocks terrain at a speed of 30 km/h is compared with response of the actual tracked vehicle of equivalent mass and road wheel stations, in the same terrain in the field condition. Vertical acceleration plots of the equivalent vehicle model and the physical tracked vehicle are as shown in the Fig. 15. In the equivalent vehicle model, the vertical acceleration response is captured at the sprung mass CG. But in the physical vehicle, as it was not possible to measure the response at the centre of mass location, the vertical response was captured at the top of turret structure using accelerometers. The experimental results, shows that the values observed are within ±8 m/s^2. Whereas, in the case of the equivalent vehicle model with the flexible road wheel arms, for the same terrain input at same speed, majority of the acceleration peaks are within ±8 m/s^2, neglecting some unwanted acceleration peaks, because the equivalent tracked vehicle model does not have the damping characteristics exactly same as the physical tracked vehicle.

Lateral acceleration plots of the equivalent vehicle model and the physical tracked vehicle, captured near fourth suspension station are as shown in the Fig. 16. In the physical vehicle, as it was not possible to measure the response at the centre of mass location, the lateral acceleration was captured at the side plates of the chassis structure. In the equivalent vehicle model, since there is no side plate available, the lateral acceleration response is captured at the fourth suspension station location which is

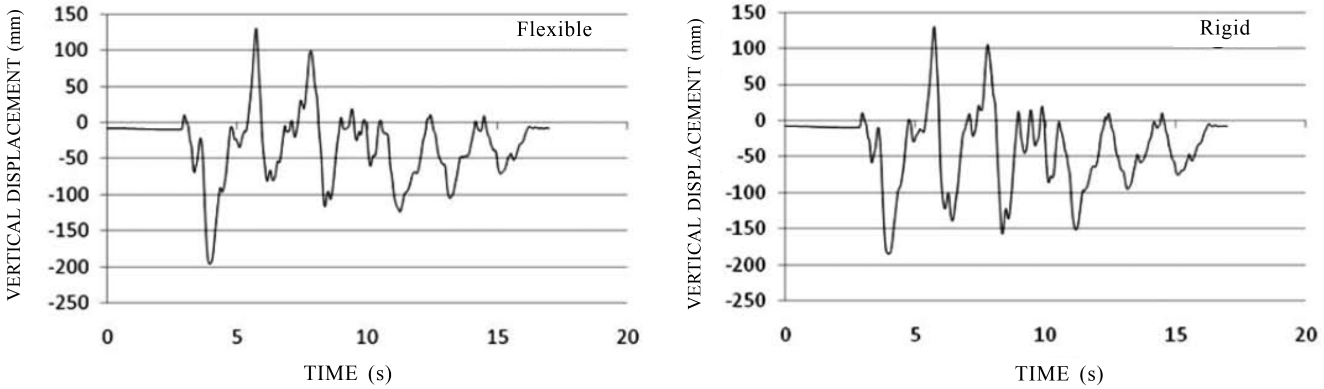

Figure 7. Vertical displacement of sprung mass CG (along Y-axis).

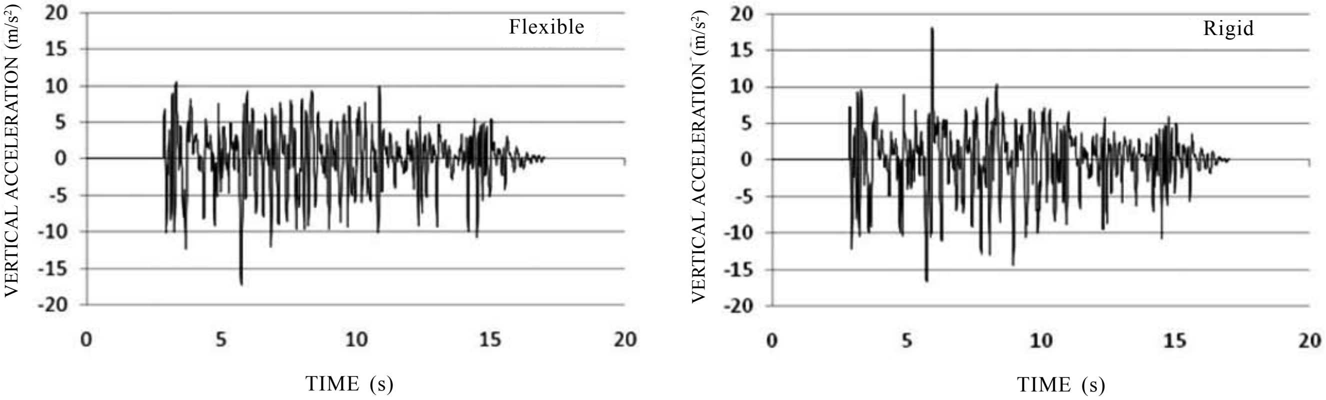

Figure 8. Vertical acceleration of sprung mass CG (along Y-axis).

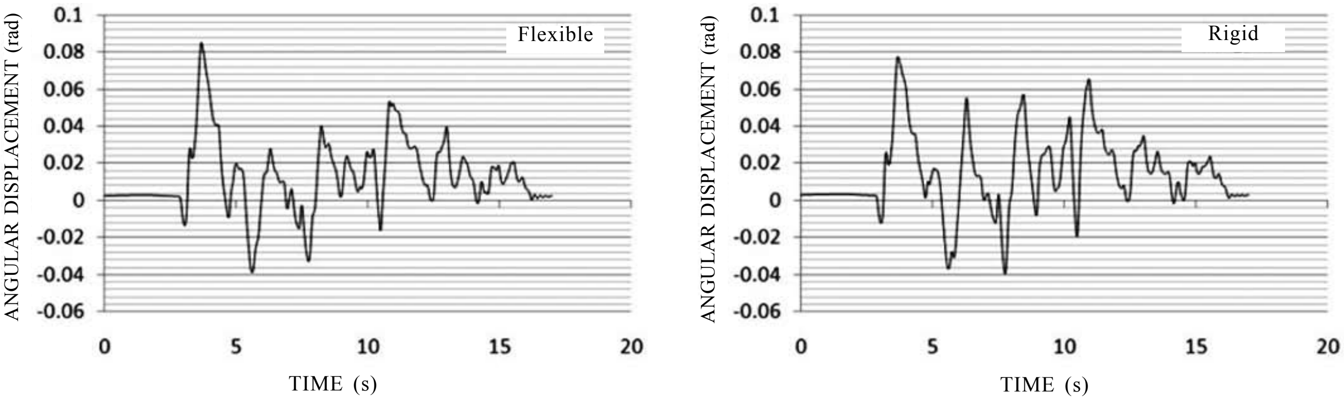

Figure 9. Pitch angular displacement of sprung mass CG (about X-axis).

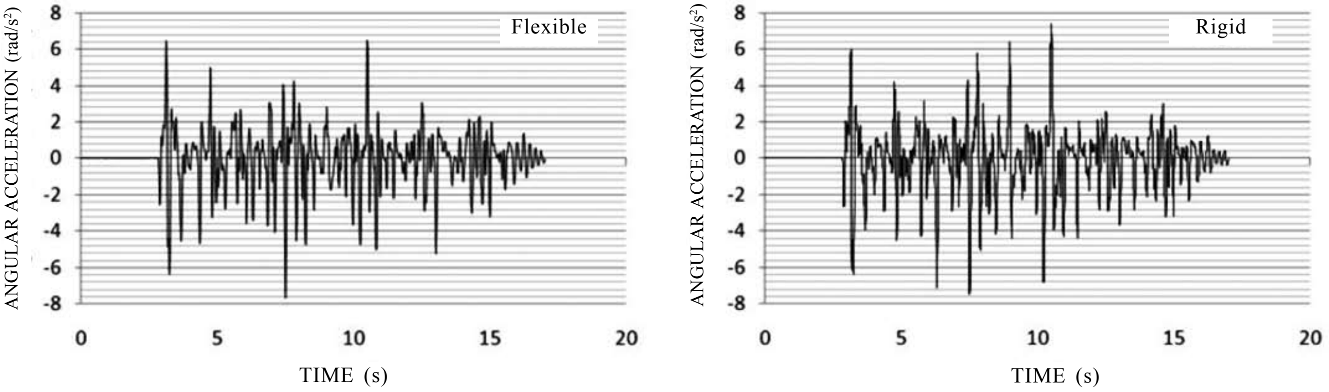

Figure 10. Pitch angular acceleration of sprung mass CG (about X-axis).

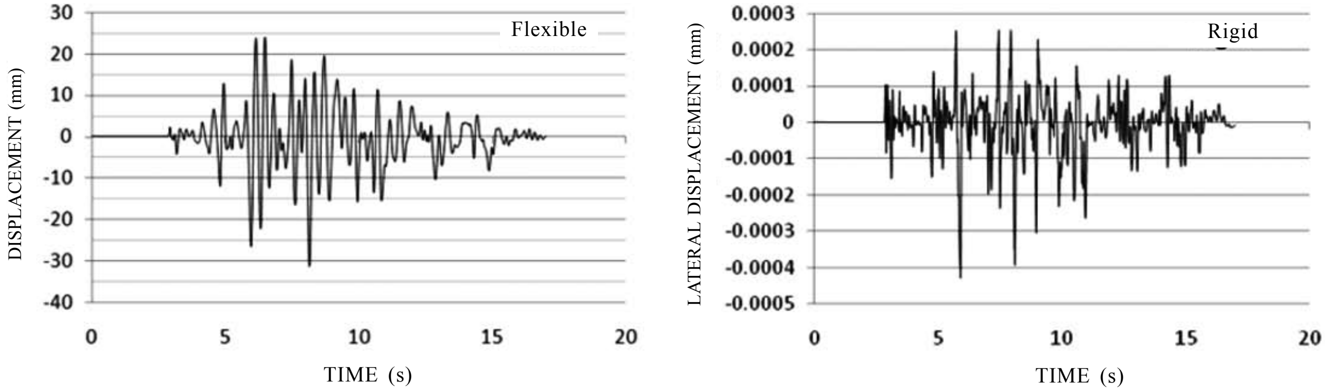

Figure 11. Lateral displacement of sprung mass CG (along X-axis).

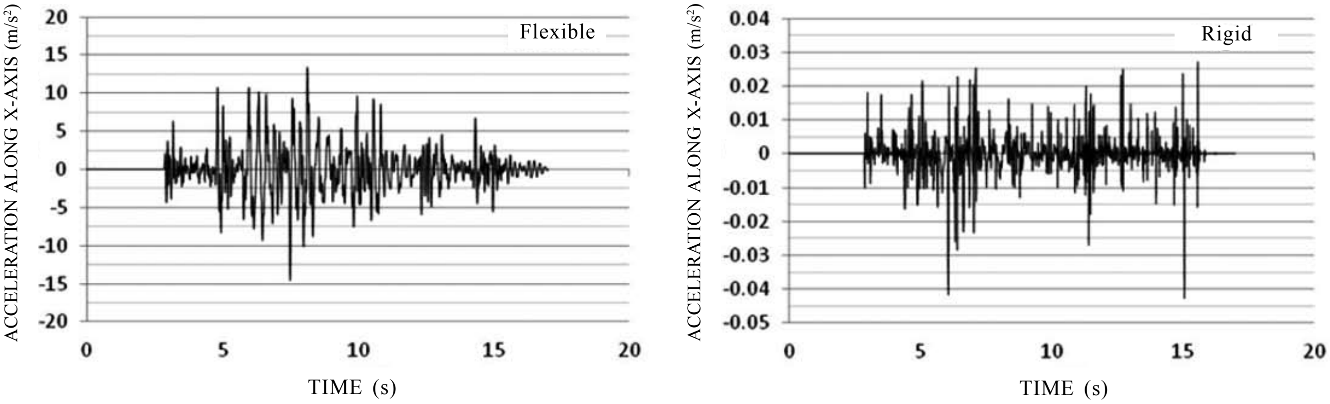

Figure 12. Lateral acceleration of sprung mass CG (along X-axis).

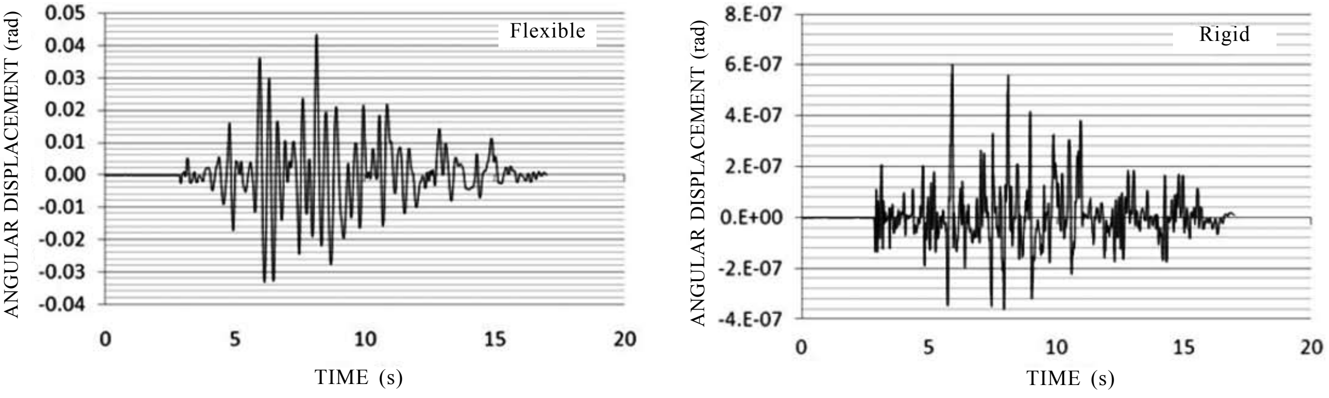

Figure 13. Roll angular displacement of sprung mass CG (about Z-axis).

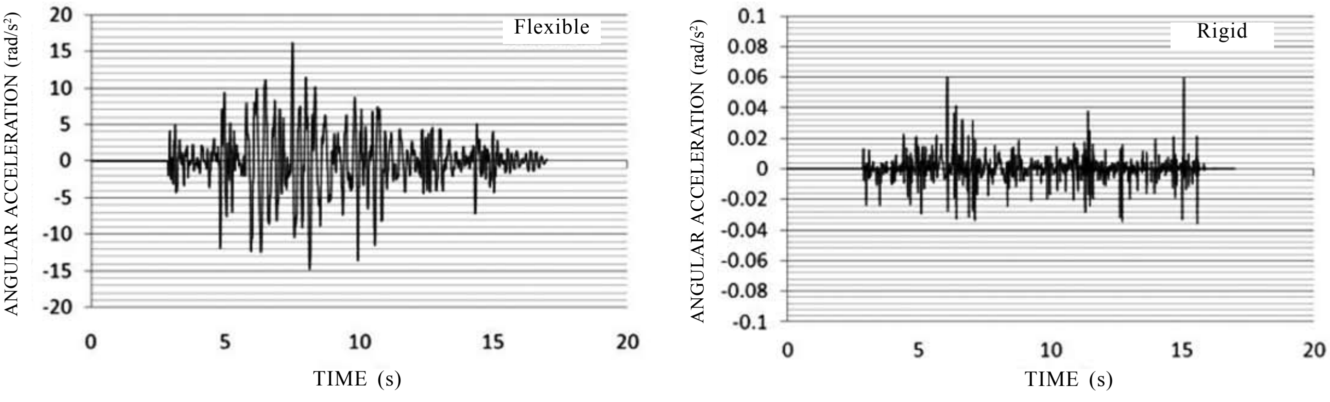

Figure 14. Roll angular acceleration of sprung mass CG (about Z-axis).

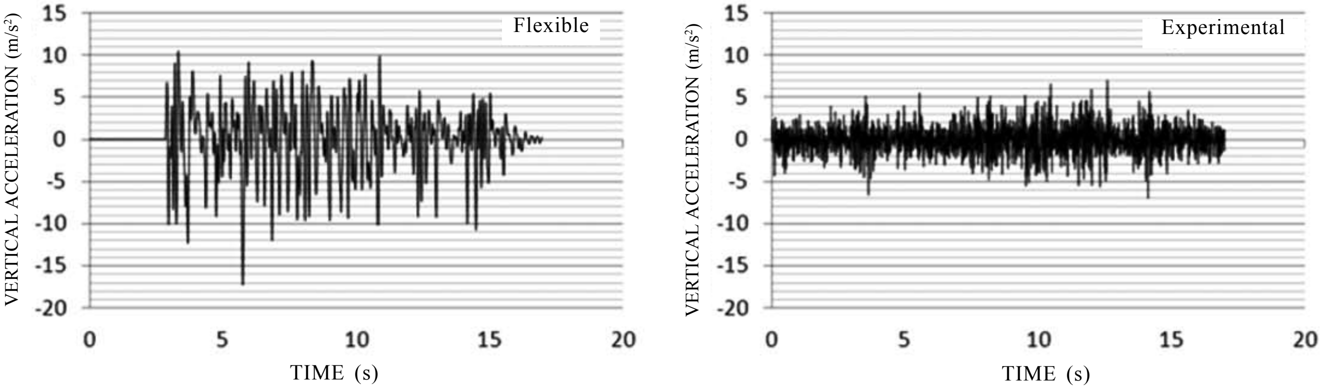

Figure 15. Vertical acceleration of flexible vehicle model and the actual vehicle.

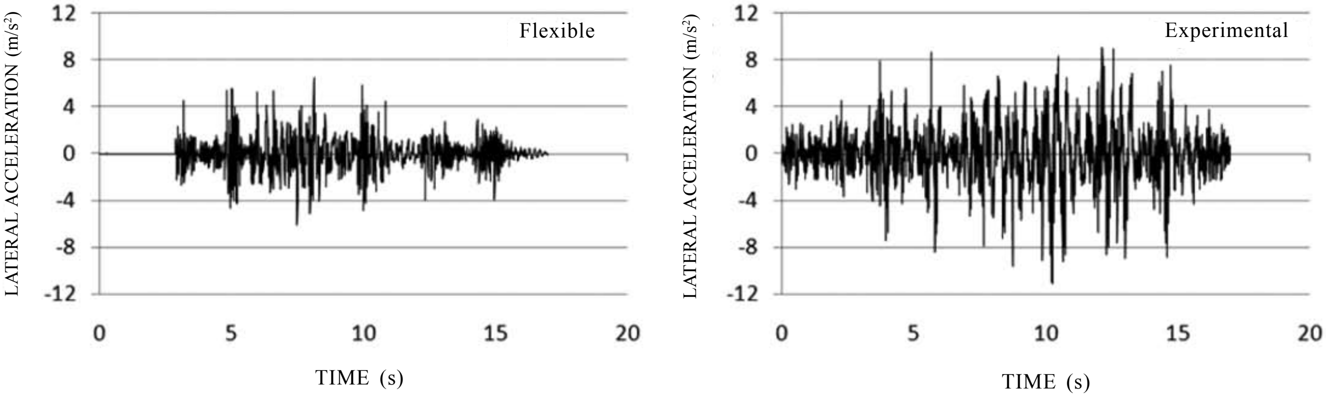

Figure 16. Lateral acceleration of flexible vehicle model and the actual vehicle.

close to the vehicle CG. As per the experimental results, the lateral acceleration values are mostly within ±8 m/s^2. Whereas, in the case of the equivalent vehicle model with the flexible road wheel arms, the acceleration peaks are within ±6 m/s^2. In both the plots, only the trapezoidal blocks portion along with a small plain road portion is plotted.

8. CONCLUSION

An equivalent tracked vehicle finite element model is prepared to study the ride dynamics of a tracked vehicle on Trapezoidal blocks terrain. In this study, the road wheel arm is modelled as flexible body in one vehicle model and as rigid body in another model using Finite element method. In the dynamic simulation, the terrain input is given as vertical displacement input at the road wheel locations. In order to validate the equivalent vehicle model, the responses such as vertical acceleration and lateral acceleration of the equivalent vehicle model with flexible road wheel arm, captured from the simulation with Trapezoidal blocks terrain for 30 km/h speed, is compared with the experimental results measured at the physical tracked vehicle on the actual trapezoidal blocks terrain, which exhibits fairly closer results.

Dynamic simulation of flexible and rigid vehicle models is done using the ABAQUS finite element analysis software. Dynamic response of the vehicle with flexible road wheel arm is compared with the rigid road wheel arm vehicle model. Result of the study shows that the influence of including the flexible road wheel arm in the tracked vehicle exhibits a significant difference in the lateral dynamics and roll characteristics of the vehicle when compared to the vehicle model with rigid road wheel arm. But in the case of bounce and pitch, the dynamic response of the vehicle with flexible road wheel arm is not noteworthy. In this study, only the road wheel arm is considered as flexible body and the study brings out the effect of considering the flexibility in the ride dynamic response of the vehicle.

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