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Influence of Flexible Bodies in Military Tracked Vehicle Dynamics

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ABSTRACT:

Tracked vehicles are meant to be used in the harsh cross country environment. In particular, the military tracked vehicles are highly exposed to severe terrains and critical handling conditions. Yet while carrying out the dynamic studies, the tracked vehicles, in general, are modeled as rigid bodies. Hence in this article, an attempt has been made to understand closely the dynamics of a tracked vehicle with the inclusion of some parts of the tracked vehicle viz., hull side plates and road wheel arms, as flexible bodies in the dynamic analysis using the finite element method. Result of the flexible dynamic simulation is also compared with the tracked vehicle analysis with the same parts modeled as rigid bodies. In this investigation, dimensions of the standard staggered trapezoidal blocks terrain meant for testing the tracked vehicles is used to carry out the dynamic studies on the tracked vehicle. The dynamic simulation result of the flexible tracked vehicle model is also compared with the experimental test result of the actual tracked vehicle conducted in the actual trapezoidal blocks terrain.

KEYWORDS:

Tracked vehicle dynamics; Flexible body; Rigid body; Finite element method; Road wheel arm; Side plate

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ACRONYMS AND NOMENCLATURE:

m	Sprung mass
m_1 to m_7	Unsprung masses at the wheel stations 1 to 7
k_1 to k_7	Spring stiffness at the wheel stations 1 to 7
c_1 to c_7	Damping value at the wheel stations 1 to 7
k_w	Road wheel stiffness
x	Vertical displacement of sprung mass
x_1 to x_7	Vertical displacement of unsprung masses
y_1 to y_7	Ground excitation of road wheels
C	Sprung mass centre
θ	Sprung mass pitch motion coordinate
a_1 to a_7	Location of unsprung masses
$\dot{x}$	Vertical velocity of sprung mass
$\ddot{x}$	Vertical acceleration of sprung mass

1. Introduction

Rubinstein and Galili [1] developed a computer program for the design and analysis of the off-road tracked vehicle suspension system and ride comfort evaluation. The program can be used for optimization of the suspension system, its performance and evaluation of vehicle mobility. The output of simulation will be in the form of velocity, acceleration, forces and moments at any desired location. Dhir and Sankar [2] developed an in-plane, non-linear computer simulation model in order to study the suspension dynamics and ride quality assessment of high mobility tracked vehicle which incorporates detailed modeling of the trailing arm suspension system. Ma and Perkins [3] presented a mathematical model of track-wheel-terrain interaction in order to simulate the dynamics of the tracked vehicle, thereby studying the track and terrain interaction using the finite element method. Lee et al [4] carried out structural dynamic analysis of a multi-flexible body system with both flexible body subsystems using beam finite elements and rigid body subsystems.

Dietz et al [5] discussed the inclusion of quadratic terms in the formulation and methods of global mode preparation for the flexible multibody system modeling and simulation. Yamakawa and Watanabe [6] developed a spatial motion analysis model to carry out the numerical simulation so as to evaluate the ride performance, stability and steerability of high mobility tracked vehicles equipped with independent torsion bar suspension system. Park et al [7] ventured to develop three different quarter-car models viz. single point contact model, flexible wheel contact model and the rigid wheel contact model, thereby carried out the numerical simulation to understand which is the best model. Els [8] investigated the military vehicle ride comfort by considering four methods including ISO 2631 and concluded that the driver and the crew positioned in the rear portion of the vehicle are subjected to severe acceleration levels due to the combination of vertical acceleration, pitch and roll of the vehicle.

Milli et al [9] carried out the dynamic studies on the steady-state skid-steering manoeuvre of tracked vehicles and presented a new technique to predict the track forces. Carlbom [10] dealt with a non-linear multibody model of a rail vehicle combined with a finite element model of its car body, and also reduced the finite element model by eigen mode representation. From the literatures, it is understood that the inclusion of flexible bodies is very less in the investigations on the military tracked vehicle dynamics. Hence this paper focuses on the dynamic analysis of a military tracked vehicle by modeling only the road wheel arms at all the suspension stations and the vertical side plates on either side of the tracked vehicle as flexible bodies using finite element method. Simulation result of the flexible vehicle model is compared with the simulation result of the rigid body vehicle model and also with the experimental test trials of the actual tracked vehicle. Schematic tracked vehicle configuration is shown in Fig. 1.

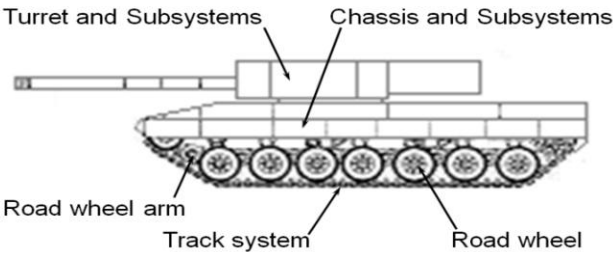

Fig. 1: Tracked vehicle configuration

2. Tracked vehicle model

Generally, in most of the literatures related to tracked vehicle dynamics, the vehicle chassis assembly is modelled as one rigid body, representing the sprung mass, which is supported by the suspension systems which are modelled as the spring and damper elements at the respective suspension stations. The road wheel arms, track chain system and the road wheels are also modelled as rigid bodies represented as the unsprung masses and springs. Half car mathematical model of a military tracked vehicle with seven suspension stations is shown in Fig. 2. The kinetic energy of the system, considering the sprung & unsprung masses, is given by,

$$K = \frac{1}{2}\begin{pmatrix} m\dot{x}^2 + m_1\dot{x}_1^2 + m_2\dot{x}_2^2 + m_3\dot{x}_3^2 + m_4\dot{x}_4^2 \\ + m_5\dot{x}_5^2 + m_6\dot{x}_6^2 + m_7\dot{x}_7^2 + I_X\dot{\theta}^2 \end{pmatrix} \quad (1)$$

The potential energy of the system is given by,

$$V = \frac{1}{2}\begin{pmatrix} k_w(x_1 - y_1)^2 + k_w(x_2 - y_2)^2 + k_w(x_3 - y_3)^2 \\ + k_w(x_4 - y_4)^2 + k_w(x_5 - y_5)^2 \\ + k_w(x_6 - y_6)^2 + k_w(x_7 - y_7)^2 \\ + k_1(x - x_1 + a_1\theta)^2 + k_2(x - x_2 + a_2\theta)^2 \\ + k_3(x - x_3 + a_3\theta)^2 + k_4(x - x_4 - a_4\theta)^2 \\ + k_5(x - x_5 - a_5\theta)^2 + k_6(x - x_6 - a_6\theta)^2 \\ + k_7(x - x_7 - a_7\theta)^2 \end{pmatrix} \quad (2)$$

The dissipation function is given by,

$$D = \frac{1}{2}\begin{pmatrix} c_1(\dot{x} - \dot{x}_1 + a_1\dot{\theta})^2 + c_2(\dot{x} - \dot{x}_2 + a_2\dot{\theta})^2 \\ + c_3(\dot{x} - \dot{x}_3 + a_3\dot{\theta})^2 + c_4(\dot{x} - \dot{x}_4 - a_4\dot{\theta})^2 \\ + c_5(\dot{x} - \dot{x}_5 - a_5\dot{\theta})^2 + c_6(\dot{x} - \dot{x}_6 - a_6\dot{\theta})^2 \\ + c_7(\dot{x} - \dot{x}_7 - a_7\dot{\theta})^2 \end{pmatrix} \quad (3)$$

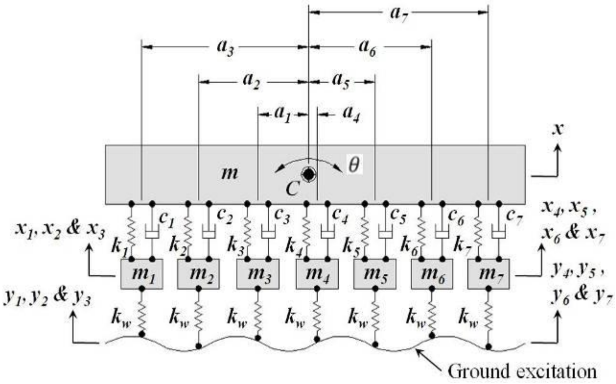

Fig. 2: Tracked vehicle mathematical model

From the Lagrange formulation, the equations of motion for the above system can be arrived in the following form,

$$[m]\{\ddot{x}\} + [c]\{\dot{x}\} + [k]\{x\} = \{F\} \quad (4)$$

Where $[m]$, $[c]$ and $[k]$ are assembled mass, damping and stiffness matrix respectively. $\{F\}$ is the force vector. But, in this paper, instead of doing the rigid body dynamic analysis, either by using a mathematical model or by using some rigid body analysis tool, the tracked vehicle is modelled using the finite element method with some components as flexible bodies in order to closely capture the dynamics of the vehicle. The flexible finite element vehicle model is shown in Fig. 3.

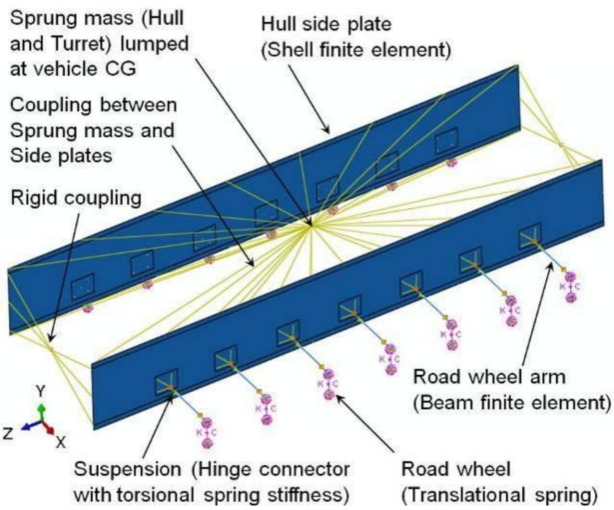

Fig. 3: Flexible vehicle model

In this vehicle model, except the vertical side plates, the assembly consisting of chassis, turret, top rollers, sprockets, idlers and upper part of track chain system, is modeled as a lumped mass at the centre of gravity of the combined chassis and turret system assembly. The suspension system is hydro-gas suspension system which is modeled as hinge connector element in this analysis at all the seven suspension station locations, with an 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 modeled as unsprung mass. Road wheel assembly is modeled as a translational spring with appropriate stiffness. Mass of the 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 representing the road wheel.

In order to distinguish the dynamic performance of the tracked vehicle, two different vehicle models are prepared and the analysis was carried out with same ground excitation data and the analysis results are captured at the same locations and compared. In one vehicle model, the hull side plates are modeled with two dimensional 8 node quadrilateral shell elements and the road wheel arms which connect the vehicle chassis with the road wheel assembly are modeled with beam finite elements, so that the objective of including the flexible components in the tracked vehicle simulation is partially met, because these components are the prime members in the tracked vehicle which transfer the ground excitation to the sprung mass. In another model, all the vehicle components including the hull side plates and the road wheel arms are modeled as rigid elements.

3. Simulation input data

As the military tracked vehicles are meant to be in operation in any type of terrain, there are some standard terrains available in order to test the vehicle during the prototype phase. One such staggered trapezoidal blocks terrain available for tracked vehicle testing is shown in Fig. 4. In the dynamic simulation, the bottom nodes of the seven road wheels each on LH and RH side of the vehicle are allowed with linear degrees of freedom along the x, y and z directions. The hinge connectors are provided with only the rotational degree of freedom with appropriate suspension spring stiffness and damping, so that initially the static settlement of the tracked vehicle due to its self weight is ensured. Then the vehicle is simulated with the vertical displacement ground excitation input due to the trapezoidal blocks terrain for a speed of 30 kmph using the dynamic implicit method in the Abaqus, which is one of the standard Finite element analysis software. The vertical wheel displacements for 30km/h speed on the trapezoidal blocks terrain are captured at the seven road wheel locations on the LH and RH sides of the vehicle using ADAMS-ATV, a multi-body tracked vehicle dynamics software, so that the wheel displacement on the terrain profile is closely represented. This vertical wheel displacement is given as the input to the respective road wheel locations on the LH and RH sides, in this analysis. One such wheel displacement data noted from the ADAMS-ATV software for the trapezoidal blocks terrain at 30 kmph, is shown in Fig. 5.

Fig. 4: Standard trapezoidal blocks terrain

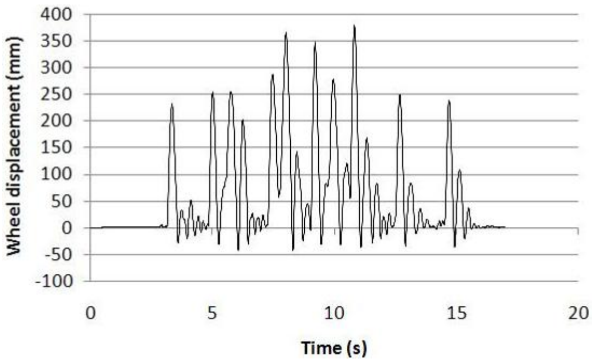

Fig. 5: Wheel excitation input data

4. Vehicle dynamic simulation

Dynamic simulation of the tracked vehicle model with trapezoidal blocks terrain data for a speed of 30 kmph as vertical wheel displacement input to the dynamic analysis is carried out using finite element method, for the flexible vehicle model with flexible side plates and road wheel arms and as well as for the fully rigid vehicle model, for a period of 17 seconds. Dynamic response at the centre of gravity of the vehicle sprung mass and at the hull side plate for both the models are shown in Figs. 6-15. Outcome of the analysis shows that there is no noticeable difference exists between the flexible body vehicle model and rigid body vehicle model as far as the vertical bounce displacement, vertical bounce acceleration, pitch angular displacement and pitch angular acceleration are concerned, which is clear from Figs. 6-9.

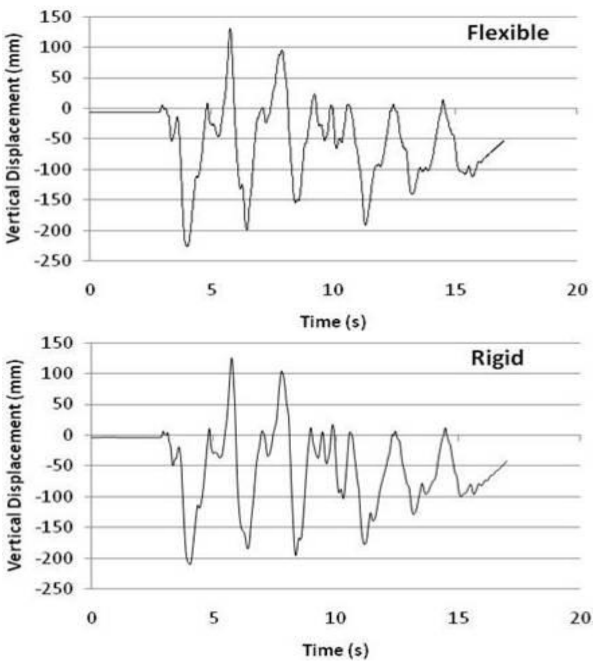

Fig. 6: Vertical bounce displacement of sprung mass CG (along Y-axis), Flexible (top) and Rigid (Bottom)

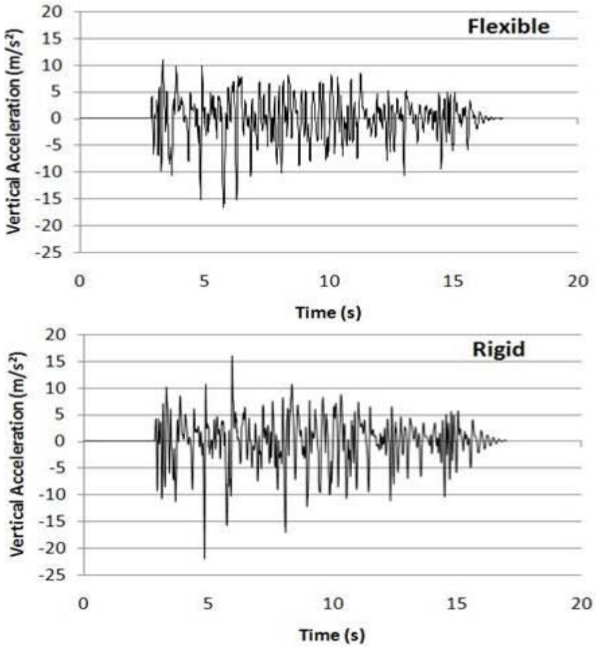

Fig. 7: Vertical bounce acceleration of sprung mass CG (along Y-axis), Flexible (top) and Rigid (Bottom)

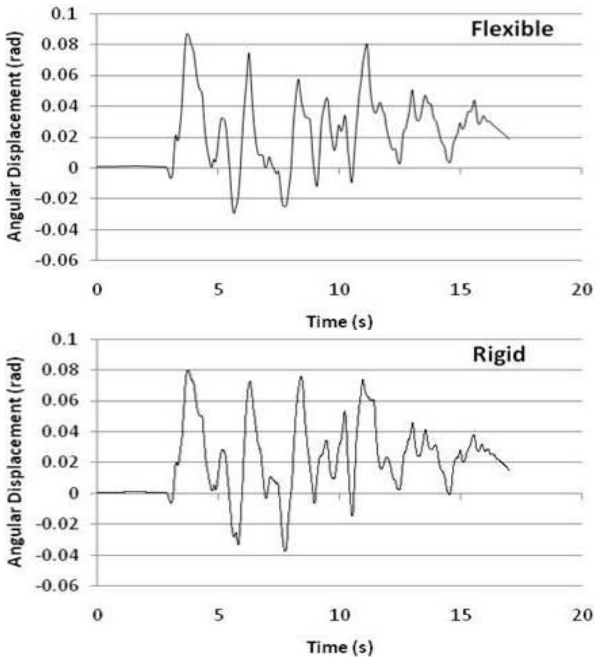

Fig. 8: Pitch angular displacement of sprung mass CG (about X-axis), Flexible (top) and Rigid (Bottom)

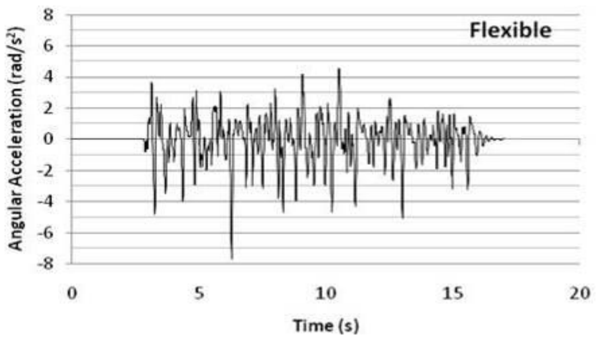

Fig. 9(a): Pitch angular acceleration of sprung mass CG (about X-axis) for flexible model

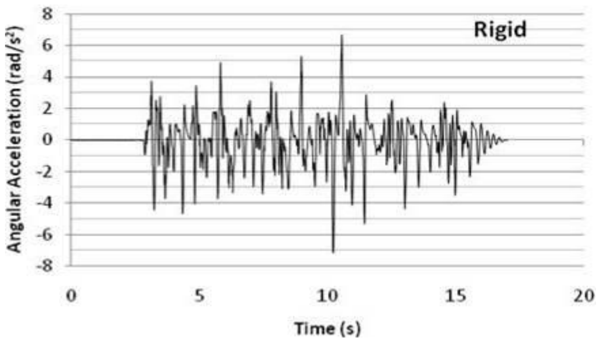

Fig. 9(b): Pitch angular acceleration of sprung mass CG (about X-axis) for rigid model

The influence of including the flexible components is significant only in the lateral dynamics (along X-axis) and roll characteristics (rotation about Z-axis) of the tracked vehicle, which is evident from the lateral displacement, lateral acceleration, roll angular displacement and roll angular acceleration plots of the vehicle sprung mass CG and the lateral displacement and lateral acceleration plots of the side plate at the fourth suspension station location, shown in Figs. 10-15. Just for the visual clarity, Y-axis of the dynamic response plots in Figs. 10-15, are plotted with different scales for the flexible and rigid vehicle models.

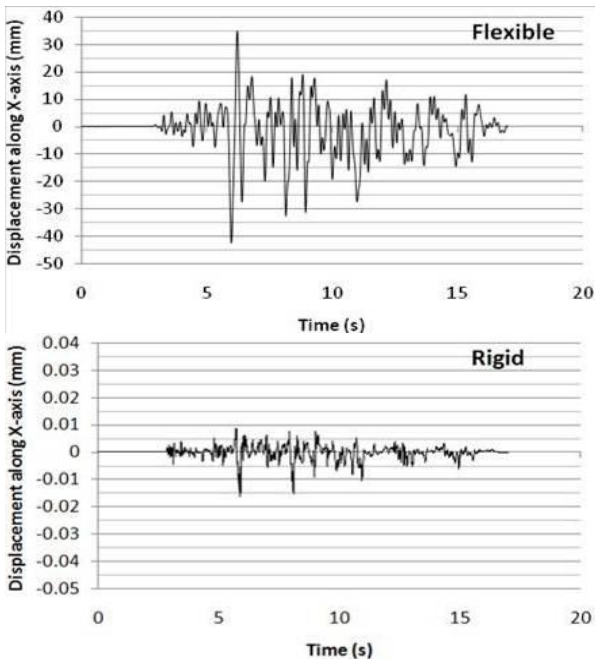

Fig. 10: Lateral displacement of Sprung mass CG (along X-axis), Flexible (top) and Rigid (Bottom)

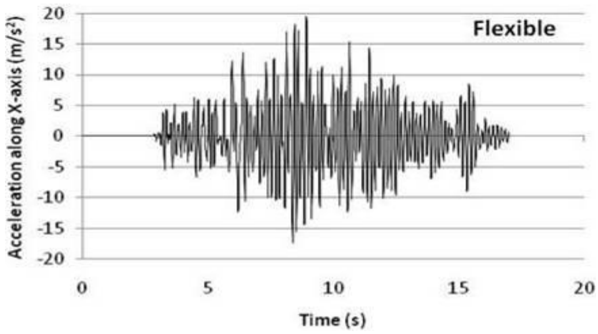

Fig. 11(a): Lateral acceleration of Sprung mass CG (along X-axis) for flexible model

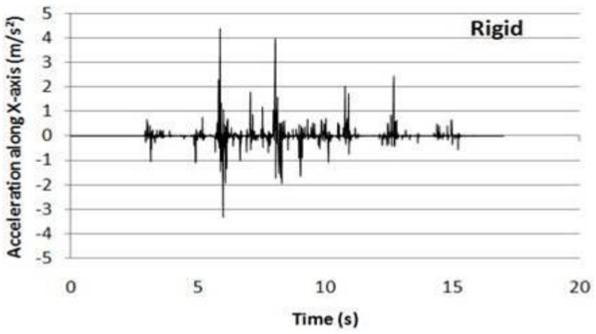

Fig. 11(b): Lateral acceleration of Sprung mass CG (along X-axis), for rigid model

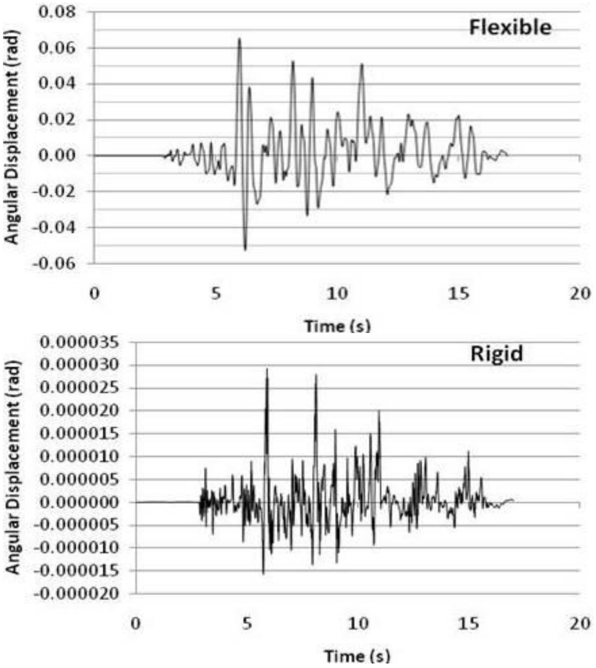

Fig. 12: Roll angular displacement of Sprung mass CG (about Z-axis), Flexible (top) and Rigid (Bottom)

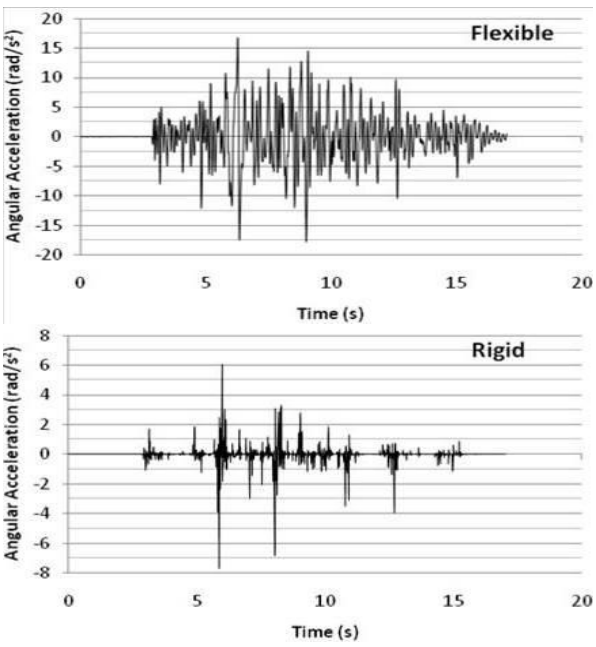

Fig. 13: Roll angular acceleration of Sprung mass CG (about Z-axis), Flexible (top) and Rigid (Bottom)

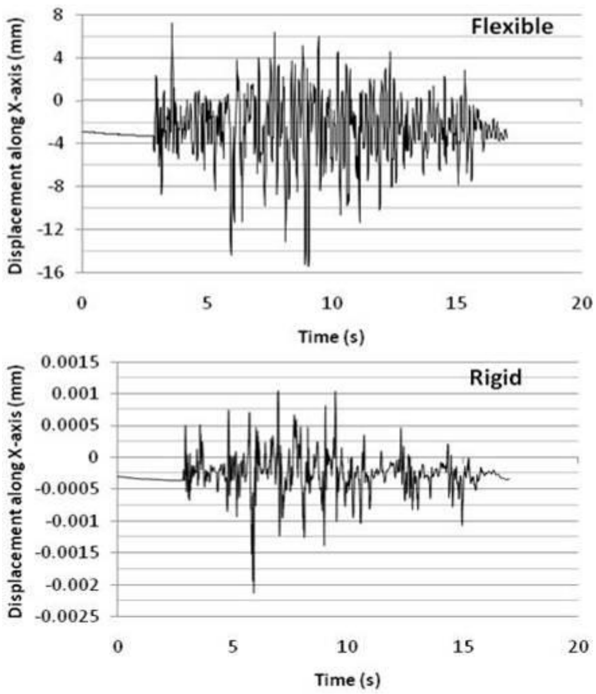

Fig. 14: Lateral displacement of side plate at 4th Wheel station (along X-axis), Flexible (top) and Rigid (Bottom)

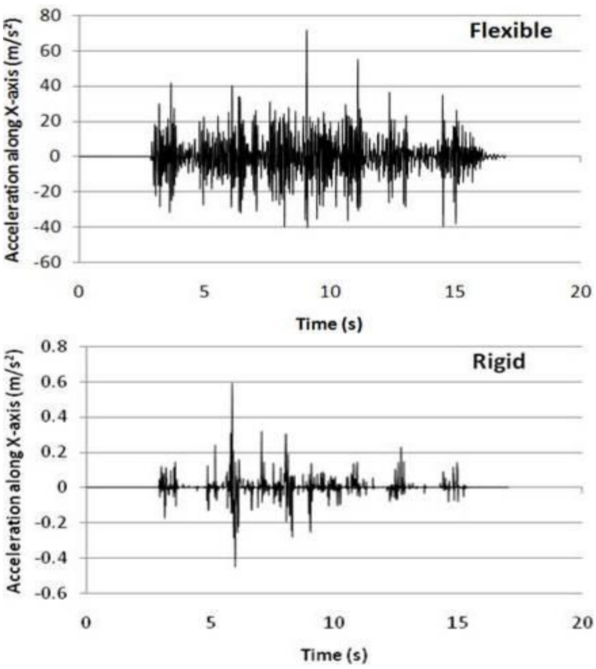

Fig. 15: Lateral acceleration of side plate at 4th Wheel station (along X-axis), Flexible (top) and Rigid (Bottom)

5. Experimental validation

In order to validate the flexible vehicle model, the results of the dynamic simulation of the flexible vehicle model in the lateral direction (along X-axis), is compared with the actual experimental results observed on the physical tracked vehicle. The experimental setup on the physical tracked vehicle is as shown in Fig. 16, wherein the accelerometer is mounted on the side plate of the chassis of the tracked vehicle for capturing the lateral acceleration of the vehicle. Dynamic lateral acceleration response of the flexible vehicle model observed at the fourth suspension station location on the LH side of the flexible vehicle model for the simulation on the trapezoidal blocks terrain at a speed of 30 kmph, is compared with the lateral acceleration response of the physical tracked vehicle measured during the field test conducted at the actual trapezoidal blocks test track at the same speed is plotted in the Fig. 17. In both the cases, the lateral acceleration of the vehicle is captured at the LH side plate of the vehicle chassis near the fourth suspension station location, which is close to the vehicle CG. The experimental measurement shows that the lateral acceleration values are mostly within ±40 m/s^2. In the case of flexible tracked vehicle model also most of the lateral acceleration values are within ±40 m/s^2, except few peaks because the flexible vehicle model does not have the same damping properties as the physical tracked vehicle.

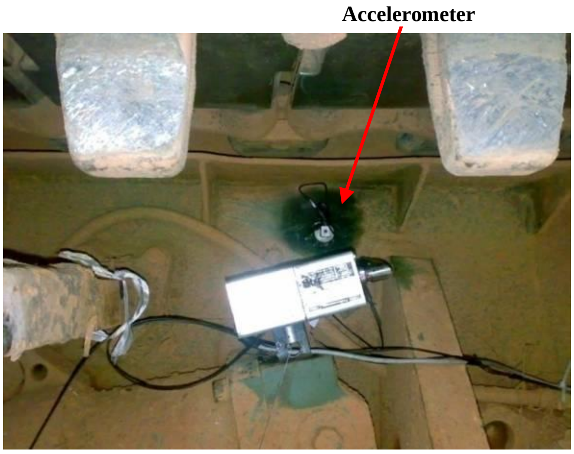

Fig. 16: Accelerometer mounted on the side plate of the physical tracked vehicle

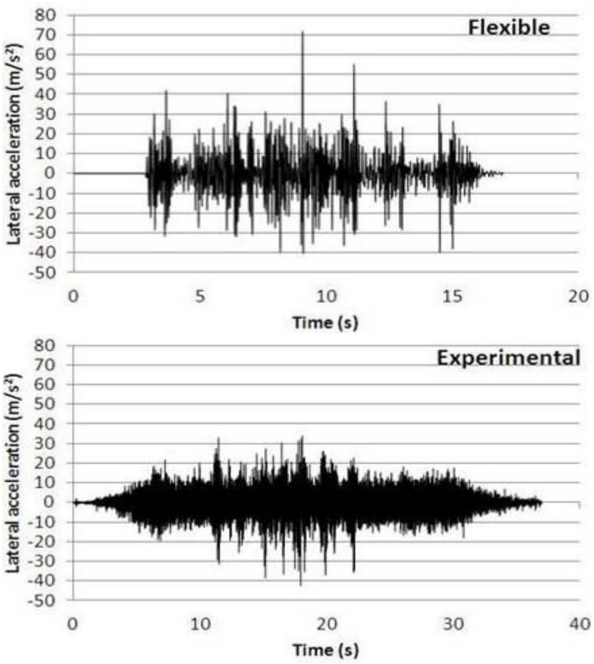

Fig. 17: Lateral acceleration responses, Flexible vehicle model (top) & Experimental results of the physical tracked vehicle (bottom)

6. Conclusions

In this paper, an attempt has been made to understand the military tracked vehicle dynamics with the inclusion of some components as flexible bodies. The dynamic simulation has been carried out on two finite element models using Abaqus finite element analysis software. In first model, the vertical side plates and the road wheel arms of the vehicle are modeled as flexible components. In second one is a complete rigid body model. A standard staggered trapezoidal blocks terrain has been considered for analysis and its profile has been given as the input to the analysis. Outcome of the dynamic simulation shows no observable difference between the flexible and rigid vehicle models as far as the bounce and pitch dynamics of the tracked vehicle are concerned. But there is a significant difference exists in the lateral dynamics and roll dynamics of the flexible tracked vehicle model when compared to the rigid tracked vehicle model. For validating the flexible vehicle model, the lateral acceleration response noted at the vertical side plate near the fourth suspension station location is compared with the lateral acceleration value measured during the field trial of the actual military tracked vehicle on the physical trapezoidal test track at the speed of 30 kmph, which exhibits a close correlation between the dynamic analysis result and the experimental measurement. Hence, this study presents the value addition in doing the dynamic analysis of the tracked vehicles considering component flexibility.

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