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Dynamic Analysis of a Military-Tracked Vehicle

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ABSTRACT

The ride dynamic characteristics of a typical medium weight, high speed military-tracked vehicle for negotiating rough cross-country terrain have been studied. The vehicle is modelled using finite element simulation method with beam and shell elements. An eigenvalue analysis has been done to estimate natural modes of vibration of the vehicle. The dynamic response of certain salient locations is obtained by carrying out a transient dynamic analysis using implicit Newmark beta method. A constant forward vehicle speed and non-deformable sinusoidal terrain profile are assumed.

1. INTRODUCTION

Military-tracked vehicles are designed for negotiating rough cross-country terrain. Due to increased power-to-weight ratio and mobility requirements of these vehicles, crew and sophisticated electronic equipment are exposed to severe ride environment due to dynamic terrain-vehicle interactions. Invariably, the ride vibrations transmitted to the crew are of low frequency and high amplitude. Prolonged exposure to such vibrations causes human fatigue, bodily discomfort and physiological damage, and thus reduces the performance efficiency of the crew[1], which in turn causes severe limitation on the mobility performance of the vehicle. The International Organisation for Standardisation (ISO) has developed a standard for exposure to whole body vibration, which specifies the limits in terms of acceleration, frequency and exposure duration (ISO 2631, 1974).

Deriving a mathematical and a computer simulation models has become an effective tool for evaluating vibration characteristics of ground vehicles. In view of the detrimental effects of terrain-induced vibration, the ride dynamic characteristics of off-road vehicles have drawn extensive study. Only few studies on the ride dynamics of tracked vehicles have been reported, which are mostly the in-plane, rigid body type of modelling, wherein the vehicle is modelled as springs and masses. Eppinger[2] and others have developed a 2-degrees-of-freedom (DOFs) mathematical model for a tracked vehicle. Murphy[3] and others have developed a vehicle dynamics (VEHDYN) module to predict the ride and shock limiting speeds for multiwheeled- tracked vehicles. Rakheja[4] and others have considered a 10-road wheel-tracked vehicle characterised by 7-DOFs in-plane model, incorporating kinematics of the road wheel suspension. Ride dynamic response of tracked vehicles is evaluated for excitations arising from random undeformable terrain excitations. Dhir[5] and others have studied the response of the off-road tracked vehicles considering an in-plane model with 3+N DOFs, where N is the specified number of road wheels on one side of the vehicle

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with pitch and bounce DOF associated with vehicle-sprung body (hull) and an optional vertical DOF for the driver's seat. Each road wheel-and-axle assembly is represented by a lumped unsprung mass with a vertical DOF. This model has also been validated through actual ride measurements. Hada[6] has studied the dynamic characteristics of a 12-bogie wheel-tracked vehicle by a mathematical model with 78-DOFs. In this, the torsion bars connecting the road arm to the hull chassis are considered as beams with 6-DOFs and the sprung mass with 6-DOFs.

Most of these studies have considered in-plane models which are of rigid body type, wherein the vehicle is modelled as springs and masses. As the stiffness and mass of the vehicle structure is a distributed parameter in the structure, rigid body modelling will not give as accurate results as the finite element modelling (FEM). FEM approach enables the analyst to generate a model based on the structural blueprint dimensions and material properties. A number of finite element methods of vehicle dynamic studies for wheeled vehicles have been reported [7]. However, not many similar studies have been reported for tracked vehicles.

In the present study, a military-tracked vehicle used for carrying sophisticated electronic equipment and armoured personnel has been considered. Finite element method has been used for modelling the vehicle. The natural modes of vibration of the vehicle have been obtained by an eigenvalue analysis. Also, a transient dynamic response of the vehicle, when the vehicle moves over a bump, is evaluated by direct time integration using Newmark beta method.

2. VEHICLE DESCRIPTION

The hull has 7-bogie stations with torsion bar suspension system (Fig. 1). The hull is made up of welded assemblies of high strength armour steel plates with stiffeners. It is a frame, including power plant compartment, driver's compartment and equipment compartment. A number of maintenance hatches are provided as the side plates for easy access and maintenance of the equipment mounted inside the vehicle.

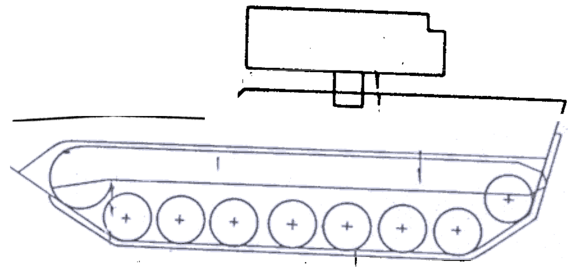

Figure 1. Military-tracked vehicle with seven-bogie wheel stations.

3. FINITE ELEMENT MODELLING

The hull with the topdeck structure has been modelled using quadrilateral 4-noded plate elements and stiffeners as 2-noded, 3-D beam elements (Fig. 2). The turret mechanisms mounted on the turret-slewing ring, engine, transmission, sprocket, track and other dead loads are modelled as lumped mass elements at the appropriate nodes (Table 1). The suspension elements torsion bar and the axle arm have been modelled as beam elements. The connectivity between the torsion bar and the hull in the axle arm side of the torsion bar is established through spring elements with a high stiffness value in order to simulate the bush bearing. The bogie wheel is modelled as spring element with lumped mass. The centre of the bogie wheel is assumed to have simply supported boundary condition. The overall weight of the vehicle is about 20 tons. Some small components of the structure which do not contribute significantly in load carrying and stiffness/strength of the structure have been ignored. The track tension of 88,000 N is applied as tangential load on the drive sprocket. The present model of the vehicle has 2506 nodes and 14,966-DOFs.

Table 1. Mass details of the dead loads

Name of the system	Mass (kg)
Turret equipment	2000
Turret mechanisms	3000
Powerpack	1255
Fuel tank (2 Nos)	500
Track (2 Nos)	722
Sprockets (2 Nos)	80.8
Idler (2 Nos)	70.4
Final drive (2 Nos)	158

Natural frequencies of the military-tracked vechicle

No.	Frequency (Hz)
	1.2449
2	2.4300
3	2.8670
4	5.5858
5	8.1648
	8.8341
	12.1500
8	13.1190
9	14.0680
10	14.6180
11	18.7920
12	21.1460
13	21.7530
14	25.0400
15	25.5280
16	26.1550
	26.8740
18	27.6070
19	28.4810
20	28.6700
21	29.0870
22	29.6890
23	29.9380
24	30.3290
25	30.7820

4. FREE VIBRATION ANALYSIS

The military-tracked vehicle is subjected to vibration excitation from various sources, the major contributors being the terrain undulations, the rotating wheel, the track assemblies, the driveline and the engine. Ride performance is also influenced by the incidental variations in the vehicle components, firing of ammunition from the vehicle, hitting of ammunition on the vehicle body, etc. Experimental studies have shown[8] as many as 25-identifiable vibration modes that potentially affect the ride performance. Hence, an eigenvalue analysis has been done using accelerated sub-space iteration and 25-natural modes of vibration have been obtained (Table 2). Figs 3(a) – 3(g) show some of the typical modes of vibration. It could be noted that natural freqyency of the vehicle in the bounce, pitch and roll modes are 1.245 Hz, 2.43 Hz and 2.867 Hz, respectively. These modes are dependant on the suspension system. Figs 3(b) – 3(g) indicate the higher modes which are structural modes. These modes are essential especially when dealing with structural responses due to impact situations, wherein higher modes participate in overall response. Modes 5,6 and 7 [shown in Figs 3(c) and 3(d)] indicate higher structural modes in which the top plate is vibrating. Mode 8 shown in Fig. 3(d) is the mode in which side plate is vibrating. Modes 9 and 10 are the modes, wherein the vehicle front top and bottom plates (near the engine) are vibrating.

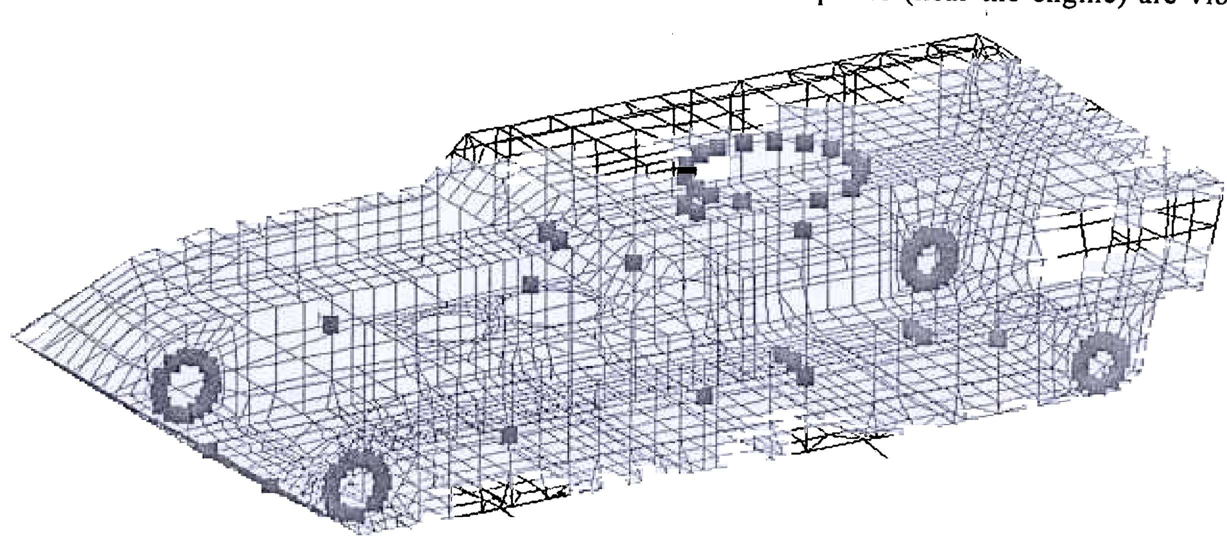

Figure 2. Finite element model of military-tracked vehicle; total number of nodes: 2506; total number of DOFs: 14,966

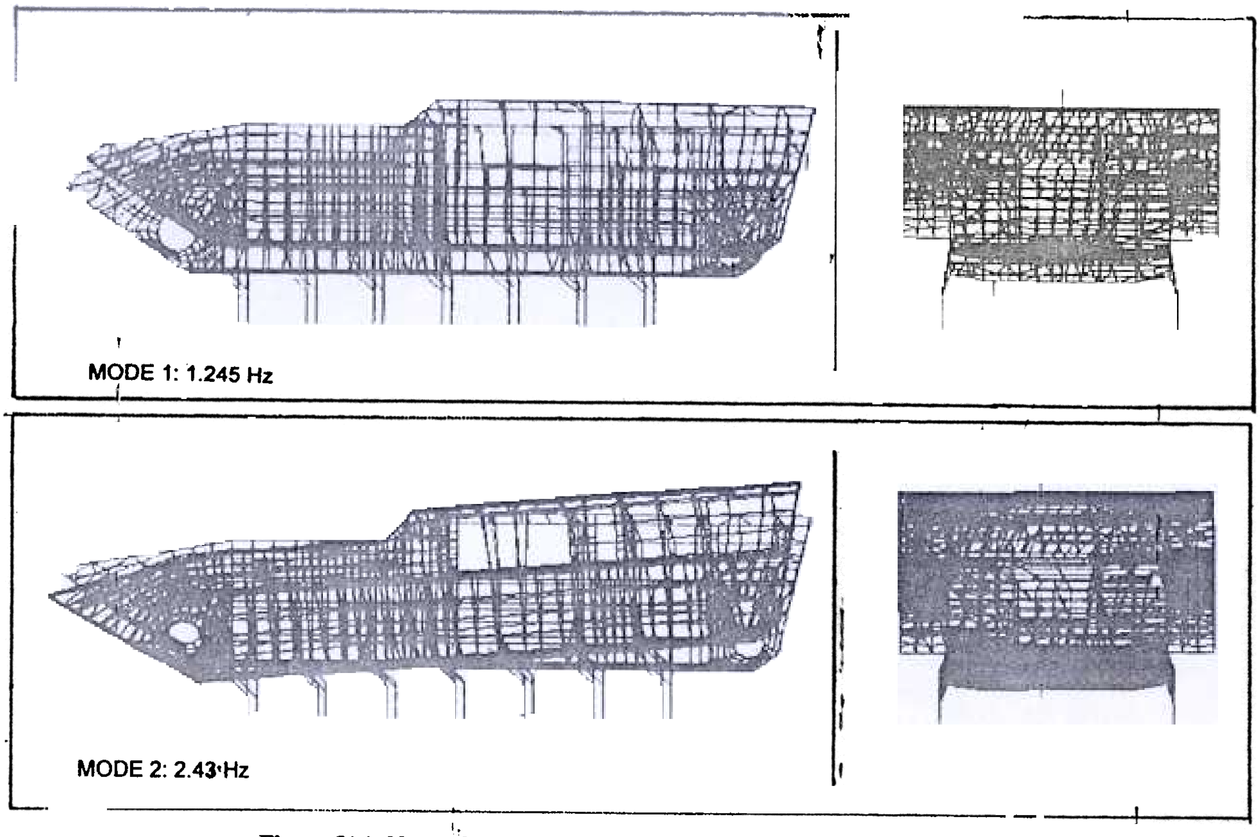

Figure 3(a). Natural modes of vibration of the military-tracked vehicle

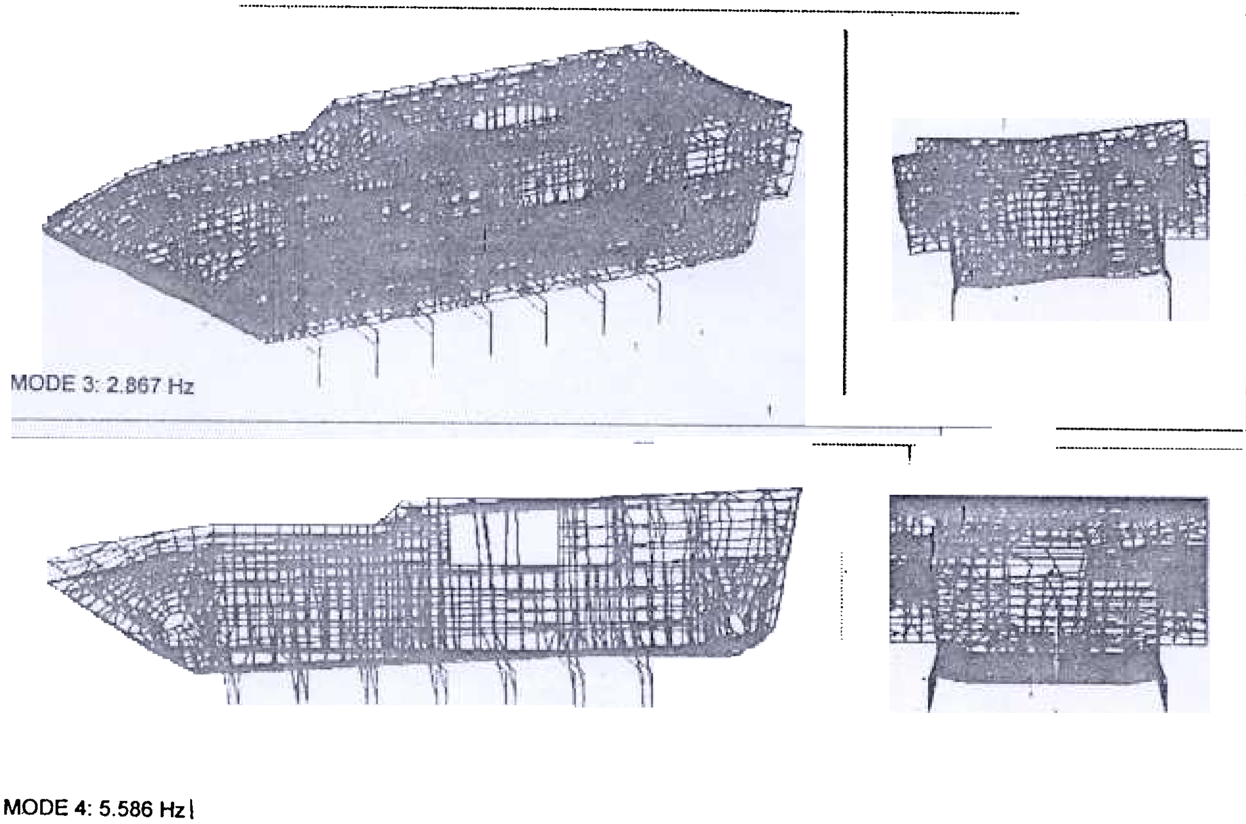

Figure 3(b). Natural modes of vibration of the military-tracked vehicle

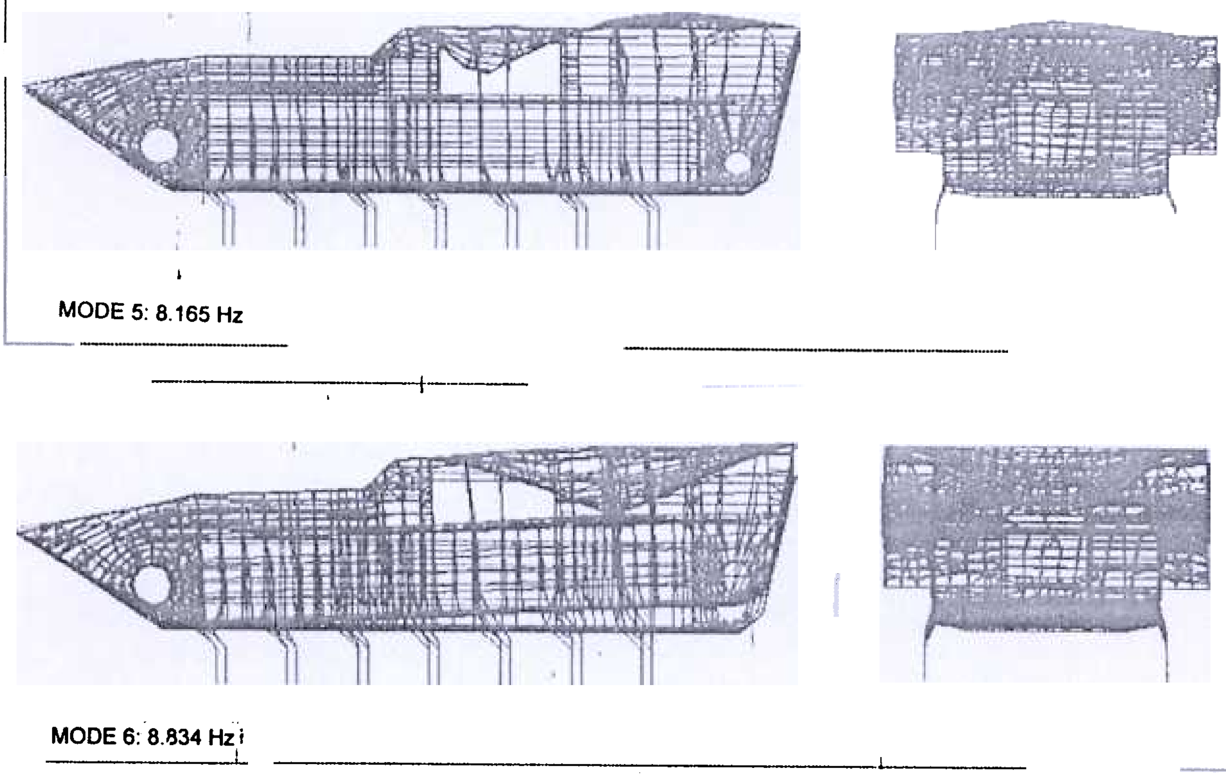

Figure 3(c). Natural modes of vibration of the military-tracked vehicle

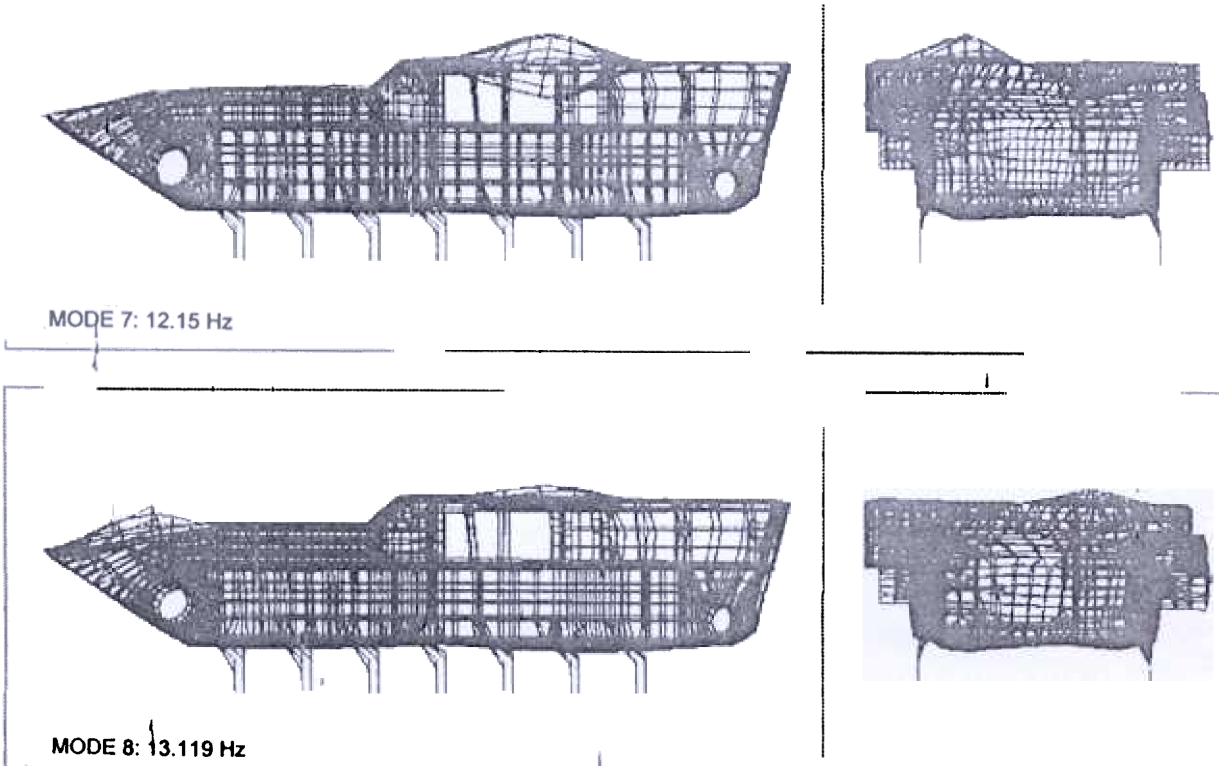

Figure 3(d). Natural modes of vibration of the military-tracked vehicle

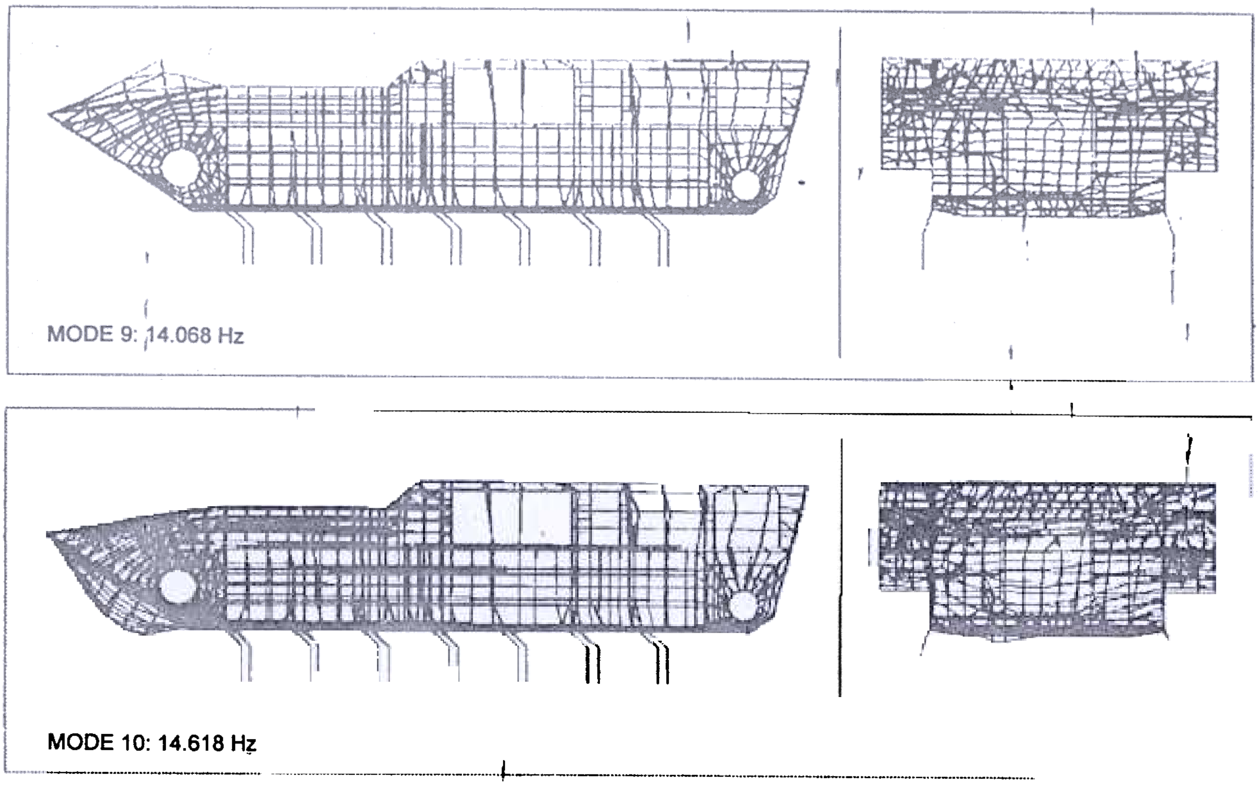

Figure 3(e). Natural modes of vibration of the military-tracked vehicle

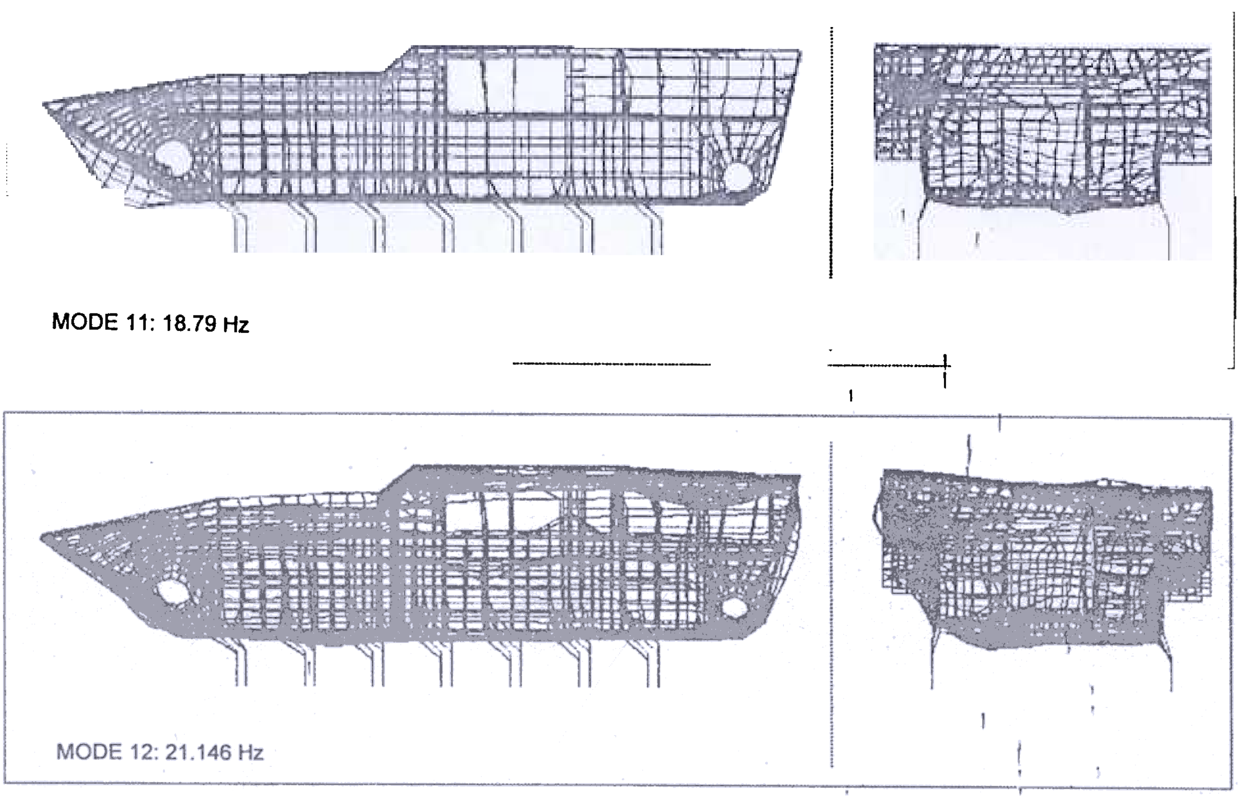

Figure 3(f). Natural modes of vibration of the military-tracked vehicle

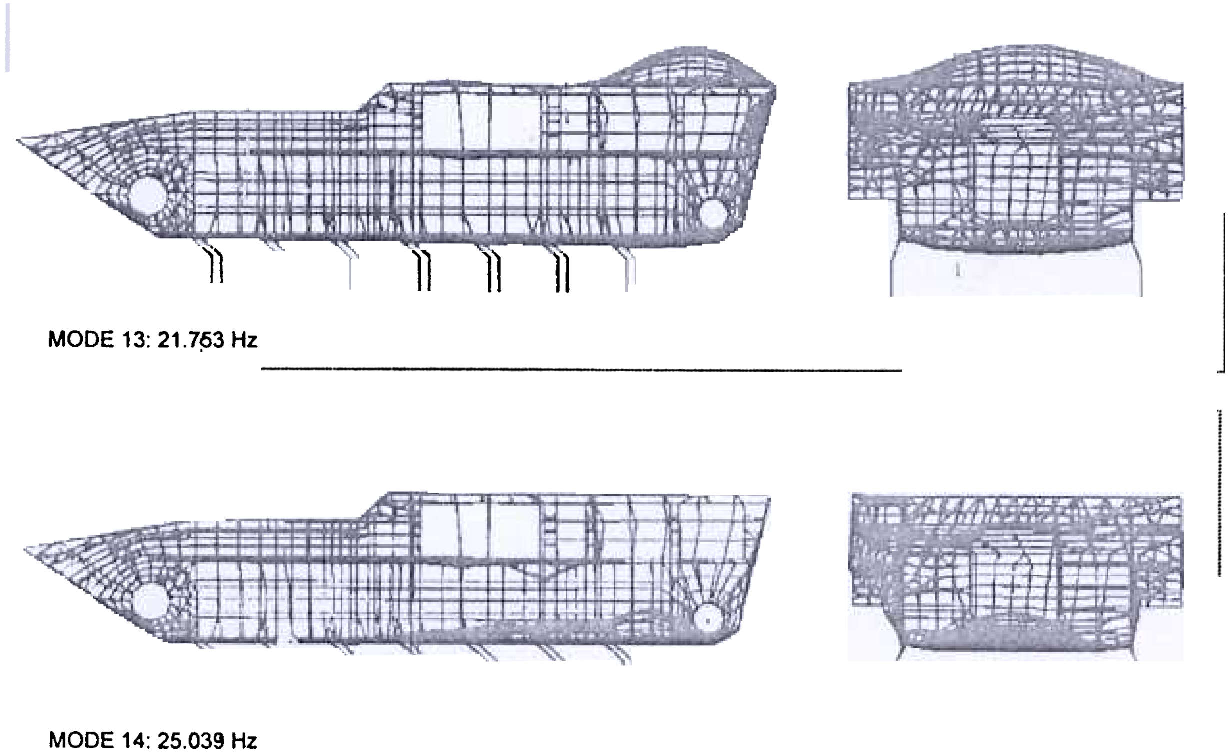

Figure 3(g). Natural modes of vibration of the military-tracked vehicle

Figs 3(f) and 3(g) show the modes 11, 12, 13 and 14 which are complex structural higher modes.

5. TRANSIENT DYNAMIC ANALYSIS

The ride dynamics of the tracked vehicle when it moves over a sinusoidal bump of 100 mm height and 200 mm length (Fig. 4) at 40 km/hr has been studied by carrying out a transient dynamic analysis, using implicit Newmark beta method[9]. The integration parameters are $\beta = 0.3025$ and $\gamma = 0.6$. The time-step used for the analysis is 0.0015 s. The initial displacement, velocity and acceleration were assumed to be zero. Damping is neglected and number of equations used for the transient dynamic analysis are 13,722. Figure 5 shows the motion of the topdeck location near turret-slewing ring. It could be noted from the figure that there is no displacement for fraction of second, since the vehicle has not reached the obstacle and is 1.5 m away. It could be observed that there is superposition of two oscillations in each displacement. High frequency, low amplitude oscillation is due to local structural vibration, and low frequency, high amplitude oscillation is due to overall vehicle motion. *Ux*, *Uy* and *Uz* displacements represent the bounce, pitch and roll motions of the vehicle, respectively. Small traces of *Uz* oscillation (roll) is due to the offset between the right and left bogie wheel of each suspension station. Figure 6 shows the acceleration levels near the turret-slewing ring. The maximum acceleration level in the vertical direction (bounce) is 5010 mm/s^2 (i.e. 0.511g).

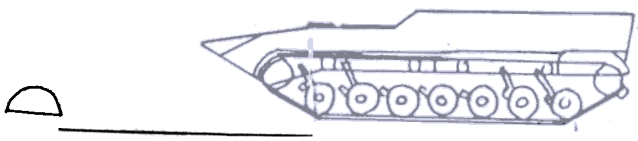

Figure 4. Details of the bump

Similar results are given for the 4^{th} torsion bar centre location in Figs 7 and 8. It could be noted that the bounce acceleration level is 22,500 (i.e. 2.29 g). The deflection and acceleration levels near the powerpack mounting are as given in Figs 9 and 10,

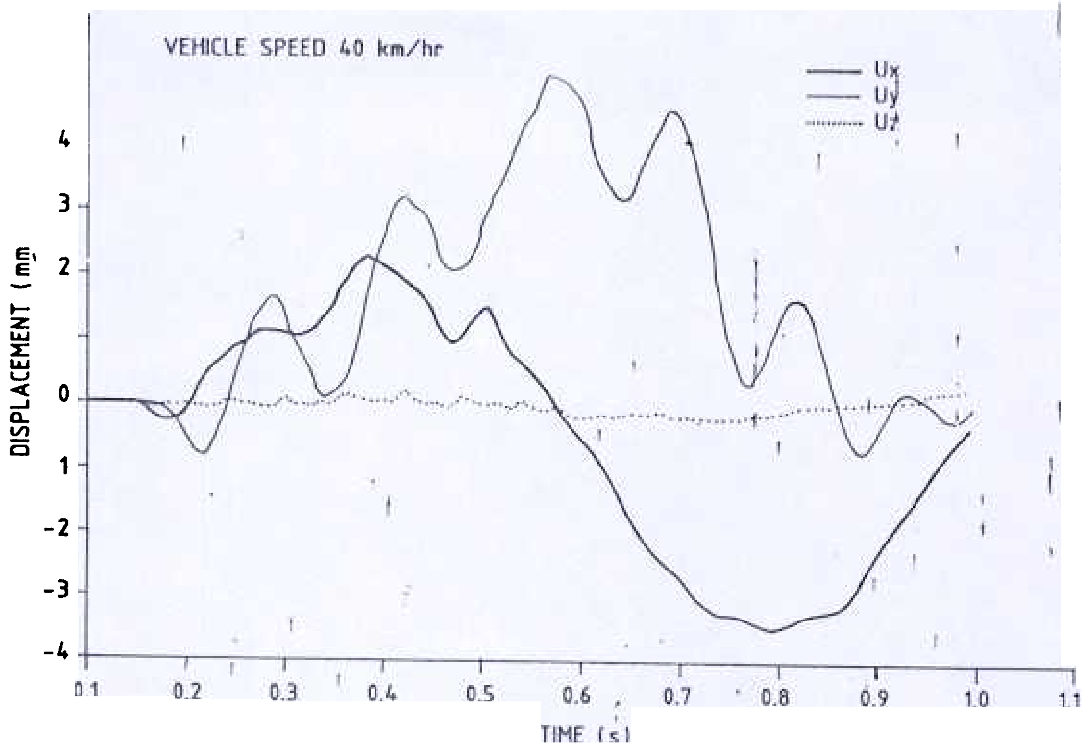

Figure 5. Displacement near slewing ring

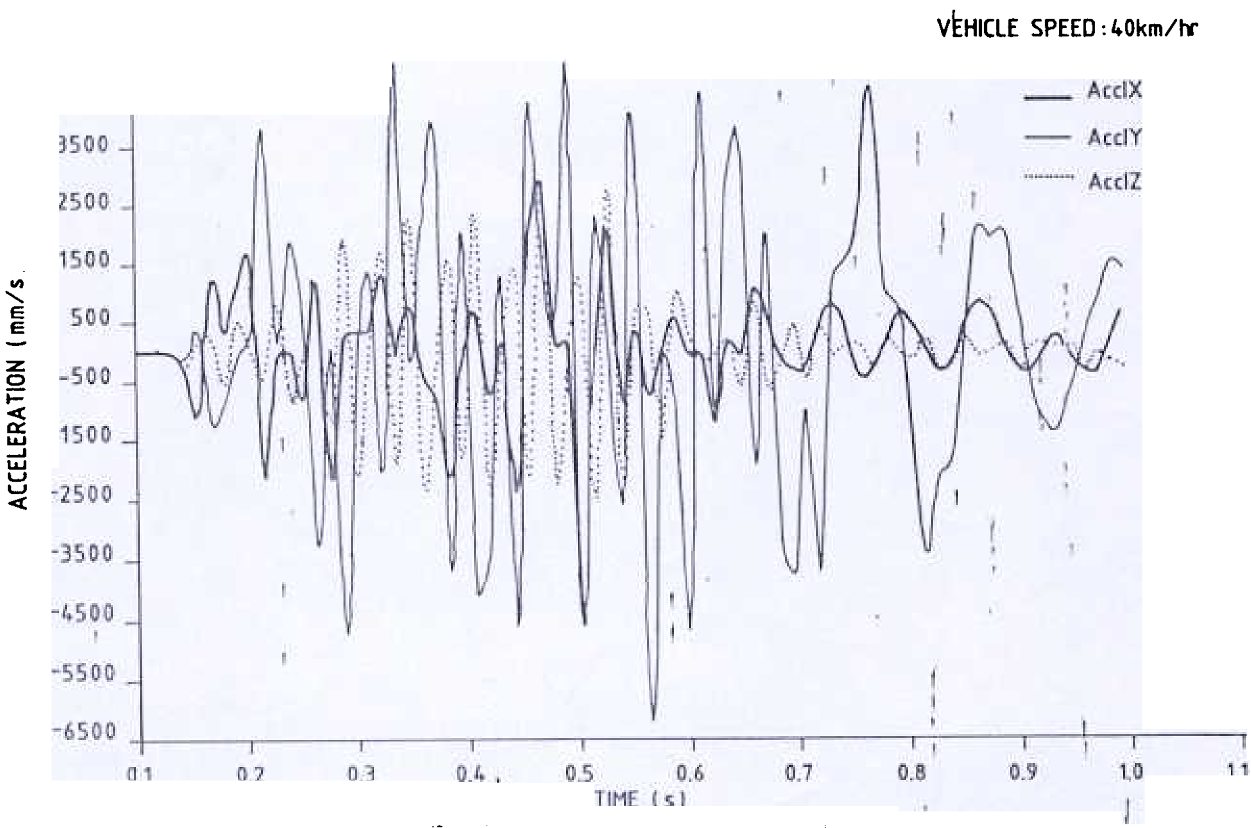

Figure 6. Acceleration near slewing ring

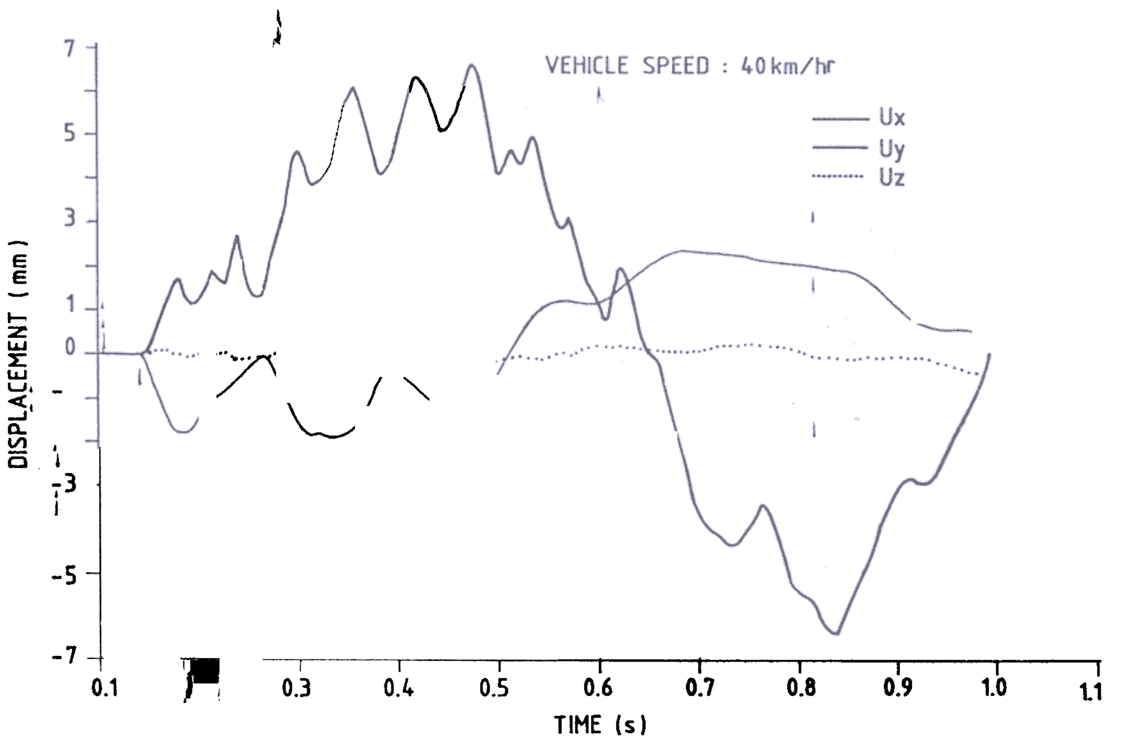

Figure 7. Displacement near the 4[th] torsion bar centre

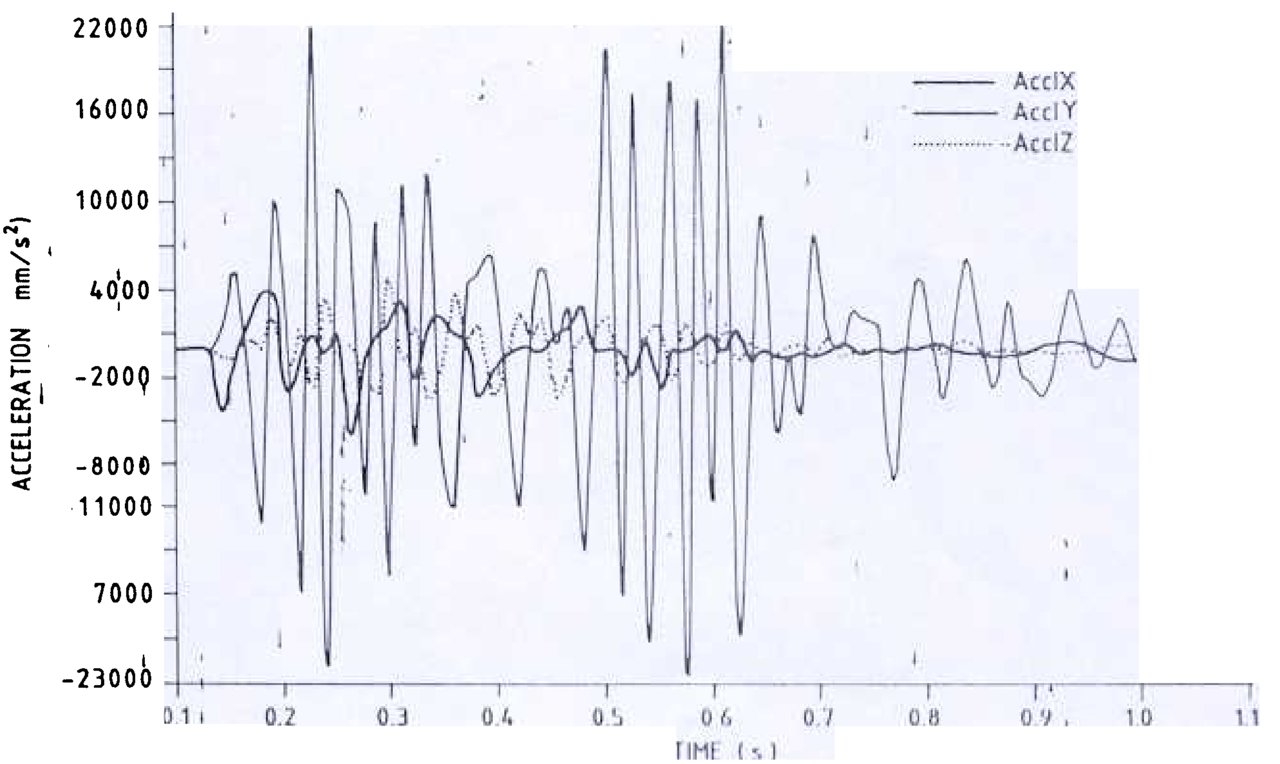

Figure 8. Acceleration near the 4[th] torsion bar

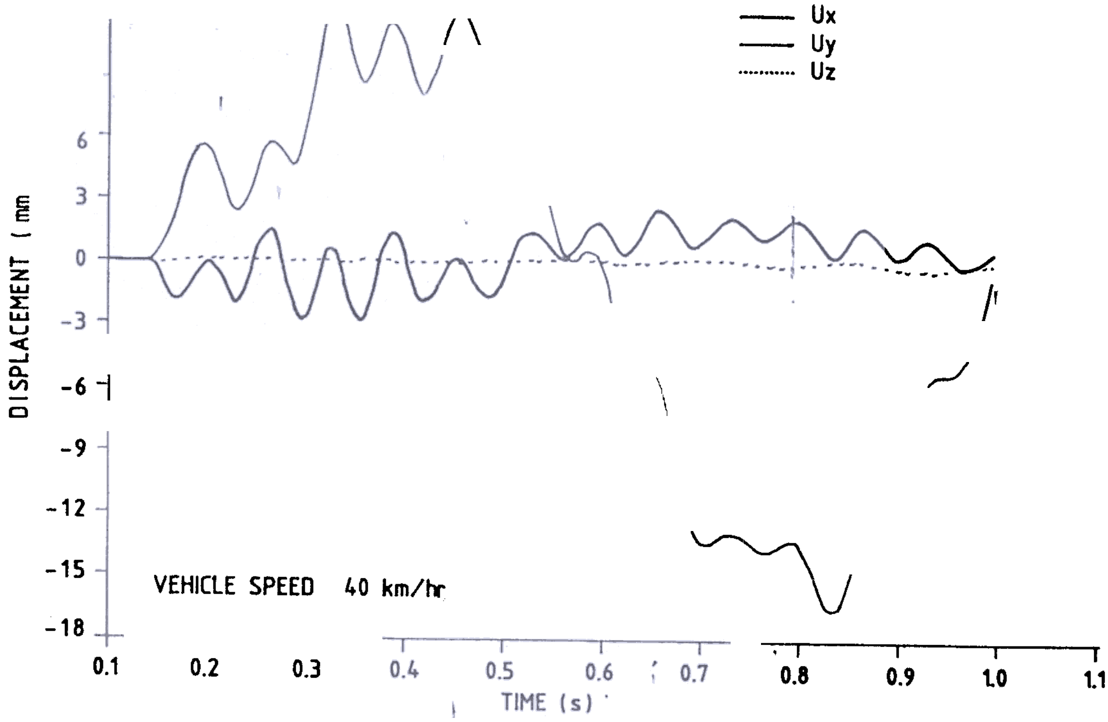

Figure 9. Displacement near the powerpack mounting

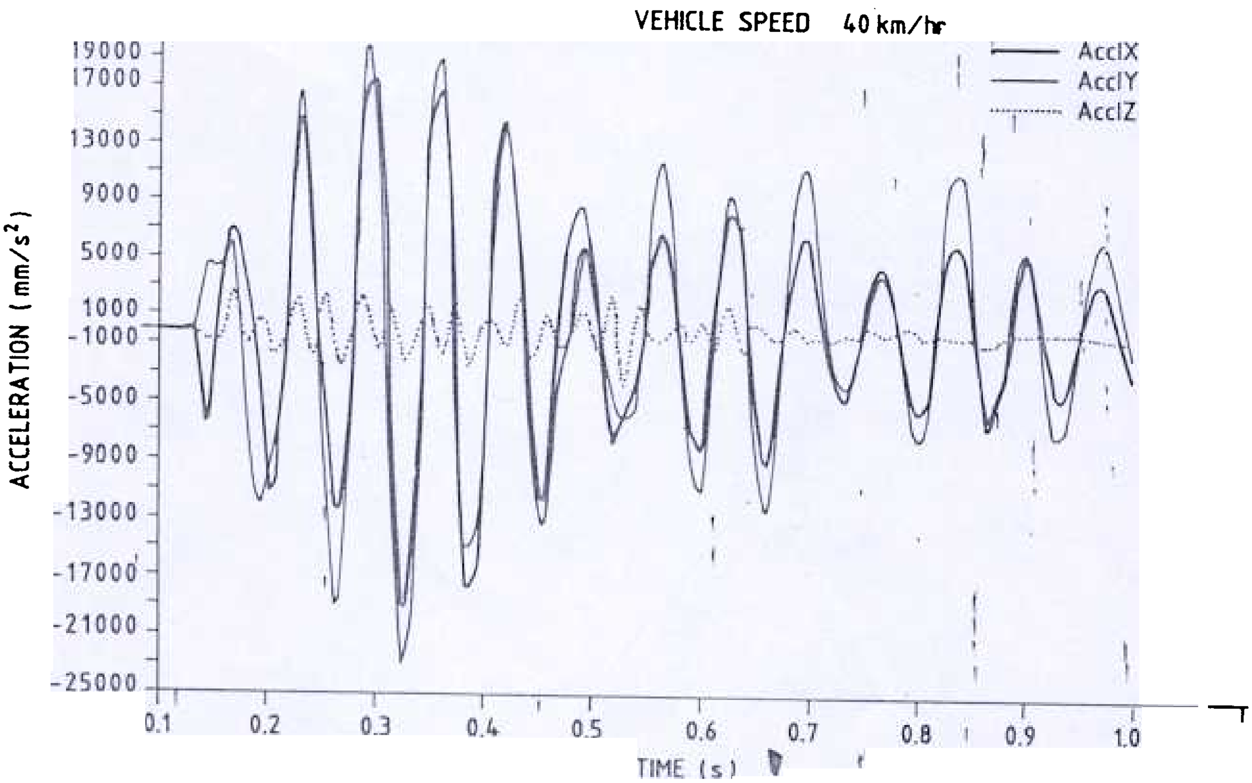

Figure 10. Acceleration near the powerpack mounting

respectively. The maximum acceleration level in the vertical direction (bounce) is 23,000 mm/s^2 (i.e. 2.34 g).

6. CONCLUSION

A finite element simulation model has been developed to investigate the vibration and ride dynamic characteristics of a typical medium weight, high-speed military-tracked vehicle negotiating a non-deformable terrain at constant speed. This model could be utilised for detailed ride dynamic study when the vehicle negotiates random cross-country type of terrain and for optimisation studies using different types of suspensions.

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