A 3-DIMENSIONAL DYNAMICS MODEL FOR GENERATING TRACKED VEHICLE SEISMIC SIGNALS

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ABSTRACT

The U.S. Army Corps of Engineers is developing a capability to simulate seismic signatures of moving armored vehicles. To generate vehicle specific signatures, these high-fidelity simulations require vehicle-generated forces acting on the earth's surface at the vehicle. We present a description of customized enhancements to commercially available dynamic analysis software known as DADS (Dynamic Analysis Design System, LMS-CAE, Coralville, Iowa). The customizations simplify creation of a 3-D dynamics model of a tracked vehicle, particularly its suspension. A GUI interface facilitates creation and layout of suspension elements, the creation of the basic track block, and the proper positioning of track block links at the initial configuration of the vehicle. Our first application of this modeling capability is to an M1 tank. Our output data are time histories of the track/ground forces at all points of contact between the track and the deformable soil. We present sample output from a simulation of variable speed straight-ahead driving. Simulations conducted to-date include constant and variable speed driving and cornering on high and low-friction surfaces.

1.0 INTRODUCTION

The development of unattended battlefield sensor systems is currently being supported by the creation of high-fidelity simulations of the seismic signals that propagate from moving tracked armored vehicles.[1] These simulations require realistic representations of the force distributions applied to the ground at the vehicle track, which are determined by the vehicle sprung and unsprung mechanical properties, track suspension configuration, soil type, and vehicle motion (speed, acceleration, turning rate, etc.). Detailed 3-dimensional mechanical models that account for these factors are needed in order to accurately define the dynamic interaction (and resulting forces) between track and ground.

Several vehicle dynamic models were examined to evaluate their suitability for generating tracked vehicle input forces for seismic simulations. VEHDYN-II[2], a 2-dimensional model used primarily for ride quality studies, accounts for inertial, stiffness and damping characteristics of the sprung and unsprung elements of a tracked vehicle. Track tension is included in VEHDYN-II, but the track is treated as a continuous element, and the interactions between individual road wheels and track blocks are not represented. This includes the transition of a rolling road wheel from one track block to the next, which is believed to contribute to the seismic signature of a tracked vehicle. Soil properties are also not represented in the model, and it lacks the 3-dimensional depiction desired for high-

[1] Moran, M., Ketcham, S., and Greenfield, R., "Three Dimensional Finite-Difference Seismic Signal Propagation", Proceedings of the 1999 Meeting of the MSS Specialty Group on Battlefield Acoustics and Seismics, 1999.
[2] Creighton, D.C., "Revised Vehicle Dynamics Module: User's Guide for Computer Program VEHCYN-II", U.S. Army Corps of Engineers, Waterways Experiment Station, Vicksburg, MS, Tech. Report No. SL-86-9, 1986.

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fidelity seismic signature generation. A model used by the U.S. Army Tank Automotive Command known as TRACKDYNE[3] contains detailed treatments of the mechanical interactions between a track block and the road wheels and ground, but like the previous model, is 2-dimensional in nature. Another model developed for the U.S. Army, TRAXION[4], also provides a detailed treatment of the dynamic properties of vehicle and track. Its usefulness was demonstrated in an exploratory study of the seismic signatures generated by a single track of a dual-track vehicle[5]; it is capable of representing both tracks as well. TRAXION only deals with vehicles moving at constant speed however. A commercial multi-body dynamics software tool known as DADS (Dynamic Analysis Design System, LMS-CAE, Coralville, Iowa) is currently being used by the U.S. Army Tank Automotive Command and the U.S. Army Engineering Research and Development Center to model wheeled and tracked vehicles, and other mechanical systems. The current version of DADS includes a “Track” Super Element that enables one to construct a vehicle with road wheels, idler and drive sprocket constrained within a continuous track loop. Like VEHDYN-II however, the DADS Track element does not model the interactions between an individual track block and road wheel. It would be possible to accomplish this in DADS without using the Track Super Element, but the development time required to create the large number of track block bodies and force elements needed would be inordinately high. It would also be difficult to initially assemble the track blocks properly in the model. The developers of DADS (LMS-CAE) recently addressed this problem by developing a specialized front-end graphical user interface (GUI) to streamline the tasks of developing track block and track suspension designs. It also automates the tasks of reproducing and initially positioning track block elements at the start of a simulation.

1.1 DADS MULTI-LINK TRACKED VEHICLE MODELING ENHANCEMENT

The specialized DADS multi-link tracked vehicle modeling GUI emphasizes the design and creation of the suspension and track assemblies, with the rest of the vehicle (i.e., hull and turret) being represented as a single sprung mass with user-specified mass, center of gravity and principal moments and products of inertia. A series of menus query the user for inputs related to the suspension and track. One pertains to the layout of suspension elements (number of road wheels, support rollers, etc.) (Figure 1). Others pertain to the dimensional, inertial and mechanical properties of components common to the suspension and track (road wheel, road arm, support roller, idler, track tensioner, sprocket, track block) (Figure 2). Armored tracked vehicles primarily employ torsion-bar suspensions, so this suspension type is assumed for any vehicle model built using the GUI. For vehicles employing struts in addition to torsion bars, the former is added outside the GUI using the standard DADS[6] Translational Spring-Damper-Actuator Contact Force element (TSDA).

Figure 1. Vehicle Suspension Layout menu.

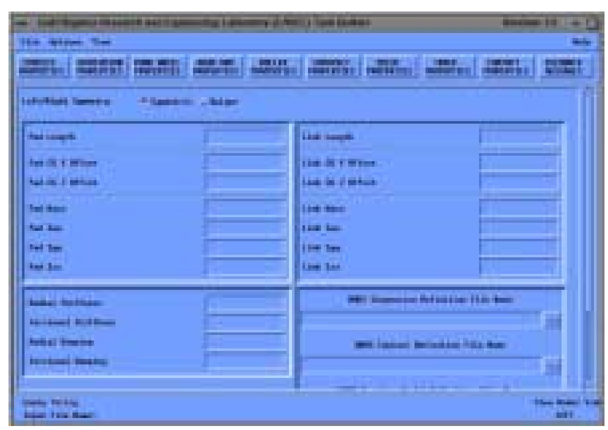

Figure 2. Track Block Properties menu.

[3] Hoogterp, F.B., "Track Dynamics: A New Age," Proceedings of the Summer Computer Simulation Conference, Baltimore, MD, July 1991.
[4] Galaitsis, A.G. “TRAXION: A Model for Predicting Dynamic Track Loads in Military Vehicles”, Transactions of the ASME, Vol. 106, April, 1984.
[5] Coney, W. and A.G. Galaitsis, “Exploratory Predictions of Tracked Vehicle Seismic Signatures”, BBN Technologies, 10 Moulton Street, Cambridge, MA, August, 1998.
[6] DADS Version 9.5 On-Line Documentation and User’s Guide, LMS-CAE, 2651 Crosspark Road, Coralville, IA 52241, 2000.

Four basic track block geometries are currently handled within the advanced GUI: one dual-pin configuration and three single-pin configurations (Figure 3). The former is accommodated using the standard DADS Revolute-Revolute joint (two revolute joints separated by a fixed distance). By utilizing this type of joint instead of two separate revolute joints, the need to represent each pin connector as a separate body is avoided. This results in a large reduction in the total number of bodies required by the model. Single pin configurations are accommodated using standard revolute and bushing elements in DADS. The enhanced GUI automatically reproduces the basic track block created, correctly initially positioning each track block to produce two complete track assemblies.

Forces resulting from the interaction between a track block and a road wheel, roller, sprocket or idler are computed using the DADS Point-Segment contact element. This element models forces that occur between a pair of objects when they collide. One body is designated the "point" body, and the second is designated the "segment" body. The point body is a sphere with radius comparable to the principal dimension of the first object (such as the rolling radius of a wheel), while the segment body is a curved element based on the actual surface geometry of the second object. Contact surface normal force is calculated from the depth of penetration of the first body into the second, and its relative normal velocity. Tangential force is calculated based on the relative tangential velocity. Stiffness and damping properties for the contacting bodies are specified by the user. Forces resulting from interactions between the track blocks and ground are computed using the DADS "Point-Ground" contact element. This element is similar to the Point-Segment contact element, except that the segment body is replaced by a "ground" body. Normal and tangential responses are calculated from a soil subroutine based on a modified set of Bekker[7] soil equations. Figure 4 illustrates how track pad and road wheel contact surfaces are represented using the point-segment approach.

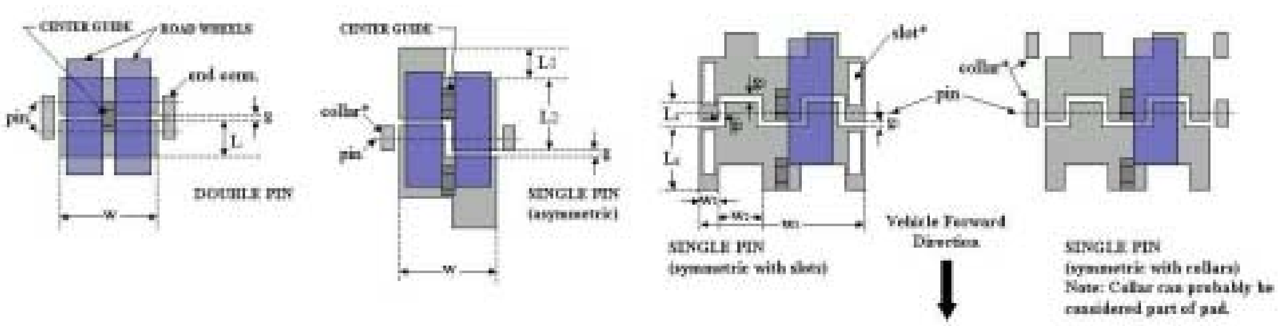

Figure 3. Four basic track block configurations handled within the DADS tracked vehicle GUI.

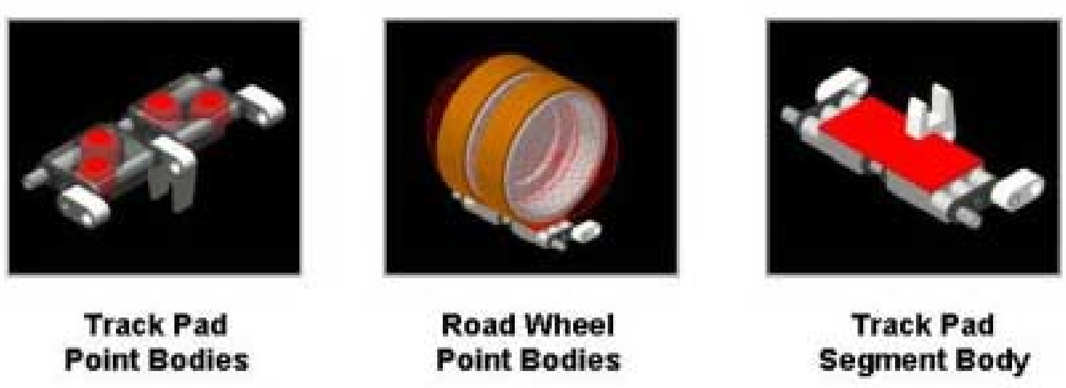

Figure 4. DADS Point-Segment contact force element "Point" and "Segment" bodies.

[7] Bekker, M.G., *Introduction to Terrain-Vehicle Systems*, Ann Arbor, MI, University of Michigan Press, 1969.

1.2 INITIAL APPLICATION OF DADS MODELING ENHANCEMENT

The new multi-link tracked vehicle modeling utility in DADS is initially being applied to the development of a seismic signature model for an M1A1 tank. Personnel at the U.S. Army Tank Automotive Research and Development Center (TARDEC) provided design inputs for the model.[8] A DADS visualization of it is shown in Figure 5; Figures 6 and 7 show close-ups of the track, road wheel and idler. The M1A1 uses a tensioned dual-pin track. Track tension is established by manually adjusting the length of a tensioner strut on the vehicle. A modeled track tensioner is shown in Figure 7. The correct lengths for the modeled struts were determined using a simple simulation of the vehicle settling onto the ground. The length of each strut was increased during the simulation until a strut compressive load was achieved that matched a TARDEC furnished value for the M1A1.

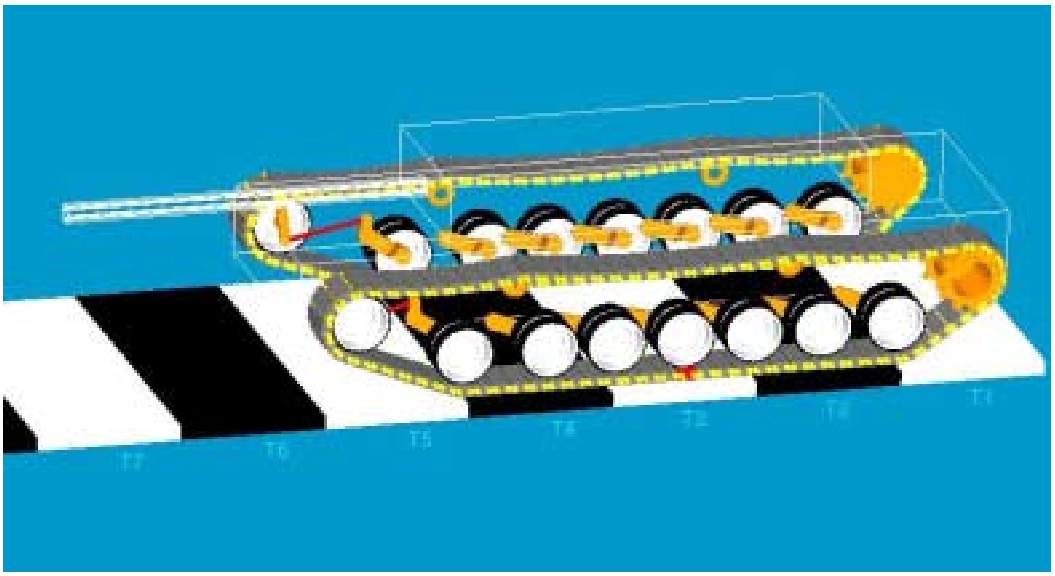

Figure 5. DADS M1A1 tracked vehicle seismic model.

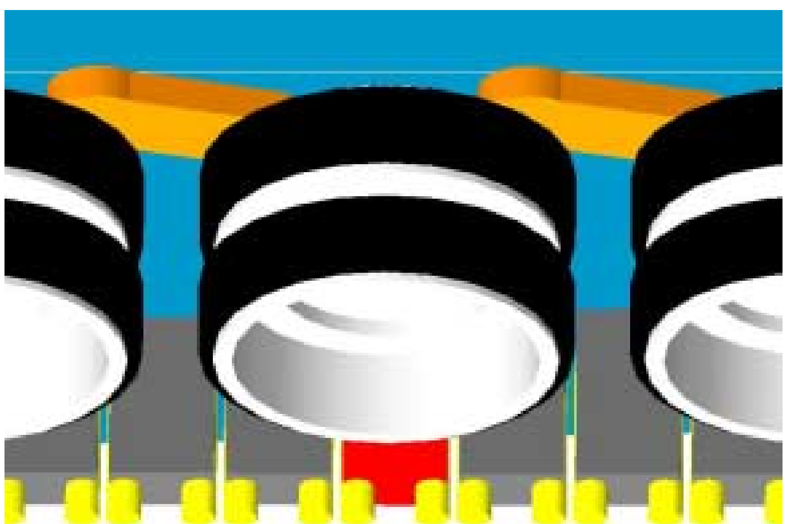

Figure 6. Close-up view of road wheels in DADS M1A1 seismic model.

[8] Kovnat, A.R., Personal communication, TARDEC, Warren, MI, May, 2000.

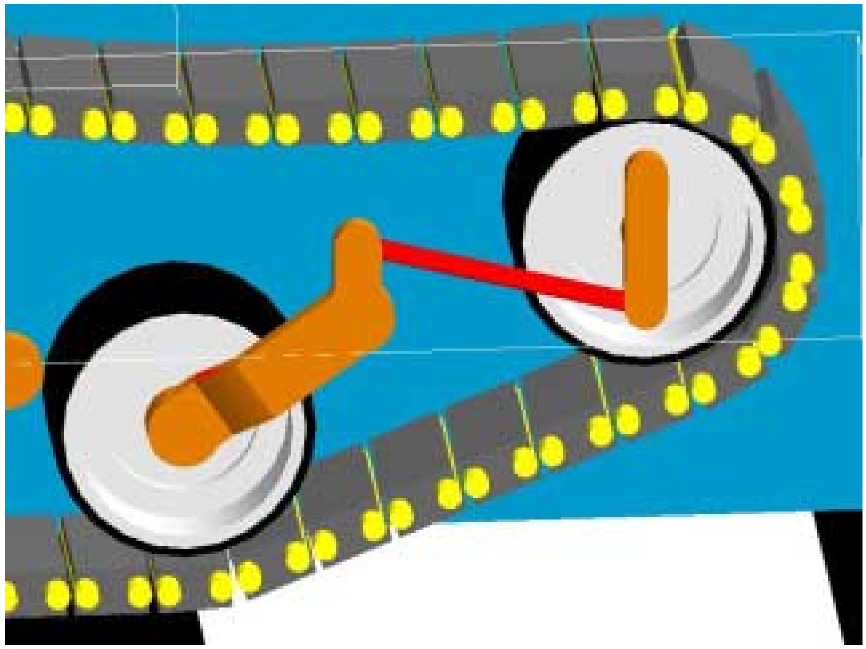

Figure 7. Close-up view of idler and track tensioner in DADS M1A1 seismic model.

Figure 8 illustrates the level of detail that is incorporated into the shape of the drive sprocket to achieve realistic interactions with the track block pins and pin connectors. Point-Segment force elements are utilized here, as elsewhere in the model, to define interaction forces. Point bodies are defined at the ends of each pin connector, while a segment body is defined for the sprocket, based on its surface contour. Vehicle steering and speed control are achieved by regulating input torques to the drive sprockets. This is accomplished using standard DADS Control elements.

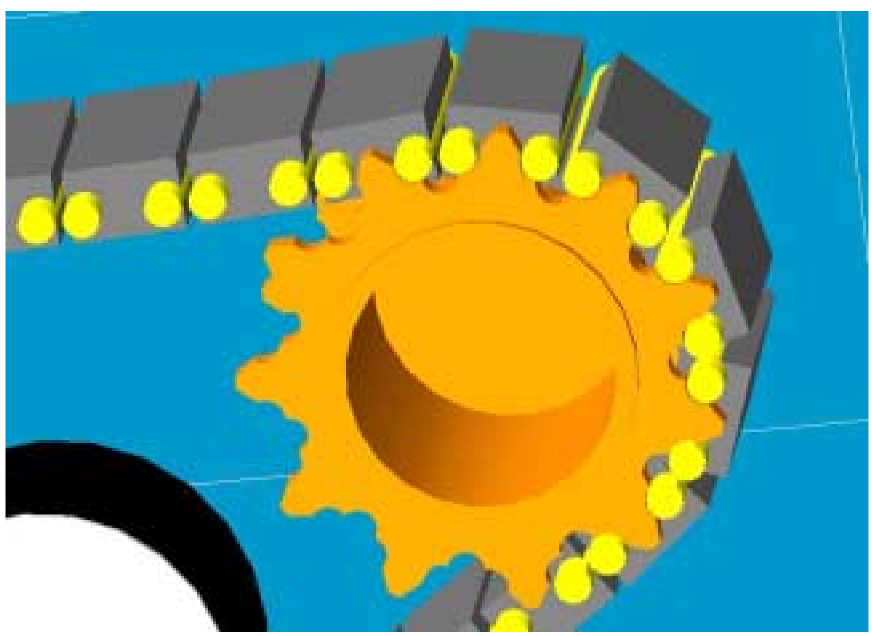

Figure 8. Close-up view of drive sprocket in DADS M1A1 seismic model.

Although it is not visually represented in the model, an additional force element segment body exists at each track block. This is the track center guide. This segment body interacts with the two point bodies assigned to each "pair" of wheels that make up a road wheel or idler assembly. Interaction forces tend to keep the center guide between the wheel pair. The net effect of all the center guides is proper alignment of the track on the vehicle.

1.3 PRELIMINARY SEISMIC FORCE PREDICTIONS

Just prior to going to press, the following simulations were conducted using the M1A1 seismic model.

M1A1 Simulations Conducted To-Date

1. Straight ahead acceleration from rest to 32 km/hr on a firm "ice-like" slippery surface (coefficient of friction = 0.1)
2. Straight ahead driving on the same slippery surface at constant speeds of 16, 32 and 48 km/hr.
3. 32 km/hr lane change maneuver on the same slippery surface.
4. Straight ahead driving at constant speed (32 km/hr) on 3 surfaces (dry pavement, clay and sand).

A general discussion of the results from these simulations is not presented here, as the material has yet to be analyzed. A single example of model output is provided instead. Figure 9 shows time histories of the normal and shear forces into the ground by a single track block during the "straight ahead acceleration" simulation. Each "spike" corresponds to the passage of a road wheel over the track block. Vehicle acceleration is apparent from the closer spacing of the spikes over time.

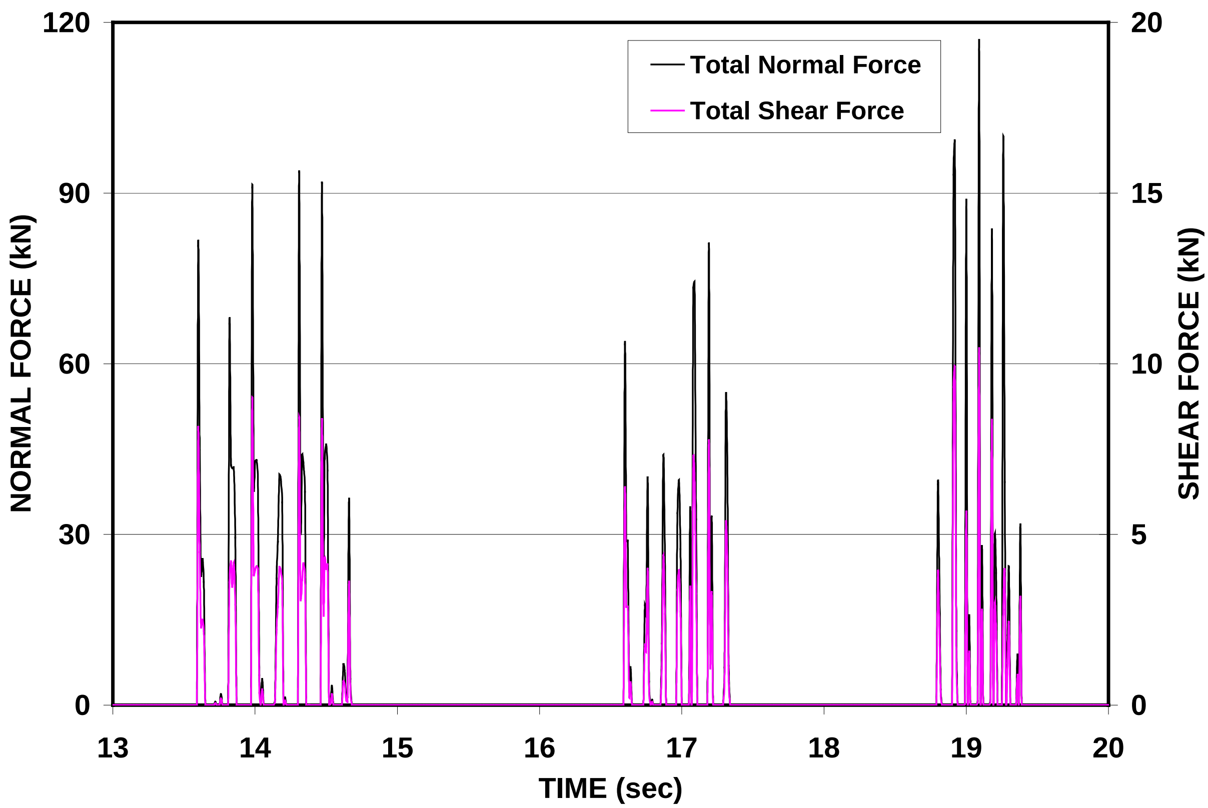

Figure 9. Predicted ground forces from a single track block for an accelerating M1A1 tank.

1.4 SUMMARY

A customized GUI has been added to the commercial dynamic analysis software package DADS to simplify creation of military tracked vehicle models suitable for seismic analyses. These models emphasize details within the track and suspension elements, and treat the hull and turret as a single rigid body. Suspension layout inputs are specified by the user in the GUI, as are dimensional, inertial, stiffness and damping properties of common suspension elements (road wheel, road arm, idler, sprocket, support roller and track block). Four different track block configurations are handled by the GUI, which automatically reproduces and positions individual track blocks to create entire track assemblies. The ground forces generated by each track block are defined using a modified set of Bekker soil equations.

1.5 FUTURE PLANS

Future plans include improving the customized GUI by adding the capability to calculate aggregate seismic forces within different sections of the vehicle footprint. They also include conducting simulations of M1A1 drawbar pull tests to generate vehicle traction forces for different driving conditions. These results will be compared against measured data to verify soil algorithms used in the model. Where possible, controlled vehicle tests will also be conducted to verify other aspects of the model. Once verification is complete, additional vehicle models will be created for use in seismic propagation simulations.

1.6 ACKNOWLEDGEMENTS

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