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Soft soil track interaction modeling in single rigid body tracked vehicle models

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ABSTRACT

Single rigid body models are often used for fast simulation of tracked vehicle dynamics on soft soils. Modeling of soil-track interaction forces is the key modeling aspect here. Accuracy of the soil-track interaction model depends on calculation of soil deformation in track contact patch and modeling of soil resistive response to this deformation. An algorithmic method to calculate soft soil deformation at points in track contact patch, during spatial motion simulation using single body models of tracked vehicles, is discussed here. Improved calculations of shear displacement distribution in the track contact patch compared to existing methods, and realistically modeling plastically deformable nature of soil in the sinkage direction in single body modeling of tracked vehicle, are the novel contributions of this paper. Results of spatial motion simulation from a single body model using the proposed method and from a higher degree of freedom multibody model are compared for motion over flat and uneven terrains. Single body modeling of tracked vehicle using the proposed method affords quicker results with sufficient accuracy when compared to those obtained from the multibody model.

1. Introduction

Mathematical models are used extensively in studying and predicting dynamics of tracked vehicles. In these models, basic track dimensions, mass and inertia of vehicle are considered as a single rigid body with its 6 motion degrees of freedom (DOF); and external interaction forces on it are modeled. Thus results from the simulation are motion coordinates of the single rigid body and the interaction forces, for a given input controlling the motion. Single rigid body models are used when only these results are of interest (Kitano et al., 1988; Ferretti and Girelli, 1999; Hong et al., 2009; Al-Milli et al., 2010). The single rigid body assumption is a major simplification; here the accuracy of modeling the interacting forces is of much importance.

Modeling of soil track interaction forces is the key modeling aspect in single rigid body models. Within these, most important are traction forces and support reaction from terrain. For hard terrains, the mechanism of generation of traction is friction. Knowledge of slip velocity, friction coefficient and normal force acting is sufficient to calculate soil track interaction forces on hard terrain (Kitano and Kuma, 1977). When the terrain is soft, considerable sinkage of vehicle into terrain occurs. This is treated as a spatial motion case with the rigid body having all 6 DOF (Murakami and Watanabe, 1992). The mechanism of generating traction here is soil resistance to shear deformation. Points in the track contact patch have different magnitudes of shear deformation imparted on them, corresponding to the varying durations for which they are being sheared and shearing rates they are subjected to. This distribution of shear deformation magnitudes at different points in track contact patch must be known to calculate the corresponding traction available. The support reaction from soil is due to the soil resistance to compression resulting from the sinkage of track. Thus magnitude of shear displacement and level of sinkage experienced at a point in soil are the soil deformation quantities of interest to calculate traction and support forces on soft soil. Calculation of soft soil deformation, in spatial motion simulations using single rigid body model of tracked vehicles, is the specific research problem addressed in this work.

Once the deformation imparted by the track to terrain is known, knowledge of resistive forces offered by soil in response to this deformation is required to calculate the corresponding soil track interaction forces. Calculation of soil track interaction forces in dynamic simulations thus involves two distinct aspects. These are calculation of deformation imparted by the track to terrain, and a model representing the resistive response of terrain to this

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deformation. The existing relations based on Bevameter technique (Wong, 2009) are used to model soil response to deformation in the soil track interaction models discussed here. Modeling of soil response to deformation is a research area of its own, and is not a research problem addressed in this work.

Fig. 1 shows the shear displacement distribution in track contact patch, calculated by various methods in existing single body models in literature. Variation of shear displacement along the Center line of track is shown in the figures. Direction of motion of vehicle and direction of turning is also mentioned. *L* represents track contact length in the figures and point *C* in Fig. 1(b) denotes longitudinal position of instantaneous Center of rotation during the turn.

The dashed line in Fig. 1(a) shows longitudinal shear displacement distribution for steady state straight line motion case. In this case, the distribution is varying linearly along the length of track, increasing from zero at the front end of track to a maximum at the rear (Wong, 2009). For any given longitudinal position on track contact length, the distribution is constant along the width. Thus a complete description of shear displacement distribution over the entire contact area of track is being calculated in this case.

Wong and Chiang (2001) discuss planar steady state turning motion on firm ground. The mechanism of traction is considered to be shear displacement by Wong and Chiang (2001). Dashed line in Fig. 1(b) shows the shear displacement distribution in lateral direction of track during steady state turning calculated by Wong and Chiang (2001). Here shear displacement under a point on the track is calculated by integrating the slip velocity experienced by that point for the time duration from beginning of its contact. Lateral shear displacement distribution over the complete track contact area is calculated by Wong and Chiang (2001). Al-Milli et al. (2010) uses the general theory of skid steering by Wong and Chiang (2001) to formulate a traversibility predictor based on traction requirement for steady state turning of a particular radius.

Ferretti and Girelli (1999) discuss a dynamic model of shear displacement under track for simulating dynamic motion cases. A partial differential equation (PDE) describing the variation of shear displacement with respect to longitudinal position on track and time is derived. Assuming a linear distribution of shear displacement along the length of track, this is reduced to an ordinary differential equation (ODE); representing the dynamics of a single mean value of shear displacement along length of track. Here the longitudinal traction force alone is assumed to be from shear resistance of soil, hence shear displacement in lateral direction of track is not calculated.

Solis and Longoria (2008) extend the differential equation method proposed by Ferretti and Girelli (1999) to capture shear displacement distribution under the track in a distributed sense over the track contact length. The track is divided into segments in the longitudinal direction and PDE governing shear displacement distribution is reduced to ODE corresponding to each segment, assuming a linear distribution within it. The differential equation method is extended to calculate shear displacement in the lateral direction of the track too. Solid line in Fig. 1(a) shows the longitudinal shear displacement and solid line in Fig. 1(b) shows the lateral shear displacement distribution calculated by Solis and Longoria (2008). The shear displacement distribution is assumed to be constant along the width of the track, for a given longitudinal position in track contact length. This assumption is realistic only in the case of straight line motion. For turning motion case the actual shear displacement distribution will be varying along both length and width dimensions of the track.

The supporting reaction from soil is a function of sinkage of vehicle into the soil. The loading of terrain in sinkage direction is not always monotonously increasing in nature. During motion of track over a point on soil, the terrain will be subjected to loading, unloading and reloading cycles. Also there exists the possibility of intermediate loss of contact due to unevenness of terrain. Wong (2009) discusses response of terrain in repetitive loading in sinkage

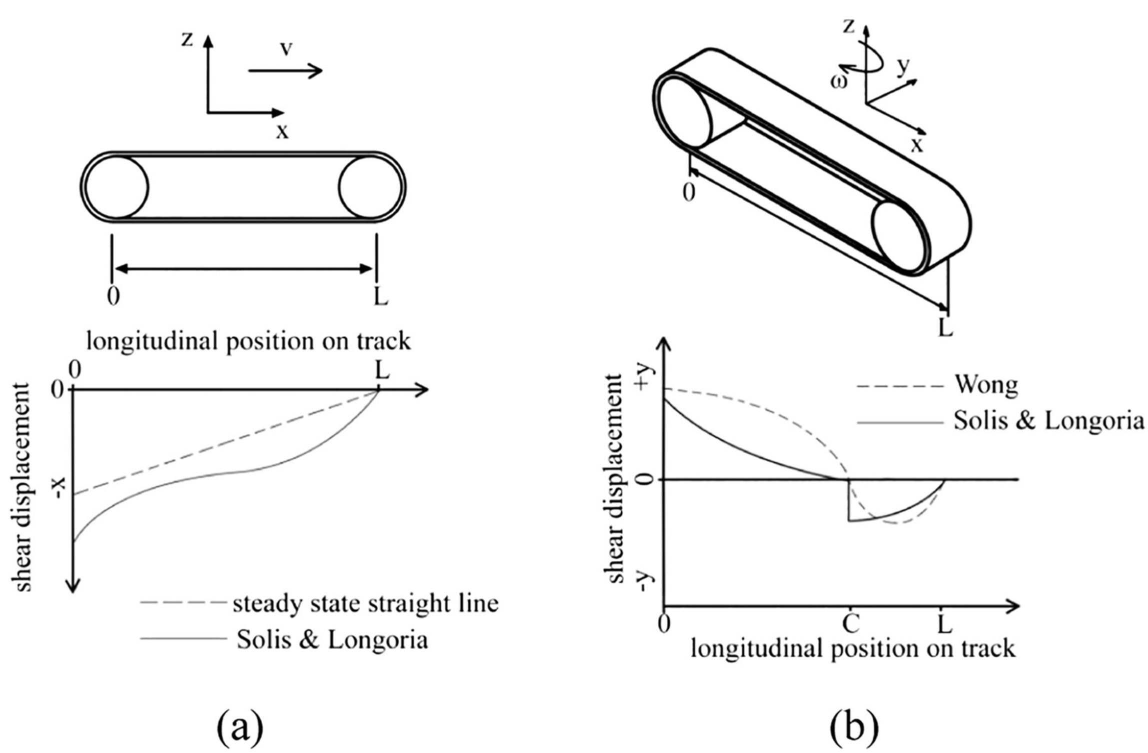

Fig. 1. Shear displacement distribution in track contact patch.