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Mobility algorithm evaluation using a consolidated database developed for wheeled vehicles operating on dry sands

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Abstract

A substantial number of laboratory and field tests have been conducted to assess performance of various wheel designs in loose soils. However, there is no consolidated database which includes data from several sources. In this study, a consolidated database was created on tests conducted with wheeled vehicles operating in loose dry sand to evaluate existing soil mobility algorithms. The database included wheels of different diameters, widths, heights, and inflation pressures, operating under varying loading conditions. Nine technical reports were identified containing 5253 records, based on existing archives of laboratory and field tests of wheels operating in loose soils. The database structure was assembled to include traction performance parameters such as drawbar pull, torque, traction, motion resistance, sinkage, and wheel slip. Once developed, the database was used to evaluate and support validation of closed form solutions for these variables in the Vehicle Terrain Interface (*VTI*) model. The correlation between predicted and measured traction performance parameters was evaluated. Comparison of the predicted versus measured performance parameters suggests that the closed form solutions within the *VTI* model are functional but can be further improved to provide more accurate predictions for off-road vehicle performance.

Keywords: Mobility; Sand; Drawbar pull; Motion resistance; Sinkage; Vehicle Terrain Interface (*VTI*); Database

1. Introduction

There is a need for studies on the tire-soil properties, in relation to vehicle characteristics, to support a better understanding of wheeled vehicle performance in coarse grained soils. Acquisition of an off-road vehicle is based, in part, on the maximum slope grade negotiable in loose soils. The maximum slope grade negotiable is directly related to the maximum drawbar pull (*DBP*) that a vehicle can develop on level terrain (Freitag and Knight, 1962). Wheel design is a primary factor in the traction performance of a vehicle contributing to ability to negotiate slopes and soft soils. For example, larger tires experience greater traction (T) with more surface area, but the weight of the tire may increase sinkage (z) and motion resistance (MR) at the tire-soil interface (e.g., Sharma and Pandey, 2001; Ani et al., 2012). The vehicle performance is primarily influenced by traction and motion resistance forces.

Finite difference models (e.g., Karafiath and Nowatzki, 1978; Creighton et al., 2009) and closed formed solutions (e.g., Bekker, 1951; Priddy, 1999; Vong et al., 1999) have

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been developed for relating vehicle/terrain mechanics. The NATO Reference Mobility Model (NRMM) (Vong et al., 1999; Ahlvin and Haley, 1992) and the Virtual Autonomous Navigation Environment (VANE) (Jones et al., 2007, 2015) have been used extensively for developing vehicle specifications to support off-road vehicle acquisition. As part of NRMM and VANE, the Vehicle Terrain Interface (*VTI*) model was developed to provide a practical alternative to support virtual prototyping of off-road vehicles. The *VTI* model is a high-resolution model for the prediction of forces and displacements at the traction-terrain element interface (Jones et al., 2007). The *VTI* model is a series of lumped parameter algorithms that define the performance of wheeled or tracked vehicles operating in a straight line or steered mode, on ridged or flexible materials (Rohde et al., 2009).

Data sets representing vehicle performance are used to assess the accuracy of soil mobility algorithms such as those defined in the *VTI* model. Substantial amounts of vehicle performance tests have also been conducted since 1974 (e.g., Freitag and Knight, 1962; Leflaive, 1966; Turnage, 1972) to support evaluations and modeling for vehicle acquisition and other purposes, and this data has been used to verify or further enhance the closed formed solutions contained in NRMM and *VTI*. A substantial number of tests have been conducted in the laboratory and field to assess the pulling potential of various wheel designs. While a tremendous amount of data has been reported in the literature, there is no consolidated database which includes a considerable portion of the data collected at government, university, and private laboratories. Such a database can provide an excellent source for further verifying and improving the accuracy of existing soil mobility algorithms.

In this study, a consolidated database was created from reports on tests conducted with wheeled vehicles operating in loose dry sand. The database included wheels of different diameters, widths, heights, and inflation pressures, operating under varying loading conditions. Nine technical reports were identified, including 5253 records based on existing archives of laboratory and field tests for wheels operating on sands. The database created in this study was used to evaluate the performance and accuracy of the *VTI* closed form solutions for several performance parameters such as drawbar pull, traction, motion resistance, and sinkage.

2. Vehicle performance parameters

Fig. 1 illustrates the general aspects of vehicle performance for non-steered (Fig. 1a) and steered (Fig. 1b) wheeled vehicles. The tire forces, ground forces, average cone index in the first 15 cm depth of soil (CI_{0-15}), failure zones (forward and backward), and stress distributions along the vertical plane of travel are illustrated in Fig. 1a for a non-steered wheel (Priddy, 1999). The major (σ_1) and minor (σ_3) principal stresses, as well as the normal (σ_n) and shear (τ) stresses along the oblique plane of travel, are illustrated in Fig. 1b for a steered wheel (Karafiath and Nowatzki, 1978). The lateral slip angle (α) and lateral force (L_F) are also illustrated in Fig. 1b, where α represents the steering angle oblique to the vertical plane of the wheel and the instantaneous velocity vector of the vehicle/wheel and is indirectly defined as:

$$\alpha = \tan^{-1}\left(\frac{V_y}{V_x}\right) \tag{1}$$

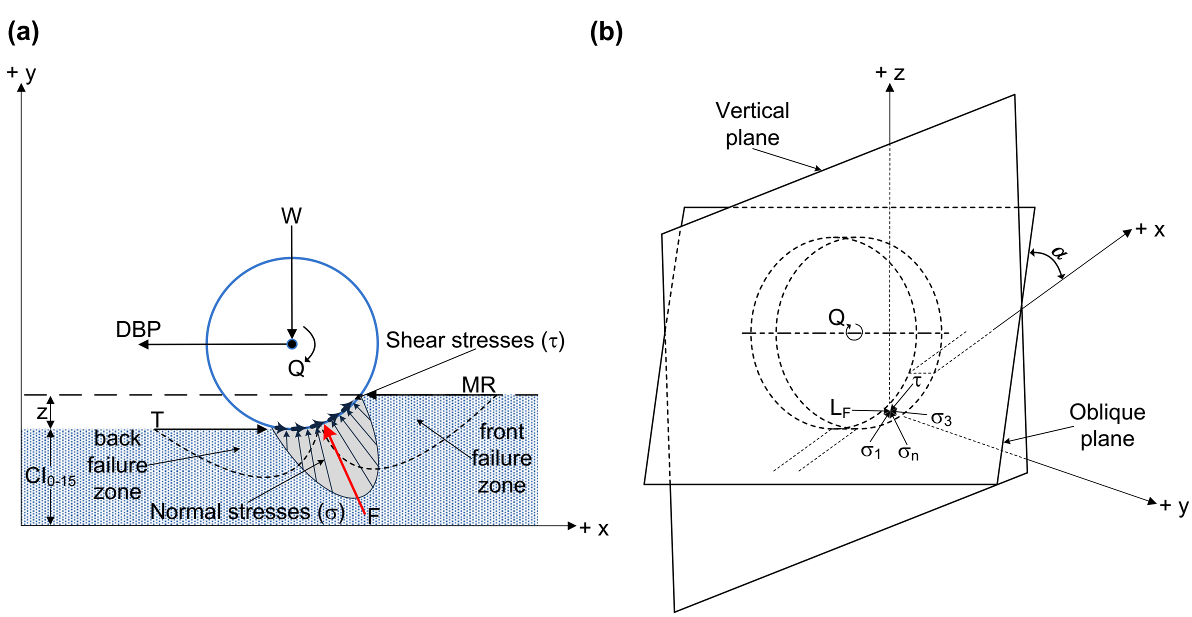

Fig. 1. Coordinate system and vehicle performance parameters: (a) tire forces, ground forces, and stress state for a non-steered wheel and (b) lateral slip angle for a rigid steered wheel operating along the vertical and oblique planes of travel.