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The shearing edge of tracked vehicle – Soil interactions in path clearing applications utilizing Multi-Body Dynamics modeling & simulation

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Abstract

Tracked vehicle – soil interactions were modeled and analyzed to compare the mobility of two notional path clearing implements pushed by a tracked vehicle. This exploration assesses the capabilities and limitations of the state-of-the-art in tracked vehicle dynamics modeling and simulation over soft-soil terrain. Unique modeling and simulation methods to stretch the capability of the current state-of-the-art contribute to the overall discussion. One path clearing implement was a roller and rake combination. The other was a quickly rotating flail system that cleared a definitive path by impacting and flinging the soil away. Geotechnical forcing functions implemented Coulomb's lateral earth pressure theory and Terzaghi passive soil failure models to compute the forces at the soft-soil – implement interfaces. Coulomb theory was reimagined to account for anomalies present when modeling the flail, mainly its arced motion and non-semi-infinite soil resistance zone. The path-clearing implements were simulated over discrete events and compared by means of load and acceleration time histories. The discrete events include side-slopes, grades, half-rounds, potholes, cross country terrain, and 'V' shaped ditches (V-ditch). Overall, the flail system experienced lower peak loads at the interface brackets and lower peak accelerations at the vehicle's center of gravity than the roller-rake system.
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Keywords: Terramechanics; Soft-soil mobility; Coulomb soil theory; Tracked vehicle mobility; Design comparison; Terzaghi passive soil failure; Flail route clearance implement; Roller-rake route clearance implement

1. Introduction

This study focuses on isolating and changing the path-clearing implement while keeping most other parameters constant to maintain scientific integrity. Of note, the notional tracked vehicle was constant. The tracked vehicle was designed with the abstract goal of going most places that people can go. The vehicle was thin enough to fit in most doorways, capable of going up most sloped terrain, and able to traverse cross country. The vehicle had a set power output limit, which may be distributed as necessary between the powertrain and the path-clearing implement. The sprocket, idler, and road wheel geometries were also held constant. The path-clearing implement and soil type were varied.

Fig. 1 highlights the differences between the path-clearing implements. The mobility of the combined vehicle and path-clearing device systems were compared. Discrete events were conducted over different types of soft soil. Events included half-rounds, potholes, grades, V-ditches, and cross country terrain.

To maintain the utility of the notional study for future specific designs, the extracted results were chosen so as to

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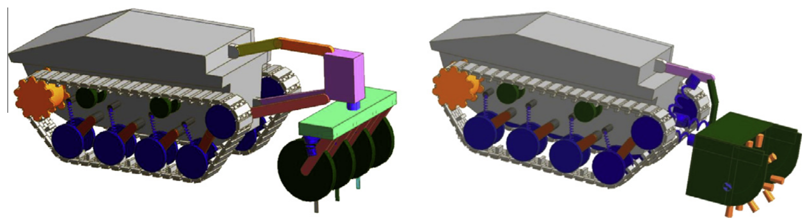

Fig. 1. Notional vehicle with a notional roller-rake (left) and a notional flail (right) path clearing implement attached.

serve as a universal comparison between the changing variables on any generic design. The study compares load and acceleration responses in order to guide design recommendations. The methodology presented herein for applying soft soil terramechanics is unique in its ability to enhance the existing capabilities of Multi-Body Dynamics (MBD) software. The study presented was performed using the RecurDyn MBD software package, although the presented soft-soil modeling techniques are applicable to any code that allows for custom expressions and/or functions.

2. Soft soil theory

The software used includes support for Bekker's pressure-sinkage soil model (FunctionBay, 2012), a linear approximation of soil rebound during unloading, and the Janosi and Hanamoto shear stress–displacement relationship (FunctionBay, 2012). The vehicle-terrain models supported by the software were not modified for the purpose of this study.

Of major importance for this study are the methods for modeling shear failure of the soil at the path-clearing implement-to-terrain interaction. The Mohr–Coulomb failure criterion is one of the most widely used and is the basis of this model. The failure criterion is shown in Eq. (1) (Wong, 2010):

$$\tau_{max} = c + \sigma \tan \varphi \tag{1}$$

where τ_{max} is the soils' maximum shearing strength, c is the cohesive strength of the soil, σ is the normal stress on the shearing surface, and φ is the soil's angle of internal friction (Wong, 2010).

Once this criterion is met in an idealized elastoplastic material, the surface provides no additional resistance as shear strain increases. This idealized elastoplastic assumption is not valid for all soil types, though it is suitable for modeling dry sand and clay (Wong, 2010). The passive soil resistance to a shearing surface, such as a rake, was derived in previous research (Wong, 2008) according to Eq. (2):

$$\sigma_p = \gamma_s z * N_\varphi + 2c * \sqrt{N_\varphi} \tag{2}$$

where $N_\varphi = \tan^2(45^\circ + \varphi/2)$, γ_s is specific weight of the terrain and z is the depth at the bottom of the failure region.

N_φ is known as the flow value and is related to the internal resistance of the terrain (Wong, 2010). When there is external pressure (q) acting on the surface of the terrain, Eq. (3) shows the passive failure stress (Wong, 2008).

$$\sigma_p = \gamma_s z N_\varphi + q N_\varphi + 2c\sqrt{N_\varphi} \tag{3}$$

2.1. Soft soil theory: rake

When passive failure is caused by a physical device, such as a rake, with width of the rake's blades (b) acting at a depth within the soil (h_b), Eq. (4) models the passive failure resistive force of the terrain onto the device (Terzaghi, 1943).

$$F_p = b * (0.5\gamma_s h_b^2 N_\varphi + q h_b N_\varphi + 2c h_b \sqrt{N_\varphi}) \tag{4}$$

Fig. 2 shows the fully developed failure pattern as a blade moves horizontally through the terrain (Wong, 2010). The slip line field is composed of parallel lines sloped to the horizontal, the direction of the major principle stress, at an angle of 45°–φ/2.

The Rankine Zone is the volume of resisting terrain under stress prior to plastic flow (failure) caused by expansion or compression of the soil (area ABC in Fig. 2) (Wong, 2010). In a fully developed failure pattern in a terrain of high internal friction, the Rankine Zone is very large compared to a terrain with low internal friction.

Eq. (4) above, using N_φ as the coefficient of passive failure, can oversimplify the problem since it relies only on the soil's internal friction, ignores the friction on the rake blade-soil surface, and assumes the rake blade is perfectly vertical and the terrain is perfectly flat. As discussed in detail in the following section, Coulomb theory captures these additional parameters, and through the use of modeling and simulation, the resistive forces are recalculated at every time step during the simulation based on the positions of the bodies. Eq. (5) models the passive earth coefficient K_p as calculated by Coulomb theory. Fig. 3 shows the geometric representation of the Coulomb theory terms (ω, β) and also shows the effect of the blade–soil interface friction angle (δ).

$$K_p = \frac{\cos^2(\varphi + \omega)}{\cos^2(\omega) * \cos(\delta - \omega)\left[1 - \sqrt{\frac{\sin(\delta+\varphi)*\sin(\varphi+\beta)}{\cos(\delta-\omega)*\cos(\beta-\omega)}}\right]^2} \tag{5}$$

K_p replaces N_φ in Eq. (4) to calculate the resultant passive failure resistive force, as shown in Eq. (6).