ORIGINAL ARTICLE

Influence of the Forward Speed in the Cutting Forces of a Vibrating Subsoiler

Influencia de la velocidad de avance en las fuerzas de corte de un subsolador vibratorio

https://cu-id.com/2177/v32n1e01

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ABSTRACT: In the present work, it is analyzed the behavior of the cutting forces (draft force and vertical force)of a vibrating subsoiler tilling a silt loam soil (ferralitic), by a soil-tillage interaction simulation model, developed applying the Finite Element Model and using the elastoplastic Drucker-Prager constitutive model and Solid Works design software. The soil parameters and properties required for simulation, the boundary conditions and acting loads were assigned to model and the meshing of the model was realized. Several running of the model were also realized for four forward speeds (0 ms^{-1}; 0, 4 ms^{-1}; 0, 8 ms^{-1} and 1, 2 ms^{-1}). The results showed the quadratic behavior of both forces with the increasing of forward speed.

Keywords: FEM, Draft Force, Simulation Model, Forward Speed.

RESUMEN: En el presente trabajo se analiza el comportamiento de las fuerzas de corte (tracción y vertical) de un subsolador vibratorio labrando un suelo arcilloso limoso (ferralítico), mediante un modelo de simulación de la interacción suelo-herramienta de labranza desarrollado aplicando el Método de Elementos Finitos, utilizando la forma lineal del modelo constitutivo elastoplástico de Drucker-Prager y el software de diseño Solid Works. Se asignaron al modelo las propiedades y parámetros del suelo requeridos para la simulación, se aplicaron las condiciones de frontera y cargas actuantes, así como fue realizada la discretización del mismo. Fueron realizadas, además, las corridas del modelo de simulación para cuatro velocidades de avance (*Vm*) distintas (0 ms^{-1}; 0,4 ms^{-1}; 0,8 ms^{-1} y 1,2 ms^{-1}). Los resultados mostraron el comportamiento cuadrático de ambas fuerzas con el aumento de la velocidad de avance.

***Palabras clave*:** MEF, fuerza de tracción, modelo de simulación, velocidad de avance.

INTRODUCTION

Soil tillage has always been a major research area in agriculture. As a tillage operation is a procedure for breaking up soil, soil failure depends mainly upon the soil properties, tool geometry and cutting speed (Abu & Reeder, 2003). The speed effects of the farming tool on the soil, both static and dynamic, and their influence in the cutting forces has been analyzed by several investigators (Ibrahmi *et al.*, 2015; Lamia *et al.*, 2020). The MEF has shown to be able to simulate different forms of farming tools and the dynamic effects of the forward speed (Abu & Reeder, 2003; Marín *et al.*, 2011).

The Finite Element Method (FEM) is a numerical technique for analyzing the complex engineering problems, especially for dynamic systems with large deformation and failure (Rosa & Wulfsohn, 2002). This method has been used by numerous researchers to analyze problems related to soil mechanics and the interaction between soil and tillage tools (Abo *et al.*, 2003; 2004; Gebregziabher *et al.*, 2007; Topakci *et al.*, 2010). However, for an accurate modeling of soil working implement, important physical and mechanical properties of soil should also be taken into account (Hesar & Kalantari, 2016).

The objective of this study is to analyze the prediction of the cutting forces behavior in the direction of forward movement of the farming tool (vibratory subsoiler), tilling a silt loam soil (ferralitic) with forward speed and work depth assigned, as well as physical and mechanical properties of soil (humidity, density) determined.

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Received: 12/06/2022

Accepted: 09/12/2022

MATERIAL AND METHODS

Model of Soil

The lineal form of the extended Drucker-Prager model, according to De la Rosa *et al.*(2016) was used to model (Fig.1). It was classified as an elastoplastic material, as a Rhodic Ferralsol according to Soil Survey Staff (2014); Oxisol according to Soil Survey Staff (2010) and Typical Red Ferralitic according to the third Genetic Classification of Soils in Cuba (Hernández *et al.*, 1999). According to their texture, it can be considered a clay very plastic loam, with 17% of sand, 36% silt, 47 clay% and organic matter content 2,58% (Herrera *et al.*, 2008b; 2008a). According to Naderi *et al.* (2013); Ibrahmi *et al.* (2017); Arefi *et al.* (2022), this model is the most appropriate for the soil material simulation, because it can be gauged by obtaining data from triaxial tests. The yield function of the Drucker & Prager (1952) model lineal is expressed as:

$$f(\sigma_1, \sigma_2, \sigma_3) = t - p\,.\,tan\beta c \quad (1)$$

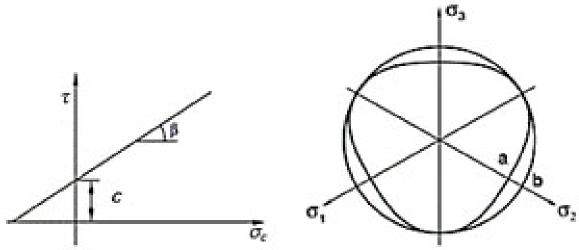

FIGURE 1. Yield surface and flow direction in meridional plane of extended linear Drucker-Prager model.

Properties and Soil Parameters

The elastic module (E) was determined as the tangent module to the effort-deformation curve of the soil in its right tract, obtained by Herrera *et al.* (2008b; 2008a) for this type of soil. The Poisson coefficient was determined by means of the equation:

$$\nu = \frac{E}{2 \times G} - 1 \quad (2)$$

The shear modulus G is determined by:

$$G = \frac{E}{2 \times (1 +)} \quad (3)$$

The properties or parameters required by the MEF model (Table 1) were obtained in the Laboratory of Soil Mechanics of the Company of Applied Investigations to Construction in Villa Clara (CAIC.VC).

Finite Element Model

It is formed by the farming tool (arm scarifier) which is treated as rigid body and the soil block (deformable in interaction with the arm scarifier). Both, the arm and the soil block were modeled using the design software *Solid Works* and its complement *Simulation*. The soil block dimensions were longitude (2 m), wide (1 m) and height (1 m). The soil block was considered isotropic and homogeneous, with movement restrictions for side, bottom and upper surfaces (Fig. 2a), to which confining pressures were applied. On the soil model, the gravity force and the atmospheric pressure act. It is accepted that the increase of the dimensions of the prism of cut soil beyond those assigned does not affect the cutting forces (Bentaher *et al.*, 2013; Marín & García de la Figal, 2019). The interaction soil-tool was modeled tangent to the attack surface of the tool, with contact model surface to surface. The general meshing of the model was carried out with a size of elements (e) maximum of 0,008 m, minimum size of 0,006 m and the Newton-Raphson iterative method was used. The surfaces in contact, both, of the tool and of the soil prism cut were modeled applying meshing control with size of elements of 0,004 m (Fig. 2b). The arm cuts the soil block to constant speed of 0, 65 ms^{-1} in the direction of the X axis, to a working depth of 0,

TABLE 1. Properties or parameters required by FEM model

Property or parameter	Symbol	Dimension	Source
Internal friction angle	φ	27,19 º	Herrera *et al.* (2015)
Elasticity module	E	104 272 kPa	Herrera *et al.* (2008)
Poisson coefficient	υ	0,44	Calculated
Bending stress	σ_f	693,2 kPa	González *et al.* (2014)
Cohesion	d	217,2 kPa	González *et al.* (2014)
Dilatancy angle	Ψ	13º	González (2011)
Shear Resistance	τ	40 kPa	Herrera (2006)
Shear module	G	1 793, 4 kPa	Calculated
Soil type	Lineal elástoplástico		
Soil-metal friction angle	δ	23,68º	Herrera *et al.* (2015)
Humidity	H	23,9 %	Herrera *et al.* (2008)
Density	ρ	1 200 $kg.m^{-3}$	Calculated

3 m and cutting wide 0,081 m. The soil cut slips above the surface of the tool after the fault.

RESULTS AND DISCUSSION

3D models have been developed using the MEF for the realization of both, dynamic analysis (Abo *et al.*, 2003; Mollazade *et al.*, 2010) and narrow farming tool behavior (Payne, 1956). Most of them have been used for slow tools and have not had into account the speed effects. For the analysis of the influence of the tool forward speed (*Vm*) on the soil cutting forces, the results were evaluated for four different speeds: 0 ms^{-1}; 0,4 ms^{-1}; 0,8 ms^{-1} and 1,2 ms^{-1} (Fig 3). Several runs of the simulation model were carried out, with the parameters in Table 1 and those that appear related in Table 2.

The analysis carried out showed the increase in a quadratic way, of both, the draft force (Fx) and the vertical force (Fy) with the increase of the forward speed (Fig. 4), which coincides with several authors as Onwualu & Watts (1998) and Wang *et al.* (2019).

CONCLUSSIONS

The cutting forces of soil, both, vertical and draft forces increase in a quadratic way with the increase of the forward speed, being the last one, the force with more magnitude.

The FEM has been able to simulate, in an appropriate way, the effects of the forward speed of the farming tool on the soil cutting forces.

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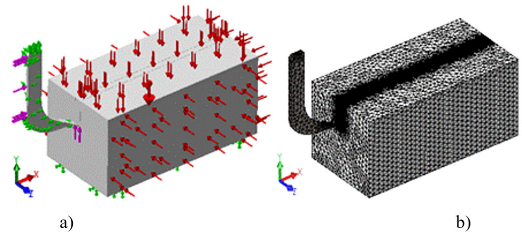

FIGURE 2. Finite element model: a) Boundary conditions b) Mesh of model.

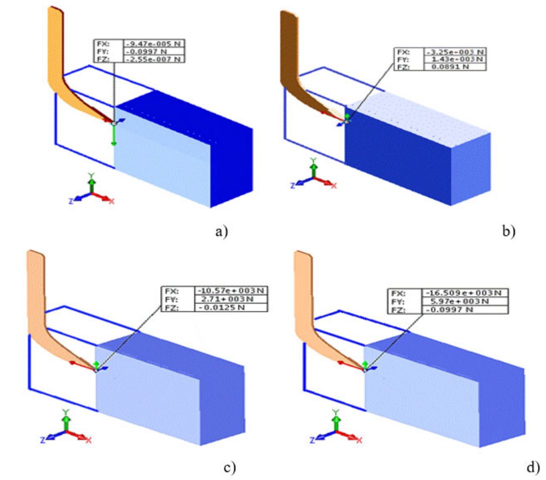

FIGURE 3. Soil cutting forces at different forward speed: a) *Vm* = 0 ms^{-1}; b) *Vm* = 0,4 ms^{-1}; c) *Vm* = 0,8 ms^{-1}; d) *Vm* = 1,2 ms^{-1}.

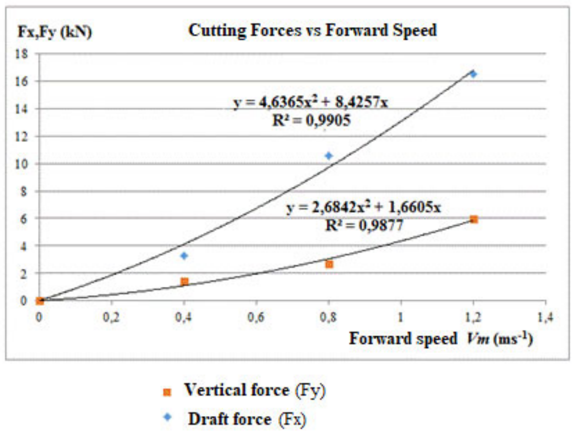

FIGURE 4. Cutting forces behavior to different forward speeds.

TABLE 2. Arm scarifier parameters of simulation model

Name	Category	Value	Unit	Comment
Density	Simulation ▼	1.2 ∑	g/cm³ ▼	
Humidity	Simulation ▼	23.9 ∑	N/A ▼	
Frequency	Simulation ▼	14 ∑	rad/d ▼	
Width,	Simulation ▼	11 ∑	N/A ▼	
Speed	Simulation ▼	∑	N/A ▼	
	Bench mark of the model▼	0	N/A ▼	

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The authors of this work declare no conflict of interests.

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