A semi-empirical dynamic ground interaction model for the forces of excavator blades

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1 Overview

A semi-empirical model has been developed to represent the performance of excavator blades during a normal bulldozing operation in a dynamic fashion. By making use of well-established geotechnical concepts and theories of Terramechanics, the authors present a new dynamic excavator blade versus ground interaction model. This system accounts for variable inputs from user, vehicle and surroundings during operation in order to calculate the loads under which the blade is operating over time. In addition, the evolution of the heap volume is taken into account, as a function of the blade type, its position and the vehicle speed. Experiments carried out in the field are used to calibrate the unknown ground parameters via linear regression and validate the model. The target function is the overall force being exerted by the machine.

2 Methods

The blade is modelled as a movable retaining wall (Bekker, 1962), shearing the ground on its path, which is compressed until reaching a state of passive failure as described in (Wong, 2009). The main part of the resistance against the motion of the excavator blade is therefore the passive earth pressure $\boldsymbol{\sigma_p}$ of the ground in front of the blade, see Fig. 1. Additional factors and phenomena have to be accounted for, such as adhesion and friction between the blade and ground (Wong, 2009), as the blade is not an infinitely smooth surface, as well as the blade-soil inclination, due to its own typical nature and operation (rake and pitch angle). Fig. 1 also shows the two-dimensional representation of the blade-ground problem with the added factors.

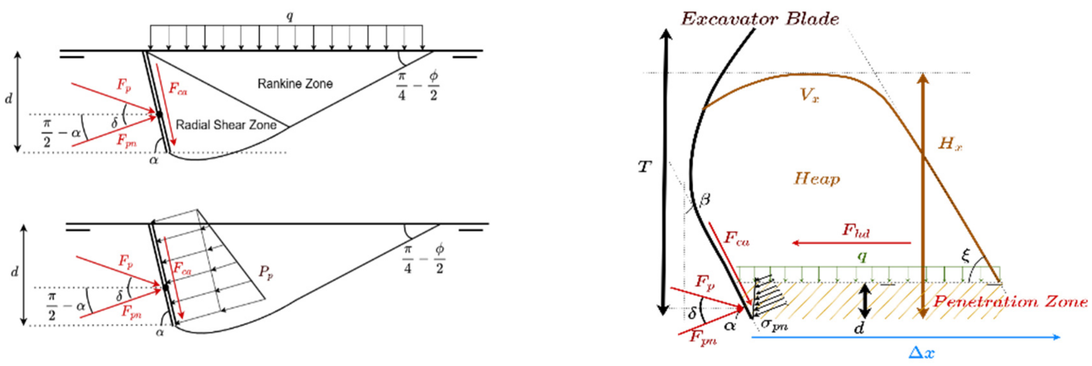


Fig. 1: Overall excavator blade problem representation.

The resultant force is composed of 5 terms: passive earth pressure force due to cohesion, $\boldsymbol{F_{pc}}$, soil weight, $\boldsymbol{F_{p\gamma}}$ and surcharge, $\boldsymbol{F_{pq}}$, as well as the adhesion force between blade and soil, $\boldsymbol{F_{ca}}$ and finally the heap friction over the soil drag, $\boldsymbol{F_{hd}}$. These are then projected to the motion axis, which will thus result in:

$$F_x = \left(F_{pc} + F_{p\gamma} + F_{pq}\right) cos\left(\delta + \alpha - {}^{\pi}/_{2}\right) + F_{ca} \, cos \, \alpha + F_{hd} \qquad (1)$$

The angles in Eq. (1) are: $\boldsymbol{\alpha}$, representing the blade rake angle and $\boldsymbol{\delta}$**,** denoting the soil-metal friction angle.

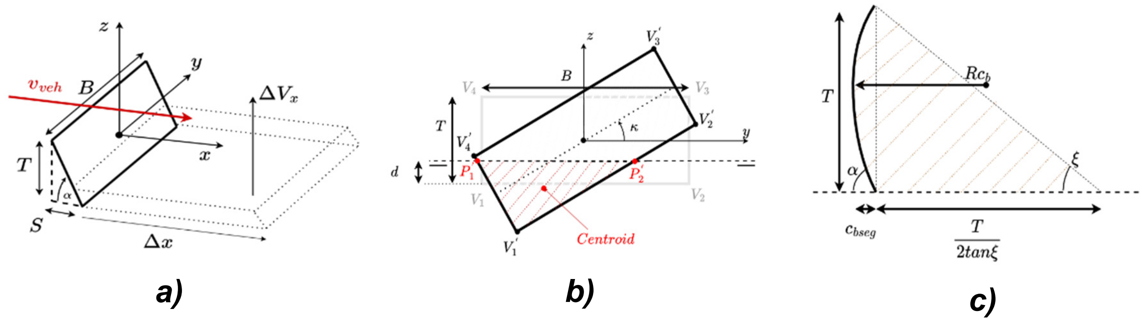
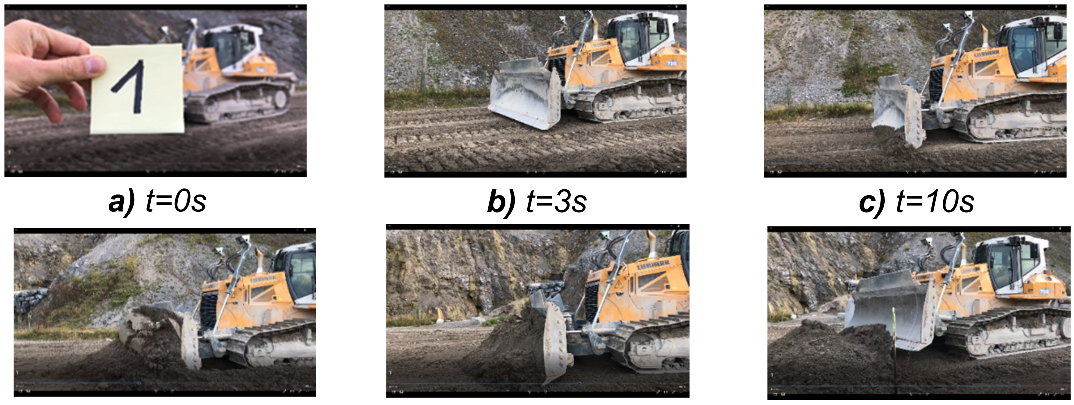


Fig. 2: Excavator blade representations. **a)** Scraped volume per differential displacement. **b),** Effect of the blade tilt to the penetration area. **c)** Approximation to the maximum potential volume (Reproduced from Klanfar, et al., 2014).

A very important issue is to identify the amount of piled up material in front of the blade. A function has to be defined to describe the heap volume change. It depends on the vehicle speed (and time step size), the potential maximum blade volume, $\boldsymbol{V_{max}}$**,** (Klanfar, et al., 2014, Rubinstein, et al., 2012), the blade position relatively to the vehicle and the ground and the terrain type and conditions (see Fig. 2). Therefore, the heap volume at every time step $\boldsymbol{i}$ is calculated as:

$$V_x{}^i = \left(A_x{}^i - \frac{TB}{\sin\alpha}\left(\frac{V_x{}^{i-1}}{V_{max}}\right)^{(2k_n+1)}\right)\Delta x + V_x{}^{i-1};\ \Delta x = v_{veh}\Delta t \qquad (2)$$

The parameter $\boldsymbol{k_n}$ controls the heap material loss rate. Field experiments have been performed in order to calibrate the ground and ground-vehicle/tool parameters and eventually validate the outcomes, see Fig. 3.



a) *t=0s* ***b)*** *t=3s* ***c)*** *t=10s*

d) *t=22s* ***e)*** *t=34s* ***f)*** *t=45s*

Fig. 3: Test field experiment. Bulldozer at field facilities.

3 Results

Some parameters of the model are set to obtained values from the field tests and literature (Wong, 2009). The actual vehicle speed, blade penetration depth and tilt angle (zero for this case) are taken from the experiment. The unknown parameters are calibrated to the target function using linear regression. The target function is the resultant vehicle load, which is derived from measured values in the hydraulic lines. The list of calibrated parameters can be found in Tab. 1. The outcomes can then be seen in Fig. 4.

Tab. 1: Calibrated model parameters after processing.

Parameter	**Symbol**	**Value**	**Unit**
Soil cohesion	c	20.2873	kPa
Soil friction angle	ϕ	24.124	°
Blade-soil friction angle	δ	18.23	°
Angle of repose	ξ	36.74	°
Specific soil weight	γ_s	1.45e4	N/m^3
Adhesion	c_a	18.73	kPa
Heap loss exponent	k_n	99.36	$-$
Heap friction coefficient	K_v	0.7146	s^2/m^2
Vehicle friction coefficient	μ	994.829	kg/m

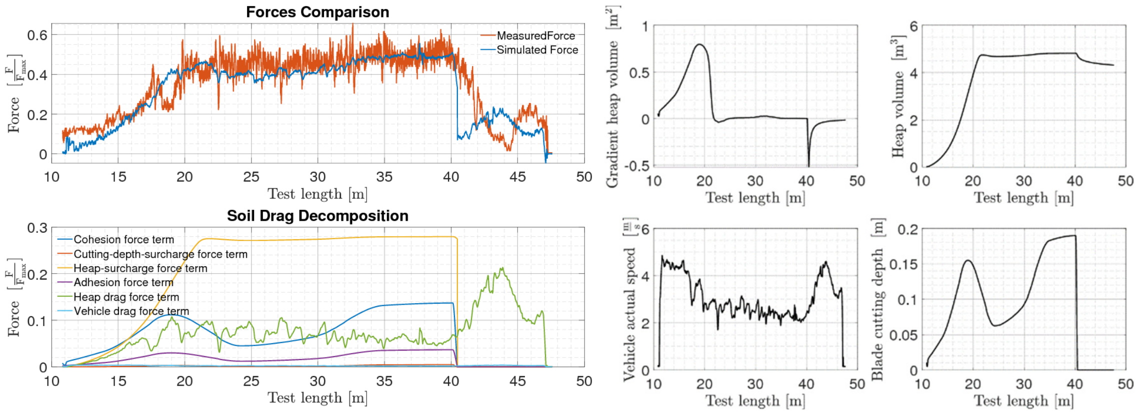


Fig. 4: Forces, heap volume and volume change; vehicle speed and blade cutting depth as input parameters.

4 Conclusions

Though the results seem promising, further testing is required to perform reliable calibration and to validate the model's performance for this terrain and vehicle type. In addition, some dynamic effects have to be improved within the model, such as the "heap release", occurring at 40 metres, which is not properly covered by the model. Other approaches as shown i.e. in (Luengo, 1998, Aslonov & Irisov, 2023) could be included, where additional effects are added, such as the inclination of the terrain during the operation or the remolding force, which may be interesting to add to the equations set.

5 References

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