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A calculation method of track shoe thrust on soft ground for splayed grouser

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Abstract

Thrust of track shoes on soft ground is affected by soil moisture content, shear rate and structure parameters of track shoes. A lack of comprehensive consideration of these factors exists for normal calculation methods. A method to predict thrust for track shoes on soft ground with splayed grouser was established based on experimental results and theoretical derivations. Model track shoe traction experiments were conducted for verification and correction of the thrust formula. It was observed that the thrust for the track shoes decreased with the increase in moisture content of the soil. Increases in shear rate, grouser height, and grouser splayed angle resulted in greater tractions. Effect of grouser thickness and grouser draft angle on tractions was not obvious. A corrected thrust formula allowed accurate prediction of thrust for a single track shoe on soft ground.

Keywords: Track shoe thrust; Soft ground; Splayed grouser; Shear stress; Soil strength

1. Introduction

Soil mechanical properties are known to be complex, therefore, prediction of vehicle traction on soft ground has been investigated and reported in literature using semi-empirical methods. Several research studies have demonstrated the reasonable accuracy of semi-empirical techniques in traction prediction equations. Traditional traction prediction equations depend on pre-determination of soil mechanical properties and do not take into account grouser shape of track shoe and vehicle driving parameters.

Soil shear strength is known to be affected by several factors, particularly soil moisture content and shear rate. An understanding of the relationship between moisture content and soil shear characteristics would allow for an improvement in the accuracy to estimate vehicle traction on soft ground. It was observed that moisture content had a significant influence on soil mechanical properties. Vanapalli et al. established a relationship between soil–water characteristic curve and unsaturated shear strength behavior of the soil based on results of consolidated drained direct shear tests. Shear strength of an unsaturated soil and soil–water characteristic curve depend on soil structure or the aggregation, which in turn is dependent on initial water content (Vanapalli et al., 1996). Several studies have been reported in literature with the conclusion that shear forces increases proportionately with decrease in moisture content of soil (Li and Sandu, 2007). Schjonning focused on characterizing mechanical properties of different soil types as a function of moisture content of soil using the drop-cone penetration and direct shear test (Schjonning, 2000). Sadek et al. concluded that, in general, shear forces increased with increase in dryness and density of soil (Sadek et al., 2011). Dechao et al. experimentally

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Nomenclature

τ	shear stress, Pa
C	soil cohesion, Pa
Σ	normal pressure, Pa
Φ	internal friction angle, °
c_0	cohesive strength when the moisture content is 0, Pa
λ_c	slope of soil cohesive strength fitting curve for moisture content
w	moisture content of soil, %
φ_0	soil internal friction angle when moisture content is 0, °
n_φ	exponent of soil internal friction angle fitting curve for moisture content
$\eta_{\max}$	ultimate shear strength ratio at high shear rate and extremely low shear rate
v	shear rate, mm/s
a	test value for specific soil, mm/s
η_v	amplification coefficient
F_1	horizontal force acting on the bottom of track shoe, N
F_2	horizontal force acting on the bottom of grouser, N
F_3	force acting on the vertical surface of grouser, N
F_4	horizontal force acting on the ends of track shoe, N
m_0	total mass of soil sample before drying, g
m_b	mass of container, g
W	vertical load of track shoe, Pa
p_1	pressure acts on the bottom of the track shoe, Pa
p_2	pressure acts on the bottom of the grouser, Pa
L	length of track shoe, m
Z	sinkage depth of track shoe, m
h	height of grouser, m
k_c	cohesive modulus, N $m^{-(n+1)}$
k_φ	frictional modulus, N $m^{-(n+2)}$
γ_s	unit weight of soil, N m^{-3}
z'	depth of soil, m
$K_{p\gamma}$, K_{pq}, K_{pc}	coefficients relating to soil strength
b	width of track shoe, m
b_1	length of oblique grouser, m
F_{pn}	normal pressure acting on the vertical surface of grouser, N
δ	internal friction angle of steel and soil, °
α	splayed angle of grouser, °
β	draft angle of grouser, °
w_d	moisture content of soil, %
m_1	total mass of soil sample after drying, g
d	grouser thickness, mm

demonstrated that decrease in soil water content resulted in an increase in soil shear strength (Dechao and Yusu, 1991). Jiupai et al. experimentally established a relationship between cohesive strength, internal frictional angle of soil and soil moisture content. Soil cohesive force initially increased, followed by a decrease with increase in soil water content. Soil internal frictional angle decreased linearly with the increasing soil water content (Jiupai et al., 2009). Yao et al. investigated the relationship between soil shear strength and moisture content for sandy pebble type soil using direct shear test technology. Results showed that, with its good permeability, there are few changes in shear strength index with increase in moisture content of sandy pebble soil (Yao et al., 2008). Typically, relationship between soil shear strength and shear rate reflects damping characteristics of the soil. Kimura et al. investigated the influence of shear rate on residual strength parameters. (Kimura et al., 2014). Yang et al. revealed the influence of different shear rate impacts on the anti-shear strength index of weathering sand improved expansive soil (Yang et al., 2014). Xu et al. investigated strength and deformation characteristic of coarse-grained soils under different shear rates using a direct shear apparatus (Xu et al., 2013). Grecenko experimentally re-examined thrust generation by a track plate in field conditions. Tests showed that the initial stage of thrust generation for compressible ground always resulted in horizontal soil compression by grousers. Initially, this behavior resulted in the soil being divided under a track into separate blocks at rest. Grecenko established a compression-sliding (CS) approach based on field measurements with an original double plate (DP) meter. This takes into account the existing shear plane theory in view of the CS approach. A practical thrust-slip function complying with the CS logic was developed as a result of this work (Grecenko, 2007a, 2007b).

For vehicle design factors, traditional calculation takes only a few main parameters into account such as vehicle weight, bearing area, length and width of track. Effect of grouser shape needs to be taken into consideration, as this would provide a more accurate estimation of the traction force and would aid in the design and optimization of the crawler board. Research in the effect of the grouser shape is carried out using both experiments and simulation. Hong et al. carried out an experimental comparative study to study the effect of grouser shapes on traction for a soft seabed surface (Hong and Choi, 2001). Nakashima et al. designed a quasi-2D experiment to reproduce experimental