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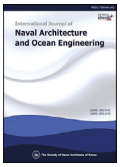

Tractive performance evaluation of seafloor tracked trencher based on laboratory mechanical measurements

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Abstract

To evaluate the tractive performance of tracked trencher on seafloor surface, a new shear stress-displacement empirical model was proposed for saturated soft-plastic soil (SSP model). To validate the SSP model, a test platform, where track segment shear test can be performed in seafloor soil simulacrum (bentonite water mixture), was built. Series shear tests were carried out. Test results indicate that the SSP model can describe the mechanical behavior of track segment with good approximation in seafloor soil simulacrum. Through analyzing the main external forces applied to seafloor tracked trencher during the uniform linear trenching process, a drawbar pull prediction model was deduced with the SSP model. A tracked walking mechanism of the seafloor tracked trencher prototype was built, and verification tests were carried out. Test results indicate that this prediction model was feasible and effective; moreover, from another side, this conclusion also proved that the SSP model was effective.

Keywords: Shear stress-displacement relationship; SSP model; Tractive performance; Drawbar pull; Seafloor tracked trencher

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1. Introduction

With growing demand for offshore wind energy, the number of seafloor cables required to export energy from wind farms to shore has also increased in recent years (Royal Haskoning and BOMEL Ltd, 2008). As a result, large number of cables associated with energy delivery and telecommunications will be installed during the coming decades. Sometimes seafloor cables cross busy shipping routes, fishing areas where the seafloor is frequently disturbed by dredging, trawling and anchoring. The seafloor cables may be damaged when exposed on seafloor surface, and thus, these cables need proper protection. To reduce the risk of damaging cables, effective cable protection, careful execution of cable laying and burial operations are required. Cable burial is a preferred way to protect cables against these impacts. Seafloor trenching is usually done by equipments mounted on a seabed carriage or sled, which may be either self-propelled or towed. Seafloor Tracked Trencher (STT) equipped with jetting system is designed to meet the burial requirements of pipelines and cables above-mentioned.

STT's mobility requires both sufficient traction and bearing capacity. The working capacity depends principally on vehicle dimensions and seafloor soil property. Tracked walking mechanism has a larger contact area with ground than wheeled running gear, so, it can provide better floatation and larger traction forces. By shearing seafloor surface soil, tracks can produce traction force that propels the trencher forward, and the available traction must be sufficient to enable trencher to overcome various resistances, including vehicle weight due to slope/vehicle pitch and compaction resistance which arises as a consequence of creation of ruts.

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Trafficability evaluation of the seafloor surface and potential traction optimization of the tracked walking mechanism are essential and some research works have been done. Through experiments analysis, Janosi and Hanamoto (1961) proposed a drawbar pull model as a function of slip for a tracked vehicle in deformable soils. Watanabe and Kitano (1986) presented a theoretical and experimental analysis of steering performance of articulated tracked vehicles on level ground, and developed a mathematical model for predicting the steerability of articulated units. Considering possible factors related to steering problems such as track slippage, centrifugal force and vehicle configuration, Kitano and Jyozaki (1976) developed a steering model for uniform turning motion and steerability in plane motion of vehicles. Baladi and Rohani (1978), have studied and developed the application of tracked vehicles on soft soil. Hyung-Woo Kim (2005) analyzed underwater tracked vehicle's dynamics on extremely soft soil by using Euler Parameters and investigated the hydrodynamic effects on the performance of tracked vehicle. Based on deep sea soil situ measurements and bentonite soil laboratory tests, Schulte (2001) developed a shear stress-displacement relationship function for deep sea soil. This function fits measurement result of segment shear test well in descending part and residual part; but in the hump part, the calculated curves appears some deviations, and there exists an offset for $s = 0$.

In this paper, based on comprehensive analyses of seafloor soil shear deformation and the track segment shear tests, a new shear stress-displacement relationship empirical model was proposed for saturated soft-plastic soil (SSP model). To verify the SSP model, a test platform, in which track segment shear test can be performed in seafloor soil simulacrum (bentonite water mixture), was designed and built. Series of track segment shear tests are carried out. Through analyzing the main external forces, including environmental loads from the seafloor soil and current applied to tracked trencher during the uniform linear trenching process, a drawbar pull prediction model was deduced with SSP model. At last, for validating this prediction model, drawbar pull tests were carried out with a tracked walking mechanism of STT prototype.

2. Mechanics of track–soil interaction

The attainable locomotion of the STT over seafloor surface is mainly based on shear forces which are developed by track segments shearing soil surface in longitudinal directions of track links. So, seafloor surface soil conditions have significantly effects on tractive performance to tracked trenchers. The mechanical behavior of surface soil varies considerably under a wide variety of environmental conditions. For example, composition, moisture levels and porosity affect mechanical behavior of bulk soil relative to vehicle/terrain dynamics. Some experiments indicated that the shear behavior of seafloor surface sediments shows a similar behavior as a type of "undisturbed firm soil" (Kim et al., 2005; Schulte et al., 2001; Wu and He, 2010). As shown in Fig. 1, this type of soil exhibits characteristics as follows described, shear stress initially increased sharply and reached a "hump" of maximum shear stress (τ_{max}) at a particular shear displacement, and then decreased and approached a relative constant residual value (τ_{res}) with further increase in shear displacement.

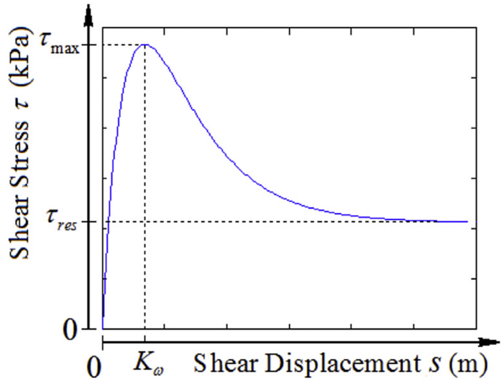

Fig. 1. Shear curve exhibiting a peak and constant residual shear stress.

2.1. Physical and mechanical characteristics of seafloor surface soil

The physical and mechanical characteristics of seafloor surface soil are special. With the increase of depth, the soil mass presents flow state, fluidal plastic state, and plastic state (Enderby, 1974). Elastic-plastic deformation may play an important role in track segment shearing process. Taking surrounding soil deformation of track segment into account, the schematic diagram of soil deformation can be shown as Fig. 2-a. The deformation is not linear. The influence zone (D_w, D_h) depends on many factors, such as normal stress (σ), soil cohesion (c), soil internal friction angle (ϕ), shear deformation modulus (K), soil moisture content (w), etc. A typical shear process can be described as follows: at the beginning, the shear stress increases proportionally to the shear displacement, indicating that the soil is deformed mostly elastic; at a certain shear displacement, the soil starts to fail and plastic deformation occurs, the shear bock starts to form; when the maximum shear stress is reached, the soil is completely broken; after this, the shear stress declines to its residual value; but the soil mass under shear bock is still in deformation state caused by frictional effects. As shown in Fig. 2-b, it was not difficult to observe the deformation process above-mentioned during the shear tests.

Through analyzing the test data, it's very interesting to find that the hump zone energy loss ΔE_H seems to be caused mainly by elastic–plastic deformation of the shear bock and the soil mass around track segment, and the residual zone loss ΔE_R can be considered as energy loss caused by friction of the soil mass around track segment. And these two types of energy losses seem to be independent from each other. Therefore, here, when analyzing and modifying the shear stress-displacement model, these two types of energy losses are considered and modified independently. The mechanical behavior analysis of seafloor soil shear deformation and theoretical derivation of shear stress-displacement model are