Applied Ocean Research 50 (2015) 155–162

Contents lists available at ScienceDirect

Applied Ocean Research

journal homepage: www.elsevier.com/locate/apor

A tool for ROV-based seabed friction measurement

S.A. Stanier [a,*], D.J. White [a], S. Chatterjee [b], P. Brunning [c], M.F. Randolph [a]

[a] Centre for Offshore Foundation Systems (COFS), University of Western Australia (UWA), Australia
[b] Indian Institute of Technology, Bombay (IIT Bombay), India
[c] Subsea 7, Singapore

ARTICLE INFO

Article history:
Received 5 June 2014
Received in revised form
16 December 2014
Accepted 25 January 2015
Available online 18 February 2015

Keywords:
Friction
Measurement
In situ
ROV
Pipeline
Mooring chain

ABSTRACT

This paper describes a new device for measuring seabed sliding resistance *in situ*, and provides an associated interpretation procedure. The device is designed to use a work class ROV as a testing platform to allow measurements to be obtained without use of a specialized geotechnical survey platform. The measurements are to assist pipeline design or analysis of the sliding resistance of other on-bottom infrastructure such as anchor chains. The device has been trialled using three tools: a flat plate, a cylindrical pipe section and a length of chain. The tools are dragged axially along the seabed using the ROV thrusters or a separate hydraulic actuator. An interpretation technique has been developed to estimate the passive resistance mobilized by the faces of the tools to eliminate end effects and to account for shape effects such as wedging. Onshore-trial tests were performed in a bed of dry sand. The individual tools exhibited different overall coefficients of friction, but the back-analysis method yielded equal interface friction angles acting on all three devices, indicating internal consistency. The interface friction angle also matched shear box test results. These outcomes confirm the correct operation of the device in drained seabed conditions, and yield useful information on the sliding resistance of pipes and chains. In addition, the back-analysis method allows measurements from one shape of tool to be used to estimate the response of other objects.

1. Introduction

Conventional offshore site investigation typically involves a combination of *in situ* penetrometer testing and sampling for laboratory testing. These penetrometer tests and sampling processes are usually conducted using a specialized vessel and drilling system. The costs of operation are high and the volume and spatial distribution of data collected are often limited.

Pipeline design requires a lengthy route to be surveyed, with accurate characterization of the surficial soil. A key design parameter is the pipe-seabed friction, which controls the tendency for progressive axial pipe movement ('walking') through cycles of operation (Bruton et al., 2008 [1]). Seabed sliding resistance or friction is also an important parameter in the design of shallow foundations and temporary clump weights used for installation operations.

There is also much uncertainty surrounding the axial sliding capacity of mooring chain resting on the seabed, as used to connect floating vessels to seabed anchors. The ISO-19901-7 [2] international standard states that "*the coefficient of friction* [between the chain and the seabed] *depends upon the nature of the seafloor and on the type of mooring line.*" In the absence of more specific data, a sliding coefficient of friction of 0.7 is given. However, this value is then qualified: "*Industry experience indicates that coefficients of friction can vary significantly for different soil conditions, and much higher values for the sliding coefficient of friction have been encountered.*"

Other standards quote different values: DNV-OS-E301 [3] quotes a chain-seabed friction coefficient of 1.0 while DNV-RP-301 [4] gives a best estimate of 0.7 and a range of 0.6–0.8. There is clearly uncertainty surrounding chain-seabed friction and *in situ* measurement of this parameter offers a solution to the dependency on the soil conditions.

This paper explores the concept of an ROV-based investigation tool for measuring seabed friction *in situ*. An ROV-based tool requires less specialized equipment compared with a conventional geotechnical survey. It is shown that the tool is able to gather repeatable and reliable data on seabed sliding resistance, which is consistent with laboratory testing using the same material.

A similar concept was described by Lambrakos [5]. In that study, a special seabed vehicle incorporating two separate pipeline segments was towed by a surface vessel. Seabed friction coefficients were back-calculated from the measured tow forces in both sand and clay soils in water depths of 9–18 m in the Gulf of Mexico. However, the system was limited to relatively shallow water locations due to the need to drag the vehicle along the seabed using a surface vessel.

* Corresponding author. Tel.: +61 447571092.
E-mail address: sam.stanier@uwa.edu.au (S.A. Stanier).

0141-1187/$ – see front matter © 2015 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.apor.2015.01.016

Nomenclature

α	inclination angle
A	contact area
A_p	projected area
B	tool or chain link width
d	displacement
D	diameter
D_c	chain bar diameter
δ_i	interface friction angle
e	void ratio
F	force
F_h	horizontal force
$F_{p\text{-}end}$	passive force at tool end
$F_{p\text{-}int}$	internal passive force
g	gravitational acceleration
G_s	specific gravity
γ	unit weight of soil
γ_w	unit weight of water
I_D	relative density
I_R	relative dilatancy index
K_p	coefficient of passive earth pressure
m	tool mass
μ_i	interface friction coefficient
μ_t	tool friction coefficient
n	number of chain links
N	normal contact force
p'	mean stress
ϕ'	operative friction angle
Q	natural logarithm of the grain crushing strength
T	traction
τ_{ave}	average shear stress at the interface
θ	enclosed angle of circular segment
V	vertical tool-seabed reaction force
w	embedment depth
W	tool weight
$\bar{z}$	depth to centroid of area
ζ	wedging factor

A more sophisticated platform is the SMARTPIPE ([6] and [7]), which is an *in situ* testing system intended for use in deep water (down to 2500 m). A 200 mm diameter polypropylene-coated pipe section is manipulated using a three degree of freedom actuator that provides vertical, lateral and axial displacement. This tool provides detailed measurement of both pipe–soil resistance forces and also the pore pressure acting on the pipe surface. However, the hardware is highly specialized and has not found routine usage.

Remotely operated vehicles (ROVs) are routinely used offshore for support of exploration, installation and integrity monitoring work. Work class ROVs typically have a plan area of ~1 by 2 m and provide a platform from which geotechnical testing can be performed at the seabed. The wider use of ROVs as a geotechnical survey platform has long been proposed [8], and the development of ROV-based geotechnical tools has increased in recent years ([9], [10]).

This paper describes a simple apparatus for performing axial drag tests to measure seabed friction, from an ROV (see Fig. 1), using different shaped tools: a flat plate, a pipe section and a length of chain. The tool is actuated by ROV thrusters or by an electrical or hydraulic cylinder when the ROV is stationary. The drag force on the tool caused by seabed friction is measured by a load cell at the end of the tool. Trial tests of the device onshore in a test bed of dry sand have proved the concept of the device through back-calculations of the interface friction generated by each of the three tools. The tool was developed in collaboration between Subsea 7 and the University of Western Australia.

Table 1
Drag tool properties.

Tool	Property		
	Length (m)	Width (m)	Weight (N)
Plate	0.6	0.1	215.8
Pipe	0.6	0.08	255.1
Chain	0.62	0.11	127.5

2. Description of drag tool

The apparatus consists of a stainless steel frame constructed from 25 by 25 mm square hollow section (SHS). The frame measures 1 m in length, by 0.5 m wide and 0.3 m deep. This size was designed for the tool to be mounted within the standard skid of a typical work-class ROV. The corners of the frame are gusseted for rigidity and six uprights are provided for the tool suspension cables *via* 11 holes at 20 mm vertical centres (see Fig. 2).

The three tools are shown in Fig. 3 and their properties are given in Table 1. They were all made from steel and finished to the same surface roughness by sandblasting. Adjacent chain links were welded at 90° so as not to form a catenary between the suspending cables when the ROV is in flight. Stainless steel padeyes at the ends and sides of the tools connected them to the suspending cables.

Stainless steel D-shackles - attached to the suspension cables of each of the tools - are fitted through the tool padeyes, allowing adjustment of the height of the tool relative to the frame. The suspension cables are 2 mm diameter stainless steel wire cables with an ultimate breaking strain of ~2 kN. The drag force measuring cables at the ends of the tools attach to the frame *via* a pair of 3 kN pillar type load cells, which were custom-built in house at UWA and were waterproofed by being potted in urethane prior to pressure testing to 1.5 MPa.

The lengths of the suspending cables were chosen so that the weight of the tools is evenly distributed between all of the cables when the ROV is in flight with the base of the tool hanging ~150 mm below the frame. Turnbuckles on the load cell connections allow fine adjustment of the pulling cable lengths. With correct tensioning, a small tension is carried in the pulling cables when the ROV is in-flight, providing the operator with an indication of tool touch-down as the ROV is lowered to the seabed and the cables become slack.

The signals from the load cells are passed into a sealed enclosure (pressure tested to 1.5 MPa) *via* Subconn® cables and connectors. Within the sealed enclosure a DigiDAQ device [11] is used to digitize the analogue signals from the load cells. Communication to the surface vessel is achieved *via* a serial multiplexer onboard a typical work-class ROV. The DigiDAQ device was modified to output the digitized data *via* the RS232 protocol rather than the standard Ethernet interface. On the surface vessel an RS232 to Ethernet adapter (Lantronix EDS2100) converts the serial output to Ethernet, where it is logged at a PC using the standard DigiDAQ software ([11]). The data acquisition system utilizes 24 V DC power from the ROV and uses a DC–DC converter to provide the 12 V DC supply required by the DigiDAQ system.

3. Test procedure

Operation of the drag-testing device entails seven main steps:

1. The ROV is flown to the chosen test location.