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Physical modelling of the effect of lubricants in pipe jacking

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ABSTRACT

Pipe jacking and microtunnelling are important trenchless construction techniques that are seeing increasing application globally. The maximum length achievable with a single pipe jacking drive has a strong dependency on the skin friction resistance that develops over the pipeline surface as it advances through the soil. Bentonite or polymer slurries are commonly injected into the soil from ports on the surface of the pipe with the intention of reducing this skin friction resistance and allowing for longer drives with lower jacking force requirements. Field studies have shown that this procedure can achieve reductions in skin friction resistance of up to 90%, however the exact mechanism by which these slurries act is not fully understood. This paper presents the results of a series of interface friction tests carried out to investigate this resistance using a conventional direct shear device and a novel triaxial testing apparatus, where a lubricant was injected into the interface between a coarse-grained soil and a rough concrete surface similar to a concrete jacking pipe, while the soil was shearing against the rough concrete surface. It is shown that, for coarse-grained soils, the main beneficial mechanism of pipe jacking lubricants is the reduction of the local effective stress acting on the pipe through the generation and retention of excess pore water pressure in the soil near the interface.

1. Introduction

Pipe jacking and microtunnelling are related trenchless construction techniques that allow for the installation of long horizontal distances of pipeline with a minimum of excavations to the ground surface. Microtunnelling is a special case of pipe jacking, where remote control of an automated microtunnel boring machine (MTBM) is employed. Excavated soil is removed from the face of the pipe jacking shield or MTBM and transferred to the surface for disposal while the shield or MTBM and the product pipes to be installed are driven through the ground using the force developed by a jacking frame installed in a fixed shaft.

2. Skin friction and lubrication in pipe jacking

The skin friction resistance is the resistance developed over the surface of the pipeline as it advances through the ground. It is an important consideration in pipe jacking, as the magnitude of the skin friction resistance force often dictates the maximum drive length possible without the use of unwieldy and time-consuming intermediate jacking stations. The provision of an overcut, which is an annular gap around the product pipes created through the use of a pipe jacking shield of a diameter greater than that of the product pipes, is the primary means of reducing the skin friction resistance on a pipeline. Further significant reductions are possible through the injection of a lubricant slurry through ports in the skin of the product pipes. A typical arrangement of lubricant injection ports on a product pipe is shown in Fig. 1. Pipe jacking lubricants in common usage are bentonite- or polymer-based slurries, mixed in a grout mixer on the surface and delivered through a network of pipes by a semi-automated or an automated delivery system. The lubricant injection process is usually guided on the basis of "common sense and experience" (Borghi, 2006) or prescribed injection volumes (Ulkan, 2013).

Through the injection of lubricants, reductions in skin friction resistance greater than 90% are commonly achieved in the field (Marshall, 1998; Pellet-Beaucour and Kastner, 2002; Staheli, 2006). A number of mechanisms by which the lubricants reduce skin friction function have been proposed, which are illustrated in Fig. 2 and are as follows:

(1) The lubricant forms a lubricating boundary layer between the soil and the pipe.
(2) The lubricant mixes with the soil to form a layer of material with a lower angle of friction than the soil.

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Notation

A_C	corrected area of triaxial test failure surface	σ_m	correction for membrane resistance
C_U	coefficient of uniformity	ϕ'_{cv}	constant volume angle of effective friction resistance
D_{50}	mean particle size	$\phi_{cv,ds}$	ϕ'_{cv} determined in direct shear
R_a	average surface roughness	$\phi'_{cv,tx}$	ϕ'_{cv} determined in triaxial compression
R_{max}	maximum surface with a length	ϕ'_r	residual angle of friction (in clay)
R_n	normalised surface roughness		
θ	inclination of the preformed failure plane		

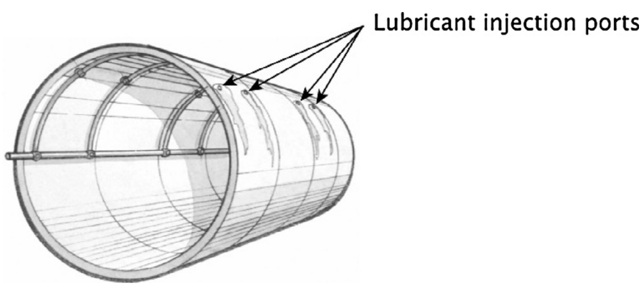

Fig. 1. Typical arrangement of lubricant injection ports (Image: Pipe Jacking Association).

(3) The lubricant fills the overcut, stabilising it and making the pipeline partially or fully buoyant.
(4) The lubricant under pressure permeates into the soil until such time as a filter cake forms in the soil thereby reducing the effective stress on the pipeline.

Physical modelling of the lubricant injection process in pipe jacking has been carried out by many researchers, however to date such modelling has been conducted largely in direct shear (McGillivray, 2009; Shou et al., 2010; Staheli et al., 2006) or small-scale tank tests (McGillivray, 2009; Phelipot et al., 2003). Shortcomings have been identified in these approaches in their ability to maintain continuous control of the pore fluid pressure as it is considered that pore fluid pressure may play an important role in the reduction of skin friction resistance. Lubricant slurries applied to an interface and not subject to pressurisation were found by other researchers to have negligible benefits in reducing skin friction resistance (McGillivray, 2009; McGillivray and Frost, 2010).

This paper presents the results of a series of research experiments carried out with the intention of identifying the beneficial mechanisms of both pressurised and unpressurised pipe jacking lubricants in the reduction of the skin friction resistance in the interface between coarse-grained soils and concrete jacking pipes.

3. Experimental apparatus and procedure

Two separate series of tests are reported. The first series of tests was carried out using unpressurised lubricants in a conventional direct shear apparatus while the second series of tests was carried out using lubricants introduced to the interface under pressure in a modified triaxial compression testing apparatus developed specifically for this research. The materials and apparatus used and procedures followed for each series of tests are described briefly hereunder while further details are available in Reilly (2014).

3.1. Test soils

Two types of sand were used for testing, identified as IGB sand and Banagher sand. IGB sand is an even-graded, fine to medium

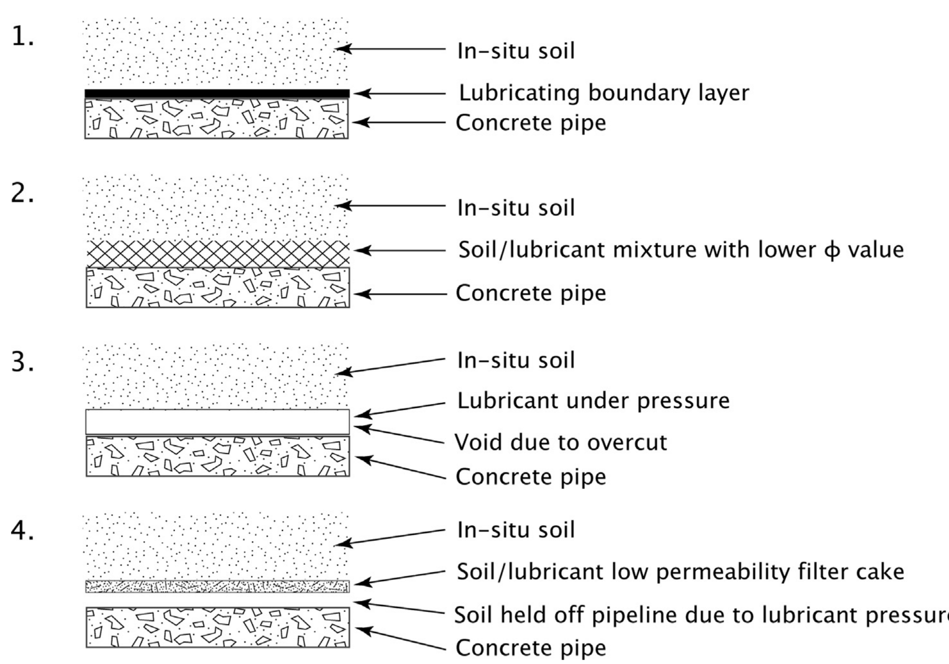

Fig. 2. Mechanisms of skin friction reduction due to lubrication in pipe jacking.