Soil conditioning for earth pressure balance machines

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Abstract

Earth pressure balance (EPB) tunnelling machines are commonly used for the construction of tunnels in soft soils ranging from coarse sands and gravels to stiff clays. These machines use the excavated soil in a pressurised head chamber to apply a support pressure to the tunnel face during excavation. A screw conveyor is used to discharge controlled volumes of soil from the machine, and to dissipate the pressure in the head chamber. By balancing the volume of soil flowing into and out of the machine, an earth pressure balance is established during excavation. The control of the excavation process and the EPB machine performance depend critically on the properties of the excavated soil. Conditioning of the soil by injecting foams, polymers, and other agents is usually required to modify the properties of the excavated soil to form a soft plastic paste. Effective soil conditioning significantly improves the machine performance and control of the soil flow through the screw conveyor. Although soil conditioning is commonly used in practice, effects of different conditioning treatments on soil properties and the machine performance are not clearly understood, and problems with EPB machine operations related to the soil properties are often encountered.

This thesis presents experimental investigations of soil conditioning for clays, and of the mechanics of a model EPB screw conveyor operating with clay soils.

Index tests were performed to investigate effects of foam and polymer conditioning treatments on the undrained strength of London Clay samples. The index tests allowed assessment of conditioning treatments for clay soils, and optimum ranges of treatments for London Clay are suggested.

An instrumented 1:10 scale model EPB screw conveyor was designed and commissioned. The soil flow rates, the pressure gradients and casing shear stresses along the conveyor, and the screw torque were measured during tests with varying soil properties and conveyor operating conditions. Tests were performed with consolidated kaolin and compacted conditioned natural clay soil samples.

During steady state conveyor operation with a constant soil flow rate, the casing shear stress and the total pressure gradient were constant along the conveyor, and the screw torque was constant. The total pressure gradient is influenced by conveyor operating conditions including the sample pressure, the discharge outlet restriction, the screw speed, and the screw pitch. Depending on the operating conditions and the soil strength, the total pressure can increase or decrease along the conveyor. The screw torque is proportional to the casing shear stress, and increased with the undrained strength of the soil. Conditioning natural clay soils with polymers and foams to form a soft plastic paste allowed controlled operation of the screw conveyor, with uniform soil flow rates and pressure gradients.

A theoretical model describing the screw conveyor operation is proposed. The model relates the total pressure gradient and the screw torque to the soil flow rate, the shear stresses acting in the conveyor, and the screw conveyor geometry. The model is expressed in dimensionless form to allow application to screw conveyors of varying scale. Close agreement between the predictions of the theoretical model and the measured pressure gradients and torques from the model screw conveyor tests was obtained, indicating the proposed model can accurately describe the conveyor operation.