Determinaton of the cutterhead torque for EPB shield tunneling machine

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ABSTRACT

Cutterhead torque is an important parameter for the design and operation of earth pressure balance (EPB) shields. Based on the analysis of several completed project cases from job sites, the conventional torque determination model based on experimentation proves rough enough to be improved. Composition and corresponding calculation method of cutterhead torque are presented, taking into account of cutterhead structure, cutting principle and the interaction between cutterhead and soil. Considering a Φ1.8 m EPB test machine in the lab, theoretical calculation following the improved model and test are carried out with three typical types of soils. Calculation and test results indicate that the cutterhead torque varies with geological conditions apparently, and the opening ratio of the cutterhead as well as earth pressure turns out to be the two most important factors in determining the cutterhead torque. The test results also show that the torque calculation formula for EPB shield tunneling can reasonably predict the excavation torque required by the cutterhead in clay soil tunneling, but for cohesionless tunneling, soil conditioning reduces the amount of torque necessary.

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1. Introduction

Rapid economic development and urban population growth have been increasing the necessity for underground space exploration and utilization due to the need of upgrading and expanding the existing infrastructures. Tunneling plays a very important role in the underground engineering, providing a premium solution for those needs with minimum surface impacts [1]. Of all tunneling methods, EPB tunneling performed by EPB shield tunneling machines has attained the most extensive application due to its ability to adapt to a variety of geological conditions and discharge control. So EPB shield tunneling machine is of great importance to the tunnel construction for subway, highway, etc.

The two important tasks of the EPB machine are the cutting of frontal soils and face support with excavated soil by the cutterhead [2]. Because of this special task, it consumes a vast amount of energy accounting for more than half of the total required power of the machine. Therefore, when designing an EPB tunneling machine, more attention should be paid to the cutterhead drive and associated soils to determine the necessary power requirements. It is essential for engineers not only to estimate the loads, but also to know which factors may affect the loads [3].

Rotational speed and torque are two critical parameters of the cutterhead drive, and they are directly related to drive power. The former one is to be controlled as a constant during tunneling in a homogeneous layer while the latter varies with the different geological conditions. The torque capacity of cutterhead has to be considered in the design stage, taking into account a range of soils faced by the machine.

This paper gives a review on the empirical formula for calculating the cutterhead torque, then analyzes the factors resulting in the load torque and creates the mathematical models. Based on the theoretical modeling, the experiments are carried out on a tunneling test rig to verify the torque determination method for cutterhead drive of EPB shield tunneling machine.

2. Conventional model

At present, the torque equipped for cutterhead is empirically determined in terms of the diameter of shield machine [4]. The formula widely adopted by many designers is described as follows.

\[ T = \alpha D^3 \]  

where \( T \) is the provisional cutterhead torque (ton-m), \( D \) is the shield machine diameter (m), \( \alpha \) is an empirical coefficient. For the EPB shield, it requires an \( \alpha \) of 1–2.5. To clearly illustrate the relations between torque and diameter, the above equation is also shown in Fig. 1.

From Fig. 1, it can be concluded that the empirical equation just gives a quite rough estimate of the torque, as a reference for system design. In other words, the torque value may vary within the hatched area shown in Fig. 1, following variables \( \alpha \) and \( D \) in design. Take the widely used \( \Phi 6 \) m EPB shield in metro tunnel construction as an example, its cutterhead torque can have an indeterminate value.