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Investigation of the structural effect induced by stagger joints in segmental tunnel linings: Direct insight from mechanical behaviors of longitudinal and circumferential joints

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ABSTRACT

It is generally accepted that cross joint tunnels have bigger deformation capability, while T joint tunnels have larger safety coefficients of bearing capacity, when it comes to difference in structural mechanics. The major cause of this different behaviour is the transfer loading mechanism through circumferential joints. However, there are few direct experimental investigations focusing on such transfer loading mechanism to the authors' knowledge. In this work, systematic experiments are conducted to analyze the inter-ring transfer mechanism, which include a three-ring compression-bending test, a single-ring compression-bending test and a shear test on circumferential joints. Based on the outcome, the experimental results of the T joints configuration are discussed in terms of stresses and inter-ring shear forces. The results show that the inter-ring effect of the T joint segments is mainly due to the incompatibility of the deformation between rings as well as their capacity to transfer shear force. The loading level of the longitudinal force along the tunnel and the circumferential joint technology are the main factors influencing the transfer loading mechanism in such a staggered configuration. Moreover, the coefficient of moment adjustment, which is a vital parameter during the design of segmental tunnel linings, can be further defined and computerized. The investigation presents a deep insight into the effects of the segment layout and connection details along longitudinal and circumferential joints.

0. Introduction

Shield tunneling, which is a commonly adopted excavation technique for urban rail transit, provides segmental lining installation in a straight or staggered configuration. In straightly jointed segmental tunnel linings, the designed load is thought to be mainly carried by a single ring, and the longitudinal joints are to be the vulnerable link (Liu et al., 2015). While in staggered segmental tunnel linings, the adjacent rings would help and the load transfer loading mechanism among rings is different. The circumferential joints, longitudinal joints and segments could potentially prove to be the weak parts (Liu et al., 2017a). When modifying the routine method to conduct structural design, the coefficient of moment adjustment ξ is a vital parameter in evaluating the force transmission performance between rings of the stagger joint segment. It is generally recognized that the coefficient of moment adjustment is related to joint bending stiffness, and the factor is normally set to be 1.3 for soft soil (JSCE, 2001; Koyama, 2003). The International Tunneling Association (2000) released the coefficient of moment adjustment concept without a commonly used computational method. To date such a method is not yet proposed but required.

In tunneling engineering, compression-bending test on segmental lining is commonly adopted to determine the moment adjustment coefficient (Japan Society of Civil Engineers, 2001). Li et al. (2015), for example, conducted a bending resistance failure test on the longitudinal joints of a segmental lining of a shield tunnel. The test was interpreted numerically by the authors, simulating the behaviour of the longitudinal joints, thus analyzing the influence of the concrete resistance, of the bolts and gaskets on the mechanical behaviour of the longitudinal joints. Liu et al. (2017a, 2017b) performed an experimental test to evaluate the ultimate bearing capacity of the longitudinal joints of segmental lining of a shield tunnel, analyzing the effect of the load-carrying capacity of the bolts and the longitudinal joint inclination angle in relation to the tendency of cracking development. As far as the behaviour of the circumferential joints is concerned, Putke et al. (2015) investigated the groove and tongue of a joint, as well as the shear-resistance stiffness and strength of the shear key. However, the

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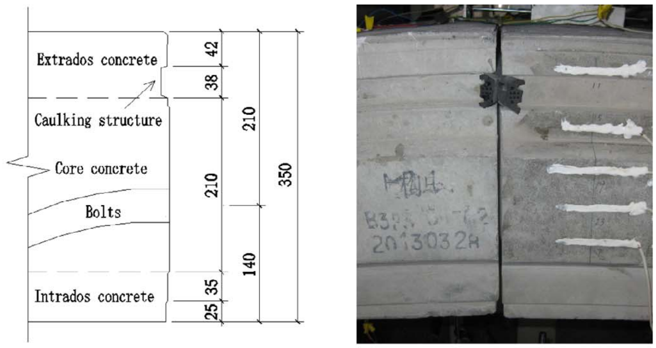
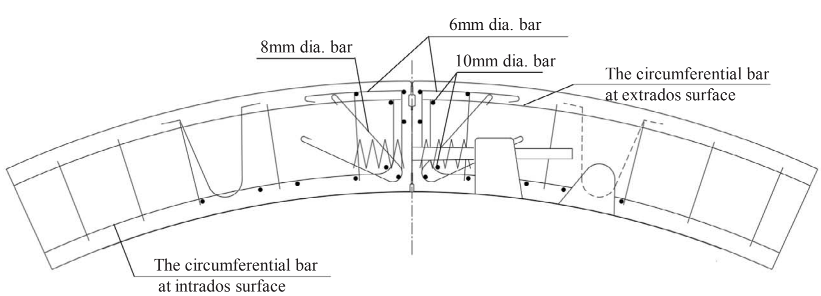
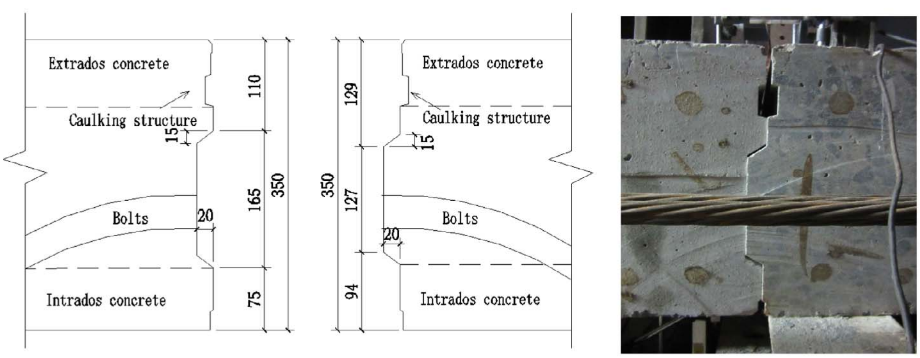


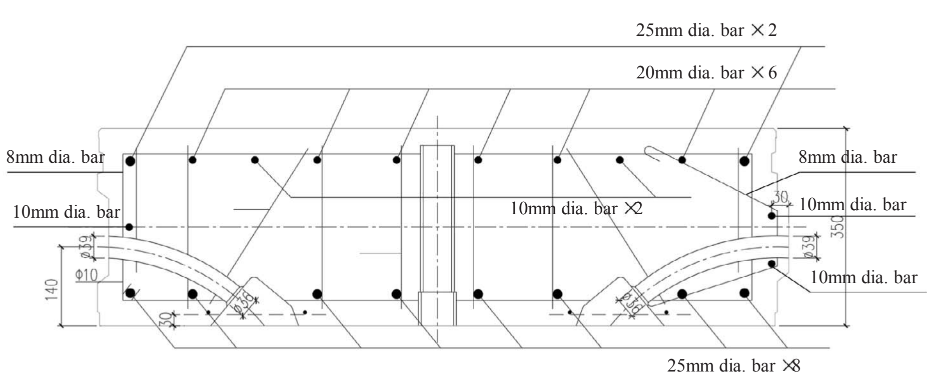
(a) Illustration of longitudinal joint



(b) Reinforcement layout of longitudinal joint



(c) Illustration of circumferential joint



(d) Reinforcement layout of circumferential joint

Fig. 1. Layout of the longitudinal and circumferential joint. (a) Illustration of longitudinal joint, (b) Reinforcement layout of longitudinal joint, (c) Illustration of circumferential joint, and (d) Reinforcement layout of circumferential joint.

researchers only focused on the experimental and numerical behaviour of the circumferential joints, and the behaviour of the longitudinal joints was not covered.

Experimental literature on this issue also proposes a different approach to study the joint behaviour based on full-ring tests. Schreyer and Winselman (2000), for example, conducted full-scale tests on full-ring segments to explore the bearing capacity and stability of the Elbe River Tunnel in Germany, and learned the bearing and deformation