Model Test Study on Longitudinal Equivalent Flexural Rigidity of Shield Tunnels Considering Axial Force Effects (Postprint)

Authors: Ren Luyao, Guan Zhenchang, Qiu Huasheng, Qiu Yujin, Zheng Junxing

Date: 2025-07-21T00:00:00+00:00

Abstract

Shield tunnels are slender tubular structures assembled from precast segments through bolting. Numerous joints between segments lead to a significant reduction in the tunnel' s longitudinal flexural stiffness, making it prone to longitudinal flexural deformation under external loads. The longitudinal equivalent flexural stiffness is a key parameter for calculating the longitudinal response of shield tunnels. In existing scaled model tests, long-strip tunnel models are often fabricated at large scale ratios, with joints simulated through springs, slotting, or other methods, failing to realistically reproduce the actual structure of circumferential joints and making it difficult to accurately reflect the influence mechanism of axial force on longitudinal flexural stiffness. To investigate the influence mechanism and patterns of axial force on longitudinal equivalent flexural stiffness, this study employs 3D printing technology to precisely fabricate segment models, which are assembled into a two-ring lining model using curved bolts and staggered joints to reproduce the actual structure of circumferential joints. Furthermore, a self-designed test apparatus directly measures the opening displacement of circumferential joints under different axial forces, and the longitudinal equivalent flexural stiffness of shield tunnels is calculated based on physical principles, thereby further investigating the influence mechanism and patterns of axial force on the longitudinal equivalent flexural stiffness of shield tunnels. The following main conclusions are obtained: The longitudinal equivalent flexural stiffness of shield tunnels decreases nonlinearly with increasing bending moment and can be divided into three stages. In the static resistance stage, the inter-ring opening displacement is minimal, and the longitudinal equivalent flexural stiffness is close to that of a homogeneous cylinder. In the elastic flexural stage, the inter-ring opening displacement gradually increases, and the longitudinal equivalent flexural stiffness decreases rapidly. In the plastic flexural stage, the inter-ring opening displacement continues to increase, and the longitudinal flexural stiffness decreases slowly and gradually approaches a constant value. Axial force significantly enhances the longitudinal equivalent flexural stiffness of shield tunnels by suppressing the opening of circumferential joints. Considering the influence of axial force, the variation range of the effective ratio of longitudinal flexural stiffness with bending moment gradually expands, extending from 5%~17% (without considering axial force) to 7%~40%. For convenience in engineering applications, the stabilized effective ratio of longitudinal flexural stiffness is taken as representative, which increases approximately exponentially with axial force, ranging from 6.08% to 16.82%. The above research results can provide references for longitudinal design and longitudinal response calculation of shield tunnels.

Full Text

Model Tests on the Longitudinal Equivalent Bending Stiffness of Shield Tunnels Considering Axial Force

Luyao Ren[1], Zhenchang Guan[1]*, Huasheng Qiu[2], Yujin Qiu[2], Junxing Zheng[3]

[1] College of Civil Engineering, Fuzhou University, Fuzhou 350116, China

[2] China Construction Fourth Engineering Bureau Co., Ltd, Guangzhou 510630, China

[3] School of Civil and Hydraulic Engineering, Huazhong University of Science and Technology, Wuhan 430040, China

Abstract

Shield tunnels are slender tubular structures assembled from precast segments using bolts. The numerous joints between segments significantly reduce the tunnel' s longitudinal bending stiffness, making it prone to longitudinal flexural deformation under external loads. The longitudinal equivalent bending stiffness is a key parameter for calculating the longitudinal response of shield tunnels. In existing scaled model tests, long strip tunnel models are often fabricated at large scales, with joints simulated using springs or slots. These methods fail to accurately reproduce the actual structure of circumferential joints, making it difficult to reflect the influence mechanism of axial force on longitudinal bending stiffness.

To investigate the influence mechanism and pattern of axial force on longitudinal equivalent bending stiffness, this study employs 3D printing technology to fabricate precise segment models, which are assembled into a two-ring lining using curved bolts and staggered joints to replicate the actual circumferential joint structure. Furthermore, a self-designed test apparatus was developed to directly measure the opening displacement of circumferential joints under varying axial forces, enabling calculation of the longitudinal equivalent bending stiffness based on physical principles.

The main conclusions are as follows: The longitudinal equivalent bending stiffness of shield tunnels decreases nonlinearly with increasing bending moment, exhibiting three distinct stages. (1) Static resistance stage: joint opening is minimal, and the longitudinal equivalent bending stiffness approaches that of a homogeneous cylinder. (2) Elastic bending stage: joint opening gradually increases, and the longitudinal equivalent bending stiffness decreases rapidly. (3) Plastic bending stage: joint opening continues to increase, and the longitudinal equivalent bending stiffness decreases slowly, gradually approaching a constant value. Axial force significantly enhances the longitudinal equivalent bending stiffness of shield tunnels by suppressing the opening of circumferential joints. When considering axial force, the variation range of the longitudinal bending stiffness efficiency with bending moment expands from 5%-17% (without considering axial force) to 7%-40%. For engineering applications, the stabilized longitudinal bending stiffness efficiency, taken as a representative value, increases approximately exponentially with axial force, ranging from 6.08% to 16.82%. The above research findings can provide references for the longitudinal design and longitudinal response calculation of shield tunnels.

Keywords: shield tunnel; circumferential joint; longitudinal equivalent bending stiffness; model test; axial force

Note: Figure translations are in progress. See original paper for figures.