Technical Research and Practice on Ultra-Large Diameter Shield Tunneling Through Composite Strata for Cutting Existing Building Pile Groups (Postprint)

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Abstract

As shield tunneling technology extends towards super-large diameters and complex geological conditions, safety control of shield excavation through existing building pile foundation groups has become a key engineering challenge. This paper takes the Guangzhou Haizhuwan Tunnel Project as the research object, relying on the engineering practice of a 15.07m super-large diameter slurry pressure balance shield machine undercrossing the Zhonghe Business Building and residential building complex, to systematically study the construction risk control system for shield excavation of pile groups in composite strata. The study reveals the deformation mechanism and risk pathways of shield tunneling undercrossing pile groups: during the interaction between shield and piles, when the cutterhead cuts pile bodies, significant changes in side friction resistance occur at the pile-soil interface, triggering stress redistribution in the soil; in composite strata, the clay mineral content of argillaceous siltstone reaches 35%, where low-density slurry causes muck disintegration leading to rapid increase in slurry density, which in turn causes cutterhead clogging and accelerated tool wear; during load transfer between underpinning structures and original structures, uneven load transfer at the instant of pile cutting can easily lead to structural instability. Based on the above mechanistic understanding, an innovative four-in-one intelligent control system of "ground improvement-tool arrangement-parameter matching-dynamic monitoring" was constructed, achieving three major technical breakthroughs: (1) Innovation in parameter coupling mechanism—A multi-parameter coupling functional relationship was established among face pressure ($±$0.1bar), cutterhead rotation speed (0.8-1rpm), and thrust force (8000-11000T). Analysis of trial excavation section data revealed that when face pressure fluctuation

exceeds $±$0.2bar, ground surface settlement variation reaches 10-30mm, whereas when controlled within $±$0.1bar, settlement variation stabilizes within $±5mm; The proportional relationship between slurry density (1.15 − 1.2g/cm^{3}) and shield torque/thrust was revealed, where each 0.05g/cm{3}$ increase in slurry density corresponds to approximately 1500T increase in thrust and 800kN·m increase in torque, providing quantitative basis for parameter matching; (2) Breakthrough in information feedback closed-loop control—A dual-source integrated monitoring technology of "above-ground building vibration-displacement monitoring system + shield cutterhead dynamic response" was developed, and a superstructure vibration prediction model based on deep learning was constructed, achieving real-time closed-loop control of "monitoring-analysis-decision-adjustment", reducing shield parameter adjustment response time to within 15 minutes. Monitoring data shows that when building settlement rate exceeds 0.5mm/d or tilt change exceeds 0.005°/d, the system automatically triggers parameter optimization, adjusting face pressure by $±$0.05-0.1bar and reducing cutterhead rotation speed by 0.1-0.2rpm, effectively controlling structural deformation; (3) Innovation in shield gap control technology—The KNM method was applied for shield gap filling, combined with dynamic slurry density control and synchronous grouting volume optimization (grouting volume controlled at 130%-135% of theoretical gap, grouting pressure 0.15MPa higher than face water-soil pressure), effectively controlling overlying soil subsidence during shield passage, reducing ground surface settlement by 30%-40% after KNM grouting. Engineering practice demonstrates: after achieving physical isolation between building pile foundations and shield zone using prestressed concrete underpinning beams, the intelligent control system successfully completed continuous grinding operations of 67 cast-in-place piles and pipe piles. According to field monitoring results, building settlement and tilt were both significantly better than control thresholds. In terms of numerical verification, comparison between predictions from the "underpinning structure-underpinned structure" 3D dynamic calculation model and extreme gradient boosting tree machine learning algorithm with measured data shows that the relative error of key parameter predictions is $ $10%, verifying the high-precision prediction capability of the control system. The research results provide a replicable technical pathway for high-efficiency, low-disturbance tunneling with large-diameter slurry shields in composite strata, offering engineering guidance value for solving the challenge of pile group avoidance in urban core area underground projects. It should be noted that this technical system is mainly applicable to argillaceous siltstone composite strata with 30%-40% clay mineral content; for strata with non-rounded gravel content exceeding 50%, working conditions with muddy soft interlayer thickness greater than 3m, and extreme hydrological conditions where groundwater level is more than 20m above tunnel crown, further optimization of ground improvement, KNM injection parameters, and slurry density control range is required; In high-pressure water-bearing strata, shield tail sealing system and backfill grouting technology should be enhanced to prevent groundwater infiltration-induced stratum instability. The clarification of these technical

boundary conditions provides a scientific applicability assessment framework for similar projects.

Full Text

Preamble

Technical Research and Engineering Practice of Excavating Existing Structures' Pile Groups in Composite Strata with Super-Large Diameter Shield Tunneling Machines

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Abstract

As shield tunneling technology advances toward super-large diameters and complex geological conditions, safety control for excavating existing building pile groups has emerged as a critical engineering challenge. This paper presents a systematic study on construction risk control systems for shield excavation of pile groups in composite strata, based on the Haizhuwan Tunnel project in Guangzhou. The research draws upon engineering practice involving a 15.07m super-large diameter slurry balance shield machine underpassing the Zhonghe Business Building and residential complexes.

The study reveals the deformation mechanisms and risk pathways during shield underpassing of pile groups. During shield-pile interaction, contact between the cutterhead and piles induces significant changes in side friction resistance at the pile-soil interface, triggering soil stress redistribution. In composite strata, the argillaceous siltstone contains 35% clay minerals, where low-density slurry causes rapid muck disintegration, leading to swift increases in slurry density that result in cutterhead clogging and accelerated tool wear. During load transfer between underpinning structures and original structures, uneven load transfer at the instant of pile cutting can cause structural instability.

Building upon these mechanistic insights, an innovative four-in-one intelligent control system integrating "soil conditioning-tool arrangement-parameter matching-dynamic monitoring" was developed, achieving three major technical breakthroughs. First, parameter coupling mechanism innovation established a multi-parameter functional relationship among face pressure ($±$0.1bar), cutterhead rotation speed (0.8-1rpm), and thrust (8000-11000T). Trial excavation data analysis demonstrated that face pressure fluctuations exceeding $±$0.2bar produce surface settlement variations of 10-30mm, whereas controlling within $±$0.1bar stabilizes settlement variation within $±5mm.Thestudyalsorevealedaproportionalrelationshipbetweenslurrydensity(1.15−1.2g/cm^{3})andshieldtorque/thrust:each0.05g/cm{3}$ increase in slurry density corresponds to approximately 1500T increase in thrust and 800kN·m increase

in torque, providing quantitative basis for parameter matching. Second, breakthrough in information feedback closed-loop control was achieved through dual-source monitoring technology combining "above-ground building vibration-displacement monitoring system + shield cutterhead dynamic response" . A deep learning-based superstructure vibration prediction model was constructed, enabling real-time closed-loop control of "monitoring-analysis-decision-adjustment" that shortened shield parameter adjustment response time to within 15 minutes. Monitoring data indicated that when building settlement rate exceeds 0.5mm/d or tilt change exceeds 0.005°/d, the system automatically triggers parameter optimization by adjusting face pressure by $±$0.05-0.1bar and reducing cutterhead speed by 0.1-0.2rpm, effectively controlling structural deformation. Third, shield gap control technology innovation applied the KRM method for shield gap filling, combined with dynamic slurry density control and optimized synchronous grouting (grouting volume controlled at 130%-135% of theoretical gap, grouting pressure 0.15MPa higher than excavation face water-soil pressure), effectively controlling overlying soil settlement during shield passage and reducing surface settlement by 30%-40% after KRM injection.

Engineering practice demonstrates that after implementing physical isolation between building piles and shield zone using prestressed concrete underpinning beams, the intelligent control system successfully completed continuous grinding of 67 cast-in-place piles and pipe piles. Field monitoring results indicate that building settlement and tilt were significantly better than control thresholds. Numerical validation using a three-dimensional dynamic calculation model of "underpinning structure-underpinned structure" and extreme gradient boosting tree machine learning algorithm showed prediction relative errors for key parameters $ $10%, verifying the high-precision prediction capability of the control system. The research provides a replicable technical pathway for efficient, low-disturbance tunneling of large-diameter slurry shields in composite strata, offering engineering guidance for solving pile group avoidance challenges in urban core underground projects. It should be noted that this technical system is primarily applicable to argillaceous siltstone composite strata with 30%-40% clay mineral content. For strata with non-rounded gravel content exceeding 50%, soft mucky interlayers thicker than 3m, or extreme hydrogeological conditions where groundwater level exceeds tunnel crown by more than 20m, further optimization of soil conditioning, KRM injection parameters, and slurry density control range is required. In high-pressure water strata, enhanced shield tail sealing systems and backfill grouting processes should be implemented to prevent groundwater infiltration-induced instability. These clearly defined technical boundary conditions provide a scientific applicability assessment framework for similar projects.

Keywords: Super-large diameter slurry shield; Pile group excavation; Building underpassing; Composite strata

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