Postprint: Graded Prevention and Control Measures for Thermal Hazards in Deep-Buried Tunnels

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Date: 2025-08-20T00:00:00+00:00

Abstract

Deep-buried tunnels face coupled multi-hazard threats from high rock temperature, high-temperature water, and harmful gas outbursts, inducing thermal hazard effects such as deterioration of the temperature-humidity environment within the tunnel, intensified deformation and failure of surrounding rock, cascading failure of support structures, and multi-dimensional gaseous disaster chains. Traditional single cooling technologies are inadequate to cope with the highly concealed and abrupt chain reactions of thermal-water-gas disasters, seriously threatening construction safety and structural durability. To overcome the limitations of existing weak prevention and control systems and achieve full-chain governance of various thermal hazard effects from source blocking to post-disaster response, first, by systematically reviewing the research focuses and achievements of various prevention and control measures, multi-dimensional disaster control technologies are formed, including concrete composite modification to enhance the heat resistance of support systems, dynamic ventilation for thermal environment regulation, efficient heat resistance, surrounding rock reinforcement, and dynamic humidity-temperature balance, thereby constructing a collaborative prevention and control strategy integrating the trinity of "heat source blocking-environment regulation-structure protection". Then, classification-based prevention and control measure recommendations are proposed for coupled disaster scenarios involving multiple factors such as surrounding rock temperature, harmful gas concentration, surrounding rock classification, and humidity. Finally, future research trends for deep-buried tunnel thermal hazard prevention and control are discussed, which should shift from passive response to active regulation, deepen intelligent regulation of thermal hazard dynamic responses through digital twin technology, and explore engineering integration innovations for geothermal resource recovery and low-carbon materials. The research findings provide theoretical basis and technical reference for

promoting the systematization and standardization of tunnel thermal hazard prevention and control systems.

Full Text

Graded Prevention and Control Measures for Thermal Disasters in Deep-Buried Tunnels

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Abstract

Deep-buried tunnels face coupled multi-hazard threats from high rock temperatures, hot water inrush, and harmful gas emissions, which induce severe thermal effects including deteriorating temperature-humidity environments, accelerated surrounding rock deformation and failure, cascading support structure failures, and multi-dimensional gaseous disaster chains within the tunnel. Traditional single cooling technologies struggle to address the highly concealed and abrupt thermal-water-gas chain reactions, posing serious threats to construction safety and structural durability. To overcome the limitations of existing weak prevention and control systems and achieve full-chain management of thermal hazards from source blocking to post-disaster response, this study first systematically reviews research priorities and achievements in various prevention measures. This review informs the development of multi-dimensional disaster control technologies, including concrete composite modification to enhance support system heat resistance, dynamic ventilation for thermal environment regulation, high-efficiency heat resistance, surrounding rock reinforcement, and dynamic moisture-heat balance management. Based on these, a collaborative "heat source blocking-environmental regulation-structural protection" trinity prevention and control strategy is constructed. Subsequently, graded prevention and control measures are proposed for coupled disaster scenarios, incorporating multiple factors such as surrounding rock temperature, harmful gas concentration, rock classification, and humidity. Finally, future research trends in deep tunnel thermal hazard prevention are discussed, emphasizing a shift from passive response to active regulation, deepening intelligent control of thermal hazard dynamic responses through digital twin technology, and exploring engineering integration innovations for geothermal resource recovery and low-carbon materials. The research findings provide theoretical foundations and technical references for advancing the systematization and standardization of tunnel thermal hazard prevention and control systems.

Keywords: tunnel engineering; geothermal anomaly zones; prevention and control measures; thermal hazards; cooling and insulation; graded prevention and control

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