

Groundwater Dewatering Prediction, Verification, and Response for Yong' an Tunnel Excavation in the Western Chongqing Water Resources Allocation Project: Postprint

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Abstract

Tunnel excavation and groundwater dewatering constitutes a major environmental geological issue in tunnel engineering projects. The hydrogeological analogy method and analytical method were employed to predict the influence radius of groundwater drainage resulting from Yong' an Tunnel excavation in the Western Chongqing Water Resources Allocation Project. The results demonstrate that the influence radius ranges from 0-533 m in the severely affected zone, 533-1470 m in the moderately affected zone, and 1470-2500 m in the generally affected zone. Construction verification reveals that the actual severely affected zone of groundwater drainage increased by 12.57%, the moderately affected zone increased by 12.75%-23.80%, and the generally affected zone increased by 23.80%-20.00%, thereby confirming certain reliability of the predictive outcomes. Consolidation grouting treatment was implemented on the surrounding rock in tunnel sections experiencing concentrated and linear water inflow to prevent water seepage from the rock mass into the tunnel and restore the groundwater level. Based on relevant engineering experience, the groundwater level in the tunnel surrounding rock requires 3-5 years to recover during consecutive wet years and 5-10 years during dry years, with a recovery degree of approximately 80%-93%.

Full Text

Prediction, Verification, and Countermeasures of Groundwater Dewatering During Yong'an Tunnel Excavation in the Western Chongqing Water Resources Allocation Project

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Abstract

Groundwater dewatering during tunnel excavation represents a major environmental geological challenge in tunnel construction projects. This study employs the hydrogeological analogy method and analytical method to predict the influence radius of groundwater dewatering during the excavation of the Yong'an Tunnel in the Western Chongqing Water Resources Allocation Project. Previous researchers have utilized imaging technology to classify the dewatering influence range into damaged zones, groundwater seepage field zones, and critical damage zones, analyzing the relationship between tunnel reinforcement rings and groundwater seepage fields, thereby evaluating the comprehensive permeability of tunnel surrounding rock and analyzing the impact of dynamic water heads on tunnel excavation dewatering. Li et al. conducted research on the variation patterns of groundwater level and water chemical composition in tunnel surrounding rock, discovering that water inrush during tunnel excavation causes groundwater to flow into the tunnel, leading to spring depletion and intensifying hydrochemical processes in the dewatering zone.

Domestically, with the implementation of the national Western Development Strategy, the number of tunnel constructions has increased, making this problem relatively more complex. Continuous exploration has been conducted on the prediction and prevention of groundwater dewatering during tunnel excavation. For example, Yang Lizhong et al., in their study of the Huayingshan Tunnel, proposed that tunnel drainage would cause ecological and environmental problems such as groundwater circulation imbalance and groundwater resource loss, leading to karst spring depletion, artificial water shortage in the area, groundwater quality pollution, and a series of negative environmental effects including surface soil erosion. Wu Zhisheng et al., analyzing tunnel construction in karst areas, found that the Hengguang Double-track Naling Tunnel, which adopted a "drainage-first" approach, experienced severe mud and sand loss. After tunnel completion, the soil erosion rate in the project area was nearly 5,000 times faster than under natural weathering conditions.

Prediction of groundwater dewatering influence radius during tunnel excavation mainly employs the hydrogeological analogy method and analytical method. The hydrogeological analogy method involves investigating and analyzing

the hydrogeological environment of 28 typical existing tunnel projects in Chongqing, summarizing the dewatering influence radius for tunnel excavation in the Chongqing area, with strongly affected zones having a radius of 0–1500 m, moderately affected zones 0–1000 m, and generally affected zones 1000–2000 m. The analytical method primarily includes the influence radius calculation formula recommended in the “Technical Guidelines for Environmental Impact Assessment—Groundwater Environment” and the Kusakin formula.

This paper discusses the prediction of groundwater dewatering influence radius, construction verification, and groundwater recovery countermeasures for the Yong’ an Tunnel excavation in the Western Chongqing Water Resources Allocation Project, and evaluates the effectiveness of groundwater restoration based on actual project conditions and relevant engineering experience. The research results provide valuable reference for predicting the influence range of groundwater dewatering during tunnel excavation and developing corresponding countermeasures.

Keywords: Western Chongqing Water Resources Allocation Project; Yong’ an Tunnel; groundwater dewatering prediction; construction verification; countermeasures

Introduction

Groundwater dewatering phenomena during tunnel excavation frequently occur and often produce negative ecological and environmental effects on industrial and agricultural production as well as residential water supply, representing a significant environmental geological issue in engineering construction. For instance, during the construction of the Zhongliangshan Tunnel on the Xiangyu Railway from January 1971 to December 1978, 48 water wells were dewatered, water levels in 82 springs declined, and over 29 collapse points developed, with a dewatering influence range of 1.0–2.1 km. Similarly, the Gele Mountain Tunnel on the Yuhuai Railway, constructed between April 2001 and December 2002, experienced water inrush that caused flow reduction in reservoirs and springs, triggered surface karst collapses, and produced a dewatering influence range of 2.5–6.1 km. Another example is the Mingyueshan Tunnel on the G42 Highway, constructed from 2005 to 2007, which experienced water and mud inrush resulting in severe loss of surface water and groundwater resources, with a strongly affected area of 36.8 m², moderately affected area of 152.3 m², and generally affected area of 608.8 m².

Research on the environmental effects of tunnel excavation on groundwater systems has been conducted both domestically and internationally. International studies include work by Juan Ramon Rapso et al., who conducted field monitoring and water balance model analysis to predict groundwater dewatering ranges and proposed post-construction recharge measures to gradually restore the groundwater environment in tunnel surrounding rock. Lipponen et al. applied rock fracture data from tunnel construction for environmental analysis.

Domestic research includes Zhao Jinfeng's (2004) study on the impact of Gele Mountain Tunnel construction on the surrounding groundwater system and environmental effects. Qin Renpei, Xiao Jun, and Jiang Feng (2007) investigated comprehensive treatment measures for water and mud inrush in the Mingyueshan extra-long tunnel. These studies collectively demonstrate the critical importance of predicting, monitoring, and mitigating groundwater dewatering impacts during tunnel excavation.

2.1 Project Overview

The Western Chongqing Water Resources Allocation Project is the largest water diversion project in Chongqing in terms of investment, coverage area, and beneficiary population. It has been included in the national "14th Five-Year Plan" and the State Council's list of 150 major water conservancy projects, classified as a large-scale (Type 1) project. The Yong'an Tunnel is located on the west main line of the Western Chongqing Water Resources Allocation Project, with a total length of 12,351.2 m, maximum burial depth of 225 m, inlet floor elevation of 274.84 m, outlet floor elevation of 270.76 m, a city-gate arch cross-section with clear dimensions of 3.5 m (width) \times 4.3 m (height), and a design flow rate of 16.0 m³/s. Full-scale excavation began in January 2022, and the tunnel breakthrough was achieved on April 7, 2024 [Figure 1: see original paper].

2.2 Meteorology and Hydrology

(1) Climate

The Yong'an Tunnel project area has a subtropical monsoon humid climate, with an average annual rainfall of 1095-1155 mm. Precipitation from July to October accounts for approximately 85.0% of the annual total. The average annual evaporation is 925.0-1137.5 mm.

(2) Hydrology

The Yong'an Tunnel project area belongs to the Yangtze River system. Surface water and groundwater flow toward the northwest and southeast wings, respectively. The Yangtze River serves as the lowest drainage base level for the project area.

[Figure 1: see original paper] Schematic layout of Yong'an Tunnel

2.3 Engineering Geology

The Yong'an Tunnel sequentially crosses the Bishan Syncline (Chainage Y0+000 to Y7+800), the Libixia Anticline (Chainage Y7+800 to Y12+351.2), and intersects them at a large angle, with a tunnel axis orientation of 317° [Figure 1: see original paper]. The geological conditions are as follows:

Chainage Y0+000 to Y5+476: The strata consist of Jurassic Upper Suining Formation (J_{3s}) mudstone, argillaceous siltstone intercalated with sandstone;

located at the core and wings of the Bishan Syncline, with gently dipping rock strata.

Chainage Y5+476 to Y8+688: The strata consist of Jurassic Middle and Lower series (J_2s , J_2xs , J_2x , $J_1\ 2z$, J_1z) with lithology of mudstone, argillaceous siltstone, and shale; located on the northwest wing of the Bishan Syncline and southeast wing of the Libixia Anticline, with gently to moderately dipping rock strata.

Chainage Y8+688 to Y9+250: The strata consist of Triassic Upper Xujiuhe Formation (T_3xj) feldspathic quartz sandstone intercalated with gray-black shale, carbonaceous shale, and thin coal seams; located on the southeast wing of the Libixia Anticline, with moderately to steeply dipping rock strata.

Chainage Y9+250 to Y11+518: The strata consist of Triassic Lower Jialingjiang Formation (T_1j) limestone, dolomite, and argillaceous limestone, with well-developed surface karst features including peak-cluster depressions, karst valleys, and sinkholes; located at the core and wings of the Libixia Anticline, with moderately dipping rock strata.

Chainage Y11+518 to Y12+025: The strata consist of Triassic Upper Xujiuhe Formation (T_3xj) sandstone intercalated with gray-black shale, carbonaceous shale, and thin coal seams; located on the northwest wing of the Libixia Anticline, with moderately dipping rock strata.

Chainage Y12+025 to Y12+351.2: The strata consist of Jurassic Middle and Lower series (J_2s , J_2xs , J_2x , $J_1\ 2z$, J_1z) with lithology of mudstone, argillaceous siltstone, and shale; located on the northwest wing of the Libixia Anticline, with moderately dipping rock strata, with the outlet adjacent to the Shimiaochang Syncline.

2.4 Hydrogeology

In the bedrock of the Yong' an Tunnel project area, mudstone, argillaceous siltstone, and shale constitute relatively impermeable rock formations that act as aquitards; sandstone is a moderately permeable rock formation that acts as a relative aquitard; limestone, dolomite, and argillaceous limestone are permeable rock formations that serve as aquifers. Groundwater types include pore water, fissure water, and karst water. Pore water is distributed in the Quaternary overburden; fissure water is distributed in sandstone fractures; karst water is distributed in limestone, dolomite, and argillaceous limestone. Groundwater in the Yong' an Tunnel project area is recharged by atmospheric precipitation and discharges into the excavated tunnel or topographic low points, ultimately draining into the Yangtze River through surface runoff. No confined groundwater has been identified.

2.5 Tunnel Excavation Water Inflow

Yong' an Tunnel excavation caused groundwater to discharge into the tunnel. Water inflow was primarily concentrated in the sandstone tunnel sections at Chainage Y8+622 to Y9+281 and Chainage Y11+177 to Y12+176 [FIGURE:2(D)], and in the limestone tunnel section at Chainage Y9+281 to Y11+177 [FIGURE:2(E)]. The inflow occurred as concentrated, linear, and point-form flows. In 2022, there were 40 concentrated and linear inflow points during excavation, with individual discharges of 260–2160 m³/d and a total annual inflow of 11,874,910 m³/d, accounting for approximately 94.83% of the annual total (Table 1). In 2023, there were 75 concentrated and linear inflow points, with individual discharges of 250–1980 m³/d and a total annual inflow of 22,852,765 m³/d, accounting for 86.72% of the annual total (Table 1). In both 2022 and 2023, drip-form inflow accounted for only 5.17%–13.28% of the total inflow.

Monthly drainage volumes for Yong' an Tunnel in 2022 and 2023 (Unit: m³)

3.1 Prediction Methods for Dewatering Influence Radius

The main methods for predicting the dewatering influence radius during tunnel excavation are the hydrogeological analogy method and the analytical method. When the hydrogeological conditions and parameters of a new tunnel are similar to those of existing tunnels, the hydrogeological analogy method can be used to predict the dewatering influence radius. When the hydrogeological boundary conditions of a new tunnel are clear and the aquifer permeability coefficient is reliable, the analytical method can be used, such as the prediction formulas recommended in the “Technical Guidelines for Environmental Impact Assessment—Groundwater Environment” (Equation (1)) and the Kusakin formula (Equation (2)), both of which belong to the analytical method.

3.2 Parameter Values

Parameter values for Equations (1) and (2) are provided in Table 2 .

Prediction parameters for dewatering influence radius of Yong' an Tunnel excavation

3.3 Prediction Results

The prediction of dewatering influence radius for Yong' an Tunnel excavation employed both the hydrogeological analogy method and analytical method.

(1) Hydrogeological Analogy Method

Using the dewatering influence radius data from 28 typical existing tunnel excavations in Chongqing, arithmetic averages were calculated as the predicted influence radius for Yong' an Tunnel excavation (Table 3).

(2) Analytical Method

Equations (1) and (2) were applied to calculate the dewatering influence radius for Yong'an Tunnel excavation, with results presented in Table 4.

The predicted dewatering influence radius for Yong'an Tunnel excavation was taken as the average of the hydrogeological analogy method results and the calculations from both the "Technical Guidelines for Environmental Impact Assessment—Groundwater Environment" recommended formula (Equation (1)) and the Kusakin formula (Equation (2)). The strongly affected zone was predicted to be 0–533 m, the moderately affected zone 533–1470 m, and the generally affected zone 1470–2500 m.

The dewatering influence range of Yong'an Tunnel excavation primarily expands along both sides of the tunnel axis toward the north and south of the anticline, extending north to "Qilongxue" and south to the "Dabasi" area, east to the tunnel inlet at "Dalangou," and west to the tunnel outlet at "Aopingshang." Based on the predicted influence radius, the affected area has a maximum north-south length of approximately 12.310 km, a maximum east-west width of 1.590 km, and a total affected area of approximately 19.625 km². The strongly affected zone is located in the limestone strata at the core of the Libixia Anticline, covering an area of 0.892 km² (4.54% of the total affected area). The moderately affected zone consists of sandstone strata, covering an area of 3.140 km² (16.14% of the total). The generally affected zone comprises mudstone, argillaceous siltstone, and shale strata, covering an area of 14.198 km² (79.31% of the total). Six ponds are located within the generally affected zone. Comparison between the actual dewatering impact range and the preliminary prediction (Table 5) shows that the strongly affected zone increased by 12.57%, the moderately affected zone increased by 12.75%–23.80%, and the generally affected zone increased by 23.80%–20.00%.

Hydrogeological analogy method prediction results for dewatering influence radius (Unit: m)

Analytical method prediction results for dewatering influence radius (Unit: m)

Comparison between measured and predicted influence radius values for Yong'an Tunnel excavation (Unit: m)

4.1 Construction Verification

Yong'an Tunnel excavation was conducted from July 2021 to April 2024, with the peak period from January 2022 to December 2023. The excavation caused surface water bodies to dry up and groundwater levels to decline within a certain range, resulting in surface water and groundwater dewatering phenomena. Field investigations confirmed that the dewatering impact zone is located within the dissolution valley of the Libixia Anticline [Figure 3: see original paper].

The strongly affected zone extends approximately 500 m on both sides of the tunnel axis, encompassing surface water bodies such as the limestone quarry, Yuanjiawan Pond, and Tangjiawan Pond. The moderately affected zone spans

500–1820 m, including seven ponds such as the Danfeng drinking water source sinkhole, the Jidong Cement Chongqing Jiangjin Co., Ltd. machine well, and Xinwuji. The generally affected zone covers approximately 1820–3000 m, including the Moxiakou Reservoir and Sibao Cave.

[Figure 3: see original paper] Actual range of groundwater dewatering during Yong’ an Tunnel excavation

4.2 Countermeasures

To address the groundwater dewatering issues caused by tunnel excavation, the following countermeasures were implemented:

- (1) Groundwater dewatering caused drinking water difficulties for residents in the Danfeng sinkhole area, affecting 5,173 people with a water supply scale of 296 m³/d. An emergency water supply solution was adopted during construction, sourcing water from the Jianchaogou Reservoir at the mountain foot to the original Danfeng water plant to meet the needs of affected residents.
- (2) Surface water bodies such as hill ponds and reservoirs could not retain water normally due to increased infiltration gradients and leakage channels formed by tunnel excavation. Anti-seepage treatment was applied to the reservoir periphery and basin.
- (3) The original machine well of Jidong Cement Chongqing Jiangjin Co., Ltd. dried up due to groundwater level decline caused by tunnel excavation. Four new deep wells were installed with depths of approximately 150 m to meet the enterprise’ s water demand.
- (4) Consolidation grouting treatment was applied to the surrounding rock in tunnel sections with concentrated and linear water inflow to block water ingress from the surrounding rock into the tunnel and gradually restore and raise the tunnel groundwater level.

4.3 Expected Effect Evaluation

- (1) The emergency water supply solution for the Danfeng area during construction effectively resolved domestic drinking water problems for residents. Anti-seepage treatment of pond and reservoir peripheries and basins can address long-term local production and domestic water needs.
- (2) The installation of four new deep wells approximately 150 m deep can meet local enterprise water requirements.
- (3) Consolidation grouting treatment blocks water ingress from surrounding rock into the tunnel and gradually restores and raises the tunnel groundwater level. Influenced by atmospheric precipitation and hydrogeological factors, relevant engineering practice predicts that the groundwater dynamic equilibrium cycle in tunnel surrounding rock recovers relatively

quickly within 3-5 years during consecutive wet years, and more slowly within 5-10 years during consecutive dry years, with a recovery degree of approximately 80%-93%.

Conclusions

- (1) In the Yong' an Tunnel surrounding rock, mudstone, argillaceous siltstone, and shale are relatively impermeable rock formations; sandstone is moderately permeable; and limestone, dolomite, and argillaceous limestone are permeable aquifers. Groundwater types include pore water, fissure water, and karst water. Tunnel excavation causes groundwater to discharge into the tunnel, resulting in groundwater dewatering and negative ecological environmental effects, representing a major environmental geological problem in engineering construction.
- (2) Both hydrogeological analogy and analytical methods were used to predict the dewatering influence radius for Yong' an Tunnel excavation. Results indicate a strongly affected zone of 0-533 m, moderately affected zone of 533-1470 m, and generally affected zone of 1470-2500 m. Construction verification revealed that the actual strongly affected zone increased by 12.57%, the moderately affected zone increased by 12.75%-23.80%, and the generally affected zone increased by 23.80%-20.00%, demonstrating that the prediction results have certain reliability and significance for engineering prevention measures.
- (3) Countermeasures for tunnel excavation dewatering include emergency measures and long-term measures. Emergency water supply solutions effectively resolve domestic drinking water problems; consolidation grouting treatment of sections with strong water inflow blocks water ingress and gradually restores and raises groundwater levels, with recovery taking 3-5 years during consecutive wet years and 5-10 years during consecutive dry years, achieving a recovery degree of approximately 80%-93%.
- (4) With the advancement of national water network projects, groundwater dewatering during tunnel excavation will become a major environmental issue in tunnel engineering construction. Continuous accumulation of experience is needed to improve prediction technical levels. The widely used hydrogeological analogy and analytical methods for predicting dewatering influence radius have been verified through Yong' an Tunnel practice, achieving prediction accuracy of 76.20%-87.25%, with results providing important significance for pre-emptive engineering prevention measures. Furthermore, with accumulated engineering experience, analytical prediction formulas need continuous improvement to enhance prediction accuracy.

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