Advanced Geological Forecasting in the Main Plant of Hydropower Stations

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Abstract. Based on the TGS360Pro advanced geological forecasting method, a three-dimensional geological forecasting system was developed for a hydropower station tunnel with a long route, significant burial depth, high groundwater level, and multiple large fault crossings, highlighting major engineering geological issues. Research shows that by applying the solid-liquid dual-phase medium theory, combined with on-site working conditions and geological information revealed at the face, and conducting a comprehensive analysis of corresponding stress, water content probability, longitudinal wave velocity, transverse wave velocity, the ratio of longitudinal to transverse wave velocities, Poisson's ratio, Young's modulus, and surrounding rock hazard levels, predictive forecasting results can be obtained. The differences in data and wave field characteristics were analyzed, and successful application was achieved at a certain hydropower station. This method effectively addresses the challenges of advanced geological forecasting in hydropower station tunnels, with excavation verification yielding good results.

Keywords: Underground Tunnels; Comprehensive Advanced Geological Forecasting; Seismic Wave Forward Modeling Technology.

1. Introduction

In recent years, the country has increased the construction efforts for infrastructure and major livelihood projects, planning many transportation and water conservancy hydropower projects with long routes, deep burial, and high technical difficulty[1,2]. However, due to the treacherous terrain and complex geological conditions, the ground geological survey work is extremely challenging. Despite the use of many new technologies, methods, and equipment in the geological survey process, engineering geological issues remain difficult to clarify. Therefore, it is essential to adopt advanced geological forecasting for underground caverns. This article combines engineering practice and innovatively incorporates the seismic wave propagation mechanism in a biphasic medium into the advanced forecasting of underground caverns based on the theoretical foundation of TGS advanced geological forecasting. It expands the attribute range of the target body for seismic wave method advanced forecasting, constructing a technical system for TGS advanced geological forecasting that extends from detecting unfavorable geological structures such as soft rock fracture zones and alteration zones to water-rich structures. This serves as an important means to ensure the safety of tunnel construction, reduce construction risks, and safeguard personnel and equipment safety[3,4].

2. Basic Principles

The theoretical foundation of seismic wave forward modeling technology mainly consists of two categories: ray equations and wave equations. Numerical simulations based on wave equation theory can comprehensively characterize various dynamic properties of seismic waves, such as energy, frequency, wavelength, and phase. With advancements in computational technology, the academic community has developed many numerical simulation methods for seismic wave fields based on wave equation theory, such as finite difference method[5], pseudospectral method , finite element method , and spectral element method . The spectral element method was introduced into seismic wave numerical simulation from fluid mechanics numerical simulation[6]. This method is a numerical solution approach for partial differential equations that organically combines finite element methods and spectral methods. In the application process, finite element methods are first used for discretization, and spectral methods are used for interpolation within the elements, with orthogonal polynomials constructed for the shape functions of the elements. The spatial discretization has very high precision, and the computational accuracy can be adjusted by changing the order of the approximate polynomials. It not only possesses the inherent advantage of the finite element method in flexibly handling complex boundary problems but also absorbs the advantages of the pseudospectral method, such as fast convergence and high accuracy.

3. System Overview

3.1 System Introduction

TGS360Pro is a new generation geological forecasting system from Russia and is also the world's leading and advanced geological forecasting system[7]. The TGS360 Pro system is based on the method of forecasting using seismic reflection waves of different polarizations, allowing for the selection of different sources (large hammer, hydraulic hammer) and explosives[8]. The hammer source can achieve a detection range of up to 100 meters under suitable geological conditions, while the explosive source can reach 200 meters. The data acquisition system is preset with three-component geophones, which can be distributed on both sides of the tunnel wall or at the face, with a maximum of 8 three-component geophones (Figure 1). Receiving holes are arranged within a certain range on both sides of the underground chamber wall or at the face. By artificially exciting seismic waves on both sides of the wall or at the face, the seismic waves propagate in the tunnel surrounding rock in the form of spherical waves. When the wave impedance of the surrounding rock changes (for example, encountering karst, faults, or interfaces of rock layers), a portion of the seismic waves will be reflected back, while another portion will continue to propagate forward. The reflected waves are received by high-precision receivers and transmitted to the main unit to form seismic wave records.

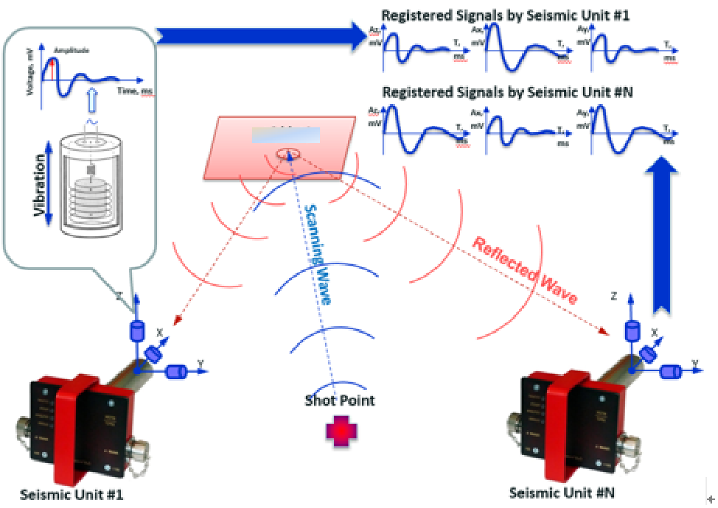

Figure 1. TGS360Pro Geological Forecasting System

3.2 Data Collection

The test site should be free from mechanical vibration interference. The sensor is installed in the borehole and is tightly coupled. The instrument should be placed in a dry and safe area. After powering on the early warning system, if the sensor indicator light shows green, it means the sensor is installed correctly; if the indicator light shows red, it means the sensor installation exceeds ±6°. The appropriate sampling interval and recording length should be selected based on the rock type of the test surface, and according to relevant regulations, the sampling interval should not exceed 0.5 ms. The instrument report includes: project name, file name, test surface location, L (sensor arrangement length), W (width of the underground chamber), h1 (height of the lower row sensor from the bottom of the face), h2 (height of the upper row sensor from the bottom of the face), R (distance from the sensor to the face), h (height of the sensor from the bottom of the hole), excitation method, recording length, instrument delay, etc.

4. Engineering Examples

4.1 Project Overview

The underground powerhouse cavern group of this hydropower station consists of the main powerhouse, main transformer cavern, tailgate chamber, water diversion tunnel, busbar tunnel, and tailwater tunnel. The scale of the underground powerhouse cavern group is relatively large, and the rock mass of this cavern group is metamorphic fine sandstone in the T3z2(4) rock formation, characterized by thick to medium-thick layers, with well-developed structural surfaces, mostly weak interlayer surfaces, and gently dipping structural surfaces; the slope unloading is severe, and the geological conditions are complex. The proportion of the three major caverns (underground main powerhouse/main transformer room/tailgate chamber, spatial position as shown in Figure 6-3) of IV and V class surrounding rock reaches 20% to 40%. At the same time, considering the small angle (30° to 40°) between the rock layers of the hydropower station and the axis of the cavern group, the steep dip, and the severe unloading of the high side walls during the excavation process, in addition, the development of the gently dipping f20 fault and Ph compression zone within the plant area also has a certain impact on the stability of the surrounding rock of the cavern.

4.2 Test Results

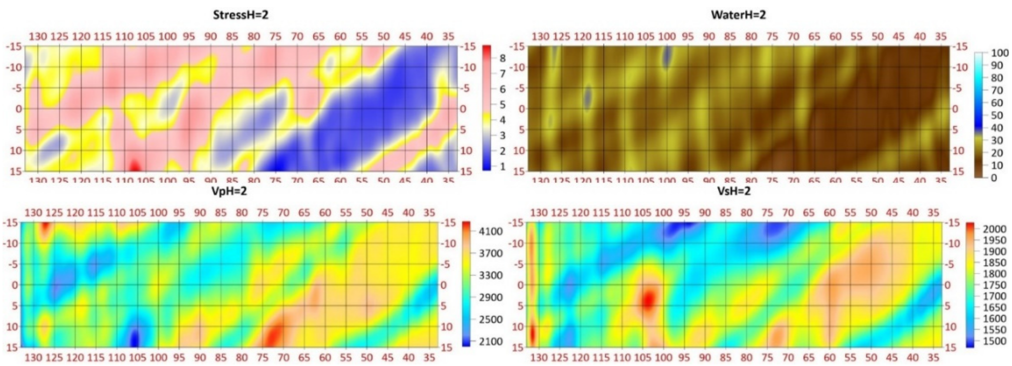

Figure 2. Distribution map of stress, water content probability, longitudinal wave velocity, and transverse wave velocity levels

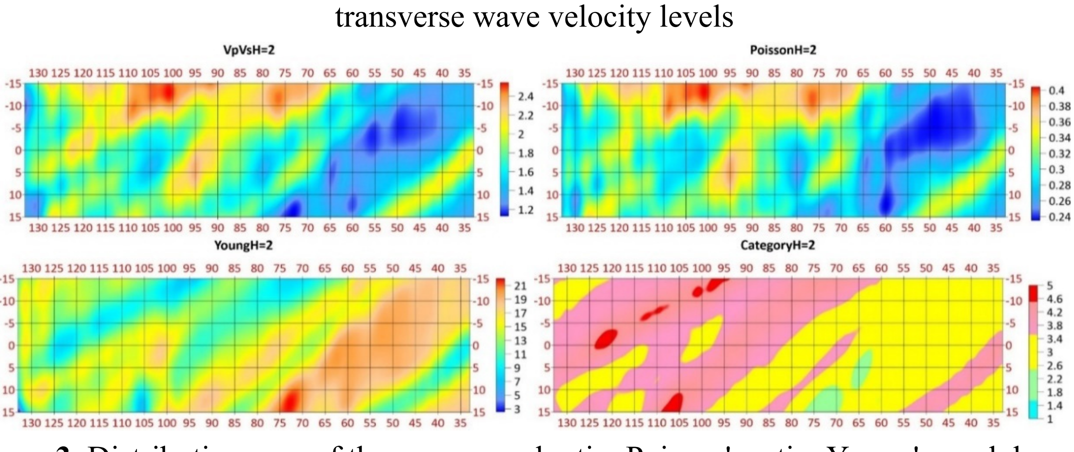

Figure 3. Distribution map of the wave speed ratio, Poisson's ratio, Young's modulus, and surrounding rock hazard level

The advanced geological forecast for the section from 0+133m to 0+033m on the right side of the hydropower station has an effective forecast length of 100m. Ten sets of valid data collected were used for software processing and analysis. The results within a 100m range in front of the face include corresponding stress, water content probability, longitudinal wave velocity, transverse wave velocity, ratio of longitudinal to transverse wave velocity, Poisson's ratio, Young's modulus, and surrounding rock hazard level, as shown in the result chart (see Figure 2- Figure 5).

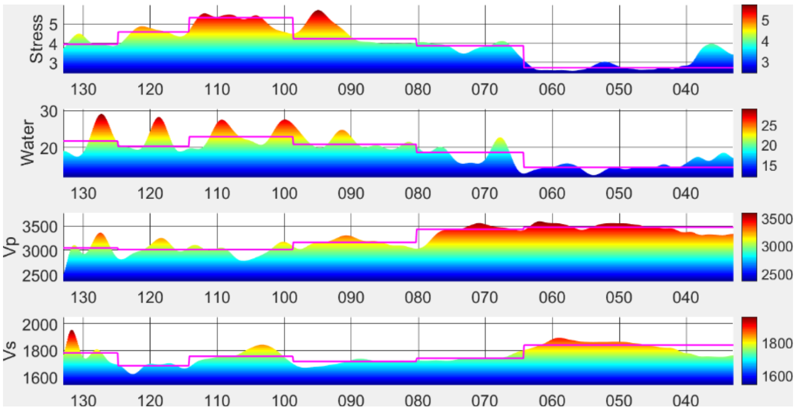

Figure 4. Corresponding changes in stress, water content probability, longitudinal wave velocity, and transverse wave velocity levels

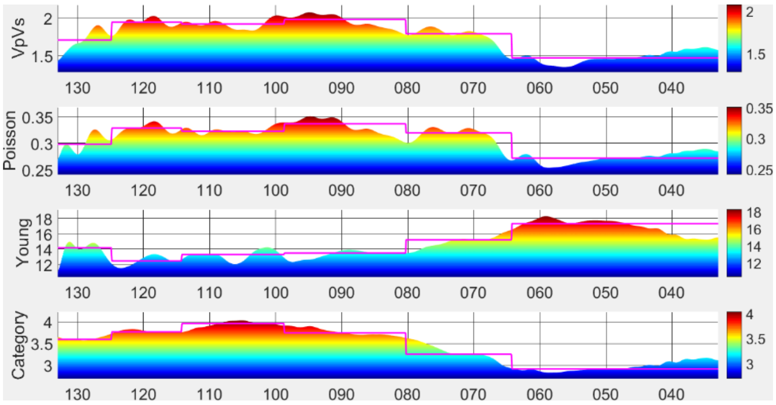

Figure 5. Variation diagram of the wave speed ratio, Poisson's ratio, Young's modulus, and surrounding rock hazard level

4.3 Results Analysis

Based on the on-site working conditions and the geological information revealed at the face, a comprehensive analysis of the corresponding stress, water content probability, longitudinal wave velocity, transverse wave velocity, ratio of longitudinal to transverse wave velocity, Poisson's ratio, Young's modulus, and the hazard level of the surrounding rock is conducted.

0+133m~ 0+124m: The overall integrity of the surrounding rock in this section: relatively fragmented ~ poor integrity, mainly fragmented, accounting for 82%. The rock mass structure is gravelly and angular ~ boulders and gravel-like structure; the surrounding rock category is mainly Class IV. Within the testing range, the average value of Young's modulus is about 13.9 GPa, and the range of hazard level variation is: 3.6 ~ 3.7. Comprehensive assessment of this tunnel section: the surrounding rock category is mainly Class IV; the rock mass quality is poor, with certain risks, severely affected by geological structures, and well-developed joints; after excavation of the surrounding rock, if the arch is unsupported, significant collapses can occur, and the side walls may sometimes lose stability.

0+124m~ 0+114m: The rock mass is generally quite fragmented with poor integrity, primarily fragmented, accounting for 71% of this measurement section; the rock mass structure is characterized by gravel and cobble-like structures; the surrounding rock category is mainly Class IV. Within the testing range, the average Young's modulus is approximately 12.5 GPa, and the range of hazard levels varies from 3.7 to 3.8. Overall, this tunnel section is assessed as follows: the surrounding rock category is mainly Class IV; the rock mass quality is poor, with certain risks present, severely affected by geological structures, and well-developed joints; after excavation of the surrounding rock, significant collapses can occur at the arch without support, and the sidewalls may sometimes lose stability.

0+114m~0+080m: The surrounding rock is relatively fragmented, primarily classified as Category IV; the rock mass quality is poor, severely affected by geological structures, with well-developed joints; when the arch has no support after excavation of the surrounding rock, significant collapses can occur, and the side walls may sometimes lose stability. In this section, the average value of the Young's modulus is about 13.2 GPa, and the range of danger levels is: 3.8 to 4.0. Overall, it is determined that this tunnel section has a surrounding rock category mainly of Class IV; the rock mass quality is poor, with certain risks present, severely affected by geological structures, and the joints are well developed. After excavation of the surrounding rock, if there is no support at the arch, significant collapses can occur, and the side walls may sometimes lose stability.

0+080m~0+064m: The rock mass is generally fragmented with poor integrity, primarily characterized by poor integrity, accounting for 75% of this measurement section; the rock mass structure is gravelly and angular, with boulders and gravel-like structures; the surrounding rock category is mainly Class III. Within the testing range, the variation of Young's modulus is: 13.5GPa~16.5GPa, and the variation of hazard level is: 2.9~3.6. Overall assessment of this tunnel section: the surrounding rock category is mainly Class III; the rock mass quality is average, with certain risks and developed joints; after excavation of the surrounding rock, if there is no support at the arch, significant collapse may occur, and the side walls may sometimes lose stability.

0+064m~0+033m: Overall integrity of the surrounding rock: relatively fractured ~ poor integrity, mainly poor integrity, accounting for 73% of this measurement section; the rock mass structure is gravelly angular structure ~ boulders and gravel structure; the surrounding rock category is mainly Class III. Within the testing range, the average value of Young's modulus is approximately 16.9 GPa, and the range of hazard level variation is: 2.8 ~ 3.2. Comprehensive assessment of this tunnel section: the surrounding rock category is mainly Class III; the rock mass quality is average, severely affected by geological structures, with developed joints and layered weak planes (or interbedded hard and soft rocks); poor interlayer bonding, with many separation phenomena; after excavation of the surrounding rock, small collapses may occur at the arch without support, while the side walls are generally stable, but excessive blasting vibrations can easily lead to collapses.

4.4 Comparison of Results

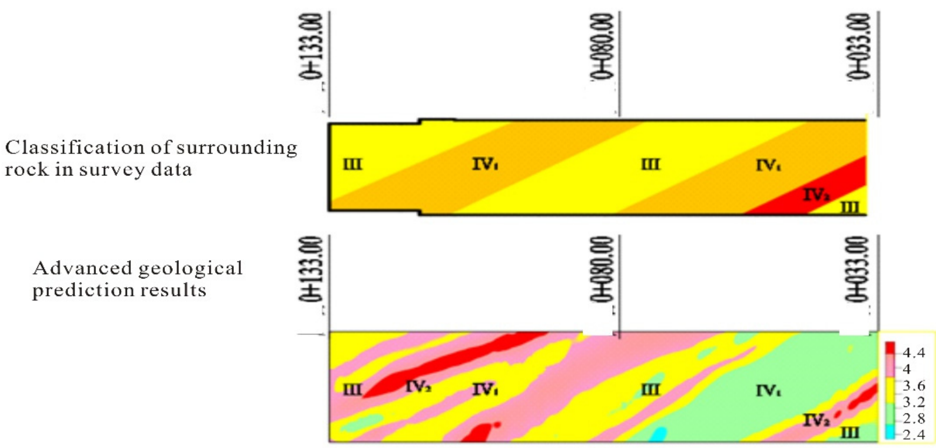

Figure 6. Comparison of the classification results of surrounding rock types in the main plant

The comparison chart of the classification results of surrounding rock types in the main plant shown in Figure 6 indicates that in the preliminary survey data, the first segment had Type III and Type IV surrounding rock, while the middle segment had Type III surrounding rock and the tail segment had Type IV surrounding rock. In this advanced geological forecast, the first segment has

Type III and Type IV surrounding rock, the middle segment has Type III surrounding rock, and the tail segment has Type IV surrounding rock. The classification of surrounding rock types from the preliminary survey is basically consistent with the changes observed in this advanced geological forecast, showing significant results in the fine classification of local surrounding rock types.

5. Conclusion

(1) The advanced geological forecast for the right side of the hydropower station from 0+133m to 0+033m totals 100m, with the test section from 0+133m to 0+090m. The rock mass in this section is relatively fragmented with poor integrity, and the rock mass mostly exhibits a blocky gravel structure; the joints are well developed, and the surrounding rock is primarily classified as Class IV; the water inflow at the face is generally moderate, with well-developed fissure water in the bedrock, and there may be dripping water within the excavation range. The results are basically consistent when compared with the excavation verification.

(2) The application of TGS360 Pro geological forecasting in hydropower station projects has successfully predicted adverse geological phenomena such as tunnel water inflow, mud outbursts, and collapses, effectively preventing chamber collapse and roof fall incidents. It has also provided important decision-making support for emergency response, advanced support, and support design. The conclusions of this method are intuitive, accurate, and easy to operate.

(3) Accurately forecasting the geological conditions ahead of construction is the foundation for the prevention and control of geological disasters in tunnels. Reliable advanced forecasting can not only prevent major accidents such as collapses and roof falls due to adverse geological conditions during excavation, but also provide a basis for optimizing support parameters, saving time and reducing investment. The TGS360Pro tunnel three-dimensional geological forecasting system can meet the requirements for geological forecasting in hydropower stations and related tunnel projects.

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