Research on the Impact of Hydrogeological Conditions on Mine Geotechnical Engineering Design and Countermeasures

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Abstract: This study focuses on the safety and quality issues arising from hydrogeological conditions in mine geotechnical engineering design. Based on actual engineering scenarios, it analyzes the impact of groundwater pressure, corrosivity, and water level changes on design. It summarizes the current problems in design, such as insufficient monitoring, disjointed protection measures, and delayed predictions. Through specialized investigations, material and process optimization, and dynamic control methods, it elaborates on specific countermeasures, including accurately determining groundwater parameters, implementing targeted anti-corrosion measures, and dynamically monitoring and regulating water levels. The aim is to demonstrate that these countermeasures can effectively solve problems such as rock-soil mass instability, structural corrosion, and construction safety hazards, providing scientific support for mine geotechnical engineering design and enhancing engineering safety and durability.

1. Introduction

With the continuing development of underground mining operations the hydrogeological conditions are starting to impose final limits on practical geotechnical design. Groundwater pressure changes easily lead to slope sliding. Groundwater that is corrosive decreases the service life of structures, and increases or decreases in water levels (of a sudden nature) threaten construction safety. Those things are going to just cascade into bigger engineering risk and cost if they aren't adequately addressed upfront. At present, for design, hydrogeological conditions are usually simplified and oversimplified and thus hard to be adapted in complex engineering requirements. Thus, hydrogeological conditions should be organized and collated systematically to delineate the effect mechanisms and put forward the corresponded measures so that it would give reasonable directions for mine geotechnical engineering design.

2. Impact of Hydrogeological Conditions on Mine Geotechnical Engineering Design

2.1 Decline in Rock-Soil Mass Stability Due to Groundwater Pressure

There is little attention paid to long-term dynamic monitoring of the head height of confined water levels in previously mined areas with specific reference to groundwater pressure when it comes to current mine geotechnical engineering. However, most projects only make a few head measurements during the first investigation stage without building a real time monitoring system for the whole engineering lifecycle. Over the duration of mining, variations of stratum structure and aquifer interconnectivity can produce large rapid shifts in confined water head. These dynamic changes are difficult to adapt to by changing the support parameters that were determined during the design stage e.g., based on early static data [1]. Groundwater pressure distribution is highly inhomogeneous near complex geological structures like faults. The conventional investigation techniques encounter challenges in effectively portraying the localized elevated pressure zones. In design, if these hidden danger points are ignored, it will cause the support structure to have local weakness and even endanger safety.

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2.2 Structural Damage to Engineering Structures Caused by Groundwater Corrosivity

The way we currently connect groundwater corrosivity assessment to mine geotechnical engineering design and the selection of protective measures during the design process needs improvement. Groundwater chemical property analysis is often limited only to simple detection of pH value and the concentration of common ions, mainly because of many complex physical and chemical processes involved in synergistic corrosion mechanisms caused by different chemical components within long-term environments. With respect to material selection by designers, conventional calculations based on experience are usually used that consider no targeted modifications according to localized corrosion; the details of corrosivity assessment considered in [2]. As an illustration, ordinary concrete is used in certain mine shaft and tunnel designs. In the case where the groundwater contains strongly acidic regions with a high concentration of sulfate ions, and no anti-corrosive treatment as well as measures such as making sulfate-resistant cement are taken. Concrete spalling and steel bar corrosion on shaft walls occur soon after being put into use, which greatly short the service life of structures.

2.3 Impact of Groundwater Level Changes on Construction Safety

Several prediction methods of groundwater level change have emerged for mine geotechnical engineering design but those ones are lagging behind. These practices depend primarily on historical water level data and basic seasonal experience based assessments without properly factoring in the remodeling impacts of mining activities on regional hydrogeological conditions. Mining dewatering of large scale can alter the flow path of groundwater, leading to drastic reduction in regional groundwater level. With the topography, landform and drain system limits of the mine, local water levels can be rapidly rising during extreme weather events such as heavy rain [3]. However, the logical reasoning of effective stress increase in rock-soil mass due to draw down groundwater profile how increased in dry season and that is also affected on shrinkage or crack development which lead to reduce foundation bearing capacity are often no be considered for underground mining design in worldwide. As a result, uneven settlement occurs at the bottom of the mining area, which affects the normal operation of equipment.

3. Countermeasures for the Impact of Hydrogeological Conditions on Mine Geotechnical Engineering Design

3.1 Precise Investigation to Determine Groundwater Parameters

Create a Targeted Investigation Plan   Specify the scope and depth of investigation. The area of interest should include the area impacted by mine geotechnical engineering plus an area with a scale 1-2 times that of the engineering area to capture a hydrogeological unit exhaustively. Therefore the level of the investigation has to cover all aquifers intervened in the engineering. In case, for example, the excavation depth of the engineering is 50 m the depth of investigation boreholes must reach to 30 or more 50 m below excavation surface in order to retrieve parameters of deep confined water.

Align the investigation boreholes with the characteristics of stratum distribution: In homogeneous soil layer, Buried hole should be restricted in 50-80m; In complex geological structure area or yield greater variability of soil property, they should be limited to 20-30m to ensure that the data has a representativeness Field tests:Basic parameters performed on site:Pumping tests : Steady-state pumping method. In order to stabilize water level before the test, the water level should be stabilized by standing for more than 24 h. In the pumping process, it is appropriate to divide them into 3 - 5 drawdown stages for stable time (no less than 8 h) recording water inflow and water level drawdown data. Use Dupuit equation or Theis formula for calculation of permeability coefficient (decide which formula to use based on your aquifer type). For the unconfined and confined aquifers, respectively, these are also called: Dupuit and Theis formulas [4]. Packer tests: Use single point or five point approach. Test pressure: set to 1.2 - 1.5 times the engineering design pressure, each stage of pressure is stable for not less than 30 min; Measure ground water and determine the quality measure items such as pH value, chloride ion concentration, sulfate ion concentration (detection accuracy up to 0.01 mol/L), which will provide a basis for the corrosion resistance design in the future; Build the Groundwater Numerical Model and make simulation analysis: By using the professional software, such as Visual MODFLOW or FEFLOW. Verify that the model grid division meets the accuracy requirement, and does not exceed 5 m × 5 m at a minimum. Input stratum parameters and hydrogeological parameters from investigation. Create boundary conditions Specifically, while the boundary conditions can be determined with this model, it must then be inter-related with regional hydrological data to make certain that they are consistent with real and existing hydrogeological conditions. Perform water level changes and pressure distributions based on different working conditions. The simulation duration must not only include the engineering construction period, but also the first 5-10 years of operation and discharges the water pressure data of key locations under various working conditions so as to serve as a quantitative basis for engineering design [5]. Parameter validation and correction: Compare simulation calculation results with initial field monitoring data. If the error between the calculated and measured water levels is greater than 5% mode, change model parameters, simulate again until this error can be controlled within 3%.

3.2 Targeted Selection of Anti-Corrosion Materials and Processes

Developing material selection specifications according to groundwater chemical properties: Material classification, based on human judgment of groundwater corrosivity, Water pH 2000 mg/L, the concrete will use sulfate resistant in cement strength grade of not less than 42.5R, fly ash or slag powder accounted for 20% -30% fitness cement coefficient methods can to improve the anti-corrosion performance of concrete. Steel bars should use316L stainless steel bar or epoxy coated steel bar when the chloride ion concentration exceeds 1000 mg/L. Epoxy coating thickness control at 0.18-0.30 mm and the coating adhesion not less than 5 MPa.

Test for anti-corrosion performance of materials: The 28-day chloride migration coefficient of concrete should be less than 1.5×10^{-12} m²/s as detected through the rapid chloride migration test (RCM); the corrosion resistance of steel bars should be detected through the neutral salt spray test, and there should be no coating peeling off during the whole process and not more than 5% rust area within a period time of 500 h in [6].

Optimize the parameters of anti-corrosion construction processes:

In shaft and tunnel concrete law: For shotcrete process Spraying pressure should be controlled at 0.3-0.5 MPa, and the spraying distance is kept between 1.5-2.0 m so that the concrete can not only have certain tightness but also reduce porosity. In concrete curing, it can not be less than 28 days water spraying and the top surface of concrete keep wet in the first 7 days that will avoid the early crack happened.

Floors Surfaces: For anti-corrosion coating construction the first step is surface treatment before construction, for example concrete surface, which should have a flatness deviation of no more than 3 mm/m; Floating dust and oil stains need to be removed, such as sandblasting base layer treatment grade Sa2 rust removal. The coating construction can use the high-pressure airless spraying method, And it should control the speed of spraying in 0.3-0.5 m/s, Spraying for 2 - 3 times (the interval between every two passes curing interval is not less than 4 h), so as to avoid miss spraying and guarantee a uniform coating.

Optimize the design and control of grouting for water blocking:Based on the permeability coefficient of groundwater, select a suitable type of grouting material. For permeability coefficient > 1×10^{-4} m/s, use a cement-water glass double liquid grout (water glass concentration of 35 -45 Be', cement slurry water-cement ratio of (1:1 - 1:1.5), and double liquid grout volume ratio of 1:0.5 - 1:1. Use the ultra-fine cement slurry when permeability coefficient is less than 1×10^{-6} m/s, when that value is determined with a water-cement ratio of 1:1 - 1:2 [7]. Grouting pressure is set to 1.5 - 2.0 times the static water pressure of the stratum The grouting is implemented in section, the section length controlled at 2 - 5 m, and maintain 30 min pressure after the end of grouting for each section. Conversely, when the grouting pressure remains stable while the slurry intake is less than 5 L/min, it indicates that the grouting of this section shall end. After grouting, conduct quality detection. Packer test to identify the grouting effect; packer test pressure is 80% of design grouting pressure. The grouting is qualified when the unit length water consumption is less than 0.01 L/(min·m·m), otherwise it has to re-grouting to achieve a good isolation between corrosive groundwater and engineering structure.

3.3 Dynamic Monitoring and Regulation of Groundwater Level

Dynamic monitoring system of groundwater level: Determine the locations of monitoring points reasonably based on engineering scale and hydrogeological conditions. On open-pit mine slopes, the monitoring point is arranged every 50-100 m along slope strike direction, and in each monitoring point 2-3 observation boreholes of different depths are used to monitor the unconfined water level and confined water level respectively. Research regions of the monitoring points to arrange on behalf of underground shaft and tunnel engineering, the green belt at (1)Tunnel heading; (2) Both sides of Tunnel;(3)Shaft bottom car yard arranged 30-50 m in-depth observation boreholes penetrated two or three aquifers above the tunnel roof [8]. Choose the monitoring devices of automated water level gauges which is accuracy ±1 mm. Once the data once is collected via 1 time/hour, during special periods change to 1 time/15 min. Through the wireless transmission system, the monitor can upload its monitoring data to the monitoring center in a real-time manner, so as to achieve a remedial action for water level dynamics. Establish a plan for regulating water levels: During the rainy season, the aim of regulation is to drain. Drainage demand = Maximum Rainfall Catchment Area It is required that the selected drainage pump has a drainage capacity greater than 1.2 times the value calculated in engineering practice. Open the diameter of drainage pipes in accordance with a velocity 1.5-2.0 m/s for the flushing water stream and to prevent stagnant material. Victorian Standards, 2006 Sumps should be set in pits and low points of tunnels (sump volume designed for 5-10 min. maximum water inflow) and spaced no more than 50 m apart to permit easy and rapid accumulation of water Use groundwater recharge technology in the dry season to regulate water levels. Treated mine water inflow, which meets the Class III standard of the "Quality Standard for Groundwater" (GB/T14848-2017), is preferentially used as a recharge water source. Setting up recharge wells in areas where the groundwater level has dropped obviously, controlling recharge pressure at a set-point of 0.2 - 0.4 MPa to maintain the water flow into each of the designed recharge wells and combining with regulation of a recharge volume corresponding to drop rate ensure that the groundwater constants obtained within acceptable limits are governed by engineering; preventing rock-soil mass shrinkage & cracking, along with mobilizing shallow surface layers entire ground model studied simultaneously during construction and maintenance processes stages (ps as design principles). Set up an emergency response mechanism: In the design of underground mining, it is necessary to reserve emergency drainage channels; for different working conditions, the cross-sectional dimensions should be designed according to the flow of emergency drainage. Where the flow is more than the normal drainage, the emergency drainage flow shall be double. Should be equipped with emergency drainage equipment, such as mobile drainage pumps and backup power supplies. The top elevation of the mobile drainage pumps should meet the maximum height for draining away water from hydroengineering, while the backup power supply must last at least a further 48 h (in preparation for an unforeseen loss of mains electricity, still allowing uninterrupted functioning of pumping units) [9]. Invoke when the groundwater level rise rate at monitoring data is more than 0.5 m/d or the water level arrives warning value the emergency response, the input of drainage equipment, to open the emergency drainage channels, while stopping the underground operations personnel evacuation. When the water level drop rate is greater than 0.3 m/d, you should start to recharge system, increase the volume of recharge system, when necessary,then the mining operation plan of design will be appropriate control degree replenish supplement in order to achieve best effect, if to ensure normal gale state that security engineering safety and construction schedule and keep your carry on with tempo proportions full blast dewater or partial pressure slowly so as to not lose sight of goals.

4. Conclusion

As illustrated by the above, the core hydrogeological factors affecting mine geotechnical engineering design include groundwater pressure, corrosivity and changes in water level; these may result in a gradual decrease of rock-soil mass stability, structural corrosion damage, and increased construction safety risk. In particular, targeted proposals of countermeasures such as precise investigation, optimization of anti-corrosion materials and processes and dynamic monitoring and regulation can solve the above-mentioned problems. Testing parameters via scientific investigation, concretizing adapting materials and processes, effectively regulating the water level in real-time monitoring can raise the rationality of engineering design, guarding against unsafe conditions and instability of mine geotechnical engineering within the duration of construction and operation, providing guidance for similar project designs.

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