Application Analysis of Geotechnical Engineering Survey Technology under Complex Geological Conditions

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Abstract: This study focuses on addressing the challenges of technical adaptation difficulties and low data accuracy of geotechnical engineering surveys under complex geological conditions. The paper analyzes the full application process of geotechnical engineering survey technology in this kind of environment against a multi-technology collaboration and process optimization background. A synthesis of the operational logic for four central stages is contained within this study: geo-prediction, multi-technology gathering at an exploration target level, processing & modelling and the ubiquitous validation/verification process. Moreover it discusses about three measures to find the optimization: smart device integration, targeted tests for technological fit and implementing an inter-technology data sharing platform. Through systematic and practical verification, the proposed application process can effectively avoid interference when dealing with complex geological conditions to ensure the integrity and reliability of data collection. The optimization methods reduce the errors of survey data more bases and solve the problem through reducing the operational costs formed by different types of uncertainties, which provides a sound technical way for performing geotechnical engineering surveys under complex geological conditions. In addition, this framework provides a data basis for the safe progress of subsequent engineering designs, responding to the fundamental problem that traditional survey technologies are not adaptable enough to new geological situations.

1. Introduction

At the present time, China's infrastructure construction is constantly expanding into deep and remote areas, resulting in more and more complex geological conditions such as karst development zones, fault fracture zones and alternating soft soil hard rock layers. These geological conditions are featured with a series of stratigraphic structures and great uncertainty, thus making survey problems such as borehole wall collapse and data distortion. Conventional survey methods based on only single drilling methods cannot fully reflect complex geological data and often produce the mismatch of surveying and real geology. This, in turn, impacts the rationality of engineering designs, escalates the safety risk during construction and ushers in higher cost inputs. To that end, systematically collating the application process of geotechnical engineering drilling under complex geological conditions alongside investigations into optimising approaches to survey such ground effectively have never been more prominent in ensuring safe and effective construction. The paper will interpret the whole application process and optimization methods, which can give some references for geotechnical engineering surveys under complicated geological condition.

2. Application Process of Geotechnical Engineering Survey Technology under Complex Geological Conditions

2.1 Preliminary Geological Condition Prediction and Scheme Design

Multi-source Geological Data Collection and Integrated Analysis First, collect 1:50,000 regional geological maps, previous engineering survey reports, and borehole data from local geological survey institutes. The main effort is focused on delineating the approximate distribution ranges of

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more complex geological bodies like: faults, karst caves and weak interlayers. Next, take high-resolution remote sensing images (spatial resolution ≥0.5 m), by image interpretation to identify surface cracks and abnormal topographic areas, and to make preliminary judgments on the extension trends of underground geological structures [1]. Cross-validate the data collected by confronting the stratigraphic lithology displayed in boreholes to surface features interpreted from remote sensing images. If something seems contradictory, flag those areas as needing more attention in future surveys. Now we can apply this to deal with horizontal variation the following way: Determining Survey Boundaries by Type of Engineering: In general, 1 Survey a fixed impact zone that extends from +50 m to -100 into un-impacted soils from the engineering influence area. Choose suitable technologies for different complex geological characteristics: In zones of karst development, add to routine drilling, Geological radar detection equipment with a frequency of 25–100 MHz which can detect depths of 10–30 m below the surface of the strata to find out the karst caves. In fault fracture zones, borehole layouts can be densified with a hole space reduced to 10–20 m and the holes are required to reach into the fault zone and stable stratum more than 5 m in order to obtain exact mechanical parameters of faults [2].

In Formulating Risk Disposal Procedures: Mark disposal procedures clearly in case of the possibilities that there be risks during surveys namely, water inrush, borehole collapse similar suchs and overflow of toxic gases. In the case of encountering water inrush, promptly suspend drilling, place a water-stop casing into the wellbore along with regular pumping equipment for pressure data and water inflow data record. For borehole collapse, either use casing following drilling or inject mud that is controlled to a specific gravity of 1.2 to 1.4. Quality Control Indicators of Survey: Vertically deviate of boreholes should not exceed 1%, and the rate collected by geological radar must not be less than 95% to ensure a standardization and safety scheme for implementation.

2.2 Multi-technology Collaborative Field Data Collection

Drilling Technology in Complex Strata: Alternating layers of soft soil and hard rock and weathered rock layers use 108 to 146 mm casing-following drilling. The casing is immersed beyond the unstable strata (can't exceed over 3–5 m),The drilling speed must be dynamically master based on stratigraphic lithology: control the speed at 0.8–1.2 m/min in soft soil layers and reduced to a range of 0.3-0.5 m/min in hard rock layers, which can not use too fast, maybe cause to breakage of rock core by drilling speed is excessive. Rock Core Collection and Description: Restrict each round-trip drilling advance to no more than 2 meters between advances; Rock core recovery greater than 85% (no less than 65% in broken strata). The rock cores are numbered, photographed and described, in particular features such as the degree of fracture development and cementation status should be recorded so that a basis is provided for subsequent stratigraphic classification [3]. Concurrent Geophysical Exploration: Carry out concurrent geophysical exploration during drilling activities. For high-density electrical methods, use the Wenner array with electrode spacing 5–10 m, keeping measurement depth consistent with drilling depth to detect resistivity differences between geologic bodies and find underground karst voids and water body distributions Use hammer blow source (3-5 m geophone spacing) to get travel times of high frequency surface waves that can be modeled for wave velocities and stratigraphic interfaces with seismic refraction methods. Evaluate and compare both geophysical datasets Contrasteroes refer to karst caves and water-bearing layers which can be further certified by future drilling if the low-resistivity anomaly area of high-density electrical methods coincides with the low-velocity layer that is reflected in seismic refraction methods.

In-situ Testing: Perform in-situ tests right after finishing drilling holes. Standard penetration tests are performed with a hammer of 63.5 kg that is allowed to free-fall through a distance of 76 cm and record the blows required for a penetration depth of every 30 cm. Perform tests every 1–2 m in the same borehole Use the single-point method for pressure water tests; adopt a test pressure at 1.2 times of the engineering design water head. Calculate the permeability coefficient of rock mass according to the volume of water pressure at each level and its 30–min stability. Relate well log response to the properties of drill rock cores. The standard penetration blow count is typically below

5 for softer soil layers. If an abnormally high value occurs, check whether the test equipment is normal or there are interlayers in the strata [4]. On-site Data Collection and Validation: Provide portable data collection units that input drilling, geophysical exploration, and in-situ test information into the system on a real-time basis. After each survey point, confirm at the field if the drilling advance, geophysical curves and readings of tests are already over. Collect immediately if data is abnormal or missing to prevent adhering to the difficulties of supplementation in later time.

2.3 Data Processing and Geological Model Construction

Data preprocessing: For drilling data, remove the abnormal round trips that cause the recovery rate of rock core to fall below 60% due to borehole wall collapse, and fill in with interpolation from adjacent boreholes. For both geophysical data, use professional software tools to pre-process (remove noise from electromagnetic interference and topographic effect) high-density electrical method method data using tools such as RES2DINV, and also filter seismic refraction transmission line raw response signals with SUFER. To reduce boundary effect errors, smooth the geophysical inversion results. In the case of in-situ test data, corrections can be applied for instance by modifying standard penetration test results considering groundwater level and stratigraphic density, and/or converting pressure water test data into permeability coefficients under standard conditions so that data from different survey points can be compared [5]. Geotechnical Parameters Calculation: Extract important geotechnical parameters based on the preprocessed data. The calculus of strata natural unit weight by the weighting according to layers thickness, i.e,, to calculate according to the weighted average method. Interpret shear strength performance by Mohr-Coulomb strength parameters. Statistical analysis is performed on the parameters of same stratum to determine mean, mean of standard deviation and coefficient of variation. Such as the coefficient of variation is greater than 0.3, abnormal causes such as fault influence have been analyzed to supplement test data. Params are structured by stratification which is the fundelementary information to establish a parameter table, this serves as an inputwith sample size and confidence for each param becomes reliable inputs tomodel construction. Choose modelling software (GeoStudio, FLAC3D, etc.) to build the geological model. First, Load topography data to create the surface model. Finally, stratigraphic models are built layer by layer, guided by the stratigraphic interfaces discovered through drilling and the geological structures revealed with geophysical exploration. Use fine grid subdivision to represent morphology for complex geologic interfaces (karst cave roof or fault contact surface) constrained by a grid size of 1–5 m. Specify derived geotechnical parameters for each layer, also individual classes highlighted to the observed special zone — such as a fault zones and karst caves. Perform a topology check to verify that the model's stratigraphic contact relationships are reasonable (i.e. there should be no suspended or overlapping volumes) after building [6]. Model simulation analyse: modelling engineering construction events, e.g. foundations pit excavations and tunneled cases that may occur during the construction phases. Simulate stress and displacement variation in geotechnical materials under various scenarios. Teaching example: Foundation pit excavation simulation is an important part of the foundation design, which can precipitate unloading in layers according to excavation depth. Analyze the stability of surrounding rock while boundary is moved for tunnel(tache) construction simulation. The throughput of simulation outputs from important locations such as the bottom of foundation pit and top of tunnel arch is compared against engineering safety limits. Mark risk areas if the limits are surpassed and make optimization suggestions to further designs while allowing to quantify engineering designs through model usage.

3. Approaches to Optimize the Application Effectiveness of Geotechnical Engineering Survey Technology

3.1 Introduction of Intelligent Monitoring Equipment to Improve Data Accuracy

Selection of Equipment: Based on the characteristics of complex geological conditions, the choice of equipment goes far and wide. For capturing images in regions of large topographic relief, opt for high definition optical cameras (20 million pixels resolution) mounted on UAVs and precise Inertial measurement units in mountainous areas. Use micro-strain-level accuracy non-performing fiber-optic sensors [7] in areas where monitoring of mini-changes in deep strata is needed. Immerse the UAV in open areas to fix the positioning result into ±0.5 m, which will be calibrated. Clean and smooth wall within pore-hole 4.installing fiber-optic sensors Lower the sensors along the borehole walls and fix them with special anchoring agents. Then, perform wavelength calibration and signal testing to realize stable signal transmission.

Data Collection and Analysis: Flying in 5–10 m/s at preset routes; Image collection frequency at 5–10 frames/s; Fiber-optic sensor data collected once per minute. Process the collected data through filtering and noise reduction, analyze the data with professional software to generate topography change curves and stratigraphic stress-displacement change curves, which provides accurate quantitative data support for surveys.

3.2 Establishment of a Cross-technology Data-sharing and Collaborative Platform

Pick a platform architecture: Select a distributed architecture to prevent bottlenecks and enhance data storage stability The platform must supply functional modules for Data entry, data storage, query, analysis and visualization. Data Access and Integration: Drilling data can be manually input, or can be automatically integrated using instruments into the platform. Geophysical data should first be converted to a format that can be read before being accessed. Test data of in-situ truned to the platform directly. Eliminate abnormal data using data cleaning algorithms, and build the association between two datasets from different technologies, such as linking the geophysics interpretations of stratigraphic interface depth with drilling-obtained geotechnical sample depths [8].

Collaborative Operation Function Implement: Change user authority to distinct types of access survey personnel only able to upload and update data on real-time basis while design personnel to query and analyze over the date online. The platform also needs to include online discussion and feedback functions for users, in order that a two-way channel is established between the survey results and the designs; data flows from surveys to designs smoothly, utilization efficiency of data through design increases and we minimize deviations due to information gaps.

3.3 Conducting Targeted Technical Adaptability Tests

Division of test area according to the type of geological formation: Establish 3–5 test points in high-temperature permafrost strata, and establish 5–8 test points in coastal soft soil strata. Selection of Test Technologies and Indicators: Test the influence of various drilling fluids on borehole stability and permafrost thawing for permafrost areas, backfilling methods (such as filling height (m) in gaps filled with cement slurry, formation section time (h), etc.), it can be reflected by indicators such as borehole collapse rate. Compare the shear strength parameters obtained from static penetration tests and vane shear tests, in soft soil area (maximum parameter difference rate) Testing of Implementation: Technical Tests as per norms at all test points. In the conductive processing of permafrost, control the drilling speed at 2–3 m/h and record different drilling fluids. For soft soil areas have a site with the same test environment intervals of 1–2 m and conduct two types of tests [9]. Data Analysis and Guideline Formation: Mathematical statistics: calculate each index (mean, standard deviation) from the test data. Perform multi-criteria comparison of different technical applications for the same geological target(design a technical application protocol which provides recommendations on how to choose appropriate technologies that are closely as possible to realistic engineering practices) and standardized approaches for next site investigations deploy configurations in complex geological conditions.

4. Conclusion

This study clarified the core application system of comprehensive geotechnical engineering survey techniques in complex geological conditions: By integrating multi-source geological data and cross-validation, we are able to develop customized survey plans and formulate risk contingency plans according to engineering requirements, ensuring efficient and standardized surveys. By integrating the "drilling, geophysical exploration, and in-situ testing" approach together with adjusting technical parameters and operational methods for complex strata, the sufficiency of data and information accuracy are effectively improved. The quantitative analysis of the engineering design can be realized through three-dimensional geological model, which must first preprocess the discrete survey data to obtain parameter statistics and refine modeling.

The introduction of intelligent equipment was critical for improving the data collection accuracy; the establishment of a data-sharing platform optimized data utilization efficiency; and technical adaptability tests enhanced the adaptation of technology to complex geological conditions. The combined use of the three aspects mentioned above can increase performance of traditional survey techniques, through overcoming the limitations associated with big errors and low information transmission capacity and level of technical adaptability in the surveys.

References

[1] Zhang Minze. Analysis of Geotechnical Engineering Survey Techniques under Complex Geological Conditions [J]. Architecture, Building Materials, Decoration, 2025(10): 178-180.

[2] Gao Runze. Analysis of the Application of Geotechnical Engineering Survey Techniques under Complex Geological Conditions [J]. China New Technologies and New Products, 2024(22): 104-106.

[3] Yu Jie. Geotechnical Engineering Survey Techniques and Their Application Results under Complex Geological Conditions [J]. Building Materials & Decoration, 2024, 20(29): 142-144.

[4] Wang Peixing. Exploring the Application of Geotechnical Engineering Survey Techniques under Complex Geological Conditions [J]. China Housing Facilities, 2023(11): 49-51.

[5] Xu Wei. Research on the Application of Geotechnical Engineering Survey Techniques under Complex Topographic and Geological Conditions [J]. Engineering Technology Research, 2024, 9(14): 48-50.

[6] Chen Yu. Exploration of Geotechnical Engineering Survey Techniques under Complex Geological Conditions [J]. Auto Time, 2023(9): 178-180.

[7] Wei Wei, Yuan Yongjian, Cui Kai, et al. Application of Engineering Geophysical Exploration in Geotechnical Engineering Surveys under Complex Geological Conditions [J]. Sichuan Journal of Geology, 2025, 45(1): 96-100.

[8] Han Chao, Sun Xiaowei. Discussion on the Practice of Geotechnical Engineering Survey under Complex Topographic and Geological Conditions [J]. Engineering Technology Research, 2023, 8(19): 220-222.

[9] Lu Wanxue. Exploration of Geotechnical Engineering Survey Methods under Complex Topographic and Geological Conditions [J]. Digitized User, 2024(38): 67-68.