A Cloud Database for Data-Driven and Intelligent Analysis of Slopes: Development and Application in Hubei Province, China

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Abstract: This study developed a cloud-based slope database system for Hubei Province, China, leveraging extensive existing engineering data to establish a foundational platform for data-driven and intelligent computational methods in slope engineering. The system employs MySQL as the backend database management system and adopts a Browser/Server (B/S) architecture, enabling deployment and operation in both local and cloud server environments. It supports remote data operations, including addition, deletion, modification, and query, as well as one-click export functionality. Currently, the cloud database contains 1,700 slope records from Hubei Province, comprising 34,863 data entries, covering engineering geological characteristics, stability analysis results, mitigation measures, and monitoring data for slopes along multiple national and provincial highways. Taking the deterministic identification of rock uniaxial compressive strength (UCS) as an example, empirical formulas for estimating the UCS for various rock types in the database are proposed. It demonstrates that the cloud database can provide a data foundation for engineering treatment of slopes.

Keywords: Slope, Database, Geotechnical parameter, Uniaxial compressive strength.

1. INTRODUCTION

The construction of slope databases serves as the fundamental groundwork for data-driven slope parameter identification and stability analysis. Under a data-driven framework, intelligent analysis algorithms that are efficient, highly generalizable, and capable of sustainable learning and evolution can be developed, fully leveraging the advantages of data-driven approaches [1]. In recent years, next-generation artificial intelligence research has explored the integration of data-driven methods with knowledge-guided techniques, giving rise to knowledge-data collaborative-driven methodologies [2, 3]. This emerging paradigm is expected to significantly broaden the application potential of intelligent methods across various domains. Driven by this trend, the development of geotechnical engineering databases—including slope databases—has become an indispensable foundational task for advancing informatization in geotechnical engineering.

Existing slope databases can be classified into two main categories based on different usage requirements: (1) risk management-oriented databases [4] and (2) slope engineering case databases serving investigation and stabilization purposes [5]. The primary distinctions between these two categories of databases are as follows:

The first category focuses on regional geohazard analysis and management at larger scales such as the national level, documenting the basic characteristics of individual slopes or landslides in detail. However, they contain relatively limited records of geotechnical parameters. Since their emphasis is on pre-disaster risk management, such databases rarely include records of stabilization measures.

The second category emphasizes detailed documentation of slope engineering cases, including comprehensive engineering geological data (*e.g.*, geographic location, geological structure, stratigraphic lithology, hydrogeological conditions, and geotechnical parameter values), stability analysis processes and results, as well as stabilization measures. These databases provide valuable experience for similar slope engineering projects. Table **1** presents representative slope or landslide databases developed in China and other countries and regions since the last century.

(1) Slope or landslide databases for landslide risk management purposes

In 1987, the United Nations Working Group on World Landslide Inventory proposed the landslide inventory initiative, which led to extensive landslide inventory work and subsequently gave rise to landslide databases for landslide susceptibility, hazard and vulnerability assessments [31]. The databases formed by landslide inventory serve as important information sources for quantitative zoning of landslide susceptibility, hazard, vulnerability and risk, providing information such as landslide locations, occurrence dates, types, scales, movement characteristics, causes and resulting damages within the study area [32].

Eeckhaut and Hervás [12] classified the contents of such landslide databases into three categories: core characteristic information, ancillary information and supplementary data. Core characteristics refer to

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Table 1: Representative Slope or Landslide Databases

Database	Country (or Region)	Reference	Category
China Landslide Database System	China	[6]	1
Landslide Inventories	the United States	[7]	1
National Landslide Database	New Zealand	[8]	1
The Australian Landslide Database	Australia	[9]	1
Open Pit Slope Failure Database	Australia	[10]	2
Landslide database	Albania	[11]	1
Natural hazard database of Andorra	Andorra	[12]	1
Terrain zonation according to geological–geotechnical problems	Andorra	[13]	1
GEORIOS	Austria	[14]	1
The engineering geology map of Federation of Bosnia and Herzegovina	Bosnia and Herzegovina	[15]	1
Map of landslides	Bulgaria	[16]	1
National Landslide Register	Czech Republic	[13]	1
Landslide Cadastre	The Former Yugoslav Republic of Macedonia	[17]	1
National Database of Ground Movements (BDMvT)	France	[18]	1
National landslide database	Germany	[19]	1
Geodatabase I.G.M.E./ eng_geol/ ground_failures	Greece	[12]	1
National Landslides Cadastre	Hungary	[20]	1
OLI	Iceland	[13]	1
National Landslide Database	Ireland	[4]	1
IFFI Project	Italy	[21]	1
Areas Affected by Landslides and Floods in Italy (AVI)	Italy	[22]	1
National Landslide Database	Norway	[23]	1
SOPO	Poland	[24]	1
Disaster database	Portugal	[25]	1
Landslide Register	Slovakia	[26]	1
GIS_UJME (part of larger database)	Slovenia	[27]	1
Spanish Database of Geological Hazards	Spain	[13]	1
Swedish Natural Hazards Information System (MSB)	Sweden	[12]	1
SGI Landslide database	Sweden	[28]	1
InfoSlide	Switzerland	[29]	1
National Landslide Database	England	[30]	1
The slope stability database	Global	[5]	2

unique identifiers of landslides, such as location, landslide type, occurrence date or last active time, activity status and scale. Ancillary information includes geometric elements, geological conditions, hydrogeological conditions, land use or vegetation coverage, triggering factors, impacts, investigation methods, investigation dates and investigators' names. Supplementary data include illustrations, photographs and monitoring data. As shown in Table **1**, most developed countries have established or are establishing national or regional landslide databases. The data in such databases are relatively comprehensive and mainly suitable for preparing landslide inventory maps and conducting susceptibility, hazard, vulnerability and risk zoning over large regions, thereby facilitating integrated regional geological hazard management [33]. However, such databases rarely include geotechnical physical and mechanical parameters and corresponding stability evaluation information. Only when data permit may such content be involved in hazard assessments. Reference [13] lists the national database situations in European countries. Although most countries have established national-level landslide databases, few support hazard assessment. In slope or landslide stabilization projects, geotechnical parameters are important factors influencing the slope stability. Therefore, such databases are not suitable for providing reference for investigation and design of similar slope or landslide stabilization projects.

(2) Slope engineering case databases serving investigation and stabilization purposes

This type of database focuses on recording case data for specific projects, such as slope stabilization cases along a particular highway [34-36]. These data include slope characteristic parameters (*e.g.*, geographic location, geometric features, stratigraphic lithology, geological structure, hydrogeological conditions, triggering factors, etc.), geotechnical parameters (*e.g.*, laboratory and field test data of rocks and soils, empirical values, etc.), and stability analysis data (*e.g.*, stability analysis methods, the factor of safety, and stability evaluation conclusions). By relying on these specific case data, comprehensive references can be provided for parameter selection and stability analysis in similar projects.

However, the development of these slope databases is often constrained by the specific needs of specific projects, limiting their scope to slopes along a single highway or within a specific hydropower project. These databases often fail to incorporate slope data from surrounding projects, resulting in relatively limited datasets. Moreover, most databases lack further updates and optimization after project completion, leading to partial obsolescence of the data.

This study addresses a critical gap in geotechnical data by establishing a cloud database system for slopes in Hubei Province, China, based on a large collection of detailed case data. This parameter-rich dataset provides the essential foundation for implementing next-generation data-driven and intelligent computational methods, such as machine learning and AI, for enhanced geotechnical parameter identification and slope analysis.

2. DEVELOPMENT OF THE SLOPE CLOUD DATABASE MANAGEMENT SYSTEM

Hubei Province is in the middle reaches of the Yangtze River, with mountains surrounding its eastern, western and northern sides and relatively flat terrain in the central area. Mountainous regions account for 80% of its territory while plains make up the remaining 20%. The main geomorphological units include the northwestern Hubei Qinling-Daba mountainous area, northern Hubei Tongbai mountainous area, southwestern Hubei Wuling mountainous area, northeastern Hubei Dabie mountainous area, southeastern Hubei Mufu mountainous area, and central Hubei Jianghan Plain [37, 38]. The province features predominantly mountainous and hilly terrain with complex geological structures, crisscrossed by water systems including the Yangtze River, Han River and Qing River. Frequent human engineering activities such as the Shiman Expressway, Hurong Expressway, Three Gorges Project, Danjiangkou Reservoir, and Northern Hubei Water Diversion Project have significantly modified the local geomorphology. Combined with concentrated rainfall during wet seasons, periodic reservoir water level fluctuations, and long-term natural weathering, these factors easily trigger geological hazards that may cause irreversible damage to infrastructure and people's lives and property. Slope-related geological disasters occur frequently in the province. Therefore, establishing the cloud database system for slopes in Hubei Province based on extensive field investigations of slope engineering geology and previous research achievements is of great significance.

The cloud database system for slopes in Hubei Province was developed using MySQL database management system (DBMS). The development process included four steps: requirements analysis, conceptual design, logical design, and implementation (including the creation of tables, views, etc.) [39]. As physical design depends on the DBMS, operating system and hardware configuration [40], it was not separately addressed in this development.

2.1. Requirements Analysis

Requirements analysis is the primary step in database design, directly affecting the convenience of management and comprehensiveness of functions during database usage. It includes information requirements, processing requirements, as well as security and integrity requirements. Based on the needs of data-driven parameter identification, the functional requirements of the slope cloud database system are determined as follows:

(1) Data Management Requirements

1) Both administrators and regular users should be able to add collected slope data from Hubei Province into the database, including project overviews, geotechnical parameter test and design values, stability analysis results, implemented stabilization measures, and monitoring data.

2) To ensure data authenticity, each record must specify its data source. For data obtained from investigation and design reports, corresponding project background information should be provided; for data from literature, the source must be cited.

3) For data with varying formats and attributes (*e.g.*, monitoring data of different variables) that are inconvenient to input directly, data interfaces should be established to directly call source files.

4) To ensure data security and reliability, all personnel are permitted to perform data addition operations, while administrators are granted privileges for deletion, modification, and query operations, and regular users are only authorized for query operations.

5) All data management functions should support remote operations.

(2) Data Analysis Requirements

1) All users should be able to retrieve all relevant project data for analysis using the project name (or designated ID) as a keyword. Considering variations in project name formats, fuzzy search functionality must be supported.

2) All users should be able to export queried data to formats such as .xls(x), .csv, .txt, and .hd5f for further statistical analysis.

Based on the above data management and analysis requirements, the data items and structure in the database can be determined as follows:

(1) Project overview

This part includes attributes such as project ID, slope location, slope material composition, stabilization measures, and remarks. The project ID serves as the unique identifier for each case in the database and can link other data to the corresponding project. The slope location attribute describes the geographic position of the slope. For highway slopes, this is typically represented by mileage stake numbers for quick positioning. Slope material composition is a key classification criterion, helping users efficiently query engineering data for similar slopes and providing references for parameter identification and stability evaluation. Stabilization measures record the stabilization methods applied to the slope, serving as references for similar projects.

(2) Slope characteristics

This part includes attributes such as project ID, slope dip direction, dip angle, slope height, slope material composition, stratigraphic age, bedrock lithology, weathering degree, slope structure, slope stratum attitude, controlling structural plane attitude, single-layer rock thickness, deformation and failure type, slope deformation dynamic origin, hydrogeological conditions, average annual precipitation, and remarks.

(3) Test results of soil parameters

This part includes attributes such as project ID, soil sample name, sampling position, natural unit weight, saturated unit weight, void ratio, natural water content, liquid limit, plastic limit, compression coefficient, compression modulus, Poisson's ratio, percentage of fine-grained soil and rock blocks (applicable to accumulation slopes), cohesion, internal friction angle, data source, and remarks. It primarily records the basic physical-mechanical characteristics of soil samples in soil slopes and soil-rock composite slope cases, with test methods and conditions specified in the remarks.

During actual data entry, a single raw data record may not cover all fields, and the fields covered by each record may vary. To simplify data entry and fully preserve original data conditions, parameters with conversion relationships (*e.g.*, compression modulus and compression coefficient) are not processed during entry—only the corresponding values from reports are recorded. Conversion of parameters can be performed during subsequent analysis. The design approach for tables related to geotechnical physical-mechanical parameters follows the same principle.

(4) Test results of rock parameters

This part includes attributes such as project ID, rock sample name, sampling position, weathering degree, natural unit weight, saturated unit weight, porosity, water absorption, softening coefficient, longitudinal wave velocity, point load strength index, uniaxial compressive strength, tensile strength, deformation modulus, elastic modulus, Poisson's ratio, natural and saturated cohesion, internal friction angle, swelling mineral description, free and confined swelling rates, swelling pressure, data source, and remarks. It mainly records the basic physical-mechanical characteristics of rock samples in rock slopes and soil-rock composite slope cases, with test methods and conditions specified in the remarks.

(5) Test results of solid discontinuities

This part includes attributes such as project ID, slope material composition, natural and saturated cohesion, internal friction angle, normal stiffness, tangential stiffness, data source, and remarks. It primarily records the shear strength characteristics of hard structural planes in rock slopes, with test methods and conditions specified in the remarks.

(6) Characteristics of weak interlayers

This part includes attributes such as project ID, sampling position, geological origin, interlayer material composition, interlayer (slip zone) structural features, thickness, slope aspect, interlayer dip direction, dip angle, dynamic origin of evolution, water content, density, specific gravity, porosity, liquid limit, plastic limit, liquidity index, plasticity index, elastic modulus, Poisson's ratio, cohesion, internal friction angle, data source, and remarks. It mainly records the physical-mechanical parameters of weak interlayers in slopes containing such features, with test methods and conditions specified in the remarks.

(7) Design values of shear strength

This part includes attributes such as project ID, name (referring to slip zone, structural plane, etc.), natural and saturated unit weight, natural and saturated cohesion, natural and saturated internal friction angle, and remarks. The shear strength of geomaterials is a critical indicator for slope stabilization design. For soil slopes, the design values of shear strength for the slip zone soil are recorded when the slip zone is clearly identified; otherwise, the values for the sliding mass are recorded. For rock slopes, the shear strength indices of controlling structural planes are recorded. For soil-rock composite slopes, the shear strength indices of the soil-rock interface or slip zone soil are recorded based on specific categories.

(8) Stability analysis

This part includes attributes such as project ID, initial factor of safety and corresponding working conditions, stability analysis results, unstable rock mass stability analysis results, and stability analysis methods. It mainly records the stability analysis results for slopes corresponding to project IDs, with local stability calculations included for cases involving unstable rock masses.

(9) Monitoring data

This section includes attributes such as project ID, monitoring method, monitoring report path, raw monitoring data path, and remarks. It primarily records the storage locations and links for monitoring data and reports. Due to variations in monitoring indicators and methods, data formats differ. Only storage paths are provided for monitoring data.

(10) Scales of fluctuation of soil parameters

This part includes attributes such as project ID, record number, soil type, sampling position, vertical and horizontal scales of fluctuation, test method, test metrics used for calculation, calculation method, data source, and remarks. Recording scales of fluctuation of soil parameter primarily supports probabilistic back-analysis and reliability analysis based on random field models.

2.2. Conceptual Design

Building upon the requirements analysis, the conceptual design was further developed to abstract the relationships among slope data in Hubei Province and objectively describe the connections between various data elements. The design outcome of the conceptual structure model is presented as an Entity-Relationship (E-R) diagram, as shown in Figure **1**. In Figure **1**, entity sets are represented by rectangles with the entity set name displayed inside; rounded rectangles connected to entity sets represent their corresponding attributes; entity sets are linked by diamonds containing text that describes their relationships.

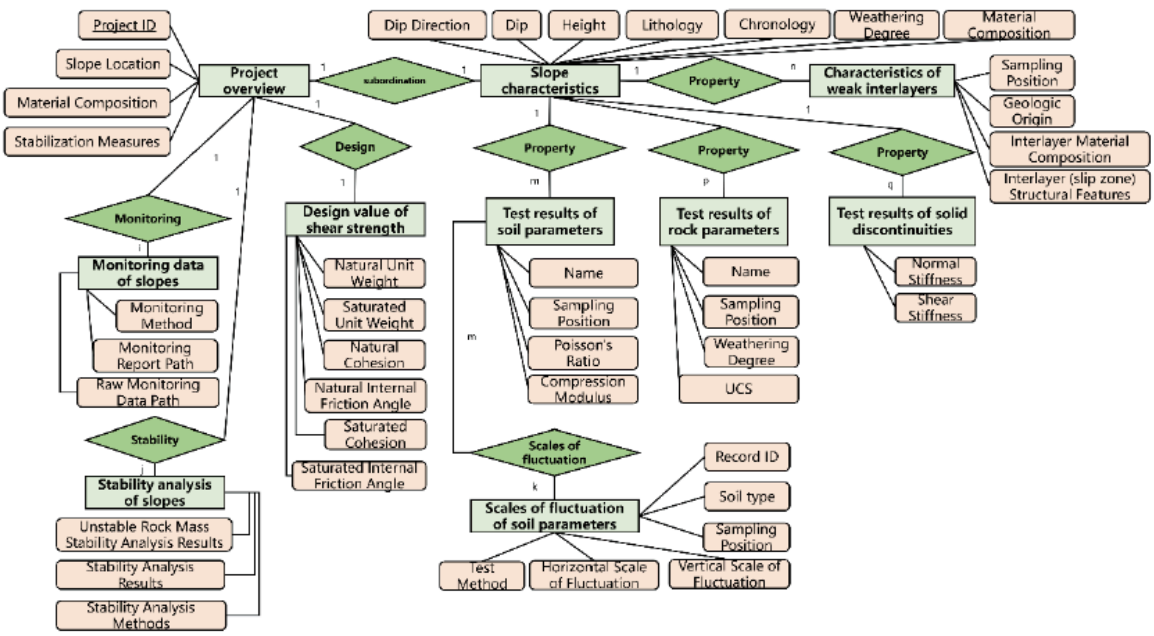

Figure 1: E-R model of the cloud database system for slopes in Hubei Province, China.

2.3. Logical Design and Implementation

Following normalization theory, the E-R model shown in Figure **1** was converted into relational models as Appendix Tables **1~10**.

Data were entered according to the ten constructed data tables. Currently, the cloud database has recorded 1,700 slope data entries from Hubei Province, comprising 34,863 data items. These cover engineering geological data, stability analyses, stabilization measures, and monitoring data for slopes along multiple national and provincial highways, including G209, G242, G318, G347, S214, S236, S246, and S338. The data entry format strictly follows Appendix Tables **1~10**, providing a data foundation for identifying geotechnical physical-mechanical parameters of slopes in Hubei Province.

The structure of the database and its export functionality are intentionally designed to foster seamless integration with mainstream data science and machine learning (ML) workflows. The relational schema, through its normalized tables and well-defined keys, ensures data integrity and facilitates the efficient joining of feature and target variables (*e.g.*, linking rock type to its corresponding strength parameters). Furthermore, the system's one-click export capability supports versatile formats, including structured files such as HDF5. This format is particularly advantageous for handling large, multi-dimensional datasets and is natively supported by key Python-based data science libraries like Pandas, TensorFlow, and PyTorch. This design allows researchers and engineers to effortlessly transition from data querying to model development, enabling the direct application of ML algorithms for tasks such as predictive stability modeling and AI-powered parameter inversion without the need for cumbersome data preprocessing.

3. DEVELOPMENT OF HUBEI PROVINCE SLOPE CLOUD DATABASE APPLICATION SYSTEM

3.1. Development Architecture

The Application System of the cloud database system for slopes in Hubei Province was developed based on a B/S architecture, enabling deployment and operation in both local and cloud server environments. The front-end technology stack includes Vue, Vue-router, Axios, and Element-UI, while the back-end technology stack comprises Spring Boot 2.0, Spring Boot JPA, JWT, Spring Security, Redis, and Swagger2. Role-Based Access Control (RBAC) is implemented for permission management, and the front-end supports dynamic route display based on user roles.

The development environment for the Cloud Database System utilizes WebStorm for the front-end and IDEA for the back-end, with JDK version 8, Maven for dependency management, and MySQL as the database. Nginx is employed to proxy Java services, which are deployed on Huawei Cloud servers. This architecture enables remote database operations such as addition, deletion, modification, query, and export.

3.2. Visual Operation Interface

The visual operation interfaces of the database system consist primarily of a login interface, main interface, and functional interfaces. The login interface ensures system security, while the main interface shows the menu of tables, providing a basis for data queries. The functional interfaces are divided into ten sub-interfaces corresponding to Appendix Tables **1~10**. Each sub-interface manages data for its respective table. Figure **2** displays the login interface, Figure **3** shows the main interface after login, and Figures **4~6**

Figure 2: Login view (in Chinese).

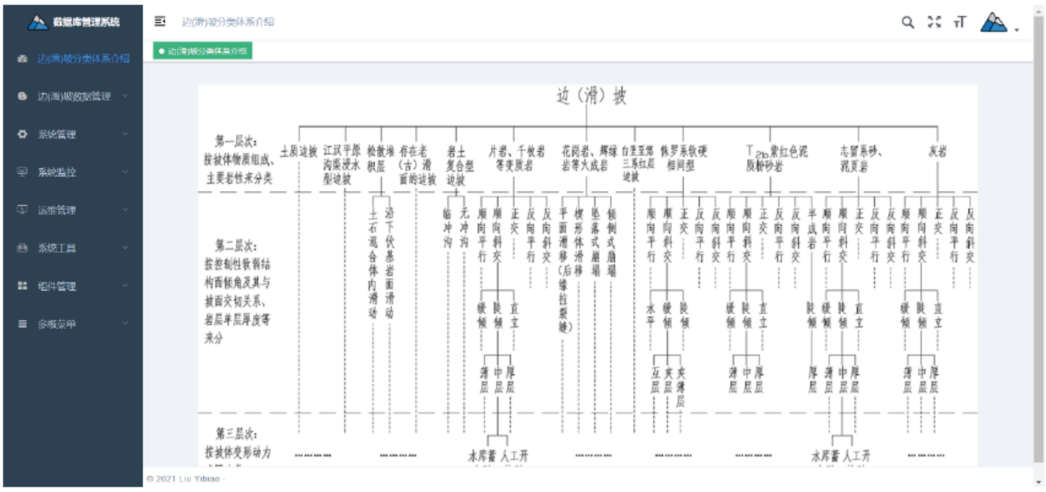

Figure 3: Main view (in Chinese).

Figure 4: Example 1 of functional views (data management view of the table of project profiles, in Chinese).

Figure 5: Example 2 of functional views (data management view of the table of slope characteristics, in Chinese).

exemplify portions of the functional interfaces. This database was finally developed in 2023.

4. PARAMETER DETERMINISTIC IDENTIFICATION DRIVEN BY THE CLOUD DATABASE SYSTEM—A CASE STUDY OF THE ROCK UCS IDENTIFICATION

4.1. Statistical Results of the UCS for Various Rock Types in the Cloud Database

Based on the slope material composition of rock slopes in the database, the UCS data of eight rock

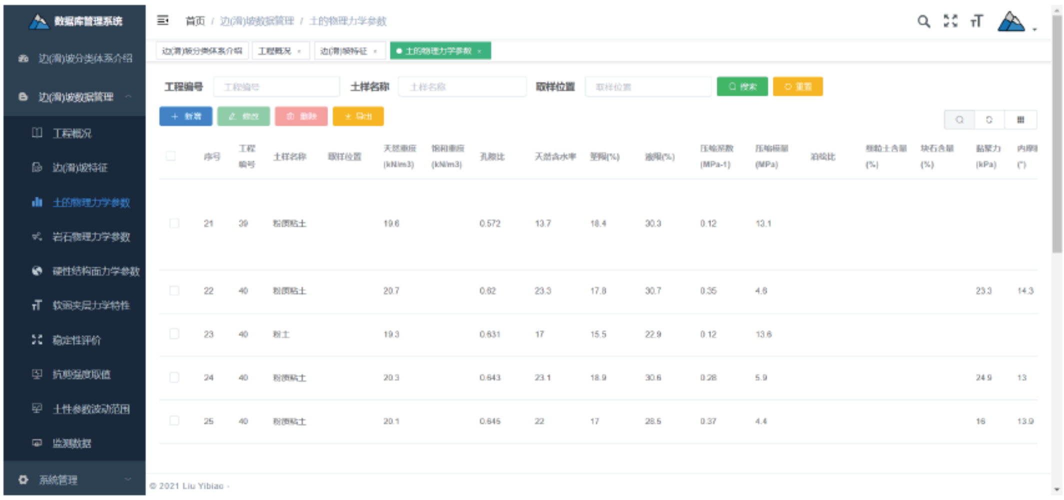

Figure 6: Example 3 of functional views (data management view of the table of test results of soil parameters, in Chinese).

types—schist, diabase, granite, mudstone, sandstone, argillaceous siltstone, shale, and limestone—were extracted and statistically analyzed from the cloud database. Figure **7** presents the distribution histograms of the UCS for these rock types. All data were obtained from standard cylindrical samples (50 mm in diameter, 100 mm in height) subjected to the UCS tests.

Five common distribution models—Gamma, Weibull, normal, log-normal, and exponential—were used to fit the data for each rock type. The goodness-of-fit was evaluated using the Kolmogorov-Smirnov (K-S) test [41], with the resulting p-values listed in Table **2**. In this test, the p-value serves as the significance level parameter. A very small p-value provides grounds to reject the null hypothesis under the small probability principle. The null hypothesis typically assumes that the data follow a specified distribution; thus, a higher p-value indicates a better fit. The distribution with the highest p-value was selected as the optimal fitting curve for each dataset, as illustrated in Figure **7**.

Table **2** and Figure **7** shows that both the Gamma distribution and Weibull distribution demonstrate good fitting performance for the UCS of all rock types in the cloud database. Furthermore, boxplots of the uniaxial compressive strength for each rock type were obtained as shown in Figure **8**.

In Figure **8**, the red rectangles represent the mean values of UCS for each rock type in the cloud database. Among these, granite exhibits the highest mean UCS at 122.29 MPa, while argillaceous siltstone shows the lowest mean UCS at 12.49 MPa.

4.2. Parameter Correlation Statistics and Empirical Formulae

Appendix Table **4** records not only the UCS but also corresponding parameters such as unit weight, elastic modulus, Poisson's ratio, tensile strength, porosity, water content, P-wave velocity, and point load strength. Using these parameters, empirical formulae for identifying UCS of various rock types can be quickly

Table 2: Hypothesis Test Results for the Distributions of each Type of Rocks

Rock type	K-S Test Results (p-value) for Different Distribution Types					Optimal Distribution Model
	Gamma	Weibull	Normal	Log-Normal	Exponential	
Schist	**0.8984**	**0.7104**	0.0456	**0.4832**	**0.1121**	Gamma
Diabase	**0.5922**	**0.6484**	**0.5865**	**0.3767**	**0.4145**	Weibull
Granite	**0.0640**	**0.3406**	**0.3798**	0.0070	0.0000	Normal
Mudstone	**0.6213**	**0.6330**	0.0002	**0.5527**	**0.6380**	Exponential
Sandstone	**0.2200**	**0.4069**	**0.3939**	0.0055	0.0078	Weibull
Argillaceous Siltstone	**0.3471**	**0.4672**	0.0023	**0.9412**	**0.2927**	Log-Normal
Shale	**0.6861**	**0.8073**	**0.1652**	**0.6329**	**0.0812**	Weibull
Limestone	**0.2375**	**0.0829**	0.0066	0.0328	0.0000	Gamma

Note: The confidence level for the K-S test was set at 0.95. Bolded p-values in the table indicate that the distribution passed the K-S test at this confidence level.

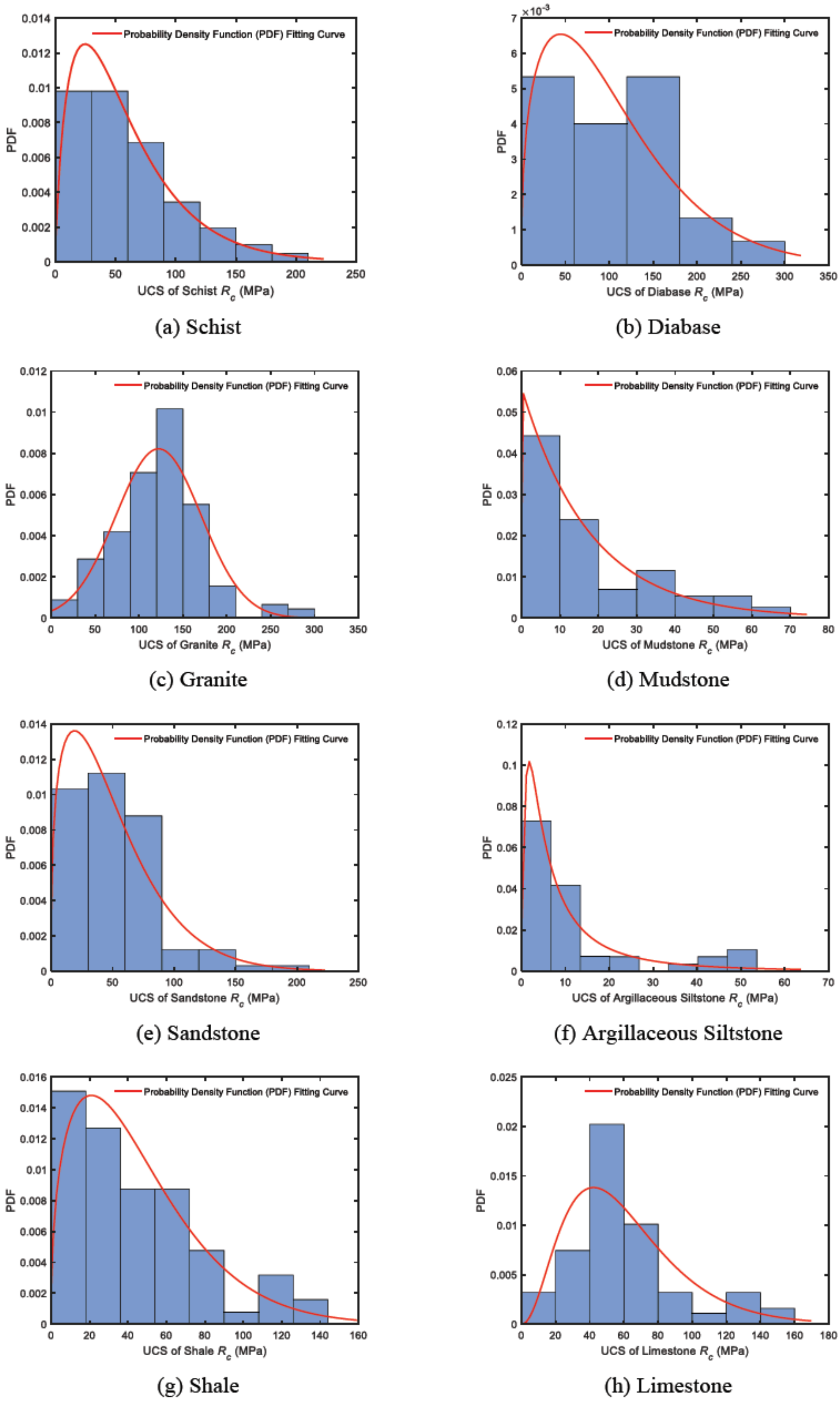

Figure 7: Histograms of the UCS of various rocks and their fitted PDF curves.

established based on linear regression methods. Table **3** presents the linear relationships between UCS and each parameter.

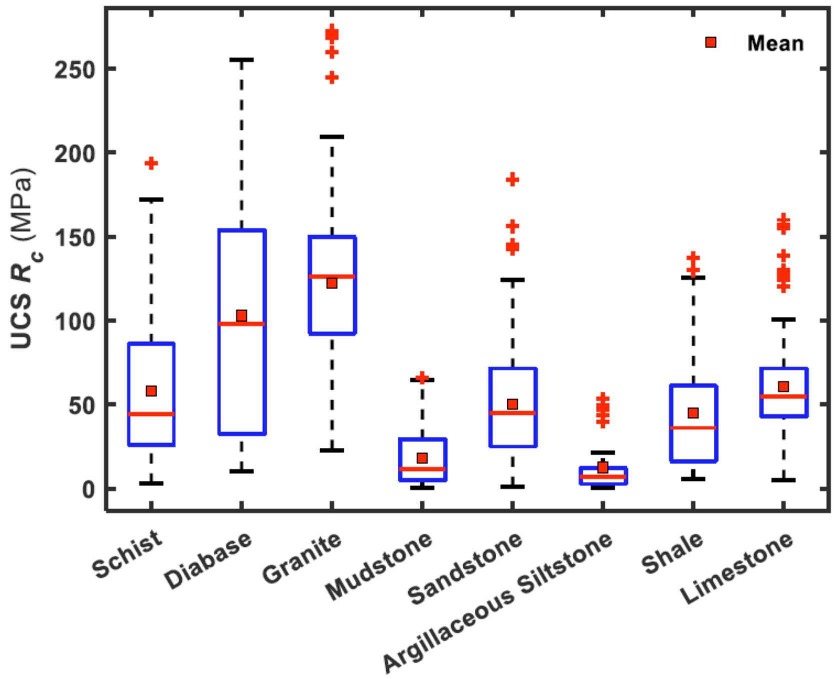

Figure 8: Boxplot of the UCS of various rocks.

Table 3: Empirical Formulae for Determining the UCS of Various Types of Rocks Based on the Data of the Developed Database

Rock type	Empirical Formulae for the UCS Identification	Correlation Coefficient r
Schist	$R_c = 0.919E_e + 29.704$	0.7728
Diabase	$R_c = 2.4152E_e + 29.425$ $R_c = 1560.8\nu - 181.69$	0.7531 0.9993
Granite	$R_c = -31.596n + 198.63$ $R_c = -30.545W_A + 103.31$ $R_c = 8.4192I_{s(50)} + 39.742$ $R_c = 10.121\sigma_t + 30.932$	0.6018 0.8944 0.5324 0.7518
Mudstone	$R_c = 4.6531\gamma - 87.076$ $R_c = 1.0066I_{s(50)} + 0.5577$	0.5106 0.9835
Sandstone	$R_c = 0.0489V_p - 64.295$ $R_c = 20.172I_{s(50)} + 28.106$	0.7277 0.9743
Argillaceous Siltstone	$R_c = 15.313I_{s(50)} - 3.4978$ $R_c = -294.21\nu + 102.09$	0.9452 0.6222
Shale	$R_c = -54.361W_A + 105.74$ $R_c = 0.031V_p - 38.16$ $R_c = 13.41I_{s(50)} + 2.2728$ $R_c = 10.906\sigma_t + 5.1884$ $R_c = 1.9691E_e + 21.771$	0.9787 0.9547 0.9869 0.8227 0.6298
Limestone	$R_c = 12.212\gamma - 264.56$ $R_c = 0.0136V_p - 17.354$ $R_c = 8.5614\sigma_t + 5.4832$ $R_c = 0.963E_e + 70.986$	0.5534 0.5389 0.7804 0.5212

For each rock type, Table **3** only lists the linear regression equations between UCS and a parameter with a correlation coefficient $r > 0.5$, indicating at least a moderate correlation between UCS and the respective parameter.

The definitions and units of each symbol in Table **3** are shown in Table **4**.

Table 4: Explanations of Physical and Mechanical Parameters

Parameter	Definition	Unit
R_c	UCS	MPa
γ	Natural Unit Weight	kN/m^3
E_e	Elastic Modulus	MPa
ν	Poisson's Ratio	/
n	Porosity	/
W	Water Content	/
W_A	Water Absorption Rate	/
$I_{s(50)}$	Point Load Strength Index	MPa
V_p	P-wave Velocity	m/s
σ_t	Tensile Strength	MPa

5. CONCLUSIONS

By incorporating accumulated engineering data, the cloud database system for slopes in Hubei Province was developed. The conclusions can be drawn as follows.

(1) Following the steps of requirements analysis, conceptual design, and logical design, the cloud database management system was developed. The system comprises ten data tables. The fields, field names, data types, and nullability constraints for each table were analyzed, defined, and summarized, along with their respective purposes. Currently, 1,700 slope (landslide) records from Hubei Province, totaling 34,863 data entries, have been entered into the cloud database, covering engineering geological data, stability analyses, stabilization measures, and monitoring data for slopes along multiple national and provincial highways .

(2) Based on a B/S (Browser/Server) architecture, the system supports deployment and operation in both local and cloud server environments, forming the cloud database application system.

(3) The application system connects with the MySQL-based database management system at the backend, enabling remote data operations such as addition, deletion, modification, and querying. It also supports one-click export of data in multiple formats (.xls, .txt, .csv, and .hdf5) for subsequent parameter identification and analysis.

(4) An analysis was conducted on the relationship between uniaxial compressive strength and various physical-mechanical parameters for eight different rock types using existing data from the cloud database, with corresponding empirical formulae being derived, demonstrating the practical value of the cloud database system.

(5) The structured and validated dataset established in this study provides an essential foundation for future intelligent slope engineering applications. Subsequent research will leverage this database to develop AI-driven models for slope stability prediction, automated parameter inversion, and spatial variability analysis using random field models. By integrating machine learning frameworks — such as neural networks and gradient boosting — the database will support the development of data-intensive, probabilistic tools for geotechnical risk assessment and decision-making, ultimately advancing smart and predictive engineering practices.

DATA AVAILABILITY STATEMENT

All data, models, or codes that support the findings of this study are available from the corresponding author upon reasonable request.

FUNDING

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CONFLICTS OF INTEREST/COMPETING INTERESTS

The author declare that there is no conflict of interests regarding the publication of this article.

Appendix

Table 1: Project Overview

Field	Field Name	Data Type	Nullable	Table Purpose Description
Project ID	Project ID	INT	NOT NULL	Recording engineering background
Location	Slope Location	VARCHAR(255)	NOT NULL	
Slope Composition	Material Composition	VARCHAR(255)	NOT NULL	

Treatment	Stabilization Measures	VARCHAR(255)	NOT NULL	
Remark	Remarks	VARCHAR(255)	NULL	

Table 2: Slope Characteristics

Field	Field Name	Data Type	Nullable	Table Purpose Description
Project ID	Project ID	INT	NOT NULL	Recording slope characteristics
Dip Direction	Dip Direction	VARCHAR(255)	NULL	
Dip	Dip	VARCHAR(255)	NULL	
Height	Slope Height	VARCHAR(255)	NULL	
Slope Composition	Material Composition	VARCHAR(255)	NOT NULL	
Chronology	Chronology	VARCHAR(255)	NULL	
Lithology	Lithology	VARCHAR(255)	NULL	
Weathering Degree	Weathering Degree	VARCHAR(255)	NULL	
Structure	Slope Structure	VARCHAR(255)	NULL	
Bedding SfAtt	Bedding Surface Attitude	VARCHAR(255)	NULL	
Controlling DiscAtt	Controlling Structural Plane Attitude	VARCHAR(255)	NULL	
Thickness	Single-layer Thickness (Applicable to stratified slopes)	VARCHAR(255)	NULL	
Deform Fail Type	Deformation and Failure Type	VARCHAR(255)	NOT NULL	
Dyn Origin	Slope Deformation Dynamic Origin	VARCHAR(255)	NOT NULL	
Hydrogeo Con	Hydrogeological Conditions	VARCHAR(255)	NULL	
Precipitation	Average Annual Precipitation (mm)	VARCHAR(255)	NULL	
Remark	Remarks	VARCHAR(255)	NULL	

Table 3: Test Results of Soil Parameters

Field	Field Name	Data Type	Nullable	Table Purpose Description
Project ID	Project ID	INT	NOT NULL	Recording test results of soil physical-mechanical parameters
Soil Name	Soil Sample Name	VARCHAR(255)	NOT NULL	
Sampling Position	Sampling Position	VARCHAR(255)	NULL	
Nat Weight	Natural Unit Weight (kN/m^3)	VARCHAR(255)	NULL	
Sat Weight	Saturated Unit Weight (kN/m^3)	VARCHAR(255)	NULL	
Void Ratio	Void Ratio	VARCHAR(255)	NULL	
Nat Water	Natural Water Content	VARCHAR(255)	NULL	
Plastic Limit	Plastic Limit (%)	VARCHAR(255)	NULL	
Liquid Limit	Liquid Limit (%)	VARCHAR(255)	NULL	
Compress Coeff	Compression Coefficient (MPa^{-1})	VARCHAR(255)	NULL	
Compress Modulus	Compression Modulus (MPa)	VARCHAR(255)	NULL	
Poisson Ratio	Poisson's Ratio	VARCHAR(255)	NULL	
Fine Content	Percentage of Fine-grained Soil (%)	VARCHAR(255)	NULL	
Rock Content	Percentage of Rock blocks (%)	VARCHAR(255)	NULL	
Cohesion	Cohesion (kPa)	VARCHAR(255)	NULL	
In Friction Ang	Internal Friction Angle (°)	VARCHAR(255)	NULL	
Data Source	Data Source	VARCHAR(255)	NOT NULL	
Remark	Remarks	VARCHAR(255)	NULL	

Table 4: Test Results of Rock Parameters

Field	Field Name	Data Type	Nullable	Table Purpose Description
Project ID	Project ID	INT	NOT NULL	Recording test results of rock physical-mechanical parameters
Rock Name	Rock Sample Name	VARCHAR(255)	NOT NULL	
Sampling Position	Sampling Position	VARCHAR(255)	NULL	
Weathering Degree	Weathering Degree	VARCHAR(255)	NULL	
Nat Weight	Natural Unit Weight (kN/m^3)	VARCHAR(255)	NULL	
Sat Weight	Saturated Unit Weight (kN/m^3)	VARCHAR(255)	NULL	
Porosity	Porosity (%)	VARCHAR(255)	NULL	
Water Absorption Rate	Water Absorption Rate (%)	VARCHAR(255)	NULL	
Softening Coeff	Softening Coefficient	VARCHAR(255)	NULL	
Pwave V	Longitudinal Wave Velocity (m/s)	VARCHAR(255)	NULL	
Is50	Point Load Strength Index	VARCHAR(255)	NULL	
UCS	UCS (MPa)	VARCHAR(255)	NULL	
Tensile Strength	Tensile Strength (MPa)	VARCHAR(255)	NULL	
Deform Modulus	Deformation Modulus (GPa)	VARCHAR(255)	NULL	
E	Elastic Modulus (GPa)	VARCHAR(255)	NULL	
Poisson Ratio	Poisson's Ratio	VARCHAR(255)	NULL	
Nat Cohesion	Natural Cohesion (MPa)	VARCHAR(255)	NULL	
NatIn Friction Ang	Natural Internal Friction Angle (°)	VARCHAR(255)	NULL	
Sat Cohesion	Saturated Cohesion (MPa)	VARCHAR(255)	NULL	
SatIn Friction Ang	Saturated Internal Friction Angle (°)	VARCHAR(255)	NULL	
Swelling Mineral	Swelling Mineral Description	VARCHAR(255)	NULL	
Free Swelling Rate	Free Swelling Rate (%)	VARCHAR(255)	NULL	
Con Swelling Rate	Confined Swelling Rate (%)	VARCHAR(255)	NULL	
Swelling Stress	Swelling Ppressure (kPa)	VARCHAR(255)	NULL	
Data Source	Data Source	VARCHAR(255)	NOT NULL	
Remark	Remarks	VARCHAR(255)	NULL	

Table 5: Test Results of Solid Discontinuities

Field	Field Name	Data Type	Nullable	Table Purpose Description
ProjectID	Project ID	INT	NOT NULL	Recording mechanical parameter test results of solid discontinuities in rock slopes
Slope Composition	Material Composition	VARCHAR(255)	NOT NULL	
Nat Cohesion	Natural Cohesion (MPa)	VARCHAR(255)	NULL	
NatIn Friction Ang	Natural Internal Friction Angle (°)	VARCHAR(255)	NULL	
Sat Cohesion	Saturated Cohesion (MPa)	VARCHAR(255)	NULL	
SatIn Friction Ang	Saturated Internal Friction Angle (°)	VARCHAR(255)	NULL	
Normal Stiffness	Normal Stiffness (MPa/m)	VARCHAR(255)	NULL	
Shear Stiffness	Shear Stiffness (MPa/m)	VARCHAR(255)	NULL	
Data Source	Data Source	VARCHAR(255)	NOT NULL	
Remark	Remarks	VARCHAR(255)	NULL	

Table 6: Characteristics of Weak Interlayers

Field	Field Name	Data Type	Nullable	Table Purpose Description
Project ID	Project ID	INT	NOT NULL	Recording physical-mechanical parameter Test values of weak interlayers in slopes
Sampling Position	Sampling Position	VARCHAR(255)	NULL	
Geologic Origin	Geologic Origin	VARCHAR(255)	NULL	
Composition	Interlayer Material Composition	VARCHAR(255)	NULL	
Structural Features	Interlayer (slip zone) Structural Features	VARCHAR(255)	NULL	
Thickness	Thickness (cm)	VARCHAR(255)	NULL	
Dip Direction	Dip Direction	VARCHAR(255)	NULL	
Dip	Dip	VARCHAR(255)	NULL	
Nat Water	Water content	VARCHAR(255)	NULL	
Density	Density (g/cm^3)	VARCHAR(255)	NULL	
Dry Density	Dry Density (g/cm^3)	VARCHAR(255)	NULL	
Specific Gravity	Specific Gravity	VARCHAR(255)	NULL	
Porosity	Porosity	VARCHAR(255)	NULL	
Plastic Limit	Plastic Limit (%)	VARCHAR(255)	NULL	
Liquid Limit	Liquid Limit (%)	VARCHAR(255)	NULL	
E	Elastic Modulus (MPa)	VARCHAR(255)	NULL	
Poisson Ratio	Poisson's Ratio	VARCHAR(255)	NULL	
Cohesion	Cohesion (kPa)	VARCHAR(255)	NULL	
In Friction Ang	Internal Friction Angle (°)	VARCHAR(255)	NULL	
Data Source	Data Source	VARCHAR(255)	NOT NULL	
Remark	Remarks	VARCHAR(255)	NULL	

Table 7: Design Value of Shear Strength

Field	Field Name	Data Type	Nullable	Table Purpose Description
Project ID	Project ID	INT	NOT NULL	Recording design values of shear Strength
Name	Name	VARCHAR(255)	NOT NULL	
Nat Weight	Natural Unit Weight (kN/m^3)	FLOAT	NULL	
Sat Weight	Saturated Unit Weight (kN/m^3)	FLOAT	NULL	
Nat Cohesion	Natural Cohesion (MPa)	FLOAT	NOT NULL	
NatIn Friction Ang	Natural Internal Friction Angle (°)	FLOAT	NOT NULL	
Sat Cohesion	Saturated Cohesion (MPa)	FLOAT	NOT NULL	
SatIn Friction Ang	Saturated Internal Friction Angle (°)	FLOAT	NOT NULL	
Remark	Remarks	VARCHAR(255)	NULL	

Table 8: Stability Analysis of Slopes

Field	Field Name	Data Type	Nullable	Table Purpose Description
Project ID	Project ID	INT	NOT NULL	Recording stability analysis of slopes
Nat FOS	Initial Factor of Safety (Natural)	FLOAT	NULL	
Sat FOS	Initial Factor of Safety (Saturated)	FLOAT	NULL	
Other Case FOS	Initial Factor of Safety (Other working conditions)	VARCHAR(255)	NULL	
Unstable Rock	Unstable Rock Mass Stability Analysis Results	VARCHAR(255)	NULL	
Stability	Stability Analysis Results	VARCHAR(255)	NOT NULL	
Method	Stability Analysis Methods	VARCHAR(255)	NOT NULL	
Remark	Remarks	VARCHAR(255)	NULL	

Table 9: Monitoring Data of Slopes

Field	Field Name	Data Type	Nullable	Table Purpose Description
Project ID	Project ID	INT	NOT NULL	Recording slope monitoring data storage paths
Monitoring Method	Monitoring Method	VARCHAR(255)	NULL	
Path Report	Monitoring Report Path	VARCHAR(255)	NULL	
Path Data	Raw Monitoring Data Path	VARCHAR(255)	NULL	
Remark	Remarks	VARCHAR(255)	NULL	

Table 10: Scales of Fluctuation of Soil Parameters

Field	Field Name	Data Type	Nullable	Table Purpose Description
Project ID	Project ID	INT	NULL	Recording regional fluctuation scales of soil parameters
Record ID	Record ID	INT	NOT NULL	
Soil Type	Soil Type	VARCHAR(255)	NULL	
Sampling Position	Sampling Position	VARCHAR(255)	NULL	
Vertical SOF	Vertical Scale of Fluctuation (m)	VARCHAR(255)	NULL	
Horizontal SOF	Horizontal Scale of Fluctuation (m)	VARCHAR(255)	NULL	
Test Method	Test Method	VARCHAR(255)	NULL	
Metric	Test metrics Used for Calculation	VARCHAR(255)	NULL	
Calculation Method	Calculation Method	VARCHAR(255)	NULL	
Data Source	Data Source	VARCHAR(255)	NOT NULL	
Remark	Remark	VARCHAR(255)	NULL	

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