Hindawi
Advances in Civil Engineering
Volume 2022, Article ID 1876435, 9 pages
https://doi.org/10.1155/2022/1876435

Research Article

Design and Implementation of an Integrated Management System for Backfill Experimental Data

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Received 21 December 2021; Accepted 25 February 2022; Published 22 March 2022

Academic Editor: Lijie Guo

With the increase in environmental awareness worldwide, the filling mining method has attracted extensive attention because this method can realize safe and green mining in underground metal mines. Recycling waste tailings in stopes to control underground rock movement, and surface settlement can reduce waste environmental pollution while ensuring mining safety. Although many test data are required to support the formulation of the mine backfill scheme, the advanced management tool of backfill test data is insufficient. In this study, a new data management method that is suitable for backfill experiments is proposed. First, this study analyses the main system requirements, including experimental business process modeling, experimental process combing, and a multidimensional query of experimental data. Then, the backfill test business flow and data flow are summarized to establish the backfill test business model and experimental index system. Then, many system functions are designed, including backfill experiment management, experimental data query, backfill knowledge maintenance, and system management. Finally, a backfill test data management system is developed based on B/S architecture. Developing a data interface, having a built-in test formula and customizing a multidimensional data analysis enable the system to solve the problems in data collection, data accounting, and data analysis. After being put into use in the Backfilling Engineering Laboratory of a group in Shandong, this system improved the data-sharing rate and utilization rate and provided a convenient data management tool for the laboratory.

1. Introduction

Mining activities produce many tons of waste tailings every year. As a kind of solid waste, the stockpiling of tailings greatly damages the environment [1, 2]. Cemented paste backfill (CPB) can fill underground goafs with solid wastes, such as waste slag and tailings. This method not only reduces the discharge of solid waste but also stabilizes the mining area, thereby avoiding the collapse of the surface due to the existence of an underground empty area. Moreover, CPB can effectively protect the surrounding environment and fully accords with the current theme of green mining [3–5].

The filling mining method is more complex than others used in mining design and production organizations [6, 7]. To ensure the backfill effect of the mine, it is necessary to rely on many experimental data from laboratory tests, semi-industrial tests, and field industrial tests to select and optimize the backfill parameters in the design or transformation of the backfill system. Therefore, managing the test process and test data is particularly important [8–10].

The backfill test theme corresponds to the problem of the mine backfill industry, and the test scheme is designed for different test themes [11, 12]. However, due to different researchers and research methods, the test schemes are different [6, 13, 14]. The construction of a backfill test platform also needs to coordinate various factors, such as materials, equipment, sites, and personnel [15]. Test data types include not only structured data but also unstructured data, such as pictures and documents [16, 17]. During data acquisition, some data need to be recorded and saved manually [18–20], and some data are automatically collected and stored by the PLC (Programmable Logic Controller) system [21, 22]. Data are easy to lose, and query steps are cumbersome.

By performing a statistical analysis of the test data, the tester obtains the backfill slurry ratio information and pipeline resistance information; both types of information provide an important basis for material consumption, pipe network layout, and equipment selection [23–25]. The above information shows that the backfill test can solve the corresponding industrial problems. Moreover, the test process and data management have many problems, such as many factors for coordinating test development and a low degree of automation in data collection, statistics, storage, and analysis.

Common process and data management tools, such as BIM [26, 27] (building information modeling), PDM [28, 29] (product data management), LIMS [30, 31] (laboratory information management systems), and TDM (test data management) are widely used in construction, pharmaceutical, petrochemical, environment, water supply, medical treatment, quarantine, customs, food and beverage, and other industries. BIM and PDM are complete information models that can integrate the information, processes, and resources of engineering projects or products at different stages in the whole life cycle into one model for easy use by all participants in engineering projects or production. LIMS is a computer software and hardware system for comprehensively managing laboratory information and quality control. Newtera TDM is a platform software designed and developed based on the "build on demand" concept. The software functions include database model, business process, business rules, permission control, web interface, electronic form, report template, statistical analysis, and user management.

However, the traditional backfill test mode can be divided into the proposed experiment, experiment preparation, the conducted experiment, experiment data processing, experiment result analysis, and the experiment summary. In addition, the standardization of the backfill test business process and data has not been reported. Currently, there is no information system for backfilling test data analysis and mining. The lack of test data integration and summary platforms leads to problems, such as low data utilization, a low degree of data sharing, and poor data security. These problems not only increase the workload of testers and affect their work efficiency but also increase the risk of data loss and disclosure. Successful testing requires testers' rich experience and rigorous working attitude. In view of the above situation, an integrated backfilling test data management system that can manage test plans, test processes, and test data.

2. System Requirements

Currently, with the construction and development of intelligent mines, digital, information, and network technologies provide a new way to reform backfill test management. Research on backfill test management is not only a key problem to be solved during technological innovation of the mine backfill process but also a new demand after fully considering the new situation, new conditions and new methods faced by mining enterprises in backfill test management. The research and development of this system can greatly promote the digital upgrading of backfill test management, improve test business processing efficiency and the data management effect, broaden the test design form, and comprehensively improve the design efficiency and practical application effect of mine backfill systems. To achieve these objectives, the system needs to meet the following requirements.

2.1. Backfill Experimental Business Modeling. The system needs to sort out the test process, propose the concept of backfill test standardization, and solve data quality problems. In many test operations, it is inevitable that the test steps are not standardized, cannot enable all key data to be completely recorded, and may even lead to test errors, thus producing difficulties for data analysis. To standardize the experimental process, the backfill experiment business process is analyzed to construct a backfill experiment business model. Besides, the experimental operation steps are also analyzed to establish a backfill experimental knowledge base.

2.2. Experimental Data Integration Management. There are many experimental data indicators, and the relationship between them is complex. To enter, convert and store many multisource heterogeneous data, it is necessary to sort and organize them. Based on this, a reliable data storage structure is designed. Developing the system should simplify personnel operation steps and improve data management efficiency. The main input data include many structured and unstructured historical data and intelligently inputted existing multisource heterogeneous experimental data. For data calculation, in view of the tedious manual calculation steps, the system should be equipped with built-in backfill experimental formula algorithms that enable automatic data conversion. For data storage, technologies such as data warehouses and fusion should be adopted to improve the system database design.

2.3. Multidimensional Query of Experimental Data. This requirement is set mainly to realize data multidimensional analysis and hierarchical authorization queries. Due to the decentralized management of historical data, it is difficult to perform a comparative analysis of experimental data. The system automatically generates analysis charts by data slicing and drilling and realizes a multidimensional data query. Hierarchical authorization data queries are realized through system settings, such as role management and permission management.

3. System Construction

3.1. Construction of the Backfill Experiment Business Model

3.1.1. Experiment Process Analysis. The backfill test needs to coordinate the test elements, such as material, site, equipment, and personnel. By summarizing the backfill industrial problems faced by the mine, the test subject is determined, and the test scheme is designed. Mine backfill demand is the basic condition information of backfill scheme design. Before writing the report, it is necessary to consult the literature to explain the deep-seated causes of the test phenomenon. Finally, the test summary is completed from the test conclusion. The business boundary of the backfill test process begins with the design of the testing scheme and ends with the generation of test summaries and reports. The backfill test process is illustrated in Figure 1.

As shown in Figure 1, the general process of the backfill test can be sorted as follows:

Step 1. The tester proposes the backfill test subject and designs the test scheme according to the needs of the mine backfill industry or personal research direction.

Step 2. The tester designs the number, proportion and manufacturing method of test samples according to the test scheme, prepares test materials, and builds a test platform.

Step 3. The experimenter will prepare, maintain, and test the samples; collect the test data; and preliminarily check the availability and accuracy of the data. If the test data are inadequate, the samples must be prepared again.

Step 4. The experimenter discards the waste samples and processes the experimental data by converting the parameters, importing, and auditing the data.

Step 5. The tester summarizes and analyses the experimental data, determines the relevant literature, analyses the experimental phenomena, and investigates the deep-seated causes.

Step 6. The tester summarizes all the data; creates, documents, and summarizes the test conclusions; and writes the test reports.

3.1.2. Business Model Construction. Using process analysis, the experimental business model is construct to design the system forms and data analysis themes. The backfill experimental business model is shown in Figure 2.

As shown in Figure 2, the backfill test business model can be divided into the following parts:

(1) The tester proposes the test scheme, plans the test contents, confirms that the test materials and test equipment are sufficient and available, and makes pretest preparations.

(2) The tester will perform each subtest in turn according to different test purposes. The main subtests include material physicochemical property tests, settlement tests, filling strength tests, and slurry rheology tests. The system provides the operation information of test steps and automatically records the data generated by equipment.

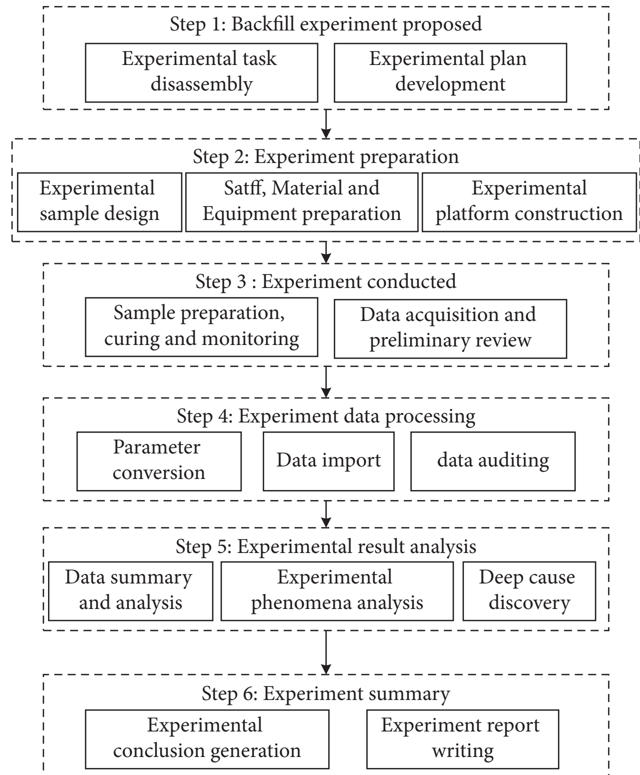

Figure 1: Flow chart of backfill experiment.

(3) The tester summarizes the data; performs the data unit conversion, test index calculation, abnormal value processing and other work; and creates the test data table after standardizing the data. Additionally, the system develops the file attachment management function to record the test pictures and documents and other information. The above structured and unstructured data form the backfill test data asset.

(4) According to the saved data, the system generates a test item data table, material physical and chemical properties table, flocculant subject analysis table, CPB strength analysis table, and slurry rheological analysis table by subject. Then, the analysis results are displayed in many ways, such as in a line chart, pie chart, and histogram.

(5) The tester summarizes the test conclusion and writes the test report according to the system accounting results and analysis chart trend.

3.2. Design of Backfill Experimental Indicator System. Backfill experimental indicators are important tools to describe, measure, and analyze backfill experiments. The backfill scheme is based on a comprehensive consideration of the relevant backfill indicators. The main body of system development is experimental data. Before carrying out the data collection, accounting, and storage work, it is necessary for us to sort out the source of the index data and its calculation method and complete the design of the index system of the backfill experiment. The design of the backfill indicator used in this article is shown in Figure 3.

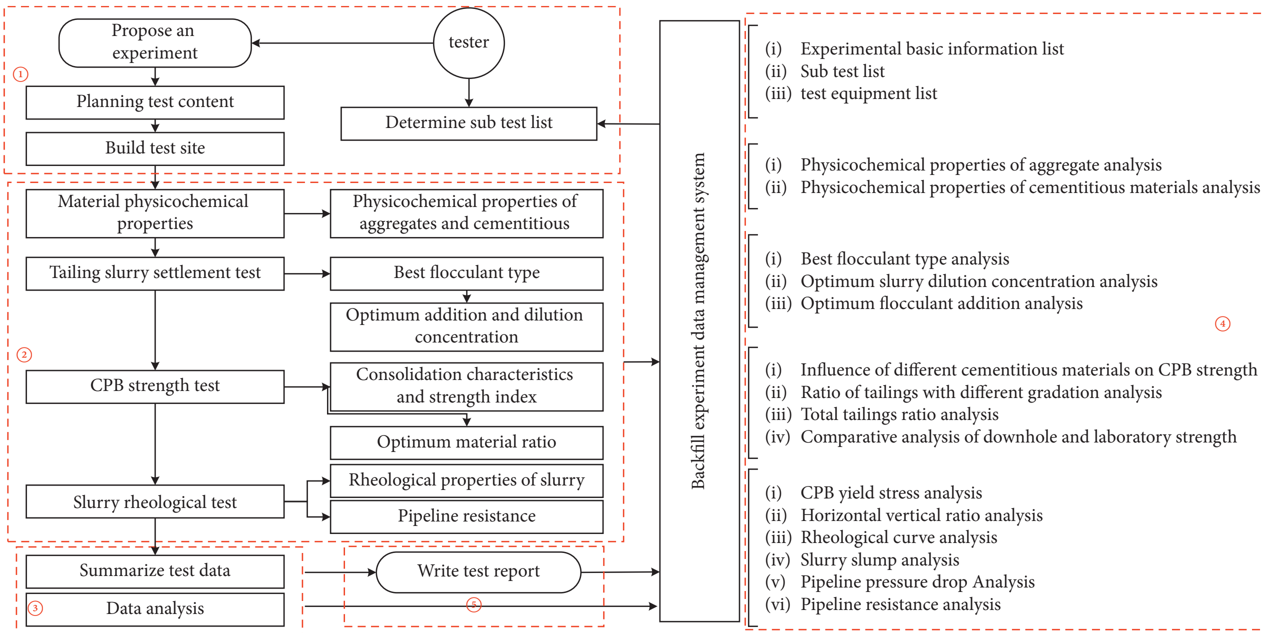

FIGURE 2: Backfill experiment business model.

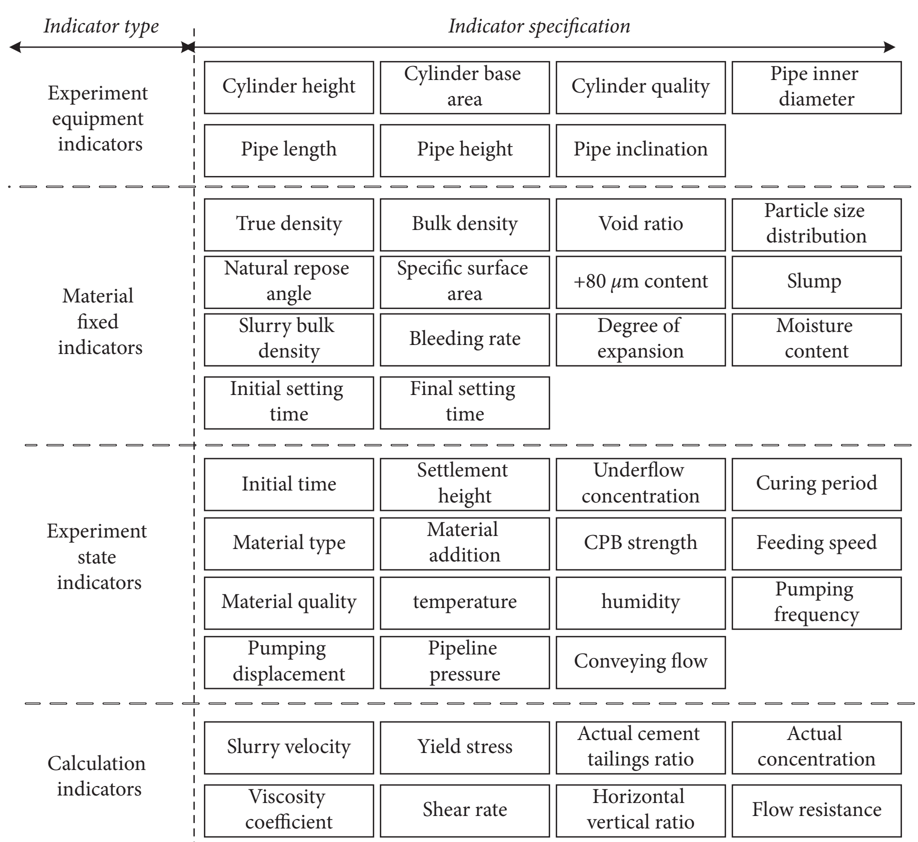

FIGURE 3: Backfill experiment indicator system.

According to the hierarchy of indicator data, backfill data indicators are divided into four categories: experimental equipment indicators, material fixed indicators, experimental state indicators, and calculation indicators.

(1) Test equipment indicators. Test equipment indicators are used mainly for calculating other test indicators, and generally, the specifications of enterprise test equipment are relatively fixed. The

system shall support user-defined modification of test equipment parameters.

(2) Material fixed indicators. The material fixed indicators, that is, the fixed parameter information of backfill aggregate, cementitious material, and other additives, were recorded. The material fixed index has a certain impact on the flocculation characteristics of the slurry, strength characteristics of the backfill body, and rheological characteristics, thus showing an obvious positive or negative correlation.

(3) Test status indicators. Test status indicator data have a wide range of sources and high update frequency. Additionally, these indicators are an important part of accounting data. Therefore, the requirements of this part should be considered in the system design, especially the database design.

(4) Calculation indicators. The output units present experimental results based on experimental equipment indicators, material fixed indicators, and experimental state indicators, which are automatically calculated by the built-in algorithms of the system.

Data update frequency, content, and type are the main bases for index classification. Among the update frequencies of the four types of indicators, the update frequency of equipment indicators is the lowest, and there is little change under normal circumstances. These indicators are independent variable indicators. Material fixed indicators generally fluctuate within a certain range. They will be remeasured only when new materials are used, or high accuracy is required. They are also independent variable indicators. The update frequency of the experimental state indicators is the fastest. Unlike other indicators, these indicators include both independent variable indicators (such as material type) and dependent variable indicators (such as CPB strength). All calculation indicators are dependent variable indicators.

4. System Implementation

4.1. System Function. The system functions include the system data dictionary, experiment management, data query, backfill knowledge maintenance, and system administration, as shown in Figure 4.

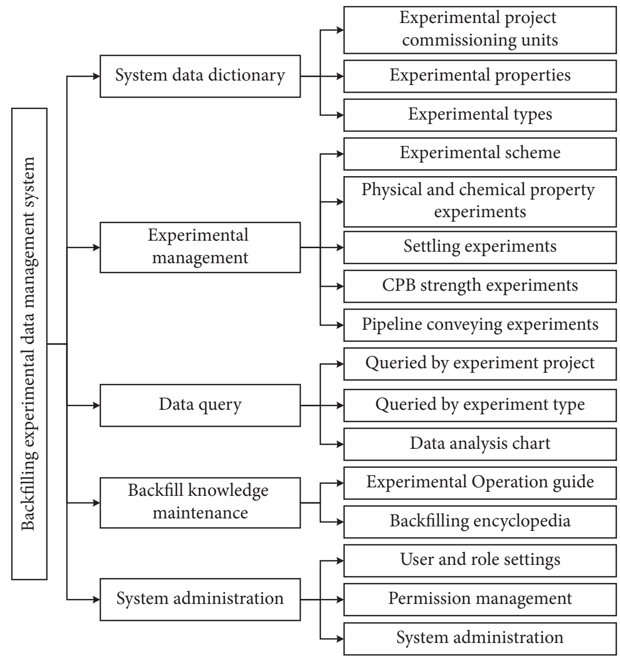

Figure 4: System function implementation.

(1) The system data dictionary is the experimental basic data management function. It contains information on experimental project commissioning units, experimental properties, and experimental types. This part of the information will constitute the basic information of experimental projects together with experimental personnel, time, and sites.

(2) Experimental management is an experimental data collection function. It is used in developing the experimental scheme (source), processing experimental data, summarizing experimental conclusions, and generating reports. In addition, at the end of the experiment, experimental management also supports experimenters in inputting the basic information of the experiment and inputting key experimental data, supports the system in automatically collecting experimental equipment data, and checks the experimental results. This function manages the whole process of all kinds of backfill experiments, such as physical and chemical property experiments, settling experiments, CPB strength experiments, and pipeline conveying experiments.

(3) Data query is an experimental data analysis and query function. With this function, the system can automatically generate data analysis charts according to user requirements and compare and analyze the same original data in multiple dimensions to enhance data utilization. The system supports a single-channel display, multichannel display, and comparative display of data. Data can be queried by experiment project and experiment type. For the former query mode, all the data of one experiment project can be queried; this capability is convenient for the vertical control of the experimental project. For the latter query mode, all the data of the type of experiment (e.g., CPB strength experiment) can be queried; this capability is convenient for the horizontal comparison of experimental data. A fuzzy matching query function is also supported to improve the data query rate.

(4) Backfill knowledge maintenance. With this function, a knowledge base of backfill experiments are formed based on many historical and search engine data, including data on existing mainstream backfill experimental methods, experimental tools, and experimental procedures. The information volume of the knowledge base gradually increases with the service time of the system. Gradually, the knowledge

base will meet enterprises' backfill experimental knowledge needs.

(5) System administration is a function that supports system data maintenance and user and role settings involved in the above modules, making the system adapted to all types of changes in laboratory and mining operations.

4.2. System Implementation. From the perspective of informalization of backfill experimental data management, a backfill experiment data management system is established based on the following ingredients:

(i) Server platform environment: Windows server.

(ii) Development tools: PHP back-end development language and HTML + JAVASCRIPT + CSS front-end development language.

(iii) Data interface tool: Restful, a data interface tool based on the HTTP protocol.

(iv) Technologies applied in system database deployment: federal database and data fusion technologies.

(v) System structure: B/S architecture.

Currently, the system has been built and used in a group's backfill engineering laboratory in Shandong. The system's data management functions and performance meet the group's design requirements, and all the designs have been fully verified. This system effectively improves the group's data management efficiency. The interfaces of experimental data collection, query, and analysis are shown in Figures 5–7.

5. Discussion

5.1. Key Technologies

5.1.1. Data Interface Development. The development of the system is based mainly on data management. Data collection has always been the biggest problem faced by system promotion and application. For example, traditional data collection methods for backfill data are error prone. These methods have cumbersome operations and low efficiency. Data interfaces are developed to solve these problems. In this system, the Restful data interface tools are used to complete batch collections of experimental equipment data, rapidly update system data, and greatly improve data transmission efficiency.

5.1.2. Standardization and Normalization of Experimental Data. Data standardization and normalization are prerequisites for data analysis and application. If the data management approach does not match the business process, there will be many problems such as low standardization of business processes and independent and scattered data storage. Therefore, the backfill experimental data is standardized and normalized, thereby laying a solid foundation for data multidimensional query and data subject analysis.

5.1.3. Data Warehouse and Fusion Technologies of the Backfill System. Enterprises have many historical backfill experimental data. Data warehouse and data fusion technologies are introduced to effectively integrate multimine and multidimensional data. These main technologies include data warehouse logical structures, data warehouse ETL technology, and data warehouse retrieval mechanisms. These technologies are used to establish a backfill system data warehouse with high reliability, strong ductility, and good performance.

5.1.4. Native Development of the Data Management Platform. To meet the requirements of the backfill experiment process and data management, the prototype method is used to carry out the native development of the experimental data management platform. This method focuses on the interaction between users and developers and has the advantages of a short development cycle, good flexibility, and strong applicability.

5.2. Application Effects. Through the application in the filling laboratory for nearly two years, the test data management system improves the comprehensive control level of the laboratory on data; the system can thereby effectively reduce the test cost and improve the degree of data sharing and utilization. The specific application effect is shown in Table 1.

5.3. Superiority and Limitations. The primary strength of this study is that it applies project management theory and data management systems in filling experiments. Compared with the traditional filling experimental data management method, the proposed filling experimental data management system requires the isolated storage of many historical data for unified management. This study improves the traditional filling data management method, reduces the data entry and calculation workload of the experimenter, and improves the efficiency of the experimenter and the degree of data sharing. The digitization of the filling experiment is the basic work of "intelligent mining for backfill," which can carry out deeper data applications.

The limitation of the system is that it is not developed at a deeper level for the problem of data postutilization. Our next step is to establish an effective connection between existing models, such as fill strength prediction and sedimentation prediction, with the system data to form a model for sustainable improvement. Artificial intelligence is used to quickly arrive at reliable filling indicator data, thereby reducing cumbersome manual experiments. The system will accumulate many experimental data over time. Using the system data set, a correlation analysis of the backfilling data index, data mining, and knowledge discovery could be carried out.

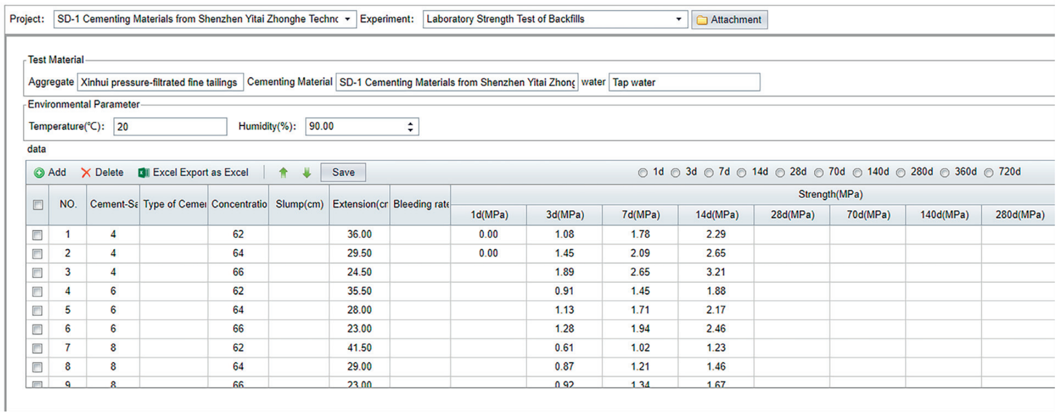

Figure 5: Input interface of backfill experiment data.

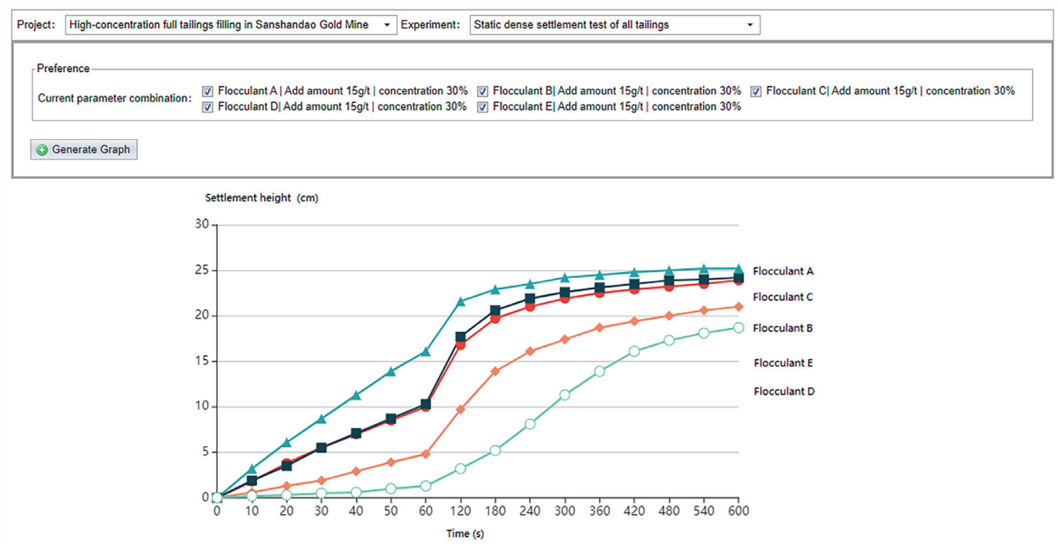

Figure 6: Analysis interface of backfill experiment data.

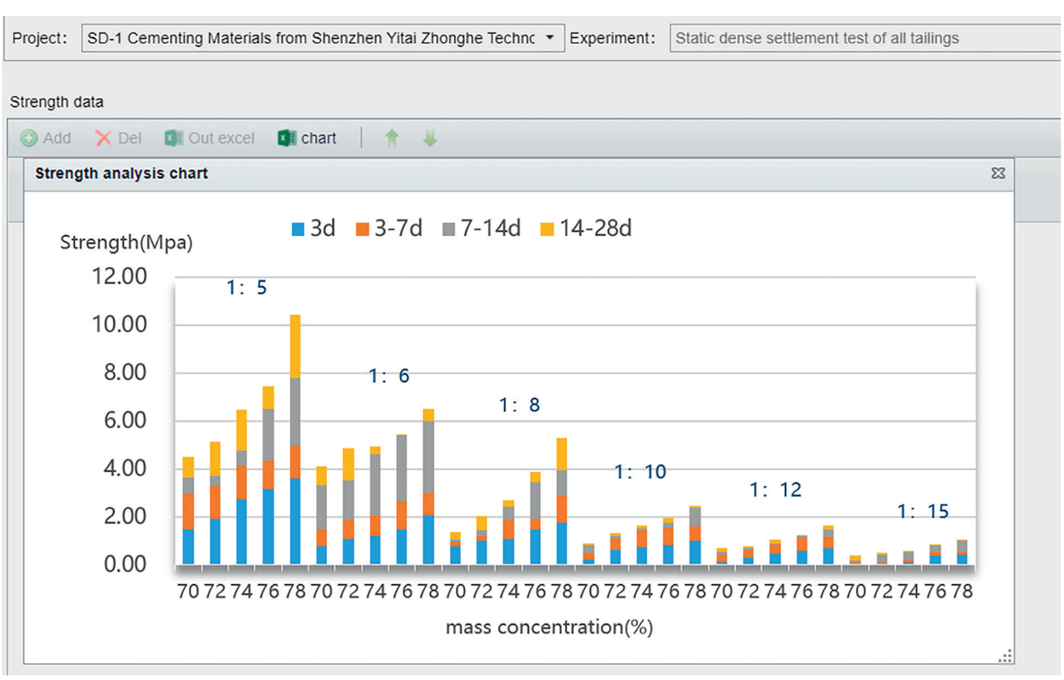

Figure 7: Strength analysis chart interface.

Table 1: Comparison of system application effects.

Items	Before system development	After system application
Test project	The administrators manually calculated material requirements and orally communicated project information to material managers and site managers.	The system automatically calculates the bill of materials and pushes relevant information to the assistant.
Sample detection	The administrators took samples according to personal memory and orally agreed to the test time and indicators with the testers.	The system pushes the sampling message and the test task to the person in charge of the test and the tester.
Data collection	The testers manually summarized machine test and manual measurement data.	The system imports machine test data in batches and integrates them with manual measurement data.
Site management	The administrators saved relevant information on personal computers and pasted it into reports.	The system saves the site information and automatically embeds it when the report is generated.
Data analysis	Administrators collected data and analyzed these data by using excel, origin, and the like	The system summarizes the data and automatically generates the analysis chart.
Test report	The administrators manually analyzed test data, summarized test conclusions, and prepared test reports.	The system automatically generates the test report according to the customized template.
Audit management	The administrator submitted the test results and other data to the leader, who signed for confirmation.	The audit business is completed in the system
Document storage	Document storage files were stored on personal computers.	Documents are recorded in the system and can be retrieved and queried at any time.

6. Conclusion

This study combs and integrates the backfill experiment data management system and proposes a data management system suitable for backfill experiment businesses. After being applied in a backfill engineering laboratory, the system manages the backfill experiment data in the laboratory. The main conclusions are as follows:

(1) The close fit between the business model and backfill experiment business process is the key to realizing data information management. Dividing the backfill experiment into six steps, this study fully considers the personality and generality of the backfill experiment and manages to establish a universal business model to ensure the ease of use of the system.

(2) Data index sorting is the premise of data management. This study classifies and arranges many complex backfill experiment indices, thereby providing an important basis for batch data collection, data processing logic design, and test data application.

(3) The backfill experiment data management system provides a new method and idea for integrating and reusing test data. Integrating and combining many historical data can effectively reduce the number and scale of similar tests. The research and development of this system can provide technical support for data reuse.

Although the backfill experiment data management system can effectively reduce the workload of experimental staff and improve the degree of data sharing, the information management of historical data needs the support of technical methods, such as character recognition and data cleaning. In addition, the knowledge discovery of experimental data needs the support of relevant intelligent algorithms. Further work can focus on building a backfill scheme optimization model. A system could integrate the monitoring data of the mine backfilling system, the parameters of the backfilling body, and the test data to optimize the backfilling scheme and the control strategy of the automatic system. Finally, the reliability and stability of the backfilling system would be greatly improved.

Data Availability

The data are generated from the field and can be available from the corresponding author upon request.

Conflicts of Interest

The authors declare that there are no conflicts of interest regarding the publication of this paper.

Acknowledgments

This work was supported by the National Key Research and Development Program of China (Grant no. 2018YFC0604405) and the General Program of National Natural Science Foundation of China (Grant no. 52074022).

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