Journal of Civil, Construction and Environmental Engineering
2024, Vol. 9, No. 6, pp. 188-196
https://doi.org/10.11648/j.jccee.20240906.12

Research Article

Design and Verification of Blockchain Enabled Monitoring Data Ownership for Foundation Pits

Yixin He[1, 2], Wu Chen[3], Jun Zhou[3], Ge He[4, *], Dan Miao[1, 2], Jianxin Ye[1, 2]

[1]Guangzhou Guangjian Construction Engineering Testing Center Co., Ltd., Guangzhou, China
[2]Guangdong Engineering Technology Research Center of Building Health Monitoring and Security Early Warning, Guangzhou, China
[3]The Guangdong Province Geotechnical Survey Design Research Co., Ltd., Guangzhou, China
[4]State Grid Shanghai Urban Electric Power Supply Company, Shanghai, China

Abstract

With the rapid development of urban construction, the demand for reliable data management systems is increasing. The Guangzhou Housing and Urban-Rural Development Bureau has recognized the necessity of data rights confirmation to enhance the management efficiency and security of monitoring data, which is crucial for ensuring the safety of construction projects. In response to the insufficient security and credibility of traditional foundation pit monitoring data during the certification process, this study proposes a design and verification scheme for foundation pit monitoring data certification based on blockchain technology. By designing smart contracts to achieve tamper proof and transparent sharing of data, we ensure the authenticity and reliability of monitoring data throughout its entire lifecycle. The experimental results show that the proposed scheme effectively reduces the security risks of foundation pit monitoring data during storage and transmission, and improves the efficiency and accuracy of data management. Meanwhile, based on the distributed nature of blockchain, the credibility of data has been enhanced, preventing the forgery and tampering of information. The design scheme of this study not only effectively realizes the certification of foundation pit monitoring data, but also provides new ideas for data sharing and security in engineering management, with important application prospects, especially in the fields of engineering safety, risk control, etc., which can provide strong data support for relevant decisions.

Keywords

Blockchain, Foundation Pit Monitoring, Data Ownership Confirmation, Smart Contract

1. Introduction

In the context of rapid urbanization and increasing infrastructure construction, foundation pit engineering, as an essential part of urban development, has its safety and stability directly impacting the surrounding environment and the safety of related projects. However, with the growing scale and complexity of foundation pit projects, traditional monitoring and management methods face numerous challenges, particularly in data storage, management, and rights verification.

*Corresponding author: 125710778@qq.com (Ge He)

Received: 25 August 2024; **Accepted:** 4 November 2024; **Published:** 14 November 2024

Firstly, the accuracy and completeness of foundation pit monitoring data are fundamental to ensuring engineering safety. However, existing centralized data storage methods often have security vulnerabilities, making them susceptible to human tampering, data loss, and other risks. This not only affects the credibility of monitoring data but may also lead to erroneous engineering decisions, potentially resulting in safety incidents. Furthermore, traditional data management approaches frequently lack effective rights verification mechanisms, making it difficult to guarantee the source, authenticity, and integrity of the data, which can lead to data disputes and hinder effective information sharing.

Secondly, barriers to the sharing and circulation of foundation pit monitoring data result in issues such as information asymmetry and resource waste. Due to the lack of a transparent sharing platform among different stakeholders, delays and increased costs in construction operations may occur due to untimely and inaccurate information transmission, ultimately affecting the efficiency and sustainability of urban construction.

In this context, the Guangzhou Housing and Urban-Rural Development Bureau has recognized the importance of data rights verification and is actively exploring new data management methods to enhance the efficiency and security of monitoring data management. This not only responds to the monitoring and management needs of foundation pit engineering but also provides necessary measures to ensure the safety of construction projects. Introducing blockchain technology as a solution can effectively address the aforementioned issues, leveraging its decentralized nature, high security, and strong transparency to provide a new approach for the storage and management of foundation pit monitoring data.

This study aims to provide new ideas and solutions for the storage, management, and circulation of foundation pit monitoring data, and promote the safe operation of foundation pit engineering and the sustainable development of urban construction. At the same time, this study will also provide practical experience and reference for the application of blockchain technology in the field of infrastructure monitoring, and promote the further application and development of blockchain technology in the engineering field.

In recent years, the application of blockchain technology in many fields such as environmental monitoring and building management is increasingly rich, which is promoting the innovative development of intelligent monitoring systems. The decentralization, security, and transparency of blockchain technology provide a new guarantee for the credibility of monitoring data and then promote the innovation and development of intelligent monitoring system [1, 2]. In addition, for the environmental monitoring of urban agglomerations, researchers have also begun to explore how to realize intelligent management with the help of advanced technology [3-5].

In the construction industry, the application potential of blockchain technology is huge, which is of great value to improve project transparency, reduce fraud risk and optimize supply chain management. For example, blockchain can record and verify the source of building materials in real time, ensuring that they meet environmental protection and safety standards, thus enhancing the trust of consumers and investors [6-8]. In addition, in large-scale construction projects involving multiple stakeholders, blockchain can provide a shared account book to ensure that all participants can obtain relevant information in time and reduce the risks caused by information asymmetry [9-11].

Despite this, blockchain technology still faces some challenges in practical application. In small-scale construction projects, how to balance technical costs and expected benefits and adapt to fast-paced project management needs has become an urgent problem to be solved [12]. In addition, information security, data privacy and other issues have also restricted the wide application of blockchain technology to a certain extent [13]. In recent years, for energy consumption monitoring and coal industry, a monitoring database based on blockchain has been built, which provides a new technical perspective and solution for monitoring systems in different fields [14, 15].

In a word, the application of blockchain technology in the field of foundation pit monitoring data confirmation shows its broad development prospects. Through in-depth exploration and practice, it is expected to further improve the storage, management and confirmation system of foundation pit monitoring data, continuously promote the innovation and application of monitoring technology, and provide more reliable technical support and guarantee for urban construction and infrastructure safety.

2. Research Method

The purpose of this study is to build a foundation pit monitoring data confirmation system based on blockchain technology. In order to achieve this goal, the following research methods are comprehensively adopted:

2.1. Literature Research

Through literature research, this paper analyzes the current situation and existing problems of foundation pit monitoring technology, paying special attention to the shortcomings of traditional monitoring methods in data credibility, security and real-time performance. At the same time, the basic principle, development path, and successful application cases of blockchain technology in other fields are deeply studied to determine the feasibility and innovation of this technology in foundation pit monitoring.

2.2. Structural Design

Based on the results of literature research, the system structure design will adopt a bottom-up method, including hardware architecture, software architecture and network architecture. The hardware architecture selects high-precision sensors, collects monitoring data of foundation pit through IoT equipment and uploads them to blockchain network in real time. Considering the distributed storage characteristics of blockchain nodes, a multi-node storage scheme is designed to optimize the accessibility and security of data. Software architecture design and implementation of intelligent contract, responsible for the verification and processing of monitoring data. Smart contracts will set rules for data uploading, processing and early warning. According to users' needs, an easy-to-operate front-end interface is designed to facilitate users to quickly query data and obtain early warning information. The network architecture selects the appropriate blockchain platform (such as Ethereum or Hyperledger), and designs the interaction protocol between nodes to ensure the safe transmission of data in the network.

2.3. Experimental Design and Implementation

In order to verify the effectiveness and performance of the system, a series of experiments are designed. Data acquisition and winding experiment build a test environment, and obtain various types of monitoring data through sensors, and record the data acquisition frequency, delay and winding success rate. The smart contract execution efficiency experiment makes test cases to verify the execution time and accuracy of smart contracts under different conditions and ensure stability in high concurrency scenarios. User experience testing recruits users to test the use of the system, collects feedback from users in the operation process and analyzes the friendliness of the interface and the ease of use of functions.

2.4. Data Analysis and Result Verification

After the experiment is completed, the experimental results are sorted and analyzed by combining quantitative analysis with qualitative analysis. Quantitative analysis By collecting experimental data, the success rate of data winding, the execution time of smart contract, the duration of user operation, and other indicators are statistically analyzed, and the experimental results are displayed by charts. Qualitative analysis is to collect user feedback, conduct thematic analysis, refine users' potential needs for the system and suggestions for improvement, and ensure the pertinence and effectiveness of subsequent iterations.

2.5. Security and Scalability Evaluation

Finally, in order to ensure the security and scalability of the system, audit and testing are carried out. Security evaluation evaluates the potential security vulnerabilities that may exist in the system and designs unit tests and system tests to ensure the security of data transmission and storage. Scalability test tests the performance of the system under the condition of increasing load and expanding data scale and evaluates its adaptability and performance in future expansion.

Through the design and implementation of the above research methods, this study will help to provide a reliable and efficient system for confirming the right of foundation pit monitoring data based on blockchain and provide support for technological innovation in the field of foundation pit monitoring.

3. System Implementation

3.1. Technical Architecture

The system adopts distributed architecture, which is divided into three main parts: application layer, service layer, and foundation layer. The application layer is responsible for interacting with users and providing friendly interfaces and functions, such as data uploading, statistical analysis, auditing, and report generation. This layer ensures a smooth user experience and can meet the needs of different users. The service layer contains core business logic and data processing functions and is responsible for submitting data, querying data and generating smart contracts. This layer is the core of the system, which ensures the effectiveness of data processing and the automatic execution of intelligent contracts. The basic layer provides the underlying technical support required by the system, including blockchain network, database and consensus algorithm. This layer ensures the stability and security of the system and provides necessary technical support for the upper applications and services. The overall architecture design is shown in Figure 1.

3.2. Data Structure

In the blockchain, each piece of monitoring data needs to be composed of multiple fields to facilitate subsequent query and management. The data record structure is as follows: the data ID uniquely identifies each piece of monitoring data; The monitoring type indicates the data type, such as displacement, stress, etc. Monitoring value actually recorded monitoring value; Time stamp records the specific time of data acquisition; The uplink hash corresponds to the hash value of this data on the blockchain for traceability. The data structure is shown in Figure 2.

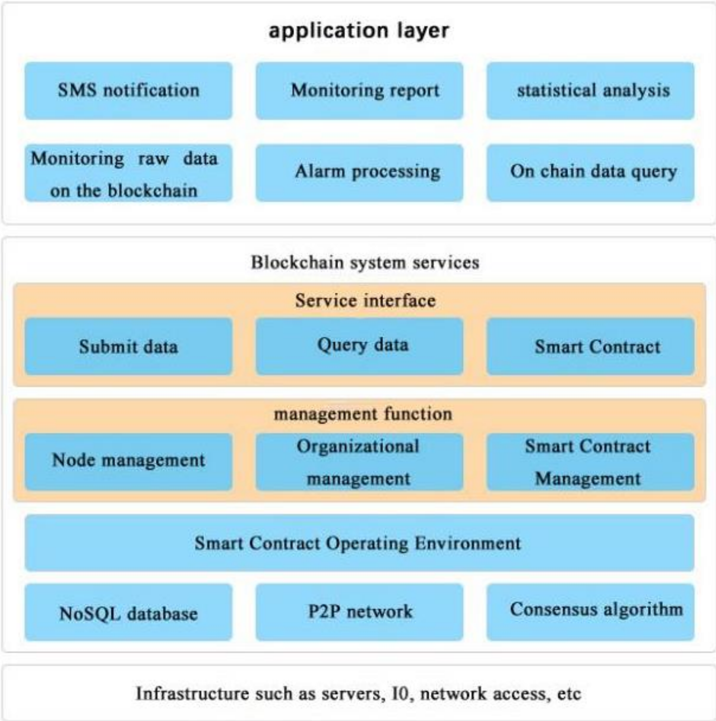

Figure 1. *Technical architecture.*

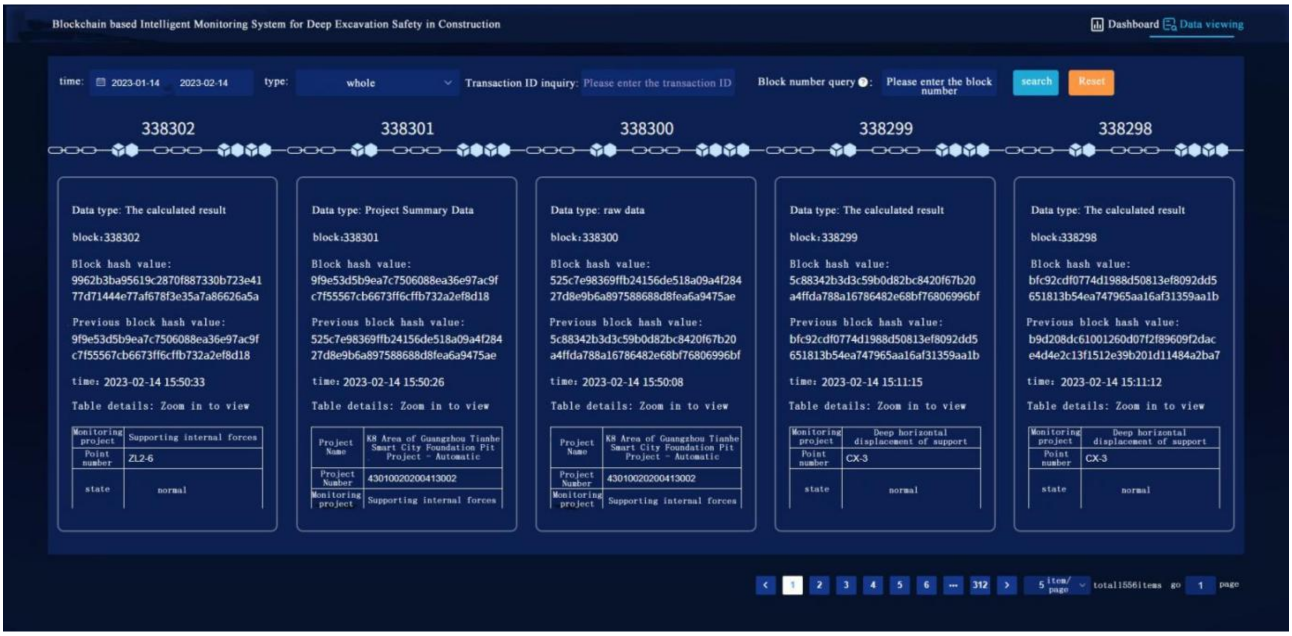

Figure 2. *Data structure.*

3.3. Uplink Process

The process of data acquisition and winding includes the following main steps: monitoring the state of foundation pit periodically through sensors and storing the data in local equipment. Format the collected original data to meet the requirements of the winding structure. Call the uplink function through the smart contract to transmit data to the blockchain. Record the returned hash value as the unique identification of this piece of data. Users can review the uplink data in the application to ensure that the data is accurate.

3.4. Smart Contract

A smart contract is used in this system to automate the process of data uploading and auditing. Data winding contracts define data structures and corresponding storage variables. Provides a winding function so that external data can be called. The data query contract provides a query interface so that users can query specific data through information such as transaction ID or timestamp. Support to return information such as data type, value and winding time. Set a multi-user audit mechanism, and the audit of each piece of data depends on the confirmation of multiple users. Update the data status and its historical hash value after each audit to ensure the integrity of the data. The automatic execution of intelligent contracts not only reduces the necessity of manual intervention but also improves the efficiency and transparency of data management.

3.5. Secret Protection

Data security and privacy protection are very important. To this end, the system has taken a variety of security measures: SSL/TLS protocol is used to encrypt data during transmission to ensure the security of data transmission. Uplink data is encrypted by hash algorithm to provide privacy protection for data. User authentication ensures that only authorized users can access and manage monitoring data. Users of different roles are granted different rights to achieve fine-grained rights management. The system records the audit log of key operations to ensure that subsequent operations can be tracked and reviewed. Audit logs provide a basis for management and regulatory agencies to review and enhance the credibility of the whole system.

3.6. Distributed Storage

In order to improve the performance and scalability of the system, the team adopted some technical means. The system uses distributed storage and indexing technology to store data in multiple nodes to improve the reading and writing performance of data. At the same time, the team used a distributed consensus algorithm to ensure the data consistency and security of all nodes in the blockchain network. Distributed storage is shown in Figure 3.

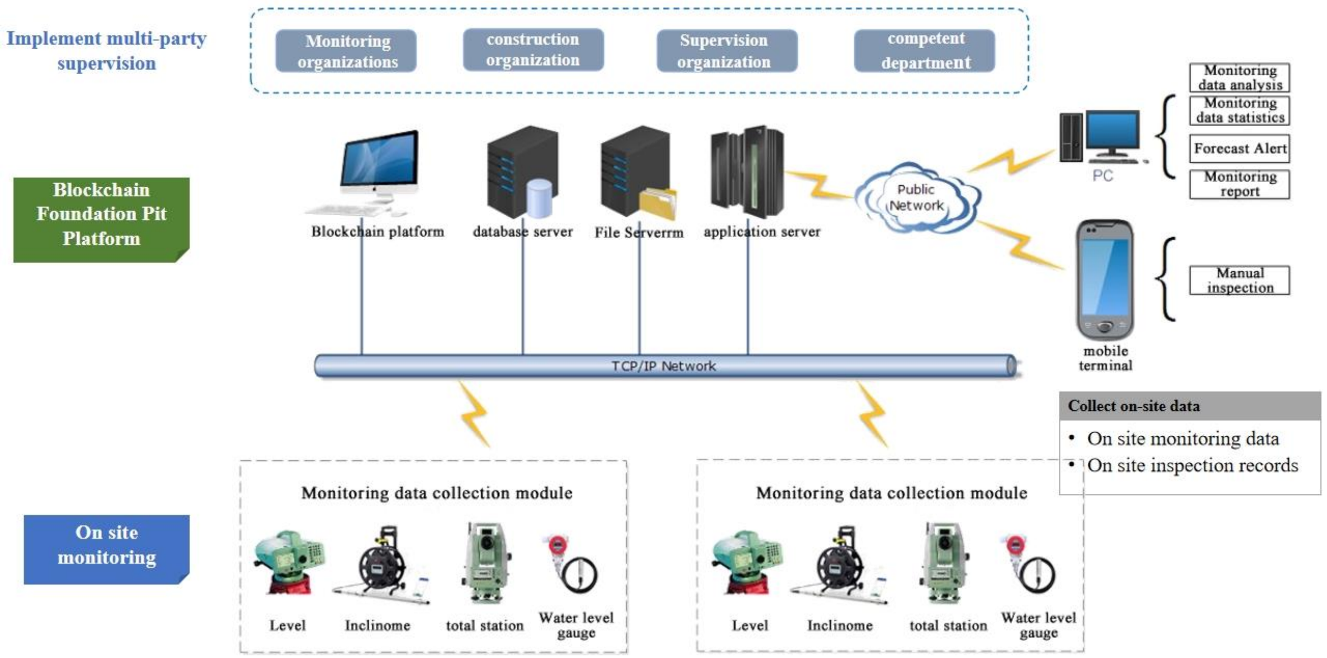

Figure 3. *Distributed storage.*

Blockchain security monitoring system covers system architecture, data structure, collection and winding process, intelligent contract and security measures. Through careful design and implementation, it not only improves the ability of data verification but also provides valuable experience for the promotion and practice of similar applications.

4. System Evaluation

Hire a professional third party to conduct a comprehensive safety and expansibility evaluation of the foundation pit monitoring data confirmation system based on blockchain. The evaluation will cover data transmission security, smart contract security and system scalability analysis to ensure the robustness of the system in daily operation and the potential for future development.

4.1. Data Transmission Security Evaluation

The security of data transmission is the key factor to ensure that the monitoring data will not be maliciously tampered with and accessed without authorization in the process of collection, transmission and storage. In order to evaluate the security of data transmission, we adopt the following measures: The system uses strong encryption algorithms (such as AES and TLS) to encrypt the transmitted data. This ensures the confidentiality of information during real-time data transmission. Through penetration testing and security scanning tools, the security of the system in the open network environment is evaluated. The vulnerabilities found in the test will be recorded and fixed in time to prevent potential threats to the data. Strict identity authentication and role authority allocation are implemented to ensure that only authorized users can access or operate specific data, thus reducing the risk of internal disclosure.

4.2. Security Evaluation of Smart Contract

The smart contract is an important component of the system, which is responsible for automatically executing data confirmation and transaction flow, so it is very important to evaluate its security in depth. To this end, the team conducted a comprehensive audit of the smart contract code through a third-party organization, focusing on potential risk points such as reentry attacks, overflow errors and logical loopholes. The problems found will be corrected in time and re-audited to ensure the safety and reliability of the contract. In addition, unit testing and integration testing will be used to verify the functions of the smart contract to ensure that it can be executed normally under various conditions. In order to further enhance the security, the system will establish an intelligent contract exception response mechanism. Once the abnormal behavior of the contract is detected, it will immediately trigger an alarm and restrict the execution of the contract to prevent possible losses or failures. Through the above measures, the security and stability of smart contracts are effectively improved, which provides a solid guarantee for the whole system.

4.3. Scalability Evaluation

The scalability of the system refers to its ability to quickly increase or adjust functions according to future demand changes without affecting performance. In order to evaluate the scalability of the system, the team conducted a system analysis. First of all, the system adopts modular architecture, and each functional module is independent of each other, and communicates through API, so that it is convenient to add new functions or services in the later stage and improve the adaptability of the system. Secondly, the team conducted a stress test to simulate the performance of the system in a highly concurrent environment, so as to evaluate its response ability and processing ability in large-scale foundation pit monitoring projects. In addition, for the blockchain part, the team adopts an extensible technical framework, such as fragmentation technology and two-tier expansion scheme, to ensure that the system performance remains stable with the increase of data volume. Through these measures, the team ensures that the system has good expansion potential and performance stability in the face of future needs.

4.4. Summary of Results

Through the above safety and expansibility evaluation, we can confirm the robustness of the foundation pit monitoring data confirmation system based on blockchain in many links. The system has formulated strict safeguard measures in data transmission, smart contract and user identity security, and has good scalability to adapt to future demand changes. These evaluation results have laid a solid foundation for the practical application of the system and provided the direction for future optimization and expansion.

5. Application and Optimization

Through a series of experiments, this paper verifies the function and performance of the foundation pit monitoring data confirmation system based on blockchain. Specific objectives include: testing the data processing efficiency of the system in the real environment, evaluating the stability and security of the smart contract, verifying the effectiveness of the user identity management mechanism, and analyzing the scalability of the system in the case of high concurrency.

The research team first chose a practical scene related to safety monitoring, that is, safety monitoring of deep foundation pit in construction engineering. The team cooperated with relevant monitoring institutions and organizations, defined specific application cases, and determined the objectives and requirements of the system in this scenario. Next, the team implemented and deployed a security monitoring system based on blockchain, as shown in Figure 4. By cooperating with relevant data suppliers and monitoring units, they established a data collection mechanism and uploaded the monitoring data to the blockchain network. At the same time, the team has configured authentication and access control mechanisms to ensure that only authorized users can access and query data. In addition, the team designed and implemented traceability and anti-counterfeiting mechanisms to ensure the authenticity and credibility of the data. In the practical verification stage, the team collected the operation data and user feedback of the system, and compared with the existing security monitoring methods, evaluated the effects and advantages of the system in data confirmation, verification, and access control. In addition, the team also evaluated the performance of the system in terms of throughput, delay and scalability by simulating experiments in different scenarios and data scales.

***Figure 4.** Safety monitoring system.*

5.1. Data Transmission and Processing

The experimental results show that the data transmission delay of the system under normal load is about 200 milliseconds and the data loss rate is 0.5%. In the peak period, although the delay is slightly increased, the real-time performance of the data is guaranteed within an acceptable range.

5.2. Intelligent Contract Security

The results of smart contract penetration test show that six potential vulnerabilities were found, of which three were marked as serious. It has been fixed by improving the smart contract code. After the security audit, the contract as a whole showed high security.

5.3. User Identity Management

The success rate of multi-factor authentication is 98%, and the false authentication rate is less than 2%. The system is stable in multi-role management, and the authority management mechanism effectively prevents unauthorized access.

5.4. Performance and Scalability

The stress test results show that the system can support up to 500 concurrent users and keep the response time within 400 milliseconds under this load. With the increase of the number of users, the system performance remained stable and there was no obvious performance bottleneck.

5.5. Performance Optimization

In terms of optimizing performance, upgrading the underlying technology of blockchain is the key to improve the throughput performance of blockchain platform. After studying the underlying code of Fabric, the team optimized and rewritten the code processing logic. At the same time, Redis cache is added, and efficient and secure RAFT consensus algorithm is adopted to further optimize the system. After these transformations, the performance bottleneck at the bottom of the blockchain was successfully broken, and the throughput of the platform was increased to 3000TPS, as shown in Table 1, and the second-order delay of transaction winding was realized.

***Table 1.** Platform throughput.*

Batch Time out	Max Message Count	TPS
0.5	100	3,016.053961
0.5	200	2,847.860953
0.5	400	2,830.279202

Batch Time out	Max Message Count	TPS
0.5	800	2,425.067298
0.5	1000	2,630.878498
0.5	2000	2,614.223437
0.5	4000	2621.181855
0.5	8000	2,644.817002
0.5	10000	2,605.018076

Through the application case and practice verification, it not only shows the practical application value of the safety monitoring system based on blockchain, but also provides strong support and promotion for the research and practice in related fields, bringing innovation and improvement to the data confirmation, verification and management in this field.

6. Discussion and Summary

In the context of rapid urbanization and increasing infrastructure construction, foundation pit engineering, as an essential part of urban development, has its safety and stability directly impacting the surrounding environment and the safety of related projects. However, with the growing scale and complexity of foundation pit projects, traditional monitoring and management methods face numerous challenges, particularly in data storage, management, and rights verification.

Firstly, the accuracy and completeness of foundation pit monitoring data are fundamental to ensuring engineering safety. However, existing centralized data storage methods often have security vulnerabilities, making them susceptible to human tampering, data loss, and other risks. This not only affects the credibility of monitoring data but may also lead to erroneous engineering decisions, potentially resulting in safety incidents. Furthermore, traditional data management approaches frequently lack effective rights verification mechanisms, making it difficult to guarantee the source, authenticity, and integrity of the data, which can lead to data disputes and hinder effective information sharing.

Secondly, barriers to the sharing and circulation of foundation pit monitoring data result in issues such as information asymmetry and resource waste. Due to the lack of a transparent sharing platform among different stakeholders, delays and increased costs in construction operations may occur due to untimely and inaccurate information transmission, ultimately affecting the efficiency and sustainability of urban construction.

In this context, the Guangzhou Housing and Urban-Rural Development Bureau has recognized the importance of data rights verification and is actively exploring new data management methods to enhance the efficiency and security of monitoring data management. This not only responds to the monitoring and management needs of foundation pit engineering but also provides necessary measures to ensure the safety of construction projects. Introducing blockchain technology as a solution can effectively address the aforementioned issues, leveraging its decentralized nature, high security, and strong transparency to provide a new approach for the storage and management of foundation pit monitoring data.

7. Conclusion

The blockchain-based foundation pit monitoring data rights confirmation system not only provides a new solution for the foundation pit monitoring field but also lays a foundation for enhancing the credibility and efficiency of data interaction and management. We look forward to further research and practice in related fields in the future, contributing to the realization of intelligent and digital modern monitoring management.

Abbreviations

IoT	Internet of Things
ID	Identity Document
SSL	Secure Sockets Layer
TLS	Transport Layer Security
AES	Advanced Encryption Standard
API	Application Programming Interface
TPS	Transactions Per Second

Funding

This work is supported by the Science and Technology Plan of the Ministry of Housing and Urban-Rural Development of Funder (Grant No. K20200413).

Conflicts of Interest

The authors declare no conflicts of interest.

References

[1] Wu H., Li Y., Li X., et al. Design of blockchain framework and realization of management module of ecological flow monitoring system. Yangtze River Technical Economy, 2024, 8(01): 132-138. https://doi.org/10.19679/j.cnki.cjjsjj.2024.0121.

[2] Wu J. Exploration and Application of Blockchain + Geographic Information Service. Surveying and Mapping and Spatial Geographic Information, 2023, 46(11): 66-69.

[3] Xu Q., Shen Z., Yan Y., et al. Study on regional water ambient intelligence monitoring for urban agglomeration-taking Changsha-Zhuzhou-Xiangtan urban agglomeration as an example. Journal of Xiangtan University (Natural Science Edition), 2023, 45(06): 52-61. https://doi.org/10.13715/j.issn.2096-644X.20221212.0001.

[4] Kou Y., Jiang S., Hu Z., et al. Data sharing scheme of fire monitoring system based on blockchain technology. Shanxi architecture, 2023, 49(04): 5-9. https://doi.org/10.13719/j.cnki.1009-6825.2023.04.002.

[5] Li Y., Bai X., Li J., et al. Research on environmental monitoring system based on chain block technology. Journal of Anhui University (Natural Science Edition), 2022, 46(05): 27-36. https://doi.org/10.3969/j.issn.1000-2162.2022.05.005

[6] Wu H., Zhang P., Zhou B., et al. Design of network risk detection system for earthquake industry based on blockchain technology. Modern Information Technology, 2023, 7(18): 110-113. https://doi.org/10.19850/j.cnki.2096-4706.2023.18.022.

[7] Pi J., Zhang P., Zhou J. Blockchain-based safety development supervision platform solution. Journal of Sichuan University (Natural Science Edition), 2023, 60(06): 127-134. https://doi.org/10.19907/J.0490-6756.2023.200202020206

[8] Dena M., Mehrdad A., Rebecca Y. Blockchain in construction management: Applications, advantages and limitations. Automation in Construction, 2022, 140. https://doi.org/10.1016/j.autcon.2022.104379

[9] Ahsan W., Abdul Q., Idris O., et al. Exploration of challenges to deployment of blockchain in small construction projects. Ain Shams Engineering Journal, 2024, 15(2): 102362-. https://doi.org/10.1016/j.asej.2023.102362

[10] N. A N A., Farzad R P., Nashwan D., et al. Digital Twins and Blockchain technologies for building lifecycle management. Automation in Construction, 2023, 155. https://doi.org/10.1016/j.autcon.2023.105064

[11] Bassant S., Volkan H. A Review on Blockchain Operations in Construction Management. Journal of Sustainable Construction Materials and Technologies, 2023, 8(2): 146-152. https://doi.org/10.47481/jscmt.1244244

[12] Mahsa S., Amin M., Xiaopeng D., et al. Enterprise blockchain solutions for vibrant construction ecosystem: Grey Ordinal Priority Approach. Grey Systems: Theory and Application, 2024, 14(1): 115-143. https://doi.org/10.1108/gs-07-2023-0060

[13] Moumita D., Xingyu T., C.P. J C. BIM security: A critical review and recommendations using encryption strategy and blockchain. Automation in Construction, 2021, 126. https://doi.org/10.1016/j.autcon.2021.103682

[14] Zeng J., Liu Y. Trust management of blockchain terminals in energy consumption monitoring. Electric Power Automation Equipment, 2020, 40(08): 31-37. https://doi.org/10.16081/J.EPAE.20008012.20008012006

[15] Zheng X., Tong X., Jun G., et al. Research status and development trend of intelligent monitoring and early warning technology in coal mines. Industrial and Mining Automation, 2020, 46(06): 35-40. https://doi.org/10.13272/j.issn.1671-251x.17530.

Biography

Yixin He, (1976-), male, Han nationality, native of Datong City, Shanxi Province, Guangzhou, senior engineer. Working in Guangzhou Guangjian Construction Engineering Testing Center Co., Ltd. and Guangdong Engineering Technology Research Center of Building Health Monitoring and Security Early Warning. Main research direction: the principle of geographic information system and its engineering application.

Ge He, (1997-), female, Han nationality, Shanghai, master. Research interests: power system analysis, microgrid economic analysis, multi-microgrid intelligent transaction based on blockchain.