Proceedings of CONF-FMCE 2025 Symposium: AI and Machine Learning Applications in Infrastructure Engineering
DOI: 10.54254/2755-2721/2025.MH25134

Application of BIM Technology in Displacement Monitoring of Highway Retaining Walls

Mingxuan Yang

School of Civil&Architecture Engineering of ECUT, East China University of Technology, Nanchang, China
2023211633@ecut.edu.cn

Abstract. Currently, displacement monitoring of highway retaining walls mainly relies on traditional technologies, which generally suffer from problems such as data discretization, poor real-time performance, and difficult information integration. Although BIM technology has been widely applied in the field of construction, its integrated application in highway infrastructure is still in the exploratory stage. In order to improve the level of safe operation and maintenance under complex geological conditions, and achieve visualization and dynamic warning, this paper proposes a displacement monitoring method based on BIM technology that deeply integrates FBG and GNSS. This article mainly constructs a "BIM+" technology system, which collects real-time data through fiber optic sensors (FBG) and GNSS 3D coordinate tracking, uploads it to the BIM platform to integrate multi-source information, and combines finite element analysis and 3D visualization to achieve dynamic warning and decision optimization. The results indicate that this method breaks through the information silos of traditional monitoring techniques, supports dynamic risk management throughout the entire cycle, and can be extended to intelligent operation and maintenance of slopes, tunnels, and other engineering projects in the future.

Keywords: BIM technology, Displacement of highway retaining walls, FBG fiber optic sensing, GNSS three-dimensional coordinate tracking, BIM+Deep Integration.

1. Introduction

In recent years, Building Information Modeling (BIM) technology, as a core tool for promoting the digital transformation of buildings, has demonstrated significant advantages in design optimization, construction management, and operation and maintenance stages. The core advantage of BIM technology lies in breaking the information silos of the traditional construction industry through digital integration, achieving efficient collaboration and resource optimization throughout the entire lifecycle. The penetration rate of BIM technology in the construction field continues to increase globally. BIM technology has significantly improved the overall efficiency and quality of projects through various functions such as visualization, parameterization, collaboration, and optimization. However, the popularity of BIM technology in small and medium-sized cities is still relatively low, and its application in highway construction is still in its early stages [1].

© 2025 The Authors. This is an open access article distributed under the terms of the Creative Commons Attribution License 4.0 (https://creativecommons.org/licenses/by/4.0/).

DOI: 10.54254/2755-2721/2025.MH25134

The characteristics of highways are mainly reflected in high speed, high safety, high efficiency, and strong connectivity. Their large span and long line also require protective construction to meet complex and changing geological conditions. Currently, displacement monitoring of highway retaining walls mainly relies on traditional methods such as total stations. Although this method can obtain local data, it has problems such as monitoring discretization and information islanding, making it difficult to achieve real-time dynamic analysis and visual risk warning [2]. To solve the above problems, new technological means need to be introduced. In response to the signal interference and insufficient accuracy issues faced by GNSS technology in monitoring dam slope deformation in complex environments, Luo Youfu designed a slope deformation monitoring system that integrates GNSS and multi-source data fusion [3], and Tian Suhui et al. proposed a displacement monitoring method based on FBG sensors for the displacement monitoring needs of gravity retaining walls in mountainous highways [4]. The BIM+deep fusion technology proposed in this article, which combines the above two methods, effectively compensates for the limitations of traditional methods for monitoring the displacement of retaining walls.

Based on the above issues, this article aims to analyze the application of BIM technology in displacement monitoring of retaining walls. At the same time, this article focuses on exploring the deep integration of BIM technology with FBG sensing technology and GNSS technology to achieve dynamic acquisition and 3D visualization expression of displacement data [4]. To provide high-precision and full-cycle digital support for the stability assessment of retaining walls, while promoting the deep application of BIM technology in geotechnical engineering safety control, and providing new ideas for intelligent operation and maintenance of infrastructure under complex geological conditions.

2. Failure mechanism of retaining walls on highways and existing displacement detection technology

2.1. Failure mechanism of retaining wall

The relevant regulations indicate that the failure mechanism of retaining walls mainly involves multiple factors such as design, materials, construction, environment, and maintenance [5]. This article mainly analyzes the failure mechanism of retaining walls under mechanical influence.

Sliding failure refers to the sliding of the retaining wall along the foundation bottom when the anti-sliding force of the retaining wall foundation bottom is insufficient to resist the horizontal thrust generated by the backfill behind the wall. Overturning damage refers to the situation where the overturning moment generated by the backfill behind the wall on the retaining wall is greater than the anti-overturning moment generated by the weight of the retaining wall itself, causing the retaining wall to overturn outward around the toe of the wall, and even causing the wall to collapse. During the filling process, if the shear strength of the backfill behind the wall is insufficient, it will cause sliding surfaces inside the backfill, resulting in the loss of lateral support and damage to the retaining wall. If the pressure on the bottom surface of the retaining wall foundation exceeds the bearing capacity of the foundation soil, the foundation soil will undergo shear failure, causing the retaining wall to sink, tilt, or even collapse. In this case, the foundation soil around the retaining wall foundation may experience uplift, cracks, and uneven settlement of the retaining wall [6].

DOI: 10.54254/2755-2721/2025.MH25134

2.2. Current monitoring technology for retaining walls

At present, the monitoring technology for retaining walls in China is mainly divided into traditional monitoring and modern monitoring. Among them, traditional monitoring refers to the technology of using conventional instruments and methods to monitor the displacement, deformation, and other aspects of retaining walls, including leveling measurement, tilt measurement, total station measurement, etc. Modern monitoring technology refers to the use of advanced sensing technology, information technology, data analysis methods, and other techniques for high-precision, real-time, and automated monitoring of retaining walls.

Traditional measurements are classified according to the tools used, such as leveling, which measures the elevation changes of different points on a retaining wall using a level gauge to obtain settlement data of the wall. Its scope of use is limited and requires personnel to measure point by point. Tilt measurement is an important basis for the safety assessment of retaining walls by installing inclinometers at different positions to monitor real-time changes in the inclination of the wall. Total station measurement is the process of measuring the coordinates of monitoring points on retaining walls using a total station and comparing them with the initial coordinates to obtain the displacement. It can measure displacement in both horizontal and vertical directions simultaneously, suitable for various terrain conditions, but is greatly affected by weather.

Fiber optic sensing monitoring technology is an advanced method for monitoring the displacement of retaining walls.

Embedding fiber optic sensors inside or on the surface of retaining walls can cause changes in the optical signal in the fiber optic cable, such as intensity and wavelength when the retaining wall deforms or is affected by other physical quantities [7]. By measuring and analyzing the changes in these optical signals, parameters such as strain and temperature of the retaining wall can be obtained, and the displacement of the wall can be inverted accordingly.

GNSS system is also a precise modern monitoring technology.

The GNSS system consists of three parts: space satellites, ground control components, and user receivers. Space satellites continuously emit signals containing satellite position, time, and other information. User receivers receive signals from multiple satellites and determine the distance between the receiver and the satellite by measuring the signal propagation time. Then, using the principle of triangulation, the three-dimensional coordinates of the receiver are calculated [3]. In the displacement monitoring of retaining walls, GNSS receivers are placed at monitoring points on the retaining walls to receive satellite signals in real time and obtain the three-dimensional coordinates of the monitoring points. By comparing the coordinate changes at different times, the displacement of the retaining wall can be obtained.

Compare traditional monitoring techniques with modern monitoring techniques, as shown in Table 1.

DOI: 10.54254/2755-2721/2025.MH25134

Table 1. Comparison between traditional monitoring technology and modern monitoring technology

	advantage	disadvantage
Traditional monitoring techniques	Low cost Mature technology Simple operation	Poor real-time performance Small coverage area inefficient
optical fiber sensing technology	high sensitivity anti-interference Wide coverage Strong real-time performance	high cost Complex installation
GNSS system	high precision Wide coverage Strong real-time performance Suitable for complex environments	high cost Poor anti-interference ability

3. Innovation of BIM driven monitoring technology

BIM technology is a digital 3D data model that integrates rich attribute information [8]. It creates and manages digital representations of buildings or infrastructure throughout their entire lifecycle, covering planning, design, construction, operation, maintenance, and demolition. It builds a centralized information database, providing a platform for information sharing and collaborative work among project participants, and ultimately providing reliable support for project decision-making. It aims to achieve refined project management, improve efficiency, reduce errors, and optimize cost control.

The characteristic of BIM technology lies in its core of three-dimensional parametric modeling, integrating physical and functional information of the entire life cycle of buildings, achieving dynamic collaboration across stages and specialties through a single data source, and breaking information silos through standardized data formats. BIM technology has been widely promoted worldwide due to its advantages of visualization, simulation, and coordination [9].

3.1. "BIM+" deep integration technology

The deep integration of BIM technology and modern monitoring technology achieves dynamic interaction and collaborative optimization between physical entities and digital twins by constructing a closed-loop logic of "perception mapping analysis decision-making" throughout the entire chain. Its core is to use multi-source monitoring technologies such as fiber optic sensing and GNSS systems to collect real-time building physical parameters, accurately bind them with the spatial coordinates and component attributes of the BIM model, and form a dynamically updated model. The platform can analyze monitoring data and predict risks, reverse drive construction adjustments or optimization of operation and maintenance strategies, and achieve human-machine collaborative decision-making through the visualization of BIM models [10]. This fusion logic breaks through the static attributes of traditional BIM and constructs a bidirectional loop from data-driven model iteration to model-guided monitoring feedback, promoting the transformation of building lifecycle management towards real-time, refinement, and intelligence.

DOI: 10.54254/2755-2721/2025.MH25134

3.2. Innovative technology system

The innovative technology system driven by BIM is an intelligent technology system that covers the entire life cycle of buildings, with building information modeling as the core data carrier, integrating cutting-edge technologies such as fiber optic sensing, the Internet of Things, and digital twins. This includes three parts: data collection, data fusion, and decision-making and application, bringing value to society such as cost reduction and efficiency improvement, industrial chain collaboration, and green and low-carbon development.

3.2.1. Data collection

The monitoring technology system driven by multi-source modern monitoring technology is the core in the data collection stage, and key parameters such as retaining wall displacement are obtained in real time through fiber optic sensing (FBG) technology and GNSS system.

Fiber optic sensors are embedded inside the retaining wall structure to capture microscopic strain and deformation through changes in the wavelength of optical signals. This method can accurately measure small strain and displacement changes with an accuracy of micrometer level, providing accurate data support for deformation monitoring of retaining walls. Fiber optic cables are usually made of materials such as glass or plastic, which have good corrosion resistance and are suitable for various harsh environmental conditions, such as humid, acidic and alkaline corrosive environments. GNSS receivers are deployed at monitoring points to continuously track changes in three-dimensional coordinates. This method can also provide millimeter-level or even higher precision three-dimensional coordinate measurements, accurately monitoring displacement changes of retaining walls [3]. And it can cover a large area of retaining wall areas, suitable for long-distance linear retaining wall monitoring.

All data is synchronized to the cloud platform through wireless transmission technology, forming a structured real-time database.

3.2.2. Data fusion

BIM based data fusion is a method of fusing multi-source data. It mainly integrates and interacts a series of structured and unstructured data generated during the design, construction, and operation stages of a building, such as geometric models, material properties, environmental parameters, sensor monitoring data, etc., using BIM platform for data standardization. To achieve the goal of enhancing project visibility, optimizing resource allocation, avoiding engineering risks, and promoting the transformation of the construction industry towards intelligence and sustainability.

3.2.3. Decision making and application

In the decision-making and application stage, the finite element analysis module built into the BIM platform is used to simulate the mechanical response of retaining walls under different load conditions and real-time monitoring data is used to evaluate structural stability [11]. When the displacement or strain exceeds the standard value, the system automatically triggers a graded warning and generates emergency plans, such as reinforcement suggestions and evacuation routes. The visualization of BIM models presents real-time monitoring data of retaining walls through three-dimensional dynamic presentation, deeply integrating multi-source information such as fiber optic sensors and GNSS with the model, enabling managers to intuitively identify areas of structural abnormalities and quickly locate risk points through three-dimensional coordinates. Its visual

DOI: 10.54254/2755-2721/2025.MH25134

interface not only supports real-time monitoring and historical data comparison, but also combines finite element simulation to predict potential failure modes, thus breaking the information island problem of traditional monitoring, realizing the transformation from passive response to active warning, providing intuitive basis for multi role collaborative decision-making, and significantly improving the accuracy and timeliness of risk control.

4. Suggestions and prospects

The research on displacement monitoring of highway retaining walls will face multiple challenges in future promotion. At the technical level, it is necessary to overcome the challenges of real-time synchronization and deep fusion of heterogeneous data from multiple sources, especially in extreme conditions such as landslides and earthquakes where data may be disrupted due to signal interference or equipment failure. There is a problem of high hardware cost in terms of engineering applicability. And in practical engineering, there is a lack of long-term adaptability data to support complex geological conditions.

Addressing future challenges requires phased breakthroughs. At the cost control level, promote the localization of sensors and the development of lightweight BIM platforms, adopting a graded deployment strategy of high-precision monitoring in key areas and low-power sensing in edge areas to optimize costs. At the level of technological optimization, it is possible to establish test fields for multiple disaster scenarios and complex geological conditions and accumulate a large amount of extreme working condition data. Ultimately, through technological iteration, cost control, and standardized mandatory application, the system is promoted to penetrate into the intelligent operation and maintenance of infrastructure in areas such as slopes and tunnels, achieving a leap from single point warning to system self optimization warning.

5. Conclusion

This article mainly explores the displacement monitoring method of highway retaining walls based on BIM technology, which integrates FBG, GNSS, and BIM models. On this basis, a technical model for data collection, multi-source fusion analysis, and 3D visualization decision-making of displacement monitoring of highway retaining walls was proposed.

This study proposes using BIM models as the core carrier to combine micro scale strain monitoring of fiber optic sensors with high-precision 3D coordinate tracking of GNSS, achieving dynamic perception and mapping of retaining wall displacement and solving the discretization and non real time problems of traditional monitoring methods. This solution not only allows for direct observation of structural deformation and potential risk points through a 3D visualization platform but also utilizes dynamic data to drive construction and operation plan adjustments, effectively reducing labor costs and enhancing the accuracy of collaborative decision-making.

The research still has the following limitations: the deep integration of BIM and sensing technology requires high hardware equipment and computing power, and the actual engineering application cost needs to be optimized; The current research is mainly theoretical and lacks stability testing in large-scale complex scenarios.

In future research, the integration technology of "BIM+" can be further deepened, and the application of "BIM+" technology can be extended to the full life cycle monitoring of complex geological conditions such as slopes and tunnels, promoting the safety management of civil engineering towards intelligence and integration.

DOI: 10.54254/2755-2721/2025.MH25134

References

[1] Dong Ying, Xu Chang, Lu Zhiheng.Research on the Application of BIM Cross Platform Model Integration in Highway Construction [J]. Intelligent Buildings and Smart Cities, 2025, (04): 117-119.DOI: 10.13655/j.cnki.ibci.2025.04.036.
[2] Chen Jian .Monitoring method for deformation of high retaining walls on civil airport slopes [J]. Mass standardization, 2024, (10): 136-138.
[3] Luo Youfu.Research on the Integration and Accuracy Improvement of GNSS Technology in Dam Slope Deformation Monitoring System [J]. Information and Computer, 2025, 37(03): 87-89.
[4] Tian Suhui, Xiong Xin, Li Yingna, etc.Application of FBG Sensor in Gravity Wall Displacement Monitoring [J]. Sensors and Microsystems, 2015, 34(10): 158-160.DOI: 10.13873/J.1000-9787(2015)10-0158-03.
[5] China Communications Second Highway Survey and Design Institute Co., Ltd Design and Construction Design Rules for Highway Retaining Walls [M]. Beijing: People's Communications Press, 2008.21-29
[6] Chen Yueqi.Analysis of the causes of instability and failure of gravity retaining walls [J]. Railway construction, 2016, (06): 112-115.
[7] Liang Junxi, Chang Ying, Li Yuanhao, etc.Sensitivity adjustable substrate fiber Bragg grating strain sensor [J/OL]. Infrared and laser engineering, 1-11 [2025-05-22].http: //kns.cnki.net/kcms/detail/12.1261.TN.20250516.1059.002.html.
[8] Zou Junjie.Research on the Application of BIM Technology in the Design of Gravity Retaining Walls for Highways [D]. Chongqing Jiaotong University, 2022.DOI: 10.27671/d.cnki.gcjtc.2022.001145.
[9] Xianzhu Xin, Li Ying, Liu Shiyi.Application of BIM in Fire Engineering Pipeline Design [J]. Residential and Real Estate, 2017, (33): 60.
[10] Wang Wenwei Full life cycle management of highway slopes based on BIM technology [J]. Public standardization, 2025, (08): 167-169.
[11] Wang Kang, Xin Cong.Application of BIM Technology in Highway Construction Safety Management [J]. Automotive Weekly, 2025, (06): 81-83.