# Research and Application Progress of Ship Lock Engineering Safety Monitoring Technology

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**Abstract.** This paper lists the methods and applications of safety monitoring in ship lock engineering. The application scenarios of structural health monitoring, environmental monitoring, operating condition monitoring and other technologies in ship lock engineering are deeply discussed. Through a detailed introduction to each technology, the significance of safety monitoring in ship lock engineering is revealed. The paper also examines the development trends in safety monitoring technology for ship lock engineering and identifies future directions for development. Ultimately, this paper presents several prospects that offer valuable insights for research and development in the field of safety monitoring in ship lock engineering.

**Keywords:** Ship Lock; Engineering; Safety monitoring; Monitoring technology

## 1 INTRODUCTION

The field of lock engineering plays a crucial role in China's national economy and transportation sector, as it boasts the world's largest lock system. Its primary function is to regulate river water levels and ensure smooth passage of vessels [1]. Safety monitoring of lock engineering aims to promptly identify and prevent potential safety hazards, ensuring secure operation. Real-time monitoring of lock structures, environmental conditions, and operational status provides a scientific basis for project management and decision-making [2-4]. This article reviews the research progress and application of safety monitoring technologies in lock engineering, discusses monitoring methods and applications, proposes trends in monitoring technology development, as well as provides prospects.

## 2 OVERVIEW OF SAFETY MONITORING TECHNOLOGY FOR SHIP LOCK ENGINEERING

The safety monitoring technology of ship lock engineering has undergone an evolution from traditional monitoring methods to modern automatic monitoring systems. Tradi-


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tional approaches, such as manual inspection and measuring instrument monitoring, suffer from drawbacks including time-consuming processes, low efficiency, and susceptibility to human interference [5-6]. Currently, the manual inspection method is gradually being replaced by remote automatic monitoring systems that effectively overcome various unfavorable factors in real-time monitoring with enhanced efficiency and stability [7]. The safety monitoring technology of ship lock engineering encompasses the following categories:

### 2.1 Structural Health Monitoring

To ensure the safety of lock construction and validate the rationality of the construction process, it is often necessary to monitor critical components of the lock for settlement, foundation stress, structural stress, and other control indicators [8]. Real-time and continuous monitoring of the lock structure enables assessment of its health condition and prediction of potential safety hazards. This encompasses methods such as vibration monitoring, acoustic monitoring, infrared thermal image monitoring, ultrasonic monitoring, and optical fiber sensing.

### 2.2 Environmental Monitoring

Environmental monitoring focuses on observing changes in the surrounding environment near the lock area. This includes hydrological monitoring, meteorological monitoring, and geological disaster monitoring.

### 2.3 Operating Status Monitoring

Operating condition monitoring concentrates on ship and gate operations within the lock system. It involves tracking ship operations, gate operations as well as upstream and downstream water level observations.

### 2.4 Other Monitoring Techniques

Furthermore, drones usage along with satellite remote sensing have been applied to ensure safety during ship lock engineering projects.

## 3 METHODS AND APPLICATIONS OF SAFETY MONITORING FOR SHIP LOCK ENGINEERING

### 3.1 Structural Health Monitoring

(1) Deformation monitoring

The deformation mesh is a specific type of mesh structure utilized for monitoring and measuring deformation phenomena in order to analyze the trend and stability of deformable objects by comparing observed data at different time points.

GPS can be employed as a highly precise, reliable, and globally applicable method to measure relative position changes between reference points and monitoring points, thereby obtaining displacement, settlement, tilt, and other relevant data pertaining to deformable objects.

An inverted hole serves as a specialized method used for monitoring vertical displacement in buildings or structures with large vertical displacement requirements such as high-rise buildings and bridges.

The tensioning method is an approach specifically utilized for measuring displacements in elongated structures like bridges, tunnels, and dams that are prone to deformation.

Laser collimation method has the advantages of high precision and strong anti-interference ability. It is suitable for deformation monitoring projects that require high precision.

(2) Vibration monitoring

Vibration monitoring aims to assess the structural integrity of ship lock structures during operation by analyzing their vibration characteristics. Common methods for vibration monitoring include the use of acceleration sensors and Fiber Bragg Grating (FBG) vibration sensors. Acceleration sensors, widely employed in this field, effectively convert vibration signals into electrical ones. By analyzing data collected from these sensors, one can determine the dynamic behavior of ship lock structures during operation. The advantages of acceleration sensors lie in their rapid response, high sensitivity, and strong anti-interference capabilities, making them suitable for real-time monitoring purposes. On the other hand, FBG vibration sensors utilize Fiber Bragg Gratings to convert vibrations into optical signals and analyze them based on wavelength changes within the fiber grating structure. These FBG-based sensors offer high sensitivity, robust anti-interference properties, and a compact design that makes them well-suited for monitoring vibrations in ship lock structures.

(3) Acoustic monitoring

Acoustic monitoring uses the propagation characteristics of sound waves in the structure to detect whether there are defects such as cracks and cavities in the structure. Acoustic monitoring methods include ultrasonic detection and seismic wave detection. The water level and flow velocity in the ship lock are monitored by the sonar system to improve the safety performance of the ship lock operation.

(4) Infrared thermal image monitoring

Infrared thermal image monitoring detects the temperature distribution on the surface of the ship lock structure and analyzes the thermal conductivity of the structure, so as to find potential damage areas.

(5) Fiber Optic Sensing

Fiber optic sensing utilizes the inherent sensitivity of optical fibers to structural deformation, strain, and other physical quantities in order to achieve real-time and remote monitoring of ship lock structures. This technology encompasses fiber Bragg grating sensors, distributed fiber optic sensing technologies, among others. Distributed Fiber optic Sensing (DFS) is a technique that enables simultaneous monitoring of multiple locations on the measured object through an optical fiber transmission system. The distributed fiber optic sensing system primarily consists of distributed fibers, fiber gratings, signal demodulation devices, and data processing systems. By detecting wavelength changes in the fiber gratings, valuable information regarding deformations, temperatures, and more can be obtained for the measured object. Fiber grating sensors are suitable for specific object or scene monitoring such as strain and temperature measurements on bridges, dams, buildings etc., while distributed fiber optic sensing technology is well-suited for long-distance and multi-point synchronous monitoring applications like pipeline leakage detection or underground tunnel deformation tracking.

## 3.2 Environmental Monitoring

(1) Hydrological monitoring

Hydrological monitoring focuses on the changes of hydrological elements such as water level and flow upstream and downstream of the ship lock [9], providing a basis for the operation and scheduling of the ship lock. The methods of hydrological monitoring include float type water level gauge, capacitive water level gauge, ultrasonic water level gauge, etc.

(2) Meteorological monitoring

Meteorological monitoring involves the monitoring of meteorological elements such as temperature, humidity, wind speed, precipitation, etc., providing data support for the safety management of the ship lock project. The equipment of meteorological monitoring includes temperature and humidity sensor, wind speed meter, rain gauge, etc.

(3) Geological disaster monitoring

Geological disaster monitoring mainly aims at the early warning and monitoring of landslides, debris flow and other geological disasters around the ship lock. The methods of geological disaster monitoring include inclinometer, inclinometer, borehole inclinometer, etc.

## 3.3 Operational Condition Monitoring

(1) Ship Operation Monitoring

Ship operation monitoring focuses on the parameters such as the sailing speed and direction of ships in the ship lock to ensure the safe passage of ships. Ship operation monitoring equipment includes radar speed detector, laser range finder, camera, etc.

(2) Valve Operation Monitoring

Valve operation monitoring focuses on the opening and closing speed, position and other parameters of the valve to ensure the smooth operation of the valve. Valve operation monitoring equipment includes encoder, limit switch, camera, etc.

(3) Upstream and Downstream Water Level Monitoring

Upstream and downstream water level monitoring real-time monitoring of the upstream and downstream water level changes of the ship lock through water level meter and other equipment to provide data support for the operation and scheduling of the ship lock.

### 3.4 Other Monitoring Techniques

(1)UAV monitoring

UAV monitoring employs unmanned aerial vehicles equipped with high-definition cameras, lidar, and other devices to conduct aerial surveillance and generate 3D models of ship lock engineering structures.

(2)Satellite remote sensing monitoring

Satellite remote sensing monitoring analyzes satellite image data to monitor environmental changes in the vicinity of ship lock engineering projects, thereby providing valuable data for enhancing engineering safety management.

## 4 DEVELOPMENT TREND OF SAFETY MONITORING TECHNOLOGY FOR SHIP LOCK ENGINEERING

### 4.1 Automation

The safety monitoring of ship locks will be automated and networked, and technologies such as the Internet of Things and cloud computing will be widely used in the safety monitoring of ship locks. Automation technology includes automatic collection, automatic processing, automatic alarm, etc. Remote monitoring, data transmission and real-time analysis are realized. Through the establishment of databases and monitoring information systems, all kinds of monitoring data are integrated, processed and analyzed to realize real-time mastery of the safety status of ship locks, reduce the workload of manual inspection and improve the monitoring efficiency. Chen et al. [10] proposed a data recovery model based on the single beam array data variation algorithm, devised multiple detection methods for ship draft, constructed a three-dimensional draft information management system for ships passing through locks, and accomplished automatic online detection of ship draft.

### 4.2 Integration

The safety monitoring technology of locks is evolving towards integration, aiming to achieve the seamless integration of various monitoring technologies and enhance the comprehensiveness and reliability of monitoring data. This integrated approach encompasses data collection, processing, analysis, display, among others. Yang et al. [11] proposed a life cycle operation reliability model for critical equipment in large locks and established evaluation indices and standards for ensuring safe operations.

### 4.3 Intelligentization

Revised sentence: "The advancement of artificial intelligence technology will enable the intelligentization of ship lock safety monitoring, enhancing the speed and accuracy of data processing. Intelligent monitoring techniques encompass machine learning, deep learning, and big data analysis. By utilizing numerical simulation methods such as finite element analysis (FEA), the stress, strain, and displacement of ship lock structures under various working conditions are calculated and analyzed to achieve intelligent safety monitoring through artificial intelligence and big data technologies. Through mining and analyzing monitoring data, potential safety hazards can be automatically identified to enhance real-time monitoring precision. Liu et al. [12] developed a high-precision perception system for dynamic ship navigation in lock waters, proposed and established a multi-ship synchronous navigation control platform for ships passing through locks, enabling automatic ship following into the lock as well as precise automatic stopping within the lock.

## 5 RESEARCH PROSPECT OF SAFETY MONITORING TECHNOLOGY FOR SHIP LOCK ENGINEERING

With the advancement of cutting-edge technologies such as artificial intelligence, big data, and cloud computing, the safety monitoring of lock engineering will attain a heightened level of automation, integration, and intelligence. This will enhance both the speed and accuracy in processing monitoring data while providing robust technical support for the safety management of ship lock engineering.

In the forthcoming era, the application scope of lock engineering's safety monitoring technology will further expand to encompass domains like unmanned aerial vehicle surveillance and satellite remote sensing monitoring. These advancements aim to achieve comprehensive environmental monitoring surrounding ship lock engineering.

The safety monitoring equipment for ship lock engineering is expected to advance towards higher precision, increased functionality, and enhanced integration as the scale of this field continues to grow exponentially.

Strengthen the integration and sharing of ship lock engineering safety monitoring data, enhancing the efficiency of data utilization, and providing robust support for engineering safety management.

Establish and enhance the maintenance and management mechanism of ship lock engineering safety monitoring equipment to ensure its uninterrupted operation and improve the quality of monitoring data.

Continuously strengthen research, development, and innovation in ship lock engineering safety monitoring technology to offer more reliable technical support for ship lock engineering safety.

## 6 CONCLUSION

This paper provides a comprehensive overview of the methods and applications of ship lock engineering safety monitoring, encompassing structural health monitoring, environmental monitoring, operation status monitoring, and other related technologies. Additionally, an analysis of the future development trends in ship lock engineering safety monitoring is presented, highlighting automation, integration, and intelligence as crucial directions for advancement. The following prospects are proposed:

(1) Ship lock engineering demands increasingly higher levels of accuracy in monitoring technology. To meet this requirement for high-precision monitoring, one important future direction is to enhance the accuracy of such technology.

(2) Ship lock engineering safety monitoring involves multiple physical quantities and environmental factors; therefore, it is necessary to develop multi-parameter monitoring techniques that enable comprehensive and accurate data collection. Consequently, increased investment should be made in research and development efforts aimed at improving the accuracy, stability, and reliability of ship lock engineering safety monitoring technology to fulfill the demand for high-precision and multi-parameter measurements.

(3) Given the large number of equipment involved in ship lock engineering safety monitoring along with its heavy maintenance and management tasks; strengthening equipment maintenance practices becomes essential to ensure normal operations while enhancing data quality. Establishing an improved mechanism for data management and sharing is imperative by constructing a dedicated platform facilitating effective integration and sharing of ship lock engineering safety-monitoring data.

## REFERENCES


1. Wu P. Opportunity and challenge of inland navigation development in China[J]. Port & Waterway Engineering, 2010, 2: 11-16.
2. Ehlers S, Le Sourne H, Buldgen L, et al. A review of technical solutions and simulation approaches for ship collisions with lock gates[J]. Ship Technology Research, 2015, 62(1): 14-25.
3. Bugarski V, Bačkalić T, Kuzmanov U. Fuzzy decision support system for ship lock control[J]. Expert Systems with Applications, 2013, 40(10): 3953-3960.
4. Junling Qi, Dongyuan Chen, Peng Wu, et al. Key technology research and outlook for large ship lock navigation in Xijiang River and the Yangtze River[J]. Port & Waterway Engineering, 2024, (01): 137-143.
5. Wu N. Study of Safety Index System Based on Risk Assessment in the Construction of Deep Excavation Project[J]. Journal of Underground Space and Engineering, 2011, 7(3): 599-603.
6. Wu I C, Lu S R, Hsiung B C. A BIM-based monitoring system for urban deep excavation projects[J]. Visualization in Engineering, 2015, 3: 1-11.
7. Yu W, Peng W, Ming L I, et al. Reliability Analysis of Automatic Monitoring System in the Deep Foundation Pit Monitoring[J]. Geomatics & Spatial Information Technology, 2019, 42(03): 222-224.
8. Yuan F, Chen W. Stability analysis of temporary cofferdam of a ship lock construction project in coastal area[C]//IOP Conference Series: Earth and Environmental Science. IOP Publishing, 2021, 768(1): 012118.
9. ZHOU Ming. Analysis of monitoring results of Hejiagou Reservoir dam during construction and operation period[J]. Water Resources and Hydropower Engineering, 2022, 53(S2): 372-379.
10. De-Shan C, Jian-Hua Z, Ji-Xiang L I, et al. Inland ship draft detection based on multi-beam echo sounder in pitch-up setting[J]. Port & Waterway Engineering, 2016(1):152-157.
11. Jue Yang, Yongxin Li, Bing Yang. Operation reliability analysis and improvement measure of single-stage ship lock [J]. Port & Waterway Engineering, 2021, (02): 17-21.

12. Liu C, Qi J, Chu X, et al. Cooperative ship formation system and control methods in the ship lock waterway[J]. Ocean Engineering, 2021, 226: 108826.