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A Study on The Wireless Remote Safety Measurement Device for Structures based on Multi-Waterproof Sensors

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Abstract: Recently, as the need for constant safety management increases due to collapse accidents caused by external displacement of buildings, it is necessary to manufacture a construction ground gradient meter and serial open information technology (IT) sensor that can be monitored wirelessly based on epoxy resins, polyvinyl chloride (PVC) pipes, and communication cables. In particular, waterproof performance is required for ground monitoring of underground spaces with water, and for this purpose, research was also conducted to double mold the inside of the incline system. Construction IT convergence's building slope measurement device technology can respond to safety accidents by checking the amount of change in building displacement through a real-time online monitoring system. In addition, it is an industry with various application markets by converging IT technology into the existing construction industry and can be used as a pre-quake detection monitoring system for structural collapse accidents caused by external displacement. Therefore, it is intended to secure a sustainable facility safety management system through research in the field of real-time measurement technology on various facilities and surrounding ground behavior.

Keywords: multi-waterproof sensors; safety; structure; real-time online system; wireless remote

1 INTRODUCTION

1.1 Research Background and Need

It is difficult to manage the safety of the structure with the field measurement method that has been previously implemented about once a week. In order to prevent accidents in advance, real-time safety measures at the site by permanent measurement management are necessary [1]. Civil and building structures need continuous maintenance during and after construction, and the need to establish a permanent safety monitoring system in preparation for changes in social environment and disasters (Floods, typhoons, earthquakes) is emerging [2].

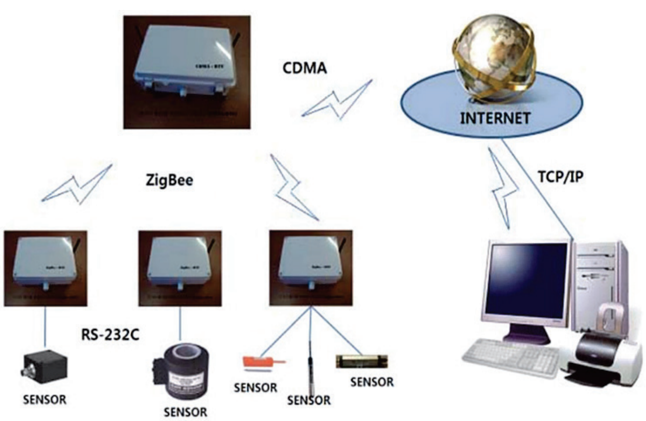

Figure 1 Conceptual map for remote sensing

And soil barriers have been preparing for detailed rules such as tunnels, bridges, dams, nuclear power plants, and pardons disaster, and the Earthquake Disaster Prevention Act has been implemented first for government offices since 2010 [3]. Safety diagnosis of facilities in South Korea relies on visual inspection or inspection using diagnostic equipment (Safety check: 2 times/year, Precision check: 1 time/2 years). In addition, there are limitations in active facility safety management, such as difficulty in accessing facilities during inspection, raising the need for a permanent installed safety monitoring system [3].

Therefore, in order to analyze the safety status of the structure and measure displacement, we intend to study a management program that remotely controls measurement data in real time by standardizing data analysis and measurement methods using wireless measurement terminals and upgrading measurement devices. Fig. 1 is a conceptual diagram of remote measurement.

1.2 Current Status of Measurement Management Methods in Korea

In most sites in Korea, manual measurement methods are mainly applied, in which a technician directly puts a sensor into a measurement position installed underground and then pulls it upward to measure the slope of the slope. Usually, reports are prepared and managed based on data regularly measured by underground slopes installed at major points and field managers judge the stability of structural stones based on the measurement reports and visually check the displacement and deformation of nearby buildings [4].

Since these manual measurements are directly measured by humans, there is a limit to the reduction in the frequency of measurement in relation to the increase in labor costs, making it difficult to recognize abnormalities and respond immediately. In addition, survey errors may occur depending on environmental changes and technician proficiency, and it is difficult to obtain continuous data due to the influence of field conditions, weather changes, and frequency of measurement. Real-time measurements shall be made in the field to prevent damage caused by large accidents and recently, automatic measurement technology is applied as an alternative to compensate for the weaknesses of manual measurement technology and ensure the continuity and reliability of measurement data. As shown in Fig. 2, the existing automatic measurement technology connects sensors inserted inside the incline tube to the data logger through data measurement lines and transmits measurement data through wireless communication devices, allowing administrators to check the displacement of dirt barrier facilities [5, 12].

However, as the number of sensors to be installed increases according to the measurement depth, a number of measurement lines are used to connect each sensor to the data logger, which causes problems of limiting the measurable depth or increasing the diameter of the slope.

Conversely, when connected to the outside of the inclined system pipe, the measurement line may be disconnected, and a leakage problem may occur while being connected to a sensor inside the inclined system pipe. In addition, existing data logger equipment is expensive and power cables are required to build data loggers and wireless communication devices as system elements, and unit system (Combination of data logger and communication device) components are bulky, making it difficult to install and maintain on-site.

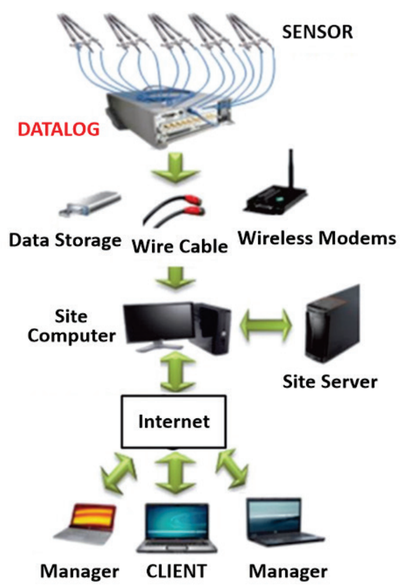

Figure 2 Conceptual diagram of the automatic measuring system currently used

1.3 Current Status of Overseas Related Technologies

As shown in Tab. 1 overseas companies are divided into sensor manufacturers and specialists that manufacture and distribute each sensor element technology as a unit system, and each unit system is composed of standardized equipment for measurement purposes, so it does not actively accept users' technical requirements. In the case of overseas shipping countries, it is being developed focusing on disaster response and structure maintenance such as earthquakes using ubiquitous technology (RFID Tag) to detect vibrations caused by earthquakes, transmit data and minimize damage to buildings themselves.

In the future, it is under development as a system that controls overall risk factors by monitoring various fields such as acceleration, deformation, temperature, light, sound and measurement.

Table 1 Current status of overseas measurement technology

Category	Content
Tunnel data management	- Systematization of basic tunnel data necessary for tunnel maintenance and management - Systematization of history management for maintenance and reinforcement necessary for maintenance
Measurement	- The construction of the pole tunnel is carried out in real-time monitoring by performing automatic measurement overall - Temporary measurement is carried out at the same level as in Korea, and systematization is possible to collectively process data organization of measurement results
Safety diagnosis and evaluation	- Properly carry out the initial inspection items for safety diagnosis - Establish an evaluation system so that it can be an objective evaluation - Development and application of techniques that can perform quantified evaluation
Integrated maintenance	- Developing a system that collectively manages tunnel construction to public training after completion - Developing a system that can comprehensively perform maintenance
Measuring equipment	- Development and use of automatic measuring sensors with proven durability and precision - Use data logger development with proven durability and precision

According to the characteristics of measurement systems at home and abroad, there is a need to develop a new wireless remote measurement technology that can be efficiently used in construction sites.

2 TECHNOLOGY MECHANISM

With the recent development of communication-broadcasting technology, a high-speed network environment and high-performance-miniature terminals have emerged, creating an environment where safety management is possible at all times. By combining such communication technology, it is possible to economically operate and manage real-time monitoring systems that can measure and manage temporary facilities and structures at all times by wirelessly transmitting measurement data of soil membrane displacement. Based on these environmental changes, it was judged that if the technology was improved in the following respects, the problems and limitations of the existing measurement management technology could be solved. The main research and development matters are as follows:

- Application of a high-resolution gradient sensor to improve reliability of measurement.
- In order to improve the workability of multi-faceted sensors, the development of an inclined meter sensor that can be extended according to the measurement depth and is easy to install on-site.
- Power supply other than wired cables to improve workability and maintenance of wireless remote measuring devices.
- Simplification of unit system (data logger + communication device) components to facilitate construction and maintenance.

- Development of a monitoring system that can collect and analyze measurement data in real time and is easy to use and maintain.

The conceptual diagram of the new wireless remote measurement management applied by reflecting the technology improvement points of the above contents is shown in Fig. 2. It is believed that this will be used to realize the advancement of safety management in the actual field.

2.1 A Study on Real-Time Wireless Remote Measurement Using Multi-Waterproof Washing Machine

A wireless remote management program for gradient measurement was developed to evaluate the stability of the structure, and as shown in the conceptual diagram of program development in Fig. 3, a DB and server management program that can manage data transmitted from sensors to sub and a client program that allows customers to check measurement results at all times.

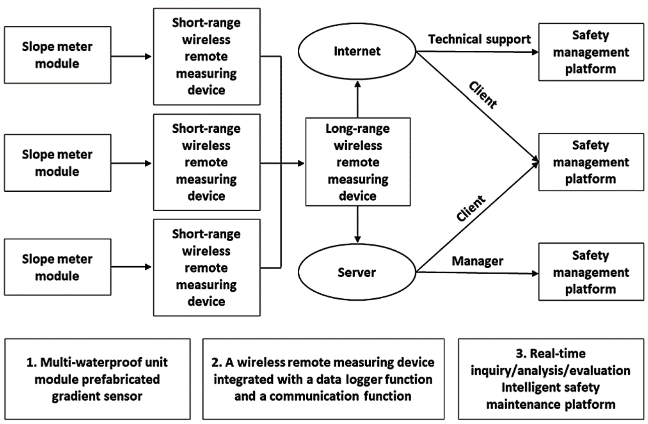

Figure 3 Improved wireless remote measurement management process

There are Global Monitoring technologies and Local Monitoring technologies to measure changes in the dynamic behavior of structures using sensors such as accelerometers, speedometers, displacement meters, stress gauges, ground-reaction meters, and anemometers. Global Monitoring is a monitoring and maintenance system for the overall behavior of the structure and Local Monitoring is divided into monitoring and maintenance systems for the stability of each member of the structure, such as columns and beams [6]. In addition, it is intended to develop a multi-waterproof sensor for displacement monitoring that can measure the curvature and sagging of a structure using a Micro Electromechanical System (MEMS) gradient chip and to study a wireless remote measuring device that wirelessly collects data from a long distance [7]. In the structural design phase, the assumption, idealization and simplification of the material properties and analytical models inevitably include actual structure behavior and significant errors. Therefore, interpretation and evaluation techniques based on instrumentation data are required and a level-specific alarm and maintenance system of structures can be built based on these interpretation and evaluation techniques. Therefore, structural analysis technology, field measurement data analysis technology and comparison and analysis technology of analysis results and measurement results are established [8].

The simplest way to determine the existence of safety by comparing and analyzing the measurement results is to make a judgment in accordance with the relevant standards and if there are no related standards, it is necessary to establish the criteria by consulting with relevant technical data and related experts. The operation management system develops a monitoring program to store measured values from sensors and to enable users to check instrumentation data in real time according to established criteria [9]. The user can set the required level of management values step by step and the program notifies the user step by step when data is detected that exceeds the management values set by the user. It is reflected in the program to prevent unexpected accidents by sending text messages to the mobile phone in the absence of users [10]. Therefore, the most important safety assessment algorithm is developed and reflected in the operations management system to inform the user of the current structure status.

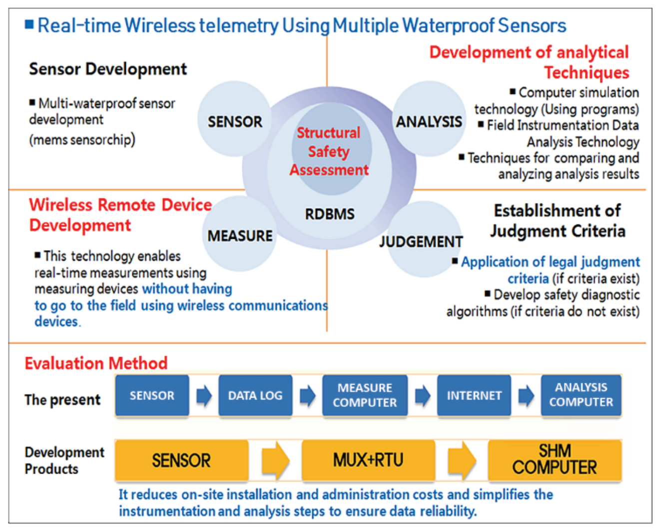

Figure 4 Concept of real-time wireless remote measurement using multiple waterproof sensors

2.2 A Research on Multi-Waterproof Sensor and Wireless Remote Measuring Device

This research is a technology that can overcome the limitations of existing automatic measurement technology, construction and maintenance for structure safety management, and significantly improve the reliability, site constructability and economic feasibility of measurement results. As shown in Fig. 4, like the concept diagram of sensor development for displacement monitoring, puts a sensor in the inclinometer tube and manufactures a multi-station inclinometer sensor that is waterproof with double molding as a unit module to enable assembly in the sensor can be assembled in the field. Therefore, it is a wireless remote safety management operation system that manages the safety status of the facility in real time by connecting multiple sensors in series and open lines to near-field and remote measuring devices that incorporate data logger functions and communication functions. The system is planned to be developed for use in the safety management of various structures by connecting various sensors to wireless remote measuring devices and the main contents of the development system are summarized as follows.

It developed a multi-waterproof sensor for displacement monitoring that improves waterproofing performance through multiple molding of MEMS chips, and studied multi-waterproof sensor for displacement monitoring that improves waterproofing performance by using a double molding method on MEMS gradient sensor chips.

In addition, we simplify system configuration by developing near- and far-field wireless remote measuring devices that integrate data logger functions and communication functions. In order to improve economic feasibility with near- and long-distance radio remote measuring devices, NFC remote measuring devices (telecommunication free) and remote radio remote measuring devices (telecommunication fee paid) were researched. Existing automated measuring technology often caused difficulties in measuring data due to waterproofing problems by putting the primary molded incline inside the incline and connecting a number of measurement lines to the data processing unit. To solve these problems, the inclinometer sensor board is assembled in a small tube and the primary molding is performed. And it was able to improve waterproofness and durability by putting it inside the inclinometer tube and molding it once more. In the case of existing automated instruments, as shown in Fig. 4, when multiple sensor measurement lines were connected individually to data processing units by parallel and multiple wires, there was a high possibility of waterproof problems, communication line disconnection, and poor workability. And, in the case of multi-station inclinometer sensors, each communication line shall be connected through the inclinometer tube to the data processing unit. Therefore, many communication lines must be installed in the tube during multi-station measurement, so the depth of measurement was limited due to poor workability, waterproofing problems and increasing the section size of incline pipes [11].

To solve this problem, this research connects a multi-station inclinometer sensor made using a high-resolution MEMS sensor chip to a wireless remote measuring device in series and open lines. Connectivity defects are, first, not limited in depth of measurement and secondly, highly construct and thirdly, high-resolution sensor chips are used to ensure excellent economic, constructability and reliability. In addition, looking at the result values measured by the currently developed incline sensor, it is difficult to trust the measurement values because the measurement result values according to the temperature difference between Fig. 5 and night and day differ by about 2 cm. Construction sites using this make it difficult to trust the measured values converted into displacements. To solve this problem, a high-resolution MEMS sensor chip was used to study the displacement monitoring sensor with excellent performance that is not affected by temperature changes. Therefore, most sites that perform real-time monitoring by converting to displacement using the slope of an inclinometer sensor cannot trust the measured value. To address this problem, we develop a sensor for displacement monitoring with excellent performance that is not affected by temperature changes using a high-resolution MEMS sensor chip.

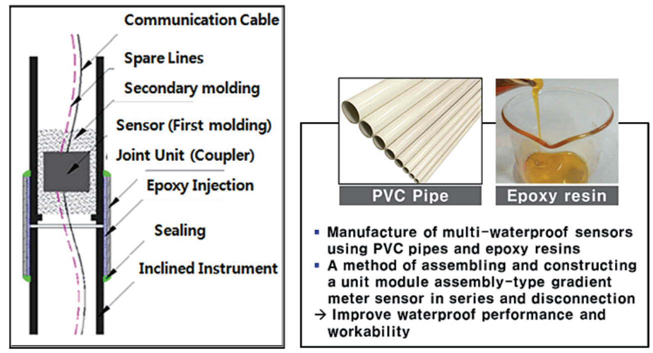

Figure 5 Composition of multiple waterproof sensor and wireless remote measuring device unit modular inclinometer sensor

As shown in Fig. 6, the unit all-type incline sensor is an integrated sensor-type incline sensor manufactured by inserting a resolution sensor into the incline tube of a predetermined length to facilitate assembly in the field and double molding the inside of the incline tube to improve waterproof performance.

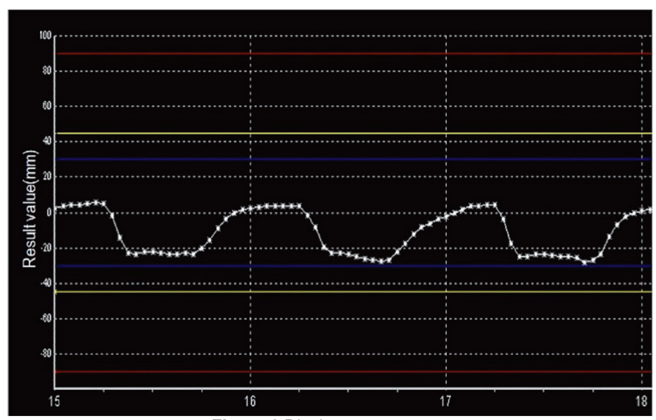

Figure 6 Displacement sensor

High resolution sensor application applied a high-resolution gradient measurement sensor chip of 0.00175 degrees, which can accurately measure the displacement of the structure, to ensure data reliability. This shows a higher resolution than 0.0023 degrees, which is the resolution of the sensor applied to the manual measurement, and 0.095 degrees, which is the resolution of the standard specification. As illustrated in Fig. 6, the unit model-type gradient sensor is manufactured by molding a sensor board manufactured using a high-resolution gradient measurement sensor chip in a small tube, and then putting it back in the gradient tube.

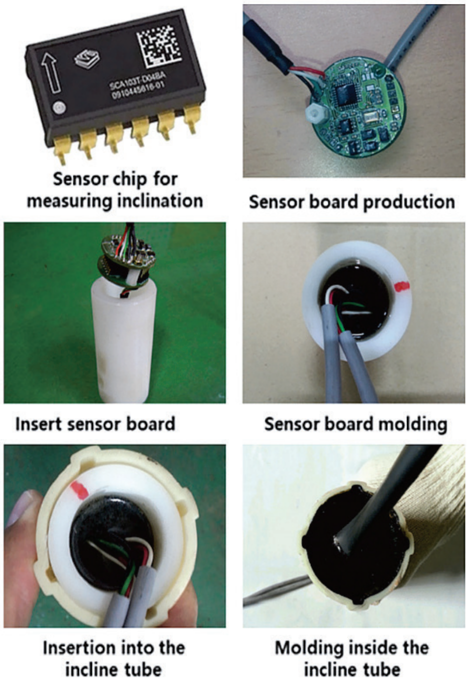

Figure 7 Unit modular incline meter sensor production

At this time, the durability and waterproof performance of the incline meter sensor were secured by double molding treatment including cable connection parts between sensors. Serial open circuit connection between sensors is manufactured such that a multi-view sensor and one data processing device are connected in series so that data can be transmitted to each other, so that multiple sensors can be connected regardless of the diameter of the incline tube. The unit modular gradient sensor connected in series can be extended in length through simple field assembly, making it easy to respond according to the measurement depth.

2.3 Network Configuration Using a Wireless Remote Measuring Device

The wireless remote measuring device applied to this technology integrates a data logger function and a communication function, and is a device that transmits measurement data recorded in the data logger using a near-distance wireless network. The network can be configured and operated by receiving data transmitted from a short-range network from a long-distance wireless integration device and transmitting it to a web server using a short-range wireless remote integration device without communication fees.

Fig. 8 shows the situation in which the displacement of the earth barrier wall is monitored using the measurement management system. A user can verify the data automatically measured according to the setting cycle and transmitted to a web server through the measurement management system and determine the stability of soil barrier facilities in real time using the automatic notification function for sudden displacement.

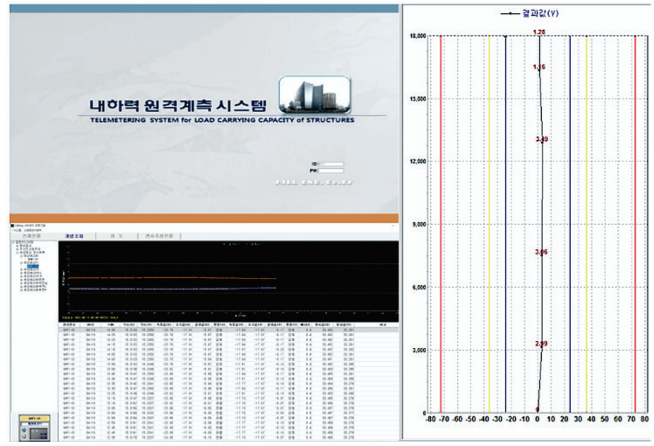

Figure 8 Measurement management system

2.4 Using a 3d-Mems-Based Gradient Sensor Chip for Displacement Monitoring

MEMS (Micro Electro Mechanical System) is a system that integrates micro-unit mechanical structures and electronic circuits using semiconductor process technology. Because silicon is mainly manufactured on substrates, signal processing circuits and MEMS devices can be manufactured on the same chip, which can minimize the impact on the surrounding environment due to low noise and small size. Because it is easy to manufacture sensors and can be manufactured through a batch process, price of development devices has a low advantage.

MEMS technology is similar to semiconductor technology, but each 3D microstructure manufacturing process and application system has unique design and manufacturing technology. Therefore it is difficult to standardize, so it is a technology that is used in various types of small-volume production (Application: Sensor, RF, Bio) in various application fields.

2.5 Sensor Features for Displacement Monitoring

- Using 3D-MEMS-based inclinometer sensor chips-High precision and small manufactured using semiconductor process technology
- Sensing function and RS485 communication embedded sensor
- Measuring ranges: ±15° (SCA103T-D04)
- Resolution: 0.0012° (10 Hz BW, analog output)
- Damped Frequency Response Rate: –3 dB 18 Hz
- Shock durability: 20,000g
- Excellent stability not affected by changes in ambient temperature
- Use differential measurement principles to reduce measurement errors and noise
- Power: DC 12 V

2.6 Development of Near-Range Wireless Remote Measuring Device with Integrated Data Logger Function

The traditional data processing method is to measure data using a data logger (Usually 18 or 36 channels are used as data processing units) wired with sensors and to verify data by sending it to the management server using portable data storage devices, wired and wireless communication devices. This method requires AC power for data logger and communication device to process data measured at multiple stations because data logger, communication device, and management server are composed of one unit. As a result, the volume of the data processing unit increased and the need for power cables and management servers resulted in many initial costs, making it economical.

In this research, first, the system configuration was simplified by integrating data logger functions and communication functions, and secondly, it plans to develop near-field wireless remote devices that are free of charge and remote wireless remote devices that are paid for communication. Therefore, constructability was secured by simplifying system composition, and economic feasibility could be achieved by reasonably deploying near- and long-distance wireless remote devices.

2.7 How to Build Near-Field and Long-Range Wireless Remote Measuring Devices

First, this research constructs an NFC remote measuring device where the location of measurement locations in the field is relatively close (within 80 m) and communication costs are free. Second, it is a method of receiving data from a near-field network from a remote wireless integrator and transferring it to a web server, making it possible to build an economical system that does not require cable laying.

- When configuring a NFC remote measuring device: If the distance between the measurement locations is relatively close-range, only one remote device will be installed and the rest will be composed of NFC remote measuring devices. Consequently, communication costs are saved.
- When configuring a remote wireless network: If the close-range network cannot be configured due to the distance between the measurement locations, install a remote wireless remote device at each measurement location. Constructability is improved because there is no need for separate cable laying.
- Wireless Remote Measuring Device Main Functions: Bi-directional communication (multi-connect multiple devices). Wireless communication method selection functions (RF and WCDMA selection and mix)

2.8 Development of a Safety Management Monitoring Program

Fig. 9 shows the conceptual diagram of safety management monitoring, which is managed by storing instrumentation data transmitted from wireless remote devices (RTU) in a database of remote server systems. In addition, stored instrumentation data can be viewed and managed through remote management programs wherever the Internet is connected and SMS text information will be automatically delivered in the event of an alarm.

Fig. 9 illustrates the conceptual diagram of program development and summaries the following: First, the program consists of a wireless remote measuring device and a client program capable of collecting instrumentation data, sending control commands, and controlling devices for DB and server management. Second, the main functions of the server program include storing measurement data in databases, setting up databases and field records, setting up Internet IP for communication, monitoring communication device status, controlling communication devices, and database management. Finally, the main functions of the client program are the measurement data inquiry and output function. It has measurement data analysis and output functions, safety and usability assessment functions, and alarm management functions.

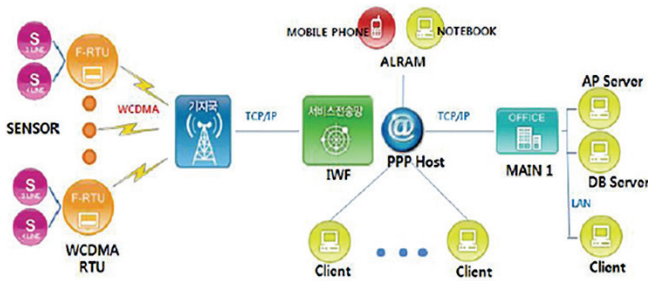

Figure 9 Conceptual map of safety management monitoring

If research result on the wireless remote safety measurement device for a multi-waterproof sensor-based structure is applied to the field, it can proceed with the platform process as shown in Fig. 10. Through these research results, it is possible to provide data necessary for preliminary safety diagnosis and damage recovery of structures through continuous management of facility safety maintenance.

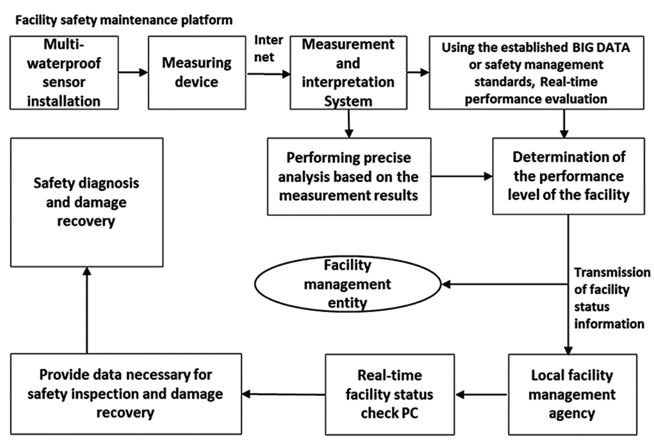

Figure 10 Platform process for field application of research technology

3 CONCLUSIONS

Recently, the construction industry is paying attention to permanent safety management of major national facilities. Research and development of facility safety management based on a real-time safety monitoring system can prevent large-scale accidents of structures in advance. Real-time data can be collected through short- and long-distance communication by connecting wireless-RTUs through research on wireless remote safety measurement devices based on multi-waterproof sensors. In addition, the stability of the structure can be managed in real time during or after construction by researching a management and analysis program that can be shared with field managers and rescue experts in a web environment by data base the collected data. The main research results are as follows.

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As structural stability can be determined and control signals can be calculated quickly, risk management of structures can be effectively performed, safety accidents can be minimized. Using a wireless telemetry device (RTU), the system is simplified and easy to operate and manage. By developing multiple waterproof sensors, waterproof performance is excellent even in places where water is used. Since technicians can detect it in real time without waiting at all times, it is expected to reduce the risk of disasters or casualties that may occur in the event of an abnormality as much as possible, and further use it in shipbuilding and other fields.

It is necessary to add various sensors that can monitor the condition of various structures in the future and develop them into intelligent systems such as life cycle prediction of structures, and expand the development and distribution of wireless network-based systems.

As a limitation of this study, it is necessary to verify the economic efficiency through field applicability evaluation to the existing research system. In future research, quantitative analysis should be analyzed through application data of actual projects.

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Notice

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