Committee Report : JCI- TC151A

Technical Committee on Systematization of the Various Sensor Technology with an Emphasis on Applicability to Actual RC structures

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Abstract:

This research committee conducted a survey to improve the production and maintenance of reinforced concrete structures by utilizing dramatically-advanced sensor and network technologies in the construction field. Many types of sensors have been installed in civil engineering structures and buildings over several decades, and while assuming that the structure users and managers are using the building while effectively utilizing measurement data, our goal is to lead the investigative research results for the purpose of constructing that foundation. The investigative research was implemented through 3 WGs; (1) the need for sensor technology in construction production and maintenance, (2) the trends of seed technologies related to sensor and measurement, and (3) the case of monitoring and the method of utilization.

Keywords: sensor, sensor network, electronic data, monitoring, quality control, maintenance

1. Purpose and Investigative Method of the Investigative Research

1.1 Purpose of Committee Establishment

In recent years in the construction field, there has been an urge for the practical use of sensor technology in the maintenance and management of social infrastructure, and active efforts are being made to make full use of sensor monitoring technology in construction production systems and maintenance management systems. In particular for civil engineering structures, the Ministry of Land, Infrastructure, and Transport has implemented the "SIP Strategic Innovation Creation Program" to achieve a reasonable preventative maintenance system[1], and is working on national technologies.

In order to judge the construction quality and soundness (degree of deterioration) of structures and parts, this research committee measures what and at which part in the actual structure, regardless of the measurement constraints, clarifies which physical property will be evaluated, and aims to establish various sensor measurement technologies that are necessary in order to realize a rational evaluation.

1.2 Investigative Research Method

In this research, utilizing a dramatically advanced sensor network technology in the construction field, we conducted a survey for the improvement of construction production and maintenance. Many types of sensors have been installed in civil engineering structures and buildings over several decades, and while assuming that the structure users and managers are using the building while effectively utilizing measurement data, the investigation was carried out for the purpose of constructing that foundation.

The committee organized the following 3 workgroups (WG) and carried out the investigative research.

・WG1: Organize the needs for sensor technology in construction production and maintenance, and systematize technology

・WG2: Survey on trends of seed technology related to sensors, measurement and networks

・WG3: Case study on inspection and monitoring, and data utilization method

WG1 examined the current status and future analysis of construction production and maintenance using sensor technology. Specifically, we extracted the sensor needs for inspection technology, diagnostic technology, etc. to ensure construction quality of structures and components, and to prolong the lifespan (maintaining soundness) of structures. The information was collected into a database; for the method of displaying the analysis result, by selecting the item to be searched for by the categories of objects (buildings, civil engineering structures, bridges, etc.), utilization timing (manufacturing, construction, maintenance,etc.), usage (intensity estimation, deterioration prediction, status monitoring, etc.), measurement value (change in position, temperature, acceleration, etc.), the corresponding sensor information can be viewed.

In WG 2, the seeds of the current sensor technology were organized. In the seeds investigation, starting with the industrial field, the various sensors used in many fields were systematically classified, and the principle and characteristics thereof were sorted. Hearings and questionnaires regarding the investigation, sensor manufacturers and companies using sensor technology were conducted, and then the info was organized systematically, including applicability to actual structures.

WG 3 examined the inspection and monitoring data storage technology and its method of application. Specifically, the monitoring cases that had been done so far were investigated, and the method of data recording and utilization was examined. Even if the time and effort is made to make a measurement using a sensor, it's all meaningless if the data recorded cannot be used. Additionally, the importance of selecting data according to measurement purpose, recording method, sharing method, recording frequency and so on was brought to attention.

1.3 Research System

The committee conducted activities with the members shown in Table 1.

Table 1 – Committee Composition

Committee Chair	Ohkubo Takaaki (Hiroshima Univ.)	Committee Vice Chair	Watanabe Hiroshi (Public Works Research Institute)
WG1 Lead Investigator	Sugiyama Hisashi (Utsunomiya Univ.)	WG2 Lead Investigator	Eriguchi Akira (TAIHEIYO CEMENT Co., Ltd.)
Sscretary	Uchida Shinya (Ritsumeikan Univ.)	Sscretary	Ohno Kentaro (Tokyo Metropolitan Univ.)
	Tamaki Kazukiyo (Sumitomo Mitsui Construction Co., Ltd.)		Taniguchi Madoka (Hokkaido Research Organization)
	Hasegawa Takuya (Hokkaido Univ.)		
Members	Inada Hiroshi (SHIMIZU CORPORATION)	Members	Ueda Hiroshi (Railway Technical Research Institute)
	Ogawa Akiko (Takenaka Corporation)		Otsuka Yuta (Taiheiyo Consultant Co., Ltd.)
	Kawase Minami (Constec Engi,Co.)		Takaya Satoshi (Kyoto Univ.)
	Nakamura Akihiro (BUILDING RESEARCH INSTITUTE)		Nakamura Hideaki (Yamaguchi Univ.)
	NAM Jeong-soo (Chungnam National Univ.)		Hosono Yasunari (IPEC Co., Ltd.)
	Miyauuchi Hiroyuki (BUILDING RESEARCH INSTITUTE)		Watanabe Satoshi (TAISEI CORPORATION)

The results of this committee are limited to the extent studied by the members belonging to the committee, and as such, we do not believe that it covers all of the technologies. In addition to the technologies summarized here, please understand that there are sensor technologies useful for the quality control and maintenance of RC structures.

2. Sensor Technology Needs in the Construction Field

2.1 Examination Regarding Cases of Usage of Sensor Technology in the Construction Field

In the construction field, there are many cases where measured values are obtained by using sensor technology, which are then used in actual construction and maintenance. Additionally, various ideas have been proposed for trying to make sensor technology useful in the future. In this section, we will investigate what kind of situations in the construction field the sensor technology is used, what kind of situations the sensor technology is expected to be used, and the need for sensor technology in the construction field from both the present and the future viewpoints.

First, every member of this committee has extracted cases of sensor technologies that are already in use, as well as cases where sensor technology is expected to be used in the future (hereinafter, collectively referred to as usage cases). Researchers and practitioners who specialize in materials, structure, maintenance, etc. in the construction field (building and civil engineering field) participated in the committee as members of this committee. The extraction work was done from various viewpoints by the committee members in this construction field.

Subsequently, the extracted usage cases are organized into two forms - the "Usage Case List" in table form, and the "Usage Case Sheet" in card form.

The following 9 items were shown in the Usage Case List.

(1) Title

(2) Objective (for sensor usage)

(3) Current Status and Future Issues (for sensor usage)

(4) Target Objects (for sensor installation)

(5) Utilization Timing (for sensors)

(6) Application (for sensors)

(7) Measurement Value (by sensors)

(8) Current Sensors (currently in use)

(9) Future Sensors (sensor expected to be developed or improved upon in the future)

The following 9 items were shown in the Usage Case Sheet.

(1) Title

(2) Abstract (short paragraph explaining the case study online)

(3) Outline Drawing (Drawings and images explaining the status of the case study)

(4) Target Objects (for sensor installation)

(5) Utilization Timing (for sensors)

(6) Application (for sensors)

(7) Measurement Value (by sensors)

(8) Current Sensors (currently in use)

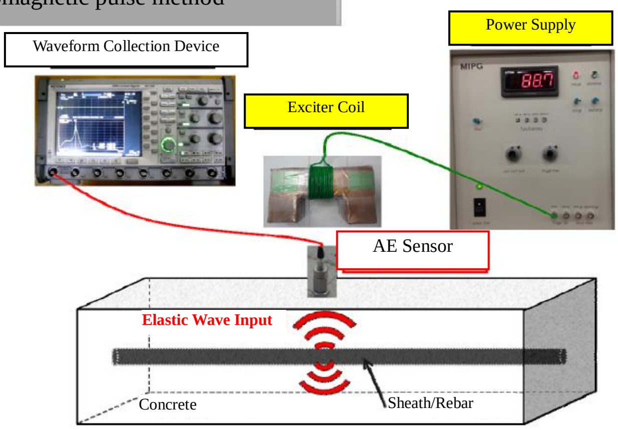
(9) Future Sensors (sensors expected to be developed or improved upon in the future)

An example of the Usage Case Sheet is shown in Figure 1. Sheets are characterized by the usage cases described in the "Outline Drawing". The intent is to express the usage situation of sensors more concretely through the utilization of figures and photographs.

Maintenance Management	Inspection	No.16

PC Girder PC Grout Packing Condition Evaluation (Electromagnetic Pulse Method)

Non-destructive grasp of the PC grout-filled state in sheath by the electromagnetic pulse method



For example, Toshiro Kamada, Shinya Uchida, Hotaru Tsunoda, Koji Sato: Study on Evaluation Method of PC Grout Filling by Non-Burst Test in Actual Bridge PC Girder, Proceedings of the Japan Society of Civil Engineers E2 (Materials · Concrete Structure), Vol. 4, pp. 238-250, 2012

Target Object	Usage	Measurement Value	Current Sensor	Future Sensor
Bridge	Safety Management	Vibrations/Waves	AE Sensor	A sensor with the same sensitivity identification as the AE sensor, and with a flat sensitivity in a frequency band up to about 40kHz.

Figure 1 – Example of Usage Cases Sheet

Regarding the "Current Status and Future Issues" in the Usage Case List, although the personal opinions of the committee members are included, it was decided to respect the opinions of specialists in their respective fields. Similarly, the "future sensors" in the Usage Case List and Sheet is also based on the thoughts of the committee members.

The items common to both the Usage Case List and Sheet, "Target Objects", "Usage Timing", "Application", and "Measurement Values" are used as categories for classification of the usage cases. After the committee collected the cases, all of the information was summarized and established. Around 10 types of keywords were established in each category for later database utilization. The categories and keywords are shown in Table 2. Also, the number next to each keyword displays the number of cases. The division of each category is not set by division and classification through a strict set of standards, but rather are positioned as a reference for thoroughly analyzing trends. Additionally, the Usage Case Sheet was classified and shared as a database through these keywords.

Table 2 – Established Keywords and No. of Cases for Each Category

Target Objects		Utilization Timing		Application		Measurement Value	
Building/Civil Engineering	88	Production/Transportation	1	Quality Management	16	Temperature	9
Building	16	Construction (Placing)	2	Safety Management	12	Moisture	16
Civil Engineering Structure	7	Construction (Curing)	8	Environmental Management	1	Power	12
Bridge	34	Construction (Demolding)	5	Load History	5	Shape/Dimension	15
Road	3	Construction (General)	11	Status Monitoring	37	Position/Displacement	14
Port Facility	1	Construction (Safety Management)	4	Abnormality Detection	24	Acceleration	10
		Maintenance (Inspection)	103	Deterioration Prediction	13	Vibration/Wave	33
		Maintenance (Repair)	9	Estimation of Strength	9	Chemical Measurement Value	10
		Disaster Period	6	Structural Performance Evaluation	16	Image	10
				Amount of Deformation	2	Other	20
				Crack Measurement	2		
				Other	12		

2.2 Current Situation and Future Image of Sensor Utilization in the Construction Field

The needs of sensor technology in the construction field have been summarized from the number of case examples for sensor technology shown in Table 2.

In regards to the target objects, there were many usage cases for construction and civil engineering, illustrating the situation where sensor technology is used in a wide range for general construction and civil engineering. Subsequently, as there were many usage cases for bridges, we could understand that there are high needs for sensor technology in the bridge field.

In regards to the utilization timing, there were many cases of usage corresponding to inspections at the maintenance and management stage. Since the manufacture, transportation, and construction of concrete is completed in a relatively short period, it is possible for humans to conduct quality control and inspection directly at the construction site. On the other hand, since maintenance takes place over a long period of several decades, and it is difficult for humans to continuously make on-site inspections, we can guess the realization of the need to make usage of a sensor for long-term management and monitoring a reality.

In regards to the application, there were many cases of usage corresponding to the status monitoring and abnormality detection. This is related to the utilization timing, and we can understand that the sensor is used for the purpose of status monitoring and abnormality detection during the maintenance (inspection) period.

In regards to measurement values, although it's distributed over each keyword, there were many cases of usage that corresponded to vibration and waves. This is presumed to be related to the fact that many sensors for measuring vibration and waves have been developed, of which many are related to widespread usage.

With respect to future sensors, the needs for wireless solutions are the highest priority, and next there are high expectations for improvement sin measurement accuracy, miniaturization, and price reduction.

3. Seeds Investigation of Sensor Technology

3.1 Outline of Seeds Investigation

Various sensors are used for understanding the state of building concrete, from the manufacture of concrete structures, to maintenance and management. In this chapter, we will organize the contents obtained from the systematic arrangement of these various sensors and the interview/questionnaire, clarify the future seeds, and realize as much as possible a future where sensor technology and concrete structures can be merged together.

3.2 Each Type of General Sensor and Their Types, Used in Concrete Structures

In this section, sensors that are generally used in regards to representative measurement items that are the basis of judgment for the construction quality and soundness of concrete structures have been sorted. The target sensors are not limited to the civil engineering and construction fields; the inspection range includes sensors that are also used in other fields.

The measurement items are the 7 items of temperature, humidity, moisture, displacement/strain, vibration, pressure, and concentration (pH, oxygen/carbon dioxide, hydrogen, sulfide, and chloride). The type of sensor used for each measurement item, the measurement principles, and the merits, have been collected. Sensor type, measurement principle, and characteristics by temperature are shown in Table 3. Additionally, scenes in which each type of sensor is used or can be used in concrete structures are also shown in the table.

Table 3 – Temperature Sensor Types, Measurement Principles, Characteristics[1)～3)]

Measurement Item	Sensor Type		Measurement Principles	Characteristics	Usage Scene in Concrete Structures
Temperature	Thermocouple		Thermoelectromotive Force Corresponding to Temperature	- Wide measuring area - Fast response speed - Low cost - Easy to process	Temperature Measurement Within the Concrete
	Resistive Element Temperature Sensor	Thermistor	Changes in Electric Resistance with Temperature	- High sensitivity, high precision - Power saving measurement possible - Small shape	
		Platinum Resistance	Changes in Electric Resistance with Temperature	- High stability - High precision - Excellent durability	
	IC Temperature Sensor		Changes in Electric Resistance with Temperature	- High precision - Less change over time - Small shape - Low cost	
	Radiation Temperature Sensor		Infrared Energy Radiated from the Surface of the Measurement Object	- Possible to measure from a long distance - Fast response speed - Measurement possible without contact - Fast temperature changes can be measured - Measurement of moving objects and small objects possible	Concrete Outer Surface Temperature Measurement

For the sensors listed in this section, while some have already been applied to concrete structures, others have not been applied. For sensors applied to concrete structures, since there are the issues of 1) securing power supply, 2) handling of cables, 3) sensor durability and weather resistance, 4) measurement accuracy and 5) cost, there are plenty of sensors that have a low frequency of usage.

3.3 Inspection of Various Sensor Technologies and Sensor Application Technologies, and Analysis of Inspection Results

Through cooperation with those who actually provide various sensors and measurement technologies, as well as those who use those various sensors, this committee conducted questionnaire and interview inspections regarding the various sensor technologies and sensor application technologies. The items of each investigation table were collected and divided into their respective categories of "physical information", "sensor type", “technology type", "application", and "position of the responder".

In the interviews and questionnaires, responses were obtained for all 57 cases from 18 companies (8 questionnaire cooperative companies, 10 interview cooperative partners). If we divide each technology by the position of the respondent, we have 4 companies and 9 cases of users, 7 companies and 20 cases of manufacturers, together for 11 companies and 28 cases of both uses and manufacturers. Within the multiple corporations that introduced the technologies, there were cases of their positioning differing by technology. Here, for the technical type, multiple elements were systemically organized, and classified by a group of functions that exhibited some kind of functionality, called a "system", and functionality that exhibits individual elements, called "individual elements". As a result, there are 17 systems and 40 individual technologies, and 70% of the equipment and technology (individual technologies) that exert their functions as individual elements occupy 70%. Therefore, each trend was analyzed based on the results classified by technology type. The trend analysis shown below counts the number of duplicate cases when a plurality of measurement items and uses are included in one technology. Also, it should also be noted that this trend analysis is targeted at the technologies for which information could be gathered by this committee.

Within the 17 cases classified by the system, focusing on the relationship between measurement items and usage as shown in Figure 2, most technologies, including displacement and strain, the most frequently measured items, are roughly divided up into monitoring and manufacturing, and it can be said that there are many techniques that are used for maintenance management through constant measurement and quality control at the time of construction for system development measures. Also, within the other general use sensors that don't correspond to the measurement items and are classified in other technology, we can see inspection assistance or automatic detection systems based on image sensors that utilize inspection (periodic) or IC sensors, monitoring and warning systems based on position sensors that utilize safety for construction management, etc.

On the other hand, for the 40 cases categorized as individual technology (Figure 3), while there's a deviation in monitoring for displacement/distortion and vibration, which are the most frequent in the measurement items, detailed investigation and manufacture hold a large share of the other measurement items. Also, within the other general use sensors that don't correspond to the measurement items and are classified in other technology, we can see inspection assistance or automatic detection systems based on image sensors that utilize inspection (periodic) or IC sensors, monitoring and warning systems based on position sensors that utilize safety for construction management, etc.

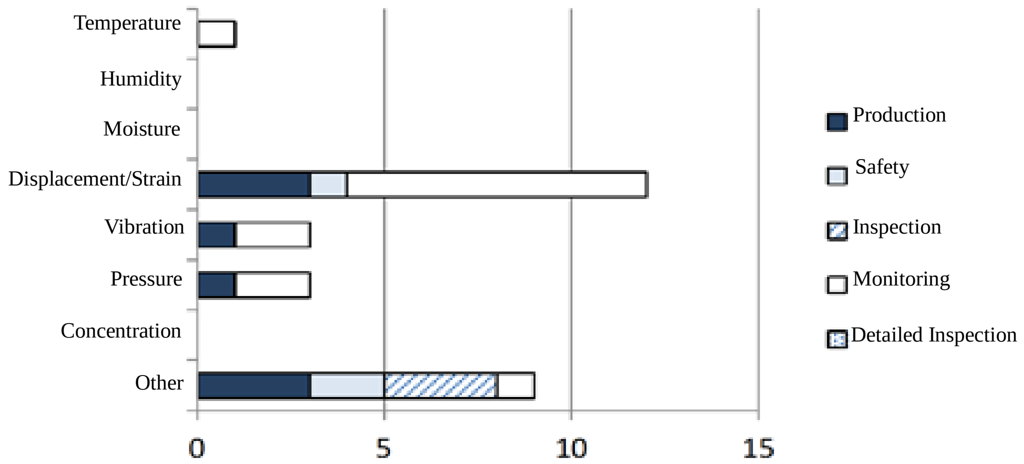


Figure 2 – Usage Distribution for Each Measurement Item in the Measurement System

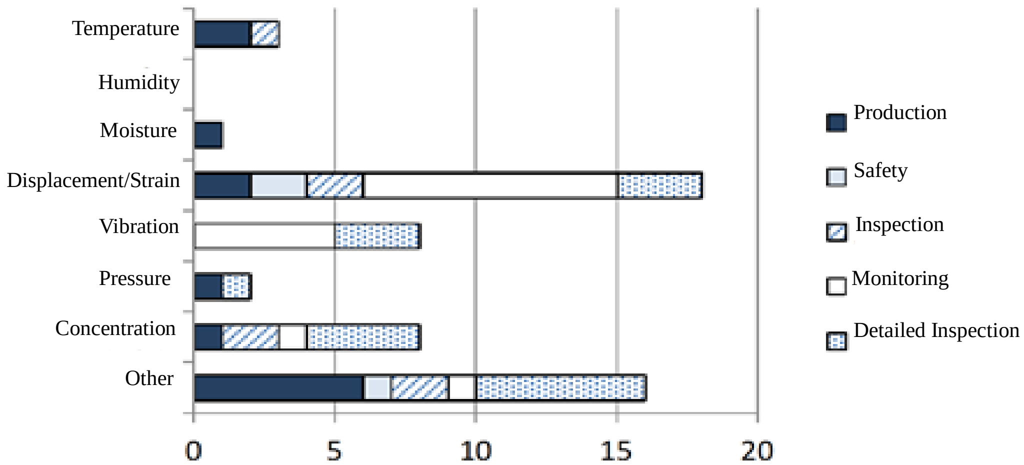


Figure 3 – Usage Distribution for Each Measurement Item in Individual Technology

3.4 Issues Regarding Sensor and Monitoring Technology

Many of the results of this investigation have already been "commercialized" or "industrialized", and as such, there weren't many products that we could say were direct seeds.

On the other hand, the current issues and future potential for each technology was realized, so we tried to extract issues from that analysis result, and clarify the technological seeds, including expectations for the future. The technological issues obtained from the analysis of the interview and questionnaire results were; 1) securing the reliability of sensor measurement values, 2) establishing the sensor mounting method, 3) standardization of sensor data formats, 4) issues for long-term monitoring, 5) the background and issues for the development of overseas product measuring instruments, 6) technical capacity issues, 7) decision on the structure system as a whole, and 8) issues for monitoring the safety at a construction site, etc.

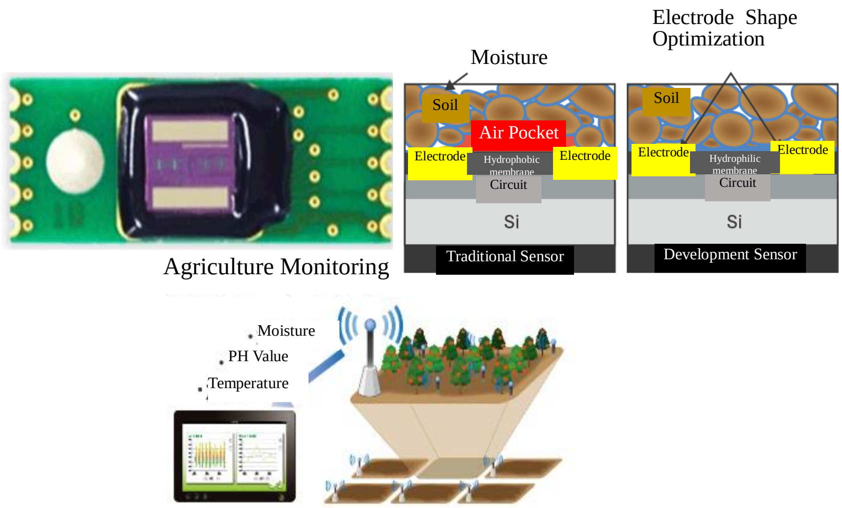


Figure 4 – New pH Sensor and Usage Example

3.5 Seed Technology Expected to Expand the Usage Scope to Actual Structures

Although many applicable cases have been seen in the past for sensors and related technologies, including experimental studies, there are still many limited technologies within the applicable range of actual structures, so it cannot be said that sensor technology is prevailing. Meanwhile, with the advancement of semiconductor and ICT technologies, and the cost reduction of sensors, sensor technologies are increasingly being used in the general public. Considering the situation where the applicability of various sensor technologies is improving, this section will look at sensor technologies among the ones investigated that are currently not being applied to the concrete fields and structures, and outline the adaptability to concrete structures.

In this paper, for example, we will introduce sensors that are considered to be applicable for pH measurements in concrete. For sensors that measure general pH, there is the method of measuring with a glass electrode, and since the object to be measured is in a liquid state, it is difficult to apply this to actual structures such as hardened concrete. The sensor shown in Figure 4 is a solid-state pH sensor which uses an Ion Sensitive Field Effect Transistor, generated by ion activity, and each moisture amount and temperature sensor is mixed with 1 chip in the semiconductor substrate by a method of detecting the surface potential of the measurement sample, and the ion-sensitive membrane that's generated by ion activity[5)]. We had already realized the difficulties of measuring pH for a soil environment up to now, so we can expect to apply this to concrete as well.

4. Case Studies Using Sensors in Actual Structures

4.1 Investigation Outline

In this section, we examined the inspection and monitoring data storage technology and its application method. Even if we go through the trouble of making measurements with a sensor, if there is a mountain of data that cannot be utilized, it's ultimately pointless. Additionally, the data recording, sharing method, recording frequency, etc. should be differ in accordance with the measurement purpose. Therefore, in this WG, we gathered examples of monitoring that has been performed up to now, understand the current status of the recording and usage methods of data, and discover future issues.

The case study was summarized in the following 6 items. For each item, the points where the sensor technology could be utilized, as well as could not be utilized well are arranged, as well as future issues for each case.

(1) Objective: Why measure with a sensor?

(2) Measurement: What measurement was performed in order to achieve the objective?

(3) Data Management: What methods were used for managing the data at the time of measurement?

(4) Data Processing: How were the measurement results processed?

(5) Usage: How was the processed data used?

(6) Issues: What are the things that will become future issues?

Also, aside from the storage and management methods of the measurement data, the items that should be initially considered when utilizing sensor technology in the construction field are sorted into Table 4.

Table 4 - Items to be Considered for Data Utilization

Item	Data Type	Advantage, Characteristic	Issues, Demands, etc.
Data Type (Digital)	Big Data	Possibility of new analysis that could not be understood up to now (Data continuity, exclusion of established concepts based only on fact, etc.)	Extremely large storage requirements Handling is heavy, special knowledge required
	Digital Image Data	High-precision deformation analysis is possible by simultaneous photography of gauge points → Improve camera resolution, accuracy improved yearly No-contact, easy to collect data from a remote place (drone tower, etc.) ○ In the near future, there is a possibility that it may replace the contact type sensor	Accurate analysis is difficult from general images without indicators such as gauge points
	Point-Group Data	w/3D coordinates and color data, and can acquire a wide range of data in a short time ○ Applications such as measurement while moving are expanded	The variation in accuracy varies depending on the data acquisition → Data with poor accuracy is mixed in with a wide range of data.
Data Type (Analog)	Analog Data (Hand-Written, etc.)	If digitized with a scanner, the possibility of image analysis (Want to effectively utilize the large amounts of old information as data)	The probability of erroneous conversion, error, etc. is high, selection and judgment by people is necessary
	Picture Data		
Temporary Data Storage	Digital Media such as PC + HDD	Common to store digital data	In the field, securing power is a large issue → Usually an inverter generator (about 6 to 8 hours) → Securing a commercial power supply is essential for long-term measurement (monitoring)
	Sensor w/Built-in Battery, Recording Medium	Easy to operate, and if it satisfies accuracy, the utilization rate of monitoring can grow dramatically	Currently, it is necessary to replace the batteries at most about one year, so it is unsuitable for multi-point measurement
Data Transfer Method	Wireless Technology (Satellite, LAN, WiFi)	No on-site wiring, installation work becomes easy	Weak at times of disaster (satellite communication is relatively strong?) The structure becomes an obstacle, the transmission distance is unexpectedly short Power consumption is high, securing a power supply is the biggest issue
Data Corrections	Scattering, Stability	There are many cases where the data is not stable due to sensor-specific problems (such as low resolution) and photography of magnetic fields in the field	Variation and stability should be understood beforehand as much as possible, and selection of sensors according to the usage is required
	Environmental Factors such as Temperature, Humidity	Almost all sensors are temperature dependent, separate temperature measurement is required, and corrections are necessary (sensor has correction factor)	The sensor position and temperature measurement position may be different (Development of temperature compensated built-in type sensor etc. is desirable)
	Absolute Accuracy (for Long-Term Measurement)	Due to deterioration of the sensor itself and wiring part, data shift may occur (sensor function is said to be lost)	It is generally difficult to judge the item to the left → Simultaneously measure absolutely immovable items and take countermeasures such as subtraction correction (Development of measuring instruments and the like with an absolute calibration function is desirable)
Data Analysis/Usage	Database	For digital data, creation is relatively easy	However, advanced knowledge is required for utilization
	Visualization (Graphs)	Good understanding of change points, singularity etc. (Data utilization is difficult without visualization)	The user needs to judge individually according to the purpose, such as which data is compared with each other → Generalizing the software is difficult, for practicality it will become a single production item
	Future Prediction (Markov Analysis)	One of the big goals of accumulating data	To improve prediction accuracy, a feedback system of measured values is required
Data Storage Location	Cloud	Effective as a means of information sharing (Administrators, past data reference on site, etc.)	Access rights and security is required
	BIM, CIM (3D Models)	Can expect mass analysis as a data storage platform combined with design and construction data	Generalization is still difficult because the amount of work is huge, and cost increases (Operated from important structures, etc.)

4.2 Case Study Target

The case study was sorted into the following 8 items.

(a) Information construction for arch bridges

(b) Bridge monitoring using FBG optical fiber

(c) Narita Airport guidance road bridge monitoring

(d) Bridge monitoring by route bus

(e) Landslide disaster monitoring system by ubiquitous network

(f) Verification test for utilization of a residential wetness sensor system

(g) Skyscraper monitoring (Korea Lotte Tower)

(h) Concrete deformation extraction using image processing by deep learning

(i) Degradation assessment of concrete structures using Raman spectroscopy

5. Summary: Expectations for Monitoring Systems using Sensor Technologies

For concrete structures and buildings, designs will be made that satisfy the required performance acting against various external forces working against them during the assumed service period. The active external forces include various loads such as seismic forces, and environmental effects such as airborne salt and freeze-thawing action. The forces working against structures and buildings are not fixed values, but a distributed probability, and as there are uncertainties in the concrete that composes the structure, as well as the structural analysis, a certain degree of reliability will be ensured in the verification by introducing partial coefficients and allowable stress levels.

However, in regards to the size of the load and the forces position applied during the structure's life cycle, number of forces, displacement of the ground in the surrounding area, as well as the environmental forces, there are probabilities that exceed the range assumed in the design. Additionally, there are plenty of things that weren't sufficiently considered during the design, such as the concrete structures that progress against concrete structures, and we cannot deny that it may become a situation where the behavior for the structure differs from what was assumed during the design.

For that purpose, for maintenance management, through the implementation of regular and fixed inspections, we can confirm if any abnormalities are occurring in the structure, and if the performance sought from the structure is being secured. Here, when a structural anomaly has been recognized, a diagnosis will be performed, and through implementing measures such as repair and reinforcement, and follow-up observation, we can guarantee the reliability of the structure's performance.

The implementation of appropriate maintenance management such as this is indispensable for preserving the reliability of the structure's performance, however the labor and costs needed for this are generally exceptionally limited, unlike at the time of construction. In the future, amidst the expected shortages of engineers involved in the construction industry, labor conservation for structure inspections will be promoted, and there will be the desire for the spread of systems that can effectively obtain, store and manage new inspection data in the place of human eyes.

On the other hand, although it's natural that the visual inspection results are essential evidence in judging the soundness and usability of concrete structures and buildings, this alone is not enough to absolutely guarantee the diagnosis quality. For example, the progression of corrosion and neutralization for reinforced steel materials such as rebar and PC steel found within concrete are very important evidence materials for structural health evaluation and future predictions, but it is difficult to obtain this kind of data just from the visual inspection result. In other words, in order to improve the quality of soundness diagnosis, obtaining objective data that is necessary for an appropriate engineering diagnosis is important. Various things are assumed for this kind of data, but for the acquisition of fixed as well as continuous data, there are limits to human power alone, and it will be necessary to construct systems that utilize sensor technology.

In this way, we can expect plans for the labor-saving inspections to replace part of the visual inspections conducted with human eyes, and the improvement of the quality of soundness inspections of buildings and structures.

However, in filling these roles, we can consider that there are still many issues that are left to be resolved. One such issue is to consider the range of events that the system should detect, at the timing of the monitoring plan. For example, we can consider a system for diagnosing soundness against corrosion of rebar in concrete by neutralization. The targeted events are very limited, and the indicators to be monitored are also relatively clear. However, from the usage situation and placed environmental conditions for the target structure, it is not always possible achieve the goal of only observing the target event (in this case, the corrosion of rebar due to neutralization). Conversely, if we use a monitoring system aimed at the comprehensive soundness evaluation of the target structures and buildings, the target objects are extremely diverse, and as a result the monitoring system will become large-scale, and we can expect the occurrence of difficult situations such as the necessary costs for the operation and maintenance of the system, as well operational complexities. Considering the role expected of the monitoring system, and the monitoring system's operational period and maintenance management system, we can consider that it is important to appropriately set the role and scope of the monitoring system at the planning stage.

Subsequently, what is important for the effective utilization of a monitoring system that utilizes sensor technology is to clarify the judgment index when performing some actions as a result of monitoring. For example, based on the monitoring result of the deflection occurring in the structure, the following decisions may be made.

・Take emergency repair measures

・Make a detailed investigation of the structure

・Do not take any special actions

The issue is setting the threshold values for when these decisions are made. We can consider than an engineering "solution" is required for this, but we can also consider that it is necessary to set an appropriate value which considers the required performance of the target structure.

In this manner, the greater the expectations in regards to monitoring systems that utilize sensor technologies, the more it will be required to establish strategies that clarify the roles of the system and to specify the usage image.

For the production and maintenance management of reinforced concrete structures, engineers in the civil engineering and construction fields will be the ones to determine a clear objective and usage method for the utilization of sensor measuring systems. In the past, we concrete field engineers have viewed working together with engineers in other fields for the purpose of increasing productivity and safety through the usage of sensor technology such as this in actual buildings in a negative light.

However, it's probably necessary for us to work together with engineers in other fields and utilize technologies we're unfamiliar with in the construction field in order to ensure the quality, safety, and long-life of concrete structures.

We hope that the results of this committee will be helpful for those who work in this field.

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