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A STUDY ON METHOD FOR DEFLECTION MANAGEMENT IN FCM BRIDGE USING SENSOR NETWORK

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Abstract

Ubiquitous technology is proposed which uses wireless sensor network for deflection management at casting and after casting of FCM bridges. Proposed method is analyzed, which is sensor experiment and existing FCM bridge by using wireless sensor network. Wireless sensor network enables low-cost sensing of environment. As a result, the field application shows that sensor network is a useful method for structural health monitoring system, which long distance away.

1. Introduction

FCM, one of the methods of constructing prestressed concrete bridges, is a method of installing 3~5m segments in sequence by using Form Traveler, and connect cantilever mold at the center of span, while maintaining left/right balance from the pier without installing any supports to resist weight under the bridge, that is suitable for constructing long bridges on deep valley, river, sea, etc., where support installation is difficult. Deflections occurring from this FCM bridge can be

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classified into downward deflection from dead weight and upward deflection from prestress, of which the latter is generated by stress of post tensioned tendon, and sometimes reduced due to dead weight of the structure, but final one cannot be neglected. The reason is that, in case of concrete, as creep and drying shrinking change over time, upward deflection can be also changed over time. When actual deflection and calculated deflection appear differently, since both design and construction may have a lot of problems, generation and development of deflection become important considerations for design and construction, general linear management is decided according to calculated deflection during construction, and material problem required for constructing bridge is also determined. When deflection of mold becomes different from expectation, design change or correction is required upon the results, and it remains economical and structural problem. After all, reasonable evaluation of downward deflection from dead weight of mold and upward deflection from prestress is required in relation with a number of issues. Deflection management is considered in the field uses manual measurement upon survey, sometimes, it is difficult to construct key- segment at the end of construction due to frequent deflection errors. Deflection management of this FCM bridge today uses mainly manual measurement (before sunrise, etc.) according to conditions of the construction site, but actually, there are a lot of difficulties and manual measurement results are introduced to reflect errors upon temperature [4]. On the other hand, recently, there are efforts for scientific maintenance and construction through convergence of construction and IT technologies in Korea, and some methods are promoted to introduce a lot of IT technologies into construction area. The most fundamental item to be introduced into the construction area may be measurement for maintenance, which a lot of researchers have been studying for several years as a national core technology development. In measuring bridges, tunnels, etc. using earlier version of modem or optical communication, different problems may crop out such as power supply problem, abnormal weather, loss of measurement system due to earth change and etc., but wireless sensor network has a significant advantage of fast reaction of the manager against the event first with real time data transmission and guided transmission to small PC terminal. Accordingly, this study has deflection sensor node in order to propose deflection management of FCM bridges by using scientific method, and proposed automatic deflection management method using sensor network technology by correcting and complementing the existing sensors.

2. Deflection Management System of FCM

Deflection management is important especially for FCM bridges. Since, aspect of actual deflection shows a trend of larger-than-expected deflection upon structural calculation, problem of connecting key-segment during construction may have effect on stability. The current deflection management system is shown on Figure 1, and influencing factors on this deflection management are summarized on Figure 2. Influencing factors for deflection management are mainly divided into internal factors and external factors, of which internal factors are generally from structural impacts related to material characteristics of concrete, effect of prestress, impact of weight, etc., and external factors include impact from form traveler, settlement problem of pier and abutment, appropriateness of expected construction period, etc., and may be neglected except for the case of direct factor of deflection management of form traveler.

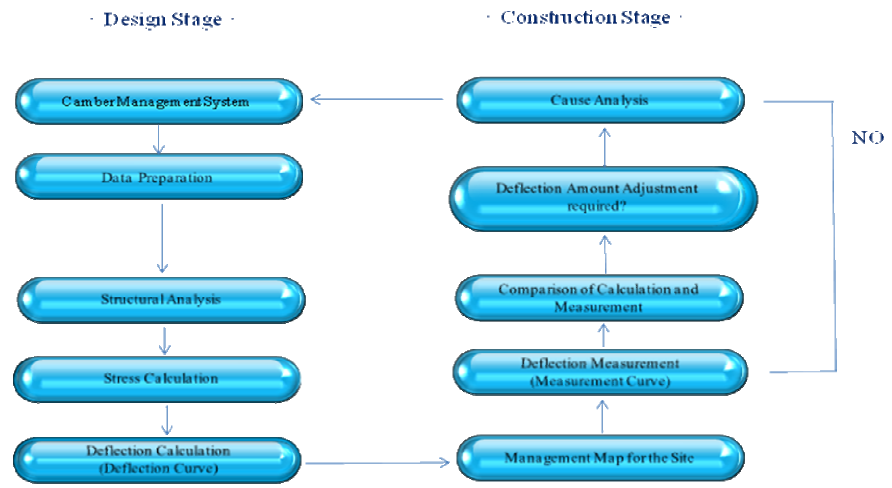


Figure 1. Previous deflection management flow chart.

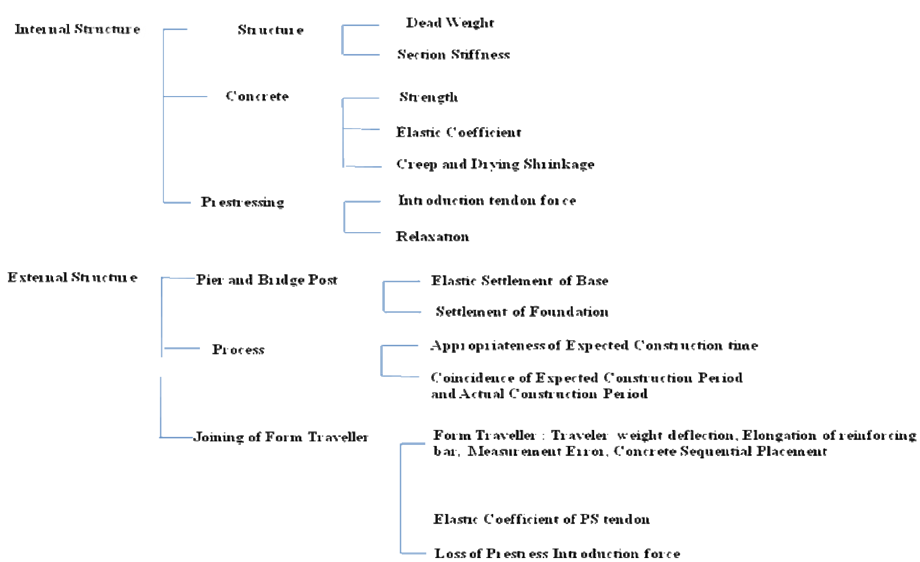


Figure 2. Deflection management effect factor.

The current deflection management system performs management by drawing field deflection management drawing as shown on Figure 1, making planned elevation upon survey from each construction, and comparing it with the calculation value. However, it is noted that this method has a problem of manual measurement, and disadvantages of having difficulties getting accurate value upon ambient environments and of possibility to have different result value of measurement from every manual survey. After all, deflection management can be classified into 4 steps including placing each segment at pylon table just before connecting key-segment, deflection management at key-segment joining step, deflection management at final step, and finally, long term deflection (additional deflection) management. Measurements of these deflection managements shall include major behaviors including downward behavior until completion of cantilever, downward behavior until construction of key-segment, upward behavior until construction of key-segment, downward behavior upon creep after completion of structure, etc., and they are important variables and characteristics of deflection management. Especially, as they are very important factors for FCM bridges, they attract interests from deflection management.

3. Proposal for Deflection Management using Sensor Network

3.1. System overview

As information industry and mobile communication technologies have developed at rapid rate, concept of computer has been spread fast beyond a concept of personal computer, and as a new paradigm, a concept of ubiquitous computing, which means installing computers on the all objects around us and connecting them with networks to provide human life with invisible computing, while cooperating and compromising with each other, comes to the front. This computing environment means development toward the network environment requiring integrated management and mutual interconnection rather than simple control of fixed and mobile nodes. Ubiquitous networking starts from the computer's recognizing environment that the user faces with. Thus, it can support the user for communication or application [1, 5].

Under such environment that the user faces with, information values for the user and changes of the information such as current location, action, work, etc. can be acquired. Those information acquired from the user or sensor with computer can be used for the current system, generally, registered on the server or used for other locations through network. The information stored on the server can be used or executed on the other terminals connected to the ubiquitous network, if necessary. In addition, when the information on the terminal is recognized and moved to the server or other terminals for execution, communication protocol has network format. Since, the bridge deflection management system proposed by this study intends to develop suitable sensor node and deflection amount evaluation technology by using sensor network, a flow chart for design has been drawn as shown on Figure 3. In addition, Figure 4 shows the existing wired system as a system to manage field deflection regardless of location and time by using wireless communication, and it would be able to check deflection amount and easily correct error from the site office by installing measuring sensors on the field. Generally, core issue of the deflection management is to replace the existing system to calculate deflection value after structural analysis, and correct it for actual construction with automatic measurement system on the site by using sensors. Accordingly, when sensors are attached upper/lower part of each segment at indication point of pylon table and deflection occurs, the sensor detects it and communicates with adjacent sensor in wireless format, corrects it and sends it to the management system for real time detection [3].

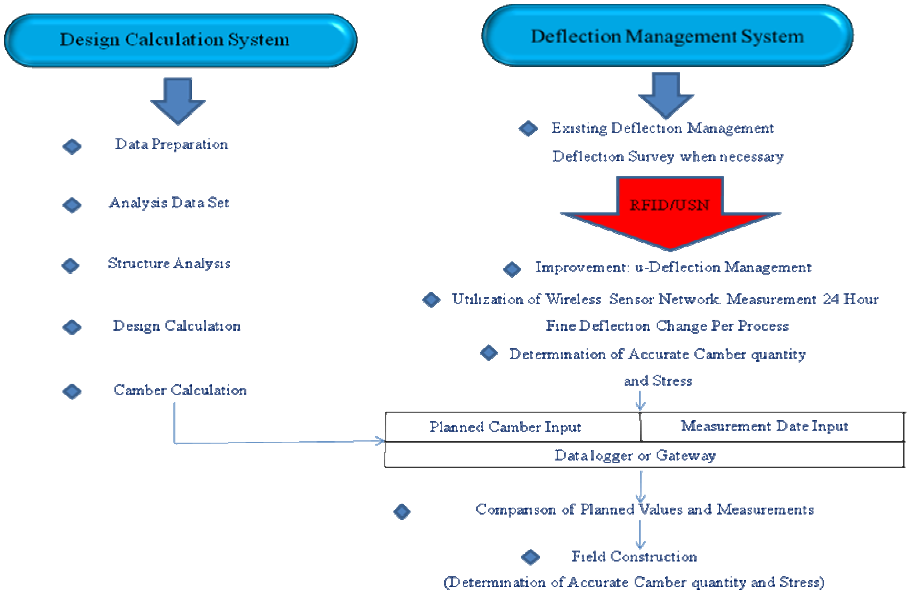


Figure 3. Proposed deflection management flow chart.

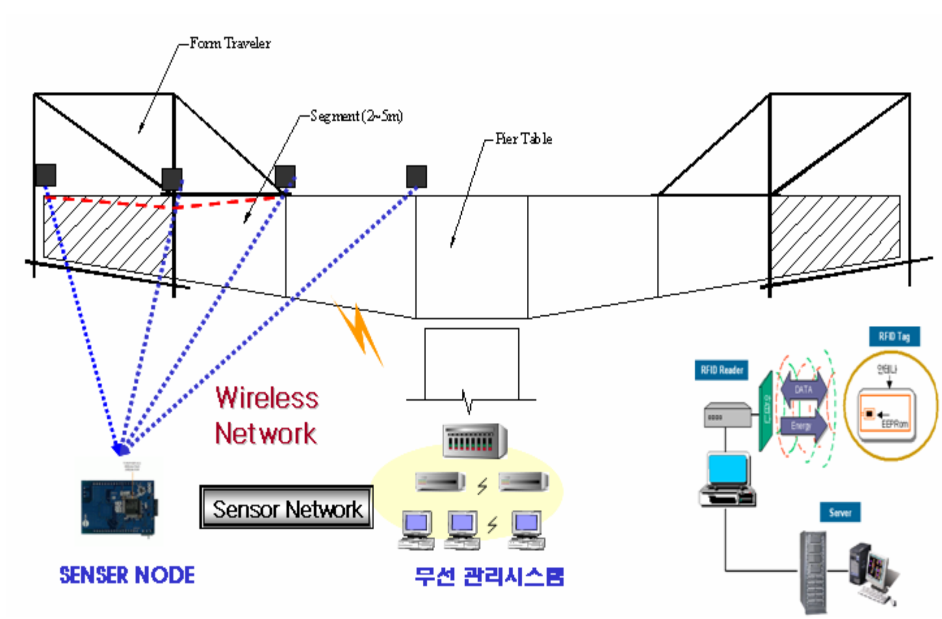


Figure 4. Proposed deflection management system.

3.2. Sensor node development

Sensor network refers to a network composed of small devices, i.e., sensor node, equipped with sensors for sensing, process to manipulate collected information, and wireless transceiver to send them. Usual characteristics of sensor network are that its size is relatively larger, and it has more sensor nodes closely arranged than Ad-hoc network with similar properties. As the sensor nodes are operating under harsh environments, their functions may fail and their network topology may frequently change [6]. The existing network considers peer-to-peer communication, but the sensor network mainly uses broadcasting paradigm (see Figure 5).

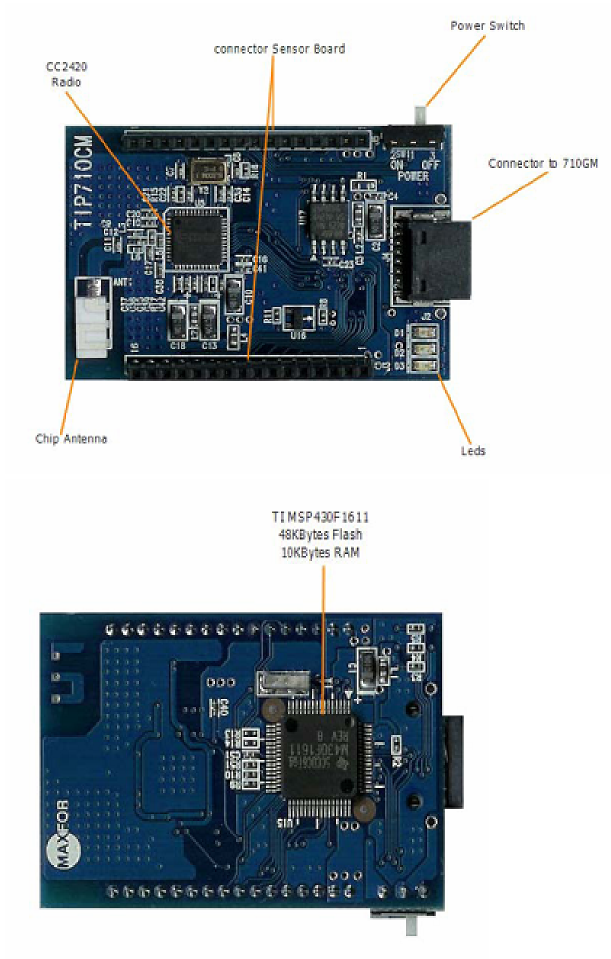


Figure 5. Developed sensor module.

In case of constructing FCM bridge, vertical line to the construction direction has tilt due to impact of dead weight. Thus, it allows installing the sensor on the segment at pylon table during construction, measuring tilt on the measuring point, comparing it with design value, reviewing deflection amount of the bridge, and taking proper action. Figure 6 shows configuration of developed system. The system consists of sensors to detect deflection of FCM bridge, MCU (Micro Controller Unit) to send detected analogue signals to the sensor node and host PC to process received data.

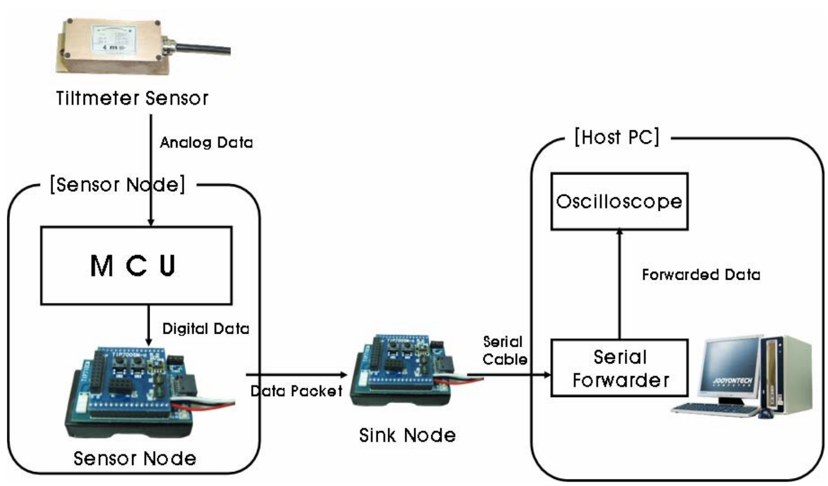


Figure 6. Sensor network system.

In order to detect tilt and deformation status of bridge structure, system configuration uses the existing tilt sensor Tiltmeter (BTM-5). Using principle of tilt detector and principle of servo accelerometer, one pendulum (mass) is located within magnetic field of position detector as shown on Figure 7, which will be inclined to the direction of gravity and, intern, current change occurs on the position detector. The current flows into the restoring coil through serve-amplifier, and the pendulum does not move as it has opposite direction of gravity to be changed first an electromagnetic force and becomes balanced. At the moment, when the current is passing through the resistance, voltage can be measured, which is proportional to the force to maintain the pendulum as balanced state. Detector (probe) of biaxial type tiltmeter includes one accelerator meter in each 90° direction. The detector (probe) moves along the groove on the tiltmeter tube (access tube), and at that moment, tilt from vertical axis can be calculated from measured voltage multiplied by proportional constant, since tilt of the detector is directly proportional to the force to maintain the pendulum as balanced state.

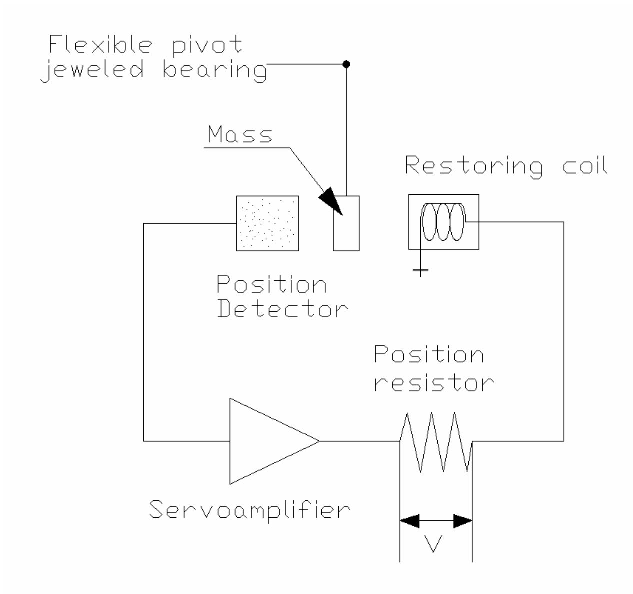


Figure 7. Sensor working principal.

Generated electric signals are connected to ADC channel of mot. Mot has 7 ADC channels, and each channel is 12 bit analogue/digital converter and samples signals in 24KB per second.

Since maximum voltage of tiltmeter sensor is $5.0V \pm 0.2\%$, it is required to adjust it to ADC voltage level of mot (2.5V), in order to output more detailed and sensitive data. Thus, a non-inverter amplifier is organized by using Op-Amp and connected between tilt sensor and mot.

Figure 8, shows circuit diagram of non-inverter amplifier, which amplifies voltage from sensor by 10 gain using rail-to-rail type amplifier, LMV 931, in order to use power supply of mot (3V) as it is.

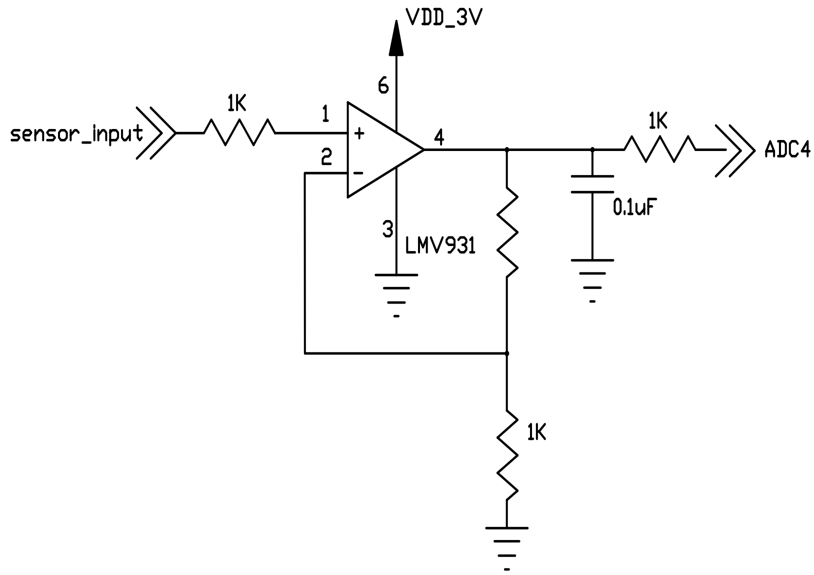


Figure 8. Amplifying circuit of developed sensor.

Figure 9 shows sampling procedures of data from sensor, where timer component is initialized and program starts at the beginning process. The timer generates events at specified time interval, and upon event generation, ADC (Analogue to Digital Converter) component converts analogue signals into digital signals through Get Data function. When data sampling is completed, event occurs, event process routine loads data to the packet, fills data buffer and transmits it to the base station. And, TinyOS that is usually used for sensor design has been used for active message. As active message includes message type within packet, the receiver performs command in responses to types.

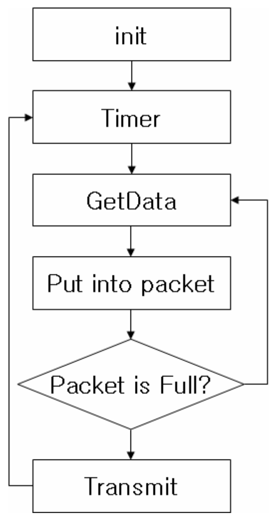


Figure 9. Data sampling process.

This study has composed packet by containing message packet of oscilloscope (OscopeMsg) that is a monitoring tool of host PC into data area of TOS_Msg packet, that is, active message structure of TinyOS [2].

Oscilloscope shows data received from host PC through graph and saves data into database.

Figure 10 shows data flow chart of the system. When initializing system, sampling rate of ADC component and the timer are determined, and when the timer is activated, TIME_REPEAT parameter is set to generate events repeatedly at a specified time interval. When timer event occurs on the component, ADC component of event processing routine samples data of tiltmeter sensor through analogue channel of MCU connected to mot and converts analogue data into digital data. Converted data is sent to the base station by using RF on the component. The base station transfers the received data to PC through serial forwarder interface, and oscilloscope program of the host PC receives data, outputs to graph and saves to database at the same time.

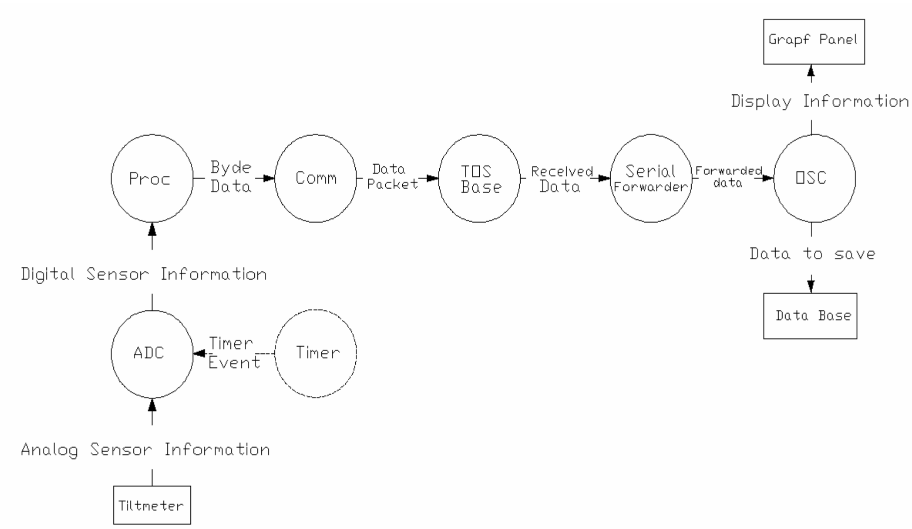


Figure 10. Data computing flow chart.

4. Developed Sensor Verification Test

4.1. Preliminary test

Before applying it to actual FCM bridge, a miniature of the bridge has been fabricated for verifying developed sensor module, and deflections have been measured and compared for load from weight of each stage. Material used for the miniature was H-Beam $(100 \times 100 \times 5.7/7.5)$ with 8m in length, and weight was made of 5 steel blocks with 10kgf, loaded at the center of the span for measurement. Model test sample is shown on Figure 11, which was made of General Structure Steel SS41.

Figure 11. Sensor verification experiment.

After applying 5 weights of 1N, 2N, 3N, 4N, and 5N in gradual steps at the center of 8m model beam for test, deflection amount and tilt deformation had been measured. Here, in order to compare deflection amount at the central sectional area, tilt sensors and displacement sensors are attached and measured in 1m interval from the center point considering that model bridge is symmetrical.

From the test results, as for deformation of sensors measured at different weights, it was found that deformation of sensors increased as general weight increased as shown in Table 1, which shows that deformation upon sensor is possible. In addition, comparison review with displacement type deflection meter generally used is shown in Table 2.

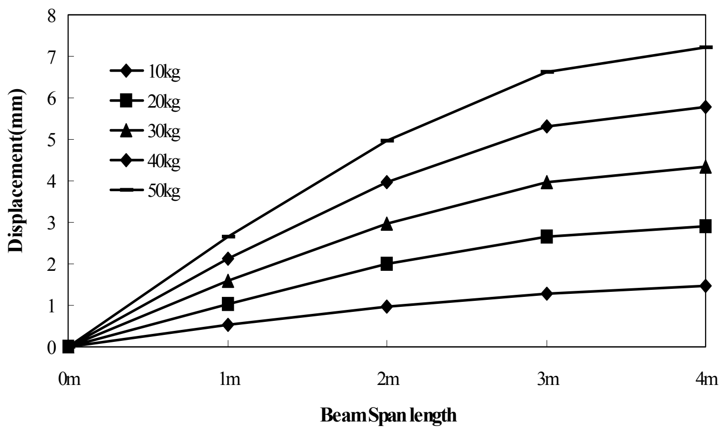
Table 1. Preliminary experiment result

Weight Steps	Position	Sensor (Degree)
1N	0	–0.03050
	L/8	–0.02550
	2L/8	–0.01925
	3L/8	–0.01050
	Center	0.00150
2N	0	–0.05975
	L/8	–0.05425
	2L/8	–0.03875
	3L/8	–0.01900
	Center	0.00375
3N	0	–0.09050
	L/8	–0.07800
	2L/8	–0.06100
	3L/8	–0.02400
	Center	0.00300
4N	0	–0.12225
	L/8	–0.10300
	2L/8	–0.08275
	3L/8	–0.03200
	Center	0.00500
5N	0	–0.15350
	L/8	–0.13325
	2L/8	–0.09725
	3L/8	–0.04200
	Center	0.00675

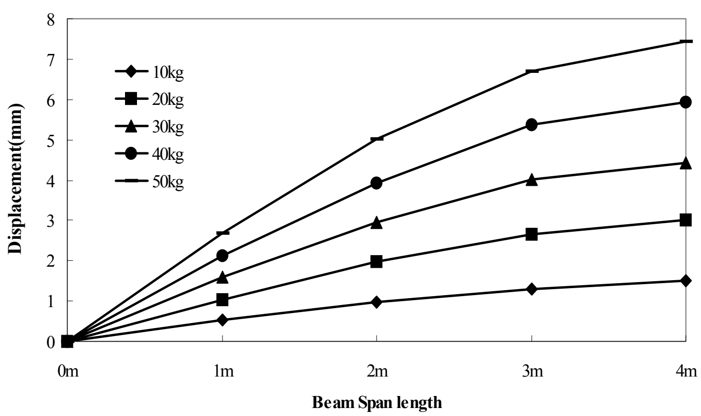
Table 2. Comparison to measurement result with load steps

Weight Steps	Position	Deflection (mm)	
		LVDT	Sensor
1N	L/8	0.530	0.532
	2L/8	0.980	0.977
	3L/8	1.290	1.313
	Center	1.470	1.497
2N	L/8	1.045	1.043
	2L/8	1.985	1.990
	3L/8	2.650	2.666
	Center	2.920	2.998
3N	L/8	1.590	1.580
	2L/8	2.955	2.941
	3L/8	3.970	4.006
	Center	4.340	4.424
4N	L/8	2.125	2.134
	2L/8	3.980	3.931
	3L/8	5.300	5.376
	Center	5.780	5.934
5N	L/8	2.660	2.679
	2L/8	4.980	5.005
	3L/8	6.630	6.702
	Center	7.230	7.435

From comparison of converted deflection results calculated from deflection amount measurement results upon deflection meter and tilt deformation measurement results upon tiltmeter, we can see that error ratio of measurement results for the analysis results occurs up to about 3%, satisfying accuracy (see Figures 12 and 13).

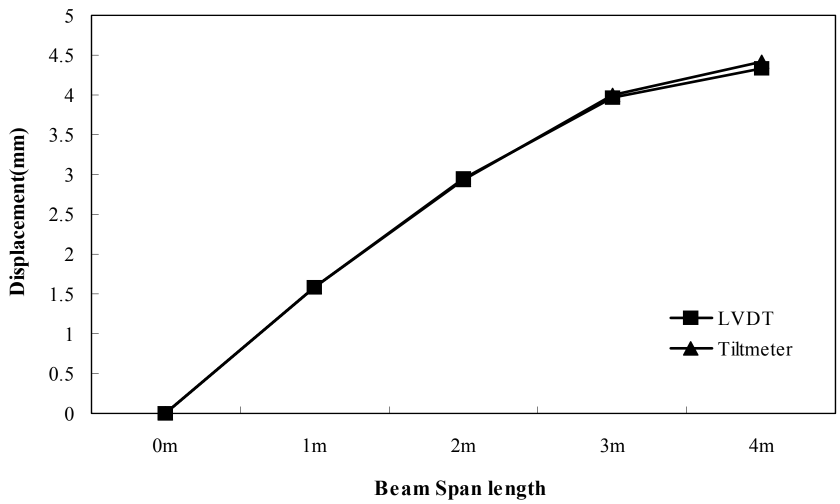


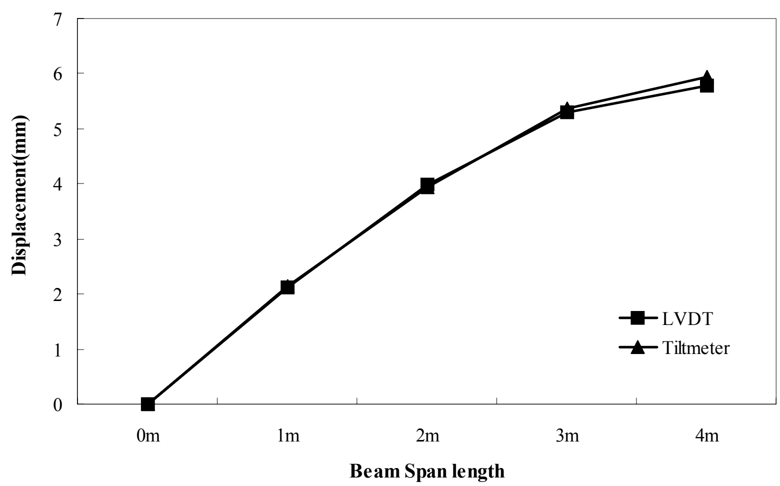
(a) Existing deflection measurement device.



(b) Sensor device.

Figure12. Deflection result with beam span length.


Displacement(mm)
5
4.5
4
3.5
3
2.5
2
1.5
1
0.5
0
0m
1m
2m
3m
4m
Beam Span length
LVDT
Tiltmeter


Displacement(mm)
7
6
5
4
3
2
1
0
0m
1m
2m
3m
4m
Beam Span length
LVDT
Tiltmeter

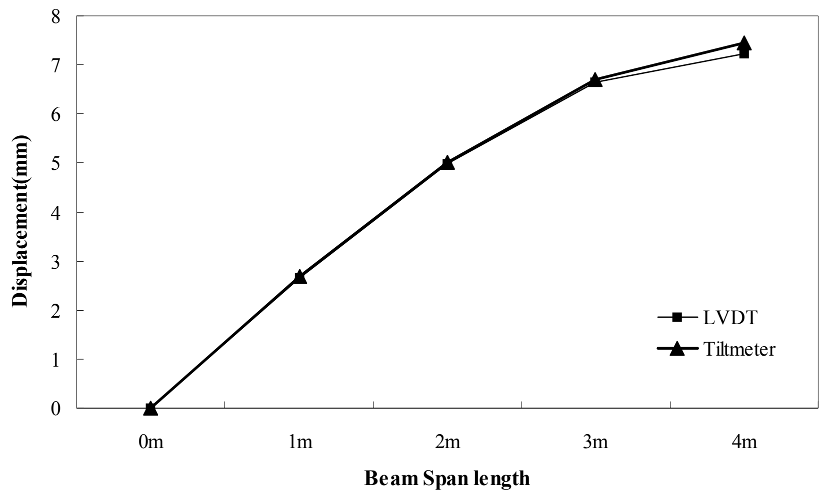


Figure 13. Model experiment result with loading.

4.2. FCM bridge test

Example test bridge

In order to consider applicability of actual bridge by using the developed sensor, sensor measurements had been conducted for FCM section of Namyangju Bridge in Korea, a part of Seoul-Chuncheon Highway. Namyangju Bridge is 1,530m long that has been constructed from 2004, applied with 2 types of temporary installation method, of which specifications are listed in Table 3, and general dimensions are shown on Figure 14.

Table 3. Specification of experiment bridge

Type	Specifications
Top structure type	P.S.C BOX GIRDER(F.C.M+F.S.M)
Span structure	F.S.M + F.S.M + F.C.M = 2@70 + 3@70 + 90 + @125 + 90 = 1,530m
Width	B = 16.20m B = 16.370m (Soundproof wall section)
Top material strength	f_{α} = 46 Concrete: MPa f_{θ} = 400 Steel reinforcement: MPa
P.S Steel	KS D 7002, SWPC 7B φ = 15.2mm
Vertical section inclination	S = (-) 0.5%
Lateral inclination	S = (-)3.0 ~ (-) 2.0%
Foundation type	Direct foundation, Cast-in-place pile and steel pipe pile

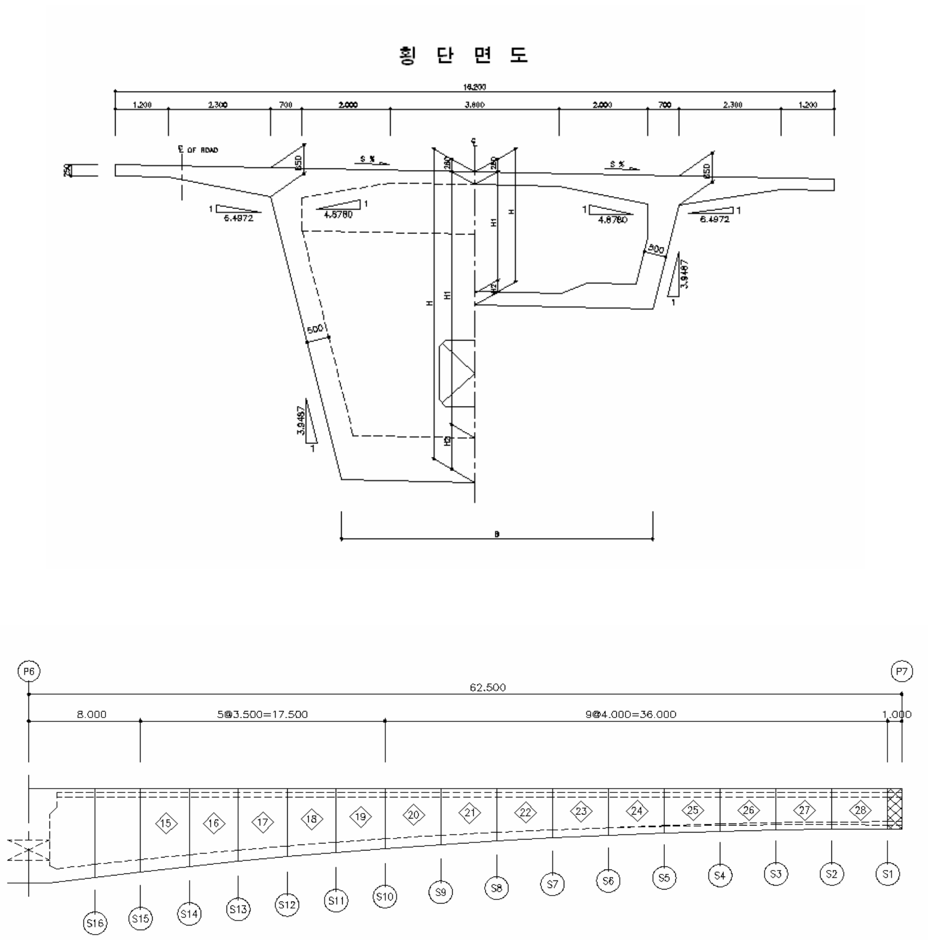


Figure 14. Detail aspect for experiment bridge.

4.3. Deflection measurement and results

In order to verify deflection management of actual FCM bridge, bidirectional network communication of sensor node had been checked on the field, and the developed sensors had been attached on the top of separately constructed concrete in order to check accuracy of measurement data and reliability of the result values. In addition, efficiency of the deflection management by using the proposed sensor network had been increased on the basis of measured data on the actual site. Constructional stages of the bridge, that is, the object of a test for this study is shown on Figures 15. Figure 16 shows a process to provide the deflection management system with information of level of deflection for structure through bidirectional communication of the attached sensor node. The current construction status of this site is in construction of segment 6, 7, and 8, and measured data twice a day had been compared and analyzed with the developed sensor.

Figure 15. Construction of FCM bridge.

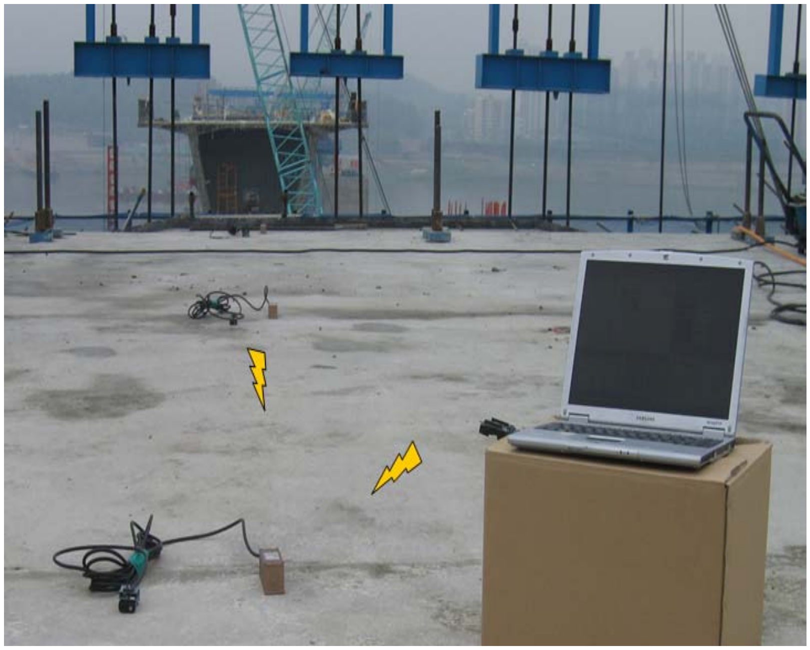


Figure 16. Measurement by sensor network.

Tilt sensors and node had been installed on the first pier, at the top/lower flanges of box type section, and the point was selected as a reference point. Averages of measurement results for each step are shown on Table 4, and the results shows about 14~18mm of elevation difference at each step, after placing concrete. The final elevation difference on the concrete section after movement of form traveler was 4mm. In addition, measurement values from the top/lower part of section showed difference, which is considered as deflection due to construction of box section occurred during formation of cantilever structure, and the deflection became small in the course of completion of fixation of sectional surface at both ends. Accordingly, this value should be corrected, when stressing the steel wires after placing the next segment.

Table 4. Measurement data of top and bottom section

Segment \ Measurement Position	After placing (mm)		After stressing (mm)		After moving F/T (mm)	
	Top	Low	Top	Low	Top	Low
No. 6	–14.96	–7.56	–5.31	–5.91	–1.83	–1.33
No. 7	–17.02	–10.66	–6.24	–7.04	–3.77	–2.45
No. 8	–18.50	–14.19	–7.00	–8.93	–4.54	–4.35

Comparisons of deflection measurement results of each segment by using sensors, results using survey level, method with structural analysis, and results using general purpose program RM used for the current design are shown on Figure 17. The results showed that sensors accurately measured deflection values of the structure and the values coincided with the results of existing structural analysis. However, since the developed sensors sensitively react against ambient construction equipment or other changes of conditions of environment, it is required to pay attention to using them, and it is considered that they could suggest useful data for measurement management for construction method of special bridges through permanent measurement per each type of construction method.

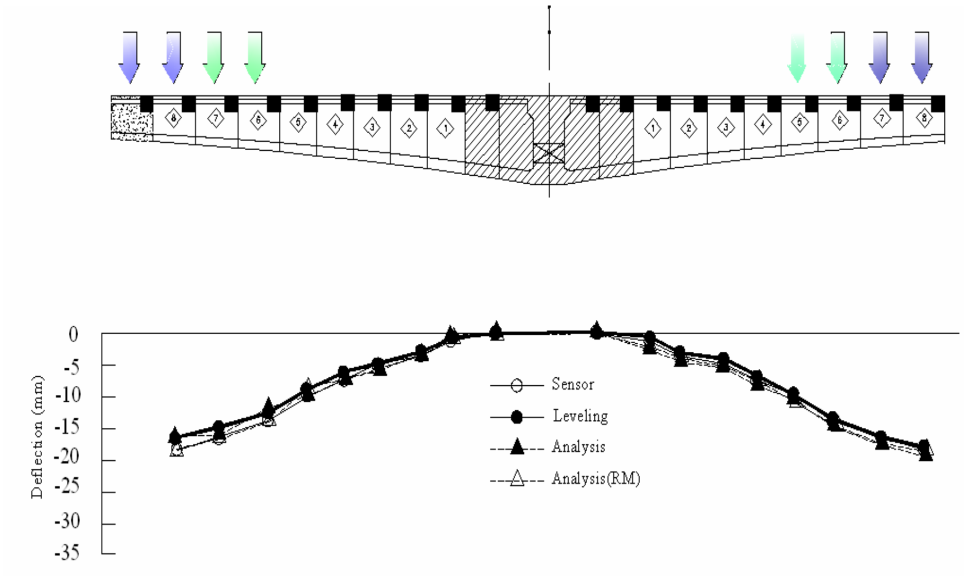


Figure 17. Comparison to site measurement result.

5. Conclusion

From the measurements and results of upward deflection upon dead weight and prestress for FCM bridge to be constructed with cantilever method, this study intends to propose wireless network based deflection management method by correcting the existing measurement system, and propose deflection management method of FCM bridge by developing sensor network system having wireless node, and bidirectional 900MHz broadband communication network for the existing tiltmeter. Results of application to the actual bridge showed values approximate to measured values. The study proposed an efficient maintenance method by applying structural diagnosis technique of the long span bridges, such as suspension bridge in the future.

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