Wireless data acquisition system for measuring the curing temperature of mass concrete

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Abstract: Timely temperature control in curing newly placed mass concrete is one of the major factors in forming quality concrete. Quick action is necessary to ensure proper designed strength of concrete and avoid cracking when the temperature of the concrete constantly changes. Generally, an automatic recording thermo-hygrograph is used to measure the curing temperature of mass concrete, but the recorded temperature data has to be obtained manually and checked before taking action, such as covering the concrete. While wireless data acquisition is being applied in a growing number of industries, this technology is applied to several fields in the construction industry, such as communication. Therefore, in this study, a wireless data acquisition system is introduced for obtaining the curing temperature of the newly placed mass concrete. Furthermore, with this system, obtaining real time temperature data and taking quick actions for controlling the temperature of mass concrete is possible.

Keywords: Wireless Data Acquisition System, Concrete Temperature, Curing Management, Mass Concrete.

1. INTRODUCTION

The quality of concrete is largely governed by the curing temperature during the first few weeks. Especially in the case of mass concrete, the curing temperature during the first few weeks affects not only long-term strength but also early age strength [1]. Obtaining sufficient early age strength is important for early form stripping and progressing coming work. Generally, the curing temperature needs to be controlled to avoid volume change differentials and restraint result in tensile strains and stresses that may cause cracking [2].

Therefore, to assure quality steady measuring of the curing temperature is undertaken in most construction sites to avoid cracking in mass concrete structures. Nevertheless, other cracking prevention measures are often required to avoid cracking resulting from thermal stresses that occurs from heat arising from hydration, but these measures' performance are insufficient. These precautionary measures use hydration heat and thermal stress analysis to (1) create the optimal mass concrete mixture, (2) ensure the optimal curing method, or (3) determine where to bury thermometer sensors inside the concrete to measure and control the curing temperature.

In some cases, they measure and control the curing temperature, focusing solely on the temperature of the concrete itself, not the ambient air temperature. However, in most cases, the ambient air temperature can greatly differ from the temperature inside the concrete. Furthermore, the curing temperature of mass concrete structure changes frequently. Therefore, steady observation is required. An automatic recording thermo-hygrograph is generally used in measuring the curing temperature of mass concrete, but the recorded temperature data had to be obtained and checked manually before taking proper actions. In other words, a systematic and steady measuring of curing temperature is insufficient. In order to maintain oversight and to prepare for subsequent phases, practical and realtime methods of measuring and controlling of curing temperature is required.

This paper proposes a wireless data acquisition system for obtaining the curing temperature of newly placed mass concrete in realtime. Through this system, one can obtain and monitor temperature data in the office, through a computer. This system is remarkably useful in concreting during cold weather when temperature differences increase rapidly, thereby allowing for quick action to ensure quality of the concrete.

2. MASS CONCRETE

Mass concrete is narrowly defined to be a concrete structure consisting of section of at least 80cm in length. After concreting this structure, temperature differences between the highest internal temperature of mass concrete structure and the air temperature are expected to be greater than 25ºC through hydration heat [3]. More broadly, the technological aspects of mass concrete are also relevant to any concrete member of such dimensions that the thermal behavior may lead to cracking unless appropriate measures are taken [1]. To avoid such cracking, there are many measures that could be taken, such as using proper materials, e.g. using cement with low hydration heat, and curing. However, when the weather cools suddenly, the only method for avoiding cracks in mass concrete is curing in a proper manner. For example, when the interior temperature of mass concrete increases, the surface temperature of the mass concrete needs to be kept warm enough to avoid sudden temperature differences between the interior and exterior of the mass concrete structure. Therefore, this paper presents proper curing method through wireless data acquisition system for observing curing temperature changes.

2.1 Thermal property of mass concrete

The thermal property of mass concrete significantly influences the volume change of mass concrete. The generally large size of the mass concrete structure has the potential for significant temperature differentials between the interior and the exterior surface of the structure. The accompanying volume change differentials and restraint result in tensile strains and stresses that may cause cracking are detrimental to the structural design [2].
As concrete has low thermal conductivity, the heat generated inside the massive concrete structure escapes very slowly unless aided artificially. Thick mass concrete structures will take several days or weeks to reach a thermally stable condition. A 1.5m (5ft) thick wall requires a week to reach thermal stability [2]. So, during thermally unstable phase placed mass concrete requires a continuous and appropriate curing.

2.2 Arisen problem in curing mass concrete

Especially in cold weather, when sudden temperature decrease takes place, mass concrete temperature variation increases, leading to cracking. To avoid this phenomenon continuous observation is required. The worker needs to know when the temperature differences occur and must react immediately. Currently, automatic recording thermo-hygrographs record the temperature history but continuous observation is not convenient. As automatic recording thermo-hygrographs are installed next to the structure, the worker needs to go to the structure to check the automatic recording thermo-hygrograph. However the inconvenience of this approach results in sparse or occasional observation. Therefore, in some cases, the proper action is either taken too late or neglected. To solve this problem, observation needs to be convenient and the temperature history needs to be observed in real time.

3. WIRELESS COMMUNICATION SYSTEM

Wireless communication technology has made great strides in many fields, enhancing their function and management and saving human effort and time. One example is the walkie-talkie, which has improved not only voice communication in the field but also the method of interchanging of data and information by saving time. Wireless internet links carry data traffic from any remote jobsite to more centralized or convenient off-site locations [4]. This remarkable progress in wireless communication technology made the provision of new wireless information services possible within jobsites to improve their outcome.

3.1 System architecture

A wireless communication system can be constructed in many ways, including circuit-switched cellular modems, specialized mobile radio using packet-switched wireless data systems, packet-switched cellular modems, wireless local area networks, paging systems, satellite-based data communications, and restriction of wireless technology based on data rate requirements. Each of these has specific advantages and disadvantages. Systems with cellular modems are usable wherever data transmission by cellular phone can be conducted. However, cellular modems require a service charge [4]. As a result, when constructing wireless communication system, the property and environment of the jobsites and project need to be considered.

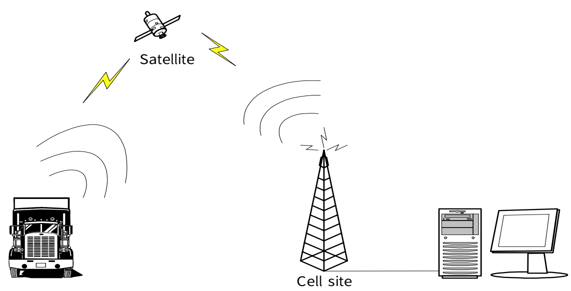

Figure 1. Wireless communication system

(Global positioning system)

3.2 Applied area

Wireless communication systems are used on many jobsites for different areas. Figure 1 shows the architecture of a Global Positioning System (GPS). The GPS is used to keep tracking of construction equipment deliveries in the office [5]. Another example of that wireless communication system is the construction of a sulfur recovery unit (SRU). The foreman of each of crews has access to the wireless communication system to inform the manager of the following information: (1) requests for information (RFI's), (2) materials management, (3) jobsite record keeping and quality control/quality assurance [4]. Each of areas has its own system's architecture which fits best to particular jobsite. The fitness of each system depends on its wireless communication unit. For example, the piezoresistive accelerometer is integrated with the wireless sensing unit for structural monitoring. This system applies the wireless sensing unit with a microelectromechanical system to transfer the data in real time for monitoring [6]. It uses the strength of wireless communication systems for a sensing unit. It can transfer data in real time and it has no service fee. Measurement requires frequent and continuous observation. Often, only recording the history is necessary but in many cases the current measured data must acted upon immediately. For this reason the wireless communication improved piezoresistive accelerometer measurement. Mass concrete curing temperature control is also a measurement exercise that requires a real time data transfer system. This paper proposes an applicable wireless communication system for mass concrete construction.

4. WIRELESS DATA ACQUISITION SYSTEM

Wireless data acquisition system is an enhanced curing management system, ensuring greater jobsite more comfort and quality. The system consists of thermal sensors, data-logger, sending and receiving RF (Radio Frequency) modems and a personal computer to show and check the received data. The RF modem system does not require any service fee and can be used without any legal restrictions. Being as small and light as possible, it is easy to set up and remove.

4.1 Thermometer sensors

Ordinary thermal sensors are listed in table 1. The T-type thermocouple, that has no major complications when applied in many fields, is the most commonly used type of thermal sensor in the fields. However, it comes at a high price.

Considering those properties, a thermal sensitive resister was selected for the wireless data acquisition system. The thermal sensitive resister is physically similar to the T-type thermocouple and is relatively inexpensive. Its measurable temperature range was -30~100°C (error range ± 1°C) and the resistance was 15kΩ. Considering mass concrete's heat of hydration and outside air temperature in cold weather, the thermal sensitive resister was the best choice for measuring the curing temperature.

4.2 Data-loggers and wireless RF modems

One data-logger can receive data through 8 channels at the same time. This makes the curing temperature measurement from different points possible. Also, the measurement period was set to every 1 minute to receive temperature data frequently. Every minute, the RF (Radio Frequency) modem must receive and send data in both directions so that it can first check whether data are received or sent rather than display the data on the monitor. The thermometer sensor connector, which connects to the data logger, was made to set up at once for convenience.

Table 1. Types and properties of thermometers

Type		Usable temperature range(°C)	Div.	Response time	Record/ Control	Cost
Glass Thermometer		-50 ~ 650	0.1 ~ 2	Normal	Not available	Low
Bimetal Thermometer		-50 ~ 500	0.5 ~ 5	Slow	available	Low
Liquid filled Thermometer		-30 ~ 600	0.5 ~ 5	Normal	available	Low
Vapour gas filled Thermometer		-20 ~ 350	0.5 ~ 5	Normal	available	Low
Platinum resistance Thermometer		-260 ~ 1000	0.01 ~ 5	Normal	available	High
Thermally Sensitive Resister		-50 ~ 350	0.3 ~ 5	Fast	available	Average
Thermo-couple	R(PR)	-200 ~ 1200	0.5 ~ 5	Fast	available	High
	K(CA)	-200 ~ 800	0.2 ~ 10	Fast	available	Average
	E(CRC)	-200 ~ 800	3 ~ 5	Fast	available	Average
	J(IC)	-200 ~ 800	3 ~ 10	Fast	available	Average
	T(CC)	-200 ~ 350	2 ~ 5	Fast	available	Average

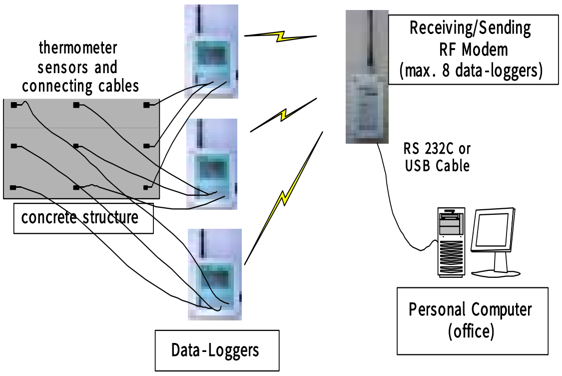

Figure 2. The composition of wireless data acquisition system

4.3 Monitoring

The data, received through the RF modem, are transferred to the personal computer in the office through the RS-232C cable. The data is displayed on the monitor in real time, allowing supervisions to check the thermal condition of the mass concrete and take any necessary immediate action.

5. APPLICATION

5.1 Description of case

The applied mat foundation was the lower part of a foundation that included the elevator pit. The section's depth was about 2.0m~2.5m and the consecutive concreting floor area reached 1200㎡. This huge structure raised concern about cracking due to temperature differences that occurs from hydration heat as time goes by. The daily mean air temperature was between 20ºC ~ 25ºC. Although this air temperature was comparatively high, a high temperature difference between the interior and exterior surface was expected. Therefore a hydration heat analysis program was used to analyze hydration heat and stress. The analysis result showed that the highest temperature in the core of the structure would be 70ºC. Through this analysis, the curing objective was made to keep the temperature difference between interior and outside surface no more than 25ºC. Appropriate mixes of concrete and surface warming planning were provided.

Before concreting the structure, thermometer sensors (thermister) for the wireless data acquisition system were buried to observe the temperature change. Those sensors were buried in the mat foundation's slab at the depth of the upper steel, central and lower steel in three sections. Center, left and right corners.

Figure 3 shows how the data logger and RF modem were installed in the field. The RF modem was installed outside the office window and was connected to the personal computer through an RS-232C cable. The data logger was banded to the exposed steel of the concreted mat foundation's slab structure. The distance between the RF modem and data logger was nearly 300m in a straight line.

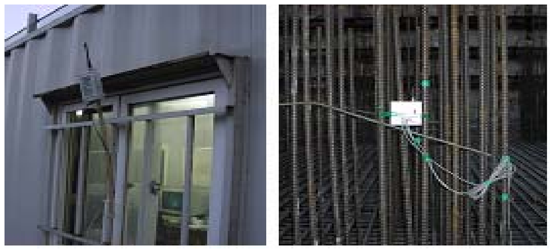

Figure 3. Installation of RF modem and data logger

5.2 Results of application

Figures 4 and 5 show the curing temperature history over time. Generally, the wireless data acquisition system measured the concrete slab's temperature well.

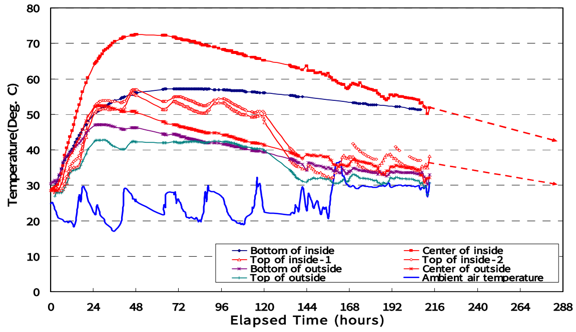

Figure 4. Temperature history output using wireless data acquisition system (1)

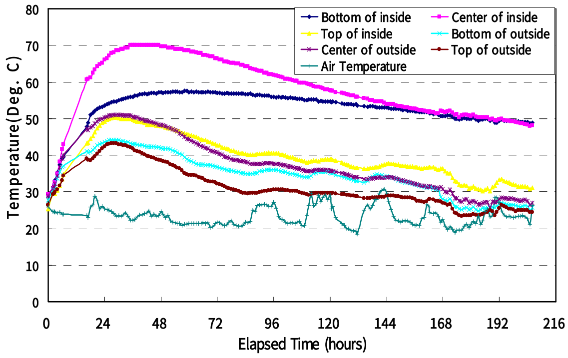

Figure 5. Temperature history output using wireless data acquisition system (2)

As shown in figure 4, by the time of between 120~144 hours, the temperature of the outside surface in the center of the structure had rapidly dropped. This was the case when rain flowed in through the curing mat and waterproof cloth. The structure surface was cooled down by the rain. Fortunately, this situation could be observed in real time through the wireless data acquisition system. Immediate action was taken to stop the cooling. Accordingly, a rapid decrease of temperature was stopped and the proper curing temperature was maintained.

The dotted line in figure 4 shows the expected temperature history. The expected curing temperature means that the temperature difference between interior and outside surface of the structure will not be greater than 25°C. This estimation resulted in form stripping at 9 days, which was an appropriate time span. The wireless data acquisition system made not only the measurement of the curing temperature ideal, but also the estimation for proper form stripping time possible.

5.3 Validation

The purpose of validation was to verify the promptness and continuity during measuring and saving the changing temperature data. The validation approach was executed with the placed mass concrete in the field. To compare the temperature history, an inspected automatic recording thermo-hygrograph was used. For this test, a thermister-type thermometer sensor was applied to the wireless data acquisition system and a thermocouple to the automatic recording thermo-hygrograph.
The test result is shown in figures 6 and 7. It exhibits the measured temperature history of the mass concrete over time.

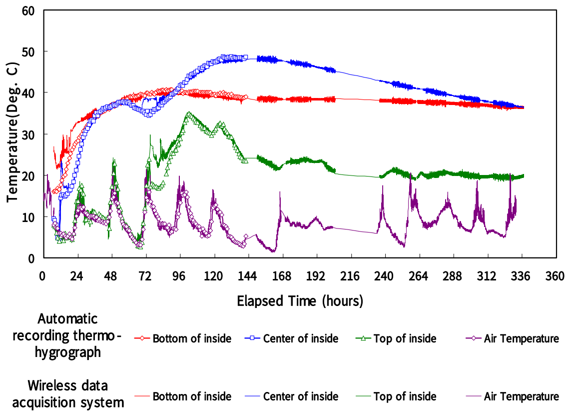

Figure 6. Comparison between automatic recording thermo-hygrograph and wireless data acquisition system (1)

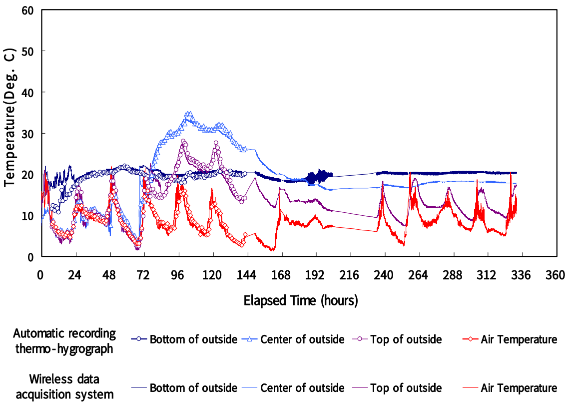

Figure 7. Comparison between automatic recording thermo-hygrograph and wireless data acquisition system (2)

As shown in figures 6 and 7, when both systems' thermometer sensors are buried in the corresponding position, the measured temperature history almost matched each other, regardless of the sensor type or data output method. However, the wireless data acquisition system had a tendency to show occasional discontinuity.
The experiment revealed concerns for the future. During the test, the wireless data acquisition system was powered through the field's power supply; however the power supply in the field is often unstable. Moreover, there are also a possibility that a jamming can occur during the frequent measurement and disturb the transmission between receiving and sending RF modem and data loggers. These need to be observed and corrected in the future.
Through the validation process the promptness and continuity of measuring and saving the steady stream of curing temperature data have been proven. This proven system has been applied in an actual construction site, where mat foundation concreting of a high-rise building was in process, and hereby the applicability to a real situation has been validated.

6. DISCUSSION

Placed mass concrete creates high hydration heat. This high hydration heat results in curing temperature differences between the interior and the exterior surface of the structure and leads finally to cracking. Also a sudden air temperature changes influence the structure's surface temperature. This is one of the critical points in curing mass concrete structures. Currently used automatic recording thermo-hygrograph observations are difficult in real time on a minute basis, rendering immediate action difficult should any problem arise. This makes the curing process useless and inadequate. The purpose of this paper seeks to compensate for this inadequacy by presenting wireless data acquisition system to obtain the curing temperature of newly placed mass concrete in real-time and properly control curing temperature differences in the structure.
The wireless data acquisition system solved this problem by using an RF modem and the data-logger for observing the curing temperature data in real time in the office. This system was validated and applied in an actual construction field successfully. Moreover, the temperature history of this system compared with the automatic recording thermo-hygrograph, did not show a significant difference. The advantage when using the wireless data acquisition system was that any temperature change could be observed in real time, resulting in immediate effective timely action. This is the critical point of the wireless data acquisition system.
Furthermore, the wireless data acquisition system predicted a proper form stripping time. The form stripping time is the most influencing point in shortening the construction duration. The sensors,

buried in 9 points of the structure, measure the curing temperature and transfer the data to a personal computer and display the temperature change on the monitor in graph form. The displayed graph makes the estimation of form stripping time possible, which is difficult with an automatic recording thermo-hygrograph, as it does not measure the curing temperature or display the output in that manner.
The wireless data acquisition system’s multi-point measuring sensors make curing control and analysis possible. Moreover, the wireless communication’s application enables convenient observation of the curing temperature history, providing a better working environment. Finally, this system improves the quality management of mass concrete structures.

7. CONCLUSION

In this paper a wireless data acquisition system was successfully applied in practice. Currently, a mass concrete structure’s curing temperature measurement is executed by automatic recording thermo-hygrographs. However, this tool exhibited problems in real time observation. To overcome this limitation, an improved measuring method is presented to avoid cracking in the mass concrete structure. The wireless data acquisition system’s critical feature is its real time data transmission. As the curing temperature may change at any time for any reason, the wireless data acquisition system improved the curing method by applying a wireless communication system. Furthermore, this system shows the possibility of application in managing the quality of a mass concrete structure. Further research is recommended to cure and manage the quality of the mass concrete.

REFERENCES

[1] A. M. Neville, *Properties of Concrete*, Longman, 1995.

[2] ACI Committee 207, Mass Concrete, *American Concrete Institute*, Michigan, 1996.

[3] Jung SG et al., *Construction Material*, Bosunggak, 1995.

[4] Jesus M. de la Garza, Ivan Howitt, Wireless communication and computing at the construction jobsite, *Automation in Construction*, Vol. 7, pp. 327-347, 1998.

[5] Amr. Oloufa, Masaaki Ikeda, Hiroshi Oda, Situation awareness of construction equipment using GPS, wireless and web technologies, *Automation in Construction*, Vol. 12, pp. 737-748, 2003.

[6] Jerom P. Lynch, Aaron Partridge, Kincho H. Law, Thomas W. Kenny, Anne S. Kiremidjian, and Ed Carryer, Design of Piezoresistive MEMS-Based Accelerometer for Integration with Wireless Sensing Unit for Structural Monitoring, *Journal of Aerospace Engineering*, ASCE, Vol. 7 No. 3, pp. 108-114, 2003.

[7] Kim HR, Yoon SC, Jee NY, "A Rational Curing Management Process for Cold Weather Concreting", *Some Fine Journal of the Architectural Institute of Korea*, Vol. 19 No. 10, pp. 51-58, 2003.

[8] ACI Committee 207, Effect of restraint, volume change, and reinforcement on cracking of mass concrete, *American Concrete Institute*, Michigan, 1995.

[9] Eduardo M.R. Fairbairn, Marcos M. Silvoso, Romildo D. Toledo Filho, José L.D. Alves, Nelson F.F. Ebecken, Optimization of mass concrete construction using genetic algorithms, *Computers & Structures*, Vol. 82, pp. 281-299, 2004.

[10] Steven B. Chase, High-Tech Inspection, *Civil Engineering*, ABI/INFORM Global, Vol. 71 No. 9, pp. 62-65, 2001.

[11] Charles K. Nmai, Cold Weather Concreting Admixtures, *Cement and Concrete Composites*, Vol. 20 No. 2-3, pp. 121-128, 1998.

[12] Bofang Zhu, Effect of Cooling by Water Flowing in Nonmetal Pipes Embedded in Mass Concrete, *Journal of Construction Engineering and Management*, ASCE, Vol. 125 No. 1, pp. 61-68, 1999.

[13] Yong Wu, Ronaldo Luna, Numerical implementation of temperature and creep in mass concrete, *Finite Elements in Analysis and Design*, Vol. 37, pp. 97-106, 2001.