S15-2

TEMPERATURE CONTROL AND COMPRESSIVE STRENGTH ASSESSMENT OF IN-PLACE CONCRETE STRUCTURES USING THE WIRELESS TEMPERATURE MEASURING SYSTEM BASED ON THE UBIQUITOUS SENSOR NETWORK

Ho Kyoo JO[1], Hyung Rae KIM[2], Tae Koo KIM[3]

[1] Principal Research Engineer, Hyundai Engineering & Construction Corporation, Korea
[2] Ph.D., Senior Research Engineer, Hyundai Engineering & Construction Corporation, Korea
[3] Vice President, Hyundai Engineering & Construction Corporation, Korea
Correspond to hr6460@hdec.co.kr

ABSTRACT: The temperature control of in-place concrete is the most important factor for an early age of curing concrete. Heat stress of mass concrete caused by the heat of hydration can induce the crack of concrete, and a frost damage from cold weather casting concrete results defect on compressive strength and degradation of durability. Therefore, success and failure of concrete work is dependant on the measurement and control of concrete temperature. In addition, the compressive strength assessment of in-place concrete obtained from the maturity calculated from the history of temperature make a reduction of construction cycle time, possible. For that purpose, wireless temperature measuring system was developed to control temperature and assess strength of concrete. And, it was possible to monitor the temperature of concrete over 1km apart from site office and to take a proper measure; mesh-type network was developed for wireless sensor. Furthermore, curing control system that contains the program capable to calculate the maturity of concrete from the history of temperature and to assess the compressive strength of concrete was established. In this study, organization and practical method of developed curing control system are presented; base on in-place application case.

Keywords: Quality Control of Concrete, Temperature of Concrete, Wireless Temperature Measurement System

1. INTRODUCTION

Temperature control of concrete at early age of concrete is the most important factor, in order to protect concrete from crack and to get the necessary strength at specified stages. Especially, inner temperature of concrete should be controlled with the tolerable difference of temperature between center and surface. And the concrete should be cured by the insulation or heating before the frost damage.
Recently, temperature measurement of concrete structures become important, in order to predict the concrete strength of structures, because the temperature history of concrete structures is not same with that of specimen in case of thick element and high strength concrete
The existing method for measuring the temperature of concrete structures was the wire type using in-place installed data-logger. In spite of that, it was hardly used in building construction site, because of the difficulty on controlling.
But, the recent development in domestic IT (information technology) industry made wireless system possible to be applied in construction site in the field of physical distribution and control of resources. And a lot of study on the application of IT to the temperature measurement and concrete curing has been in progress.
By the way, the existing wireless measurement system had contained a limitation of efficient distance to send and receive and barrier for applying entirely. So, a study for resolving the problems has been advanced. A wireless measurement system applying the sensor network method has been developed, which can be applied under the condition of barrier and long distance.
In this study, the application case of the established system was introduced, and utilization method for predicting the strength of concrete structures was considered.

2. RFID AND USN[1)]

2.1 RFID (Radio Frequency Identification)

RFID is a field of automation identification technology with a reader, function to send and receive using wireless communication. RFID uses tags attached to object or material to gather, save and trace information in order to provide services such as trace location, remote control, management, exchange of information.
RFID solved the problems from bar-code and magnetic recognition equipment method, and by the convenience of use, change of production method, change of consumer's recognition and advance of culture and technology, it may bring out the innovation in the artificial intelligence network of a physical distribution, and in the field of security, safety and environmental management

RFID system is composed of reader, antenna for send and receive of data, tag for save and exchange of data, and internet server.

2.2 Sensor Tag and USN (Ubiquitous Sensor Network)

Sensor Tag is positive type of RFID Tag which adds the sensor for acquisition of external environmental information and film battery for supplication of power to existing passive type of RFID Tag. It is consisted of Tag chip, Antenna, Sensor, and film battery.

USN is information management method which investigates necessary information by means of Sensor Tag and connects with network at the same time.

The core technology for realization of USN is WSN (Wireless Sensor Network) technology, which connects network with a lot of sensor by wireless method.

The most representative technology in the field of USN is Zigbee, local area network technology. Zigbee has good electric power efficiency so that may maintain the lifetime for several months with only two AA-battery, and is possible to consist sensor network of 10~10,000 numbers.

3. CONSTRUCTION OF WIRELESS TEMPERATURE MEASURING SYSTEM

3.1 Development of wireless measuring system

The original concept of send and receive of wireless temperature measurement system is shown in figure 1, which is composed of data logger (convert measured data from concrete), receiver (data receiving end), and site office computer. Wireless data send and receive (communication) method adopted one on one transmitting and receiving (communication) between data logger's RF modem and RF modem at receiver.

Also, in order to evaluate the accuracy of measured data from the developed wireless temperature measurement system, field test was executed shown in figure 2 and achieved almost same measured data as shown in figure 4. In addition, measured data from original system, shown

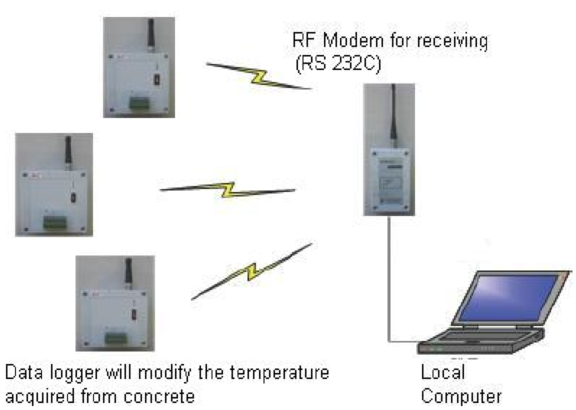

Figure 1 The original concept of send and receive (communication) of wireless temperature measurement system

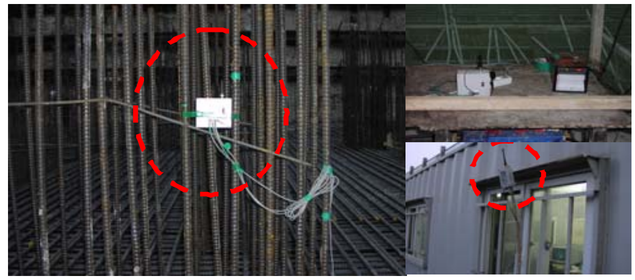

Figure 2 Site application for evaluating the accuracy of measured data by the developed original wireless system

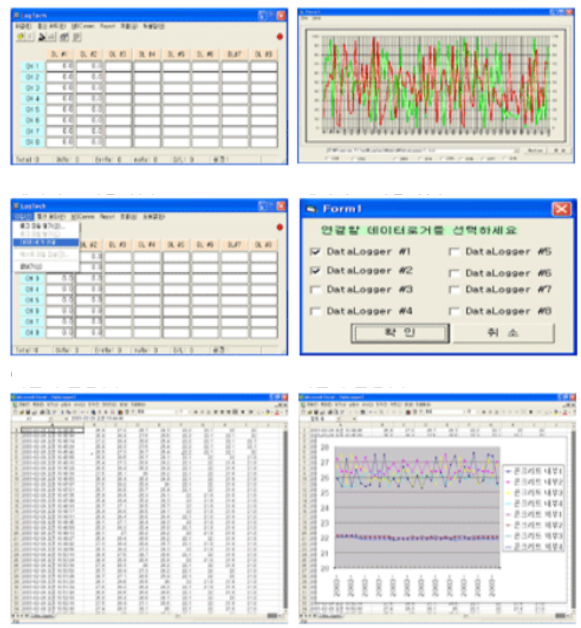

Figure 3 PC monitor output by original system

in figure 3, were saved in text file format and in order to use real time measured data on monitoring changes of temperature, the text file format were converted to excel file to make graphs shown in figure 4 and figure 5. Especially, analyzing the graph of figure 4 and figure 5, discontinuity of temperature measurement data, dotted line, can be found after certain period of time when concrete are cast in place.

Discontinuity of measurement data is caused by interference from external factors such as radio frequency interference and/or insufficient supply of power. With 10 minute data measuring interval, 85% of measured data from the data logger were received and if system were not able to receive data for 1 day or more, system should have been rebooted.

Because discontinuity of data measurement was caused by distance from data transmission end to reception end and obstacles; to complement the problem the sensor networking method was reviewed.

Sensor networking method shown in Figure 6 allows networking between the data loggers in mesh shaped module and also in same time each data logger are able to transmit data one on one with site office receiver by Zigbree RF module.

As a result, using relay communication module between measuring data logger and receiver, several kilometer of long distance data communication were made possible.

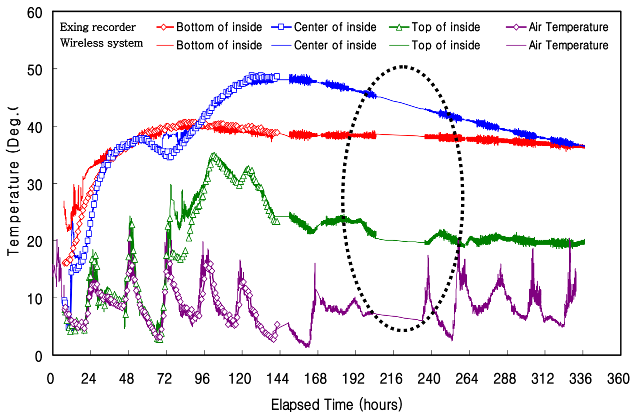

Figure 4 Comparison of temperature history converted from the text file format

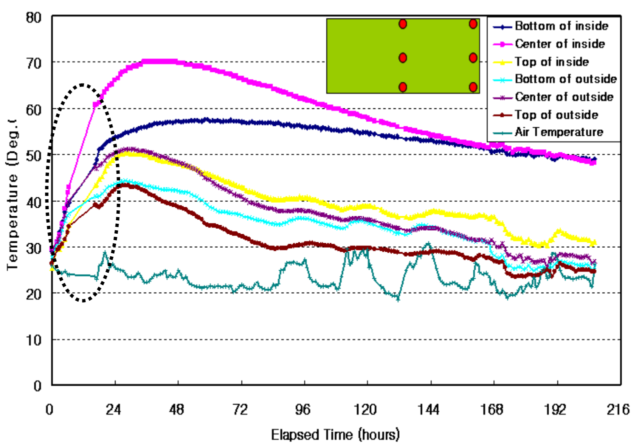

Figure 5 Temperature measurement result by original system

Figure 7 is the send and receive result by sensor networking method, and with 10 minute measuring interval 100 percent of measured data were achieved.

3.2 Construction of concrete curing management system

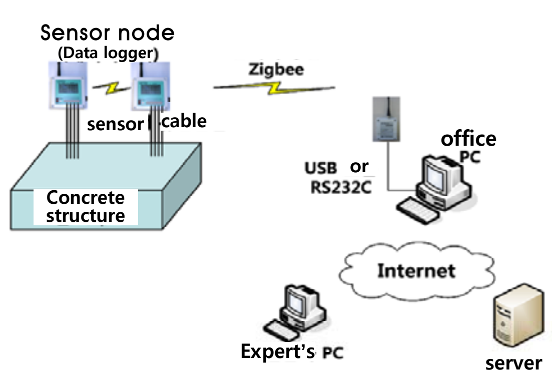

Figure 6 Composition of system by sensor networking method between the data loggers in mesh shaped module

3.2.1 Composition of system

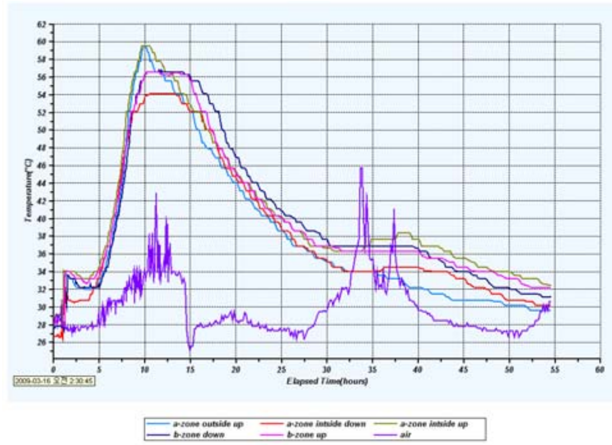

Figure 7 Send and receive result by sensor networking method

Through the development process, practical field concrete curing management system are comprised of 5 steps: temperature sensor, sensor node, Zigbee RF module, PC monitor output and saving temperature record, and saving and sharing data using internet server.

(1) Temperature Sensor

Generally, in lavatory Thermo-couple (T-Type) are used to measure temperature because of broad measurement range and accuracy, but because of high cost, applying them in construction field are difficult. Therefore system uses Thermister (resistance value 15kΩ) which can measure from -30 to 100℃ in range of ± 1℃. Even though Thermister's physical characteristics are similar to Thermo-couple, the costs are lower and also appropriate to the temperature condition for concrete's heat of hydration and South Korea outside winter temperature condition,

(2) Sensor Node (Data logger)

One sensor node can measure temperature data up to 8 channel in same time, temperature data passed from signal filter (include constant voltage end to operate temperature sensor and filter circuit for noise deduction) to analog-digital converter(microprocessor) and to internal storage device in same time are transmitted to the site office computer. Power board is controlled by user to set the operating time, which will minimize the power consumption of storage battery.

(3) Zigbee RF Module

Using Zigbee RF module the measured data are configured to communicate between field office PC (or gate-way), and with near data loggers. Not like original wireless system, Zigbee communication method is excellent technology for short distance networking system that can be used in home, and office with low cost, low speed and low power consumption. Zigbee RF module have low data transfer rate but with network flexibility, expandable capability and low power consumption, battery could last more than a year.

(4) PC monitor output and saving temperature record

Data received by Zigbee communication module are connected to computer in site office by RS232C cable, and by using curing management program. Change in concrete temperature is outputted to monitor screen in real time, which makes worker possible to immediately make response when unusual signs are detected.

(5) Saving and sharing data using internet server
Measured data from field are not only automatically saved in personal PC by real time, but also when configured(under coordinated condition) the measured data can be saved in internet based server, therefore measuring data from curing concrete can be shared between field, head quarter, and experts or consultants, which allows problem consulting and solution in real-time base.

3.2.2 Utilization of system
Structure concrete curing management process shown in figure 8 is using concrete compressive strength of real time measured data from curing management system using wireless sensor network.
Before the concrete cast, temperature sensors are first placed in points where temperature should be measured and then they are connected to data loggers to start measuring temperature. As the concrete are casted in place temperature are measured and recorded in real time, the data are transmitted and saved to site office computer and internet server automatically and also outputted into computer monitor screen so that data are shared with head office to get support from concrete expert.
Field quality manager, in real time, can manage and predict development of concrete strength, by monitoring the concrete temperature and also considering the change of outside temperature environment. By the result of this process, manager can decide the situation of concrete to give extra curing period or to start or delay next construction process.

4. STRENGTH ASSESSMENT OF IN-PLACE CONCRETE

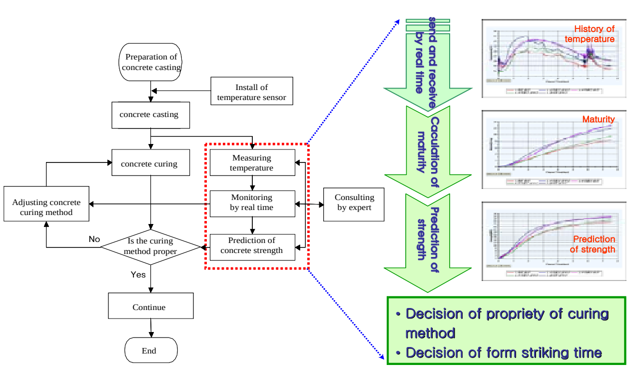

Figure 8 Flow of concrete curing management by the constructed wireless temperature measurement

The assessment of in-place strength of concrete in structures is to decide on the formwork stripping times of slabs and beams. A number of techniques are available for determining stripping times. Among them, the maturity method of concrete is described as the method for estimating in-place concrete strength.
The criteria for removal of horizontal forms are specified from the result of structural calculation by engineer.

4.1 Criteria for removal of slab forms

Although the contractor is generally responsible for design, construction, and safety of formwork, criteria for removal of forms or shores should be specified by engineer or architect. (ACI 347.04)
Determination of the time of form removal should be based on the resulting effect on the concrete. When forms are stripped there should be no excessive deflection or distortion and no evidence of damage to the concrete due to either removal of support or stripping operation.
In case of applying the aluminum formwork of the remained props type, it may be possible to use shorter periods before stripping formwork by determining the strength of the concrete in the structural element. Formwork supporting cast in-place concrete in flexure may be struck when the strength of concrete in the element is 10MPa or twice the stress to which it will be subjected, whichever is the greater, provided that the stripping at this time will not result in unacceptable deflection. (BS 8110-1)

4.2 Verification method of field concrete strength

Minimum strength of the concrete for removal of forms can be determined by tests on job-cured specimens or on in-place concrete. Other concrete tests or procedures (refer to ACI 228.1R) can be used such as the maturity method, rebound numbers, penetration resistance, or pullout tests, but these methods should be correlated to the actual concrete mixture used in the project.

4.2.1 Strength at early ages of cylinder cured alongside
Cylinder specimens are made from samples of the concrete used for the structures, and they are cured in conditions as near as possible to those in the structure. This is normally achieved by laying the specimens alongside or on top of the structure.
The gain in strength of concrete at a given point in a structure is not only a function of the concrete and the ambient conditions, but also a function of the size and shape of a section and the insulating effectiveness of the formwork. Cylinders cured alongside generally have lower maturity than concrete in structure.

4.2.2 Estimation of the concrete strength by the maturity method
The maturity of cylinder cured alongside is different from that of concrete in structure. Especially, the method using cylinder cured alongside is less appropriate with the high strength concrete in hot weather condition where the difference in maturity between cylinder cured alongside and concrete in structure becomes significant.
The limitation of cylinder cured alongside can be

overcome with cylinders cured by the several insulating method. We can obtain the maturity of cylinder cured alongside and concrete in structure by measuring the temperature. The relation between the strength and the maturity of cylinder made from samples of the concrete used for the structures can be used to estimate the strength of concrete in structure by calculating the maturity from the temperature-time history.
The accuracy of the estimated strength depends on properly determining the maturity function for the particular concrete mixture.

4.2.2.1 Maturity functions (refer to ASTM C 1074)
There are two alternative functions for computing the maturity index from the measured temperature history of the concrete.
One maturity function is used to compute the temperature-time factor as follows:

$$M(t) = \sum (T_a - T_0)\Delta t \qquad (1)$$

Where, $M(t)$ = the temperature-time factor at age t, degree-days
Δt = a time interval, days or hours,
T_a = average concrete temperature during time interval, Δt , ℃
T_0 = datum temperature, -10℃ in this study

From $M(t)$ of Eq. (1), equivalent age at a specified temperature can be computed as follows:

$$T_{es} = \frac{\sum (T_a - T_0)}{(T_r - T_0)} \qquad (2)$$

T_{es} = equivalent age by Nurse-Saul function, days or hours
T_r = standard curing temperature, 20℃
T_a = average concrete temperature during time interval, Δt , ℃
T_0 = datum temperature, -10℃

The other maturity function is used to compute equivalent age at a specified temperature as follows:

$$T_{ea} = \int_0^t \exp\left(\frac{E}{R}\left(\frac{1}{T_s} - \frac{1}{273 + T_a}\right)\right)dt \qquad (3)$$

T_{ea} = equivalent age by Arrhenius Equation, days or hours
T_a = average concrete temperature during time interval, dt , ℃
T_s = 293℃, absolute temperature (K) + 20℃
E = activation energy, in case of OPC (Ordinary Portland Cement)
When $T_a \le 20°C$,

$$E = 33.5 + 1.47(20 - T_a)KJ/mol$$

When $T_a \ge 20°C$,

$$E = 33.5KJ/mol$$

R = gas constant, 8.314 $J/mol°K$

4.2.2.2 Prediction of concrete strength on the basis of concrete maturity
For obtaining the strength and maturity of cylinder cured alongside, at least 15 cylindrical specimens was prepared. Compressive tests at ages 1, 3, 7, 14, and 28 days was performed. Two specimens at each ages was tested and the average strength was computed. If the range of compressive strength of the two specimens exceeded 10% of their average strength, another cylinder was tested and the average of the three tests was computed. When a low test result was due to an obviously defective specimen, the low test result was discarded.
At each test ages, the average maturity for specimen was recorded by the wireless temperature measurement system automatically. And, the average strength as a function of the average value of the maturity was plotted on graph paper by drawing a best-fit curve (bold line) as shown in Figure 9.

4.3 Estimation of maturity and in-place concrete strength on the basis of measured temperature data

Comparison of temperature and maturity of concrete between concrete in structure and specimen cast in place are as shown in Figure 10. The difference of temperature history between concrete in structure and cylinder specimen is significant. And the characteristic of concrete strength development of cylinder specimen and core specimen from the structure shows similar tendency as shown in Figure 10. In addition, the strength of core specimen shows over 85% of that of cylinder specimen.

5. CONCLUSIONS

The concrete curing management system by wireless sensor network method, which was introduced in this study, has been improved and utilized to present a foundation data for decision in case of the curing management through the temperature measurement. In addition, the system can be applied for reduction of concrete structure cycle time in common apartment

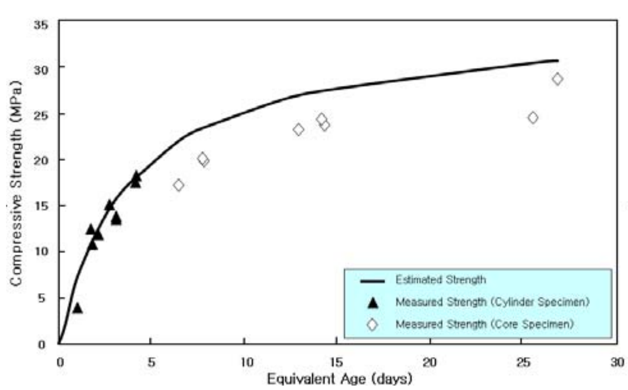

Figure 9 Comparison of the compressive strength by experiment and the prediction by wireless system

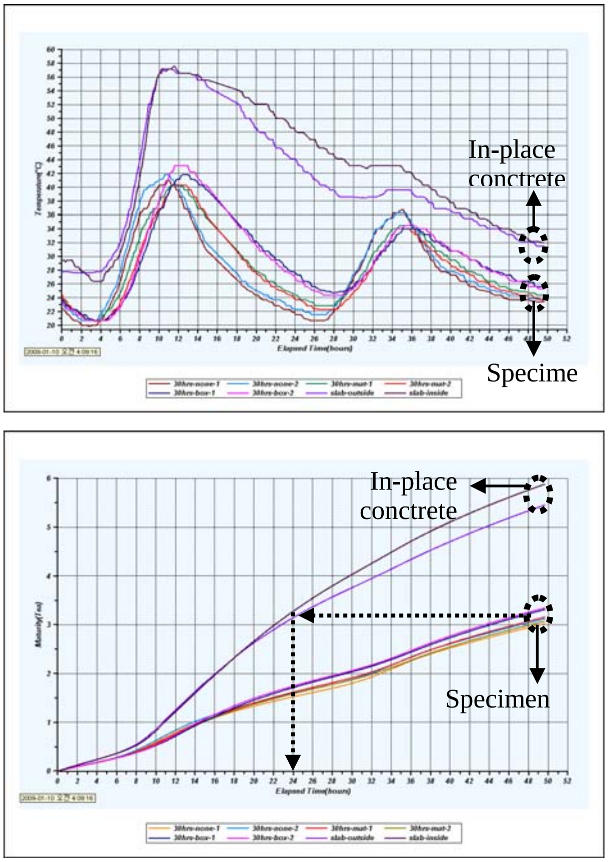

Figure 10 Comparison of temperature and maturity of concrete between structure and specimen cast in place

construction as well as for temperature management of concrete in structure under severe environmental condition.

Hereafter, it is looking forward to advancing to an integrated quality management system, which is able to measure and control the mechanical performance of concrete, in addition to the early age quality control of concrete.

REFERENCES

(1) S. B. Lee, et al., Status of Practical Use and Application of RFID/USN on Construction Site, Housing & Urban Research Institute, 2007

(2) H. R. Kim, et al., A Rational Curing Management Process for Cold Weather Concreting, Structural Journal, Architectural Institute of KOREA, Vol.19, No.10, pp.51~58, 2003.10

(3) ASTM, Standard Practice for Estimating Concrete Strength by the Maturity Method, ASTM C 1074-98

(4) ACI Committee 209, Prediction of Creep, Shrinkage, and Temperature Effects in Concrete Structures, 1992

(5) Usizima Sakae, Prediction of Compressive Strength, Concrete Journal, JCI, Vol.39, No.5, pp.73~77, 2001.5

(6) Freiesleben Hansen, F. P., and E. J. Pedersen, Maturity Computer for Controlled Curing and Hardening of Concrete, Nordisk Betong, Vol.1, p.19, 1977

(7) ACI 347.04, Guide to Formwork for Concrete, America Concrete Institute, 2004

(8) BS 8110-1, Structural use of concrete - Part 1: Code of practice for design and construction, British Standard, 1997

(9) T. A. Harrison, Formwork Striking Times – Methods of Assessment, CIRIA Report 73, CIRIA, 1087