Internal Wave Propagation based Non-destructive NPP Concrete Strength Evaluation Method using an Embedded Piezoelectric Sensor

Junkyeong Kim, Seunghee Park, and Ju-Won Kim

Abstract**—** Recently, demands for the construction of Nuclear Power Plants(NPP) using high strength concrete (HSC) has been increased. However, HSC might be susceptible to brittle fracture if the curing process is inadequate. To prevent unexpected collapse during and after the construction of HSC structures, it is essential to confirm the strength development of HSC during the curing process. However, several traditional strength-measuring methods are not effective and practical. In this study, a novel method to estimate the strength development of HSC based on internal harmonic wave measurements using an embedded piezoelectric sensor is proposed. The amplitude of propagated harmonic wave along the concrete media was tracked to monitor the strength development of NPP concrete. In addition, the strength estimation equation was derived using regression method. The results confirmed that the proposed technique can be applied successfully monitoring of the strength development during the curing process of HSC structures.

Keywords**—** Concrete Curing, Embedded Piezoelectric Sensor, Harmonic wave, High Strength Concrete, Nuclear Power Plant

I. Introduction

RECENTLY, there has been increasing demand for Nuclear Power Plants(NPP) to satisfy increasing electric demands. Therefore, there is a need for high strength concrete (HSC) with a low W/C ratio and high compressive strength for construction NPP structures. However, the HSC might be susceptible to brittle fracture if the curing process is inadequate. Therefore, to prevent this, it is essential to predict the strength development of HSC during the curing process. In addition, monitoring of the curing strength is important for reducing the construction time and cost because it can determine the appropriate curing time to achieve sufficient strength to progress to the next phase safely. The in situ strength of concrete structures can be determined with high precision by performing strength testing and material analysis on core samples removed from the structure [1]. However, this method can destroy the concrete structure. Therefore, a range of methods based on the thermal, acoustical, electrical, magnetic, optical, radiographic, and mechanical properties of the test materials have been developed to monitor the strength development without damaging the host structure [2]-[4]. These methods typically measure certain properties of concrete from which the strength and/or elastic constants can be estimated. Among the many techniques, methods using Schmidt hammer or maturity temperature are normally used. However, these methods are hard to apply solely to the construction site because the estimation accuracy of these methods is low.

The recent advent of smart materials, particularly piezoelectric materials, can provide a solution for the real-time monitoring for strength development. Ultrasonic wave based methods are a kind of NDT method using piezoelectric materials. The ultrasonic wave signals will be changed by the change of physical properties of propagated media. Using this, the concrete strength variation, especially the change of Young's modulus, can be monitored[5]-[7]. In this study, the internal harmonic wave based concrete strength estimation technique using novel embedded piezoelectric sensor have been verified through experimental study.

II. Embedded Piezoelectric Sensor

The novel embedded piezoelectric sensor is developed to measure internal wave signal of concrete. The embedded piezoelectric sensor consists of PZT which is commonly used piezoelectric sensor and semi-spherical type styrene form to protect the PZT. The inside of styrene form is hollow structure to make the one side PZT can be maintain free boundary condition. The embedded piezoelectric sensor can use not only as a actuator but also as a sensor because of its piezoelectricity. The internal harmonic wave is generated from PZT sensor at one side and propagated to the PZT at other side. The distance between two sensor is fixed at 16cm using steel wire.

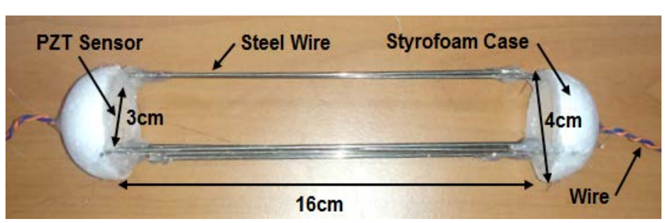

Fig. 1 (a) Embedded Piezoelectric Sensor

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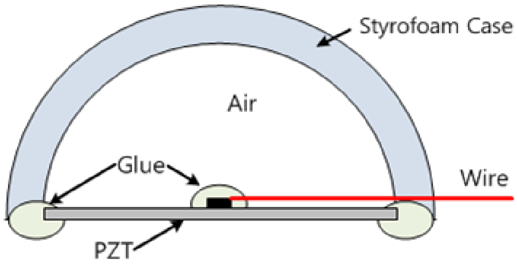

Fig. 1 (b) Scheme of Embedded Piezoelectric Sensor

III. Concrete Strength Estimation using Internal Harmonic Wave Propagation

The concrete is one of the cementitious material that has the adhesive and cohesive properties necessary to bond inert aggregates into a solid mass of adequate strength and durability. After casting, the concrete media gradually stiffens until the hydration stops. The physical properties of concrete, especially the strength is dramatically changed during this curing process. The Young's Modulus(E) is the most affecting factor that change not only the strength of concrete but also harmonic wave propagation amplitude.

The harmonic wave propagation in the concrete media using embedded piezoelectric sensor can be idealized as one-dimensional longitudinal wave propagation[5]. The wave equation of longitudinal wave is

$$\frac{\partial^2 u}{\partial x^2} = \frac{1}{c_b^2}\frac{\partial^2 u}{\partial t^2} \quad (c_b^2 = E/\rho)$$

where the u is the displacement of an element and ρ is the density of material.

The average of power p of harmonic response over a period can be expressed as

$$p = \frac{EA^2\omega^2}{2c_b} = \frac{\sqrt{E\rho}A^2\omega^2}{2}$$

$$A = \frac{1}{\omega}\left(\frac{4p^2}{E\rho}\right)^{\frac{1}{4}}$$

where A is the harmonic amplitude, and ω is the angular frequency[8]. Hence, the strength of concrete can be estimated by measure the amplitude of harmonic wave propagation through concrete media.

IV. Experimental Study

A. Experimental Setup And Test Procedure

The Mix proportion of NPP concrete is shown in Table Ⅰ. The specimen was developed by isothermal air curing. The NI-PXI 1042Q was used for measure the internal harmonic wave propagation using embedded piezoelectric sensor.

The harmonic wave signal was measured each hours after casting and the actually strength was measured at 16, 25, 38, 51, 75, 99 , 530, 674 hours after casting by destructive test using cylindrical specimen to compare with wave signals.

TABLE I

Mix Proportion of NPP Concrete

Mix Proportion(Design Strength 55MPa)					
Water	Cement	S/F	Sand	Glavel	AE
155	433	22.8	737	941	0.45

TABLE Ⅱ

Mesured Compressive Strength

Curing Age(Hour)	16	25	38	51	75	99	530	674
Compressive Strength (MPa)	10	14	19	23	26	29	50	53

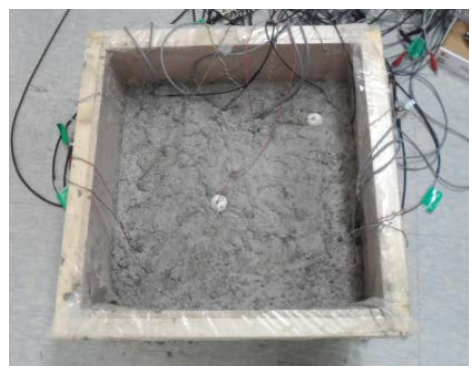

Fig. 2 (a) Test Specimen

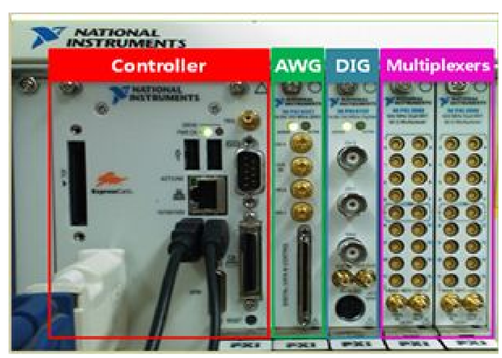

Fig. 2 (b) NI-DAQ System

B. Harmonic Wave Variations Due To Curing Process

Fig.3 shows the variations of harmonic wave signals due to curing process. The curing age is getting older, the amplitude of internal harmonic wave is getting lower. Because the amplitude of harmonic response is in inverse proportion to the Young's modulus that increase according to the curing process, the experimental results are consistent with the theory.

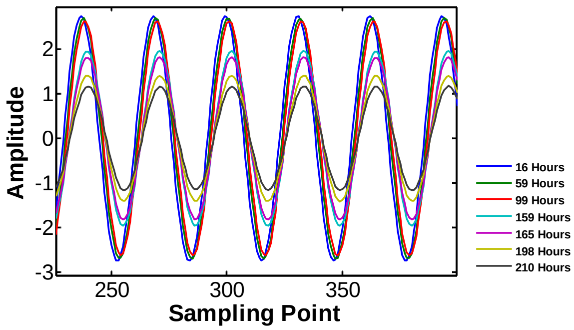

Fig. 3 Harmonic Wave Signal Variation

To find the relationship between the amplitude of harmonic wave and the strength of host specimen, the regression method are utilized. Fig.4 shows the relationship between the measured amplitude and measured compressive strength. The strength can be estimated according to the regression result.

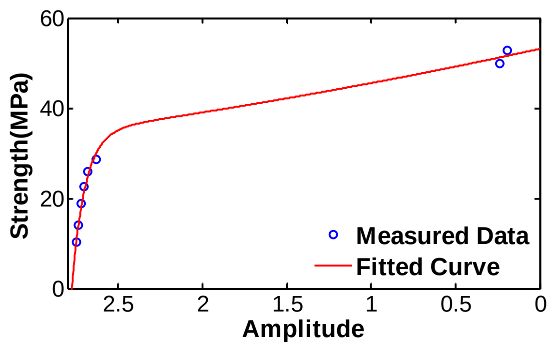

Fig. 4 Relationship Between Harmonic Amplitude And Strength

Fig.5 shows the measured strength and estimated strength using regression equation.

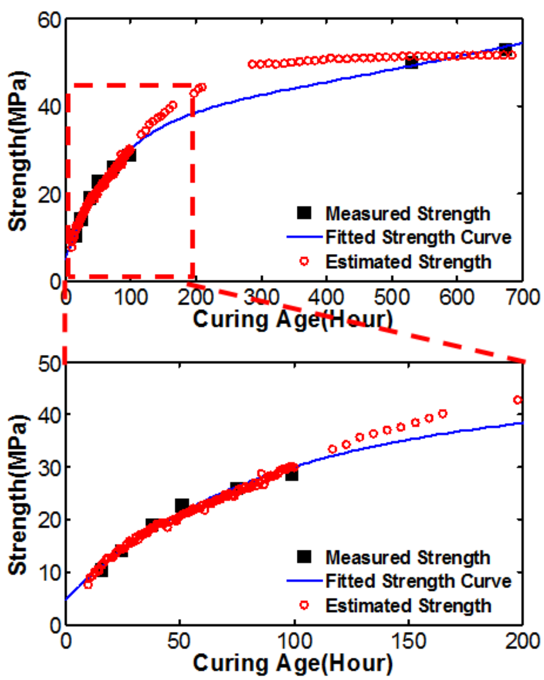

Fig. 5 Comparison of measured and estimated strength

The result show that the estimation equation calculated equivalent strength with measured strength under 30MPa. However over the 30MPa the estimation has some difference with actual strength. It considered as that caused by the minimum amplitude of specimen. The early-age strength (commonly under 10MPA) is important to manage the concrete construction process in construction site. Hence proposed concrete strength estimation method can provide meaningful information to manage the construction.

V. Conclusion

This study evaluated the application of embedded piezoelectric sensors for monitoring the strength development of NPP concrete. The applicability of the conventional ultrasonic wave measuring technique, which is normally used to detect damage, was extended to monitor the curing process of concrete. The harmonic wave signals were measured during curing process and the actual compressive strength was measured using UTM. Based on the experimental results, the amplitude of harmonic becomes weak with increasing curing time, which confirms the applicability of harmonic wave measurements using embedded piezoelectric sensor to monitor the strength development of concrete. In addition, to estimate the strength of concrete, the estimation equation was derived by regression method. The estimation equation can provide equivalent strength under 30MPa.

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