Compressive Strength Evaluation of Underwater Concrete Structures Integrating the Combination of Rebound Hardness and Ultrasonic Pulse Velocity Methods with Artificial Neural Networks

Seunghee Park, Junkyeong Kim, Eun-Seok Shin, Sang-Hun Han

Abstract**—**In this study, two kinds of nondestructive evaluation (NDE) techniques (rebound hardness and ultrasonic pulse velocity methods) are investigated for the effective maintenance of underwater concrete structures. A new methodology to estimate the underwater concrete strengths more effectively, named "artificial neural network (ANN) – based concrete strength estimation with the combination of rebound hardness and ultrasonic pulse velocity methods" is proposed and verified throughout a series of experimental works.

Keywords**—**Underwater Concrete, Rebound Hardness, Schmidt hammer, Ultrasonic Pulse Velocity, Ultrasonic Sensor, Artificial Neural Networks, ANN.

I. Introduction

As the earth's current global warming has caused elevation of sea water temperature, size of storms is foreseen to increase and consequently large damages on port facilities are to be expected. In addition, due to the improved processing efficiency of port cargo volume and increasing necessity for construction of eco-friendly port, demands for various forms of port facilities are anticipated [1]. Especially, in recent years, new methodologies to evaluate the soundness of underwater concrete structures always exposed to extreme environmental attacks are being strongly required. In this context, this study aims to verify usability of ultrasonic flaw detector and Schmidt hammer for concrete structure non-destructive testing in order to achieve cost reduction and safety enhancement by means of efficient maintenance of smart green harbor system [2], [3].

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II. Theoretical Backgrounds

A. Rebound Hardness-Based Concrete Material Property Evaluation

Among the available non-destructive methods, the Schmidt Hammer test is the most commonly used one in practice. It has been used world-wide as an index test for a testing equipment to estimate strength of concrete due to its rapidity and easiness in execution, simplicity, portability, low cost and non-destructiveness. The test is classified as a hardness test and based on the principle that the rebound of an elastic mass depends on the hardness of the surface against which the mass impinges. The energy absorbed by the concrete is related to its strength. Despite its apparent simplicity, the rebound hammer test involves complex problems of impact and the associated stress-wave propagation. The test method starts by the careful selection and preparation of the concrete surface to be tested and a fixed amount of energy is applied by pushing the hammer against the test surface. The plunger must be allowed to strike perpendicularly to the surface, as the angle of inclination of the hammer affects the results. After impact, the rebound number should be recorded by taking at least 10 readings from each tested area. Although there is no unique relation between hardness and strength of concrete, experimental data relationships can be obtained from given specimens [4].

B. Ultrasonic Pulse Velocity-Based Concrete Material Property Evaluation

This is one of the most commonly used method in which the ultrasonic pulses generated by electro-acoustical transducer are transmitted through the concrete. In solids, the particles can oscillate along the direction of sound propagation as longitudinal waves or the oscillations can be perpendicular to the direction of sound waves as transverse waves. When the pulse is induced into the concrete from a transducer, it undergoes multiple reflections at the boundaries of the different material phases within the concrete. A complex system of stress waves is developed which includes longitudinal (Compressional), shear (Transverse) and surface (Rayleigh) waves. This transducers convert electrical signals into mechanical vibrations (transmit mode) and mechanical vibration into electrical signals (receive mode). The travel time is measured with an accuracy of +/-0.1 microseconds. Transducers with natural frequencies between 20 kHz and 200 kHz are available, but 50 kHz to 100 kHz transducers are common [5].

C. Artificial Neural Network Information Technology

ANN (Artificial Neural Network) is a data processing pattern which is stimulated same as the biological nervous systems like brain processing the data. Main component of this stimulation is the new structure of the data processing system. A neural network is composed of many interconnected elements which are termed as neurons and these work in unison in order to solve particular problems. An artificial neural network is configured for particular application like data classification or pattern recognition, through a learning method. Generally, ANN learns by an example. In biological systems learning entails adjustments to synaptic association which exists among the neuron; this is similar in ANNs too. In other words, ANN is a massive network connected in parallel distributed processes which has a natural tendency for storing investigational knowledge and making this knowledge available to use. It is similar to brain in two aspects i.e. knowledge is obtained by a network by learning a method and the knowledge is stored through interconnection strengths named as synaptic weights [6].

III. Experiment Study

A. Making Underwater Equipments

1. Schmidt Hammer

The conventional Schmidt hammer, as shown in Fig. 1, is typically used in the field to measure the strength of the concrete structure. To use the Schmidt hammer under the water, casing is required. Although there are a lot of underwater divisions of marine and harbor facilities, the number of instruments that can measure the strength of underwater concrete structure has been almost none. For such reason, a waterproof case fitting to the land Schmidt hammer was manufactured to conduct the non-destructive testing under the water. Fig. 3 demonstrated the design process of the waterproof case. As presented in Fig. 2, the conventional land Schmidt hammer was covered with the underwater case to be used under water.

Fig. 1Schmidt hammer before waterproof

Fig. 2 Schmidt hammer after waterproof

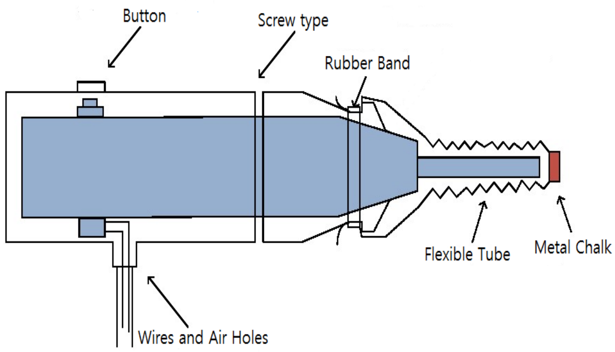


Fig.3 Design drawing that Schmidt hammer's underwater case

2. Ultrasonic Pulse Velocity Machine

As presented in Fig. 4, the head of conventional ultrasonic sensor which is used in general field is connected in BNC cable and thus cannot be used under water. Hence, in order to be applied to underwater environment, the head of conventional ultrasonic sensor was directly connected with cable and was waterproofed by the urethane form, and then was reclaimed. Fig. 5 displays the ultrasonic sensor after reclamation.

Fig. 4 Ultrasonic Sensor before waterproof

Fig. 5 Ultrasonic Sensor after waterproof

B. Making Concrete Specimen

The combination strengths of the concrete specimens used in this experiment were 25, 28, 32, 35, 37, 40, 44 and 48 Mpa and the concrete surface was cured under a general air. The ambient room temperature of laboratory was maintained at 25°C, and the test specimens size manufactured plywood was 50x40x20(cm^3). This study was carried out on the 28th day of specimen age [7].

C. Rebound Hardness Test

The Schmidt hammer, DIGI SCHMIDT (ND) of Proceq Inc., Switzerland was used and the room temperature of laboratory at the time of measurement was 25°C. Besides, according to the operation pattern of the rebound hardness method, specimens were produced in a way to retain thickness of more than 10cm and measurement point was determined at the position that was more than 10cm away from the end of specimen. Owing to the limit of specimen size, they were intensively gathered in 1cm interval. After more than 80 times of strike, values more than ± 20% biased from average value were discarded and the rest values remained for further analysis.

Fig. 6 Rebound Hardness Test in under water condition

D. Ultrasonic Pulse Velocity Test

The ultrasonic tester, TICO of Proceq Inc., Switzerland was utilized and the excitation frequency of the probe was 54 kHz. In addition, before the testing, the ultrasonic tester was verified by a calibrator to reduce error rate and a room temperature of the laboratory at the time of the measurement was 25°C.

Measurement was conducted by indirect method with distance of 200mm between ultrasonic probes. After two times of measurements, to reduce error rate, the average of the two measured values was set as an ultrasonic speed and then 80 ultrasonic speeds were obtained [7].

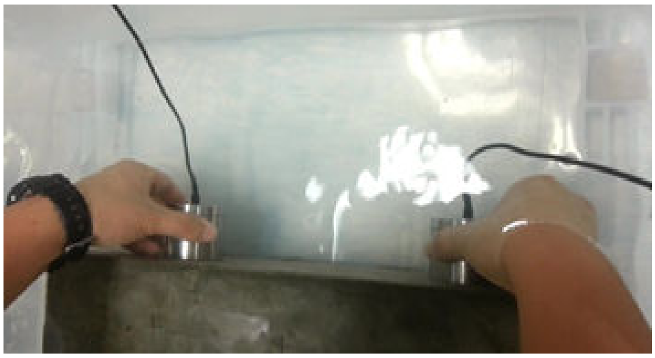


Fig. 7 Ultrasonic pulse velocity test in under water condition

IV. Applying ANN-Based Concrete Strength Estimation Technique

Table I describes the compressive strength values according to 8 kinds of concrete mix designs and corresponding rebound hardness and ultrasonic pulse velocity values that were utilized for ANN-based pattern learning process in this study. Table II shows the compressive strengths in the water test according to different concrete mix designs, and 14 out of the 20 samples were used for "test" and other 6 samples were used for the verification for ANN-based concrete strength estimation, as shown in Table III. Fig. 8 shows a comparison between real compressive strength values and the compressive strength values obtained from ANN-based pattern classification using the 14 test samples. Also, Fig. 9 shows the ANN-based concrete strength estimation results using 6 verification samples. As shown in Figs. 8 and 9, it is noted that the R-values above than 0.97 were obtained from both test and validation simulations.

TABLE I
TRAINING PATTERNS FOR ANN-LEARNING OF CONCRETE STRENGTH ESTIMATION

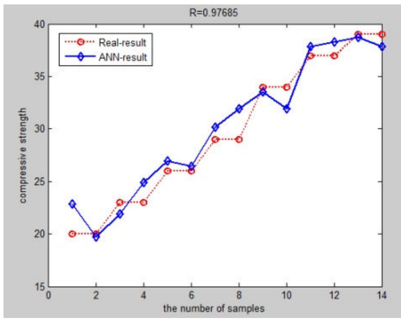
Strength(Mpa)	W(kg/m^3)	C(kg/m^3)	S(kg/m^3)
20	17.6	32.9	78.5
20	18.7	35.4	78.2
23	16.2	34.3	76.0
23	17.5	36.2	75.6
26	16.9	38.1	73.2
26	18.4	42.6	73.0
29	16.7	41.8	71.9
29	17.6	43.9	71.5
34	16.8	46.7	67.8
34	16.5	51.6	67.2
37	18.4	54.1	65.3
37	18.8	53.6	64.2
39	17.6	55.9	64.5
39	17.1	56.2	66.5
G(kg/m^3)	Slump(cm)	R	Vp(m/s)
97	12.55	8.1	3880
91.9	18.32	7.9	3890
101	8.94	11.8	3995
97.5	12.86	10.9	3925
99.4	10.36	15.5	4110
92.3	18.29	14.9	4090
99.3	10.34	19.3	4220
94.7	15.88	20.2	4180
98.5	10.66	25.5	4500
91.2	18.31	24.7	4460
90.4	18.65	29.3	4610
90.1	18.24	28.5	4680
92.1	15.22	32.2	4710
92.7	15.86	31.6	4760

TABLE II
TESTING PATTERNS ACCORDING TO DIFFERENT CONCRETE MIX DESIGNS

Strength(Mpa)	W(kg/m^3)	C(kg/m^3)	S(kg/m^3)
25	17.3	37.9	74.1
28	16.5	40.1	72.3
32	15.8	44.8	71.5
35	17.3	43.1	67.9
37	18.7	52.8	64.4
40	17.4	55.3	65.0
44	17.1	57.8	66.7
48	19.4	58.9	68.1
G(kg/m^3)	Slump(cm)	R	Vp(m/s)
96.2	11.97	12.7	3994
98.8	12.44	18.2	4170
94.3	11.02	20.7	4080
91.1	13.28	19.2	4410
90.8	15.92	23.5	4285
91.7	14.76	28.7	4505
98.8	14.58	27.6	4764
94.2	16.12	33.8	4800

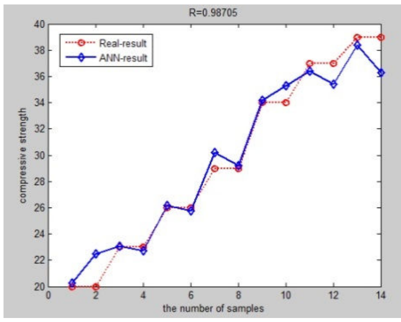
TABLE III
VERIFICATION PATTERNS FOR ANN-BASED CONCRETE STRENGTH ESTIMATION

Strength(Mpa)	W(kg/m^3)	C(kg/m^3)	S(kg/m^3)
21	16.2	32.5	77.8
25	17.5	40.3	70.8
28	15.8	37.8	72.3
32	16.7	43.9	69.8
33	17.5	42.6	71.2
38	17.9	53.8	62.3
G(kg/m^3)	Slump(cm)	R	Vp(m/s)
103.8	5.33	9.3	3950
97.6	12.83	12.2	4050
103.2	5.96	16.9	4230
98.7	11.55	22.3	4360
101.3	9.62	24.1	4410
89.2	13.45	31.7	4700



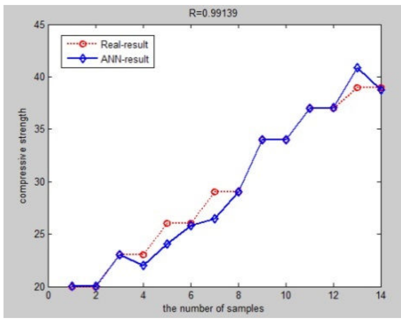
R=0.976

Fig. 8 (a) Simulation result of ANN on testing pattern



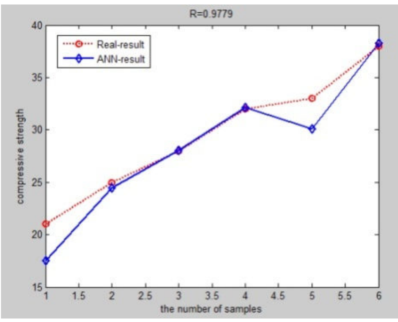
R=0.987

Fig. 8 (b)Simulation result of ANN on testing pattern



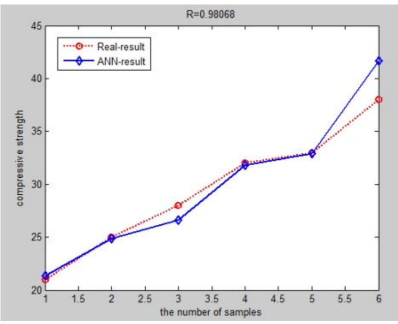
R=0.991

Fig. 8 (c)Simulation result of ANN on testing pattern



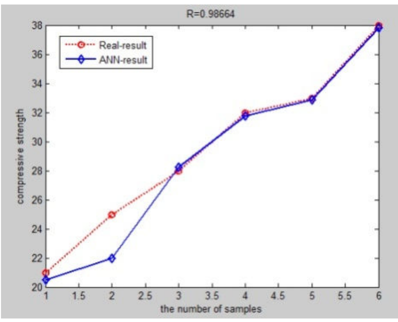
R=0.977

Fig. 9 (a)Simulation result of ANN on verification pattern



R=0.980

Fig. 9 (b)Simulation result of ANN on verification pattern



R=0.986

Fig. 9 (c)Simulation result of ANN on verification pattern

V.Conclusion

This study proposed a new methodology to estimate the underwater concrete strengths more effectively, named "artificial neural network (ANN)–based concrete strength estimation technique with the combination of rebound hardness and ultrasonic pulse velocity methods". In order to verify the feasibility of the proposed approach, a series of experimental studies have been carried out and from these experiments, the following conclusions have been obtained.

1) ANN-based concrete compressive strength estimator was established from the laboratory tests combining rebound hardness and ultrasonic pulse velocity methods for 8 different kinds of concrete specimens.
2) 14 out of the 20 samples were used for "test" and other 6 samples were used for the verification for ANN-based concrete strength estimation, conclusively, it was confirmed that the proposed approach can be very effectively utilized for evaluating the soundness of underwater concrete structures always exposed to extreme environmental attacks.

Acknowledgment

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References

[1] J. H. Yi, S. H. Han and W. S. Park."Nondestructive Testing for Concrete Harbor Facilities," Journal of the Korea Institute for Structural Maintenance Inspection, Korea, (2011).
[2] A P Smith, "Underwater nondestructive testing of concrete: an evaluation of technique," Port Hueneme, Calif.: Naval Civil Engineering Laboratory, (1986).
[3] S. J. Park and J. K. Kang, "A Study on the Evaluation of Concrete Strength at Early Age for Field Application Using Ultrasonic Velocity and Rebound Test Method," Architectural Institute of Korea, (2008).
[4] F Aydin, M Saribiyik, "Correlation between Schmidt Hammer and destructive compressions testing for concretes in existing buildings," Scientific Research and Essays, 2010M.A. Green: High Efficiency Silicon Solar Cells (Trans Tech Publications, Switzerland 1987).
[5] IS: 13311 (Part 1): Non-destructive Testing of Concrete – Methods of Test , Part 1 Ultrasonic Pulse Velocity, BIS, New Delhi, (1992).
[6] Information on The UK's expert provider of custom essays Home Page,http://www.ukessays.com/essays/information-technology/historical-background-of-neural-networks-information-technology-essay.php.
[7] J. E.Yoo, S. C. Park, M. S. Kim and Y. W. Kwon, "A New Strength Equation of Concrete by Ultrasonic Pulse Velocity Test," Conference of Korea Concrete Institute,(2004).