

Soundness Evaluation of Underwater Concrete Structures based on the Combination of Rebound Hardness and Ultrasonic Pulse Velocity Methods

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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 (see Fig.1).



Fig.1(a)

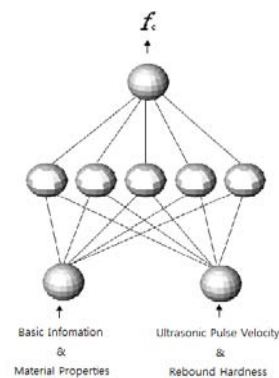


Fig.1 (b)

(a) Proposed NDE Techniques (b) ANN-based Concrete Strength Estimation
Fig. 1 Artificial Neural Network (ANN)-based Concrete Strength Estimation with the Combination of Rebound Hardness and Ultrasonic Pulse Velocity Methods

1. 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 harbour system. [2, 3]

2. Theoretical Backgrounds

2.1 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 rebound hammer test is described in ASTM C805(1993), BS 1881: Part 202 (1986) and TS 3260 (1978). 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 (ACI, 1994). Despite its apparent simplicity, the rebound hammer test involves complex problems of impact and the associated stress-wave propagation (Akashi and Amasaki, 1984). 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 (TS 3260, 1978). Although there is no unique relation between hardness and strength of concrete, experimental data relationships can be obtained from given specimens. [4]

2.2 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]

2.3 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]

3. Experiment Study

3.1 Making Underwater Equipments

3.1.1 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 port 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. 1 Schmidt hammer before waterproof



Fig. 2 Schmidt hammer after waterproof

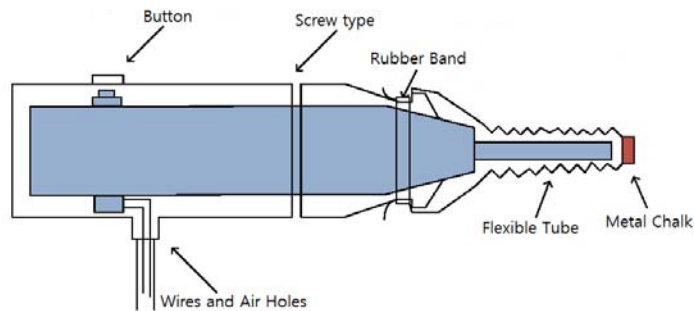


Fig. 3 Design drawing that Schmidt hammer's underwater case

3.1.2 Ultrasonic pulse velocity machine

As presented in Fig. 4, the head of conventional ultrasonic probe 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 probe was directly connected with cable and was waterproofed by the urethane form, and then was reclaimed. Fig. 5 displays the ultrasonic probe after reclamation.



Fig. 4 Ultrasonic Sensor before waterproof



Fig. 5 Ultrasonic Sensor after waterproof

3.2 Making Concrete Specimens

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 50*40*20(cm³). This study was carried out on the 28th day of specimen age. [8]

3.3 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 10 cm away from the end of specimen.

Owing to the limit of specimen size, they were intensively gathered in 1 cm interval. After more than 80 times of strike, values more than $\pm 20\%$ biased from average value were discarded and the rest values remained for further analysis.



Fig. 6 Rebound Hardness Test in under water condition

3.4 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. [8]



Fig. 7 Ultrasonic pulse velocity test in under water condition

3.5 Applying ANN-based Concrete Strength Estimation Technique

Table 1 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 2 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 3. 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.

Table1. Training Patterns for ANN-learning of concrete strength estimation

Compressive Strength (Mpa)	Water (kg/m ³)	Cement (kg/m ³)	Sand (kg/m ³)	Gravels (kg/m ³)	Slump (cm)	Rebound Hardness	Ultrasonic Pulse Velocity (m/s)
25	17.3	37.9	741	96.2	11.97	12.712	3994
28	16.5	40.1	723	98.8	12.44	18.299	4170
32	15.8	44.8	715	94.3	11.02	20.725	4080
35	17.3	43.1	679	91.1	13.28	19.221	4410
37	18.7	52.8	644	90.8	15.92	23.548	4285
40	17.4	55.3	650	91.7	14.76	28.798	4505
44	17.1	57.8	667	98.8	14.58	27.693	4764
48	19.4	58.9	681	94.2	16.12	33.887	4800

Table2. Testing Patterns according to different concrete mix designs

Compressive Strength (Mpa)	Water (kg/m ³)	Cement (kg/m ³)	Sand (kg/m ³)	Gravels (kg/m ³)	Slump (cm)	Rebound Hardness	Ultrasonic Pulse Velocity (m/s)
20	17.6	32.9	785	97	12.55	8.035	3880
20	18.7	35.4	782	91.9	18.32	7.968	3890
23	16.2	34.3	760	101	8.94	11.845	3995
23	17.5	36.2	756	97.5	12.86	10.995	3925
26	16.9	38.1	732	99.4	10.36	15.522	4110
26	18.4	42.6	730	92.3	18.29	14.922	4090
29	16.7	41.8	719	99.3	10.34	19.339	4220
29	17.6	43.9	715	94.7	15.88	20.225	4180
34	16.8	46.7	678	98.5	10.66	25.556	4500
34	16.5	51.6	672	91.2	18.31	24.779	4460
37	18.4	54.1	653	90.4	18.65	29.366	4610
37	18.8	53.6	642	90.1	18.24	28.592	4680
39	17.6	55.9	645	92.1	15.22	32.292	4710
39	17.1	56.2	665	92.7	15.86	31.668	4760

Table3. Verification Patterns for ANN-based concrete strength estimation

Compressive Strength (Mpa)	Water (kg/m ³)	Cement (kg/m ³)	Sand (kg/m ³)	Gravels (kg/m ³)	Slump (cm)	Rebound Hardness	Ultrasonic Pulse Velocity (m/s)
21	16.2	32.5	778	103.8	5.33	9.302	3950
25	17.5	40.3	708	97.6	12.83	12.221	4050
28	15.8	37.8	723	103.2	5.96	16.988	4230
32	16.7	43.9	698	98.7	11.55	22.33	4360
33	17.5	42.6	712	101.3	9.62	24.11	4410
38	17.9	53.8	623	89.2	13.45	31.75	4700

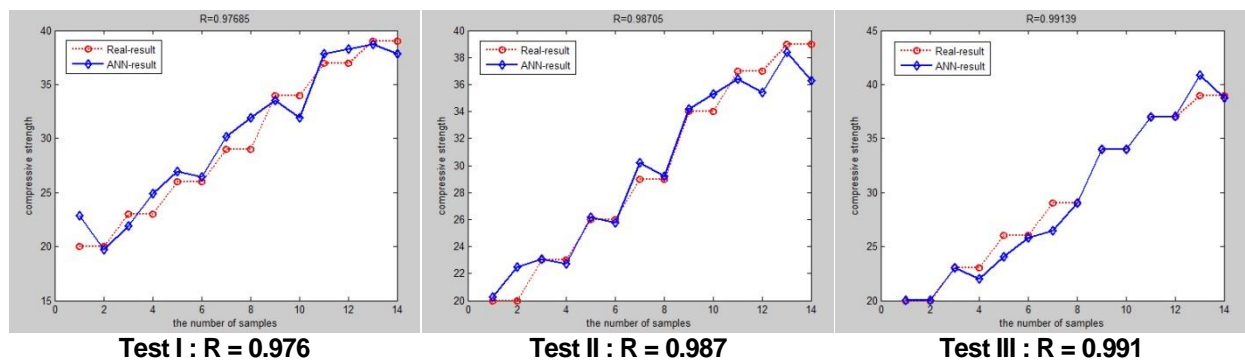


Fig. 8 Simulation result of ANN on testing pattern

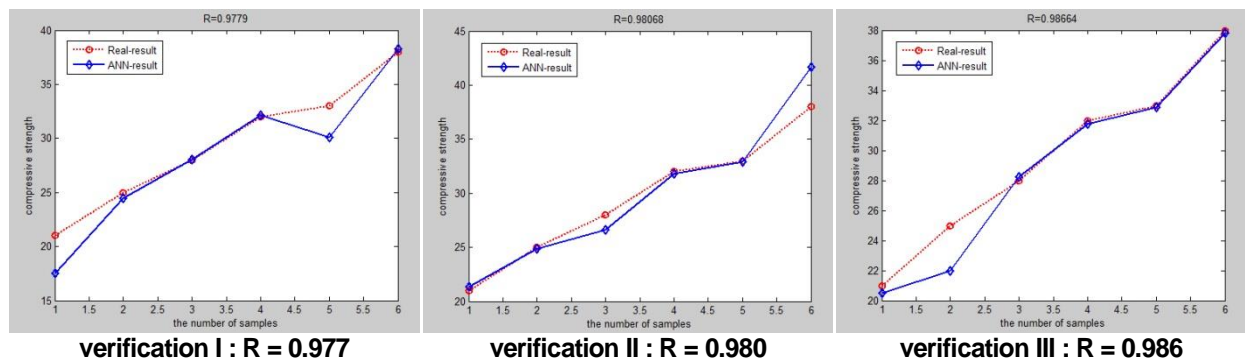


Fig. 9 Simulation result of ANN on verification pattern

4. 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.

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