

**EVALUATION OF REPAIR QUALITY FOR CONCRETE STRUCTURE BY
NONDESTRUCTIVE TECHNIQUE**

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ABSTRACT

The objective of the proposed research project is to develop a nondestructive test technique based on stress wave for quantitative evaluation of the repairing status of concrete. Concrete structures frequently exist various types of cracks due to an inferior environment and excessive loading. There are several crack repairing technique used in concrete construction. Epoxy-injection is popular maintenance method in crack repairing of the damaged concrete structure. In this paper, a technique based on the stress wave was used to evaluate the repair quality of concrete crack. Numerical simulation is also under research and results show that the stress wave propagation is capable of identifying the infill of epoxy-injection in the crack of repaired structures. The new technique under development has a high potential for evaluation of the quality of the repaired cracks.

Keywords: Evaluation of repair quality, Stress wave, Non-destructive testing(NDT)

1. INTRODUCTION

Concrete structures frequently exist various types of cracks due to an inferior environment and excessive loading. To assure the safety and the carrying capacity, a structural reinforcement work of it is requested. The cracks of concrete structure are an important indicator for the structure health diagnosis. The repairing method which injects Epoxy resin into the crack of concrete members is relatively simple and cost-effective, increases the strength of existing concrete members, blocks moisture penetration of reinforced concrete members and reduces the chance of corrosion.

2. TIME-OF-FLIGHT DIFFRACTION TECHNIQUE

To measure the depth of surface-opening cracks in concrete[1], two receivers are used and located on the opposite sides of the crack. FIGURE 1 shows the instrument arrangement. The first receiver is located on the impact side and has a distance

H_0 to the impact point. The second receiver is located on the opposite side of the crack. FIGURE1 (b) and (c) show typical waveforms recorded at the first and second receivers, respectively. After impact, the R-wave arrival at the first receiver will trigger the monitoring system. If the arrival time, t_1 , and the speed, C_R , of R-wave are known, the time of impact initiation can be calculated as $(t_1 - H_0/C_R)$. The value of t_1 is negative because a pre-trigger mode is used in recording signals to avoid losing important information. The region behind the crack cannot be penetrated by waves generated by impact until diffraction at the crack tip occurs. Thus, the second receiver initially responds to the arrival of the diffracted P-wave. The arrival time, t_2 , of the diffracted P-wave can be obtained by identifying the initial disturbance in the waveform recorded at the second receiver. Thus, the shortest travel time for P-wave from the impact point to the second receiver can be obtained as equation (1). Knowing the P-wave speed, C_P , in concrete, the shortest travel length of P-wave from the impact point to the second receiver can be calculated as $C_P \times \Delta t$. If the distances from the crack to the impact point and the second receiver are H_1 and H_2 respectively, the depth, d , of the vertical surface-opening crack can be determined by the equation (2)

$$\Delta t = t_2 - (t_1 - H_0/C_R) = t_2 - t_1 + H_0/C_R \quad (1)$$

$$d = \sqrt{\left[\frac{(C_P \times \Delta t)^2 + H_1^2 - H_2^2}{2 \times C_P \times \Delta t} \right]^2 - H_1^2} \quad (2)$$

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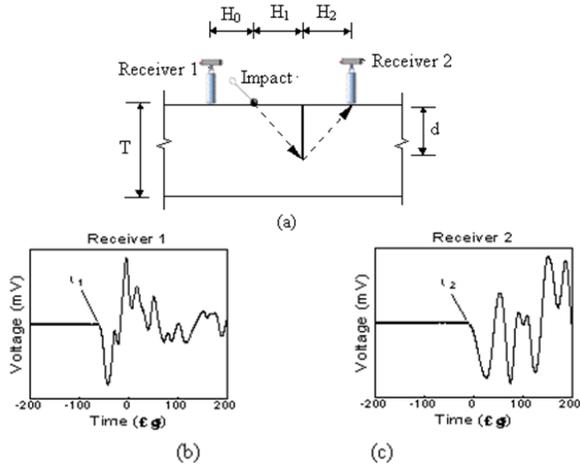


FIGURE 1: TEST SCHEME: (A) INSTRUMENT ARRANGEMENT; (B) WAVEFORM 1; (C) WAVEFORM 2.

3. NUMERICAL SIMULATION WITH DIFFERENT PARTLY FILLED SCENARIOS OF REPAIRED CONDITION

Numerical simulations of the stress wave responses of crack were carried out using the explicit finite-element program LS-DYNA. All cases are simulated using 2-D axial-symmetric, 4-node elements, and isotropic models. Concrete is modeled as an isotropic material with a Poisson's ratio 0.2 and a density 2300kg/m^3 . A Young's modulus (E) of 33.1 GPa is chosen to provide a P-wave speed of 4000 m/s [1], the material parameters of epoxy resin and air used in the numerical simulation are also shown in TABLE 1. The time-history of nodal vertical displacements were recorded every $1.334\ \mu\text{s}$, and 1024 data were recorded in each simulation.

TABLE 1: MATERIAL PARAMETERS OF THE NUMERICAL SIMULATION[1]

Material	Wave speed C_p (m/s)	Density (kg/m^3)	Elastic modulus (pa)	Acoustic Impedance Z_p ($C_p \cdot \rho$)
Air	340	1.2	-	408
Epoxy Resin	2400	1141	5.602E9	2738400
Concrete	4000	2300	33.10E9	9200000

3.1 Numerical simulation of different injection condition of crack repairing

This section examines the stress wave propagation after the epoxy resin material filled in the crack with different partly filled scenarios. In the numerical simulation, the depth of crack is setting to 10 cm and the contact time of force-time function is $20\ \mu\text{s}$ in all cases. The variables of different epoxy resin injection scenarios in numerical simulations are shown in Table 2 and Fig. 2. For all the models, the epoxy is filled from the top surface and the air pack of the crack is underneath the epoxy.

TABLE 2: VARIABLES OF DIFFERENT EPOXY RESIN INJECTION SCENARIOS

Code	Length of Epoxy Resin (cm)	Length of Air (cm)	Remark
E0 cm_A10 cm	0	10	Non- epoxy injection
E2 cm_A8 cm	2	8	Partial epoxy injection
E4cm_A6 cm	4	6	Partial epoxy injection
E6 cm_A4 cm	6	4	Partial epoxy injection
E8 cm_A2 cm	8	2	Partial epoxy injection
E10 cm_A0 cm	10	0	Fully epoxy injection
E0 cm_C10 cm	0	-	Non-crack case

The results of time-history of nodal vertical displacements with the different condition of epoxy resin injection are shown in FIGURE 2. The amplitude of R_{max} in time-history of nodal vertical displacement waveform is used as the parameter for investigation as shown in FIGURE 3. The time-histories of nodal vertical displacements are varied with different scenarios of epoxy resin injection. Table 3 summarizes the maximum displacement of the waveform (R_{max}) for all the cases. The maximum value of nodal vertical displacements (R_{max}) is obtained from the non-crack case. The R_{max} of the non-crack case(E0 cm_C10 cm) from Table 3 can be compared with the fully epoxy injected case(E10 cm_A0 cm), the value of R_{max} attenuation was 11.4%. In addition, the maximum displacement of the R-wave decreases with the decrease of the length of epoxy resin injection.

TABLE 3: MAXIMUM DISPLACEMENT OF WAVEFORM WITH DIFFERENT EPOXY RESIN INJECTION CONDITION

Code	The maximum displacement of a waveform (R_{max}), m	Loss percentage of R_{max} (%) (Base on E0 cm_C10 cm)	Remark
E0 cm_A10 cm	-5.90E-05	72.0	Non- epoxy injection case
E2 cm_A8 cm	-1.09E-04	48.3	Partial epoxy injection case
E4cm_A6 cm	-1.46E-04	30.8	Partial epoxy injection case
E6 cm_A4 cm	-1.76E-04	16.6	Partial epoxy injection case
E8 cm_A2 cm	-1.86E-04	11.8	Partial epoxy injection case
E10 cm_A0 cm	-1.87E-04	11.4	Fully epoxy injection case
E0 cm_C10 cm	-2.11E-04	0.0	Non-crack case

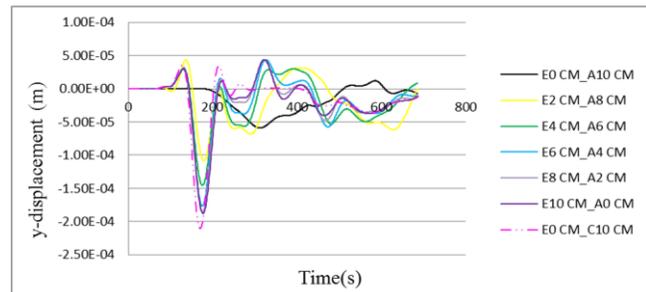


FIGURE 2: TIME-HISTORY OF NODAL VERTICAL DISPLACEMENTS WITH DIFFERENT EPOXY RESIN INJECTION CONDITION

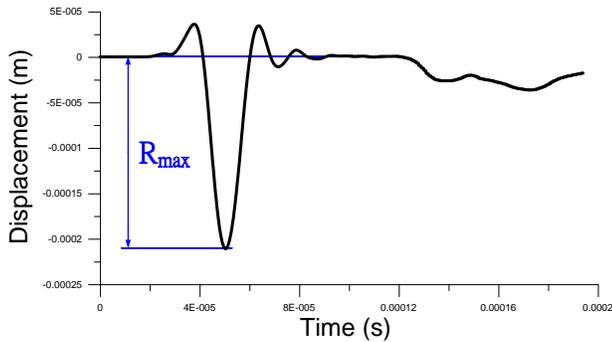


FIGURE 3: THE LENGTH OF R_{max} IN TIME-HISTORY OF NODAL VERTICAL DISPLACEMENT WAVEFORM

3.2 Experimental study on specimen

An experimental study is carried out on specimen with different injection condition of the crack in the laboratory. Laboratory concrete specimens containing vertical surface-opening cracks with 11 cm depth were used in the studies. As shown in FIGURE 4, pictures were represented specimens with fully epoxy injection and non-epoxy injection conditions. Transient stress waves are generated by the impact of a spherical steel ball and captured by the transducer. Surface displacement waveform with fully epoxy resin injection of the concrete specimen was shown as FIGURE 5. Surface displacement waveform with non-epoxy resin injection case was shown as FIGURE 6. Compared with the results of numerical simulation, the results of specimens in the laboratory are very similar.

4. CONCLUSION

Numerical simulation results show that for surface opening crack partially filled by epoxy resin, the maximum displacement of the R-wave can be served as a parameter to evaluate the different injection condition of crack. The maximum displacement of the R-wave decreases with the decrease of the length of epoxy resin in the crack and the same with the results of specimens in the laboratory. The technique has a great potential for evaluation of the repair quality of concrete structural cracks injected by epoxy resin.

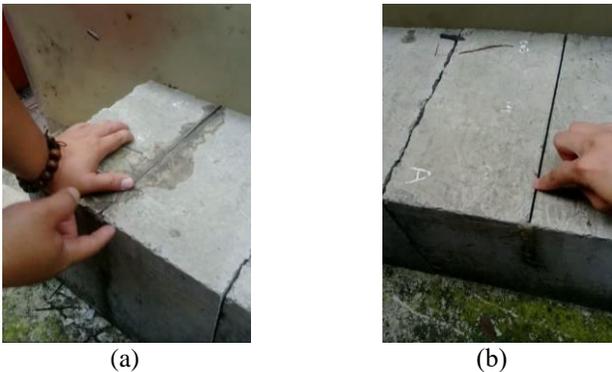


FIGURE 4: PICTURES OF DIFFERENT EPOXY RESIN INJECTION SCENARIOS OF SPECIMENS (A) SPECIMEN WITH

WITH FULLY EPOXY INJECTION CRACK ; (B) SPECIMEN WITH NON-EPOXY INJECTION CRACK

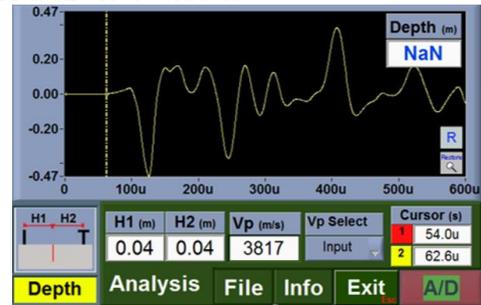


FIGURE 5: SURFACE DISPLACEMENT WAVEFORM WITH FULLY EPOXY RESIN INJECTION OF CONCRETE SPECIMEN

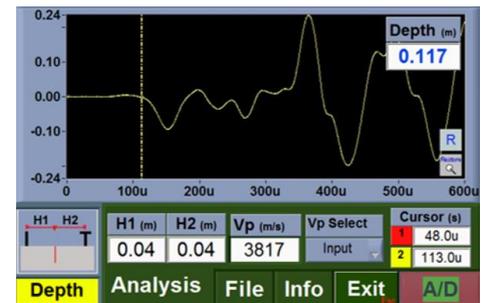


FIGURE 6: SURFACE DISPLACEMENT WAVEFORM WITH NON-EPOXY RESIN INJECTION OF CONCRETE SPECIMEN

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