ACOUSTIC INSPECTION OF BOND STRENGTH BETWEEN MORTAR AND REINFORCEMENT

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INTRODUCTION

Bond degradation has become a common, and sometimes critical problem for aging concrete bridges . Corrosion due to sea water, water pollution, acid rain as well as high salt content in concrete and its composition are threatening the structure integrity. Among the issues related to corrosion prevention and inspection, bond strength is of great concern [1, 2]. The bond strength and fiber pull-out have between fiber and surrounding composite materials have been studied by Cairns and Jones[3], Kim et al. [4] and Naaman et al. [5]. Both bond split and slip are of interests for cement-based matrices and steel reinforcing bars (so called rebar). Current study is part of an investigation aiming to simplify the inspection of corrosion and to improve the analysis of bond strength for steel reinforced concrete structure.

Pull-out tests are frequently used in most experimental work concerning bond strength. However, nondestructive evaluation is often very attractive to on-site inspection. Acoustic measurements, such as impact echo [6] and through transmission [7], have been successfully applied to inspect bridges and dams. Both pull-out tests and through transmission measurements have been performed in current study. Preliminary results demonstrate the relation between pull-out loading force and sound speed can be used to characterize the bond strength between steel rebar and cement-based materials.

SPECIMEN PREPARATION

Four sets of specimens were cast and cured one day in the mold followed by 28 days in water. Each specimen is a 150 mm cube, as specified by ASTM C234-91a. There are two cubes in each set. One with embedded steel rebar of 19 mm in diameter (6/8 inch). The other has no rebar. The cement/sand ratio of specimens is listed in table 1. Note that the first three sets of specimen (T1-T1A, T2-T2A, and T3-T3A) refer to the cube of mortar with a 0.45 water/cement ratio. The fourth set (T4-T4A) is a concrete cube for comparison and is reinforced with maximum aggregate of 19 mm (3/4 inch). The suffix A indicates a steel rebar is embedded.

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Table 1. Specimen composition.

Specimen	T1, T1A	T2, T2A	T3, T3A	T4, T4A
Water/Cement	0.45	0.45	0.45	0.58
Cement: Sand	1:1	1:2	1:3	1:1.4

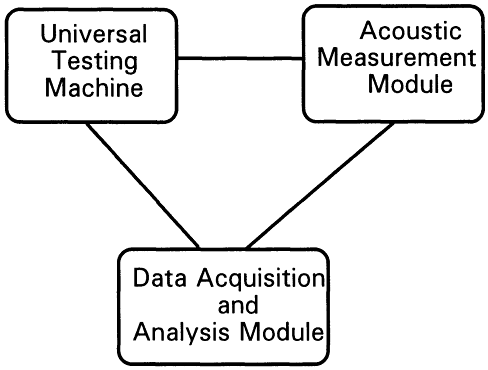

Figure 1. Block diagram for the measurement system.

MEASUREMENT SYSTEM

The measurement system consists of a stiff universal testing machine, an acoustic measurement module, and a controlling computer which is also used for data acquisition and analysis. The acoustic measurement module is composed of a high power amplifier (Controls ultrasonic concrete tester 58E46) and a HP 56400 digital oscilloscope. Available transmitter output includes 500, 1500, and 2500 volts. Working frequencies are 54, 82, and 150 kHz with a pulse repetition rate of 1 or 15 Hz. The block diagram of the measurement system is shown in figure 1.

MEASUREMENT RESULTS

The compressive strength of each specimen is estimated by compression test of a 50-mm cube of the same composition (also cast at the same time). The density of each specimen is also shown in table 2.

Measurement results of sound speed for specimens without load are shown in table 3. The working frequency is 54 kHz.

Pull-out test results are shown in table 4. The pull out load per unit length is obtained by dividing the pull out load by the embedded length [1]. The average shear stress is estimated by the pull out load divided by the surface area of the embedded rebar.

Table 2. Compressive strength of specimen.

Specimen	T1	T2	T3	T4
Compressive strength, Kg/cm^2	684	576	545	N/A
Density, Kg/cm^3	$2.09 x 10^{-3}$	$2.15 x 10^{-3}$	$2.15 x 10^{-3}$	$2.33 x 10^{-3}$

Table 4. Pull tests and average shear stresses.

Specimen	T1	T2	T3	T4
Cement: Sand	1:1	1:2	1:3	1:1.4
[1]Avg. sound speed, m/s	3750	3510	3970	4210
[2]Avg. sound speed, m/s	3240	3160	1440	3990

Specimen	T1A	T2A	T3A	T4A
Cement: Sand	1:1	1:2	1:3	1:1.4
[2]Avg. sound speed, m/s	3560	2410	2680	3790

1. Measurements taken after 28-day water curing and 110-day air curing.
2. Measurements taken after 28-day water curing.

Table 3. Sound speed measurements for specimen without load.

Specimen	T1A	T2A	T3A	T4A
Embedded length, cm	15	15	15	15
Pull out load, Kg	3800	3500	2200	6200
Pull out load per unit length, Kg/cm	253.3	233.3	146.7	413.3
Average shear stress, MPa	4.15	3.82	2.40	6.78

DISCUSSION

Sound speed is lower as the load increases and approaches the bond strength. Both mortar (T1A) and concrete (T4A) demonstrate such a tendency as the debonding starts to occur, as shown in figures 2 and 3, respectively. The reduced sound speed should be due to the covered material softening near the rebar surface.

At point 4, near the bottom of the specimen, the sound speed is relatively stable in contrast to that at point 1, near the top of the specimen. This could be due to the fact that larger bond strength is present near the bottom of the specimen.

Signal intensity, or peak to peak voltage, is also shown in the figures 2 and 3. While the decreasing tendency is also found as the load approaches bond strength, the signal intensity is fairly unstable due to the inhomogeneous nature of the specimen. A frequency domain analysis is thus necessary before further conclusion could be drawn.

FUTURE WORK

A second series of measurements is planned. More specimen will be made in each set of cement/sand ratio. Measurement error due to manually adjusting the applied load can thus be reduced. The improvement over the acoustic measurement module, such as the application of band pass filter, will be implemented to isolate true signals from unwanted noise.

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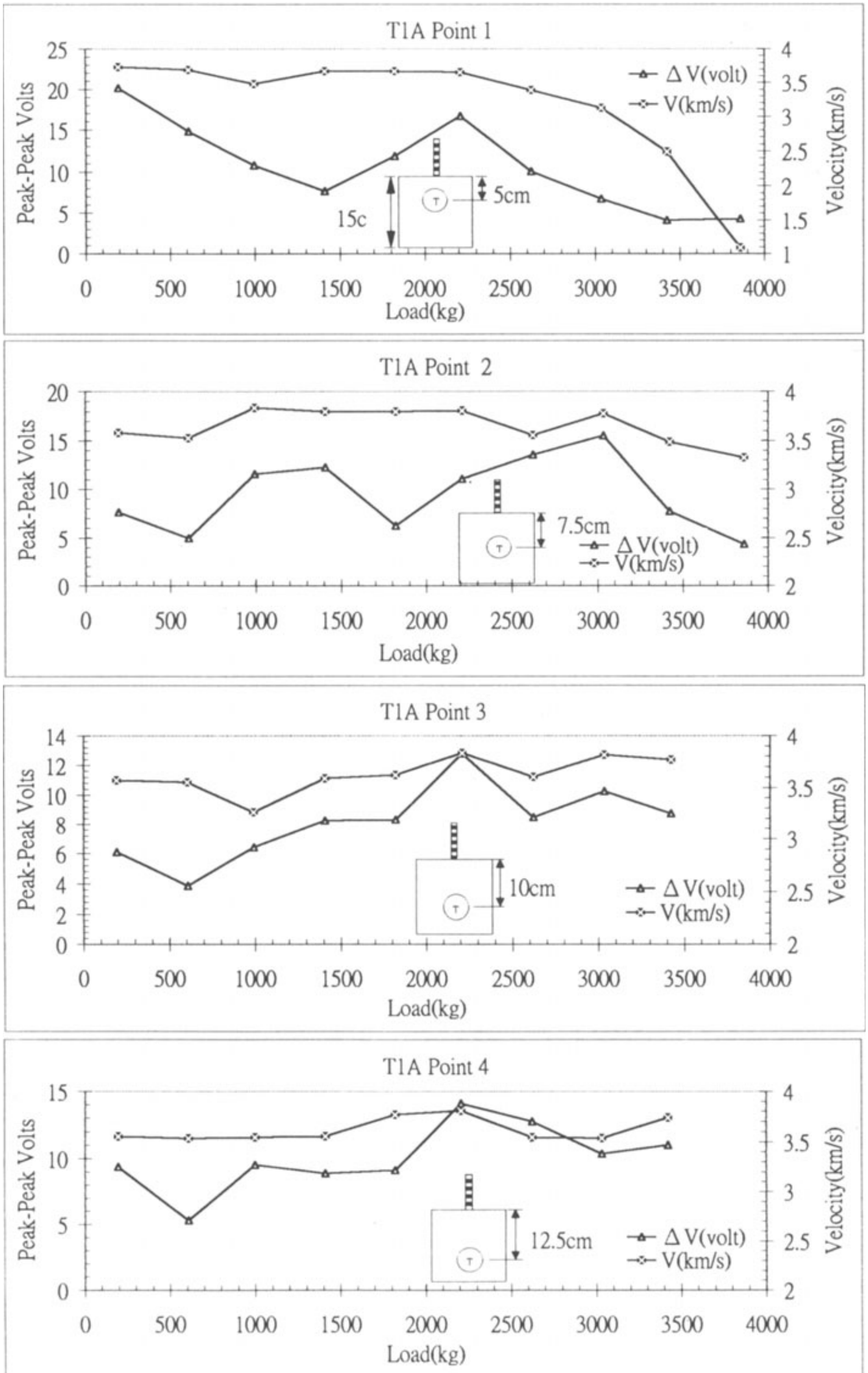

Figure 2. Sound speed and signal intensity for reinforced motar: measurement results under pull-out load.

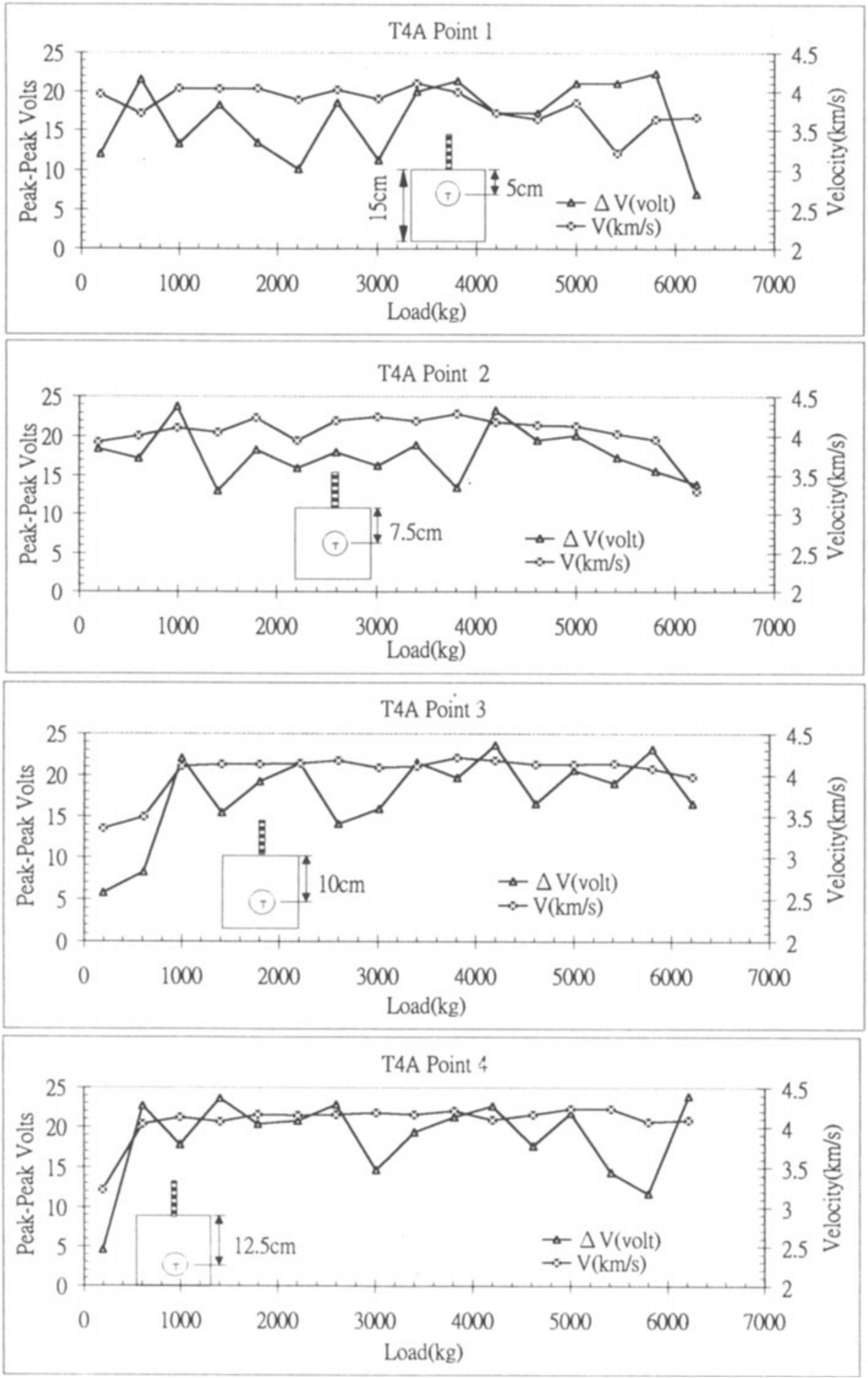

Figure 3. Sound speed and signal intensity for reinforced concrete: measurement results under pull-out load.

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