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# DETECTION OF DAMAGE IN CONCRETE STRUCTURE VIA SHIFTS IN NATURAL FREQUENCY

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**Abstract**—**In recent years, from the viewpoint of structure maintenance, the demand for Non-Destructive Evaluation (NDE) increases. The primary objective of this evaluation is to determine whether a structure performs as expected or it has an abnormality in its behavior as compared to the normal condition. Vibration based assessment is an NDE method which monitors a structure using its natural frequency. It has been recognized that changes in natural frequencies are considered as a diagnostic parameter in a structure assessment procedure. The approach is based on the fact that shifts in natural frequencies can indicate a damage in the structure. In this paper, A primary nondestructive evaluation method is used to test a sound plain concrete beam and a defected one. The decrement in the natural frequency of defected one confirms damage in the structure. For the assurance of evaluation, theoretical analysis is performed and, both theoretical and experimental results are presented.**

**Keywords— Concrete beam, Non-Destructive Evaluation, Vibration method, Natural frequency, FFT.**

## I. INTRODUCTION

It is well known that concrete deterioration mechanisms, such as chemical attacks (acids, sulfate, salts, alkalis and alkali-silica reaction), freeze-thaw deterioration and many more, which can cause concrete damage that may lead to structural serviceability issues [1]. Concrete can deteriorate for a variety of reasons, and concrete defection is often a result of a combination of factors [2]. Figures 1 and 2 show alkali aggregate reaction and salt attacks [3]. Therefore, for the maintenance of structures, Non-Destructive Evaluation (NDE) is concerned with performance monitoring of structures to ascertain the strength and performance states of critical members of the structures and determine the presence of any anomaly such as damage [4]. During the past two decades, a significant amount of research has been conducted in the area of Non-destructive damage detection via changes in the modal response of a structure [5]. The method issues early warnings on damage and deterioration prior to costly repair and catastrophic collapse [6]. NDE is one of the most attractive issues nowadays in the field of structural health monitoring due to its simplicity, cost effective means and no defection of structure serviceability.

Vibration method is an NDE method which evaluates structure health condition using its natural frequency. In this paper, an assessment of structural health condition of a sound concrete beam and a deteriorated one is conducted concerning their natural frequencies. The shifts in natural frequency of defected beam confirms damage in the structure. For confirmation of the evaluation, theoretical analysis is performed, the frequencies obtained both theoretically and experimentally are evaluated using soundness grading method to illustrate service life of the beams.

Fig.1. RC Bridge detenorated by salt attacked

Fig.2. Alkali aggregate reactions [3]

## II. OUTLINE OF THE SPECIMENS

An evaluation of structural health condition of two simply supported plain concrete beams is conducted. Specimen A is a sound beam contains no fault, but specimen B is a defected one which has a crack in the middle of bottom vicinity with a distance of 72cm from the right edge of the beam (Fig.3 and 4. The detailed explanation of the damage is described below.

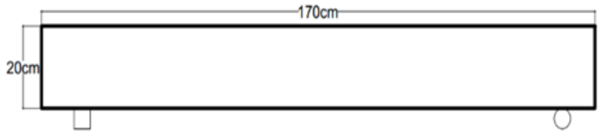


Fig.3. Sound PC beam

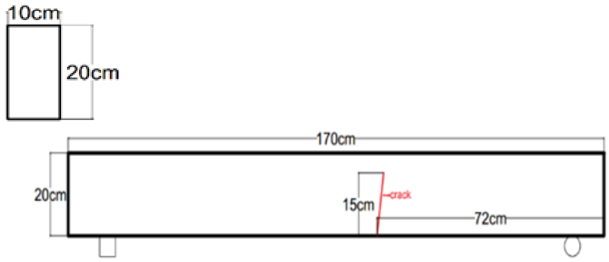


Fig.4. Damaged PC beam

As a calculative parameter, the elastic modulus of the material used for the construction of beam specimens is to be known. Hence, equations (1) and (2) are used to calculate the elastic modulus from compressive strength of concrete [7]. Schmidt Rebound Hammer test is executed to find out the compressive strength of concrete. Figure.5 shows Schmidt Rebound Hammer and the state of the experiment

$If\ Fc < 30N/mm^2$ Then,

$$Ec(N/mm^2) = \left(2.2 + \frac{Fc - 18}{20}\right) \times 10^4 \qquad (1)$$

$If\ Fc \geq 30N/mm^2$ Then we have,

$$Ec(N/mm^2) = \left(2.8 + \frac{Fc - 30}{33}\right) \times 10^4 \qquad (2)$$

Fig.5. Schmidt R Hammer and compressive strength testing

## III. VIBRATION METHOD

### A. Vibration method system

Vibration method is an NDE method that assesses structures without causing any damage, due to its simplicity and cost effectiveness, it has a broad range of usage. The vibrational frequencies were measured by accelerometer can change rapidly in time, especially if a fault has occurred [8]. In this paper, a basic vibration method is used that contains the following components. A plastic hammer impact force is applied to generate vibration waves in the beams. An acceleration transducer (AR-10TF) is placed on the middle of the side surface of specimens. A personal computer is connected to AR-10TF through EDX-11 (Kyowa) for obtaining the vibration data. DAS-200A analyzing software is installed on a computer for simulation using FFT to convert the data to frequency spectrum (Fig.6). With the help of above method, specimen A and B are evaluated separately, and the test is conducted at an exposure field of the University of the Ryukyus.

## IV. FREQUENCY ANALYSIS USING FFT

FFT (Fast Fourier Transform) is used to calculate the natural frequency of the beams.  FFT is a DFT (Discrete Fourier Transform) for speed, DFT is a Fourier that transforms a discrete number of samples of a time wave and converts them into a frequency spectra (Fig.7). However, calculating a DFT is sometimes too slow, because of the number of multiples required. An FFT is an algorithm that speeds up the calculation of DFT [9].

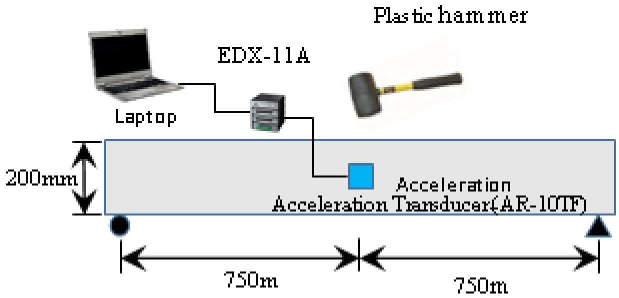


Fig.6. Vibration test method and system

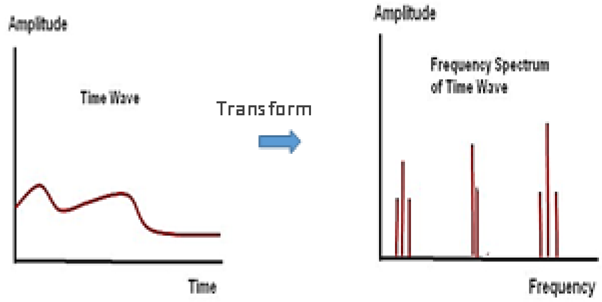


Fig. 7. Outline of FFT

## V. THEORETICAL NATURAL FREQUENCY

### A. Schmidt Rebound Hammer Test

Table 1 shows the concrete compressive strength (Fc) estimation acquired by rebound hammer test. The results are an average of 8 times measuring. Table 2 shows elastic modulus calculated by equation (1) and (2).

Table 1. Schmidt Rebound Hammer Test for Fc

| Concrete Compressive Strength (Fc) | | |
|---|---|---|
| **No. Tests** | **Specimens** | |
| | **Sound Beam** | **Cracked Beam** |
| 1 | 43.6 | 26.5 |
| 2 | 33.8 | 21.6 |
| 3 | 33.8 | 31.4 |
| 4 | 38.7 | 26.5 |
| 5 | 38.7 | 25.3 |
| 6 | 31.4 | 27 |
| 7 | 32.6 | 26.5 |
| 8 | 36.3 | 25.5 |
| **Average (N/mm$^2$)** | **36.1** | **26.3** |

Table 2. Elastic Modulus of Concrete Material and Fc

| Elastic Modulus | | |
|---|---|---|
| **Beams** | **Fc (N/mm$^2$)** | **Ec (N/mm$^2$)** |
| Sound Beam | 36.1 | 29848.4 |
| Cracked Beam | 26.3 | 26878.7 |

B. Natural frequency and deflection of Beams

Here, equations (3) and (4) are used to translate natural frequencies of applied self-weight simply supported beam.

$$f(Hz) = \frac{1}{2\pi} \times \sqrt{\frac{G}{\delta}} \qquad (3)$$

$$\delta(mm) = \frac{5}{384} \times \frac{W \times L^3}{E \times I} \qquad (4)$$

$G(mm/s^2)$ : Gravitational acceleration
$\delta(mm)$ : Beam center deflection
$W(N)$: Self-weight
$L(mm)$: Length of span
$E(N/mm^2)$: Elastic Modulus (estimated by using equation (1) or (2))
($I(mm^4)$: Section moment of inertia

Table.3 shows natural frequencies and beams deflection obtained theoretically.

Table 3. Deflection and Natural Frequency of the Beam

| Beams | Delta (mm) | F (Hz) |
|---|---|---|
| **Sound Beam** | 0.015772 | 125.46 |
| **Defected Beam** | 0.018522 | 115.77 |

VI. EXPERIMENTAL NATURAL FREQUENCY

Once, a sound simply supported plain concrete (PC) beam which contains the dimensions 1700mm×100mm×200mm and 1500mm span is tested (Fig.10). Next, the test is performed for a faulty beam having the identical dimensions but holding a crack located at a distance of 72cm from the right edge of the beam. AR-10TF is attached to the center of specimen A and specimen B accordingly. DAS-200A software is installed on a personal computer connected to the AR-10TF through EDX-11A. An impact force of plastic hammer is introduced to acquire the vibration data in a period of 10 seconds. The data is analyzed in DAS-200A analyzing software using FFT. The graphs obtained from FFT represent shifts in natural frequency of the structure, which confirms damage in the structure.

Fig.11 and Fig.13 show the time-history graphs where, Fig. 12, 14 show Fourier spectra transformed graphs. The results illustrate natural frequencies of specimen A and B 121.4Hz and 21.5 Hz, respectively.

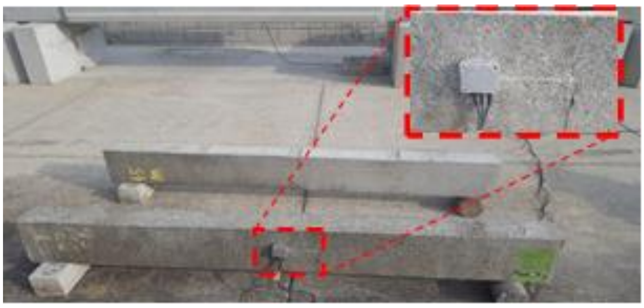

Fig.10: Vibration test of Plain concrete beams

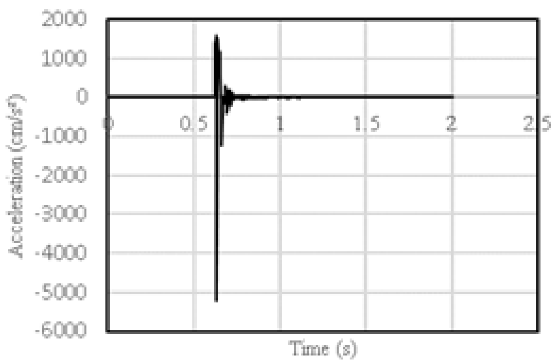


Fig. 11. Time history of acceleration

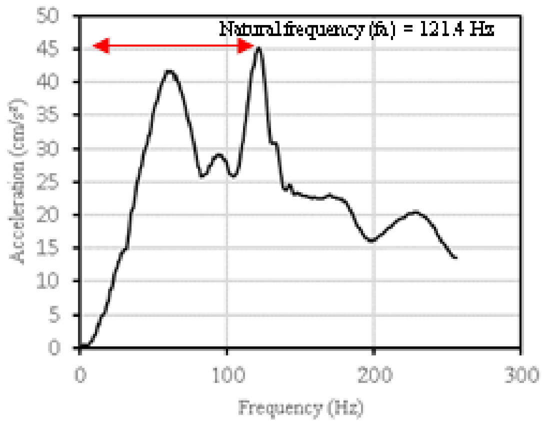


Fig.12. Frequency spectra

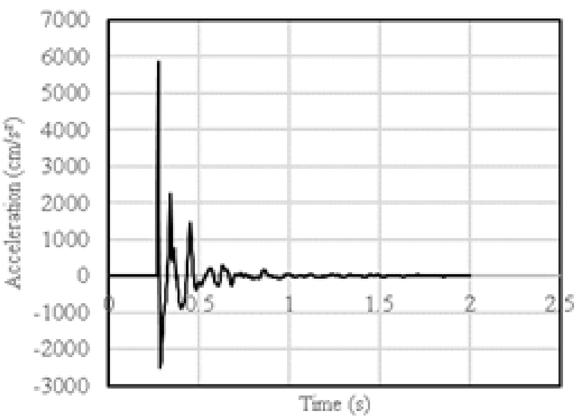


Fig..13. Time history of acceleration

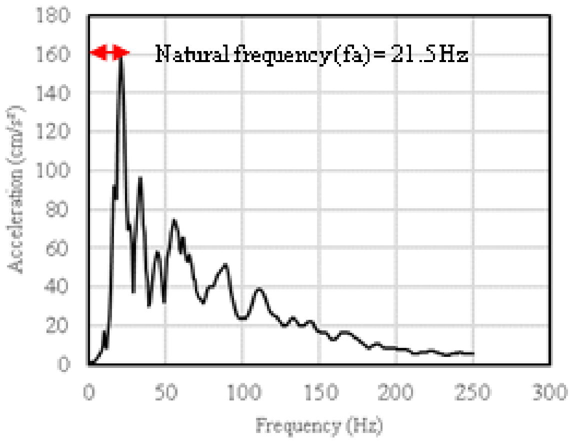


Fig.14. Frequency spectra

## VII. Soundness Evaluation of the Beams

The results obtained from both FFT and equation (3) are compared to evaluate the soundness of the beams as follow in equation (5). It is considered that the grading of soundness can be evaluated by a magnitude of equation (5).

$$\frac{fa}{f} \geq 1 \;\text{Sound} \qquad \frac{fa}{f} < 1 \;\textit{not sound} \qquad (5)$$

Where, fa is natural frequency obtained from FFT, and f is theoretical natural frequency acquired from equation (3). fa/f is the ratio of both frequencies that shows the soundness grading of the specimens as shown in table.4. It is attained that natural frequencies of beams are responsive to the aged deterioration and damage of materials. Thus, it is possible to evaluate the soundness grading of concrete structures using their natural frequencies.

Table 4. Soundness Evaluation of the Beams

| Beams | fa/f | Evaluation |
|---|---|---|
| Sound Beam | 0.96 | Almost sound |
| Defected Beam | 0.18 | Critical state |

## CONCLUSION

In this paper, a non-destructive vibration evaluation is performed to evaluate the natural frequencies of a sound PC beam and cracked one. The frequencies are obtained both theoretically and experimentally, and they are graphically represented. The decrement in natural frequency of defected one confirmed damage in the structure. Afterward, a soundness evaluation was carried out to show the status of the beams. It demonstrated that specimen B lost almost 80% efficiency and it is in a critical state. It can be concluded that the easiest and cheapest way to evaluate a structure without harming its serviceability, is Non-Destructive Testing.

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