FIFTH INTERNATIONAL CONGRESS ON SOUND AND VIBRATION
DECEMBER 15-18, 1997
ADELAIDE, SOUTH AUSTRALIA

Invited Paper

NON-DESTRUCTIVE ESTIMATION OF THE POSITION OF A CRACK IN A CONCRETE BLOCK

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ABSTRACT

This paper describes a method to estimate, using several sensors, the position of a crack in a concrete block, most of which is buried in the ground. An array of sensors is attached on the surface of the concrete block, and a vibration pulse is forced using a small hammer.

Since the forced vibration reflects at the position of a crack, the position will be easily estimated by picking up the reflection wave with an array of sensors using a beamforming technique if only the reflections from the crack can be detected.

However, there were many reflections from the boundaries such as side walls and the bottom of the concrete block, and the surface wave, whose magnitude is much greater than that of the necessary reflection wave from the crack. Therefore, conventional beamforming technique does not offer a good result.

By the proposed method, not only the effect of the surface wave but also that of the reflection waves from the side walls are decreased, and the necessary reflections (primary and secondary waves) from a crack are extracted. The position of the crack is estimated using the extracted waves by a beamforming technique.

We made three concrete blocks with different types of cracks and the positions of the crack were estimated well with the proposed method.

INTRODUCTION

This paper describes a method to estimate the position of a crack in a concrete block using several vibration pick-ups. An array of vibration pick-ups is attached on the concrete block, and a vibration pulse is forced by using a small hammer. If there is a crack, a reflection wave is generated from the position of the crack. Therefore, conventional methods to estimate the position of vibration source seems to be useful for this purpose.

However, since the concrete block is elastic, there are three wave propagation modes; the surface wave mode, the primary wave mode and the secondary wave mode. Since the necessary primary wave mode is not significant in magnitude, we cannot estimate the position by the conventional methods. (The surface wave mode and secondary wave mode are considered as noise for our purpose.) Therefore, to increase the S/N, we had proposed a method to eliminate the first-coming surface wave. However, the method was insufficient to achieve a better S/N. Therefore, this paper proposes a new method to achieve a better estimation. Some experiments were carried out, and good results were obtained.

EXTRACTION OF ONLY THE PRIMARY WAVE

It is assumed that there is an elastic block with a crack as shown in Fig. 1. Most part of the block, which should be investigated in our project, is buried under the ground, and its size is very big. Therefore, it is difficult to use an ultra-sonic technique, and low frequency components of the vibration signal are used in this paper.

Several vibration pick-ups are attached on the air side of the block, and almost the center of the array of the pick-ups is hit with a small hammer. Considering the mirror effect, a reflection wave can be assumed to be the direct wave from the corresponding image source [1].

An example of the waveform of a sensor output is shown in Fig. 2.

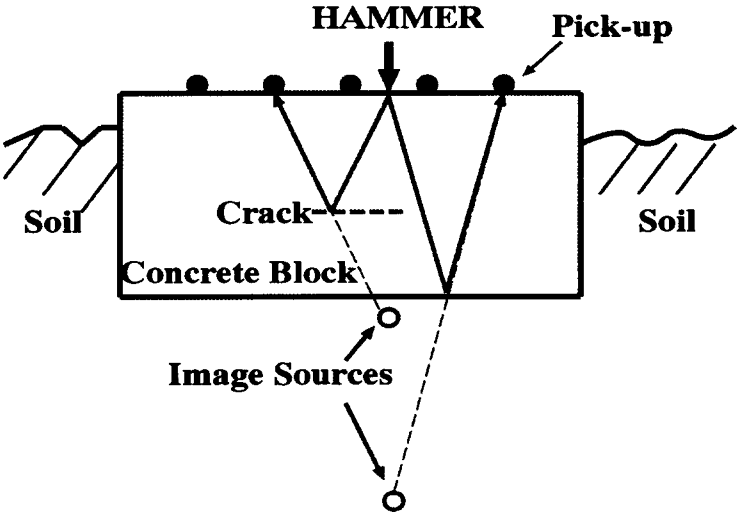

Figure 1: An elastic block buried in the soil.

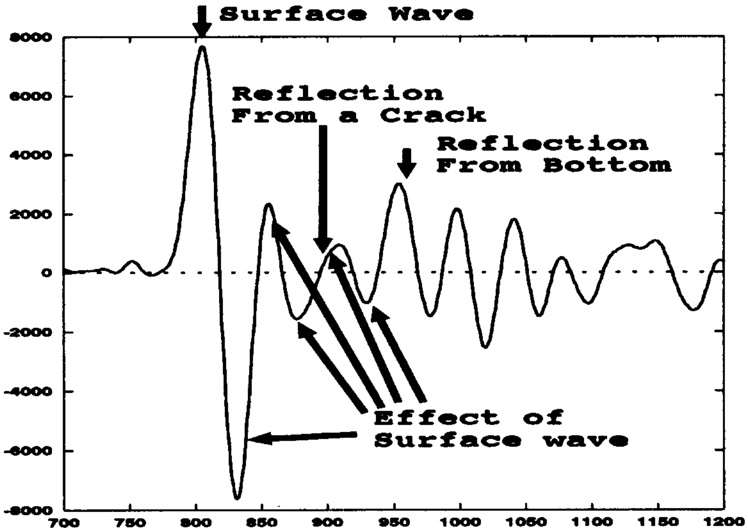

Figure 2: An example of the waveform $y_m(t)$ of a sensor output

The vibration wave $x_m(t)$ at the m-th pick-up due to the direct sound caused by a hitting with a small hammer is represented as follows:

$$x_m(t) = a_{hm}\,\delta(t - \frac{r_{hm}}{c_S}) + \sum_p \{b_{pm}\,\delta(t - \frac{r_{pm}}{c_p}) + c_{pm}\,\delta(t - \frac{r_{pm}}{c_s})\}, \tag{1}$$

where a_{hm} is the attenuation coefficient for the surface wave from the hitting point to the m-th pick-up, and b_{pm} and c_{pm} are the attenuation coefficients for the primary and the secondary waves from the p-th real or image source to the m-th pick-up, respectively. δ is the delta function, r_{**} the propagation distance, and c_S, c_p and c_s are the velocities of the surface, the primary and the secondary waves, respectively. We had proposed a method to eliminate the surface wave to achieve a higher S/N [1]. However, since the sensor outputs were passed through charge amplifiers and the hammer pulse cannot be represented by the delta function, we can observe not many impulses but many positive and negative peaks as shown in Fig. 2. That is, the output $y_m(t)$ of the m-th charge amplifier is expressed as follows:

$$y_m(t) = x_m(t) * h(t) * f(t) \tag{2}$$

where * denotes the convolution integral and $h(t)$ and $f(t)$ the impulse responses of the charge amplifier and the waveform forced by the hammer hitting, respectively. Since the proposed method could eliminate only the first positive peak, the successive part of the surface wave, whose power is greater than that of a primary or secondary wave, remains unchanged. Therefore, the necessary reflection pulse cannot be observed clearly even by the previously proposed method [1]. Furthermore, since many reflections overlaps each other, it is difficult to estimate the attenuation coefficients, and the necessary primary wave could not be extracted even by the method.

Therefore, this paper describes a new method to achieve a higher S/N as follows:

(1) Let $y_1(t)$ the output of the pick-up which is the nearest to the position of the hitting.

(2) Subtract $d_m y_m(t-\tau_m)$, $m \neq 1$ from $y_1(t)$, where d_m and τ_m are the constants and are determined so that the following error E is minimum.

$$E = |d_m y_m(t-\tau_m) - y_1(t)|^2 \tag{3}$$

Since the power of the surface wave is dominant, d_m and τ_m may be chosen so that the effect of the surface wave becomes minimum, and the resultant wave $z_m(t)$ is expressed as follows:

$$\begin{aligned} z_m(t) &= y_1(t) - d_m y_m(t-\tau_m) \\ &= \sum_p \{b_{p1}\,\delta(t-\frac{r_{p1}}{c_p}) + c_{p1}\,\delta(t-\frac{r_{p1}}{c_s}) - d_m b_{pm}\,\delta(t-\tau_m-\frac{r_{pm}}{c_p}) \\ &\qquad -d_m c_{pm}\,\delta(t-\tau_m-\frac{r_{pm}}{c_s})\} * h(t) * f(t) \end{aligned} \tag{4}$$

Figure 3 shows an example of $y_m(t)$ and $z_m(t)$. It is easily found that not only the first positive peaks but also the successive negative and positive peaks due to the surface wave are decreased in $z_m(t)$. Then, the peaks due to the crack and other boundaries appear clearly in $z_m(t)$ as shown in Fig. 3 for the case that their positions of the peaks in $y_1(t)$ are not the same as those in $y_m(t)$. Therefore, to avoid the effect for the case, the power of the positive peak in $y_1(t)$ and that of $z_m(t)$ are compared. That is, if the latter one is bigger, it means the following two cases:

(1) the effect of negative peak due to the surface wave is eliminated (S/N increases in this case).

(2) the effect of negative peak due to the reflection waves is eliminated (S/N decreases in this case).

However, the the effect of the case (2) is much smaller than that of the case (1), and the effect of case (2) decreases by averaging $z_m(t)$, $m = 2, 3, \cdots$.

If the latter one is smaller, it means the effect of positive peak due to the surface wave in most cases, since the effect of the surface wave is dominant. Therefore, in our method the peak, where the power peak in $z_m(t)$ is smaller that that in $y_1(t)$, is eliminated.

Furthermore, since the impedance of the concrete is higher than that of soil or air, a negative peak is also eliminated.

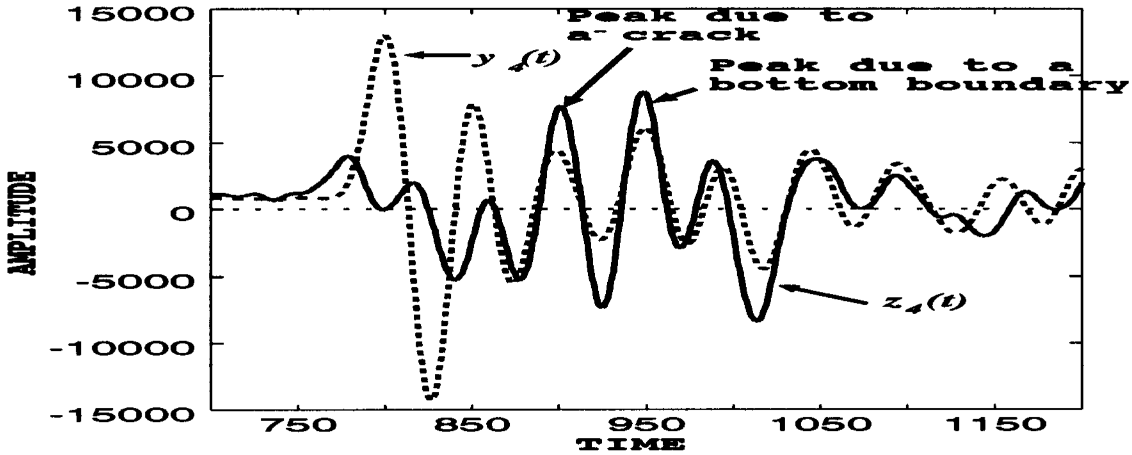

Figure 3: An example of $z_m(t)$ and $y_m(t)$.

NEAR FIELD BEAMFORMING

Since the positions of hitting point and sensors are known and the velocity c_S, c_p and c_s can be estimated by the positions of the peaks in $y_m(t)$, the position of the crack is estimated by the near field beamforming [1].

In the method, an imaginary source is first assumed. Then, under the free field assumption, the distances between the imaginary source and all of the pick-ups are calculated, and all of the signals $z_m(t)$ are shifted in time domain to compensate the propagation delay. Then, the compensated signals are averaged. If the number of pick-ups is sufficiently large, the averaged compensated signal takes a large value in case that the position of the imaginary vibration source coincides with that of a real vibration source. Otherwise, it takes a small value.

The position of the imaginary vibration source is scanned in the space to be investigated. The estimated position of a real vibration source is the position where the absolute value of the averaged spectrum yields a peak.

EXPERIMENT

6 pick-ups and two concrete blocks with the same size of 1.5m x 3.6m x 0.3 m were used for the experiment. One has a crack (crack #2 only), and the other has two cracks (crack #1 and #2) as shown in Fig. 4. The crack is a polyethylene sheet with a size of 1.0m x 0.3 m x 200 μm.

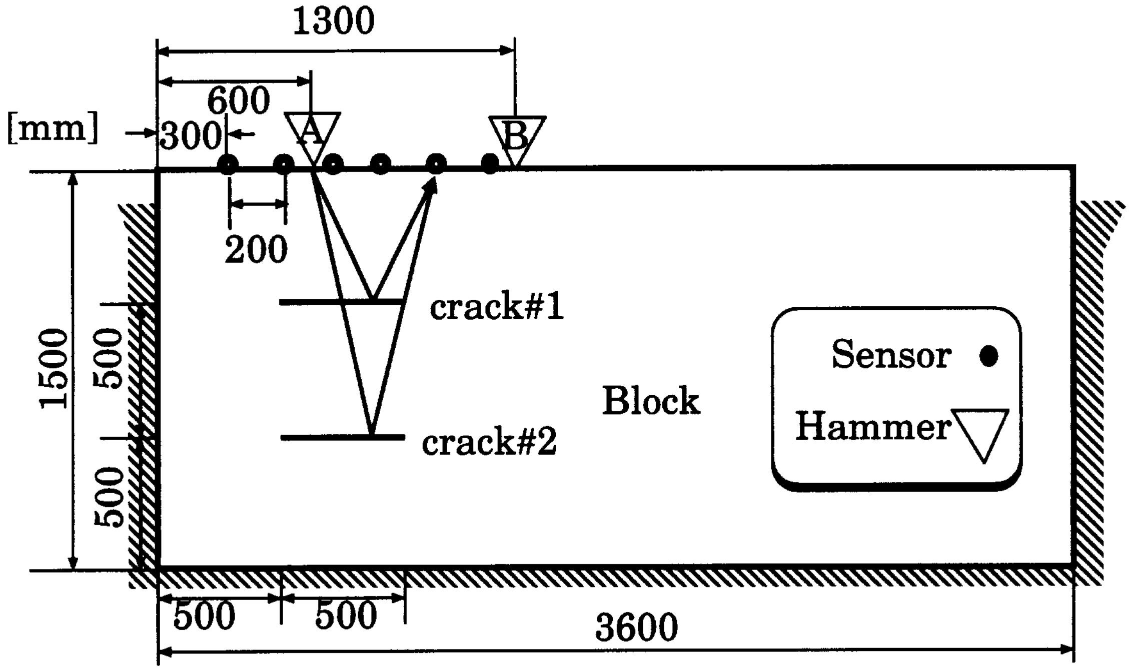

Figure 4: Pick-ups and a concrete block with a crack.

Figures 5-7 show the results of the near field beamforming, which are the absolute value of the averaged power of a peak, which is illustrated by contour lines for the case of only one crack (crack #2). Figures 5 and 6 are the results for the case of hitting point A. Figure 5 shows the result which was obtained by the previously proposed method where only the first positive peak was eliminated. It is found that the positions of the largest 4 peaks are not near the expected position. It is also found that there are many peaks in the unexpected positions, whose power is about the same as that in the expected position. Figure 6 shows the result by the newly proposed method. Two peaks due to the crack and the bottom boundary are clearly observed. The power of the peaks in the unexpected positions are less by more than 10 dB.

Fig. 7 shows the result by the newly proposed method for the case of hitting point B. It is found in Fig. 7 that two large peaks are also observed clearly as well as in Fig. 6.

Figure 8 shows the result by the newly proposed method for the case of hitting point A and two cracks (crack #1 and #2). Three peaks due to the two cracks and the bottom boundary are clearly observed.

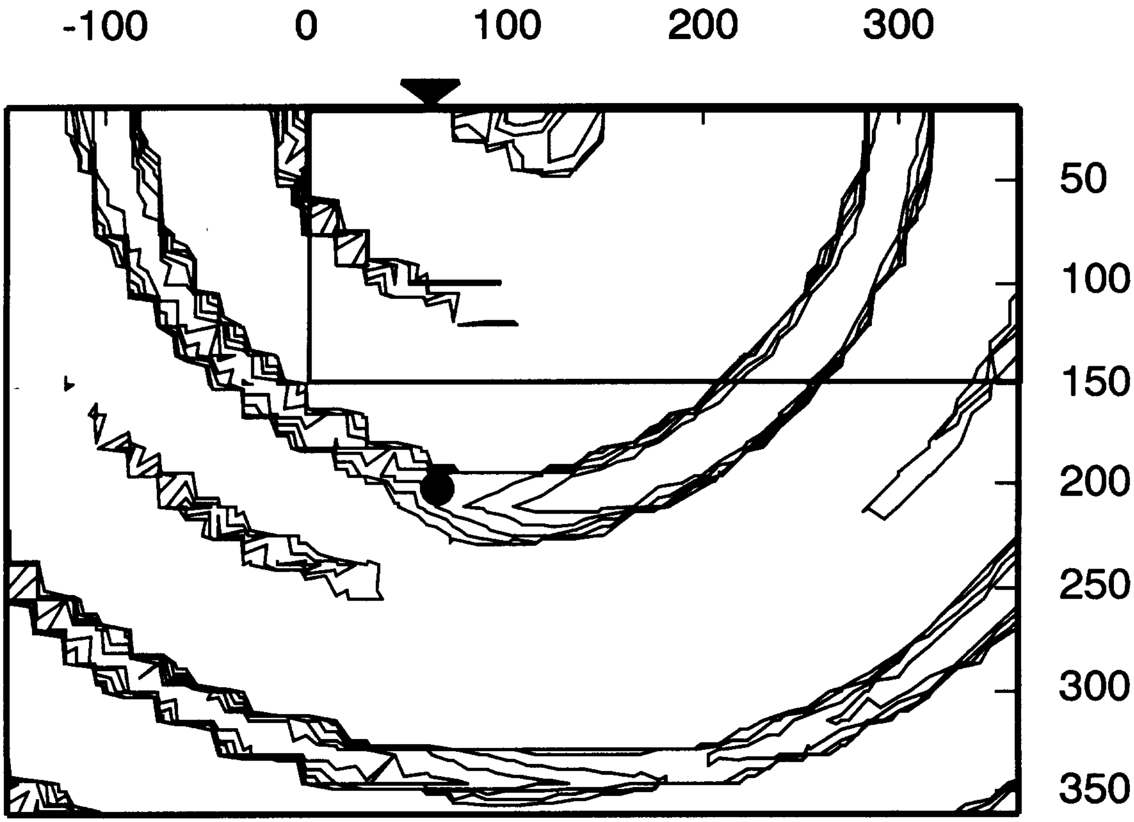

Figure 5: Result of the near field beamforming by the previously proposed method (hitting point : A, One crack #2).

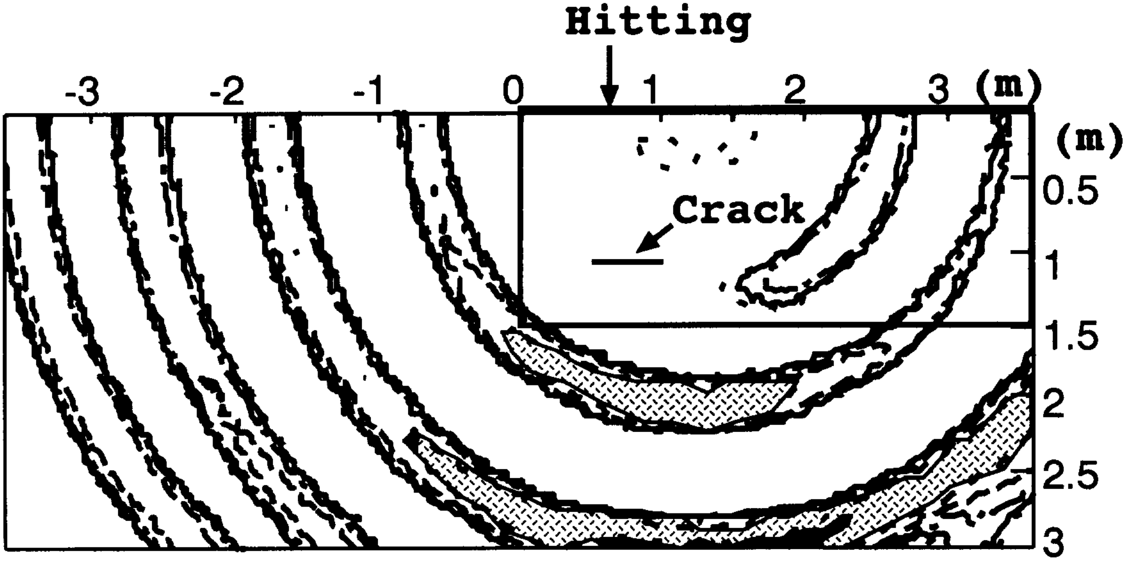

Figure 6: Result of the near field beamforming by the newly proposed method (hitting point : A, One crack #2).

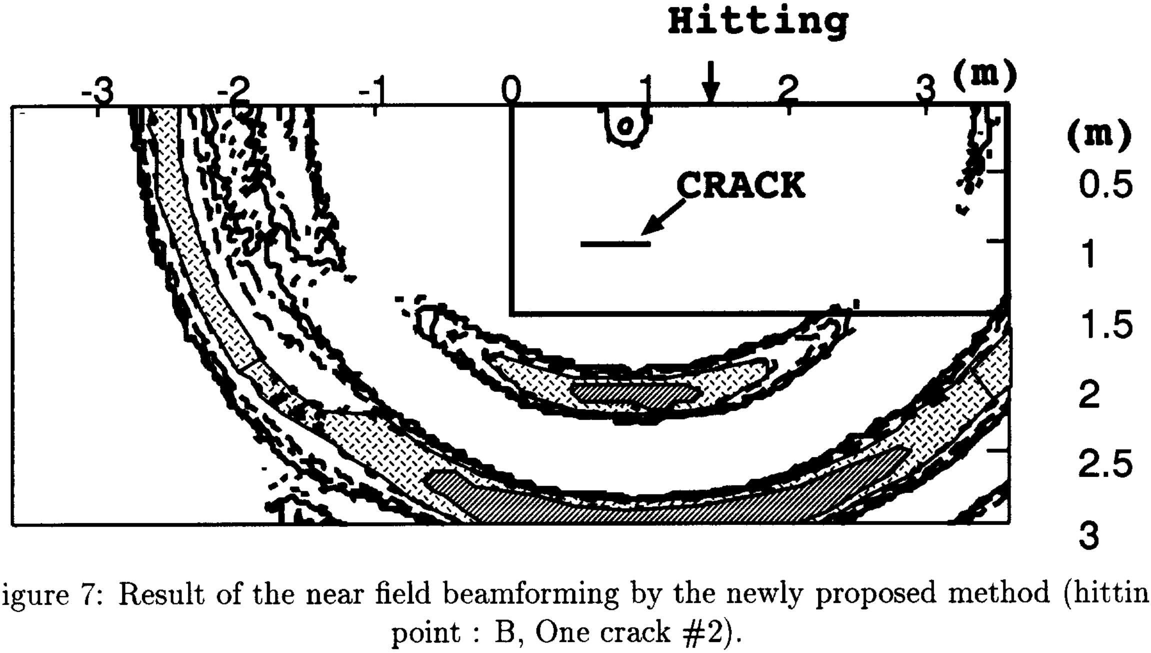

Figure 7: Result of the near field beamforming by the newly proposed method (hitting point : B, One crack #2).

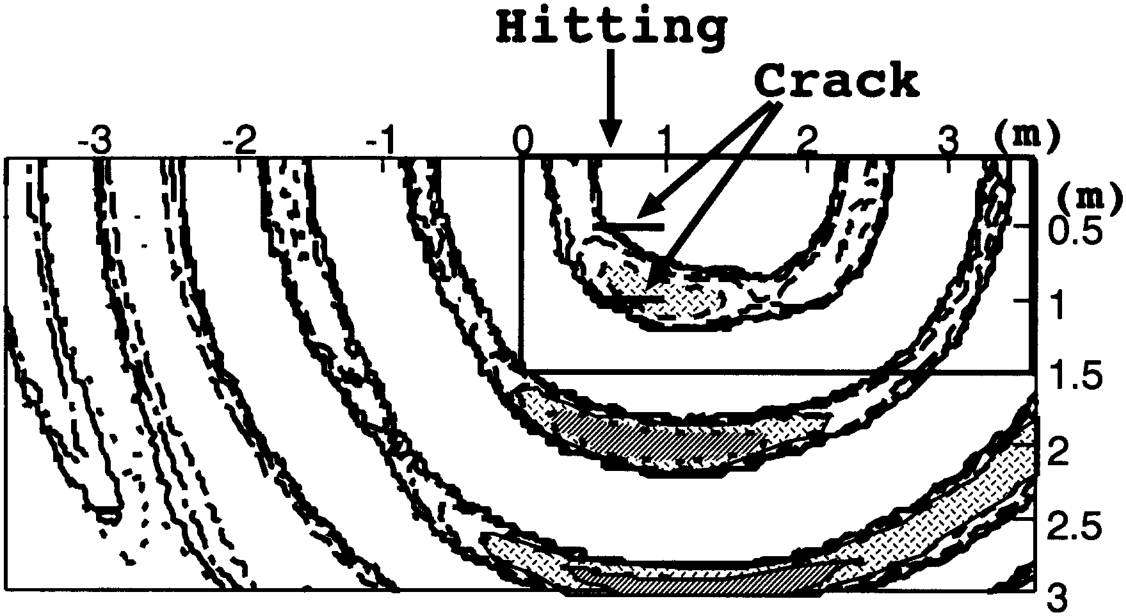

Figure 8: Result of the near field beamforming by the newly proposed method (hitting point : A, Two cracks #1 and #2).

CONCLUSION

This paper described a method to estimate the position of a crack in a concrete block using several vibration pick-ups. Since the concrete block is elastic, there are three wave propagation modes, and we could not estimate the position by the conventional beamforming technique. Therefore, we proposed a method to estimate the position of a crack in an elastic block. Some experiments were carried out, and it is found that whether a crack exists or not could be inspected. It is also found that the position of the crack could be estimated.

References

[1] Masato Abe, Satoshi Hongo, Yoshiaki Nemoto, and Yoshinori Chubachi," NON-DESTRUCTIVE TECHNIQUE TO ESTIMATE THE POSITION OF A CRACK IN A CONCRETE BLOCK BURIED IN THE GROUND," Proc. Third International Congress on Air- and Structure-Bone Sound and Vibration, Vol. 3, pp. 2045-2052, June 13-15, 1994

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