Non contact acoustic exploration method for concrete using SLDV and LRAD

Tsuneyoshi Sugimoto, Ryo Akamatsu, Noriyuki Utagawa, Syuichi Tsujino

ACOUSTICS 2012

Non contact acoustic exploration method for concrete using SLDV and LRAD

T. Sugimoto[a], R. Akamatsu[a], N. Utagawa[b] and S. Tsujino[b]

[a]Toin Univ. of Yokohama, 1614, Kurogane-cho, Aoba-ku, 225-8503 Yokohama, Japan
[b]Sato Kogyo Co., Ltd., 4-12-19, Nihonbashi-honcho, Chuo-ku, 103-8639 Tokyo, Japan
tsugimot@cc.toin.ac.jp

The hammering test is a representative method in inspection for cavities and delaminations at shallow area of concrete surface. Although this method is used widely because it is not expensive, efficiency of the defect-judging largely depends on the tester's experience and long measurement time is necessary for wide area inspection. Other methods have been developed, however, it is necessary to contact or approach to the inspection object during a measurement. Therefore, we propose a new non-contact acoustic imaging method for nondestructive inspection using scanning laser Doppler vibrometer (SLDV) and long range acoustic device (LRAD). In this method, Surface vibration, which is generated by air borne sound, is measured using SLDV. This time, the styrofoam board was buried at shallow depth in the concrete are used as a substitute of a cavity in the concrete. As an experimental result, a styrofoam board is clearly imaged by the vibration velocity of the concrete surface. Furthermore, we confirmed that our proposed method can apply even 10 m away distance, and the measurement distance is about within 20 m under the present conditions. It means that the non destructive inspection for concrete from a long distance is possible.

1 Introduction

Up to now, a number of concrete structures have been built in Japan such as buildings, tunnels, bridges, and so on. Thirty years have passed since a lot of them were constructed. Thus, accidents of a concrete block falling occur frequently. To prevent such a case, hammering test is frequently used for inspection. A hammering test is the most popular method in inspection for shallow area under concrete surface, because it is low in cost. In this method, we hit concrete surface by a hammer, then distinguish defect parts from fresh parts by use of the hammering sound differences. But efficiency of the defect-judging largely depends on the tester's skill and long measurement time is necessary for wide area inspection. Especially, it is difficult to inspect the places where people cannot reach. Other methods have been developed: impact acoustic method, ultrasound inspection, infrared detection, electromagnetic detection. But during the inspections using these methods, we must contact or approach the targets. Although laser-ultrasonic testing enables remote measurement, it is underdevelopment and the large measurement devices are required, because it needs a lot of the electricity consumption [1] .

Meanwhile, an extremely shallow underground imaging method for a land mine detection using air-coupled sound wave and a Scanning Laser Doppler Vibrometer (SLDV) has developed [2-3]. And we apply this method for shallow area under concrete surface. Using a Long Range Acoustic Device (LRAD) as a vibration source, we expect that the maximum measuring distance in this method will be longer than that of other methods.

We conducted two experiments using concrete test pieces in which styrofoam boards were buried as a cavity. The purpose of the first experiment is to confirm the possibility in this method for concrete [4-5]. And the second experiment is a test in the practical situations. In the real inspection, we sometimes have to measure from a distant place. Moreover, we examined the detectable size and depth, and the maximum measuring distance in this method.

2 Methodology of Non-Contact Acoustic Imaging Method

Fig.1 shows the fundamental concept of Non-Contact Acoustic Imaging method (NCAI) [6]. A sound wave emitted by a vibration source excites the measurement surface. The SLDV (Polytec, PSV400-H4) measures the vibration velocity in the vertical direction two-

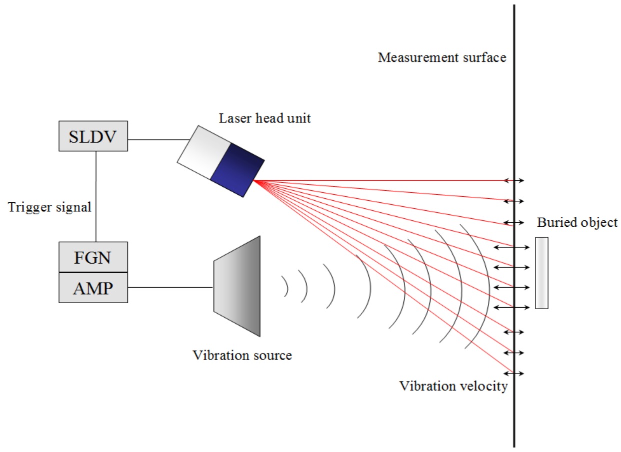

Fig.1:Fundamental concept of NCAI.

dimensionally. If a buried object exits in an area, resonance characteristics are definitely different between the buried object area and the surrounding area. Therefore, it can be visualized and detected by using distribution of the vibration velocities. A frequency range which contains strong response from the buried object is referred to as a frequency response range. The frequency response range relates to a resonance frequency of a buried object [4]. A transmitted wave which has a frequency response range of the buried object must be sent to form a sharp image.

Flat Speaker (FPS Corp., FPS2030M3P1R) which has sharp directivity was used as a vibration source in our past researches. In this study, the LRAD (LRAD Corp, LRAD100-X or LRAD300-X) is used as a vibration source. The LRAD can emit the sound pressure of 100 dB or more at a distance of 10 m, and also has a sharp directivity. Because the stronger source LRAD is used in the present study, the maximum measuring distance in our propose method becomes longer.

The input signal to the LRAD is generated by a function generator. At the same time, the function generator sends a trigger signal to the SLDV. Thus, the SLDV and the LRAD are synchronized.

3 Examining Possibility of NCAI for Concrete

3.1 Experimental setup

To confirm the feasibility of our proposed method for shallow area under concrete surface, an experiment using a concrete test piece is carried out. The concrete test piece includes a styrofoam board($30\times30\times20$ cm^3) as a cavity in concrete. The buried styrofoam board is at 5 cm depth in the concrete test piece. The experimental setup is shown in Fig.2. The concrete test piece was arranged 1 m from the vibration source.

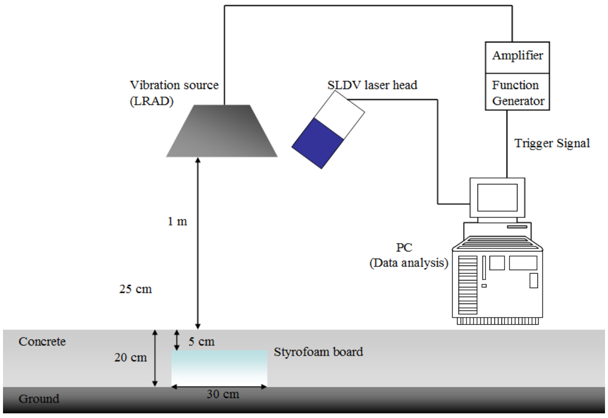

Fig. 2: Experimental setup for inspection possibility test using a concrete tests piece. A styrofoam (300 × 300 × 150 mm^3) as a substitute for a cavity are buried in the concrete. The distance between concrete surface and buried object is 50mm

A white noise is used to search a frequency response range of the buried object. After detecting the frequency response range, a linear chirp wave which contains the frequency response range is sent to form a clearer image. A duration time of the white noise is 1 s. And a duration time of the linear chirp wave is 0.64 s. Each trigger interval is 2.15 s. The emitted sound pressure is about 110 dB near the surface of the concrete test piece. Setting of scanned points is shown in Fig.3**.** The area for scanning is about 50 × 56 cm and the number of the scanned points is 195 (13 × 15). It needs a few minutes to measure the vibration velocities at all scanned point.

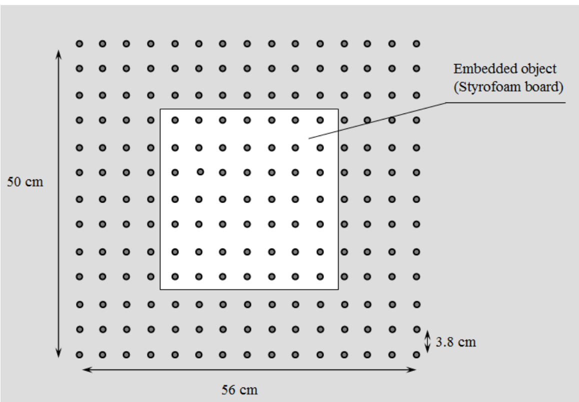

Fig. 3: Dimensions of scan area (500 × 560 mm^2). The number of the scan points is 195 (13 × 15).

3.2 Experimental results

An example of the experimental result is shown Fig.4. The white flame shows the size and the actual position of the buried styrofoam. Fig.4(b) shows an example of vibration velocity distribution by SLDV software at 2198 Hz . From this figure, we can clearly see the response of the buried object. As the result of this experiment, we confirmed efficiency of our propose method for shallow area under concrete surface.

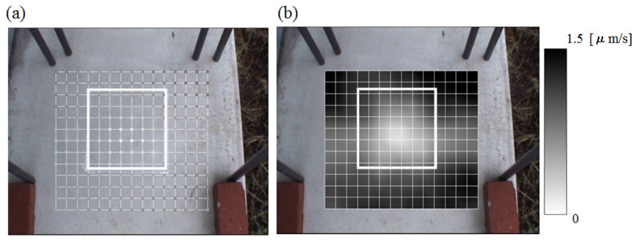

Fig. 4: Experimental result. A styrofoam board (300 × 300 × 150 mm^3) as a substitute for a cavity at the depth of 50 mm. The sound pressure is about 110 dB near the surface of the concrete test piece. The white flame shows the size and the position of a styrofoam. (a) Scan area and position of buried object by CCD camera, (b) Imaging result by SLDV. Imaging frequency : 2198 Hz. Output wave : Linear chirp (2100 – 2500 Hz).

4 Experimental Test in a Long Distance

4.1 Experimental setup

In previous section, we established that our proposed method is effective for concrete in a relativity short distance (1 m). Fig.5 indicates the experimental setup in a long distance. The distance between the LRAD and the concrete test piece is 10 m. The test pieces are five reinforced concrete boards of 2 m in width, 1.5 m in height, and 0.3 m in thickness. The defect of delamination and cavity are imitated by burying the board made of the styrofoam in concrete. There are 32 kinds of the defect by changing the size and the depth of the styrofoam. The shape of the styrofoam is a square. The one side of the length of the square from 50 to 700 mm. The depth of the defect is from 25 to 150 mm. There is a case where the defect is arranged at the position of the reinforced bar. In this experiment, the LRAD (LRAD Corp, LRAD-300X) is used. For maximizing the energy of acoustic wave, the LRAD parallel to the concrete test piece is placed. Thus, irradiation angle of laser from the SLDV is slightly oblique. The sound pressure near the concrete surface is about 110 dB. The number of scanned points is 195 (13 × 15), but the dimension of the scanned area was changed by the size of the buried object.

4.2 Experimental result at 10m distance

An example of the vibration velocity distribution is shown in Fig.6. In this case, the concrete test piece includes a styrofoam board (300×300×25 mm^3) at 5 cm depth. This image was acquired at 2004 Hz by SLDV software. A flexural oscillation of the styrofoam board can be clearly seen by the difference of the vibration velocities. It indicates a potency of our proposed method in a long distance(10 m).

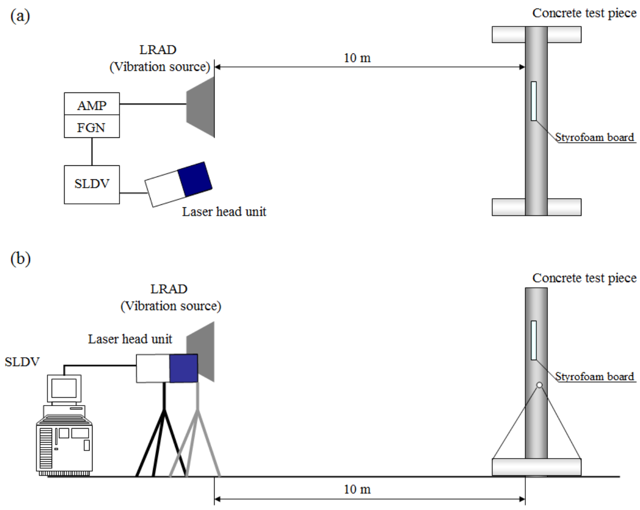

Fig. 5: Experimental setup for long distance emisson using a concrete tests piece. The distance between the LRAD and the concrete test piece is 10 m. Number of scan point is 195 (13 × 15). Dimension of the scan area is changed by the size of the buried object. (a)upper view, (b)side view.

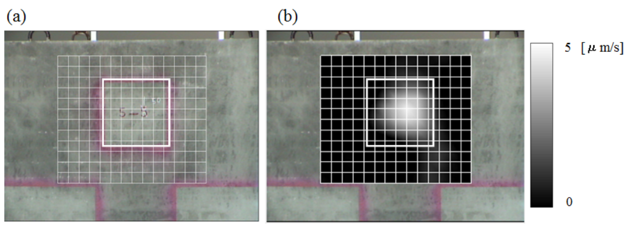

Fig. 6: Experimental result. A styrofoam board (300 × 300 × 25 mm^3) is buried in 50 mm depth of the concrete test piece. (a) Scan area and position of the buried object by CCD, (b) The vibration velocity distribution imaging result by SLDV. Chirp(1800-2400 Hz) is used, imaging frequency is 2004 Hz.

4.3 Detectable size and depth

Fig.7 shows examples of the vibration velocity distribution. In these case, the styrofoam board (200 × 200 × 25 mm^3) is buried in 45 mm depth, the styrofoam board (100 × 100 × 25 mm^3) is buried in 25 mm depth, and the styrofoam board (500 × 500 × 25 mm^3) is buried in 75 mm depth are shown in Figs.7(a)-(c) respectively. From these figure, we can clearly see the difference of vibration velocities between the area on the buried object and the surrounding area. However, in the case of the large target (700 × 700 × 25 mm^3), it is difficult to form a clear image, because the uniform vibration is difficult in the case of a large target. Therefore, the detectable size is from about 100 × 100 mm^2 to 500 ×500 mm^2, and the detectable depth is about 75 mm from the concrete surface at the current moment. By increasing the scanned points on the area, smaller target and plural target will be available.

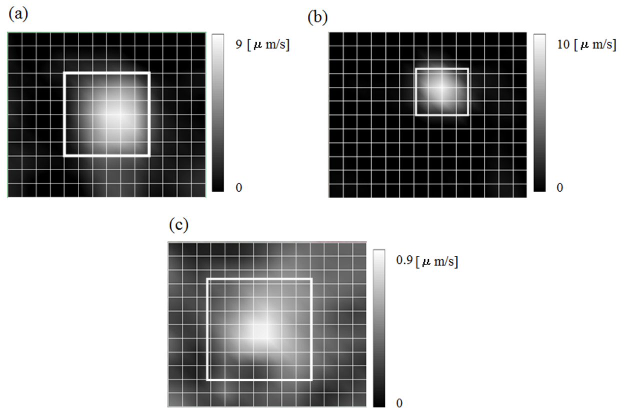

Fig. 7: Experimental results of the vibration velocity distribution image. (a) A styrofoam board (200 × 200 × 25 mm^3) is buried in 45 mm depth, imaging frequency is 2800 Hz, (b) A styrofoam board (100 × 100 × 25 mm^3) is buried in 25 mm depth. imaging frequency is 4000 Hz, (c) A styrofoam board (500 × 500 × 25 mm^3) is buried in 75 mm depth, imaging frequency is 1187.5 Hz,.

4.4 Detectable distance

To check the measurable distance in our proposed method, an experiment using the same target as Fig.6 was carried out. The set distances between the LRAD and the concrete test piece were 10 m, 15 m and 20 m respectively. Fig.8 shows the comparison of the brightness images when changing the distances. [6] The sound pressure near the concrete surface is adjusted about 120 dB. Linear up chirp (1800-2400 Hz) is used. From this figure, we can see that the frequency response range is clear and wide at 10 m distance, but the range is not clear and become very thin at 20 m distance. Therefore, we can confirm that the measurable distance is about within 20 m.

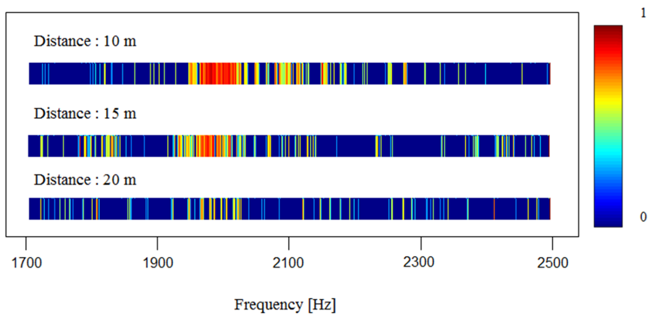

Fig. 8: Brightness image of the frequency response of the vibration velocity. The distance between a concrete test piece and a LRAD is 10, 15 and 20 m.

4.5 Effectiveness of OFR method

Fig.9 shows an example of the vibration velocities images which the buried object is buried diagonally. A styrofoam board (300 × 300 × 25 mm^3) is used. The average buried depth is 15 mm, but the upper side depth is 9 - 10 mm and lower side depth is 20 - 21 mm. From these figures, the high vibration velocity area moves according to each frequency. It is difficult to generate a uniform vibration, because the buried depth is not uniform. In such a case, the integration of the frequency response range is effective. A plane scale can be detected by applying the optimum frequency range method (OFR method) which we have already studied for underground exploration [7]. Fig.10 shows an applying example of the OFR method. In this case, a frequency range from 1300 to 1600 Hz were integrated. From this figure, we can see clearly the size and position of the buried object.

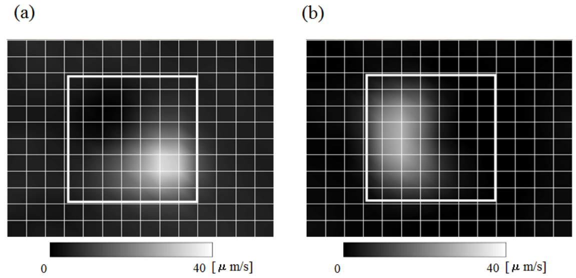

Fig. 9: Examples of the vibration velocities images which the buried object is buried diagonally. A styrofoam board (300 × 300 × 25 mm^3) is used. Average buried depth is 15 mm, but the upper side depth is 9 - 10 mm and lower side depth is 20 - 21 mm. (a) Imaging frequency is 1553.5 Hz, (b) Imaging frequency is 1422.5 Hz.

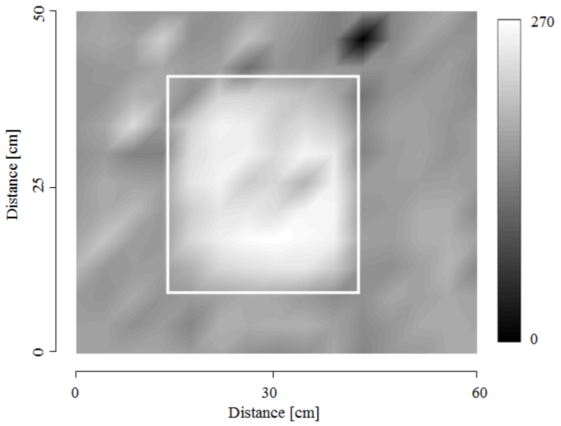

Fig. 10: An applying example of the optimum frequency range method (OFR method). In this case, frequency range from 1300 to 1600 Hz are integrated .

5 Conclusion

We proposed a new method of non-contact acoustic imaging method for non-destructive inspection using the SLDV and the LRAD. As a result of this experiment, a styrofoam which simulates a cavity in the concrete was clearly imaged as the vibration velocity anomaly on the concrete surface. Furthermore, we confirmed that our proposed method can apply even 10 m away distance, and the measurement distance is about within 20 m under the present conditions. It means that the non destructive inspection for concrete from a long distance is possible. Thus, there is a great likelihood that our proposed method will replace hammering test one of these days. As our future task, we will examine the minimum detectable thinness of a defect like a crack, and the influence of the angle with the measurement object by our proposed method.

Acknowledgments

This work was supported by JST, Seeds excavation examination A (2009 No.04-186) and Ministry of Land, Infrastructure, Transport and Tourism of Japan. Technology research development to contribute for improvement of the quality of the road policy (2010 Feasibility Study)

References

[1] Y.Shimada, O.Kotyaevm, H.Watanabe, M.Shinoda, H.Ohmura, Y.Sakamoto, T.Ozaki, K.Kondo : Jpn Soc Civil Eng **66** (2011) 246 [in Japanese].

[2] J.M.Sabatier and Ning Xiang : IEEE Trans. Geosci. & Rem. Sens. **39** (2001) 1146

[3] T.Abe and T. Sugimoto : Jpn. J. Appl. Phys. **48** (2009) 07GC07

[4] R.Akamatsu and T.Sugimoto : Acoust. Soc. Jpn. Spring. Meet. **3-8-7** (2011), 1569 [in Japanese].

[5] N.Utagawa, R.Akamatsu and T.Sugimoto : Jpn. Soc. Civil. Eng. **66** (2011) 1569 [in Japanese].

[6] T.Abe and T. Sugimoto : Jpn. J. Appl. Phys. **49** (2010) 07HC15.

[7] T.Sugimoto and T.Abe : Jpn. J. Appl. Phys. **50** (2011) 07HC18.