DEVELOPMENT OF ULTRASONIC TESTING TECHNIQUE TO INSPECT CONTAINMENT LINERS EMBEDDED IN CONCRETE ON NUCLEAR POWER PLANTS

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Abstract: The purpose of this study is development of ultrasonic testing technique to inspect containment liners embedded in concrete on nuclear power plants. Integrity of containment liners on nuclear power plants can be secured by suitable present operation and maintenance. Furthermore, non-destructive testing technique to inspect embedded liners will ensure the integrity of the containment further.

In order to develop the non-destructive testing technique, ultrasonic transducers were made newly and ultrasonic testing data acquisition and evaluation were carried out by using a mock-up.

We adopted the surface shear horizontal (SH) wave, low frequency (0.3-0.5MHz), to be able to detect an echo from a defect against attenuation of ultrasonic waves due to long propagation in the liners and dispersion into concrete. We made transducers with three large active elements (40mm x 40mm) in a line which were equivalent to a 120mm width active element.

Artificial hollows, Φ200mm - 19mm depth (1/2thickness) and Φ200mm - 9.5mm depth (1/4thickness), were made on a surface of a mock-up: carbon steel plate, 38mm thickness, 2,000mm length, 1000mm width. The surfaces of the plate were covered with concrete in order to simulate liners embedded in concrete.

As a result of the examinations, the surface SH transducers could detect clearly the echo from the hollows at a distance of 1500mm.

We evaluate that the newly made surface SH transducers with three elements have ability of detection of defects such as corrosion on the liners embedded in concrete.

Introduction: A containment vessel (C/V) on pressurized water type nuclear power plants (PWRs) is important equipment, which has functions to keep a reactor cooling system in the inside and to prevent the possible release of fission products to the environment in the event of a serious incident. The function of the final barrier of C/V can be confirmed by the leak rate test. It is assessed that there is almost no possibility of corrosion which influences the function of C/V on PWRs. [1)] Even if such possibility arises in future, it is possible to confirm existence of corrosion which influences the leaktight and structural integrity by the visual testing. However, a lower part of liner is embedded in a concrete structure. Hence it is inaccessible to inspect by the visual testing. Therefore, it is advisable to prepare inspection technology to provide against corrosion on embedded liners.

It is necessary to inspect an embedded wide area from an accessible point on liners. There are various candidate techniques under consideration for the inspection of embedded liners using ultrasonic waves by Electromagnetic Acoustic Transducers (EMAT)[2)] etc. All of them have still room for improvement, contact and access of sensor, Signal-Noise ratio, a distance of propagation and so on. It is thought that there is nothing to be applicable in the fields.

Selecting UT generally applied as non-destructive test technology for a structure from among these candidate techniques, we performed development of UT system for embedded liners. We have made newly surface SH wave transducers with large-size active elements. Since we considered that surface SH wave is effective in detection of defects on a surface and has little dispersion from a steel plate to concrete. Using a mock-up with artificial hollows simulating corrosion, we performed examinations to detect the hollows. As a result, the surface SH transducers could detect clearly echoes from the hollows at a distance of 1500mm. We evaluated that the newly made surface SH transducers with three elements have ability of detection of hollows on the mock-up embedded in concrete.

Results: Experiments were carried out in order to evaluate ability of detection of artificial hollows on a mock-up with UT transducers.

(1) Mock-up

A mock-up used for the experiments is shown in Fig.1. The mock-up was made of a carbon steel plate with a thickness of 38mm, a length of 2000mm, and a width of 1000mm. Artificial concave hollows simulating corrosion with a diameter of 200mm and a depth of 19mm (1/2 thickness of the plate) and a diameter of 100mm and a depth of 9.5mm (1/4 thickness of the plate) were made on one-side of the plate. These are located at a distance of 400mm from an edge of the plate. Simulating liners embedded in concrete, both sides of the plate were covered with concrete with a thickness of 200mm. A gap between the concrete and the hollow, which was considered to be made in the case of actual corrosion, was given. The hollow had a rough surface.

Installing transducers in the position not covered with concrete on a side far from hollows, incidence of ultrasonic waves was tried. To evaluate ability of detection of transducers, reflected echoes from the hollows at a distance of about 1500mm and the end of the plate at a distance of about 1900mm were investigated.

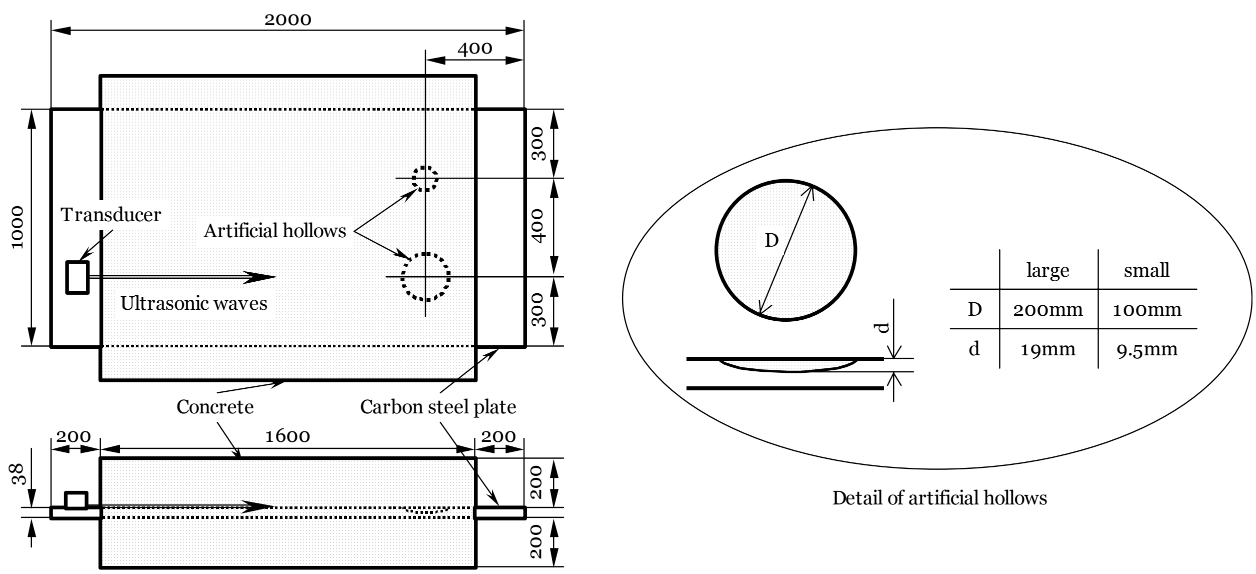


Fig.1 A view of a mock-up

(2) Selection of transducers

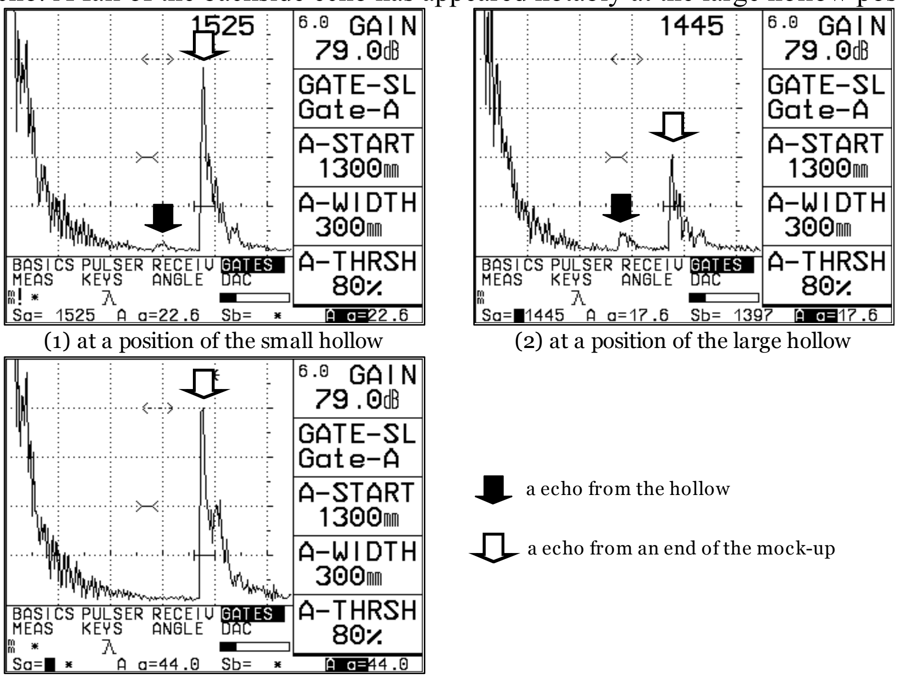
To apply ultrasonic waves to an embedded plate, the following is required.

- Ability to detect reflected sources on a surface such as corrosion
- Ability to propagate ultrasonic waves to a long distance
- Little dispersion of ultrasonic waves to concrete

In consideration of the above points, the surface shear horizontal (SH) wave was selected. We tried to adopt transducers with a large size of active element and low frequency for wide and long distance propagation. But there was a limit on an element size to generate SH waves which could be made. So, we tried to use conventional surface SH transducers, which had an element size 20mm (D) x40mm (W) with frequencies of 0.3, 0.5, and 0.7MHz. And a conventional ultrasonic flaw detector was used.

First, examination to investigate reflected waves from the hollows and the end of the mock-up was carried out with the mock-up not covered with concrete.

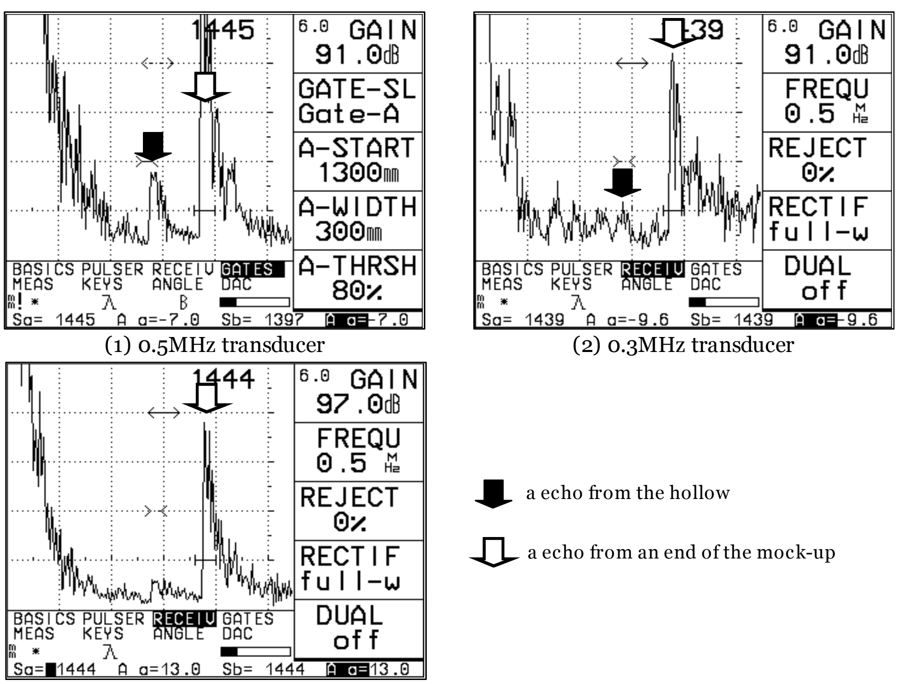
The results with 0.5MHz transducer are shown in Fig. 2. The transducer was set in a position of 120mm from the end of the mock-up far from the hollows. The large indication in the figures was a reflected echo from a backside of the mock-up at a distance about 1900mm from a transducer. Echoes from the large and small hollows could be discriminated at the time precedent to the backside echo. A fall of the backside echo has appeared notably at the large hollow position.



(1) at a position of the small hollow (2) at a position of the large hollow

(3) at a position of no hollow

Fig.2 Experiments with a mock-up not covered with concrete
(0.5MHz surface SH transducer with single element)



(1) 0.5MHz transducer (2) 0.3MHz transducer

(3) 0.7MHz transducer

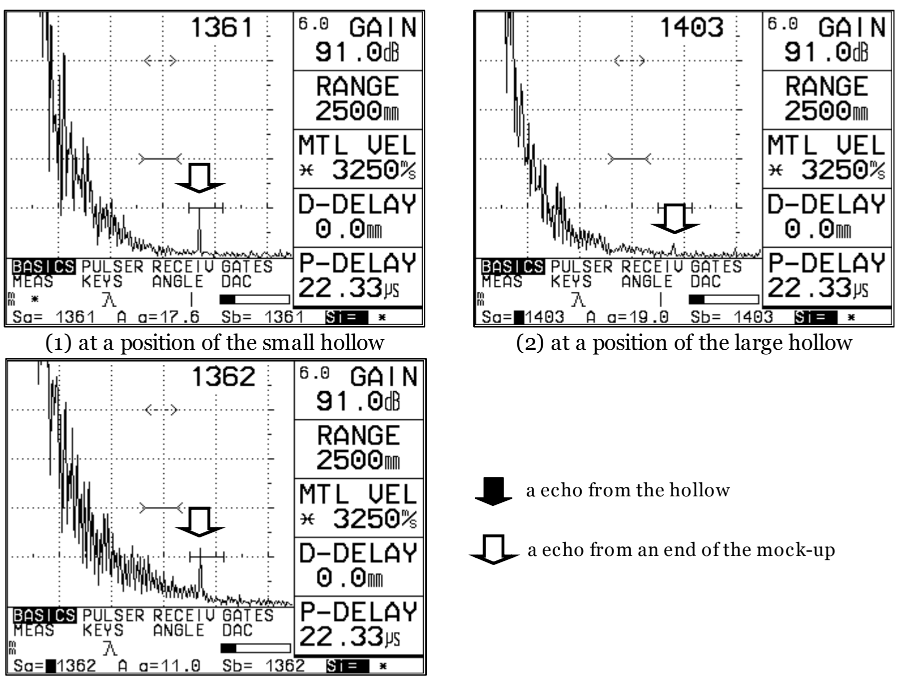
Fig.3 Experiments with a mock-up not covered with concrete
(0.3, 0.5, 0.7MHz surface SH transducer with single element at a position of the large hollow)

Fig.3 shows the results with different frequency transducers for the large hollow. The echoes from hollows and the backside with 0.7 MHz transducer were low compared with 0.5MHz. 0.3MHz transducer showed a result similar to 0.5MHz, but the S/N ratio of the echo from the hollow was low.

Next, examinations with the mock-up covered with concrete were performed. The results with 0.5MHz transducer are shown in Fig. 4. Echoes from the hollows, which were discriminated with the mock-up not covered with concrete, could not be detected and the backside echo was also low. These results showed that influence of dispersion to concrete on propagation of ultrasonic waves is great.

In order to take measures against ultrasonic waves dispersion, we tried to propagate ultrasonic waves more widely and powerfully. Using two transducers with 20mm(D)×40mm(W) elements in parallel, which were equivalent to a 20mm(D)×80mm(W) element, further experiments were carried out. The results with two transducers are shown in Fig. 5. These combined transducers could not detect echoes from the hollows either. But reflected echoes from the backside of the mock-up were more noticeable than single element transducers'.

The results mentioned above showed that it was effective to adopt transducers with large size element and low frequency (0.3MHz or 0.5MHz). There was still room for improvement.

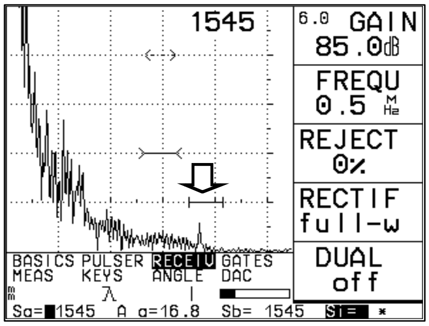


(1) at a position of the small hollow

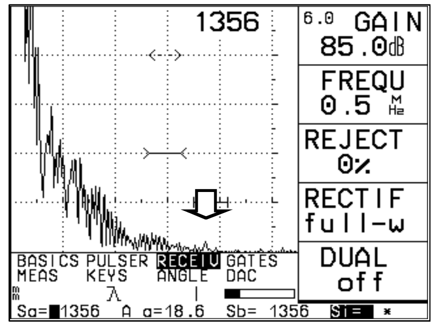
(2) at a position of the large hollow

(3) at a position of no hollow

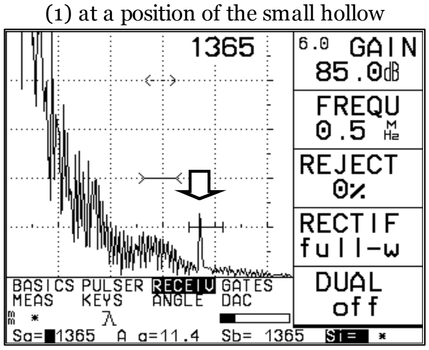
Fig.4 Experiments with a mock-up covered with concrete
(0.5MHz surface SH transducer with single element)



(1) at a position of the small hollow



(2) at a position of the large hollow



(3) at a position of no hollow

a echo from the hollow

a echo from an end of the mock-up

Fig.5 Experiments with a mock-up covered with concrete
(Using two 0.5MHz surface SH transducers with single element in a line)

(3) Improvement of transducers

On the basis of the effectiveness of the combined transducers, we made new transducers with three active elements of a size which could be made. Three elements were arranged in a line and driven at the same time. The transducer is shown in Fig. 6 and its specification is shown in Table 1. Frequency of transducers was 0.3MHz and 0.5MHz. A depth of active elements was 40mm which was twice the size of the conventional transducer used on the first experiment. Three active elements of 40mm width, which were equivalent to 120mm width, were assembled into one housing.

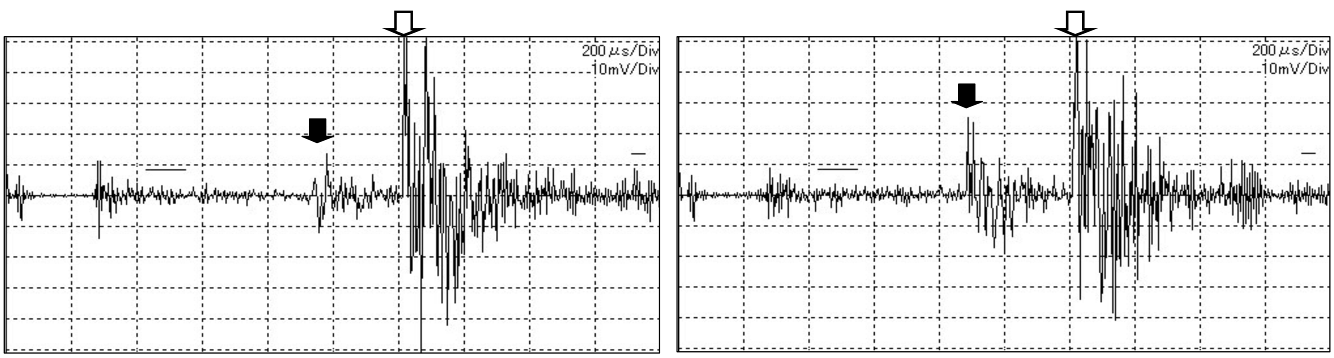
Fig.6 A view of the newly made surface SH transducer with three elements

Table.1 The specification of newly made transducers

Wave mode	Shear Horizontal Wave
Frequency	0.3 MHz, 0.5 MHz
Beam Angle	90°
Active Element	Ceramic 40mm × 40mm 3 Elements

Furthermore, since low frequency was effective, a low frequency ultrasonic pulsar/receiver which has a 0.08-6MHz frequency band (-3dB) was used. Ultrasonic waves signals were taken through a digital oscilloscope unit by a portable PC. We could make a frequency filter process to acquired signals.

Fig.7 shows the results of examinations with newly made transducers on the mock-up not covered with concrete. The frequency of transducer was 0.5MHz. A distance from the transducer to the hollows is about 1500mm, which is the same as the first experiment. These experiments with the three elements transducer showed that the ratio of the hollows echoes to backside echoes was high and the hollows echoes were clearly discriminable compared to the experiments with the single element transducers shown in Fig. 2. Though the echo from the small hollow was lower than the large hollow's, both echoes could be discriminated clearly.



(1) at a position of the small hollow (2) at a position of the large hollow

a echo from the hollow a echo from an end of the mock-up

Fig.7 Experiments with a mock-up not covered with concrete
(Newly made 0.5MHz surface SH transducer with three element)

The results with the mock-up covered with concrete are shown in Fig. 8. Echoes from the large and small hollows could be discriminated clearly. The attenuation of the backside echoes due to dispersion to concrete was not noticeable compared to the single element transducers.

The result with 0.3MHz three elements transducer is shown in Fig. 9. Echoes from hollows with 0.3MHz three elements transducers were also discriminated and clear.

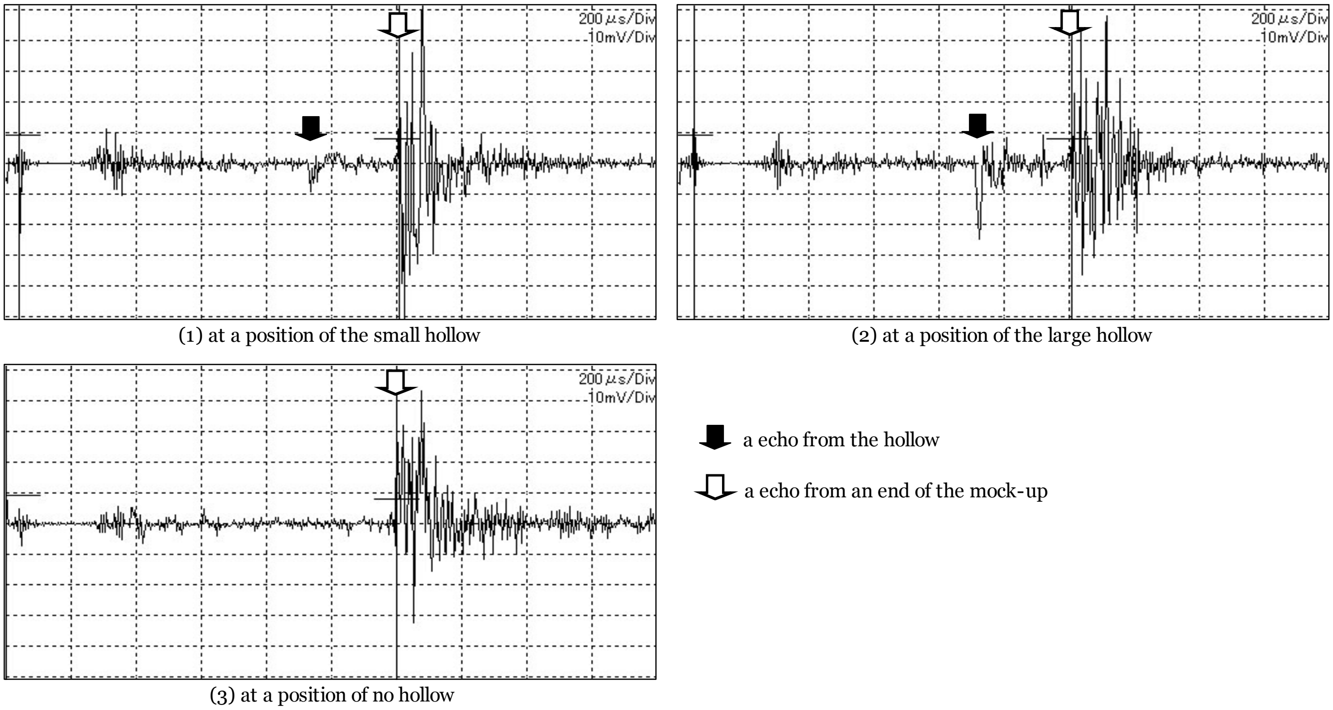


Fig.8 Experiments with a mock-up covered with concrete
(Newly made 0.5MHz surface SH transducer with three element)

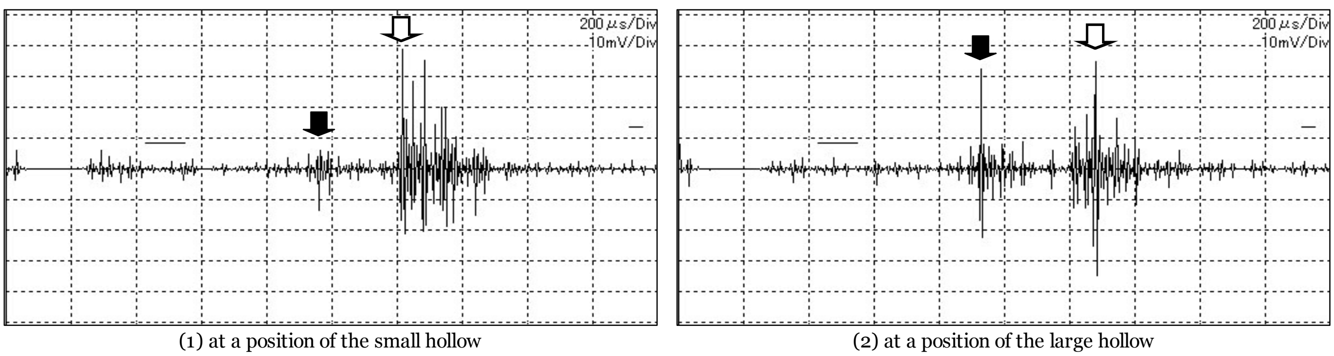
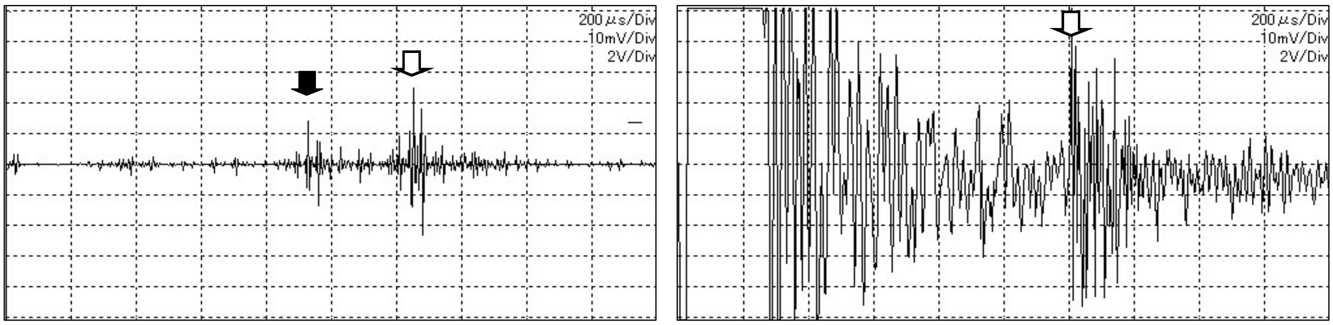


Fig.9 Experiments with a mock-up covered with concrete
(Newly made 0.3MHz surface SH transducer with three element)

Discussion: Conventional surface SH transducers, which have a single active element, used in the first experiment were not able to detect echoes from the hollows on the mock-up covered with concrete. We presumed that there was a mismatch between a pulsar/receiver's frequency band and transducers'. So, we adopted a low frequency ultrasonic pulsar/receiver. Moreover we tried various frequency band pass filter processes by computer to the ultrasonic waves signals acquired with the newly made three elements transducers. The investigations shown in Fig.7-9 were obtained by a frequency band pass filter process with about 70-250kHz.

A difference due to the frequency band pass filter process with 0.3MHz transducer is shown in Fig. 10. It was difficult to detect an echo from a hollow without the frequency band pass filter process. But using the frequency band pass filter process, we were able to detect echoes from hollows. The low frequency band pass filter was effective in discrimination of echoes from the hollows. And the low frequency band pass filter conformed with the frequency of transducers and pulsar/receiver well.

Attenuation of the backside echoes due to ultrasonic dispersion to concrete with the three elements transducers was small compared with the first single element transducers. This showed that enlargement of active element by using three elements was effective to propagation of ultrasonic waves on a surface of the plate covered with concrete.



(1) with frequency band pass filter process (2) without frequency band pass filter process

a echo from the hollow a echo from an end of the mock-up

Fig.10 A difference due to the frequency band pass filter process
(Newly made 0.3MHz surface SH transducer with three element at a position of the large hollows)

Conclusions: Experiments for detection of the hollows simulating corrosion on the mock-up covered with concrete were performed. The obtained conclusion is shown below.

- Low frequency (0.3 - 0.5MHz) surface SH transducers with three active elements were made newly.
- The hollows with a depth of 9.5, 19mm on the mock-up covered with concrete were clearly discriminated at a distance of about 1500mm from hollows.
- It was effective to adopt 70-250kHz frequency band pass filter process with the newly made transducers and low frequency pulsar/receiver.

Therefore we evaluate that the newly made surface SH transducers with three elements have ability of detection of defects such as corrosion on the liners embedded in concrete.

References: 1) Japan Electric Association, *Inservice Inspection of Light Water Cooled Nuclear Power Plant Components*, Japan Electric Association Code 4205-2000, Japan Electric Association, Commentary 12(2000), [in Japanese]

2) J. Li, J.L. Rose, “Guided wave testing of containment structures”, Materials Evaluation, 59[6], 783-787(2001)