EXAMINATION OF AE WAVE PROPAGATION ROUTES IN A SMALL MODEL TANK

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Abstract

This paper presents the results of a mock-up test executed to confirm accurate acoustic emission (AE) wave propagation routes. A 5-m diameter model tank was used and the propagation characteristics of the AE waves generated on the tank bottom plate were measured with sensors arranged at 100 mm intervals on the bottom plate and the wall plate in the test. It was confirmed that Lamb waves reached the wall plate, and the Lamb waves converted into other modes in water.

Keywords: Oil storage tank, Corrosion, Evaluation, Propagation route

1. Introduction

In evaluating the corrosion status of oil-storage tank bottom plates, acoustic emission (AE) waves that propagate in liquid are measured because AE attenuation is smaller in liquid than in steel. Although some studies up to 2002 have reported experimentally that the corrosion AE waves generated on the outside surface of the tank bottom plate propagate in water, no papers have conducted a detailed analysis of the results. It is important to accurately understand AE wave propagation routes. This is because locating the source of the AE wave generation requires the processing to be executed at a sound velocity that has been set to match the AE wave propagation route.

This study is aimed at confirming accurate AE wave propagation routes by conducting precision measurements (with densely located measuring points) of the pseudo AE waves generated on the tank bottom plate with a mock-up using a small model tank.

2. Experimental Procedures

2.1 Targets

This study was conducted under the following five test conditions (Points A, B and C are shown in Fig. 1).

a. AE waves generated on the center (point B) of the inside surface: Confirm the propagation conditions of AE waves generated at point B on inside the tank bottom plate without large effects by detoured AE waves through the tank wall plate.

b. AE waves generated on the quarter-point of the radius (point A) of the inside surface of the tank bottom plate: Confirm the propagation conditions of the AE waves that are propagated on the tank bottom and wall plates from point A on inside the tank bottom.
c. AE waves generated on the opposite quarter-point of the radius (point C) of the inside the tank bottom plate: Same as above in b.

d. AE waves generated in water 50 mm above point B: Confirm the propagation conditions of AE waves in water. In water sources are expected to be affected less by steel plates.

e. AE waves generated at point B on the outside surface: Confirm the propagation conditions of AE waves generated at point B on the outside surface of the tank bottom plate. This simulates the corrosion AE waves generated on the outside surface of the tank bottom plate.

2.2 Test Procedure

On a small, indoor model tank, we installed the pseudo-AE sources inside and outside of the tank, as shown in Fig. 1. The sources generated AE waves at each position. We measured AE waves with 19 AE sensors attached to the wall and bottom plate of this tank (refer to Fig. 2). We measured AE waves at 19 locations at a time. The measurement positions are on the intersection of grids shown in Fig. 2. This test also used the waveguide shown in Fig. 3 in order to generate AE waves in contact with the bottom plate (conditions a, b, c) and in water for the condition d.

Fig. 1 The view of the model tank and the positions A, B and C on the tank bottom plate.

On a wall plate, sensors (30 kHz) are attached ranging in height from 0 to 800 mm with a 100 mm pitch over the range of 1/4 round.

For the tank bottom plate, sensors (30 kHz) are mounted in one fourth of the ranges of bottom plate with 100 mm pitch.

Fig. 2 Sensor mounting position and water surface height.
3. Results

A typical result of the AE wave propagation is shown in Fig. 4. The data are represented by a three dimensional graph, which corresponds to one fourth of the tank shown in Fig. 1 (oblique lines). The bar graph that projects from the bottom plate upward represents the intensity of the AE waves measured on the bottom plate. The amplitude is color-coded in 10 dB range; i.e., 0 dB or more in red, 0 to -10 dB in purple, etc. followed by yellow, blue and green. The bar graph that projects from the wall plate horizontally is the intensity of the AE waves measured on the wall plate. In this figure, the red, blue and green solid lines indicate the furthest reach of propagating waves on the bottom plate and up the wall (green only in this example). These represent the theoretical wave velocities (calculated values) of the AE waves. The slowest waves propagate through the liquid (red circle), next is A\textsubscript{0}-mode (blue circle) and the fastest S\textsubscript{0}-mode (green circle) Lamb waves that propagate through the steel, respectively. The respective velocities were calculated as 1480 m/s, 2400 m/s and 5460 m/s, respectively.

From the tip of the A\textsubscript{0} and S\textsubscript{0} waves, mode-converted waves are radiated into the liquid as “bow-waves”. The positions of these waves on the center-cross-section are marked by blue and green lines at angles, $\theta_1$ and $\theta_2$. As shown in Note 1 and 2 in Fig. 4, these are 31.7° and 15.2°, respectively.

3.1 AE Wave Propagation Results

The propagation results in each test are as follow:

a. AE waves at the center of tank bottom plate (B point)
   Results of this test are given in Fig. 5, and we confirmed that AE waves spread concentrically. AE waves with amplitude of –20 dB or less spread first, followed by stronger AE waves with the amplitude of –20 dB or more. These AE waves are Lamb waves that propagate in steel because of their faster sound velocities than liquid propagating waves. The first waves propagated are S\textsubscript{0}-mode Lamb waves and the second, higher amplitude waves are A\textsubscript{0}-mode Lamb waves. The sensors attached to the wall plates observed AE waves radiated into water from the bottom plate. When the Lamb waves spread in steel while radiating P-waves into water, the first AE waves that propagate in water with the inclination defined by the ratio of velocities of water and Lamb waves. As noted above, these are $\theta_1$ and $\theta_2$.

b. AE waves from the quarter-point (A point)
   We verified that AE waves of Lamb A\textsubscript{0}-mode propagated concentrically, centered at the quarter-point (A point), but S\textsubscript{0}-mode Lamb waves could not be measured. It appears that the tank frame support was directly under the AE generation point, and S\textsubscript{0}-mode waves were attenuated by the rubber board inserted between the support and bottom plate.

c. AE waves at the second quarter-point (C point)
   We verified that AE waves at C point of the tank bottom plate propagated concentrically to the wall plate near the AE source before they reached the other sidewall.
AE waves in water above the center of tank bottom plate (B point)
This test was intended originally to measure only the water propagating waves. The results, however, were similar to ‘a’ above in which AE waves were generated on the tank bottom plate. It appears that AE waves first entered into steel through water, then propagated in steel. This is because the distance between the AE source and the tank bottom plate was ~50 mm and waves through water are much slower than the Lamb waves.

E. AE waves at the back surface of B point
In this test, AE waves generated at the back surface of the center tank bottom plate were detected. The results were similar to AE waves generated on the face shown in ‘a’ above.

4. Discussion
The test results given in Fig. 5 indicate that, although the first AE waves generated on the center of the bottom plate is small with its amplitude less than -20 dB, it reached the bottom plate circumference 600 μs after the generation. Using the relationship between the propagation distance and the arrival time, the sound velocity of the first arrival wave was calculated as 4,167 m/s. While this sound velocity was close to that of the Lamb waves in $S_0$-mode (5460 m/s), it is about one-fourth slower. It is difficult to presume it to be the $S_0$-mode Lamb wave. Since the Lamb waves radiate mode-converted AE waves in water moving at the slow P-wave velocity (1480 m/s), as shown in Fig. 4, the first waves reaching the wall plate are likely to be the mode-converted P-waves. If the first arrival waves propagate in the bottom steel plate 2/3 of the time
and the rest through water, the observed wave velocity is expected. In distance term, the waves propagate almost 90% in steel and 10% in water.

Next, we examined the state of propagation of the AE waves indicating high maximum amplitude (hereafter the maximum AE waves), shown by orange bars in Figs. 4 and 5. This indicates a large amplitude of -20 dB or higher. The maximum AE waves reached the circumference of tank bottom plate in 1,300 µs. The sound velocity of the maximum AE waves was calculated to be 1,923 m/s. This is close to that of the A0-mode Lamb waves, but again it is slower, giving a high possibility that the maximum wave is mode-converted waves from the A0-mode Lamb waves.

We confirmed the propagation of the P-waves in water, shown in red in Figs. 4 and 5, which expand spherically. In this test, many of the sensors that were installed on the wall plate measured the maximum value at times between 1,600 to 1,700 µs when the waves propagating through the water reached the wall plate.

In this study, we confirmed that, with a small tank of 5 m in diameter, the Lamb waves propagate through the steel and reach the sensors without much attenuation. It was also found that the AE waves, which have undergone a mode conversion from the Lamb waves entering from the bottom plate into the water, reached the wall plate. In actual tanks, the bottom plate contacts the ground, probably causing Lamb wave attenuation. In measuring AE waves in small tanks, however, it is essential to take into account the effect of the Lamb waves.

5. Conclusion

This study clarified the details of the propagation of AE waves on the bottom plate and the wall plate, and the following findings were obtained:

1) It was confirmed that the AE waves generated on the bottom plate propagate in the liquid and reach the wall plate.
2) For a small tank (5 m in diameter), the attenuation of the Lamb waves propagating in the steel is small, and the waves reach the wall plate with their signal intensities above the threshold of 40 dB AE (−40 dB in the data of this test) as prescribed in corrosion evaluation by the AE method. Therefore, it is important to evaluate corrosion by taking into account the effect of the waves propagating in water.

Based on the results of this test, it was confirmed that, in applying the evaluation technology for tank bottom plate corrosion to large actual tanks according to the AE method, the AE waves that propagate in liquid with a little attenuation could be made the main measuring means. It was confirmed that, in applying the AE measurement to small tanks, it is necessary to set measuring conditions that take into account the effect of the Lamb waves that propagate in the steel plate.

References

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Fig. 5 AE waves generated at the tank bottom plate center (B point) surface.