QUANTITATIVE STUDY OF ACOUSTIC EMISSION DUE TO LEAKS FROM WATER TANKS

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Abstract

Leakage from tank floor can possibly pollute the environment or cause major accidents. To prevent them, acoustic emission (AE) testing has come to the fore as a means of inspecting tanks without taking them out of service. Under the AE method, however, there are almost no data on leakage; the basic characteristics for leakage have not been elucidated. This paper presents the results of a study, using a water tank for fire-fighting, involving the measurement of AE waves generated by leakage of water from small holes made in the bottom, in order to identify the fundamental characteristics and clarify the differences from AE results in the case of corrosion.

Key Words: Acoustic emission; Oil tank; Leak detection; Tank bottom; Tank floor; Corrosion; Location

1. Introduction

Although the number of oil tanks installed in Japan is steadily declining (1), the number of accidents associated with leakage is steadily rising (2). The principal cause of these accidents is deterioration due to factors such as corrosion. Caution is required particularly with large-capacity oil tanks, because leakage from them can assume large proportions if detection is delayed. To prevent such accidents, the law requires all oil tanks with a capacity of at least 1,000 kl to undergo an overhaul inspection at a prescribed interval. In contrast, such overhaul inspections are not legally required for oil tanks with a capacity of less than 1,000 kl; the enterprises in question are to fix overhaul intervals and check them on their own initiative (3). In some cases, leakage of contents from floor is not immediately detected; it is discovered only after being carried by groundwater under the tank foundation into rivers, etc. Such accidents pose major pollution problems.

Regardless of the amount, leakage from the bottom of oil tanks constitutes a serious social obligation of the parties responsible for preserving their safety and imposes a substantial economic burden. Deterioration associated with corrosion is the cause of most such leakage, and its prevention is therefore one of the key tasks of oil tank safety management. In recent years, acoustic emission (AE) testing has been attracting attention as a technology for fulfilling this task. It enables assessment of the damage from corrosion on the tank floor without overhaul (i.e., opening). In Japan, AE testing has been conducted on over 20 tanks (4 - 8), and the country is beginning to acquire its own database for AE testing (6). Nevertheless, data on leakage from tank bottoms are not included in this database, and the fundamental characteristics of AE waves for leakage detection have not been illuminated.

The study that is the subject of this paper was conducted with a tank storing industrial water for firefighting (to be referred to as "water tank"). It consisted of the measurement of AE waves...
generated in the event of leakage of water from small holes made in the bottom. Its objective was to ascertain the fundamental characteristics and to clarify the differences from AE waves associated with bottom damage due to corrosion.

2. Experimental Procedures

Test objectives

We deliberately made holes of varying diameters in the floors of the water tank, and detected and analyzed the AE signals from actual leakage in order to identify the marginal hole diameter (measurements) for leakage detection. An additional objective was to collect quantitative data related to the signal energy level, etc.

Test method

Water tank specifications are given in Table 1.

Table 1 Specifications of the water tank used in the study.

<table>
<thead>
<tr>
<th>Capacity (kl)</th>
<th>Diameter (m)</th>
<th>Height (m)</th>
<th>Content</th>
</tr>
</thead>
<tbody>
<tr>
<td>200</td>
<td>6.7</td>
<td>6.0</td>
<td>Water</td>
</tr>
<tr>
<td>Max water</td>
<td>Floor board thickness (mm)</td>
<td>Side board thickness (mm)</td>
<td>Years used</td>
</tr>
<tr>
<td>Level (m)</td>
<td>6.0</td>
<td>6.0</td>
<td>24</td>
</tr>
</tbody>
</table>

(1) System: The study applied the system shown in Fig. 1 for detection of AE due to leakage from the tank floor. Three AE sensors (30-kHz resonant) with built-in preamplifiers were installed along the tank circumference at equal intervals and in an equilateral triangle array, 1.2 m above the bottom. For AE measurement and assessment, we utilized the DiSP system manufactured by Physical Acoustics Corp.

![System diagram](image)

Fig. 1 The system applied in the study.

(2) Fabricated leakage holes: A total of five holes were made to simulate damage resulting in leakage. Based on the diameters of holes discovered in oil tank bottoms thus far, the smallest had a diameter of 1 mm, and the other four were given respective diameters of 3, 5, 7, and 9 mm in order to confirm detection limits. To facilitate the extraction of plugs inserted into the holes from the manhole on top of the tank, the holes were opened under it. Figure 2 shows the hole array.
As for plugs, we used iron wire to plug the 1-mm hole and sheathed copper wire to plug the 3-mm hole. The wires were inserted into the holes and then caulked with putty to seal any interspaces. For the 5-, 7-, and 9-mm holes, plugs were fabricated from silicon rubber caps and forced into the holes. Once the plugs were inserted into the holes, stainless steel wires (with a diameter of 0.3 mm) were attached to them and strung to the manhole at the top. The water level was set at 5.7 m (the full-tank level) in the first AE measurement and 2.0 m (the minimum fluid level of ordinary oil tanks) in the second measurement. After the water was put into the tank, we waited for at least two days before starting the AE measurement, in order to stabilize the water surface.

(3) Test procedure: We first made an AE measurement when there was no leakage, then extracted the plug from the 1-mm hole by pulling the wire attached to it from the top manhole, and measured AE during the resulting leakage. This was followed by plug extraction and AE measurement with the other holes. Therefore, beginning with the 3-mm hole, there was leakage from multiple holes, until all of the holes were finally unplugged.

3. Test Results

(1) 1-mm hole: As shown in Fig. 3, although almost no AE were detected before the plug was extracted from the 1-mm hole, the number of hits rapidly rose once the extraction was made, about 100 s after the start of the test. As used here, the term "number of hits" refers to the number of times that the amplitude of the detected AE waves exceeded the threshold value in one second. The threshold value was 43 dB for leakage from the holes with diameters ranging from 1 to 7 mm, and 60 dB for that from the 9-mm hole.

As for amplitude, a sensor output of 1 µV was assigned the value of 0 dB. As shown in Fig. 4, we observed the continuous occurrence of AE with the amplitude in the range of 43 - 48 dB, and also detected AE with the amplitude in excess of 60 dB at the maximum. In other words, even for leakage from the 1-mm hole, the number of AE detections was much higher than when there was no leakage, and the energy level increased as shown in Fig. 5. For the energy levels shown in Fig. 5, we used the product of the amplitude of 10 V x duration of 1 ms corresponding to 1,000. From these measurement results, it was concluded that AE testing was fully capable of detecting leakage from holes even with a diameter of 1 mm.
(2) 3-mm hole: When the plug in the 3-mm hole was extracted after leak monitoring of the 1-mm hole, the level of AE activity increased markedly. Numerous AE with amplitude in the range of
43 - 60 dB were detected in succession and made it very easy to detect leakage. In contrast, the number of hits declined, because the AE amplitude continuously exceeded the threshold value.

(3) 5-mm and larger holes: Next, we extracted the plugs from the holes with larger diameters, one after the other. AE with large amplitudes in the range of 80 - 90 dB occurred in large numbers and made leakage detection extremely easy. When the plug in the 9-mm hole was finally extracted, there arose many bursts of large-amplitude AE. These had a very high energy level, as shown in Fig. 5. On this occasion, we verified the existence of a large quantity of leakage at the tank bottom.

**Leakage location ranging**

Figure 6 shows the results of a ranging of the plane location of the AE signals detected for the 1-mm hole. Figure 7 presents 3D expressions of the integrated values for the number of AE hits detected. As is clear from these figures, the occurrence of AE signals was concentrated in the vicinity of the hole. This suggests the possibility of making an assessment to determine the leakage locations to a certain degree. As shown in Fig. 8, on the other hand, it was not possible to range the location for the 5-mm hole, because of the continuous AE waveform. Figure 9 shows the AE waveform obtained for leakage from the 9-mm hole. It can be seen that the location cannot be ranged because of the continuous occurrence of large-amplitude AE waves. Therefore, it may be concluded that ranging is possible to a certain extent in the case of leakage from a small hole with a diameter of about 1 mm but not in that of leakage from larger holes.

**Implications**

Figures 3 - 5 showed that the AE waves measured from the leakage were clearly different from those occurring when there was no leakage. Figure 10 shows an example of AE waveforms.
detected as a result of corrosion. Whereas the AE waveforms due to corrosion began to attenuate in about 1 ms, those due to leakage occurred on a continuous basis, as shown in Fig. 9. Figure 11
Fig. 8  Floor location plot; plan view (5 mm ø).

Fig. 9  Example of the waveforms in case of 9 mm ø hole.
shows the change over time in the AE amplitude obtained in the AE testing for assessment of the degree of floor corrosion before extraction of the hole plugs. Whereas the amplitude in AE due to corrosion was detected only sporadically, that due to leakage was detected continuously. These differences provide the basis for a clear distinction between corrosion and leakage in AE testing.

Table 2 presents the relationship between the hole diameters and the AE signal amplitudes obtained in the testing. The results indicate that, in the case of small-scale tanks with a diameter of about 10 m (equivalent to non-specified tanks with a capacity of less than 1,000 kl), it would be fully possible to detect leakage from holes with a diameter of about 1 mm through an AE testing and also to specify the leakage location to a certain extent. Even considering the AE wave propagation attenuation in the stored contents (9), detection of leakage is estimated to be possible in large-scale tanks with a diameter of about 80 m, provided that the leakage holes are at least 5 - 7 mm in diameter.

An overseas study presents the results of an AE test for leakage from a diesel oil tank in which a hole with a diameter of 1 mm was detected in the floor (10). In this case, the epoxy coating on the tank interior had been damaged in certain places, with the result of progressive local corrosion and the occurrence of pinholes. The leakage was confirmed by regular AE
Table 2 Relationship between hole diameter and amplitude.

<table>
<thead>
<tr>
<th>Diameter of leak hole</th>
<th>Amplitude (dB) (water level 2.0m)</th>
<th>Amplitude (dB) (water level 5.7m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 mm ø</td>
<td>43〜48</td>
<td>43〜48</td>
</tr>
<tr>
<td>3 mm ø</td>
<td>43〜50</td>
<td>43〜60</td>
</tr>
<tr>
<td>5 mm ø</td>
<td>43〜55</td>
<td>43〜70</td>
</tr>
<tr>
<td>7 mm ø</td>
<td>43〜60</td>
<td>43〜70</td>
</tr>
<tr>
<td>9 mm ø</td>
<td>43〜60</td>
<td>Max 90</td>
</tr>
</tbody>
</table>

testing, and the study described herein provides corroboration for the possibility of leak detection noted by the overseas study. Particular importance is attached to leakage detection in other countries. France and the United Kingdom are strongly recommending AE testing as a method for detection of leakage from tanks. The aforementioned recommended procedure for AE application was prepared in France. In the United States, AE testing is conducted for the purpose of preventing the occurrence of major accidents due to leakage in states with stricter environmental regulations.

This study was the first to make a quantitative analysis of the possibilities of detection of leakage from tanks through AE testing. It furnishes data that are applicable for judgments and assessments regarding leakage detection in future AE testing of tanks.

4. Conclusion

The study consisted of AE measurements related to artificial leakage from the floor of a water tank and examination of the implications of the measurement results. It showed that a clear distinction could be drawn between AE due to leakage and that due to corrosion. Furthermore, it also confirmed that AE testing would be fully capable of detecting leakage from holes with a diameter of about 1 mm in small-scale tanks with a diameter of about 10 m (equivalent to non-specified tanks with a capacity of less than 1,000 kl). In addition, it brought to light prospects for specification of the leakage location to a certain extent.

Even taking account of the attenuation of AE wave propagation in the stored contents, leakage is thought to be detectable in large-scale tanks with a diameter of about 80 m, provided that the leakage holes are at least 5 - 7 mm in diameter. It is hoped that the study results will provide a standard for judgments about leakage in AE testing.

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References