IN-SITU NON-DESTRUCTIVE MONITORING OF WATER FLOW IN DAMAGED AGRICULTURAL PIPELINE BY AE

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ABSTRACT

Deterioration of water-flow function in a pipeline system has resulted from water-leak accidents due to damage accumulation in pipe materials. The repaired pipeline system cannot be evaluated of water-leak phenomena under the inner water pressure condition. Non destructive evaluation of water-flow function in pipeline system is currently in urgent demand. In this study, acoustic emission (AE) method is applied to the evaluation of water-flow function in an existing agricultural pipeline, which was inspected and then repaired after water-leak accidents. At three conditions, experiments were conducted. First, a water leak phenomenon which the pipeline filled full with water was investigated. Secondly, an evaluation process of water-drained from full to empty condition was made in the pipeline. Thirdly, experiments were carried out condition of the pipeline was filled with water after repairing the water-leak section. AE method was applied to detecting signals of water-leak and flow under these conditions. The results show that water-leak in the pipeline system could be quantitatively evaluated by using such AE parameters, such as generation behavior and AE energy. In the third condition, AE generation behavior was varied with the situation of the pipeline until the pipeline was filled with water. AE energy showed the same tendency as AE generation behavior. When an AE sensor was installed on an air valve, AE energy dropped temporarily as the pipeline was being filled with water. However, when water was filled up to the air valve, the increase in AE energy was confirmed. Thus, it becomes clear that when a pipeline is being filled with water after the repair, the situation of water in the pipeline can be clearly identified through AE monitoring. Discharge evaluation of a damaged pipeline system can be conducted in a short time through AE monitoring.

INTRODUCTION AND RESEARCH BACKGROUND

When planning a water pipeline system, the size of a facility and a structural system are determined only from the results of hydraulic analysis. In existing pipeline systems, however, water leakage accidents have been reported in the deteriorated sections of the system due to the cumulative damage of pipeline materials (Nawa et al, 2002). The measures taken by pipeline administrators are mainly winding-up treatments on-site after leakage has been recognized. As a

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result, recently the unsafe sections have been expected to exist in the pipe system from statistical analysis using leak accident data. For maintenance and management in existing structures, non-destructive testing (NDT) methods need to be developed, because pipeline systems are installed underground and the damage can not be checked visually in service. In recent work, it was reported that elastic wave method (e.g. acoustic emission) is effective for leak detection in pipeline system (Vahaviolos et.al, 2001; Kamiya et al. 2002). The acoustic emission (AE) method is passive technique for detection of elastic wave from existing structures.

In this study, the NDT techniques are developed in water pipeline systems using acoustic emission (AE) method, which detects elastic waves passively (Suzuki et al, 2004). This paper reports 3 results of quantitative evaluation of AE measurements in an existing agricultural pipeline.

NON-DESTRUCTIVE MONITORING OF PIPELINE SYSTEMS BY ACOUSTIC EMISSION METHOD

Propagation and measurements of elastic waves

There are basically two types of hydraulic conditions in pipeline systems; a stationary state, and a non-stationary state, depending on whether the water flow velocity and water pressure change with time or not. A non-destructive evaluation method had been developed previously, focusing on water-leakage phenomena. High-accuracy non-destructive monitoring requires a quantitative evaluation of both the stationary and non-stationary states of the water flow. In the measurements of water pipeline systems by the AE method, elastic waves emitted from the structure are

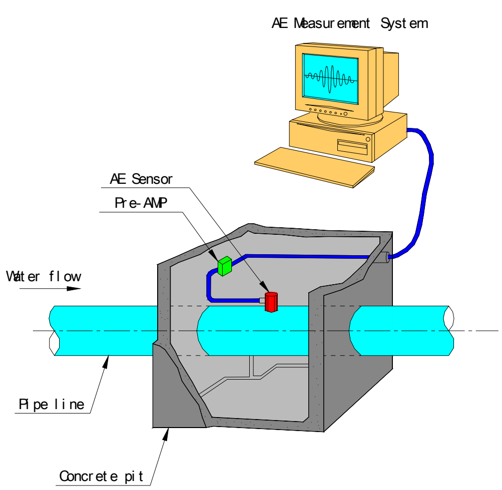

Figure 1. AE measurement system in pipeline

Photograph 1. Monitoring outline

detected passively by AE sensors, as shown in Figure 1 and Photo 1. These evaluation is conducted for the elastic waves detected by AE sensors which are attached to the pipe surface.

Properties of detected AE wave

The elastic waves transmitted from water in pipelines have different properties depending on the hydraulic conditions inside the pipeline. The elastic waves change the component properties, depending on the scale of the phenomena and monitoring conditions in the propagation process. An example of a water-leak wave, measured at a point 40 m away from the leakage point when

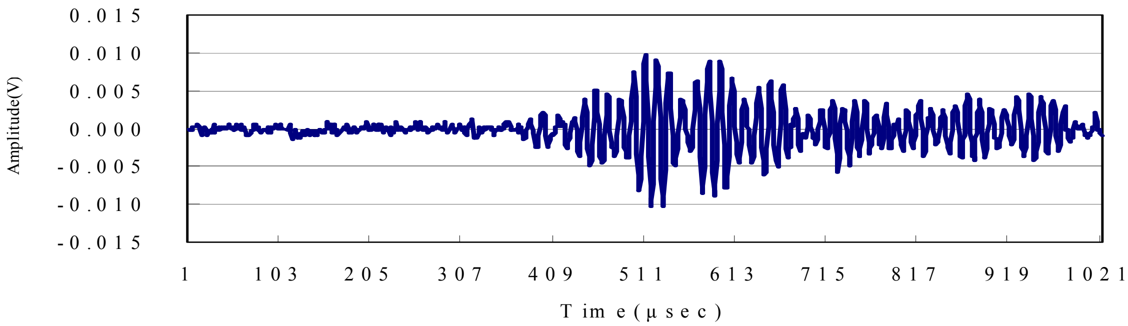

Figure 2. Leak wave detected from an existing pipeline
(V=0.0m/s, Leak point: about 40m away from monitoring site)

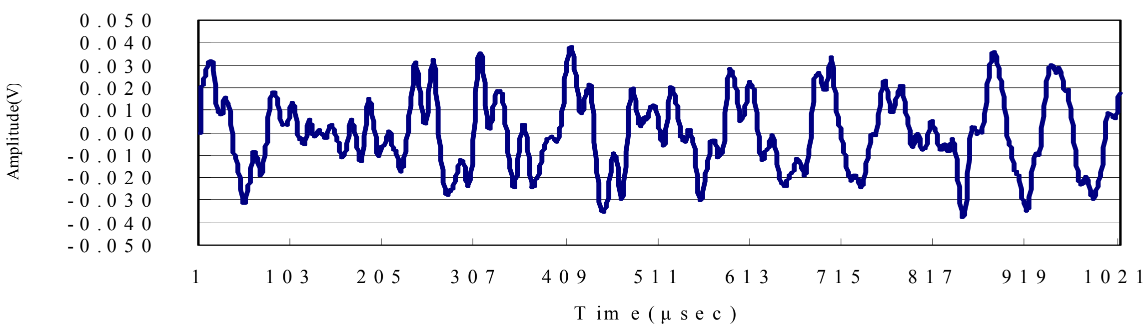

Figure 3. Leak wave detected from an existing pipeline
(V=1.5m/s, Leak point: about 50cm from monitoring site)

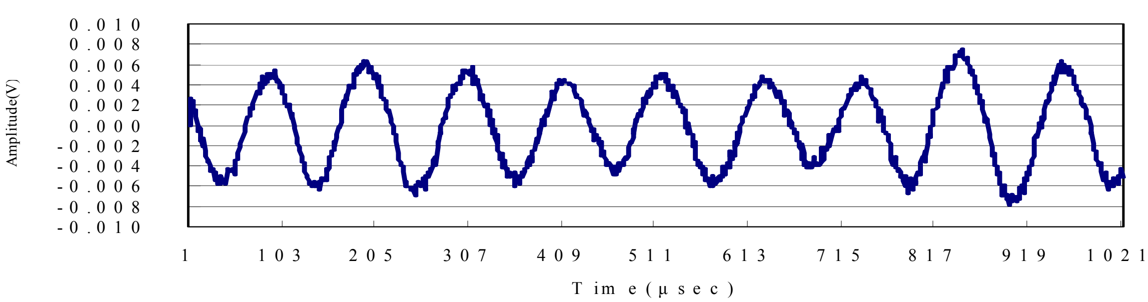

Figure 4. Water flow wave detected under inner water pressure conditions

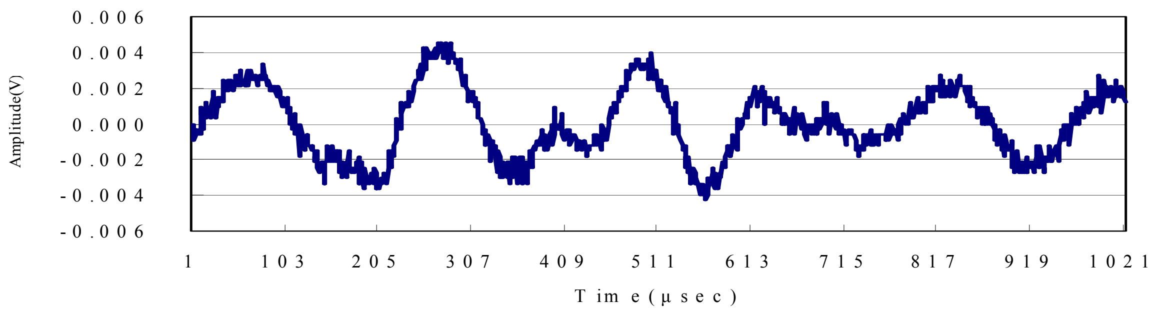

Figure 5. Water flow wave detected in pipeline that has water surface

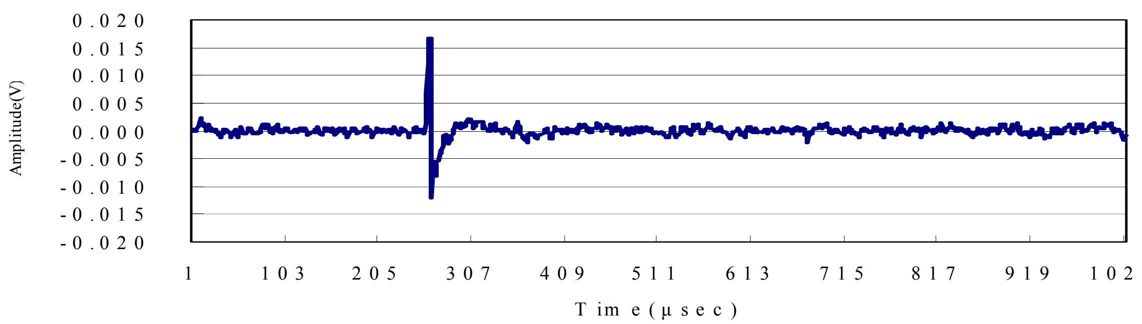

Figure 6. Environmental noise (traffic noise)

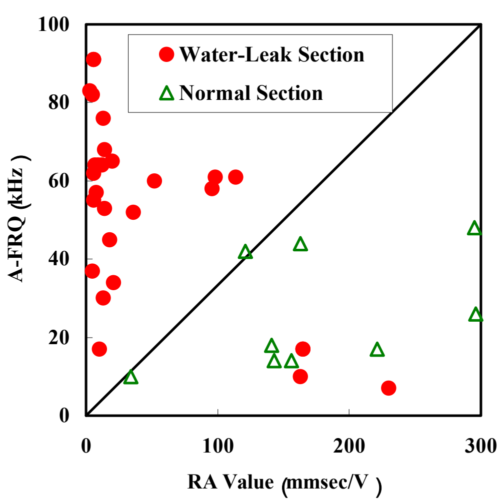

Figure 7. Relations between RA value and A-FRQ

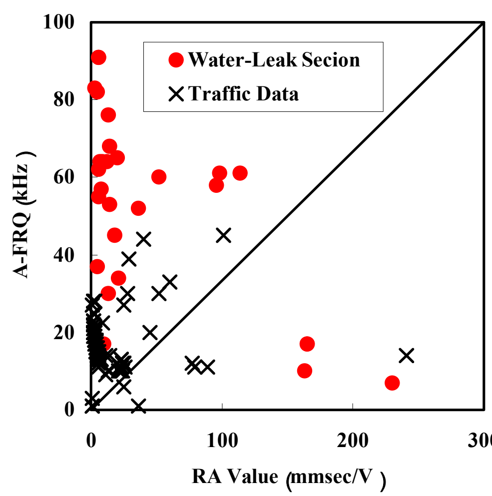

Figure 8. Relations between RA value and A-FRQ (Traffic noise)

water flow was stopped, is shown in Figure 2. Compared with the water-leak wave in Figure 2, the water-leak wave measured near the leakage point when water was flowing, exhibited properties of an irregular continuous wave, as shown in Figure 3. A comparison of Figures. 2 and 3 shows that the wave measured at a point farther from the leakage point in Figure 2 had a higher frequency than the wave measured at a near point in Figure 3. This difference may have been caused by differences in hydraulic conditions inside the pipeline. The elastic wave was shown in Figure 3, a composite wave of those in Figs. 2 and 4. The composite wave has a stronger effect from an elastic wave when water is flowing than from a water-leak wave. Therefore, to detect leakage under normal management conditions, there must be a thorough understanding of the hydrological conditions inside the pipes. Evaluating the characteristics of detection waves using AE parameters, it is possible to conduct a quantitative evaluation. For example, AE rate process analysis, and the analyses focusing on the relation between RA values and average frequency and the relationship between energy and AE generation behavior have been found to be effective for detecting leakage (Suzuki et al. 2004, Suzuki et al. 2005). In cases where the AE method is applied to discharging tests or verification of repair works to pipeline systems, continuous waves with low regularity can be detected when water is filled at the stage where there is a free water surface, as shown in Figure 5. After that, when the water has been filled, continuous waves having regularity can be detected, as shown in Figure 4. If water leakage occurs at that time, the water-leak wave shown in Figure 3 (not Figure 4) will be detected. In this series of investigations, analyses focusing on the relationship between energy and AE generation behavior were found to be effective. In monitoring with the elastic wave method, it is difficult to distinguish environmental noise from the object being measured. Very often buried pipeline systems are located under roadways. The source of environmental noise is automobile traffic. Detection waves taken from existing pipes while automobiles were passing are shown in Figure 6. As shown in Figures. 2-5, there were distinct differences between elastic waves that were detected while water was flowing or leaking and environmental noise. The above findings indicate that setting proper monitoring conditions enables the AE method to be used to detect elastic waves that occur inside pipes under various hydrological conditions even when there is environmental noise. In elastic wave method, it is effective to quantitatively evaluate the properties of detection waves; AE parameters are considered to be particularly effective.

Improving the S/N ratio by eliminating environmental noise

In non-destructive monitoring, environmental noise is usually a problem. Environmental noise with pipeline facilities is usually vibrations from passing vehicles or trains. There is also electromagnetic noise that originates from nearby high voltage power lines. One way to effectively eliminate such noise is to process mathematically the features of measured waves. AE behavior of a pipeline with water flow or leakage was associated with inner water pressure. Noise reduction was used to AE parameters of RA value (rise time/peak amplitude) and the average frequency (AE ring down count/duration).

In this study, an existing pipeline system is examined, applying AE method. AE monitoring was conducted at Kasanohara main channel located in Kanoya, Kagoshima, Japan. The pipeline system was constructed 36 years ago. Water leak accidents occurred 92 times (2.6 leaks per year on average) from 1967 to 2002. 70% of water leaks occurred at joint sections.Inner water pressure was measured as 0.44 MPa under normal operation. AE monitoring was conducted after a gate valve had been closed. The inner water pressure dropped by 23% in 30 minutes, from 0.44 MPa to 0.34 MPa.

AE generating behavior of the leaked section was compared with that of the traffic noise in terms of RA value and the average frequency (JSCM 2003). Results are shown in Figure 7 and 8. Frequencies of traffic noise were lower than 20 kHz. Water leak phenomena were higher than 30 kHz. There is a clear difference between Water-leak and Noise due to traffic. The improvement of S/N ratio that used AE parameter was possible according to relationship RA value and average frequency. Therefore, for the reduction of environmental noise of AE monitoring in pipeline system, AE parameter analysis is effective.

EFFECT OF ELASTIC WAVE PROPAGATION PROPERTIES ON MONITORING ACCURACY

Effects of distance decay and soil conditions

During the propagation process, elastic waves show noticeable energy decay due to the properties of the propagating material or reflection. The most basic factor for defining the properties of elastic wave energy decay is the distance decay. Considering the internal attenuation of the propagating medium, the amplitude *u* at a distance *r* from the vibration source can be analytically derived as Eq. (1) below:

$$u = u_0 e^{-\lambda r} r^{-n} \qquad (1)$$

In the model water leakage test, the amplitude of the detected AE wave was an average 60dB at a defective part of 2.0mm, and there were few discrepancies caused by internal water pressure. The water leakage was simulated under the following measurement conditions: water pressure inside SGP20A (20mm diameter) pipes of 0.3 to 0.8MPa, with four types of model defects (0.3, 0.5, 1.0 and 2.0mm). When water leakage is detected from a roadway by ear, a 10Hz wave is propagated 2m with the amplitude decrease by about half, assuming an attenuation ratio of 0.05 and an elastic wave velocity of 500m/s in the soil. The effect of distance decay increases as the frequency band of the water-leak wave increases. At a frequency of 20kHz (at which water leakage is detectable by the human ear), when the wave amplitude is 60dB near the defective part, attenuation results in a detected wave amplitude of 2.4dB, 96% decay at a point 2.0m from the leakage point. This makes it nearly impossible to detect from the ground surface. The peak frequency band of water leakage phenomena reported in previous studies was 10 to 50Hz, and about 50% of the amplitude had attenuated at a point 2.0m from the leakage point. From the results, and given the attenuation properties of waves in the soil, it is clearly problematic to try to detect water leakage by detecting waves in the soil. In pipelines under roadways, water-leak waves propagate through materials having different densities in asphalt, roadbeds, sub grade, etc. Therefore, wave reflection and transmission coefficients of materials greatly affect the measurement accuracy.

Effect of pipe materials on monitoring accuracy

Pipes are made of various types of structural materials, depending on what they will be transporting, the internal water pressure and the environment they will be buried in among other factors. For AE measurements, AE sensors are installed on the pipe material surface to detect elastic waves emitting from the pipe itself. In the case of water leakage phenomena, the water-leak wave is measured when it is transmitted in the pipe after being propagated through the water from the sound source. In a series of elastic wave propagation routes, the transmission coefficients of the pipe materials have the greatest effect on AE monitoring accuracy. From the perspective of elastic wave motion theory, the reflection and transmission of water-leak waves on the pipe surface can be treated as bilayer phenomena (water-material). In most cases where elastic waves are incident in the bilayer medium, the following relationship can be derived among the wave impedance ratio, the reflection coefficient, and the transmission coefficient:

$$\alpha = \frac{\rho_2 V_2}{\rho_1 V_1} \tag{2}$$

$$\beta = \frac{1-\alpha}{1+\alpha} \tag{3}$$

$$\gamma = \frac{2}{1+\alpha} \tag{4}$$

where ρ: density of medium, V: velocity of elastic wave.

Table 1. The characteristic of elastic wave in the bilayer medium
(Pipe materials - Water)

Pipe material	Sound impedance ratio(α)	Reflection ratio(β)	Transmission coefficient(γ)
PVC	1.53	-0.211	0.789
Concrete	5.33	-0.684	0.316
Steel	28.00	-0.931	0.069

Assuming that the sound impedance $Z(=\rho \cdot V)$ of materials (unit: $kgf/m^2 \cdot s$) is $Z_{water}=1.5\times10^6$ for (transported) water, $Z_{PVC}=2.3\times10^6$ for polyvinyl chloride (PVC) pipes, $Z_{con}=8.0\times10^6$ for concrete pipes, and $Z_{SP}=4.2\times10^7$ for steel pipes, the wave impedance ratio α, the reflection coefficient β, and the transmission coefficient γ will be as shown in Table 1**.**

The results of the investigation showed that the reflection coefficient of the incident wave depended on the quality of the material. For example, 93% of the incident wave was reflected in steel materials. In contrast, the reflection coefficient was only 21% in PVC. Similar trends were found for amplitude. In PVC, 79% of the wave amplitude was transmitted to the measuring point, as opposed to a mere 7% in steel materials. Elastic waves propagated in water showed significant decay at the stage of transmitting the pipe material and the decay properties depended on the pipe material. In AE monitoring, the material of the pipe to which the sensors were attached had an effect on the monitoring results; even phenomena at the same scale showed differences in AE parameters, due to differences in pipe materials. However, since only a few types of structural materials are used in pipelines, suitable AE monitoring can be taken by considering correcting measurement results beforehand based on the type of material.

Effect of pipeline structure on monitoring accuracy

In addition to pipe material, another factor affecting AE monitoring may be the pipeline structure. Either a branch-type pattern or a network pattern is used for pipeline systems. At the time the pattern is selected, the pipeline system can be quite varied. Previous studies have reported on attenuation (decrease in RMS voltage) in crooked or winding sections. Similar tendencies with AE monitoring have been mentioned by overseas researchers such as S. J. Vahaviolos(2001) and Amani Raad(2002). From the above information, auxiliary monitoring using wave guides, in addition to monitoring at concrete pit as proposed in this paper, make it possible to conduct measurements taking water pipeline structures into consideration. Given the above information, the AE measurement of water flow and leakage phenomena in pipeline facilities must consider structural characteristics in addition to material quality.

QUANTITATIVE EVALUATION OF WATER FLOW SIGNALS BY AE IN AN EXISTING PIPELINE REPARED

Investigating the effects of repairs on buried pipeline facilities

In this study, there are 3 types (cases) of measurement conditions:
--Case 1, the stage at which water leakage has been confirmed (before repairs are made)
--Case 2, the stage at which water is being drained from the pipe to prepare for the repair work (forced drainage).
--Case 3, the stage at which water is filled back into the pipe (after repairs have been completed).

Photograph 2. Defect in air valve

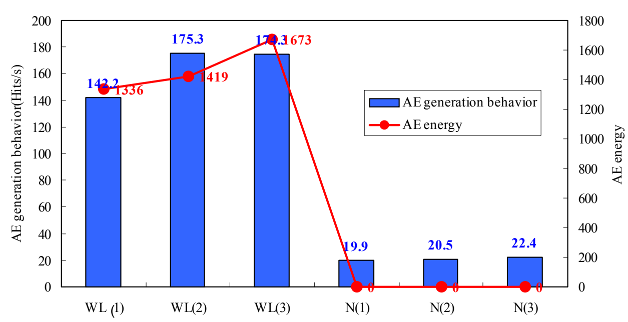

Figure 9. Relations between AE generation behavior and energy (water-leak and normal position)

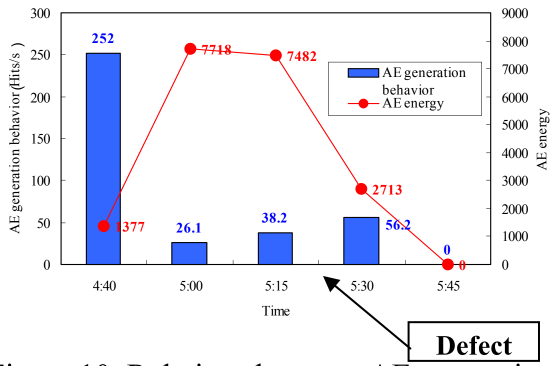

Figure 10. Relations between AE generation behavior and energy (forced drainage conditions)

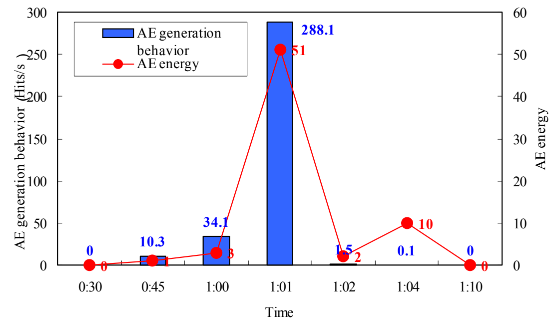

Figure 11. Relations between AE generation behavior and energy (add water conditions)

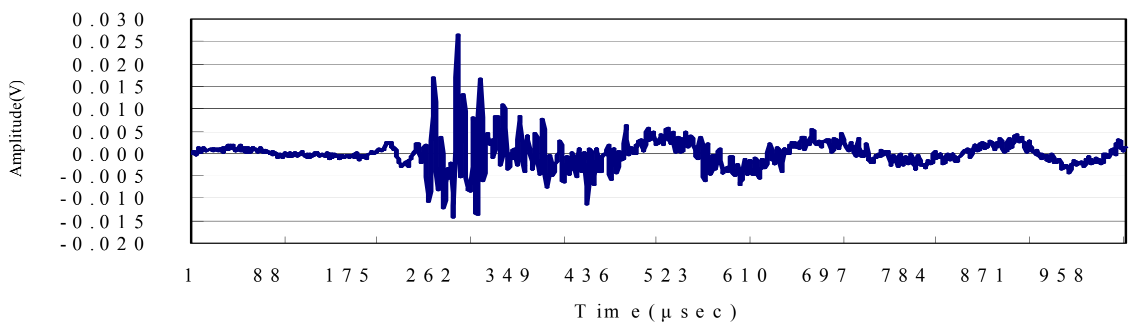

Figure 12. Elastic wave measured when float ball is completely fixed in air valve

For the AE measurements, a sensor was installed on the surface of the air valve where water leakage had been confirmed (leaking section), and measurements were taken for 30 seconds at 15-minute intervals. At the same time, measurements were taken under the same conditions in normal sections that had no leakage. The measurements were taken with resonance sensors under conditions of threshold value of 45dB and amplification of 60dB at the pre-amp and main amp.

Before repairs (Case1). The AE generation frequency at the leakage point (air valve) was 142.2 to 175.3(Hits/s), which was 7.8 times higher than in the normal section (Figure 9). This was a clear confirmation of the effect of the defect directly beneath the air valve shown in Photo. 2. Unlike generation behavior, the value for AE energy measured in the normal section was 0.0. In the water leakage section, a continuous wave was detected (Figure 3), but in the normal section, the only noise detected was from the traffic noise (Figure 6). AE energy was defined as a relative value having 1000-count energy when the 10V peak value continued for 1mmsec. At short bursts of AE (environmental noise), the measured value was 0.0. Given the above findings, the present measurements clearly showed that it was possible to use AE energy to distinguish between noise and water leakage.

During forced drainage (Case2). The case of drainage made in order to remove water using drain pump. At 4:40 a.m., when the measurements started, AE generation behavior showed a similar trend with Case 1 due to the effect of the leaking water (Figure 10). However, starting at 4:50 a.m., when forced drainage started, AE generation behavior decreased as the water level fell. AE energy of approximately 7,000 was recorded. This phenomenon apparently resulted from the propagation of water drainage sounds, and vibrations inside the pipe. At 5:45 a.m., the bobber inside the air valve dropped, signifying that the water have been completely drained at the air valve site. AE generation and energy were both 0.0.

Refilling water after repair work (Case3). AE measurements were taken when the repair work had been completed and water was being refilled. From 8:45 p.m. (immediately after starting to refill the water) until 12:30 a.m., AE was not detected. This was because the water level had not yet reached the air valve. From 12:30 a.m., when the water level inside the pipe reached the air valve, until 1:10 a.m., when the air valve have been completely filled with water, distinctive changes were detected. From 12:30 a.m. until 1:10 a.m., both the AE generation behavior and AE energy increased rapidly (see Figure 11). After that, the AE generation behavior decreased dramatically, but when the air valve bobber became completely fixed in place, elastic waves were found to be emanating from friction sounds of metals having high AE energy.

The above findings indicate that the results of pipeline facility repairs can be quantitatively investigated using AE monitoring.

CONCLUSION

In this study, the acoustic emission (AE) method is applied to the water flow signals (elastic wave) evaluation of the existing PC pipeline which is repaired with three experimental conditions after water-leak accidents. The first condition is a water leak phenomenon. The second condition is a water-drained condition in the pipeline before repairing. The third condition is being filled again in the pipeline after repairing the water-leak point. The analytical results show that water flow performance of the pipeline system could be quantitatively evaluated using AE parameters.

The monitoring accuracy is affected to distance decay and pipe material. Therefore, AE monitoring in pipeline system is necessary to make consideration of applied conditions in existing structures.

As for the relationship AE generation behavior and energy, hydraulic conditions in pipeline were evaluated. To conclude, water leak evaluation of the repaired pipeline system can be quantitatively evaluated through NDT monitoring using AE method.

REFERENCES

Amani Raad, Fan Zhang, Menad Sidahmed: Leak Detection by Acoustic Emission using Subspace Methods, J. Acoustic Emission, 20, pp.300-307, 2002.

JSCM-IIIB-5706: Monitoring method for active cracks in concrete by acoustic emission, 2003.

Kamiya, A., Morofuji, K., Enuma, K., Yamada, M. and Yuyama, S.: Quantitative Studies of Acoustic Emission due toLeaks from Water Tank, HPI Report, 40(4), pp.56-63,2002.

Nawa,N., Sonoda,K., Iwata,H. and Suzuki,T.: Survey and Evaluation Method for Deteriorated Agricultural Pipeline Function, JSIDRE, 70 (12) , pp.31-36, 2002.

Suzuki, T. Ikeda, Y. Tomoda, Y. Ohtsu, M.:Application of Acoustic Emission Method in Damaged Agricultural Pipeline for Functional Evaluation, JSIDRE, 72 (5) , pp.9-12, 2004.

Suzuki, T. Ikeda, Y. Tomoda, Y. Ohtsu, M.: Water-Leak Evaluation of Existing Pipeline by Acoustic Emission, J. Acoustic Emission, No.23, pp.272-276, 2005.

Vahaviolos, S.J., Miller, R.K., Watts, D.J., Shemyakin, V.V., Strizkov, S.A.: Detection and Location of Cracks and Leaks in Buried Pipelines using Acoustic Emission, J. Acoustic Emission, 19, pp.172-183, 2001.