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# Hammering inspection using AE sensor for embedded hardware

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## ABSTRACT

Non-destructive evaluation technique was developed for embedded hardware using hammering inspection with AE (Acoustic Emission) sensor. The integrity of the embedded hardware is judged from both the vibration duration of the embedded hardware recorded by the AE sensor and the frequency analysis of the vibration signal. Mockup tests were carried out in order to verify the effectiveness of the technique and to obtain the diagnostic criteria. The technique was then applied to the field inspection.

## KEYWORDS

*embedded hardware, hammering inspection, acoustic emission sensor, vibration duration, frequency analysis*

## ARTICLE INFORMATION

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## 1. Introduction

Many of the facilities such as power plants have concrete structures where a number of embedded hardware are used as the basis for support structures as shown in Fig. 1. The embedded hardware consists of a rectangular flat plate and several studs with a round head welded to the plate. Due to the improvement for the earthquake resistance performance, the reinforcing bars placed inside the concrete become dense resulting that the buried metal studs are sometimes interfering with the reinforcing bars and that the positioning of the hardware becomes difficult.

At the reprocessing plant of JNFL (Japan Nuclear Fuel Limited) in August 2015, an uplift of the embedded hardware was found which was connected to the support of steam piping in the common utility pit [1]. As a result of the investigation, the stud was inappropriately installed. Also, in August 2016, inappropriate installation was found at Hamaoka Nuclear Power Station [2].

JNFL decided to carry out a survey of about 483,000 pieces of embedded hardware of the reprocessing plant as a countermeasure. Of these, it has been found out that the integrity assessment is necessary for 157,000 pieces the construction record of which is insufficient. In order to confirm the integrity of the stud, UT (Ultrasonic Testing) was selected [1]. The result of UT showed that approximately 200 pieces of embedded hardware in common utility pit were below the standard.

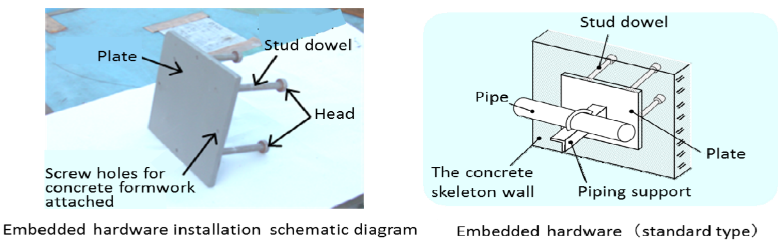


**Fig. 1. Overview of embedded hardware and its installation**

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Meanwhile, in the UT inspection, it is necessary to place the ultrasonic sensor directly above the stud of embedded hardware. However, since the support structures etc. are welded on the embedded hardware, it is sometimes impossible to place the sensor directly above the stud on the flat plate.

Therefore, the authors developed a non-destructive evaluation technique for the embedded hardware using hammering inspection with AE sensor (hereafter AE hammering inspection) to evaluate the integrity of the hardware. The technique can identify the state of fixation of the embedded hardware to concrete base by the vibration duration and the frequency of vibration [3-6]. In this report, summary results of mockup tests of the technique and its application to the reprocessing plant of JNFL.

## 2. Hammering inspection using AE sensor

### 2.1. Principle of the inspection

In the AE hammering inspection using broadband AE sensor AE-900S-WB, NF corporation, an object to be inspected is struck with a hammer to induce vibration, and the state of the object is grasped from the observed characteristics of vibration. We extracted a natural vibration peak from the frequency distribution of an acquired waveform and used the peak evaluation frequency as an evaluation index. The definition of the peak evaluation frequency is the lowest frequency of natural vibration peaks which exceed the threshold magnitude in the frequency distribution. An example of signal analysis is shown in Fig. 2.

We also used the vibration duration, time period until the maximum level of law signal becomes 10 percent level, as an evaluation index, especially to judge the fixed state of the interface between the embedded hardware and the concrete base. Note that the peak evaluation frequency and the vibration duration do not depend on the strength of hammering, resulting that AE hammering inspection is easily applicable to field inspections.

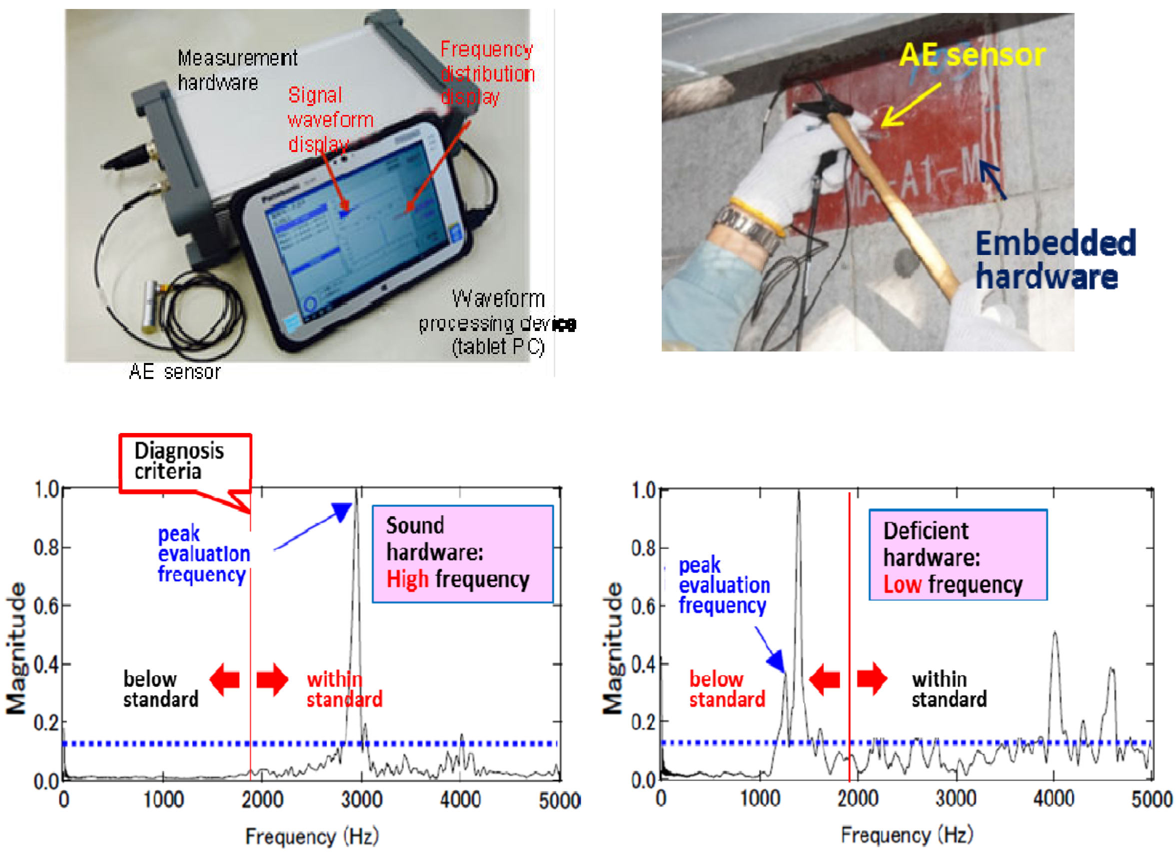



**Fig. 2. Handy-type AE hammering inspection system and examples of signal analysis**

The mockup test results indicated that the measured value by AE hammering inspection varies when the fixed state of the interface between the embedded hardware and the concrete base changes as shown in Fig. 3. Immediately after embedding the hardware in the concrete, the whole embedded hardware is adhesively connected by the concrete, so the vibration duration is very short as several milliseconds, and peaks of the frequency distribution hardly appear. When the load is applied to the embedded hardware, the fixed state of the interface between the embedded hardware and the concrete base changes, and the vibration duration increases. The wave height of the frequency distribution also increases after the loading, resulting in the appearance of sharp peaks. At this time, a sound embedded hardware exhibits a high evaluation peak frequency, while the hardware with deficient studs exhibits a low evaluation peak frequency due to less constraint from the surrounding concrete base. Thus, the integrity assessment becomes possible by the peak evaluation frequency.

Based on the mockup tests, threshold values were set for both (1) the vibration duration to judge the state without any significant change in the fixed state of the embedded hardware from loading after embedded in the concrete, namely, no loading and (2) the peak evaluation frequency to judge the soundness of studs of the embedded hardware.

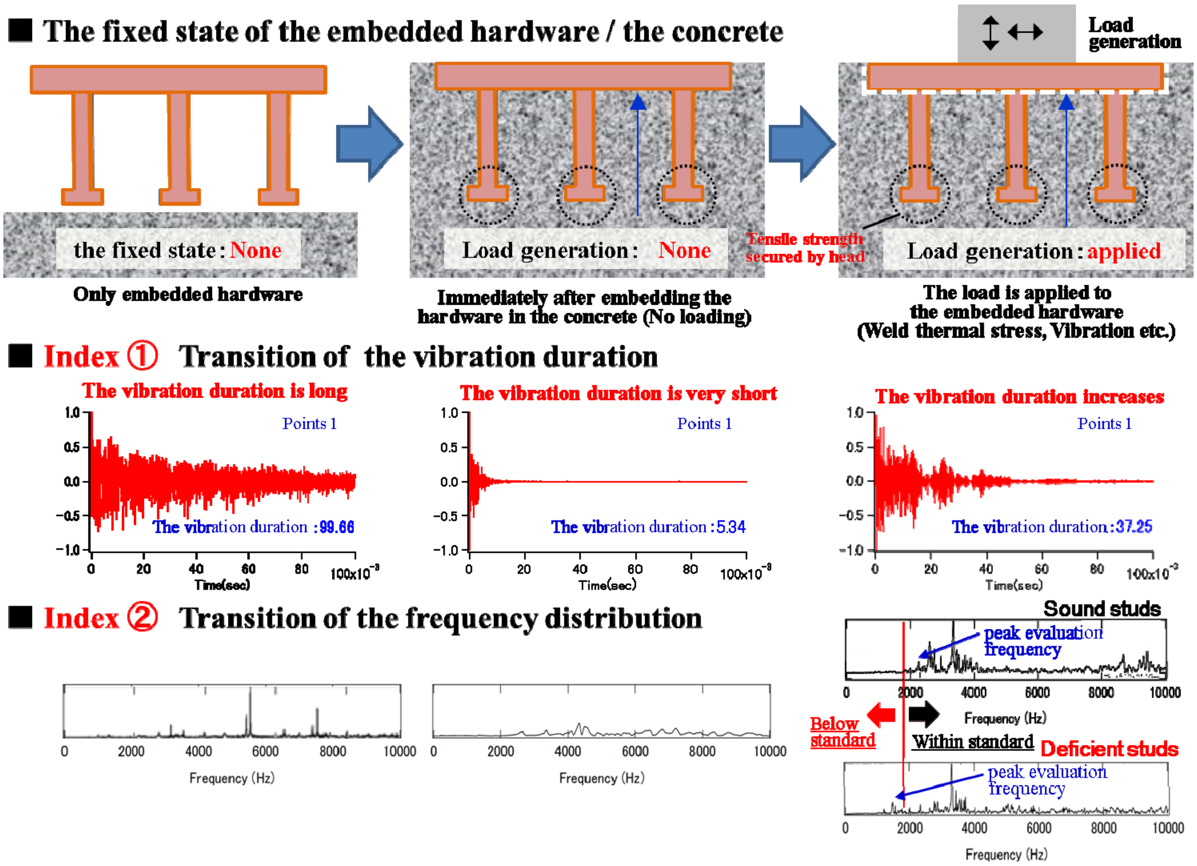



**Fig. 3. Application of hammering inspection with AE sensor to embedded hardware**

### 2.2. Mockup tests

Considering the installation conditions of embedded hardware in the reprocessing plant, sound mockups as well as mockups with deficient studs were fabricated to study the effects of deficient studs and loads to the hardware on AE hammering inspection. Among approximately 200 types of embedded hardware in the reprocessing plant with the combination of different plate size, stud size and stud number, two representative types found to be inappropriately installed in the common utility pit of the reprocessing plant were selected for mockup tests. The two types were R type (plate size: 400x400x25 mm, stud size: φ 22x160 mm, stud number: 9 pieces) and P type (plate size: 250x250x16 mm, stud size: φ 16x120 mm, stud number: 4 pieces). The numbers of the R type and P type mockups are sixty and fifty, respectively. Examples of the mockups are shown in Fig. 4. The red dots in Fig. 4 indicate the deficient studs and the green dots indicate the bent studs. The hardware was embedded in the concrete and then various types of supports were welded on the hardware. Due to the support welded on the embedded hardware, some studs are difficult to be inspected by UT.

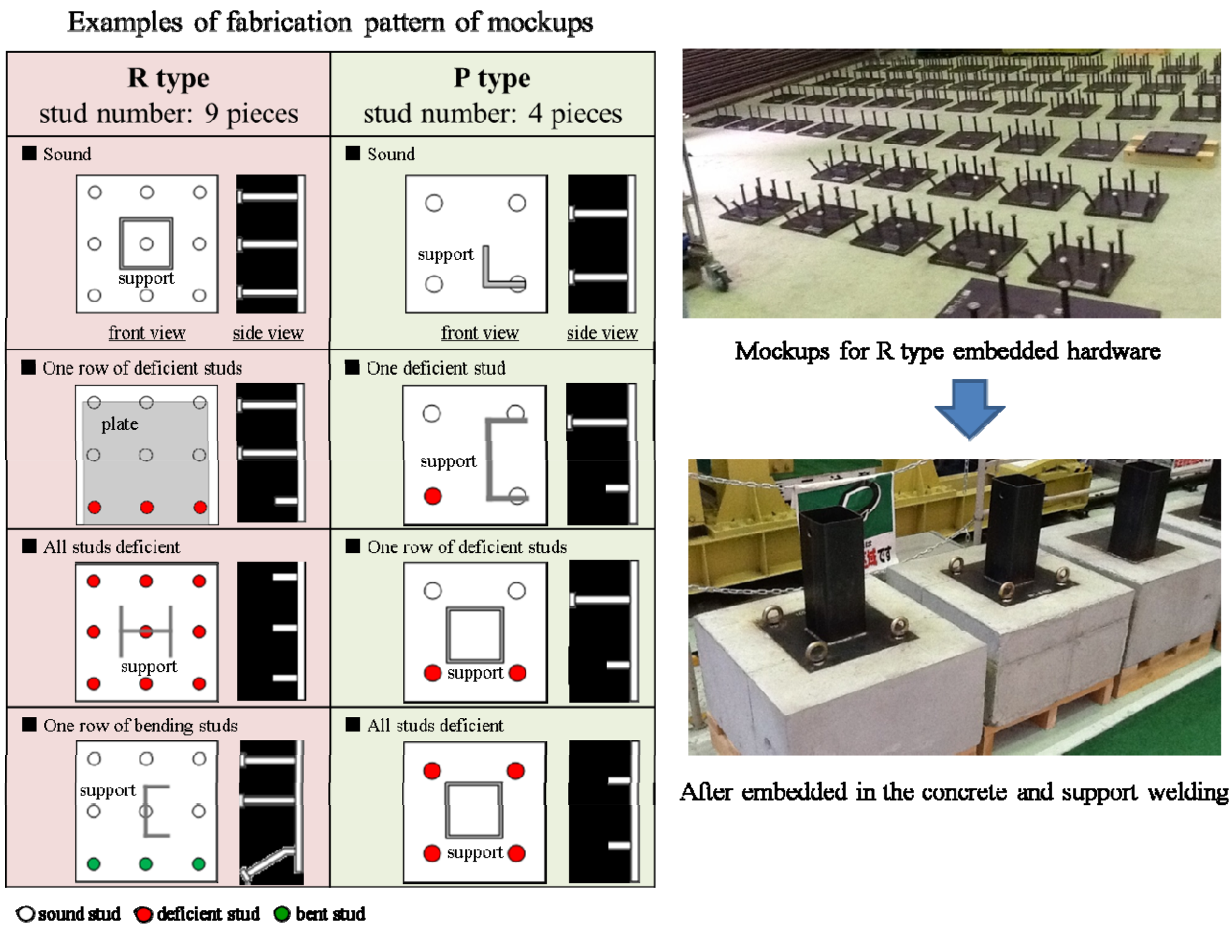



**Fig. 4. Mockups for sound and deficient embedded hardware to study the effects of deficient studs and loads to the hardware on AE hammering inspection**

### 2.2.1. Effect of deficient studs on AE hammering inspection

Fig. 5 shows typical examples of AE hammering inspections on the sound mockup and the mockup with one row of deficient studs which are colored red. These mockups are R type and a steel plate covers 2/3 of the surface, resulting that 6 out of 9 studs are in the area where UT cannot be carried out. However, since there are narrow areas close to studs on the surface of mockups where AE hammering inspections can be carried (positions ④, ⑤, ⑦ and ⑧), it is possible to inspect 4 out of 6 studs in the area where UT cannot be carried out.

As a result of AE hammering inspections at positions ①, ②, ③, ④, ⑤, ⑦ and ⑧ for the sound mockup, observed evaluation peak frequencies in the frequency distribution of all inspected positions showed relatively high frequencies. On the other hand, AE hammering inspections for the mockup with one row of deficient studs showed significant drop in the evaluation peak frequency at positions ⑤ and ⑦, which are in the vicinity of the deficient studs, and the measurement points ④ and ⑧, which are adjacent to the deficient studs. In this way, it was confirmed that AE hammering inspections can be used to identify whether or not the embedded hardware is sound or deficient.

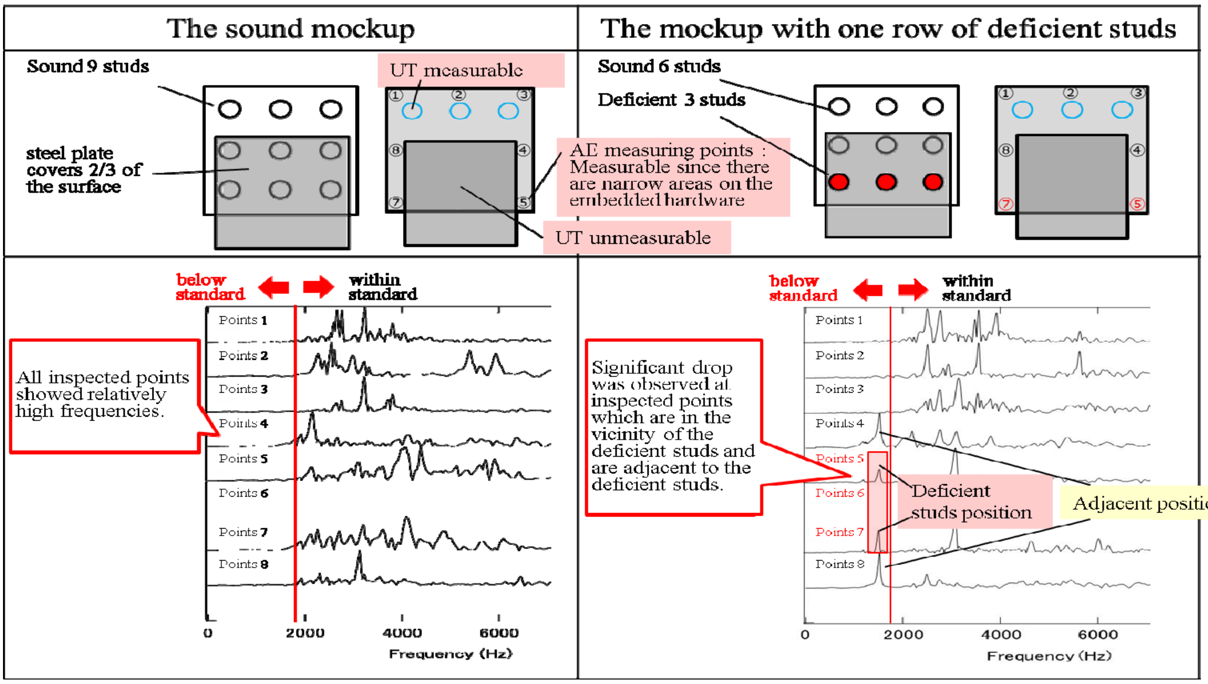



**Fig. 5. Effect of deficient studs on the frequency distribution obtained by AE hammering inspection**

### 2.2.2. Effect of loads to the embedded hardware on AE hammering inspection

Additional mockup tests were carried out to confirm the effect of loads (constant loads and impact loads) on the frequency distribution and the vibration duration. Fig. 6 summarizes examples of P type mockup with one row of deficient studs. The left side shows the frequency distribution of position ① which is in the vicinity of the sound stud while the right side shows the frequency distribution of position ⑤ which is in the vicinity of the deficient stud.

After the installation in the concrete, the vibration duration becomes markedly short compared with that of single embedded hardware and peaks in the frequency distribution hardly appear due to the adhesive and firm interaction between the embedded hardware and the concrete. However, just after the support welding, the vibration duration increases and peaks in the frequency distribution appear clearly. This is due to the mitigation of the adhesive and firm interaction between the embedded hardware and the concrete by the thermal stress during the welding process.

When the tensile load is applied and when the impact load is applied under tension, the intensity of peaks increases compared to the intensity after the support welding. Due to the effect of loads to the embedded hardware, when the peaks in the frequency distribution appear clearly, the peak evaluation frequency at the position ① is relatively high, while the peak evaluation frequency at the position ⑤ is relatively low. This means that AE hammering inspection can identify the embedded hardware with deficient studs through the evaluation peak frequency once the hardware is subjected to certain level of loading. On the other hand, when the hardware is not subjected loads, the vibration duration is very short like several milliseconds and the adhesive and firm interaction between the embedded hardware and the concrete exists.

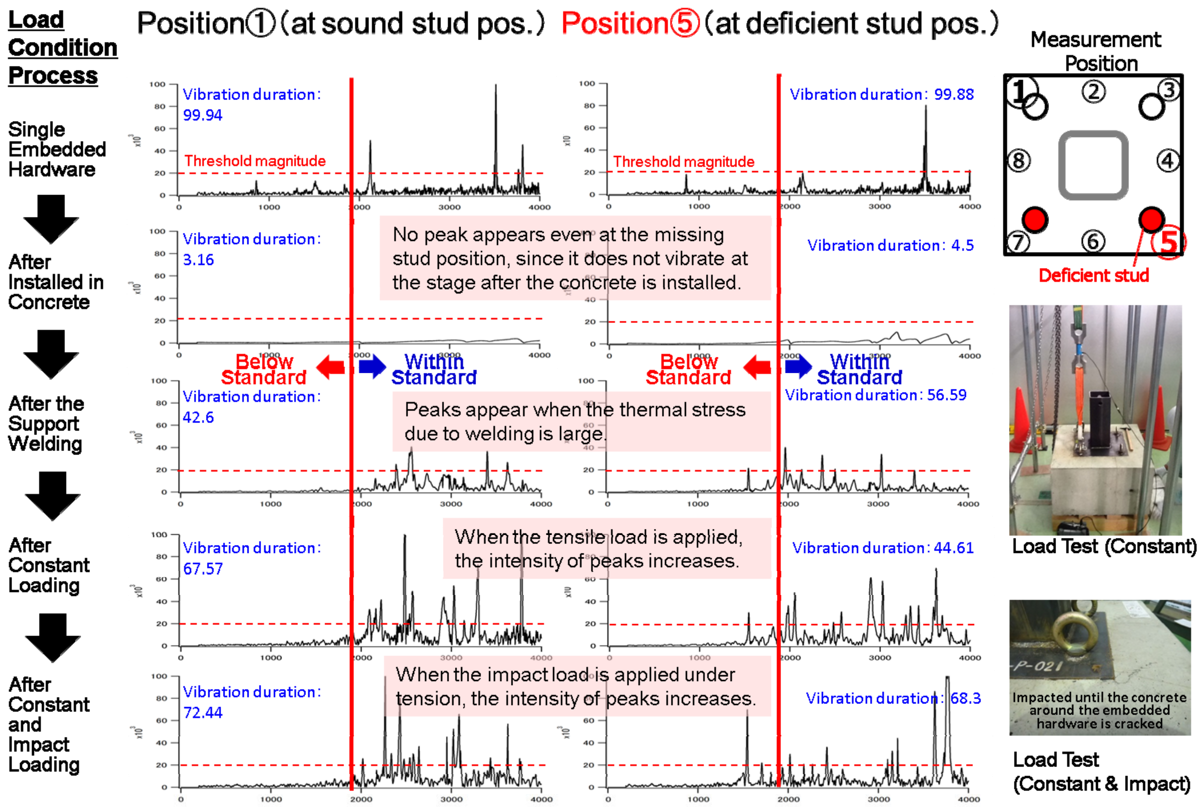



**Fig. 6. Effect of load condition on the vibration duration and the frequency distribution of AE hammering inspection**

### 2.2.3. Establishing criteria of vibration duration and peak evaluation frequency

Based on the mockup tests, criteria of vibration duration and peak evaluation frequency were evaluated and established. Figure 7 shows the change in the vibration duration of the P type embedded hardware with sound and deficient studs after installed in the concrete, support welding and constant loading. In the case of single embedded hardware, the duration is 50 ms or more, sometimes reaching 100 ms, since there are no constraints from the surroundings. However, after the hardware is installed in the concrete, the adhesive and firm interaction between the embedded hardware and the concrete makes the vibration duration less than 10 ms at the rate of 100%. After the support welding, 91% of the vibration duration is less than 20 ms. The subsequent constant loading makes the vibration duration longer. In addition, since the vibration duration of the hardware with deficient studs after the constant loading is more than 10ms at the rate of 100%, the deficient studs facilitates the mitigation of the fixed state of the interface between the embedded hardware and the concrete base.

From the above, if the vibration duration is less than 20 ms as the criteria, which is sufficiently shorter than the state of single embedded hardware, the interaction between the embedded hardware and concrete is assumed to be close and firmly fixed. With the criteria, it is anticipated that the probability of uplift of the embedded hardware is extremely low unless the hardware will be subjected to unexpected large thermal stress, continuous thermal stress, load loading event, etc. Therefore, the hardware with the vibration duration less than 20 ms is called as "no load generation".

The distribution of peak evaluation frequencies of P type mockups with the vibration duration above 20 ms is summarized in Fig. 8. Since deficient studs show less than 1900 Hz and sound studs show almost above 1900 Hz, 1900 Hz was set as the diagnosis criteria by engineering judgement.

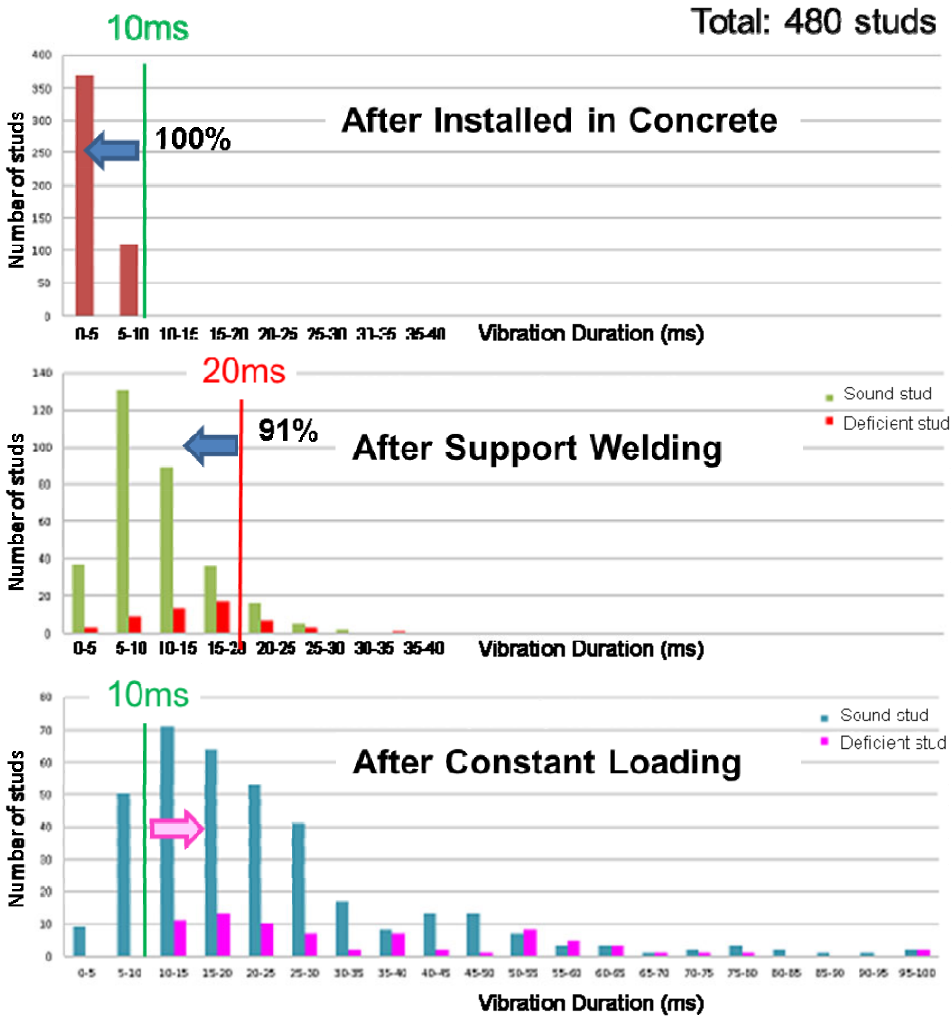



**Fig. 7. Change in the vibration duration under various conditions**

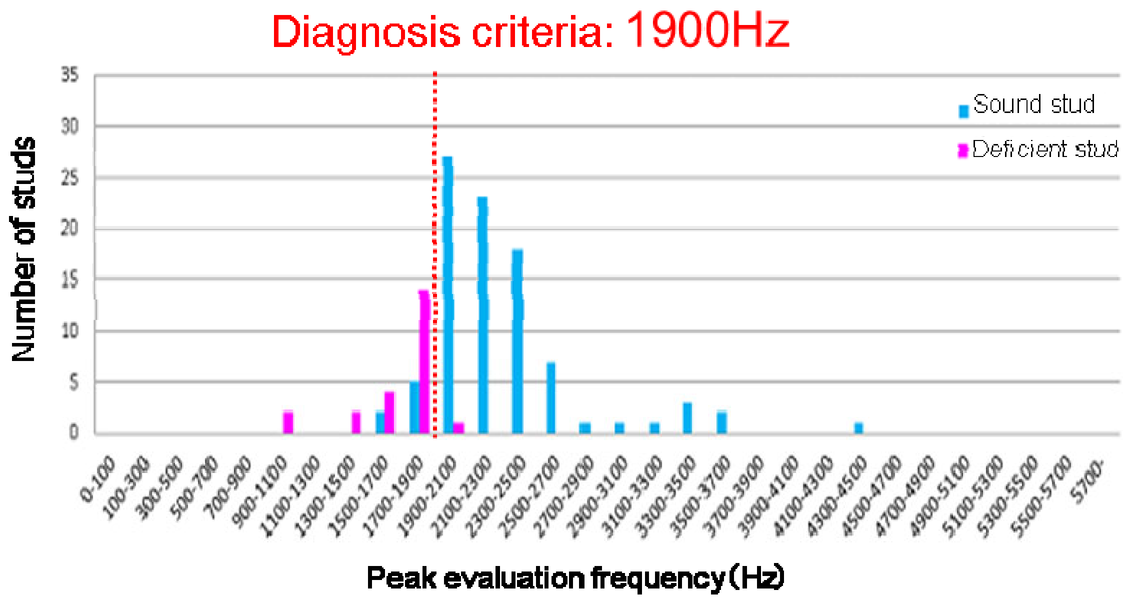



**Fig. 8. Distribution of peak evaluation frequencies with vibration duration above 20 ms**

## 2.3. Field inspections

After the survey of about 528,000 pieces of embedded hardware of the reprocessing plant, it has been found out that the integrity assessment is necessary for 176,000 pieces because the construction record is insufficient. In order to confirm the integrity of the stud, UT was mainly used and AE hammering inspections were carried out to supplement those that could not be subjected to UT and strength analysis as shown in Fig. 9.

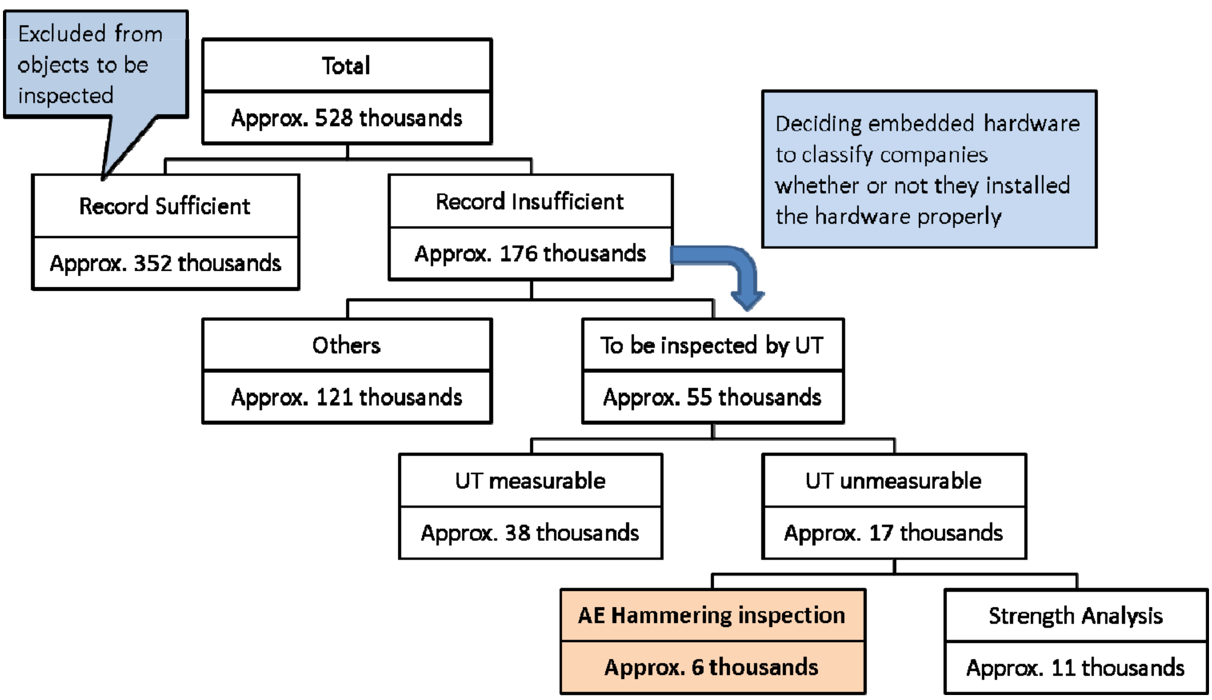
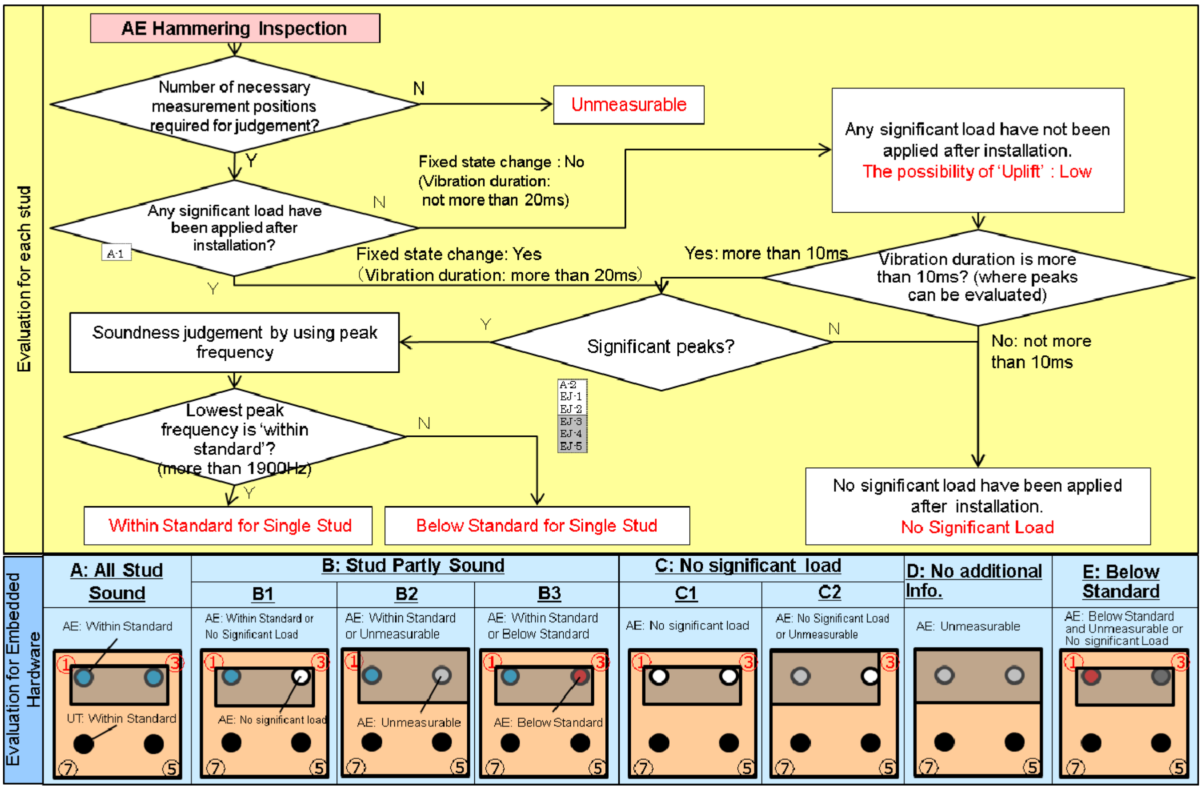



**Fig. 9. Summary of the survey of embedded hardware**

Fig. 10 shows diagnosis flow of the integrity of embedded hardware by AE hammering inspection. In Fig. 10, the upper part shows the flow to diagnose the integrity of each stud welded to the embedded hardware. The lower part shows the classification when the whole embedded hardware is diagnosed based on the integrity of each stud. The abbreviations listed on the lower left of the diamond in the flow indicate the numbers of automatic analysis and engineering judgment.

The diagnosis of the whole embedded hardware is conducted by the combination of the integrity of each stud. Embedded hardware with only "●: sound" is judged as "A: all stud sound". Embedded hardware with "○: no load occurrence" or "●: measurement impossible" or "●: NG" in addition to "●" is judged as "B: stud partially sound". Embedded hardware with no "●" judgment and only "○" or a combination of "○" and "●", is judged as "C: no load occurrence". Embedded hardware with only "●" is judged as "D: No additional information". Embedded hardware with "●", is judged as "E: Below standard". In the evaluation of each stud, measurement positions in the vicinity of stud are used, but when it is difficult to measure in the vicinity, supplementation was made at the adjacent position.




**NOTE for abbreviations**

A-1 : First order analysis (auto) Evaluation when vibration duration is below 20ms
A-2 : First order analysis (auto) Evaluation when vibration duration is above 20ms
EJ-1: First order analysis (EJ) Re-evaluation by wavelet analysis
EJ-2: First order analysis (EJ) Re-evaluation to distinguish peaks from support vibration
EJ-3: Detailed analysis (EJ) Use of AE hammering inspection results for "sound stud" judged by UT Applied to similar size of mockup embedded hardware
EJ-4: Detailed analysis (EJ) Use of AE hammering inspection results for "sound stud" judged by UT Applied to different size of mockup embedded hardware
EJ-5: Detailed analysis (EJ of Re-inspection) Re-evaluation to distinguish peaks from support vibration

**Fig. 10. Diagnosis flow of the integrity of embedded hardware by AE hammering inspection**

The inspection record sheet contains the specification, the location and photos of the embedded hardware as well as AE hammering inspection results as shown in Fig. 11. The vibration duration and frequency distribution are automatically analyzed for inspected positions. In this case, although UT cannot carried out for positions ① and ③ due to the support welding, AE hammering inspection identify that studs of the positions are sound because the evaluation peak frequency is above the criteria, 1900Hz.

Table 1 summarizes the classification of embedded hardware UT was not applied to and the ratio of AE hammering inspection results. The inspection gave additional information to complement UT for soundness assessment of the embedded hardware at about 87%.

Also, the inspection can judge the presence or absence of loads applied to the embedded hardware from the vibration duration. It was also confirmed that there was no marked load history for about 82% of studs as shown in Fig.12, which is useful information for the planning of upcoming inspections of embedded hardware.

**Table 1 Result of field inspection in terms of hardware**

| Object | Hardware ratio | Totally sound | Partly sound | No load generation | No additional information | NG |
|---|---|---|---|---|---|---|
| Building | 84 % | 19 % | 20 % | 35 % | 10 % | 0.02 % |
| Pit | 11 % | 3 % | 2 % | 3 % | 2 % | 0 % |
| Other | 5 % | 1 % | 1 % | 3 % | 0 % | 0 % |
| Total | 100 % | 22 % | 24 % | 41 % | 13 % | 0.02 % |

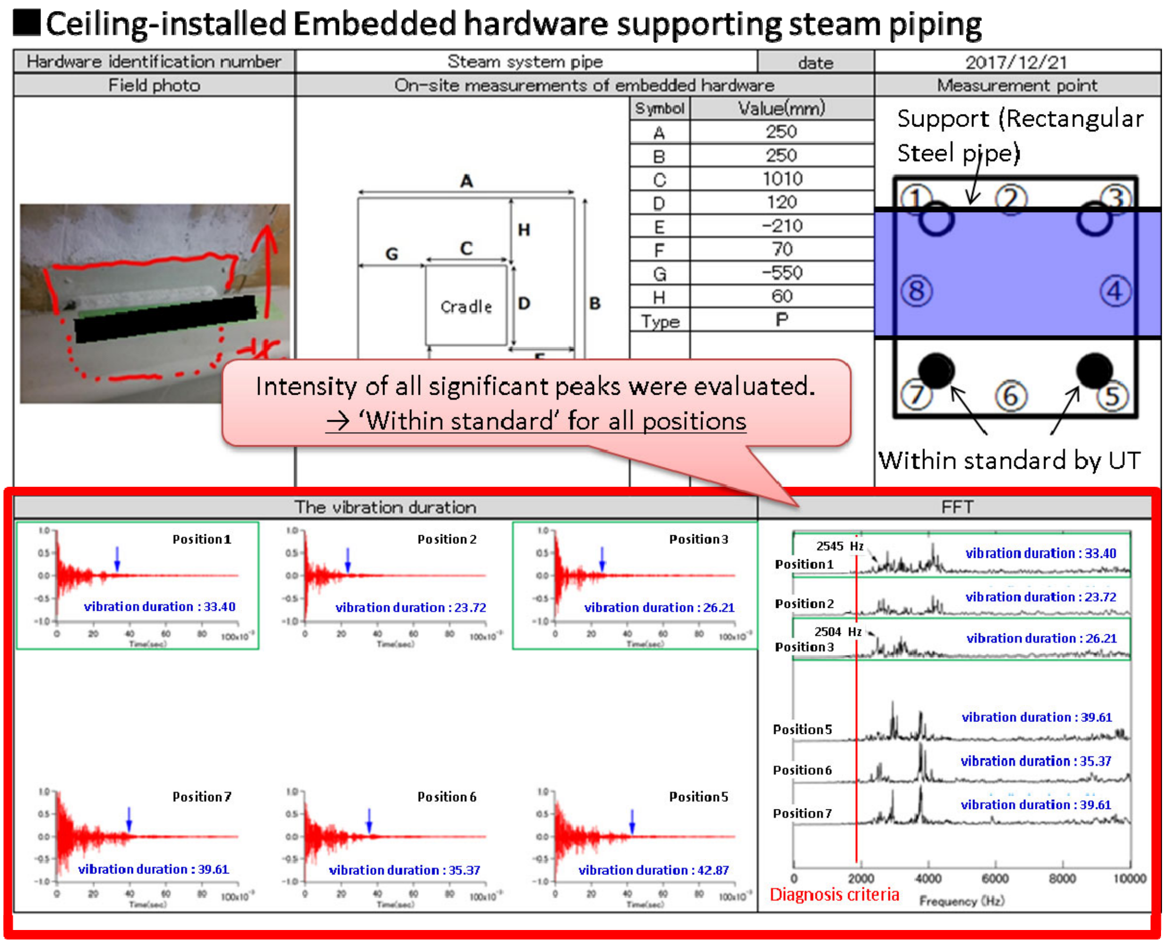
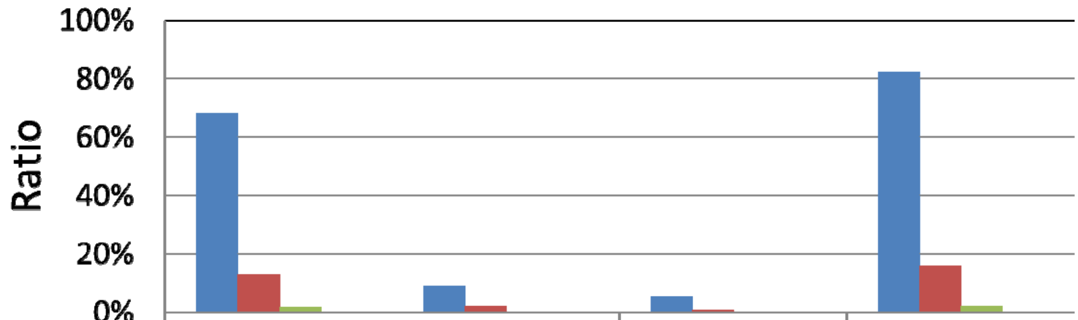



**Fig. 11. Inspection record sheet of vibration duration and peak evaluation frequency Evaluation result for Embedded Hardware: A (All Stud Sound)**




| | Building | Pit | Other | Total |
|---|---|---|---|---|
| ～20ms | 68% | 9% | 5% | 82% |
| 20ms～50ms | 13% | 2% | 1% | 16% |
| 50ms～ | 2% | 0% | 0% | 2% |
| Total | 82% | 11% | 6% | 100% |

**Fig. 12. Result of field inspection in terms of stud**

## 3. Conclusion

Hammering inspection using AE sensor for embedded hardware has been developed and field inspections have been successfully conducted using its handy-type system to be substituted for UT. The inspection gave additional information for soundness assessment at about 87%. Also, the inspection can judge the presence or absence of a load applied to the embedded hardware from the vibration duration.

## References

[1] JNFL official website, https://www.jnfl.co.jp/press/pressj2016/20160408tenpu.pdf
[2] NRA (Nuclear Regulatory Authority) official website, https://www.nsr.go.jp/data/000182571.pdf
[3] S. Miura, et al, Embedded hardware inspection using AE sensor Part1 Mockup tests, the proceedings of 15th annual meeting of Japan Society of Maintenology, pp.113-120, 2018.
[4] S. Miura, et al, Embedded hardware inspection using AE sensor Part2 Site inspection, the proceedings of 15th annual meeting of Japan Society of Maintenology, pp.121-124, 2018.
[5] S. Miura, et al, Development of nondestructive inspection for embedded hardware (1) Mock-up test, the proceedings of 2018 Fall Meeting of the Atomic Energy Society of Japan, pp.3O02, 2018.
[6] S. Miura, et al, Development of nondestructive inspection for embedded hardware (2) Field application result, the proceedings of 2018 Fall Meeting of the Atomic Energy Society of Japan, pp.3O03, 2018.