# STIFFNESS REDUCTION IDENTIFICATION OF STEEL TRUSS BRIDGE USING MICRO SHAKING DEVICE

**A.Furukawa[1] and H.Otsuka[2]**

[1] *Assistant Professor, Dept. of Civil Engineering , Kyushu University, Fukuoka. Japan*
[2] *Professor, Dept. of Civil Engineering , Kyushu University, Fukuoka. Japan*

**ABSTRACT :**

This paper describes a damage identification technique for structures using a micro shaking device, and experimental verification of the technique using a steel truss bridge. First, a technique for identifying damage to structures is proposed which uses harmonic excitation force generated by a micro shaking device. Fourier response functions (FRFs) obtained by dividing the Fourier amplitudes of acceleration responses by the amplitude of the harmonic excitation are used to identify damage. Secondly, vibration testing on a steel truss bridge was conducted to investigate the effectiveness of the proposed technique as well as the use of a micro shaking device. Damage models of the steel truss bridge were created by cutting sections of bracing members. Finally, identification of damage using the proposed damage identification technique was conducted and its validity was examined.

**KEYWORDS:** damage identification, micro shaking device, vibration testing, stiffness reduction

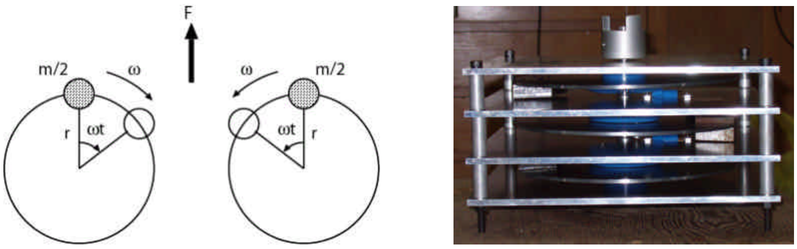
## 1. INTRODUCTION

When a large earthquake occurs, important infrastructures must be assessed and repaired immediately to prevent the expansion of secondary damage. Damage assessment, particularly regarding the need for repair or reinforcement of a structure, must be made and adequate measures taken to avoid catastrophic situations. To meet these needs, authors have been developed vibration-based damage identification techniques so far (Furukawa et.al. 2004, 2006). Damage identification techniques are divided into two types: one using artificial vibrations due to exciters or actuators, and the other using natural vibrations such as ground motion and wind force. Artificial vibration is advantageous as both input and output data can be used for identification, therefore identification accuracy is theoretically high. Artificial vibration, however, is usually expensive and impractical. In contrast, microtremor measurement using ambient vibration is freely available and a useful alternative to artificial excitation. Therefore, many researchers propose damage identification techniques using the microtremor measurement even though the input force remains unknown (Hassiotis et. al. 1995, Kaito et.al. 1995, Farrar et.al. 1997). The majority of the techniques are based on modal data and are derived from the assumption that the input force is assumed to be white noise. Therefore, there are identification errors as the assumptions do not hold true in reality. To overcome the drawbacks of both artificial and ambient vibrations, a micro shaking device was developed in this study which excites the structure with a low cost harmonic excitation force. FRF data, used for identification, was obtained by dividing the Fourier amplitude of the acceleration responses by the amplitude of the harmonic excitation force.

This paper first describes a damage identification technique for structures using a micro shaking device. The validity was then confirmed through vibration experiment using a steel truss bridge.

## 2. DEVELOPED MICRO SHAKING DEVICE

A micro shaking device excites a structure with constant amplitude and constant frequency. The device consists of three disks and three weights. The total mass of the weights is denoted by m. A weight of m/2 is attached to the center disk and the other two weights of m/4 are attached to a disk on either side. The centrifugal force of the weight attached to the rotating disks is utilized. The center disk is rotated in one direction and the other two in the opposite direction to extract the centrifugal force in only one direction (Figure 1(a)). The centrifugal force in the other direction can be cancelled out. Therefore, an excitation in an arbitrary direction is possible by changing the setting position of the shaking device. Let r denote radius of the rotating disks and $\omega$ the excitation frequency. The excitation moment is then defined as mr and excitation force as $F=mr\omega^2$. Figure 1 (b) displays the developed micro shaking device. Table 1 indicates its size and performance. The excitation moment of the micro shaking device is approximately 1/10 - 1/2000 as great as the general shaking devices used for structural experiments.




(a) principle of micro shaking device (b) developed micro shaking device
Figure 1 Micro shaking device

Table 1 Size and performance of the micro shaking device

| mass | radius of disk | excitation moment | excitation force at 7.5Hz |
|---|---|---|---|
| 1kg | 0.1m | 0.1kgm | 221.8N |

## 3. PROPOSED DAMAGE IDENTIFICATION TECHNIQUE

### *3.1 Development of damage identification equations*

The forced vibration response of an un-damped system generated by harmonic excitation is obtained by solving the equation of motion;

$$M\ddot{x}(t)+Kx(t)=f(t) \tag{3.1}$$

where $M$ and $K$ respectively are the mass and stiffness matrices of the baseline model, $x(t)$ the displacement response vector, and $f(t)$ the vector of the external harmonic excitation force. The forced vibration response in the frequency domain is;

$$X(w)=H(w)F(w) \qquad H(w)=[-w^2M+K]^{-1} \tag{3.2}$$

where $X(w)$ and $F(w)$ respectively are the Fourier transforms of $x(t)$ and $f(t)$, $H(w)$ is the transfer function of the baseline model, and $w$ is the excitation circular frequency. When stiffness is reduced by $dK$ due to damage, the equation of motion becomes

$$M\left(\ddot{x}(t)+d\ddot{x}(t)\right)+\left(K-dK\right)\left(x(t)+dx(t)\right)=f(t) \tag{3.3}$$

where $dx(t)$ is the increase in the displacement response. Then $dk_e$ denotes the proportional reduction in the stiffness of the $e$-th element. Reductions in the total stiffness matrices therefore are expressed as sums of reductions in element stiffness matrices;

$$dK=\sum_{e=1}^{n}dk_eK^e \tag{3.4}$$

The Fourier amplitude $X'(w)$ of the displacement response of the real structure is

$$X'(w)=X(w)+dX(w)=H(w)F(w)+\sum_{e=1}^{n}S^e(w)F(w)dk_e \tag{3.5}$$

where $S^e(w)$ is

$$S^e(w)=H(w)K^eH(w) \tag{3.6}$$

The frequency response function (FRF), obtained by dividing the Fourier amplitude of the acceleration response by the Fourier amplitude of the harmonic excitation force, is used. On the assumption that the excitation force is applied at point $j$ and acceleration is measured at point $i$, the FRF $a(i,j,w)$ is

$$a(i,j,w)=-w^2X'(w)/F(w)=-w^2(H_{ij}(w)+\sum_{e=1}^{n}S^e_{ij}(w)dk_e) \tag{3.7}$$

Transposing the unknown terms to the left side and the known ones to the right side,

$$-w^2\sum_{e=1}^{n}S^e_{ij}(w)dk_e=a(i,j,w)+w^2H_{ij}(w) \tag{3.8}$$

In Eq.(3.8), the measurement point $i$, excitation point $j$, and excitation frequency $w$ are arbitrary values. Choosing $l$ different sets of $i$, $j$, $w$, this relationship can be written as a set of simultaneous equations;

$$[\mathbf{U}]\{\mathbf{dk}\}=\{\mathbf{da}\} \tag{3.9}$$

Thus, $l$ different FRFs may give $l$ equations for $n$ unknowns. By solving Eq.(3.9), the stiffness reduction for each element is obtained.

### *3.2 Solution of damage identification equation*

The proposed technique identifies structural damage by solving the damage identification equation. When the amount of data numbers equals the number of unknown parameters, damage identification equations present a determined problem whose solution is uniquely established. When the number of data exceed the unknowns, the damage identification equations give an overdetermined problem which may not have a unique solution. In this case, the least-squares method provides the best-fit solution. When the number of measurements is insufficient, the damage identification equations provide an underdetermined problem which has an infinite number of solutions. To surmount this, the grouping method are introduced.

Step 1: Assume all $n$ elements are damaged element candidates.
Step 2: Divide all elements suspected of damage into $m$ groups.
Step 3: Assume elements which belong to the same group have equivalent magnitudes of damage. In this case, the parameters to identify are changes in the stiffness of the $g$-th group, $dk_g$ ($g$=1,…,$m$).
Step 4: Reconstruct the damage identification equation with respect to $dk_g$.
Step 5: Solve the damage identification equations for $dk_g$.
Step 6: Check if $\delta k_g$ are less than the threshold value assumed in advance. If yes, the elements belonging to the group are identified as undamaged; otherwise damage is still suspected.
Step 7: Check the number of elements suspected of damage.
If less than $m$, stop here; otherwise go back to step 2.

The grouping method attempts to reduce the number of unknown parameters by excluding the elements assessed as undamaged from damage candidates on a step by step basis. The grouping method also reduce the number of unknowns by grouping elements together.

## 4. VIBRATION TESTING OF A STEEL TRUSS BRIDGE USING A MICRO SHAKING DEVICVE

### *4.1 Bridge outline*

The vibration test was conducted to investigate the effectiveness of the micro shaking device. The structure is a steel truss bridge called the Kurumakaeri bridge located in Aso, Kumamoto Prefecture (Figure 2). The bridge was constructed in 1963 and has a length of 47.0m and width of 4.8m. The numbering of nodes and elements of the steel truss bridge is shown in Figure 3.

### *4.2 Measured responses*

*4.2.1. Ambient vibration measurement*

Acceleration responses due to ambient vibration were measured and the natural frequencies and the damping ratios were obtained. In each measurement, 5 minutes of acceleration responses were recorded.

*4.2.2. Forced vibration testing using the micro shaking device*

Forced vibration testing using the micro shaking device was conducted. Two excitation directions, bridge and vertical directions, were used. In each test, 5 minutes of acceleration responses in bridge and vertical directions were recorded. The excitation frequency was fixed at 7.5 Hz and the excitation force was 221.8 N.


Figure2 Kurumakaeri bridge

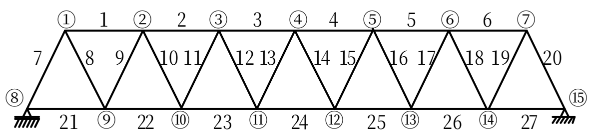
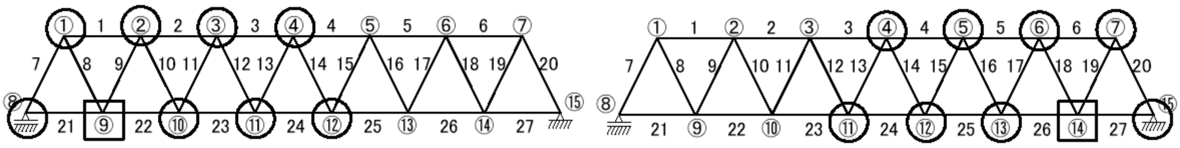


Figure3 Numbering of nodes and members

### *4.3 Arrangement of apparatus*

Acceleration response of nodes on one side of the bridge were measured in the bridge and vertical directions. Since only 16 accelerometers were available for use, all nodes in both directions could not be measured simultaneously. Therefore, two types of arrangement were used as shown in Figure 4. The nodes surrounded by squares are the excitation points where the micro shaking device was set. The nodes surrounded by circles are the measurement points where the accelerometers were set. For each measurement node, two accelerometers were set to measure the acceleration in both vertical and bridge directions.



(a)arrangement a (b) arrangement b

Figure 4 Arrangement of apparatus

### *4.4 Damage model*

Structural damage was created by cutting the section of the diagonal member (H-shaped section). The comparison between intact and damaged members is shown in Figure 5. The damaged part is in the center of the members. Damage was created in both sides of the bridge.

*4.4.1. Intact model*

Due to unforeseen events, acceleration measurements could not be obtained for the real intact structure. Therefore, the least damaged structure was considered as the intact model. In the intact model of this study, element No.8 has a 50% section reduction for 10cm along the member. Other members are intact.

*4.4.2. Damage model 1*

The length of the 50% section reduction area of element No.8 is 200cm, and that of element No.15 is 100cm.

*4.4.3. Damage model 2*

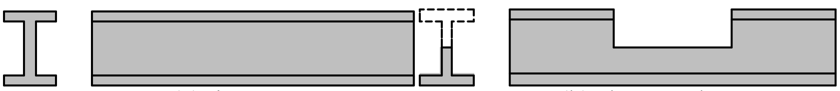
The length of the 50% section reduction area of element No.8 is 300cm, and that of element No.15 is 300cm.

*4.4.4. Equivalent stiffness reduction*

Next, the stiffness reduction of the applied damage was calculated. Let the length of the element be $L$ (m) and the length of the 50% damaged section be $dL$ (m), then the equivalent stiffness reductions for the 8th and 15th elements, $dk_8$ and $dk_{15}$, can be obtained as

$$dk_8 = 1 - \frac{1/(1+\Delta l/l)}{1/(1+10(cm)/l)} \qquad dk_{15} = 1 - 1/(1+\Delta l/l) \tag{4.1}$$

Since the intact model of element No.8 had sustained previous damage, the equation for element No.8 is different from element No.15. The calculated equivalent stiffness reductions are shown in Table 2.



(a) intact state (b) damaged state

Figure 5 Modeling of damage

Table 2 Equivalent stiffness reduction

| element No. | 8 | 15 |
|---|---|---|
| damage model 1 | 0.203 | 0.12 |
| damage model 2 | 0.280 | 0.29 |

## 5. CHANGE IN VIBRATION MEASUREMENTS DUE TO DAMAGE

### *5.1 Ambient vibration*

*5.1.1. Intact model*

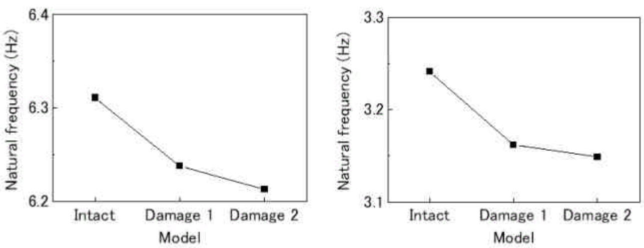
Natural frequencies were estimated as the peak frequency of the power spectra of the acceleration responses. The transition in the 1st and 2nd natural frequencies due to damage is shown in Figure 6 (a) (b). The horizontal axis indicates the model name and the vertical displays the estimated natural frequencies. From Figure 6, both 1st and 2nd natural frequencies tended to grow smaller as the damage became larger.

*5.1.2. Damping ratio*

Damping ratios were estimated based on the half power method using the power spectra of the acceleration responses. The transition in the 1st and 2nd damping ratio due to damage is shown in Figure 7 (a) (b). The horizontal axis indicates the model name and the vertical one indicates the estimated damping ratios. From Figure 7 (b), the 2nd mode damping ratio becomes larger as the damage becomes larger. This tendency, however, cannot be seen for the 1st mode damping ratio. The 1st mode damping ratio is reduced in damage model 1 from the intact model, but increased in damage model 2.

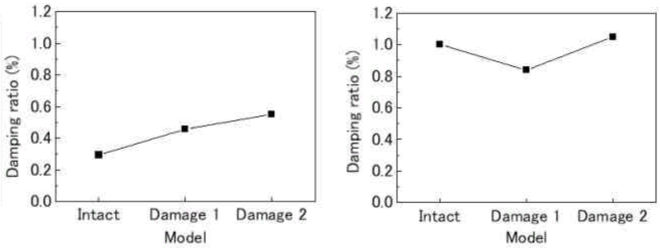
***5.2 Forced vibration testing using micro shaking device***

Fourier amplitudes at excitation frequency, 7.5Hz, were obtained by Fourier transformation of measured accelerations. The proposed damage identification technique uses a frequency response function which can be obtained by dividing the Fourier amplitudes by the amplitudes of input force. In the experiment, two excitation directions, bridge and vertical directions, were used, and responses in two directions, bridge and vertical were measured. Therefore, there are four pattern combinations of excitation and measurement directions.




(a) 1st mode (b) 2nd mode

Figure 6 Transition of natural frequencies




(a) 1st mode (b) 2nd mode

Figure7 Transition of damping ratios

*5.2.1. Fourier amplitudes in bridge direction during excitation in bridge direction*

The transition of Fourier amplitudes of acceleration in the bridge direction during excitation in the bridge direction is shown in Figure 8 (a). Explanatory notes such as 'Node 9 - Node 1' indicate that the excitation point is node No.9 and the measurement point is node No.1. In the case where the excitation point is node No.9, the apparent correlation could not be observed between the Fourier amplitudes and the structural damage. In the case where the excitation point is node No.12, the gradual decrease of Fourier amplitudes at node No.6 is observed. However, the Fourier amplitude at node No.12, which is close to the damaged member No.15, does not have an apparent correlation with the damage. This is due to measurement noise and ambient vibration from traffic and wind loads. As the excitation force of the micro shaking device is too small and vibration in the bridge direction is difficult to accomplish, the measurement was contaminated by ambient vibration and measurement noise, and clear change in the response could not be observed. Therefore, the response in the bridge direction during excitation in the bridge direction cannot be used as the input data for damage identification.

*5.2.2. Fourier amplitudes in the vertical direction during excitation in the bridge direction*

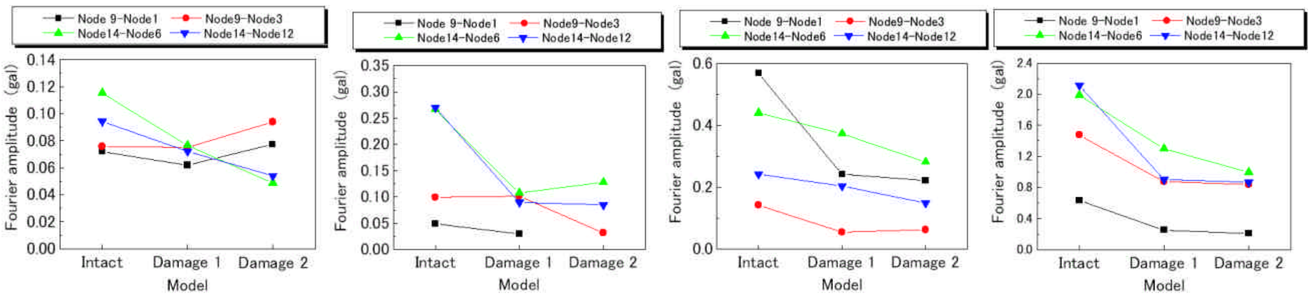
The transition of Fourier amplitudes of acceleration in the vertical direction when the bridge was excited in the bridge direction are shown in Figure 8 (b). For the case where the excitation point is node No.14, an apparent correlation could be observed between the Fourier amplitudes at nodes Nos. 5 and 12 and the structural damage. The Fourier amplitudes at nodes Nos.5 and 12 gradually decrease as the damage becomes larger. In the case where the excitation point is node No.12, however, the change in Fourier amplitudes at nodes Nos. 1 and 3 are not clear even though they are next to damaged element No.8. This is due to measurement noise and ambient vibration from traffic and wind load. Therefore, the response in the vertical direction during excitation in the bridge direction cannot be used as the input data for damage identification.

*5.2.3. Fourier amplitudes in the bridge direction during excitation in the vertical direction*

The transition of Fourier amplitudes of acceleration in the bridge direction when the bridge was excited in the vertical direction are shown in Figure 8(c). For the case where the excitation point is node No.9, a correlation was not apparent between the Fourier amplitudes and the structural damage. In the case where the excitation point is node No.12, a gradual decrease of Fourier amplitudes at node No.6 was observed but the Fourier amplitude at node No.12 which is close to damaged member No.15 does not correlate with the damage. This is because of the measurement noise and ambient vibration due to traffic and wind loads. Therefore, the response in the bridge direction during excitation in the vertical direction also cannot be used even though they are much better than the response due to excitation in the bridge direction.

*5.2.4. Fourier amplitudes in the vertical direction during excitation in the vertical direction*

The transition of Fourier amplitudes of acceleration in the vertical direction when the bridge was excited in the vertical direction is shown in Figure 8 (d). In all cases, the Fourier amplitudes decrease as the damage becomes larger. A clear change in Fourier amplitudes due to damage could be observed. Although the excitation force of the micro shaking device is small, its responses are much larger than ambient vibration. Therefore, response in the vertical direction during excitation in the vertical direction has the possibility of use as the input data for damage identification.




(a) bridge-bridge (b) bridge-vertical (c) vertical-bridge (d) vertical-vertical

Figure 8 Transition of Fourier amplitudes due to damage (excitation direction - measurement direction)

## 6 DAMAGE IDENTIFICATION

In this section, the Fourier amplitudes in the vertical direction during excitation in the vertical direction were used as input data for the damage identification technique using FRFs proposed in section 3.

### *6.1 Modeling of structure*

The bridge was modeled as a 2-dimensional truss model (Figure 3). The numbering of nodes and elements are also shown in Figure 3. The total number of nodes and elements are 15 and 27. A baseline finite element model must be defined to identify damage. A model was created from a draft of the structure. Because damping was very small, the structure was modeled with un-damped bar elements. Stiffness parameters were updated to match those of the intact model (Table 3). Stiffness reduction due to damage could then be obtained.

Table 3 Fourier amplitudes for each state

| | (a) Apparatus arrangement a | | | | | | | (b) Apparatus arrangement b | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Node 1 | Node 2 | Node 3 | Node 4 | Node 10 | Node 11 | Node 12 | Node 4 | Node 5 | Node 6 | Node 7 | Node 11 | Node 12 | Node 13 |
| Intact model | 0.634 | 2.063 | 1.475 | 0.496 | 1.865 | 1.703 | 1.100 | 0.481 | 1.954 | 1.988 | 0.756 | - | 2.116 | - |
| Damage model 1 | 0.249 | 0.968 | 0.875 | 0.409 | 0.958 | 0.702 | 0.197 | - | 1.638 | 1.229 | 0.443 | 0.301 | 0.902 | - |
| Damage model 2 | 0.208 | 0.889 | 0.838 | 0.478 | 0.916 | 0.715 | 0.227 | - | 1.412 | 0.995 | 0.352 | 0.237 | 0.867 | - |

### *6.2 Damage identification using the grouping method*

*6.2.1. damage model 1*

Next, stiffness reduction for damage model 1 was identified using the grouping method. The number of initial groups was assumed to be 8. The threshold value was assumed to be 0.0. Groups with estimated damage less than 0.0 are excluded as being damage candidates. The process of damage identification using the grouping method for damage model 1 is shown in Table 4(a). The final results were obtained after four iteration calculations. Elements identified as damaged in the final iteration calculation were elements Nos. 8 and 15, which are truly damaged elements. No undamaged elements were identified as damaged.

The identified stiffness reduction is shown in Figure 9(a). Comparing the equivalent stiffness reduction (element No.8:0.203, element No.15:0.120) shown in Table 2, the identified stiffness reductions are overestimated for both elements (element No.8:0.372, element No.15:0.213). As previously noted, the joints are not precisely hinge connections and the structural members resist bending moments in addition to axial force.

Therefore, the actual stiffness reduction should be larger than the equivalent stiffness reduction obtained on the assumption of hinge connections. The identified results can be regarded as valid values.

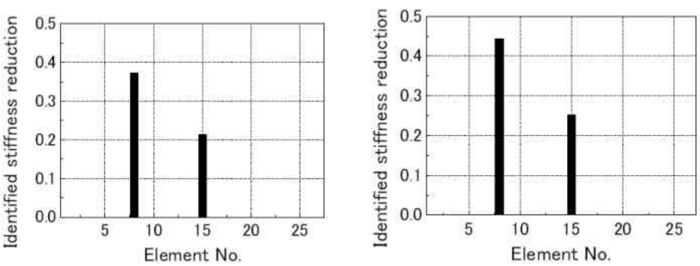
Table 4 The process of identification with the grouping method

(a) damage model 1

| | 1st iteration | 2nd iteration | 3rd iteration | 4th iteration |
|---|---|---|---|---|
| group1 | 1,7,8,21<br>suspicious | 7,8<br>suspicious | 7<br>undamaged | 8<br>suspicious |
| group2 | 9,10,22<br>suspicious | 1,9<br>undamaged | 8<br>suspicious | 15<br>suspicious |
| group3 | 2,11,23<br>suspicious | 21,22<br>suspicious | 15<br>suspicious | 22<br>undamaged |
| group4 | 3,12,13<br>undamaged | 2,11<br>undamaged | 21<br>undamaged | -<br>- |
| group5 | 4,14,24<br>undamaged | 10,23<br>undamaged | 22<br>suspicious | -<br>- |
| group6 | 5,15,16,25<br>suspicious | 5,16<br>undamaged | 25<br>undamaged | -<br>- |
| group7 | 6,17,18,26<br>undamaged | 5,25<br>suspicious | -<br>- | -<br>- |
| group8 | 19,20,27<br>undamaged | -<br>- | -<br>- | -<br>- |

(b) damage model 2

| | 1st iteration | 2nd iteration | 3rd iteration | 4th iteration |
|---|---|---|---|---|
| group1 | 7,8,21<br>suspicious | 7,8<br>suspicious | 7<br>suspicious | 7<br>undamaged |
| group2 | 1,9,10,22<br>suspicious | 1,2<br>undamaged | 8<br>suspicious | 8<br>suspicious |
| group3 | 2,11,23<br>suspicious | 9,21<br>undamaged | 10<br>undamaged | 15<br>suspicious |
| group4 | 3,12,13,24<br>undamaged | 10,22<br>suspicious | 15<br>suspicious | -<br>- |
| group5 | 4,14,15<br>suspicious | 11,23<br>undamaged | 22<br>undamaged | -<br>- |
| group6 | 5,16,25<br>suspicious | 4,14<br>undamaged | 25<br>undamaged | -<br>- |
| group7 | 6,17,18,26<br>undamaged | 15,25<br>suspicious | -<br>- | -<br>- |
| group8 | 19,20,27<br>undamaged | 5,16<br>undamaged | -<br>- | -<br>- |




(a) damage model 1 (b) damage model 2

Figure 9 Identification results with the grouping method

*6.2.2. damage model 2*

Finally, stiffness reduction for damage model 2 was identified using the grouping method. The number of initial

groups was assumed to be 8. The threshold value is assumed to be 0.0. The process of damage identification result using the grouping method for damage model 2 is shown in Table 4(b). Final results were obtained after four iteration calculations. Elements identified as damaged in the final calculation are elements Nos. 8 and 15 which are actually damaged elements. No undamaged elements were identified as damaged.
The identified stiffness reduction is shown in Figure 9 (b). Comparing the equivalent stiffness reduction (element No.8:0.280, element No.15:0.290) shown in Table 2, the identified stiffness reductions are overestimated for both elements (element No.8:0.444, element No.15:0.252). This is because the equivalent stiffness reduction was obtained on the assumption of hinge connections. The identified results can be regarded as valid values.

## 7 CONCLUSIONS

This paper describes a damage identification technique for structures using a micro shaking device, and experimental verification of the technique using a steel truss bridge.
First, an FRF-based damage identification technique is proposed that is derived from the fact that changes in vibration responses provide information about the location of damage and its severity. This information can be calculated because damage to structures causes changes in structural parameters. Damage identification equations were derived from the equations of motion of a structure before and after damage. This identification technique has the advantage that data is accumulated simply by changing the excitation point, measurement point, or excitation frequency.
Secondly, vibration of the structure by the micro shaking device and the possibility of measuring the change in the Fourier amplitudes due to damage were investigated. The results showed that when the structure is excited in the vertical direction and the accelerations are measured in the vertical direction, the Fourier amplitude due to the micro shaking device was sufficiently large compared to the Fourier amplitude due to ambient vibration. A clear change in Fourier amplitude due to the increase of structural damage can be observed.
Thirdly, the possibility of damage identification using the proposed damage identification technique employing frequency response function (Fourier amplitude) was examined. The grouping method successfully identified the correct two damaged elements.
It is important to note that the micro shaking device used in these experiments was developed by the author's laboratory and there is considerable potential for improvement in the design of the shaker. Using a micro shaking device with a higher performance and longer excitation duration will reduce input and output errors thereby improving the identification results.

## REFERENCES

[1] Furukawa, A., Kiyono, J., Iemura, H. and Otsuka, H. (2004). Damage identification method using harmonic excitation force considering both modeling and measurement errors. *Earthquake Engineering and Structural Dynamics*, **34**, 1285-1304.
[2] Furukawa, A., Kiyono, J., Iemura, H. and Otsuka, H. (2006). Vibration-based identification of stiffness reduction considering mass variation for frame structures. *European Earthquake Engineering*, **3**, 48-60.
[3] Hassiotis, S. and Jeong, G.D. (1995). Identification of stiffness reduction using natural frequencies. *Journal of Engineering Mechanics*, *ASCE*, **121**, 1106-1113.
[4] Kaito, K., Abe, M. and Fujino, Y. (1995). Quantification of change of vibration characteristics caused by uncertainty and its application to significance testing. *Journal of Structural Engineering and Earthquake Engineering*, *JSCE*, **45A**, 701-712 (in Japanese).
[5] Farrar, C.R. and James III, G.H. (1997). System identification from ambient vibration measurement on a bridge. *Journal of Sound and Vibration*, **205**, **1**, 1-18.