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A STUDY ON HEALTH MONITORING TO STRUCTURAL DAMAGE FOR TWO STORIES MODEL BY USING VIBRATION TEST

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SUMMARY

Many structures in Japan were built after the war at a revival term or rapid economic growth. These structures have been reached a life in recent years. It is economically difficult to conduct repair and reconstruction for structure only with a possibility of being damaged. This paper presents an approach to detect structural damage for a two degrees of freedom (2DOF) model. We conducted microtremor measurement, free vibration test and vibration test. The 2DOF model was demonstrated the feasibility of using the proposed approach for damage detection of structural member.

INTRODUCTION

After a large earthquake, detection of damage is especially important in structures such as hospitals, bridges, and fire stations. It is needed to prevent secondary disaster. Numerous techniques have been presented in the literature on health monitoring of structures. Each researcher has applied techniques to a different structure, it difficult to compare the merits of the various methodologies[1)-4)].

The ASCE task group recently developed structural health monitoring problem[5)]. Structural health monitoring allows the engineer to use sensing of the structural responses in conjunctions with appropriate data analysis and modeling techniques to monitor the condition of a structure.

This paper presents an approach to detect structural damage for two degrees of freedom (2DOF) model. We conducted microtremor measurement, free vibration test and forced vibration test on health monitoring of the model. The forced vibration test simply consisted of a low amplitude vibration introduced by an electro-shaker installed at the roof level.

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The proposed methodology is a three-step approach. In the first step, we conducted evaluation of change of the natural frequency of damaged structural models comparing with that of the undamaged one. In the second step, the identification of dynamic properties of the floor was analyzed by using response acceleration records on each floor level. The observed data for floor were analyzed in the frequency domain. The ratio of Fourier spectrum between the first floor levels and the second one indicated the damaged floor. In the third step, the strain was measured at specified locations on column members. We defined as the maximum strain ratio of the damaged member to the undamaged member. The strain ratio was used to detect damaged member of the model structure.

DESCRIPTION OF THE FRAME MODEL

A space pure frame model two story with one by one bay, steel profiles was designed and built. The model is 2.4m tall with a span width of 1.2m and equal 1.2m high for each story. Its whole size as well as sizes of the profiles is in an approximate scale 1:3. Each beam and column member restrained between the both joint ends has the length of 1.2 m with I-shape cross sectional height and width of 10 and 5 cm, respectively.

CONFIGURATION CASES

The measurements were performed with twelve test configuration cases. All test configurations are conducted at the full amplitude forced vibration levels. In addition to the forced vibration test, free vibration test and microtremor measurement were performed for each case. The damage in each case was introduced by cutting a fracture of the elements or disconnecting beam-column or base-column bolted connections. The damage pattern of column is shown in Fig.2. Experimental cases are presnted in Fig.3.
The configuration cases shown in Table1 are as follow:

Case I: The configuration of the frame model for the first case was an undamaged structure. The undamaged steel frame was measured for microtremor measurement, free vibration and the full amplitude for forced vibration.

Case II: The damage was introduced to the frame by cutting a fracture from the edge to 1/3 width of the both sides at the middle of the column. The damaged column was considered at the first floor and was shown in Fig.3, indicated with number II of the damage pattern.

Case III: The damage level in this case was larger than that in case II. The damage was introduced to the frame by cutting three fractures from the edge to 1/3 width of the both sides at the middle of the column in the first floor.

Case IV: The damage was introduced to the frame by cutting such damage as case II. The two damaged columns were considered at the first floor.

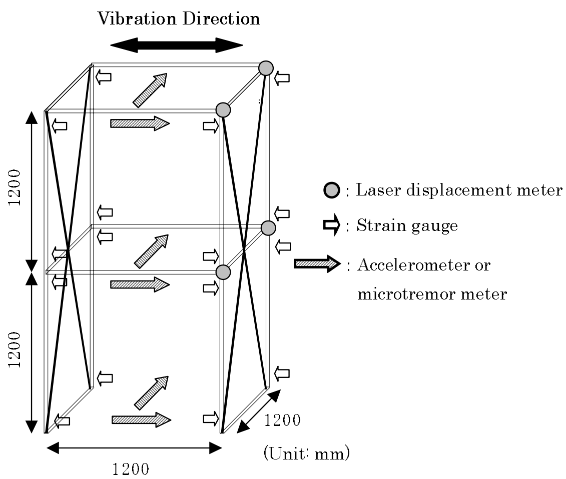


Fig.1 Experimental model

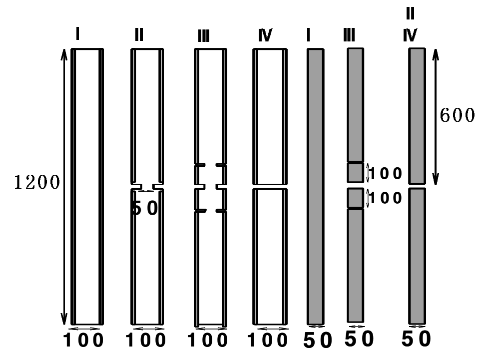


Fig.2 Damage Pattern (Unit: mm)

Table1 Configuration of damage cases

No.	Damage case	Damage pattern of column
1	No damage	
2	Small partial fracture at the first floor	II
3	Large Partial fracture at the first floor	III
4	Small partial fracture at the first floor×2	II ×2
5	Full fracture at the first floor	IV
6	Small partial fracture at the second floor	II
7	Large.Partial fracture at the second floor	III
8	Small partial fracture at the second floor×2	II ×2
9	Full fracture at the second floor	IV
10	Disconnecting at the first floor	
11	Disconnecting at the second floor	
12	Disconnecting at the fundation	

Case V: The damage was introduced to the frame by completely cutting at the middle of the column. The damaged column was attached to the first floor such as case II.

Cases VI-IX: The damage was as same as the cases II-V.

Case X: The next damage condition was introduced to the frame by disconnecting the beam-column connection in the first floor. The disconnected connection is indicated with the sign in Fig.3.

Cases XI, XII: The damage was similar to Case X; the locations differ as shown in Fig.2. The damage was introduced to the frame by disconnecting the beam-column connection in the second floor in case XI. The damage was also introduced to the frame by disconnecting the base-column connection in a different location in the second floor.

EXPRIMENTAL STUDIES

Three kinds of measurements were performed as microtremor measurement, free vibration test and vibration test by using the shaking machine.

Microtremor measurements

By microtremor measurement, it measured by using the six microtremor-meters. The meters were set up in 2 directions on the beam of the second floor, the first floor and the base level. Figure 1 shows a typical meter layout of the locations and directions on each floor level.

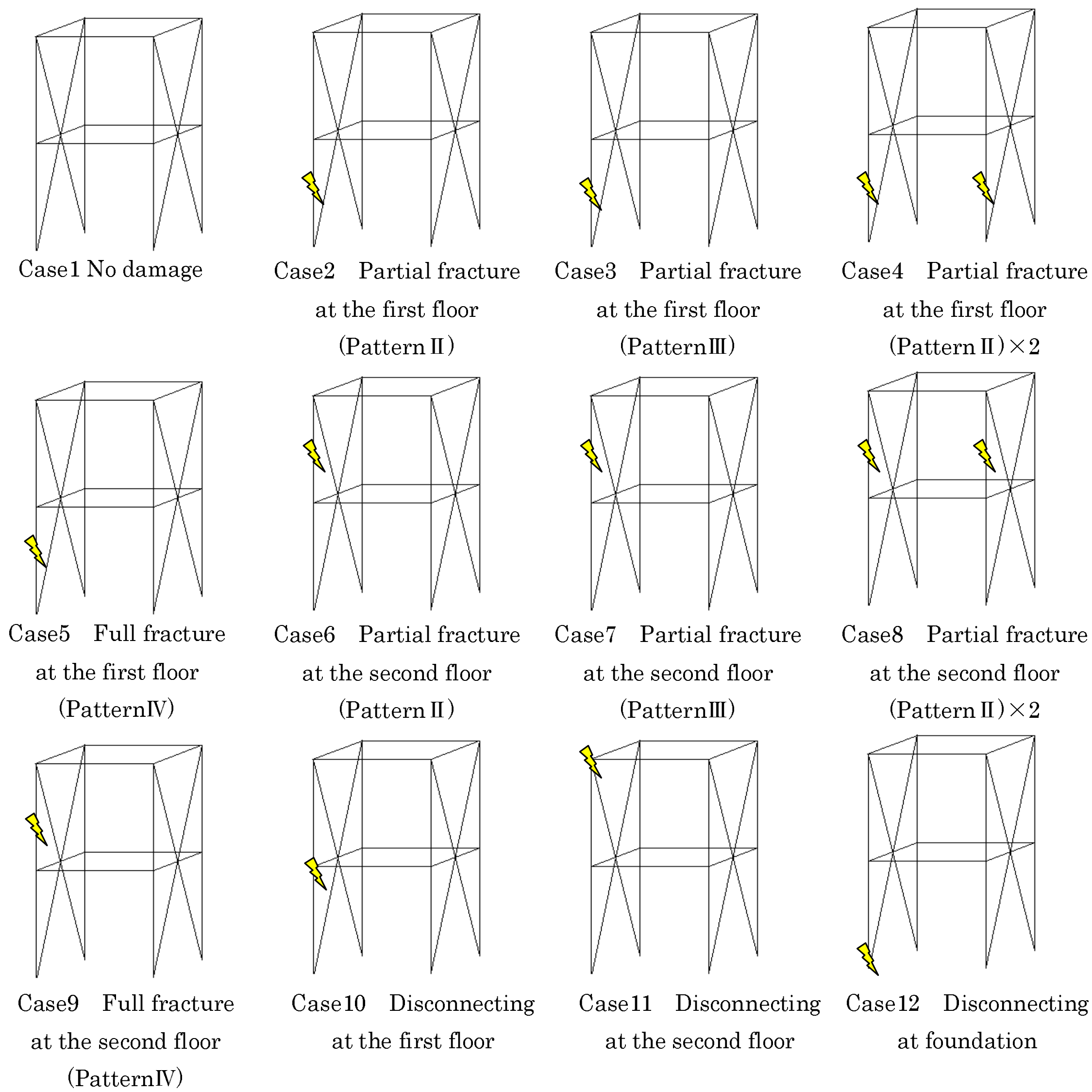


Fig.3 Damage cases

Free vibration and vibration test

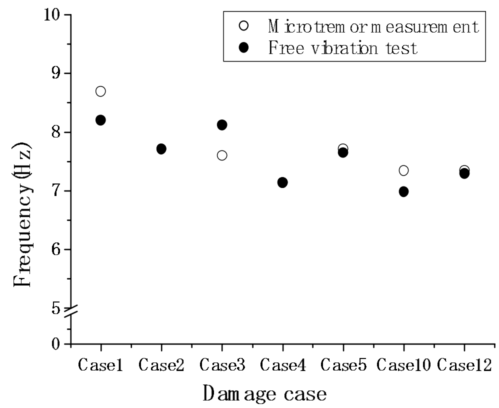
Free vibration test was performed to evaluate the dynamic properties of the model structures. Free vibration was made by applying and then sudden releasing of a static force on the beam of the roof level by the manpower. Figure 1 also shows accelerometer layout of the locations and directions of accelerometers.

The shaking machine was installed at the roof, on top of a steel plate. The weight of the machine used in vibration test is about 200N. The force vibration test is not controlled. The shaking level was full maximum magnitude of the shaker force. The applied load at roof level was chosen to be approximately 900N. Measurements were taken in three locations on each floor beginning from the roof down to the first floor. Measurements for two directions were taken in one location at the base level.

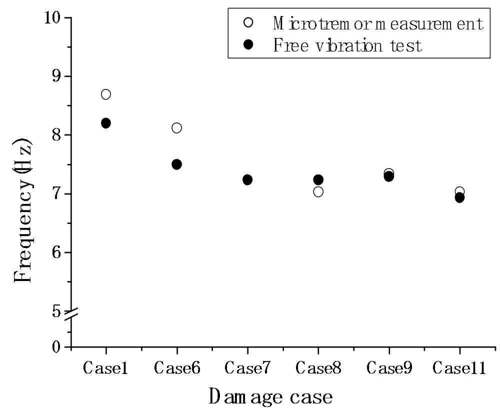
Natural frequency

The natural frequency in the lateral direction was estimated using the microtremor measurements and vibration tests. The data was analyzed in the frequency domain by using FFT analyses. The results of the testing are summarized in Fig.4. This figure shows the first order natural frequencies of undamaged and damaged steel frame. The natural frequencies of microtremor measurements of the structure are same as those obtained by the free vibration test. The results of natural frequency for all damage cases in the free vibration test and microtremor measurement were shown in Fig.4. The figures 4(a) and (b) were categorized by the results at the first floor and the second floor. The values of natural frequency in the free vibration test and microtremor measurement were similar. The values of natural frequencies of damage cases decrease for that of undamaged case. As mentioned above, it is possible to have an estimation of the sensitivity in the model and member properties. As a result, damage evaluation of the whole model from natural frequency is possible. However, it turns out that damage evaluation of model details is difficult.

In the next step, we estimate the floor position of the damaged structure. Amplitude of microtremor wave is a few microns; the signal of the laser sensor is very small. Therefore, we used the displacement at each floor level by using vibration tests. The ratio of relative displacement

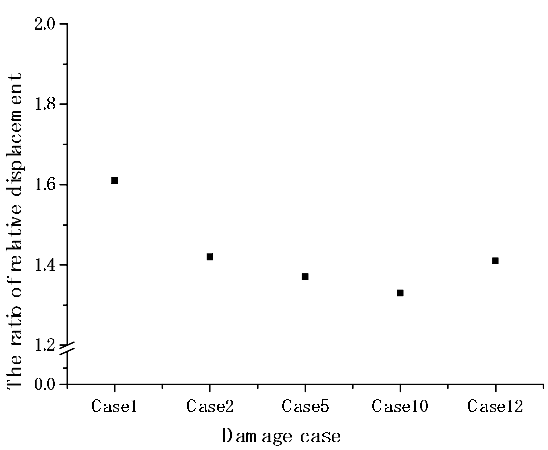


(a) Damage cases at the first floor.



(b) Damage case at the second floor.

Fig.4 Relationship between damage cases and natural frequency



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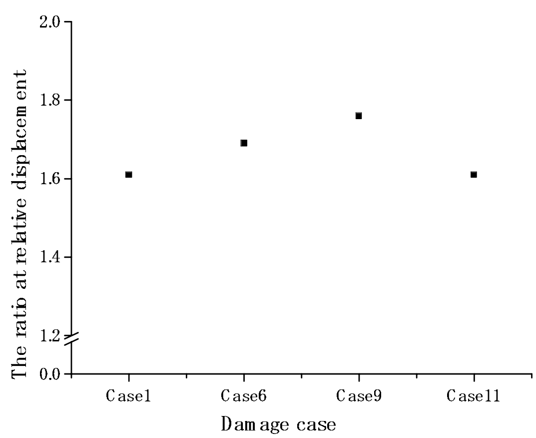


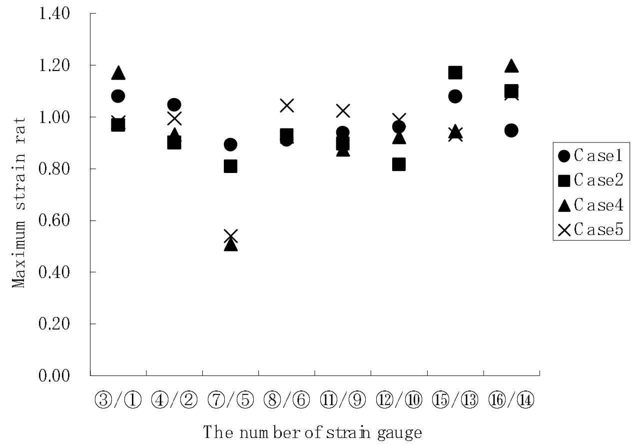
(b) Damage case at the second floor.

Fig.5 Relationship between damage cases and the ratio relative displacement

in the first and second floors was defined as the index to detect the damaged floor. Figure 5 shows the comparison between these values with damage cases. In case of the first floor, the ratios become low according to the fracture scale of the frame (Case II, V, X). In the second floor same as the first floor, the ratio also increases according to the fracture scale of the frame (Case VI, IX). However, in the damage cases by disconnecting the beam-column connection in the second floor in case XI and the base-column connection in case XII, we cannot find damage detection by using the presented ratio. Because, it is difficult to evaluate the change of dynamic behavior by disconnecting the connection.

In the third step, the maximum strain ratio of damaged frame to undamaged frame was detected the member of damaged frame. The relationship between the ratios and damage cases in the forced vibration tests was shown in Fig.6. The tendency in the results has a characteristic in which strain of the column with damage becomes small. In order to detect the damage, the ratio was calculated. The strain gauge number was shown inFig.7. The location of the strain gauge and the calculation method of the strain ratio were shown in Fig.7. The difference of the maximum strain ratio in two columns is large as damage grade becomes large. The maximum strain ratios of the undamaged frames close to 1. The similar trend was appeared at the second floor. In the disconnection cases, the ratio of No.8/6 located at the base level becomes low, if the damage occurs at another member of frame. Therefore, the method is used as benchmark for comparison with the damaged model to detect the damage.

The method has been conducted in the area of damage evaluation based on changes in dynamic properties of the structure. The method can be classified into three levels according to their performance.



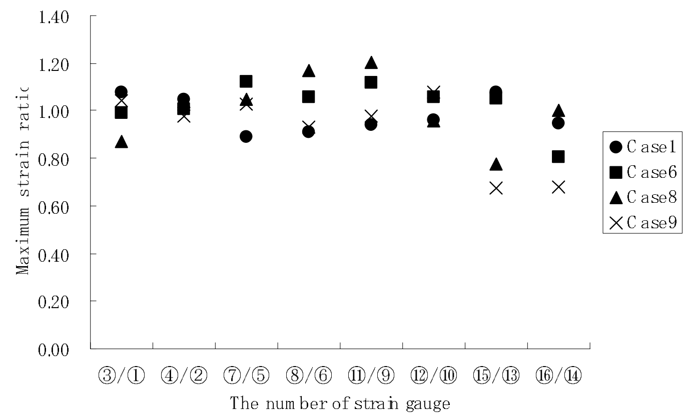


Fig.6 Relationship between damage cases and the maximum strain ratio

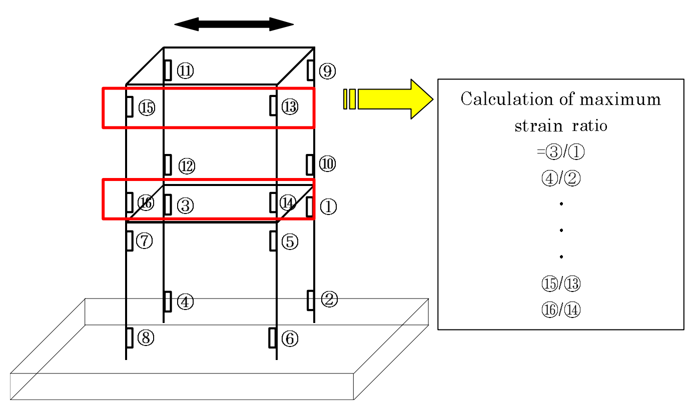


Fig.7 Location of strain gauge

Level I : the method that just identifies damage if it occurs.
Level II : the method that identifies damage if it occurs and determine the floor of the damage.
Level III : the method that identifies damage if it occurs and determines the location of the damaged member and estimates severity of the damage.

To detect the damage created to the frame, the presented method was applied to model structure. A level non-destructive damage evaluation technique was performed in this study by using the results from the forced vibration test.

CONCLUSIONS

As mentioned above, by using three steps of the health monitoring techniques, change in the of natural frequency and maximum strain ratio showed that the damage evaluation of structure models was possible. As a future subject, this technique will be applied to an actual structure. The more damage pattern like bending and buckling cases should be also considered.

ACKNOWLEDGEMENTS

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