

# MODAL PARAMETER TRANSITION OF A LOW-RISE RC BUILDING DURING RETROFITTING WORKS

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#### **ABSTRACT :**

Transition of dynamic characteristics, such as natural frequency, damping ratio, and mode vectors, was investigated by using a long-term ambient vibration test on a low-rise existing building. The measured building is a 4-story reinforced concrete (RC) building, which has been seismically retrofitted by adding concrete walls, foundations and piles. The ambient vibration had been continuously measured for nine months, from "before retrofitting" to "after retrofitting" in order to evaluate effect of the seismic retrofitting work, as well as to study on the ambient vibration test based structural health monitoring. The modal parameters are estimated by a cross-spectrum based modal identification scheme, therefore, which can be evaluated as included soil-structure dynamic interaction. By evaluating the ambient vibration records we found that the effect of seismic retrofitting on the modal parameter of the low-rise building can be clearly detected from the mode vectors, even though the natural frequency does not give a clear indication. For instance, with progresses of the retrofitting works, the natural frequency decreased due to mass effect by adding of the concrete walls, on the other hand, the rotation component of foundation and the deformation of the superstructure decreased by adding the piles and the concrete walls, respectively. Thus it is expected that the stiffness degradation of low-rise building can be also evaluated in terms of the mode vectors estimated by the ambient vibration test.

**KEYWORDS:** natural frequency, mode vectors, a low-rise building, ambient vibration test, soil-structure interaction

#### **1. INTRODUCTION**

Development of structural health monitoring (SHM) method based on ambient vibration test has been significantly carried out in recent researches, which can check structural integrity from the ambient vibration data, and which can help early recovering of urban facilities after a serious disaster such as strong earthquakes or powerful winds. Generally, low-rise buildings usually have relatively large soil-structure interaction effect in its dynamic response. Thus, when ambient vibration test is used for SHM of such buildings, it is necessary to evaluate deformation not only of super-structure but also of foundations.

The authors have estimated vibration characteristics of a low-rise RC building, which has been seismically retrofitted, as included soil-structure interaction, and have tried to evaluate a long-term change of vibration characteristics with the construction works in reinforcement. This paper shows that short-term changes of vibration characteristics always appear in a day period, and that long-term changes with the reinforcement can be detected clearly by eliminating the short-term changes from all the estimates of the vibration characteristics.





Fig. 1 Plan on the first floor of the retrofitted building



Fig. 2 A-A' section of the building after retrofit and measurement installations for ambient vibration test

## 2. SEISMIC RETROFITTING WORKS AND AMBIENT VIBRATION MONITORING

A building treated in this study is a low-rise school building in Noda Campus of Tokyo University of science, Japan. It is a 4-story reinforced concrete building on pile foundations. In order to improve the seismic performance of the building, it has been seismically retrofitted by adding concrete walls from first to third floor, foundations, and piles. These reinforcement points are shown in the floor plan of Fig. 1. The retrofitting works were carried out step by step from first to third floor, whose construction period was from August to December, 2006. In this study, transition of dynamic characteristics of the building is investigated on the point aimed at the A-A' section of the north side. This section has exiting share walls (thickness 180mm), and has been newly installed concrete walls (thickness 200mm) from the first to the third floor at one span of the west side, foundations and piles. This section of the building after retrofit is shown in Fig. 2.

Ambient vibration tests were conducted by two methods of the high-dense observation test (HD-test) and long-term continuous observation test (LT-test). Measurement installations are shown in Figs. 1 and 2. The HD-tests were conducted before (30 minutes, July 28, 2006) and after the seismic retrofit (20 minutes, December 22). In the HD-tests, 8 sets of three-component accelerometers were installed on every floor and its sampling frequency is 200 Hz. On the other hand, the LT-test was conducted from July 1, 2006 to April 9, 2007. Velocity responses were measured and its sampling frequency is 200 Hz. The measure points of the LT-tests are set to the landing between the fourth floor and the roofs, the bottom of the first floor stairs and the east- and west-outside columns.





Fig. 3 Estimated mode shape in A-A' section



Fig 4 Power spectrum of response on 4th floor

## 3. IDENTIFIED MODE SHAPE FROM THE H-D-TEST

The translational mode shapes before and after the retrofitting works are well-estimated from the record of the HD-tests. In the Fig. 3, the comparison of the mode shapes are shown. The figure is obtained by using the ARMA model based on modal identification procedure from ambient vibration records on the HD-tests. The translational mode does not change largely before and after retrofit, and in the both states the sway and rocking motions are larger than the super-structure deformation. The fact shows that the soil and foundation are softer in comparison with the super-structure. From the figures of two mode shapes before and after the reinforcement, it is difficult to distinguish the effect on the retrofitting works. In such a way, we can hardly detect the clear change before and after the retrofitting works in the case of a low-rise building with soft foundation. In such a case, we can clearly detect the slight change of the mode shape, by using the long-term monitoring as show in the next section.

## 4. MODAL IDENTIFICATION FROM THE LT-TEST

All records on the LT-test were divided by every 10 minutes with half overlapping, then the modal parameters of the building were identified by the cross spectrum based the ARMA-burg model. In the modal identification, only one velocity records at the 4th floor in east-west direction were used. It is noted that the modal parameters identified here are of the soil-structure coupling vibration system.

## 4.1. An evaluation method of a vibration characteristic

In fig. 4, power spectrum density functions (PSDF) are estimated by the fast Fourier transform (FFT) and the ARMA-burg model of responses on the 4th floor in east-west direction at 0 o'clock and 12 o'clock July 3, 2006. As shown in the figures, the PSDFs for responses both the FFT and the ARMA-burg have peaks at around 3 Hz. In addition, as compared with the night and the day, absolute values are different greatly, which are caused by different amplitude levels of the acceleration response.





Fig 5 Day fluctuation of natural frequency and acceleration response

## 4.2. Day fluctuation of natural frequency

Fig. 5 shows natural frequency transitions of the fundamental mode on the east-west (EW) directions and the root-means-square of the acceleration response on the 4th floor for a week from July 3 to 9. In the figures, the natural frequencies in a weekday become higher in the daytime and lower in the night, and such day fluctuations are confirmed clearly. On the other hand, the natural frequencies in a holiday seem to fluctuate in almost constant, and the change width is small. A big difference between a weekday and a holiday was found in the middle of night at 0 to 7 o'clock. These changes of the natural frequencies are not correlated with the changes of the amplitude of the acceleration response. Based on the above considerations, a long-term transition of modal parameter will be discussed with three different categories in the middle of the night of a holiday, in weekday the middle of the night, and in the daytime.

## 4.3. A long-term fluctuation of modal parameter

Fig. 6 shows a retrofitting work schedule (a), root-means square of the acceleration response (b), natural frequency transitions (c), and the mode rotation calculated by the mode vectors (d,e,f) on the EW directions from July 1, 2006 to April 9, 2007. And, to analyze a difference of a vibration characteristic by the above mentioned three categories, three kinds of marks are plotted. Thus, in the fig. 6, the weekday middle of the night at 3 o'clock and the daytime at 15 o'clock and the middle of the night at 3 o'clock of a holiday are plotted by  $\bullet$ ,  $\triangle$ , and  $\Box$ , respectively.

## 4.3.1. Natural frequency transition

As shown in the fig. 6 (c), the natural frequencies are different with the three marks of the evaluation hours, but each natural frequency in the same category is almost constant. And, focusing on the weekday middle of the night ( $\bullet$ ), it is found that a long-term transition is easy to read. In detail, natural frequency decreases slowly from September to October, and a tendency to increase a little in around December. However, there is not clear of these changes with the reinforcement work. In addition, to the end of the year and in the beginning of the year (from December 31 to January 3), natural frequency suddenly increases, however, the reason of the rapid increase cannot be clarified here. In such a way, it is easy to investigate the effect of a long-term transition with screening natural frequency categorized by evaluation hours. However we cannot clearly confirm correlations between the change of the natural frequency and the retrofitting works.





Fig 6 A retrofitting work schedule, acceleration response (RMS) at the roof floor, natural frequency, sway rate, rocking rate, and superstructure rate on the EW directions.



#### 4.3.2. THE MODE VECTORS TRANSITION

To investigate the change of the mode vectors, the transitions of the mode vectors are show in Fig. 6 (d) to (f). In the figure, the mode vectors are shown as three deformation rate; sway rate  $\phi_s$ , rocking rate  $\phi_k$  and superstructure rate  $\phi_k$ . The three deformation rate of modal vectors are defined as follows :

$$\phi_{B} = \frac{X_{RF} - X_{1F} - H \times \theta_{1F}}{X_{RF}}$$

$$(1)$$

$$\phi_{s} = \frac{X_{1F}}{X_{RF}}$$

$$(2)$$

$$\phi_{R} = \frac{H \times \theta_{1F}}{X_{RF}}$$

$$(3)$$

$$\theta_{R} = \frac{Z1_{1F} - Z2_{1F}}{Z_{RF}}$$

$$(4)$$

 $X_{RF}$ ,  $X_{1F}$  are the horizontal displacements of the top and the basement;  $\theta_{VF}$  is the rotational angle of the basement; H is the height of a measurement point from a top to basement; W is the distance between measurement points of the basement.

As show in Fig.6 (d),(e),(f), the changes of modal vectors can be clearly detected with the progress of the retrofitting works. We pay focus on the result of weekday middle of the night ( $\bullet$ ), and evaluate the long-term changes. The sway rate increased with casting the exterior wall reinforcement after the middle of October. Then the superstructure rate decreased, and the rocking rate remained in constant. In the details, the sway rate increased from 0.57 to 0.62 in October 18 to December 4, and the increasing ratio reached to about 5 percent. During the same period, the superstructure rate decreased from 0.19 to 0.14 and the decreasing ratio equaled to about 5 percent. These changes of the modal vectors were caused by adding the story stiffness owing to the concrete walls casting on the first to the third floors. Another change of the modal vectors can be detected in September, 2006. In this month, the rocking rate gradually decreased from 0.26 to 0.24. This decreasing might be caused by the foundation reinforcement.

#### **5. CONCLUSION**

In the paper, transition of dynamic characteristics of a low-rise existing building, which has been seismically retrofitted, was investigated based on a long-term ambient vibration test. And when we pay attention to a long-term fluctuation, it is easy to detect the changes of modal parameter due to the structural reinforcement, by screening assumed modal parameter referred in evaluation hour. It is also found that effect of seismic retrofitting on the modal parameter of the low-rise building with included soil-structure interaction can be clearly detected from the mode vectors, even though the natural frequency does not give a clear indication.

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