EXPERIMENTAL STUDY ON CHANGES IN DYNAMIC CHARACTERISTICS OF RC STRUCTURES DUE TO CRACKS

Utsunomiya University Student ○ Visal Thay Fellow Akinori Nakajima
Student Reem Al Sehnawi Student Shohei Maruyama

1. Introduction

Reliable estimates of the dynamic characteristics, namely natural frequency and damping ratio, are very essential to predict the dynamic response of structures. The accurate assessment of dynamics characteristics is becoming a major concern to many researchers, mainly in non-linear stage of structures. This paper deals with the changes of dynamic characteristics experimentally due to cracks of RC structures which are considered as an association with the stiffness and energy dissipation in the case of RC simple beam and RC pier.

2. RC simple beam experiment

(1) Experimental model and methods

The specimen's geometrics and reinforcement details are provided in **Fig. 1**. The yield strength and Young's modulus of used longitudinal reinforcing bars were, respectively, 401N/mm^2 and 210kN/mm^2. The compressive and tensile strength of concrete were, respectively, 38.1N/mm^2 and 4.96N/mm^2, and the Young's modulus was 29.1kN/mm^2.

To measure the crack size (crack width), 5 strain gauge type transducers were attached to the specimen. Cracks were induced artificially by conducting the loading test at midspan of the specimen. The free vibration test was excited by hammer impact on RC simple beam after each time of the loading test. The acceleration responses were recorded by an accelerometer in vertical direction at midspan of the specimen. The natural frequency was identified by using the Fast Fourier Transform (FFT), while the damping ratio is calculated from free vibration decay function using logarithmic decrement method.

(2) Experimental result

Table 1 presents the condition of damage level after each loading test. L0 is the original stage before applying the load. L1-L6 presents the damage level after each loading test. Total crack width in the last column is the sum of all crack widths measured after the load released.

Fig. 2 and **Fig. 3** illustrate the changes of dynamic characteristics for each damage level. In **Fig. 2**, the damage level and the natural frequency are plotted along the horizontal axis and the vertical axis respectively. Result from **Fig. 2** shows that the growth of damage decreases the natural frequency. Stiffness loss of beam due to the growth of cracks (occurrence of discontinuity in beam) might cause the decrease of its natural frequency.

In **Fig. 3**, the horizontal axis is the damage level and the vertical axis is the damping ratio. **Fig. 3** shows that the growth of damage raises the damping ratio of beam. In the case of uncracked RC structures, mainly material damping occurs, while in the case of cracked RC structures, there is

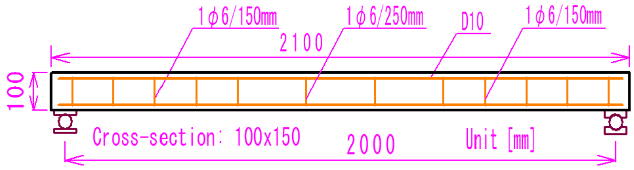

Fig. 1 Simple beam model

Table 1 Damage level

Damage level	Number of visible crack	Totoal crack width (load release) (mm)
L0	Undamaged	0
L1	0	0.019
L2	2	0.034
L3	4	0.162
L4	8	0.366
L5	11	0.569
L6	13	1.113

a combination of the material damping and the frictional damping. The frictional damping here mainly occurs due to friction between concrete and rebars near the crack (in cracked tension zone). When cracks occur, although it is considered that the material damping in structures decreases, the amount of the frictional damping is rather large. This might be the cause of increasing the damping ratio in beam system.

In addition, when comparing the percentage changes of the natural frequency to the percentage changes of the damping ratio for each damage levels, result clearly shows that changing trend of the damping ratio is more sensitive than that of the natural frequency, that is, 20-27% for natural frequency and 85-100% for damping ratio.

3. RC pier experiment

(1) Experimental model and methods

RC pier specimen's geometrics and reinforcement details are illustrated in **Fig. 4**. The pier cap is connected to the concrete block which is considered as a super structure. The material properties of pier specimen is the same as beam's ones.

In the case of pier model, 5 strain gauge type transducers are arranged to measure the crack width. The specimen was damaged by conducting the shaking table test of a record ground motion during Kushiro earthquake with peak ground acceleration (PGA) of 0.7g. The seismic excitation intensity was conducted by 20%, and then increased gradually by 10% until reaching 120%, finally 150% and 160%. The free vibration test was conducted by exciting the concrete block at the top of RC pier model using the hammer at original stage and after each excitation of shaking table test. The acceleration responses were recorded by an accelerometer in longitude axis (direction of vibration) at the top of concrete block. The same meth-

Key Words: *Dynamic characteristics, Vibration test and shaking table test, Cracks, RC simple beam model, RC pier model*
〒 321-8585 Tochigi Prefecture, Utsunomiya, Yoto, 7-1-2, Utsunomiya University Tel.028-689-6208 Fax.028-689-6208

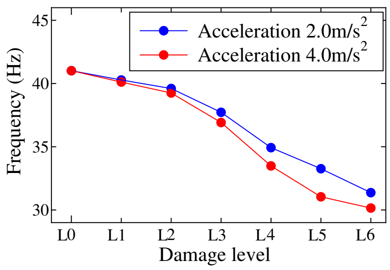

Fig. 2 Damage level versus natural frequency in beam model

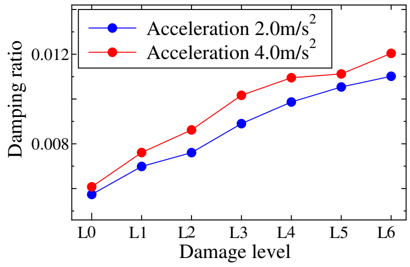

Fig. 3 Damage level versus damping ratio in beam model

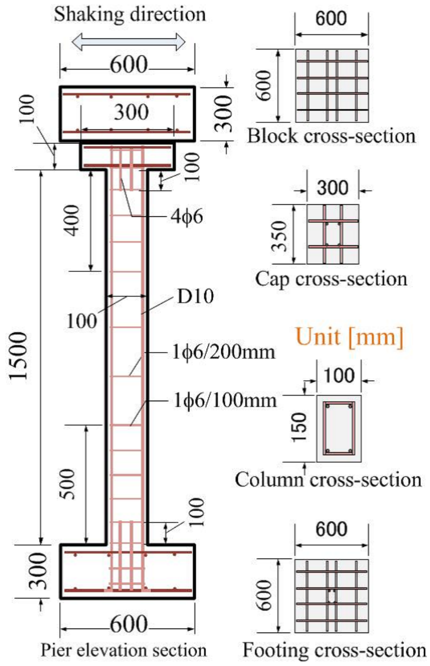

Fig. 4 Pier model

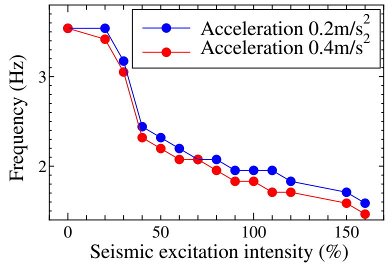

Fig. 5 Damage level versus natural frequency in pier model

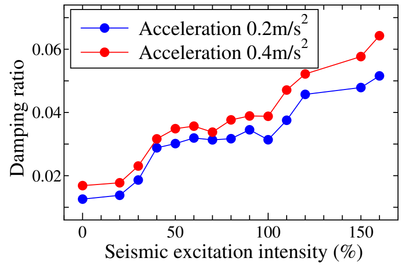

Fig. 6 Damage level versus damping ratio in pier model

ods were applied to identify the natural frequency and the damping ratio.

(2) Experimental result

Although the crack widths were measured by the strain gauge type transducers during conducting the shaking table test from 20% to 120%, there is no sign of crack width measured after finishing the excitation. However, the existence of cracks is proven according to the free vibration test data after each shaking table test. With the same impact force by hammer in the vibration test, the growth of crack width is observed, approximately from 0 to 0.04mm (20%-120%). Bond between concrete and rebar in RC member or the weight of structure can be considered as the factors which keep the crack unopened or invisible after the shaking table test. However, in case of 150% and 160%, respectively, 0.678mm and 1.733mm of crack width at 100mm from the footing surface was measured.

Fig. 5 and **Fig. 6** present the changes of dynamic characteristics in RC pier. In **Fig. 5**, the horizontal axis is seismic excitation intensity and the vertical axis is the natural frequency. Result from **Fig. 5** shows that the growth of damage (increase of excitation intensity) leads to the decrease of the natural frequency due to the stiffness loss. In **Fig. 6**, the seismic excitation is plotted in the horizontal axis, and the damping ratio in the vertical axis. Result from **Fig. 6** shows that the growth of damage leads to the increase of the damping ratio due to the occurrence of the frictional damping between concrete and rebars. Thus, the changes of dynamic characteristics can be confirmed even in the case of an unopened crack.

Moreover, when comparing the percentage changes of the natural frequency to the percentage changes of the damping ratio, similar to beam case, the changes of the natural frequency of the final stage to the undamaged pier are small, approximately 53-59%. On the other hand, the changes in the damping ratio are relatively large, that is 280-327%.

4. Discussion

By considering the crack size (crack width), the changes of dynamics characteristics of RC pier is larger than the ones of RC simple beam. It is due to the stiffness loss of the pier is larger, and the frictional damping of the pier can be took places in both sides of specimen (4 rebars) compared to 2 rebars of the beam in a crack damage. The friction between crack surfaces in the pier might contribute to the cause as well. In addition, the strain value of rebar at the bottom of the pier column is larger than that of the rebar at midspan of the beam during the vibration test. That means the frictonal damping of the pier is larger than the beam's one due to the bad bond condition between rebar and concrete (at those positions) of pier.

5. Conclusion

Therefore, these experimental results lead us to the following conclusion.

1. The growth of cracks lead to the decrease of the natural frequency and the increase of the damping ratio.
2. The changing trend of the damping ratio is remarkably larger than that of the natural frequency in both specimen models, accounting about 3-5 times.
3. The occurrence of the frictional damping between concrete and rebars due to cracks can be considered as the essential increase of the damping ratio. Moreover, the existence of the frictional damping may be considered even in unopened cracks.
4. Unopened crack also affects dynamic characteristics.

REFERENCES

1) Al Sehnawi R, Nakajima A, Takeshima R, Al Sadeq H: Experimental investigation of amplitude dependency of dynamic characteristics in elastic and inelastic stages of reinfocred concrete pier model, Journal of Civil Structural Health Monitoring, Volume 4, Issue 4, pp.289-301, 2014.11.