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Investigation on the Vertical Vibration Characteristics of Actual Structure for Earthquake Observation Records and Impactor Test

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1. Introduction

To well understand the nature of the structure's behavior due to dynamic loads, it is important to investigate the dynamic response of the actual building, which can give us more realistic information than specimen's test. In this paper the vertical motion behavior of the nine stories reinforced concrete building of the department of architecture and building science of Tohoku University at Aobayama campus has been studied. During the 1998.9.15 Miyagi-ken Nanbu earthquake, observation records are obtained at the first floor and ninth floor of this building. Also based on the test done on May 1998, an impactor machine, which is commonly used in geological reflection survey, was used to generate dynamic load. The effect of high-level as well as low-level amplitude of input waves in structure response for vertical motion has been discussed.

2. Outline of the impactor test

The impactor hit the surface ground, outside of the building on the centerline of the building at the northern side. Three components of the velocity waveforms of the structure as well as ground response were obtained. In this paper, only the vertical motion of the structure is considered and the results are compared with the records obtained during the earthquake. The vertical motion was recorded at the first floor and roof. To avoid the effect of rocking motion, in each floor two records are obtained along the centerline and the average of these two points (each floor) is taken as a representative of the structure response. The layout of the test is schematically shown in Fig.1.

The building is built on the pile foundation. Regarding the soil condition, the sandy gravel surface layers with total thickness of 20m are stratified on the soft tertiary rock. The average shear wave velocity of the surface layers is about 250m/s and the soft rock is 500m/s.

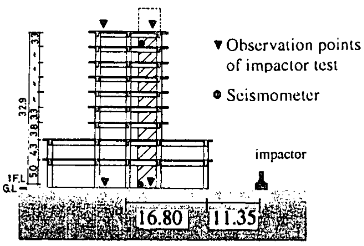

Fig. 1- Layout of the test and location of the observation points[1)].

3. Analyses of recorded data

3.1- Analyses of the earthquake's records

During the 1998.9.15 Miyagi-ken Nanbu earthquake in Sendai City, seismometers installed in the first and ninth floor of the building of department of architecture and building science (Tohoku University) recorded three component motions of the seismic waves. In this study only the vertical motion of the building is studied. According to the observed records, the acceleration waveform at the ninth floor is amplified 3 times compare to the first floor (Fig.2). To investigate the amplification characteristic, Fourier amplitude spectrum of these two levels are calculated (Fig.3). The main amplification occurs around 3Hz, 5.7Hz and 7Hz. To clarify the effect of dynamic property of the building and input motion on the amplification, the transfer function at the ninth floor (9F/1F) is calculated (Fig.4). Smoothing technique based on Hanning method is used to calculate the transfer function. From the transfer function, it can be recognized that the 3 Hz amplification is mainly due to input motion, because there is no amplification at this frequency in the transfer function. The fundamental mode of the structure in the seismic case is around 6Hz.

3.2- Analyses of the impactor's records

The dynamic behavior of the same building for the vertical motion is investigated for low-level amplitude of the input motion, generated by the impactor. The records are obtained at the first floor and roof. A low-pass filter with range 0-20 Hz is used to eliminate the noise existing in the observed wave. The waveform at top floor is amplified 1.35 times, which is less than the amplification observed for the earthquake case (Fig.5). This low amplification is due to the geometric damping, result from point excitation. Unlike the earthquake wave, which is plane wave incident, the point excitation produces spherical propagating wave, which the geometric damping becomes important. The Fourier amplitude spectrums of these waves are calculated and as expected 3Hz frequency content amplification does not exist in top floor spectrum (Fig.6). The transfer function of the roof (Roof/1F) is calculated (Fig.4). The fundamental mode for the impactor case is around 8Hz. Also based on the observation records, the response of the roof and the first floor are in-phase up to 10Hz, and become out of phase for the frequency higher than 10Hz.

3.3- Effect of high and low level amplitude of the input motion

Comparing the transfer functions of the described cases, it is understood that the fundamental frequency in the earthquake case is about 70% of the impactor case. This means that the structure stiffness in earthquake case is 50% lower for earthquake case compared to impactor case. Almost the same reduction factor is recognized for horizontal response of the building during the 1998.9.15 earthquake and microtremor test performed after the earthquake[2)]. The shapes of the obtained transfer function and earthquake case transfer function are almost similar, but the amplification in the high level input motion is larger than low level case (Fig.7). The reason of the low amplification level for the impactor case can be due to geometric damping of the spherical wave generated from point excitation loads.

The relative velocity waveforms (top to 1F) and corresponding Fourier amplitude spectrum of each case are shown in Figs.8&9. According to these results, the maximum velocity for the earthquake case is about three orders larger than impactor case. For the Fourier amplitude spectrum, it can be noted that the maximum amplitude level of the earthquake case is about two orders larger than the impactor case.

To make the simulation analyses; the transfer function of the analytical model must match to the transfer function obtained in previous parts. The analytical model can be made by simple lump-mass model with fix base, because records at the first floor are observed inside the building. The effect of soil-structure interaction already exists in the observation data.

4. Concluding remarks

The following conclusions are suggested:

1- From the calculation of the transfer function of vertical montion at the top floor, it is suggested that the stiffness of the building is about 50 % lower for earthquake (high-level amplitude) compared with impactor case (low-level amplitude).

2- Almost the same reduction factor in stiffness is recognized for the horizontal response of the building by comparing the records during the 1998.9.15 earthquake and microtremor test

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performed after the earthquake. The reduction factor in the stiffness is due to non-linearity characteristics of the reinforced concrete frame.

3- The impactor can be a right tool to investigate the dynamic behavior of actual buildings up to high frequency range. The vertical motion can not be investigated by the microtremor test, but by using the impactor it is possible to investigate the vertical motion response of the building.

5. Acknowledgment

The authors would like to express their gratitude to Professor Akira Hasegawa of Observation Center for Prediction of Earthquake and Volcanic Eruptions of faculty of science of Tohoku University, for providing the impactor machine to perform the test.

6. References

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2- M. Motosaka, *Ground motion characteristics in Sendai area and structural damage during the1998.9.15 Miyagi-ken Nanbu earthquake*, Proc. of 20th year memorial symposium of 1978 Miyagi-ken Oki earthquake, pp.17-22, 1998. (Japanese).

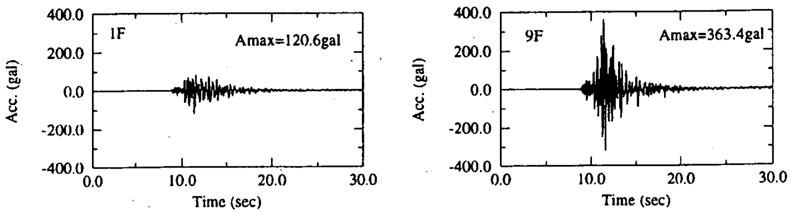

Fig. 2- Observed acceleration records for earthquake case.

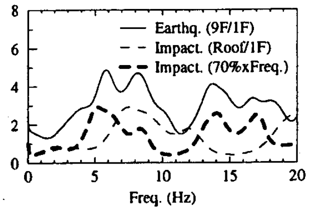

Fig. 7- Comparison of the smooth transfer functions. *(70% shift in frequency for the impactor case)*

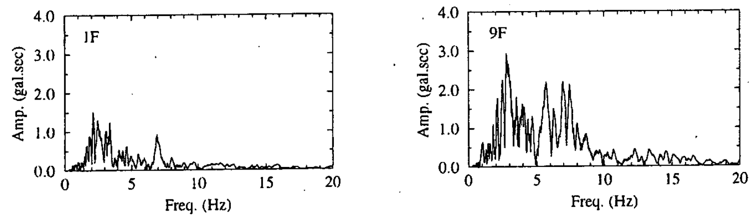

Fig. 3- Fourier amplitude spectrum for earthquake case.

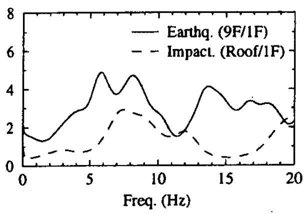

Fig. 4- Smooth transfer functions of earthquake and impactor case.

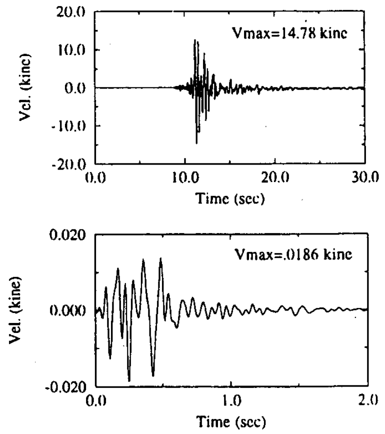

Fig. 8- Relative velocity motion waveforms for earthquake and impactor test.

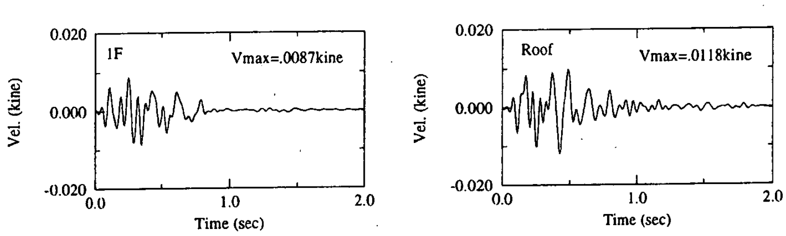

Fig. 5- Observed velocity records for impactor case.

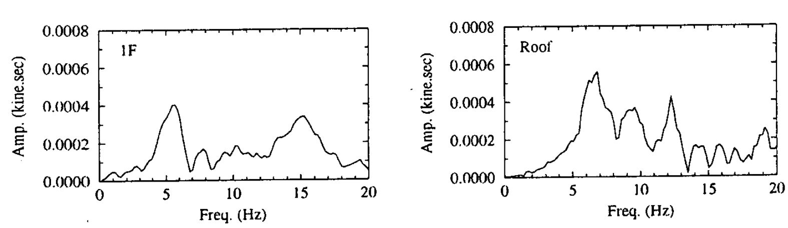

Fig. 6- Fourier amplitude spectrum for impactor case.

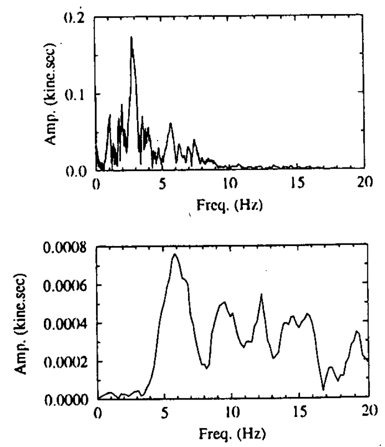

Fig. 9- Fourier amplitude spectrum of the relative velocity motion.

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