# Analytical Model of Building of Institute of Industrial Science
# Based on Seismic events and Microtremors records considering soil-structure interaction

The University of Tokyo, Institute of Industrial Science, Student Member Gabriel Calle
The University of Tokyo, Institute of Industrial Science, Member Masayuki Kohiyama
Asian Institute of Technology, Member Fumio Yamazaki

**Introduction**: The seismic response of structures has been one of the most important topics in earthquake engineering and numerous studies have been carried out. However, seismic observation systems of actual structures are still rather scarce, and hence, the seismic records from actual structures together with free field motion nearby have significance importance to examine analytical models. Recently, the Institute of Industrial Science (IIS) of the University of Tokyo has been moved from the central to the western part of Tokyo. During the relocation, a seismic observation system was set up in the institute's new building and its surrounding ground. This paper discusses on the building response based on the seismic records and microtremors as well as on the building model considering the soil-structure interaction effect.

**Structural characteristics of the Institute of Industrial Science:** The new building of the Institute of Industrial Science is 218 m long, 48 m wide. The first two stories (the base and first stories) are moment - resisting steel reinforced concrete frame structures. From the second story to the top of the structure is a combination of concentrically braced and moment-resisting steel frames. The building is composed of two wings (east and west), both oriented north and south. The two wings are separated from each other, having an open space in between. The two wings are linked by several simply supported bridges. Each wing is composed of two structures separated by an expansion joint. For administrative purposes both wings are sub-divided into blocks B, C, D, E, and F. The expansion joint is located between blocks D and E (**Figure 1**). Thus, four "independent" superstructures compose the building. This paper focuses in the analysis and modeling of the west wing between blocks B and D only. The west wing is eight-story high, while the east wing is six-story high. The first story's height is 7.25 m while the other inter-stories height is 4 m. Foundation beams linking the caps of clustered piles of reinforced concrete compose the building's foundation.

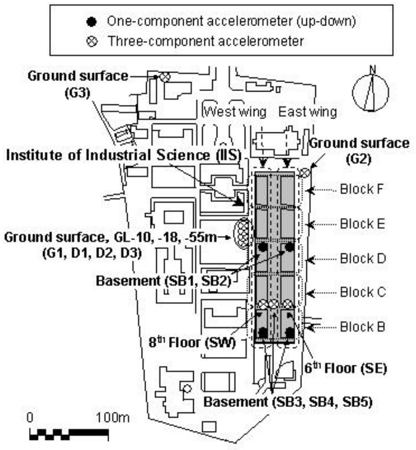


**Fig. 1**. The Institute of Industrial Science Building and location of accelerometers

**Seismic observation system:** The seismic observation system consists of nine three-component accelerometers and four one-component accelerometers, with acceleration range 0 - 2000 cm/sec$^2$, frequency range 0.1 - 30 Hz, and sampling frequency of 100 Hz. The locations of accelerometers placed in the downhole, on the ground surface and on the building floors are shown in **Figure 1**. There are three three-component accelerometers placed on the ground surface and another three three-component accelerometers buried at different depth levels (–10 m, –18 m, and –55 m). On the basement of the building, four one-component (up-down) accelerometers and one three-component accelerometer were placed. Also, two three-component accelerometers were placed between blocks B and C on the eighth and sixth floor of the west and east wing, respectively.

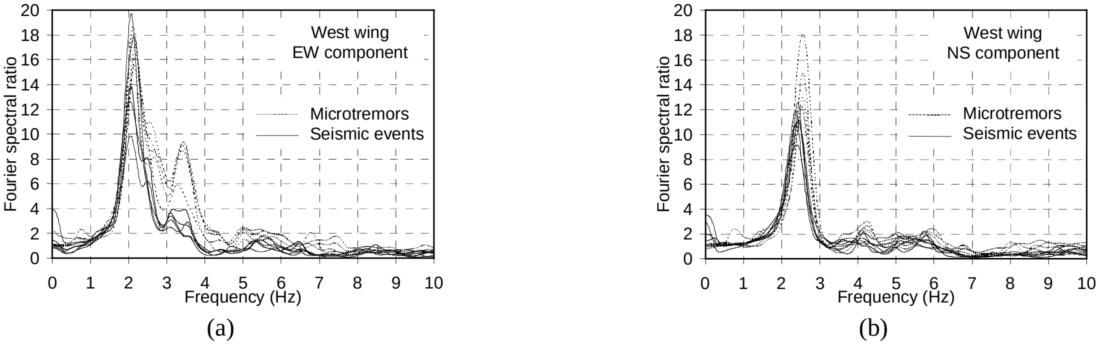
**Earthquake response of the structure:** Based on six seismic events taken out of twenty that have been recorded by the system the fundamental frequency of the building was evaluated in terms of the ratio of Fourier spectra of the seismic records at the eighth floor and those on ground surface. The Fourier spectra were smoothed by means of a Parzen window with bandwidth 0.4 Hz. Additionally, microtremors were measured on the building floors at the same locations of the accelerometers SE and SW. **Figure 2** shows the Fourier spectral ratio of the seismic records and microtremors between the eighth floor and ground surface. Good agreement is observed between microtremors and seismic events in term of the fundamental frequency although the levels of shaking are quite different between seismic records and microtremors. The fundamental frequency of the west wing (8 story) is obtained as about 2.6 Hz (period = 0.39 sec) and 2.1 Hz (period = 0.48 sec) to the NS and EW directions, respectively.

**Structural modeling of IIS Building**: The building of the Institute of Industrial Science (IIS) was modeled by three-dimensional finite elements using a structural analysis program, SAP2000.1) The linear elastic dynamic problem is solved in the time domain by means of a combination of the mode superposition and incremental methods.2) The structural damping is assumed to be of Rayleigh type. **Figure 3** shows a 3D view of the model. The model was set up based on the structural drawings and the loads acting on it were assumed to be the same as those used in the design. The modal damping was assumed to be 2% for all the modes of vibration because it is a steel structure and the seismic events that have been recorded are rather small. The building was initially modeled with a fixed-base. However, the model with this assumption was found to be stiffer than the actual structure, from the result of the seismic observation. Since soil-structure interaction seems to affect the actual building's behavior, the authors have decided to introduce the soil effects in the model. The effect that the soil has on

---

***Key Words***: *Fourier spectrum, microtremors, Finite Element Method, soil-structure interaction.*

***Contact Address***: 4-6-1 Komaba, Meguro-ku, Tokyo 153-8505, Japan. Tel: 03-5452-6388, Fax: 03-5452-6389



(a) (b)

**Fig. 2**. Fourier spectral ratios between the 8th floor of the west wing SW and ground surface for the seismic events and microtremors to the horizontal directions: (a) EW direction, (b) NS direction.

the structural response was modeled by means of massless supporting springs. The stiffness values of those springs were computed according to the methodology proposed by Gazetas.$^{3)}$ The values of these stiffnesses were adjusted by trial and error following the ATC-40 methodology.$^{4)}$ The acceleration time history responses obtained from the model for the six seismic events at the locations of the accelerometers were analyzed using the Fourier spectra. The ratio between the Fourier spectrum on the 8th floor of the building (from the model) and that on the ground surface was computed. **Figure 4** shows the comparison between the Fourier spectral ratios from the seismic records and from the model analysis. Good agreement was achieved in term of the fundamental frequency between the observed seismic records and model. However, the structural model generally overestimates the level of amplification. It could be explained based on the fact that in the model the effect of the soil was modeled only by mass-less springs, and thus, the effect of radiation damping was not considered. The second peak exhibited by the model is due to the effect of the higher modes in the “isolated” structural model. It should be noticed that the analyzed structure is rather irregular. Torsion is one of the most important modes of vibration and its contribution is significant in the model. However, this mode is constrained to a certain extent by the actual boundary condition that were not considered. As for the seismic records, the same level of matching was achieved when one compares the Fourier spectral ratios of microtremor and those computed from the model. This may be rather obvious if one observes very good agreement between the Fourier spectral ratios of microtremor and seismic records in **Figure 2**.

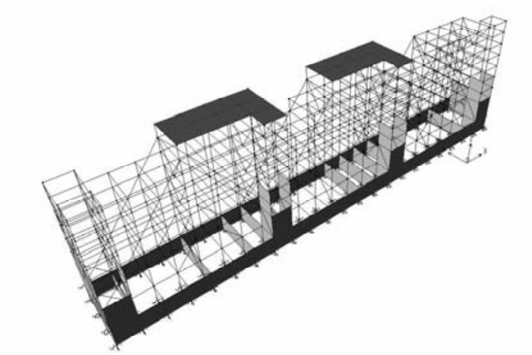
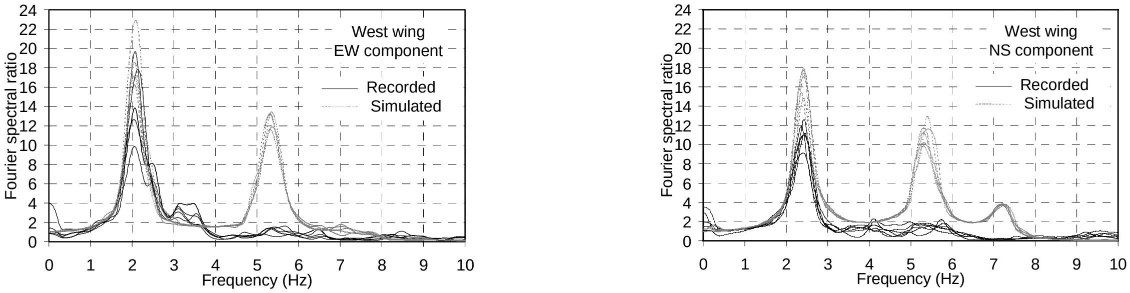


**Fig. 3**. Three-dimensional finite element model.



(a) (b)

**Fig. 4**. . Fourier spectral ratios between the 8th floor of the west wing SW and ground surface G1 from the seismic events recorded and simulated by the computer model: (a) EW direction, (b) NS direction.

**Conclusions:** Finite element model was employed to analyze the structural response of the west wing of the Institute of Industrial Science’s building. It was found that a usual fixed-base model could not represent the actual behavior of the structure properly. Hence the mass-less springs were added to the model to simulate the boundary condition of the embedded parts of the structure. The results in terms of fundamental frequencies match very well with those obtained from the microtremors and seismic records. The discrepancy in the level of amplification may be due to the simplification assumed in the model, especially that introduced in the boundary condition.

## References

1) Computers and Structures Inc, 2000. SAP2000, Integrated Structural Analysis and Design Software, Analysis Reference and User’s manual. Berkeley, California, USA.
2) Wilson, E. L, 2000. Three Dimensional Static and Dynamic Analysis of Structures, a Physical Approach with Emphasis on Earthquake Engineering. Computers and Structures Inc., Berkeley, California, USA.
3) Gazetas, G. 1991. “Foundation Vibrations,” Foundation Engineering Handbook, Ed. Fang.
4) Applied Technology Council, 1996. Seismic Evaluation and Retrofit of Concrete Buildings, ATC-40, Volume 1.