SIMULATED EARTHQUAKE GROUND MOTION FOR STRUCTURAL DESIGN

Satoru Nagase
Nikken Sekkei Ltd.
Tokyo/Japan

Abstract

The structural safety against earthquakes of skyscrapers and seismic-isolation buildings is generally calculated using computer simulations. Such calculations require a ground motion model that can be applied to structural design. Here, let us look at three such motion models—the model formerly used when filing for a building permit from the Ministry of Construction, the Nikken Sekkei-developed “Art Wave,” and the recently developed “NS Wave” model.

Old Motion Model Since skyscraper design began in Japan in the latter half of the 1960s, simulations were usually performed by adjusting the amplitudes of seismic ground motions recorded at several adjacent sites. Until the 1980s, however, too few sites were equipped to record tremors and the devices did not provide adequate records of long-period ground motion. Long-period ground motion is especially important for a building 30 or more stories high which corresponds to a natural period of 3 or more seconds (see *Fig.1*). Reliance on such observation records alone might result in an underestimation of seismic ground motions.

“Art Wave” In 1988, Nikken Sekkei developed its own seismic ground motion model, “Art Wave,” in order to remedy the underestimation problem. “Art Wave” was designed to calculate the structural strength needed to withstand ground motion at periods of 3 or more seconds (*Fig.1*).

In 2000, with revision of the Building Standards Law, the Ministry of Construction issued a notification stipulating the long-period seismic motions that had to be taken into account in designing skyscrapers.

From then on, these official specifications (called the “Kokuji Wave”) were applied to the design of skyscrapers and seismic-isolation buildings built throughout Japan (*Fig.1*).

Recently developed “NS Wave” Nikken Sekkei then developed a next new earthquake motion simulation system for structural design—the “NS Wave”— aimed to take account for earthquake-inducing faults and other ground conditions specific to different project sites. The Japanese archipelago is subject to two types of earthquakes. One is interplate quakes that result from slippage of one tectonic plate subducting another in the ocean offshore (*Fig.2 and 3*). The other is shallow earthquakes occurring inland. The tremors thus generated are transmitted through the bedrock and then amplified by the sedimentary layer near a project site (*Fig.4*). The “NS Wave” model focuses on calculations determined by the conditions of specific sites.

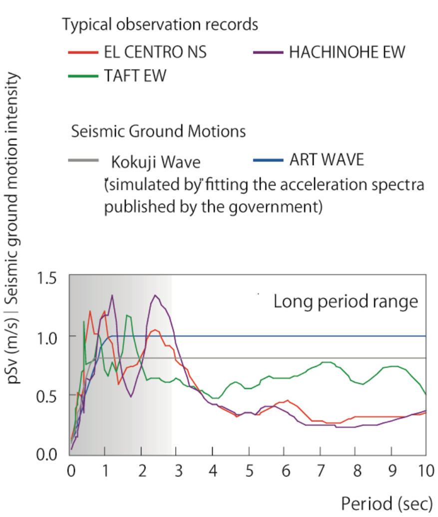
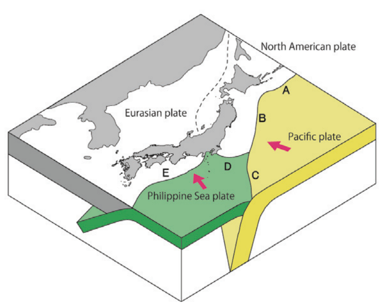


Figure 1. Comparison of observation records and seismic ground motion figures.



A:Chishima Trench
B:Japan Trench
C:Izu - Ōgasawara Trench
D:Sagami Trough
E:Nankai Trough

Figure 2. Tectonic plates around Japan.

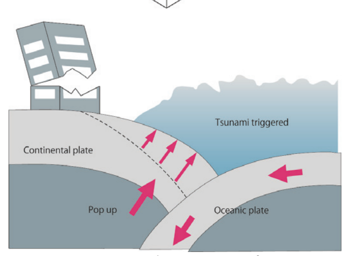


Figure 3. Mechanism of an Interpolate earthquake.

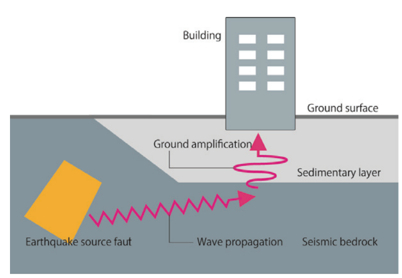


Figure 4. Propagation and amplification of tremors.

Earthquakes can be classified by type into inland earthquakes that occur at active faults and interplate earthquakes that occur at tectonic plate boundaries such as the Nankai Trough (*Fig.5*). At their epicenters, these different types of earthquakes produce vibrations with different characteristics. Surface motion also depends greatly on ground and soil conditions at the construction site. For example, observation records show clear differences in the strength of the Great East Japan Earthquake in Tokyo, Nagoya, and Osaka (*Fig.6*). The following is an introduction to the NS Wave system developed by Nikken Sekkei, an earthquake motion simulation system that can reflect separate earthquake source and ground characteristics.

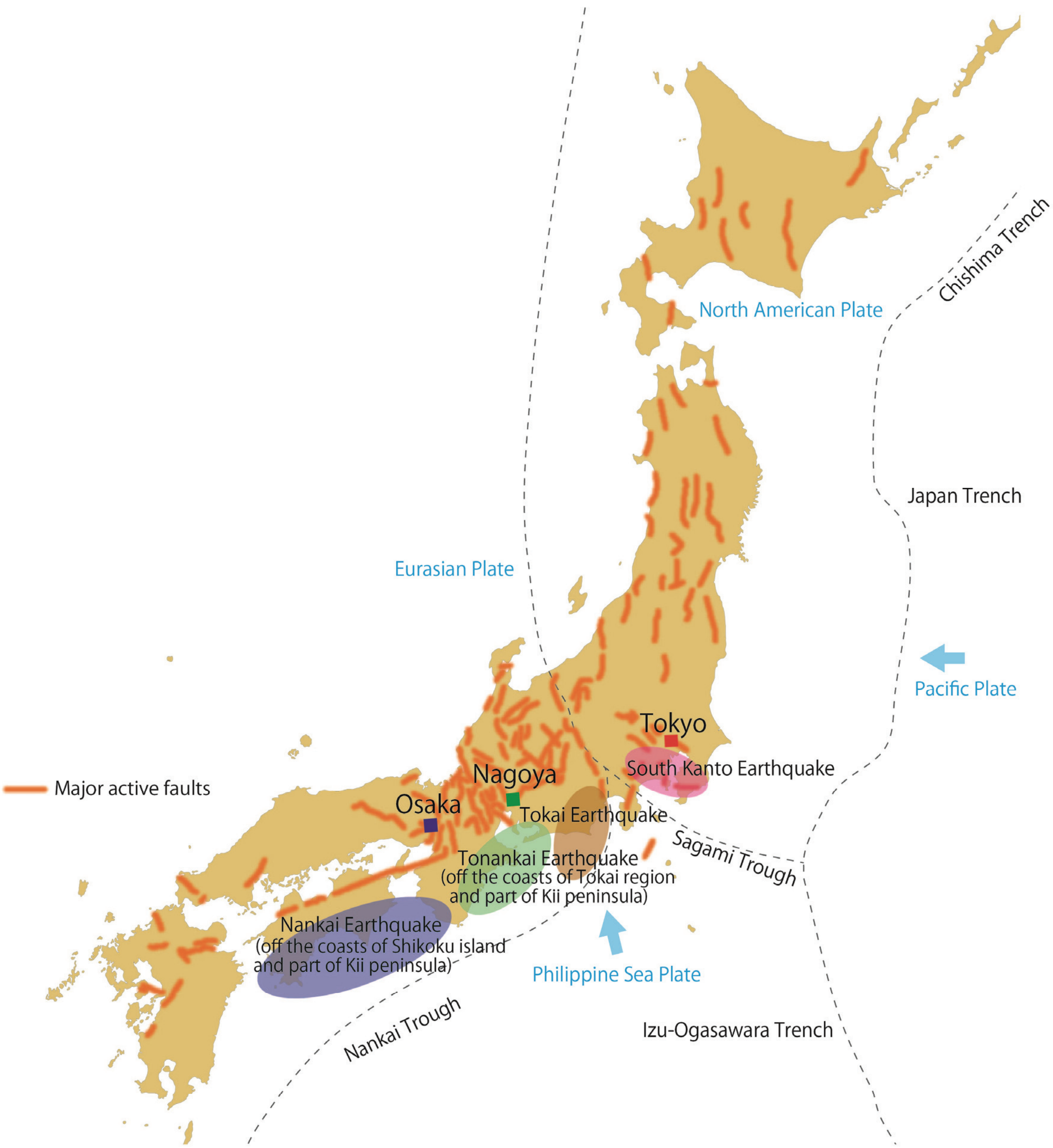


Figure 5. Active faults and plates

2. Seismic strength in Tokyo, Nagoya, and Osaka

Like sound, earthquake motion has frequency characteristics (period characteristics). An earthquake diagram expresses the strength of each period. When the peak of a period coincides with the natural frequency of a building (the time it takes to sway from one side to the other and back), the sympathetic vibration increases the swaying of the building. A diagram of earthquake strength makes it possible to grasp the effect of earthquake motion on the response of the building (*Fig.6*).

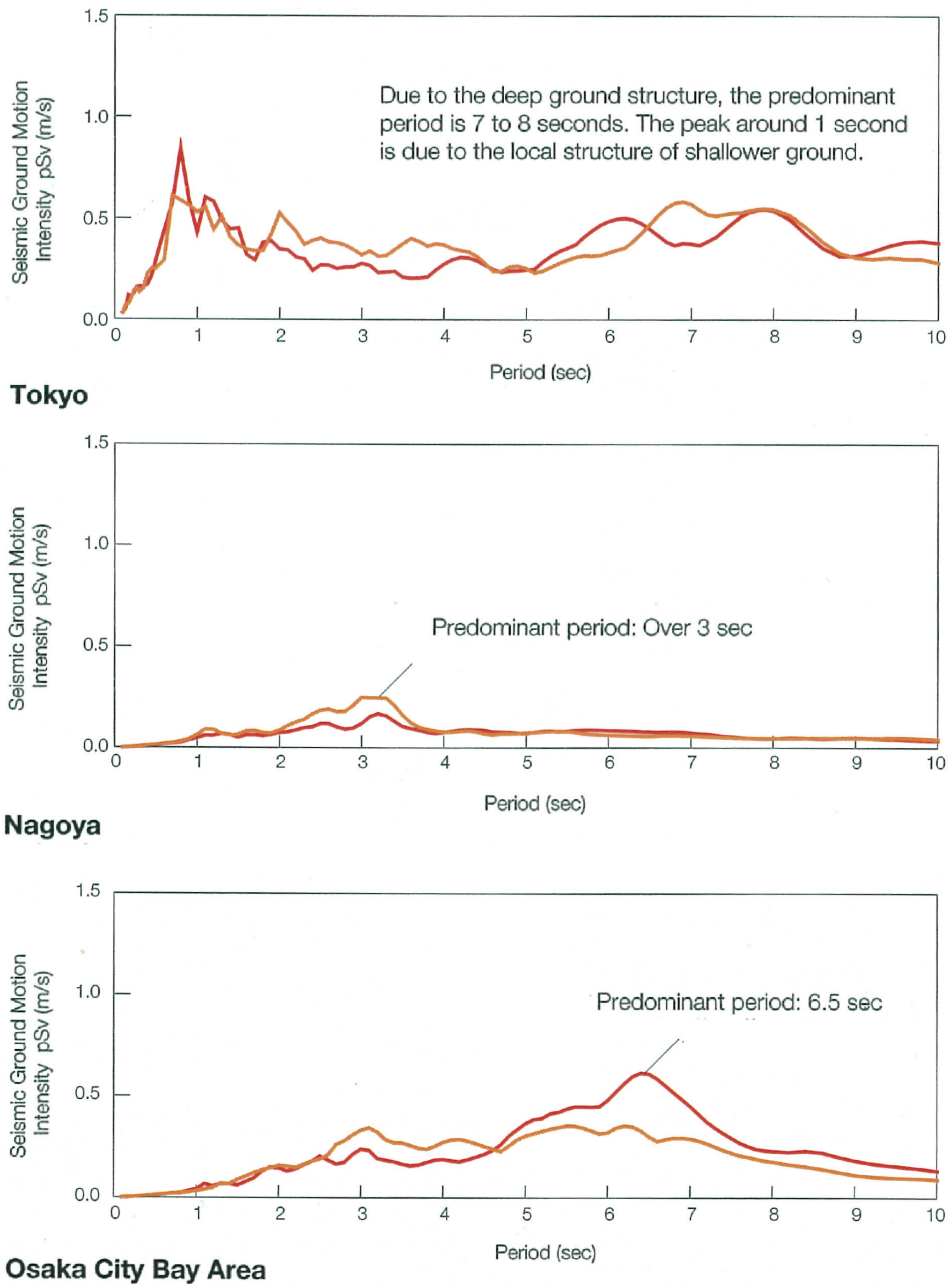


Figure 6. 2011 Great East Japan Earthquake:Seismic ground motion intensity of the observation record for the earthquake

3. The mechanisms of earthquake generation and local amplification

In simulating with NS Wave, the first decision is to determine the targeted earthquake faults. Near the Japanese archipelago, oceanic plates are subduction beneath a continental plate, and giant earthquakes (interplate quakes) occur at the boundaries between the plates. Thus, interpolate earthquakes such as Tokai, Tonankai, and Nankai earthquakes can be considered (*Fig.2 and 5*). The simulation can also consider inland eathquakes, which occur because the subduction of the plates causes pressure to build up in the surface of the Earth's crust. Vibrations at the epicenters exhibit different characteristics according to the type and scale of the earthquake. These characteristics are fed in as appropriate

Next, variations in the waves as they are transmitted through rock strata are considered, to reflect the fact that the amplitude of the waves decreases while the waveforms are dispersed and the duration lengthens. Finally, the amplification of the waves by local sedimentary layers around the building site is considered. The thickness and hardness of the sedimentary layers over the bedrock determine the predominant periods of the site. These amplification characteristics can be evaluated using publicly available ground data (*Fig.7*)

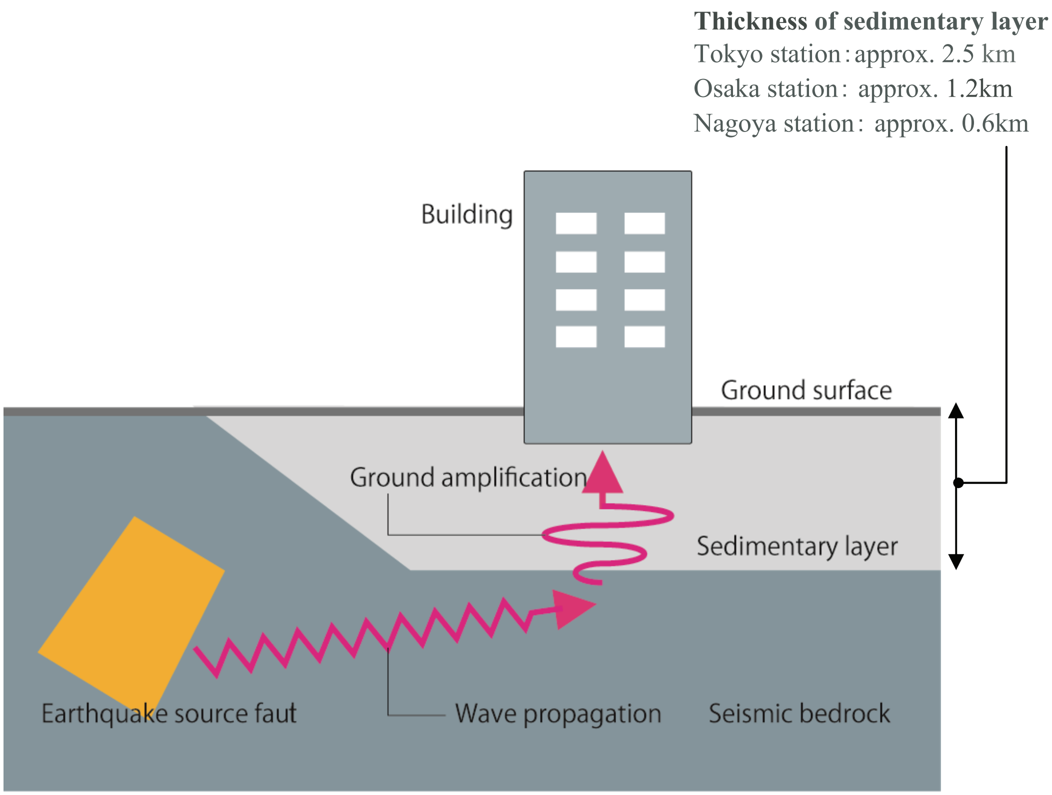


Figure 7. Propagation of seismic ground motion and amplification characteristics

4. Differences in shaking due to local ground conditions and earthquake type

Fig.8 shows examples of ground motion produced by considering earthquake source and transmission characteristics as well as local ground characteristics. The examples simulate the effect in Tokyo of a South Kanto earthquake (M7.9) and the effect in Osaka and Nagoya of a multi-fault Tokai/Tonankai/Nankai earthquake (M8.7), both of which are expected to produce strong shaking at construction sites

As examples of different earthquakes types, *Fig.9* compares the strengths of an interplate earthquake and an inland earthquake at the same site. A construction site near Osaka Station is envisioned. The interplate earthquake is a multifault Tokai/Tonankai/Nankai earthquake (M8.7), and the inland earthquake is an M7 class earthquake occurring near the site. These examples show that the strength of an earthquake can differ depending on the earthquake type, even at the same site.

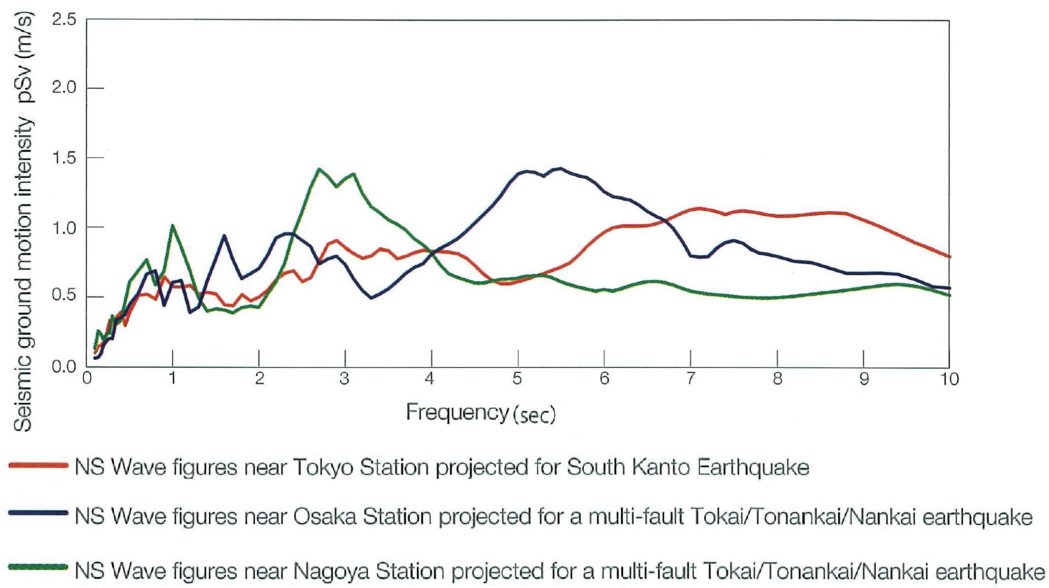


Figure 8. Differences in seismic intensity by area

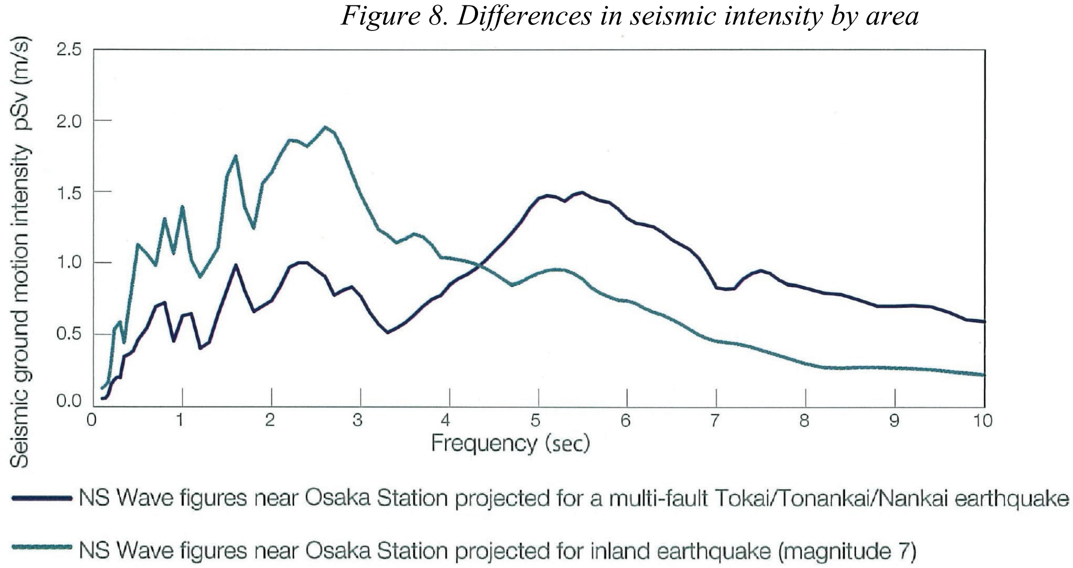


Figure 9. Differences in seismic intensity near plate boundaries inland

5. How buildings sway

To see how differences in ground motion characteristics affect the swaying of buildings, a 200m model building (natural period 5 seconds) was subjected to the Tokai/Tonankai/Nankai(M8.7) and inland (M7 class) earthquakes described above, and the displacement of the top was compared with ground motion (*Fig.10 and 11*).

In the triple-fault earthquake, three separate large-amplitude wave groups arrive (in order of arrival the main motions of the Nankai, Tonankai, and Tokai earthquakes), and then, slightly later than ground motion, the building begins to sway violently, with the motion continuing for a long time (*Fig.10*). This is the phenomenon of resonance between a building and long-period earthquake ground motion. By way of comparison, in the case when an inland earthquake occurs nearby, the main motions are concentrated. After this single shock, the swaying of the building deteriorates naturally and ends fairly quickly (*Fig.11*).

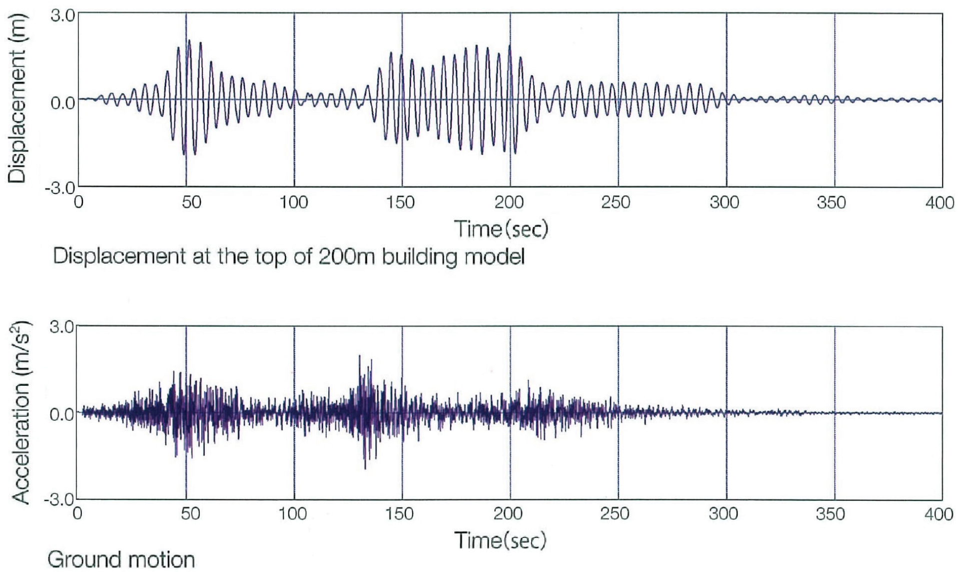


Figure 10. NS Wave near Osaka Station projected for Tokai, Tonankai and Nankai earthquakes and displacement at top of model building

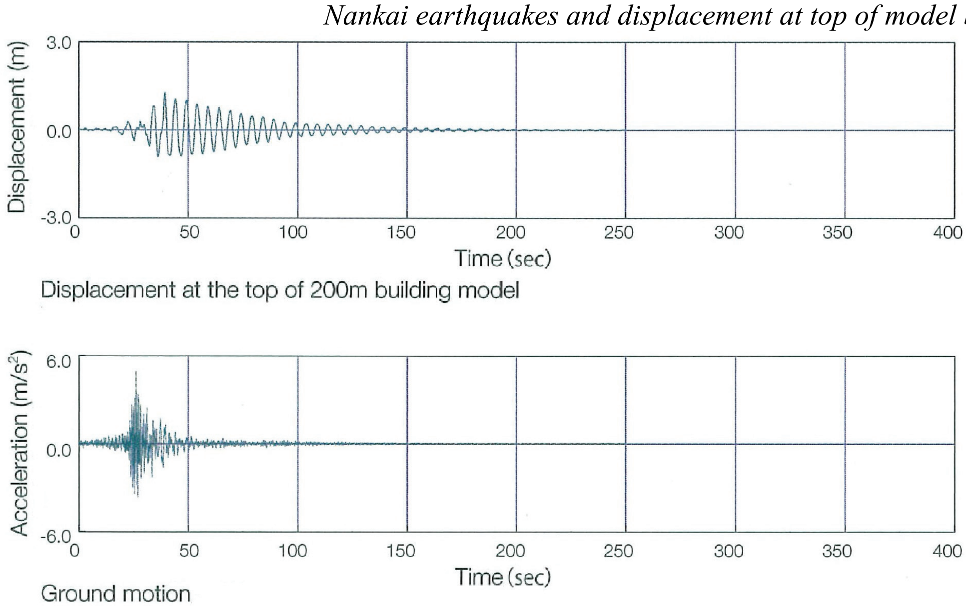


Figure 11. NS Wave Osaka Station projected for shallow inland earthquake (magnitude 7) and displacement of the top of model building

6. Verification example

To check how far NS Wave reproduces an actual earthquake, it's results were compared with records of the Great East Japan Earthquake as observed in Sendai(*Fig.12*). This simulation was created using basic data for the magnitude 9.0 earthquake source with a fault length of 450km and public ground data. It can be said that the strength characteristics of the earthquake, including the predominant period, were reproduced with fully adequate precision.

7. Conclusion：Utilization of NS Wave and future prospects

With the above features, NS Wave simulations enable rational verification of the seismic safety of buildings and their habitability during earthquakes.

The shaking of the earth varies greatly depending on the location of the epicenter and the ground conditions of a given site; moreover, the shaking during the predominant period of ground motion may be greater than the official "Kokuji Wave" figures. These differences need to be reflected in considerations of structural safety.

NS Wave system can be applied not only to new building projects but also in ascertaining the seismic safety of and needed earthquake-proof repair work for existing skyscrapers.
Since the NS Wave system can also make a relative assessment of the performance of a building due to probable earthquakes, a corporation can utilize the system to help decide priorities in repair plans for all of its buildings throughout the country.

NS Wave can also be used in overseas projects. 1f detailed information about ground conditions is lacking, it is often possible to consult surveys and come to an overall judgment. If so, NS Wave simulations can be carried out. (Settings can be made while referring to the United States Geologic Survey and other public data.) We think that this makes it possible to design safer and more secure buildings, considering separate earthquake source and ground conditions for each project.

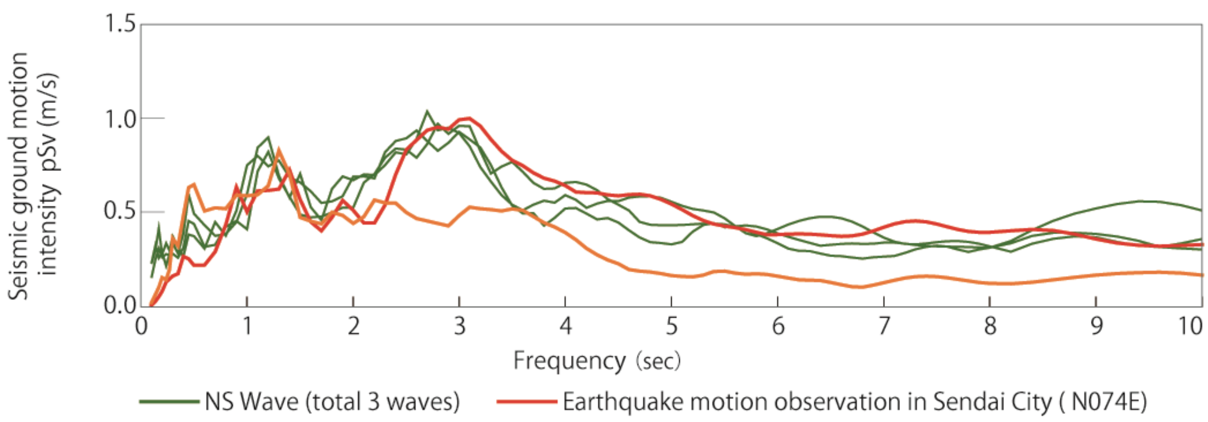


Figure 12. NS Wave comparison between observation records of the Great East Japan Earthquake Sendai City

References

Fig.2 :Seismic activity in Japan. Based on Headquarters for Earthquake Research Promotion.

Fig.5 :"Earthquake Activities in Japan" Based on Headquarters for Earthquake Research Promotion website.

Fig.6 :Tokyo, Osaka observation records: National Research Institute for Earth Science and Disaster Prevention. Nagoya observation records: Building Research Institute.

Fig.12 :Sendai observation records: Building Research Institute.