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Lessons of the 2011 Tohoku earthquake Focused on Characteristics of Ground Motions and Building Damage

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The author addresses firstly the observed high acceleration records with PGA of 2,700 cm/s/s and the corresponding JMA seismic intensity 7 at the K-NET Tsukidate station during the 2011 Tohoku Earthquake (M9.0). Structural damage was quite light in the surrounding area. The relation between high acceleration record and building damage is discussed by referring to the questionnaire intensity by authors and by mentioning unfavorable behavior with partial uplifting and slipping of the foundation of the seismometer based on the non-stationary spectral analysis and particle orbit analysis.

Many long-duration records observed during the earthquake, especially in geological basin, are also discussed. A base-isolation device with lead damper of a building in Osaki city was damaged. Many numbers of displacement cycles may affect on the damage of the seismic elements of structures due to ground motion with long duration.

Next, ground motion characteristics during the 2011 Tohoku earthquake are compared to those during the 1978 Miyagi-ken Oki earthquake (M7.4) at the same observation site. The author addresses observation records at basement floor of Sumitomo building near Sendai station, which is recognized as engineering bedrock motion. The comparison shows that the ground motion during the 2011 earthquake is larger in PGA and response spectra than 1978 earthquake, but the amount of structural damage is smaller in 2011 earthquake due to progress of seismic design and seismic retrofits. Difference of ground motion due to geological conditions is also discussed based on strong motion networks including the authors' DCRC network.

Regarding specific building damage of 8- and 9-story buildings at Aobayama campus of Tohoku University, ground motion amplification in the site was discussed based on the observation records at a 9 story SRC building of Departments of Civil Engineering and Architecture (THU building). During the 2011 earthquake, THU building was resonantly shaken and damaged (Photo 1) by the amplified ground motion compared to more than two times at the period range of 1sec compared to Sumitomo station, which is one of major reasons of the structural damage (Fig.1). The amplification was also recognized during the 1978 earthquake. Dynamic behavior of the damaged THU building due to the amplified ground motion is also discussed.

As other specific building damage, the two pile foundation buildings which were damaged during the 1978 earthquake comparatively discussed. An example of the pile foundation damage of the building constructed after the Japanese Building Code issued in 1981 is addressed. As damage of non-structural elements, the tremendous number of ceiling board dropped during the main shock and the major aftershock. Some of them caused killed persons for the first time. The 400 valley-filled housing lands' failures were caused in Sendai City. These damages are strongly related to the long duration ground motion.

Finally, the following learning and lessons from the 2011 earthquake are addressed for stronger earthquake countermeasures of urban and building structures: 1) Necessity of the seismic microzoning considering ground motion difference due to geological conditions, 2) Necessity of appropriate seismic indices corresponding to objective building damage, 3) Reconsideration of the setting place / setting method of the seismometer, 4) Necessity to evaluate the safety of structural elements for number of displacement cycles due to the long-duration earthquake and repetition by many aftershocks, 5) Consideration of non-stationary of ground motion the nonlinearity of the building for the huge earthquake, 6) Total balance of structural element, non-structural elements, and equipments, and also balance of foundation and superstructure for synthetic seismic performance of the whole building, 7) Evaluation of residue performance of the buildings damaged by past earthquakes and this earthquake.

Keywords: 2011 Tohoku earthquake, ground motion characteristics, site amplification characteristics, building damage, resonance, long duration

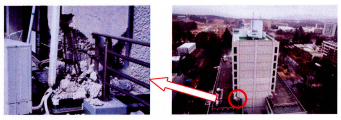

Photo 1 One of damaged four corner columns of THU building

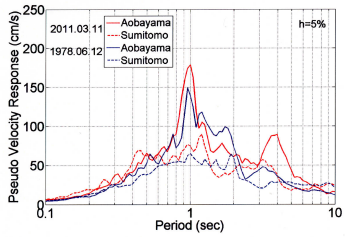

Fig.1 Site specific spectral ground motion amplification in Aobayama hill, Sendai