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研究成果報告書

研究課題名

超高層建物のＱ－Δ共振リスクの解明と耐震設計法・制震改修法の開発

Investigation of Q–Δ Resonance Risk in Super-High-Rise Buildings and Development of Seismic Design and Seismic Control Retrofitting Methods

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Abstract

Japan has a risk of large magnitude earthquakes, which generate long-period seismic motions reaching far from the epicenter. The Kanto, Kansai, and Chukyo areas are located on soft ground, which tends to vibrate for long time due to long-period seismic motions. Because super-high-rise buildings have long natural periods, they can resonate with long-period seismic motions. In fact, a building in Osaka severely damaged during the Great East Japan Earthquake although it located approximately 800 km from the epicenter. Torsional vibrations have been considered to be unlikely to occur in buildings with well-balanced mass and load-bearing elements (walls and braces). However, the Principal Investigators have discovered a phenomenon that torsional vibration can be induced in a well-balanced building under certain conditions. The mechanism (Q–Δ effect) is as follows: vertical members with different stiffnesses in the two horizontal directions generate a torsional moment proportional to the cross product Q × Δ, where Q and Δ are the restoring force and displacement vectors, respectively. When the sum or difference of the natural frequencies of the translational modes in two orthogonal directions of a building matches the natural frequency of the torsional mode, the induced torsional moment causes a resonance of the torsional mode (Q–Δ resonance).

As Q–Δ resonance is not considered at all in current seismic design, in this research project, we developed a theory to predict the response and probability of occurrence of Q–Δ resonance in super-high-rise buildings, seismic design methods for new buildings and seismic control retrofitting methods for existing buildings. First, in Fiscal Year (FY) 2019, we derived the conditions of Q–Δ resonance and constructed a theory to predict torsional response for a two-story shear-type building model assuming a Gaussian white noise ground motion. Then, we conducted finite element (FE) analysis considering geometric nonlinearity and shaking table experiments and verified the validity of the theory. In addition, we clarified the probability distribution of torsional response based on the theoretical formula for torsional response that we constructed. In FY2020, we improved the theory so that it could be applied to a multi-story shear-type building model that is subject to nonstationary colored noise ground motion. The validity of the improved theory was then verified through FE analysis and shaking table experiments using a four-layer specimen. In FY2021, we extended the theory to the case of a multi-story flexural-shear-type model. The extended theory was verified by FE analysis and a shaking table experiments using a four-layer flexural-shear specimen. In FY2022, we studied how to secure the safety of new and existing buildings by utilizing the derived conditions for Q–Δ resonance and the prediction formula for torsional response. Specifically, we developed a swinging and rolling combined-type tuned mass damper that can reduce the response even when the natural period of the two horizontal directions are different. The effectiveness of the developed damper was verified by numerical analysis and shaking table experiments.

The obtained research results are expected to contribute to the improvement of seismic performance of high-rise buildings and to reduce the risk of damage due to long-period, long-duration seismic motion that is predicted to occur in future subduction zone earthquakes.