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Abstract (Doctor)

Title of Thesis	Seismic Repair of Exposed Column Bases based on Damage Modes
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Approx. 800 words

In Japan, exposed column bases are commonly used to support steel frame buildings. They offer several advantages over other types of support structures, including ease of assembly and ease of access for maintenance and repairs. However, they are vulnerable to the elements, and their strength is lower than that of other types of column bases. Their design framework considers them as elements capable of generating plastic moments and dissipating energy. However, surveys have shown their vulnerability to anchor bolt fracture and cone-shaped failure, even in buildings designed in accordance with applicable standards.

Therefore, a more comprehensive study of exposed column bases, focusing on different damage modes, is required to describe their failure conditions fully. With this complete description, designers will be able to select the most appropriate behavior for each project and ensure that, no matter what failure mode occurs, the behavior remains predictable. Furthermore, the most appropriate repair type for an exposed column base depends primarily on the damage mode, so an evaluation of repair effectiveness for each failure mode is also required.

The general objective of this thesis was to investigate the strength, damage behavior, and effectiveness of repair of exposed column bases based on their damage mode. The scope of this thesis includes ductile and brittle failure modes.

The first damage mode studied is ductile failure due to anchor bolt yielding. While previous studies have demonstrated the ductility of exposed column bases under anchor bolt yielding and validated the retightening of anchor bolts as a repair strategy, the effects of incomplete or unbalanced repair remain poorly understood. Therefore, Chapter 2 evaluates the effects of the amount and balance of repair in a gymnasium typical of Japanese schools. Several combinations of main shocks and aftershocks were evaluated. Chapter 2 showed that a repair using partially retightened anchor bolts is not effective on the short span of the building but is effective on the long span, provided the aftershocks are smaller than 25% of the main shock. The balance of repair does not reduce or amplify the out-of-plane deformation of the walls in the gymnasium, but it causes amplification of the in-plane

deformation of the walls in the long span. Therefore, when repair by retightening of anchor bolts is performed, all column bases should be fully retightened as much as possible.

The second damage mode studied is the brittle cracking caused by cone-shaped failure of the concrete foundation. While previous studies have helped to determine the pull-out strength of anchor bolts in concrete, the residual (post-peak) behavior of the concrete is not well understood. Therefore, in Chapter 3, a Finite Element Method (FEM) model incorporating crack-spring elements was developed to simulate cone-shaped failure at exposed column bases. The model was validated against experimental results from ten test specimens, showing good agreement in maximum, residual, and yield strength. Furthermore, a parametric study was subsequently conducted to investigate the influence of longitudinal reinforcement area on strength behavior. The results revealed that increasing the longitudinal reinforcement ratio transitions the response from a sudden drop in strength to a bilinear behavior, with a minimum reinforcement ratio of 0.23% required to avoid strength degradation for the specimens considered. Finally, a simplified mechanical model was proposed to estimate residual and yield strength using only geometric and material properties.

Finally, the evaluation of cone-shaped failure in Chapter 3 was used to assess the validity of additional concrete as a repair technique for exposed column bases that experienced this type of brittle failure. While previous studies have established the effectiveness of this repair method, the type of failure after repair and the factors that influence it remain poorly understood. Therefore, Chapter 4 introduces an FEM model to evaluate the strength of exposed column bases repaired with concrete jacketing after cone-shaped failure, which is validated through experimental testing. A parametric study is conducted to investigate the effects of the reinforcement and post-installed anchor bolts. The results indicate that the amount of main reinforcement influences strength and failure mode, whereas the number of post-installed anchor bolts affects strength but not failure mode. Two post-repair failure modes, anchorage failure and interface failure, are identified.

Finally, a proposed design and repair flow is introduced in Chapter 5 to consolidate the results of this thesis in a manner understood by structural designers and to help identify the most appropriate failure mode and repair method for each particular case.