学 位 論 文 内 容 の 要 旨

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学 位 論 文 題 名

Boundary Conditions of Panel RC Slabs for Realistic Fatigue Behavior Analysis of Bridge RC Slabs
(RC 床版疲労解析における輪荷重走行試験体と実橋との等価境界条件の研究)

Reinforced concrete (RC) slabs are one of the most critical members in a bridge and are susceptible to fatigue failure, as they directly experience repetitive moving wheel loads. Owing to insufficient slab thickness in previous designs, a brittle punching shear failure mode appeared as a key failure phenomenon for bridge RC slabs in service, especially with the increase in vehicle weight and traffic volume. Consequently, the fatigue strength of bridge RC slabs is significantly reduced, posing a great threat to the structure and human life. Therefore, various experimental and numerical studies have been carried out to investigate the fatigue behavior of bridge RC slabs. In these studies, a panel of the bridge RC slab has been considered in lieu of the whole bridge RC slab due to cost, time, and space restraints. The boundary conditions (BCs) comprised of simple supports along the longitudinal edges and steel I-beams along the transverse edges of the panel RC slab have been typically used to represent the bridge RC slab with continuity between adjacent spans. These studies have employed cyclic moving wheel loads, and the punching shear failure mode of bridge RC slab has been successfully reproduced. However, the panel RC slabs with typically used BCs failed to reproduce the deformation and fatigue behaviors of bridge RC slabs. Therefore, it is essential to elucidate the effects of BCs and determine appropriate BCs of the panel RC slabs, which can simulate the realistic deformation and fatigue behaviors of the bridge RC slabs.

In this study, at first, the applicability of a numerical model based on the bridging stress degradation concept for panel RC slabs subjected to a stepwise loading sequence is investigated. In recent studies, the numerical model considering the bridging stress degradation has been developed, with which the fatigue behavior of the panel RC slabs has been simulated successfully. However, in these studies, the panel RC slabs have been subjected to a constant loading sequence rather than a stepwise loading sequence, which has been newly introduced in the improved specifications of the road bridge. Therefore, in this study, fatigue analysis of a panel RC slab subjected to a stepwise loading sequence is conducted, and the fatigue analysis results are compared with the experimental ones. The comparison confirms that the developed numerical model based on the bridging stress degradation concept successfully simulates the fatigue behavior of the panel RC slab subjected to a stepwise loading sequence.

Thereafter, a method for the determination of approximate BCs for already available panel RC slabs is developed and proposed to capture the realistic behaviors of the bridge slabs. The finite element analysis of the panel RC slab with approximate BCs shows that the approximate BCs reproduce the same bending moment distribution and displacements around the loading locations as the wheel load moves along the slab axis in the panel RC slab, which are similar to those of the bridge RC slabs. For simulation of fatigue behavior, fatigue analysis of the panel RC slab with approximate BCs is

conducted in addition to the panel RC slab with the BCs typically used in the past studies. The fatigue analysis results show that the approximate BCs do not result in a negative bending at the corners of the panel RC slab, and the cracked elements do not propagate on the top surface from the corners to the loading point, which is similar to a bridge RC slab. However, in the panel RC slab with typically used BCs, the negative bending at the corners and the propagation of the cracked elements on the top surface from the corners to the loading point produce an additional deterioration in the panel RC slab, which leads to a shorter fatigue life estimation of a bridge RC slab. Furthermore, the approximate BCs permit the propagation of the cracked elements in the panel RC slab along the longitudinal direction to a greater extent compared to the typically used BCs, which is similar to that generally observed in a bridge RC slab.

Lastly, an equivalent BCs determination method is developed numerically for a panel RC slab to realistically analyze the deformation and fatigue behaviors of a bridge RC slab. For this purpose, a static analysis of a bridge RC slab is conducted, and equivalent BCs for its corresponding panel RC slab are determined based on the calculated stiffness of the bridge RC slab. The results of the panel RC slab with equivalent BCs are found to have more similar bending moment distributions and displacement behaviors to the corresponding results of the bridge RC slab. To simulate the fatigue behavior, fatigue analysis is conducted for the panel RC slab with equivalent BCs as well for the panel RC slab with typically used BCs. The fatigue analysis results reveal that the equivalent BCs allow the propagation of cracked elements in the longitudinal and transverse directions of the panel RC slab, in a similar manner as a bridge RC slab. Moreover, in contrast to the typically used BCs, the equivalent BCs do not lead the cracked elements to propagate on the top surface from the corners to the loading point, which is similar to a bridge RC slab. Furthermore, contrary to the typically used BCs, the equivalent BCs reproduce the extensive grid crack pattern in the panel RC slab, well in accordance with that generally witnessed in a bridge RC slab.

Conclusively, this study mainly aims to elucidate the effects of BCs and develop the determination method of BCs for panel RC slabs to realistically analyze the deformation and fatigue behaviors of bridge RC slabs. The numerical results conclude that the panel RC slabs with proposed BCs behave in the same manner as bridge RC slabs, which results in a more realistic fatigue behavior analysis of the bridge RC slabs.