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主　論　文　の　要　旨

論文題目　**PERFORMANCE EVALUATION OF CONNECTIONS IN CONCRETE STRUCTURES USING 3D-RBSM**
(3次元剛体バネモデルを用いたコンクリート構造物内の接合部の性能評価)

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論　文　内　容　の　要　旨

Currently, the utilization and application of the precast concrete structure and concrete-steel composite structure have increased sufficiently in association with the increment of social demands for enhancement of the structural performance, productivity, and the renewal of existing structures. Therefore, the detailed evaluation of mechanical behaviors for such kind of structures especially the crack and stress propagation process is important to investigate for improving the structural performance as well as for developing the new members. Specifically, in terms of connections in concrete structures, the modeling of the connection of members and the boundary between different materials is very important because the mechanical and deformation performance is dominant at the region of connection. For the joints, the deformed rebar is usually used for connection and stress transmission in tension. On the other hand, for concrete-steel composite members, stress transmission between steel and concrete is that the dowel effect is utilized in shear, and the bond effect is utilized in tension. Therefore, the detailed verification including not only the bond and anchorage of deformed rebar but also dowel effect between concrete and steel is required for performance evaluation of connection in concrete structures.

To investigate the performance evaluation of connections, the interaction of

concrete with deformed rebar in cast in-situ RC joint and with the steel connector in concrete-steel composite should be determined. However, it is difficult to investigate the detailed internal failure process comprehensively from experiments. The numerical simulations are helpful in this regard as they can assess not only the capacity and deformation performance but also reveals the detailed internal failure process and the mechanism of the connections, quantitatively.

This study focused on the numerical evaluation of the loop joints in precast construction, the bond behavior between concrete and deformed rebar, and the Perfobond (PBL) shear connector in concrete-steel composite construction. In order to evaluate the interaction of concrete with steel and the detailed internal failure process at the connections, the numerical simulation based on the Rigid Body Spring Model (RBSM) was carried out. The 3D-RBSM highlights its advantage in capturing the nonlinear mechanical behavior of concrete, effectively. Moreover, to simulate detailed interaction between different materials, coupled RBSM and solid FEM method was proposed. The method is useful approach to simulate the nonlinear mechanical behavior of concrete using RBSM and elasto-plasticity of steel using FEM. The method was applied for detailed evaluation of the bond behavior of deformed rebar and the PBL shear connector to investigate the crack and stress propagation around the boundary of concrete and steel, which are strongly related to the performance of connections. The outline of each section are described below.

Chapter 1

Chapter 1 included the introduction of the study, research background, general review of the related references, and the study objectives as well as the organization of the dissertation.

Chapter 2

Chapter 2 discussed the analytical approach based on 3D-RBSM and the beam element model to simulate the mechanical behavior of the reinforced concrete (RC). The basic characterizations regarding the modeling of the concrete by employing the 3D-RBSM (constitutive models, the material parameters, and verification of mesh size dependency) and the modeling of the steel reinforcement by using the beam element were explained.

Chapter 3

Chapter 3 presented the performance evaluation especially the internal failure mechanism (crack propagation and the normal stress distribution) of the horizontal type loop joints in precast beams using 3D-RBSM and beam element model. All rebars embedded in concrete and at joint such as loop rebar were modeled by beam element.

The internal failure process and comparison of the horizontal type loop joints with and without inner reinforcing bars inside the loop were evaluated, numerically. It was determined that the failure of the loop joint without inner reinforcing rebars inside the loop was characterized by the occurrence of diagonal cracks inside the concrete between the tensile loop rebars at the joint region before the yielding of the tensile loop rebars. The presence and the bond strength of the inner reinforcing rebars inside the loop joint played the vital role in suppressing the diagonal crack propagation in concrete and consequently reproduced the compression failure behavior. Furthermore, it was observed that higher bond performance of the inner reinforcing rebars inside the loop produced more confinement to the concrete inside the loop and thus prevented diagonal crack propagation and reproduced the compression failure behavior instead of loop type failure.

Chapter 4

Chapter 4 described the limitations of the conventional combination of 3D-RBSM and the beam element model to simulate the mechanical behavior of RC. Furthermore, the background, need of proposing a new analytical model (coupled RBSM and solid FEM) and the introduction to new analytical model were also presented. The basic description regarding the modeling of the concrete using RBSM, modeling of the steel using eight nodes nonlinear solid FEM, and the concrete-steel interface between RBSM and solid element in coupled RBSM and solid FEM model were demonstrated.

Chapter 5

Chapter 5 illustrated the numerical evaluation of the macroscopic bond behavior of deformed rebar and concrete using coupled RBSM and solid FEM model under two and one end pull-out tests. The detailed internal failure mechanism of the concrete in axially loaded RC specimens under the variable factors were presented.

It was revealed that the proposed numerical model effectively captured the macroscopic bond behavior under the influence of various parameters. Through the analysis, the transformation of deformed modes was observed from splitting to the pull-

out failure against the increased confinement effect provided by the concrete cover thickness. Furthermore, the influence and importance of the test boundary conditions on the bond behavior and failure modes (splitting or pull-out) were revealed. Moreover, the quantitative evaluation for internal crack propagation under the effect of varied geometrical features of the deformed rebar was highlighted and it was found that the deformed rebar with large lug spacing reproduced cracks with the larger crack space and crack width in surrounding concrete.

Chapter 6

Chapter 6 presented the performance evaluation of shear resistance of the PBL shear connector using the coupled RBSM and solid FEM Model. The shear resistance of the PBL shear connector was investigated for the detailed internal failure process and mechanism of the concrete. The shear resistance of PBL shear connector was evaluated for, (1) Influence of varying amounts of the lateral pressures, (2) Combined effects of the hole diameters and lateral pressures, and (3) Effect of transverse rebar inside the hole. The numerical evaluation clarified that the shear capacity of the PBL increase and the failure mode change from local shear failure around the edge of the hole to splitting failure of the side concrete blocks against the increased amounts of lateral pressures applied to surrounding concrete blocks.

Furthermore, the numerical evaluations for the combined effects of the lateral pressures and the diameters of holes revealed that the combined effect occur as the envelope of compressive stresses and the region of the large compressive stresses around the concrete dowel and in the side concrete blocks expand more for larger diameter. In addition, it was also shown that the increase in the shear strength is more dominant in the large diameter case of the concrete dowel subjected to high amount lateral pressure. Moreover, it was confirmed that the parameters (diameter, yield strength, and position) of the transverse rebar inside the hole of the PBL enhance the shear resistance of the concrete dowel against applied vertical load in simple push-out test and transform the failure mode from the local shear failure to the splitting of side concrete blocks.

Chapter 7

Finally, Chapter 7 exhibited the conclusions derived from this study and recommendations for future study.