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主　論　文　の　要　旨

論文題目	Bond Behavior Evaluation of Deformed Rebar by using 3D RBSM with Beam Element (梁要素を用いた 3D RBSM による異形鉄筋の付着挙動評価)
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論　文　内　容　の　要　旨

Bond behavior of deformed rebar in concrete is directly related to the design of RC members, especially, in the context of reinforcement arrangement. Though, many experimental studies have evaluated the effects of various material and structural parameters on bond behavior of deformed rebar. And, several design rules have been formulated in prominent design codes. However, there is an utmost need to build a numerical tool that can evaluate the performance of RC members based on bond behavior and failure mechanisms. Whereas, the model should have least parametric dependency, and should be computationally efficient and economical.

The first objective of this study is the development and validation of Three-Dimensional Rigid Body Spring Model (3D RBSM) with Voronoi and beam elements to model concrete and rebar respectively. Whereas, to reproduce signature bond stress-slip behaviors of deformed rebar in concrete with various material and structural parameters, a suitable local bond model is employed to the zero-size link element connecting the Voronoi and beam elements. The applicability of model is for normal as well as high strength concrete. The second objective is to evaluate the internal cracking and stress distribution governed bond failure mechanisms of reinforced concrete at specimen as well as member level with a particular focus on lap splices with multiple reinforcement arrangement and stirrup confinement. The third objective is to conduct experimental study on cracking and deformation behavior of flexural RC members with high strength rebar and high strength concrete, and discuss the applicability of several serviceability governing equations. Whereas, the 3D RBSM being a powerful numerical tool to evaluate various type of cracking behavior (flexural, bond, etc.), is to apply for the members with higher grades of reinforcement and high strength concrete particularly. The outline of the study is given as following.

Chapter 1

Dissertation started with the background of the study along with relevant references, and gradually built up the motivation for the required research work as per Chapter 1. Also, the significance of this study for performance-based evaluation of various type of structures was outlined.

Chapter 2

Chapter 2 proceeded forward with the development of 3D RBSM for the bond behavior simulation and evaluation by utilizing a beam element model with a suitable local bond model. Verification of numerical method was based on experimental study of other researchers relevant to bond behavior under the effect of concrete cover thickness and rebar diameter variation. It was clarified that the numerical model enables to evaluate changes in internal cracking and stress distribution due to variation in concrete cover thickness and rebar diameter. Whereas, it can simulate the transition of failure modes depending on variation in parameters. Also, based on analytical results, it was confirmed that the proposed model can evaluate the bond behavior like three-dimensional rebar model with lug shape, consequently, it provides an economical and efficient alternative due to lesser computational elements than the 3D modeling of deformed rebar.

Chapter 3

In Chapter 2, the applicability of 3D RBSM to simulate and evaluate the bond stress-slip relationship and failure mechanisms of RC members was limited to the members with normal strength concrete. Also, it is to be noted that the applicability of numerical method to evaluate not only the bond parameters but also the compression, bending and fracture energy characteristics of high strength concrete has not been confirmed previously. So, in the first phase of this chapter, compression and bending tests of high strength concrete were performed. Whereas, a detailed parametric calibration of normal and shear spring models of the numerical method was carried out for the high strength concrete.

In the second phase of this chapter, the bond stress-slip relationship of high strength concrete was evaluated considering a two-end pullout test with varying cover thicknesses at first. Also, a Digital Image Correlation (DIC) method was used to investigate the influence of variation in concrete cover thickness on the bond-based failure mechanism of high strength concrete. Later, the extended numerical method was used to investigate the bond behavior of high strength concrete. Particularly, it was found that the local bond model developed in Chapter 2 for normal strength concrete is applicable to high strength concrete based on the calibration of compression and bending characteristics considering experimental study on high strength concrete. Also, the failure mechanisms for the bond behavior of high strength concrete were outlined in-depth.

Chapter 4

Chapter 4 led the study to the bond behavior evaluation of deformed rebar in concrete under active as well as passive confinement conditions. It validated that the developed model in Chapters 2 and 3 is fully applicable to performance evaluation of RC members with various material and structural domains including lateral pressure, frictional condition, size effect (c/d), stirrup confinement and stirrup arrangement. It was also showed that the model can simulate a transition from split to pullout failure mode depending on the confinement level. Furthermore, considering the vital advantages of numerical method to simulate internal cracking and concrete stress propagation, Chapter 4 underlined the failure mechanisms under the parameters such as variation in lateral pressure, frictional conditions, size effect (c/d), stirrup confinement and yield strength of stirrups.

Chapter 5

In Chapter 5, bond behavior and failure mechanism of unconfined and confined lap splices with multiple deformed rebar arrangement were evaluated numerically considering various parameters including stirrup confinement. Firstly, it was shown that the numerical model can reasonably evaluate the bond stress-slip behavior of unconfined and confined lap splices with several parameters such as splice length, splice diameter, concrete cover, concrete strength, and stirrup confinement.

As, the failure mechanisms in experimental studies for members with lap splices are mostly evaluated in the context of surface crack observation only. Whereas, it was shown in Chapters 2 and 3 that the numerical method can reliably simulate the internal cracking and concrete stress distribution of RC members with single deformed rebar. So, a detailed numerical investigation of various parameters contributing to the failure mechanism of unconfined and confined lap splices with multiple deformed rebar arrangements were carried out in the context of internal cracking including strut crack propagation between splice bars, concrete stress and rebar stress/strain distributions. As per the results, the role of dominant geometric and material characteristics of stirrup confinement in improving the failure mechanism of confined lap splices was clarified in comparison to unconfined lap splices.

Chapter 6

In Chapter 6, the flexural crack spacing, crack width and deformation behavior, which are important effects of bond and are related to serviceability and durability of concrete structures, were investigated at member level. At first, experiments were performed on the cracking and deformation assessment of flexural members constructed with either normal (30 MPa) or high strength (80 MPa) concrete in combination of either normal (SD345) or high strength (SD685) rebar. Evaluation was performed for members with single as well as double layers of flexural reinforcement. The experimental study was used as a source of comparison with the design equations for cracking governed by prominent codes including JSCE, ACI and Eurocode. Moreover, the tested members were simulated by developed numerical method and the applicability of numerical model was validated to detailed crack propagation at member level. Based on experimental and numerical investigation, the limitations of several codes to evaluate the cracking behavior of flexural members with high strength rebar and high strength concrete were clarified.

Chapter 7

At the last, Chapter 7 summarized this study in the form of conclusions and presented recommendations for future studies.