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| Department of Architecture<br>and Civil Engineering | Student ID Number | D239509 | Supervisors | Tomoya Matsui<br>Taiki Saito<br>Shoji Nakazawa |
| Applicant's name                                    | ZEV AL JAUHARI    |         |             |                                                |

**Abstract (Doctor)**

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| Title of Thesis | Effect of Shear Reinforcement on the Anchorage Strength of Mechanically Anchored Reinforcing Bars in Top-Story Exterior Beam–Column Joints |
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Approx. 800 words

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| <p>Beam–column joints (BCJs) are among the most critical regions in reinforced concrete (RC) structures because they transfer forces between beams and columns while maintaining the structural integrity of the entire system. In recent years, headed reinforcement bars, also known as mechanical anchorages, have gained increasing attention as alternatives to conventional hooked bars due to their ability to reduce reinforcement congestion and improve constructability in highly confined joint regions. However, the anchorage behavior of headed reinforcement bars embedded in roof exterior BCJs remains insufficiently understood, particularly regarding the influence of shear reinforcement, hereafter referred to as supplementary reinforcement, on anchorage performance and concrete breakout resistance.</p> <p>Previous experimental studies have demonstrated that supplementary reinforcement significantly affects the pullout resistance of headed reinforcement bars by improving concrete confinement and restraining crack propagation around the anchorage zone. Nevertheless, existing experimental investigations remain limited in scope, especially regarding variations in supplementary reinforcement parameters such as bar diameter and quantity. Furthermore, current empirical design formulations, including the modified Kubota and Murakami equation, do not explicitly account for the influence of the supplementary reinforcement ratio, thereby limiting their applicability to different reinforcement configurations. To address these limitations, this study investigates the anchorage behavior of headed reinforcement bars embedded in roof exterior BCJs through an integrated approach consisting of three-dimensional nonlinear finite element analysis (FEA), strut-and-tie modeling (STM), and empirical formula development. Previously reported pullout test results of roof exterior BCJ specimens were used as the basis for validation and analytical development.</p> <p>First, three-dimensional nonlinear FEA was conducted to reproduce the pullout behavior of headed reinforcement bars in roof exterior BCJs. The numerical results were validated through comparison with experimental observations, including pullout load–displacement relationships, crack patterns, reinforcement strain responses, minimum principal stress distributions, and failure modes. The analysis showed good agreement with the experimental results. The minimum principal stress distribution indicated that the pullout force was transferred from the headed bar</p> |
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to the surrounding concrete through diagonal compression struts formed within the BCJ region. These results confirmed that the FEA was appropriate for evaluating the internal stress-transfer mechanism and for conducting further parametric studies on supplementary reinforcement.

A parametric FE study was then conducted to examine the effects of supplementary reinforcement diameter and number on anchorage performance. Increasing the supplementary bar diameter produced a moderate increase in pullout capacity. In contrast, increasing the number of supplementary bars resulted in a more significant improvement. This indicates that the number and distribution of supplementary bars have an important influence on the stability of the compression strut mechanism by enhancing confinement, reducing stress concentration around the anchorage zone, and suppressing crack propagation.

To represent the internal force-transfer mechanism, a three-dimensional STM was developed based on the minimum principal stress trajectories obtained from the FEA. This method idealizes a complex stress field as a truss system consisting of concrete compression struts, reinforcement tension ties, and nodal zones where struts and ties intersect. A suitable truss mechanism is then established based on the assumed or observed load path. The STM showed close agreement with both the experimental and FE results. The predicted pullout capacities corresponded well with the measured anchorage strengths, with prediction-to-experimental ratios generally close to unity. The results confirmed that anchorage capacity is governed by the interaction between diagonal concrete compression struts and tensile forces carried by supplementary reinforcement. Increasing the supplementary reinforcement diameter enlarged the effective compression strut area and improved stress redistribution within the joint core. Additional supplementary bars provided a more distributed confinement effect and contributed to the formation of multiple load-transfer paths.

Finally, the results of the STM parametric study were used to modify the existing Kubota and Murakami anchorage capacity formula. The existing formula provides a reasonable basis for estimating anchorage strength, but it does not explicitly account for the effect of the supplementary reinforcement ratio. Therefore, a new coefficient was introduced to represent the contribution of supplementary reinforcement. This coefficient was derived through regression analysis using the relationship between the normalized STM capacity and the supplementary reinforcement ratio. Statistical evaluation demonstrated that the proposed modified equation significantly improved prediction accuracy and reduced statistical dispersion compared with the original empirical formulation. The modified equation successfully captured the effects of variations in supplementary reinforcement diameter and quantity, thereby providing a more reliable approach for predicting anchorage capacity in roof exterior BCJs.

The findings of this study demonstrate that supplementary reinforcement plays an active role in the anchorage resistance of headed reinforcement bars embedded in roof exterior BCJs. The proposed analytical framework provides a rational basis for evaluating the anchorage capacity of headed reinforcement bars in roof exterior BCJs. However, the applicability of the proposed formula is limited to the range of parameters investigated in this study. Further investigations are recommended for specimens with a larger number of headed reinforcement bars and different supplementary reinforcement configurations.