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Structural Behaviors of Deep RC Beams under Combined Axial and Bending Force

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Abstract

This paper presents experimental studies of deep reinforced concrete (RC) beam behaviors under combined axial and bending loads. In order to investigate the effect of axial loads on the structural behaviors of the deep RC beams, specimens are prepared to have different shear span-to-depth ratios and subjected to axial loads of 235kN or 470kN. From the experiments, structural behaviors such as failure modes, load-deflection relationships, and strains of steel bar and concrete are observed. As results, for the deep beam with shear span-to-depth ratio of 0.5, load at the beam failure decreases as applied axial load increases, while the deep beams with shear span-to-depth ratios of 1.0 and 1.5 show that the applied axial load delays the beam failure. In addition, failure mode of the deep beam changes from shear failure to concrete crushing due to compressive stress at the top corners of RC beams as shear span-to-depth ratio decreases. From the experiments, it is important to notice that deep beam with relatively small span-to-depth ratio under axial load shows early failure due to concrete crushing, which cannot be directly applied to widely known design method for deep beam, strut-to-tie model.

Keywords: Deep RC beam, axial load, failure mode, deep beam design

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1 INTRODUCTION

Deep beams in mega structures have been recently used, as needs of high rise building with high performance structures have been increased. Because classical flexural beam theory cannot be used to understand structural behaviors of deep beams, many researchers have reported their experimental/ analytical studies to investigate structural behaviors and develop design methods of the deep beams.

Ramakrishnan and Ananthanarayanana(1968) investigate structural behaviors and ultimate shear strength of simply supported deep beams. From the experimental results, an equation for predicting the ultimate shear strength of deep beams is proposed using splitting coefficient K. In their study, K of 1.12 is chosen from the lower bound of possible K ranges regardless of specimen size, shape, and loading conditions. Smith and Vantsiotis(1982) examine structural behaviors and strength of deep beams depending on vertical and horizontal web reinforcement and shear span-to-depth ratio. From their experiments, it is found that the vertical web reinforcement improves ultimate shear strength, while horizontal web reinforcement had little or no influence on ultimate shear strength.

Design method of deep beams has been developed by many research groups, such as ACI (American Concrete Institute) and committee members in Euro code. Design codes of ACI and Euro code provide guide to design deep beams considering shear behavior. The former design guide defines deep beam which satisfies at least one of the following conditions: 1) clear span is equal to or less than four times the overall member depth, or 2) regions with concentrated loads are within twice the member depth from the face of the support. On the other hand, Euro code defines a deep beam if the span is equal or longer than 3 times the overall section depth. In order to design deep beam and predict its ultimate shear strength, using strut-and-tie models are recommended generally by ACI and Euro code. Aguilar et al.(2002) investigate behavior of RC deep beams in terms of initial flexural cracking, initial diagonal cracking, initial yield of longitudinal reinforcement, and failure. They also predict shear strength using ACI318-99 building code and compare with predictions from ACI318-02 building code. The former code doesn't consider strut while the latter code does. Their conclusion is that both ACI318-99 and ACI318-02 are shown to be conservative, while the strut-and-tie model provided in ACI318-02 results less conservative. Matamoros and Wong(2003) develop an equation to understand relationship between the strength and the applied force in the main strut and ties of deep beam. The proposed equation is also used to predict shear strength of the deep beam. The proposed equation predicts shear strength and shows good agreements with the experimental results. Quintero-Febres et al.(2006) report experimental studies in order to find out strut strength factors in concrete struts and compare them with provisions in Appendix A of the ACI-02 building code. The experimental results show that the strut strength factors in Appendix A of the ACI-02 are adequate for normal strength concrete, but not for high strength concrete. According to their study, ACI-02 code predicts ultimate shear strength approximately 10% higher than the experimental results in high strength concrete. In addition minimum effective reinforcement ratio of 0.01 is suggested in high strength concrete. Arabzadeh et al.(2009) investigate the effect of concrete softening effect caused by web reinforcement in addition to strut-and-tie mechanism. Even though it is widely known that the web reinforcement has beneficial effects on deep beam behavior, their experimental results show that it is important to choose optimized amount of web reinforcement for effective behavior of the deep beam. According to their study, amount of web reinforced can be determined with a consideration of strength of concrete, span-depth ratio, and ratio of tensile main reinforcement. In addition, they propose a formulation that can predict ultimate shear strength of the deep beam, which includes concrete strength, arrangements, amount of web reinforcement, and shear span-to-depth ratio. The ultimate shear strength value predicted from the proposed formulation is compared with predictions from the existing equations proposed by other researchers including ACI318-05 and CSA(Canada Standards Association), and the experimental results. Even if many researchers have studied about deep beams and proposed design