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THESIS OUTLINE

TITLE: "Shear Behavior of Reinforced Concrete and Prestressed Concrete Beams with Variable Effective Depth"

The reinforced concrete and prestressed concrete beams with variable effective depth are widely used in the recent construction field. Since there is no rational design method in current major specifications, it is necessary to clarify the shear resistance mechanism of such beams and propose a convenient evaluation method with high accuracy and compatibility. Therefore, the experiments of totally 10 reinforced concrete haunched beams and 7 tapered beams were carried out together with the nonlinear FEM analysis. Finally, some new evaluation methods for the shear capacities were proposed.

The thesis consists of 7 chapters.

Chapter 1 Introduction
Chapter 2 Literature review
Chapter 3 Experimental and analytical outline of reinforced concrete haunched beams
Chapter 4 Shear behavior of reinforced concrete haunched beams
Chapter 5 Experimental and analytical outline of reinforced concrete and prestressed concrete tapered beams without stirrups
Chapter 6 Shear behavior of reinforced concrete and prestressed concrete tapered beams without stirrups
Chapter 7 Conclusions and recommendations

The contents of this thesis are organized as follows.

Chapter 1 introduces the background and the motivation of this study. In the current construction field, more and more structures with variable effective depth are often used in the bridge and building structures for the economic and aesthetic reasons. Such kind of structures can use the material more efficiently by reducing the self-weight and the construction cost. They also have more beautiful appearance. Despite the fact that RC or PC beams with variable effective depth are commonly used in current structures, the number of experimental data to predict the shear behavior of such kind of beams is insufficient. Moreover, rational and economical design method in current JSCE (Japan Society of Civil Engineers) standard specifications for concrete structures, *fib* Model Code 2010 or the ACI specifications has not been established yet. Engineers are using this kind of beams based on the empirical and conservative design method which is not accurate and uneconomic. Therefore, the objective of this study is to clarify the shear resistance mechanism of the beams with variable effective depth and propose a convenient evaluation method with high accuracy and compatibility to ensure the reasonable design.

In **Chapter 2**, after the introduction of the basic theory on shear for the RC beams with constant depth, the shear behavior and the existing design equations for reinforced concrete members

and prestressed concrete members in the current JSCE design guidelines are introduced. Then the previous researches on the shear behavior of reinforced concrete beams with variable effective depth are summarized, including the RC haunched beams (RCHBs) and RC tapered beams. Based on such previous results, the factors may affecting the shear behaviors of haunched beams and tapered beams are also discussed, especially the PC tapered beams. These factors become the experimental parameters in the following experimental programs.

Chapter 3 introduces the experimental and analytical programs of RC haunched beams (RCHBs). According to the discussed parameters in **Chapter 2**, the experiment of 10 specimens belonging to four series was conducted, to investigate the influence of the position of haunched portion, concrete cover, using of stirrups and the arrangement of tensile rebars. The dimensions of all the specimens and the material properties are shown first together with the consideration for each series of specimens. Next, the concrete mix proportion, manufacture of test specimens, loading methods and the measuring items of the test beams are explained as well. Finally, to get a better understanding of the effect which the bonding behavior influence on the shear resistance mechanism of RCHBs as well as to check the shape of the inclined compression zone in the shear span, the nonlinear FEM analysis was carried out. The interface elements were used to connect the tensile rebar's element and the concrete element, to simulate the bonding behaviors of RCHBs. The total strain fixed smeared crack model was applied as the crack model in the analysis. The detailed material model with the iteration method are also introduced in this chapter.

The experimental results of each series in RCHBs are presented in **Chapter 4**. By comparing the diagonal crack propagation behavior of RCHBs and the shear capacities of test beams in each group, the effects of each parameter on shear resistance mechanism of RCHBs are investigated. Further, better understanding of the shear resistance mechanism of RCHBs is achieved with the discussion on the crack patterns, load-displacement curves, arch action and shear capacities of RCHBs. The arch action occurs due to the debonding cracks in the RCHBs, while the position of the haunched portion is found to affect the shear behavior significantly. The concrete cover however has no big influence on the shear behavior. For the RCHBs with stirrups, the contribution of the stirrups are also different due to the different main diagonal crack patterns. In addition, compared with the crack patterns of RCHBs with bent tensile rebars, the shear behavior becomes totally different when the tensile rebar is changed into disconnected one in RCHBs without stirrups. Finally, the nonlinear FEM analysis results are shown to clarify the influence of arch action and bonding behavior on the shear behavior. By modifying the bond loss factor in the nonlinear FEM analyses, it is able to simulate the shear behavior of RCHBs.

Chapter 5 is related to the experimental and analytical programs of RC and PC tapered beams. There are totally 7 test beams belonging to 3 series: tapered RC short beam without stirrups, tapered RC slender beams without stirrups and tapered PC beams without stirrups. The dimensions of all the specimens and the material properties are shown first together with the consideration for each series of specimens. Next, the concrete mix proportion, manufacture of test specimens, loading methods and the measuring items of the test beams are explained as well. Finally, to get a better understanding of the shear resistance mechanism in tapered beams as

well as to determine the critical section, the nonlinear FEM analysis was carried out. The total strain fixed smeared crack model was applied as the crack model in the analysis. The detailed material model with the iteration method are also introduced in this chapter.

Chapter 6 presents the experimental and analytical results of tapered beams. The crack patterns, load-displacement curves and shear capacities are investigated to clarify the influence of each factors on the shear behavior of tapered beams. It is found that in tapered RC short beam without stirrups, there is no effect of the taper due to the arch action. For the slender tapered RC and PC beams without stirrups, there is the influence of the taper based on the experimental results that the crack patterns and the shear capacities are different from the normal constant depth beams. Further, better understanding of the shear resistance mechanism in RC and PC tapered beams without stirrups is achieved with the nonlinear FEM analysis. The inclination of the shear stress flow increases as the slope of taper increases. The simple linear relationship between the slope of taper and the inclination of the stress flow for the tapered RC beams without stirrups is proposed. In PC tapered beams, the *a/d* ratio and the prestress levels are found to affect the inclination of the shear stress flow as well. Finally, by determining the location of the critical section with a general method from the analytical results, the new evaluation method for the shear capacity in tapered beams without stirrups is proposed. And the proposed method shows a good agreement with the experimental results as well as the high accuracy and compatibility.

Finally, the conclusions obtained in this study and the recommendations for further study are given in **Chapter 7**.

This thesis provides a deep understanding on the behavior of RC and PC beams with variable effective depth. Importantly, the resisting and failure mechanisms of RC haunched beams and RC and PC tapered beams have been clarified. The findings in this study shall be helpful for the sustainable application of these two types structures as well as the development of the design for the shear capacity of RC and PC structures with variable effective depth.