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主　論　文　の　要　旨

論文題目　**EVALUATION OF SHEAR FAILURE MECHANISM OF RC MEMBER BASED ON ANALYSIS OF BEAM ACTION AND ARCH ACTION**
(ビーム・アーチ機構の分析に基づく RC 部材のせん断破壊メカニズム評価に関する研究)

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論　文　内　容　の　要　旨

In ordinary seismic design for a reinforced concrete (RC) member, one of the basic requirements is that brittle shear failure shall be inhibited. In reality, a certain number of RC structures, having good deformability under monotonic loading, nevertheless could not survive under the effect of great earthquake or reversed cyclic loading, because of dramatic shear behavior. The shear failure after yielding of longitudinal rebar (short for shear failure after yielding) and the shear failure at cut-off point in longitudinal rebar (short for shear failure at rebar cut-off point) are two of the most common shear failure patterns that occur to the RC members such as RC columns and RC bridge piers under cyclic loading which have been widely reported. Therefore, it is necessary and crucial to explain the mechanisms of the above shear failures in order to achieve a more optimized seismic shear design and an improvement of seismic shear performance.

This study reproduced the shear failure after yielding of RC member subjected to cyclic loading and quantitatively assessed the process of shear strength degradation, based on the numerical analysis using three dimensional Rigid-Body-Spring-Method (3-D RBSM).

Furthermore, the mechanism of shear failure after yielding, i.e. the mechanism of shear strength degradation, was explained basing on the analysis of the degradation processes of beam action and arch action. Secondly, a parametric numerical study on the effect of main structural variables on the mechanism of shear failure after yielding of RC member was carried out. Thirdly, the effect of section crack, which is observed during the generating and connecting of flexural cracks from both sides of section under cyclic loading, on shear strength and capacity of arch action was investigated by loading experiment for the RC beams with section crack and 3-D RBSM analysis. Finally, the relatively worse shear performance, caused by rebar cut-off point, of RC beam was simulated and was further explained by the adverse effect of the rebar cut-off point on the development of arch action.

Chapter 1

This chapter is the introduction part. The general background of this study, a review of the related literatures and the motivation of this study were described.

Chapter 2

This chapter introduced the basic numerical tool, i.e. 3-D RBSM, for the simulation of mechanical behavior of reinforced concrete, employed in this study, and the basic method for analysis of the development of shear components of RC member, i.e. beam action and arch action, using the local stress result from 3-D RBSM. For 3-D RBSM, the method for modeling of concrete and rebar and the relevant parameters for constitutive models were introduced. On the other side, the theory of shear resistance mechanism consisting of two shear components, beam action and arch action, obtained from the relationship between the external moment and internal forces sustained by concrete and rebar along member axis were introduced, and the approach for decoupling of shear resistance hysteresis by 3-D RBSM into the hysteresis of beam action and arch action was explained by an numerical example of RC column failing by shear.

Chapter 3

This chapter clarified the mechanism of shear failure after yielding of a RC column for bridge pier subjected to cyclic loading. The structural behaviors of the RC column under cyclic and one-side repeated loadings were simulated and it was numerically confirmed that the deformability is decreased if subjected to cyclic loading, because of shear failure. Moreover, the shear strength degradation due to cyclic loading, which is the reason of shear failure, was quantitatively assessed by using numerical method. And the numerical shear strength degradation curves were compared with the statistical models summarized based on the extensive experimental database which are employed in the current design codes. In addition, the shear strength at each displacement ductility was decoupled into the shear components of beam action and arch action. As the results, as the most important achievement concerning the mechanism of shear failure after yielding, it was clarified that the degradation of arch action is the crucial reason of the shear strength degradation which reaches lower value than the shear demand corresponding to the flexural strength.

Chapter 4

In this chapter, on the basis of the structural details of the RC column studied in chapter 3, a parametric study concerning the effect of main structural variables, i.e. shear reinforcement ratio, shear span to effective depth ratio, tension reinforcement ratio and axial compression load, on shear strength degradation was carried out. The mechanism of shear failure after yielding concluded in chapter 3 worked for the other cases as well. As the effect on the degradation process of arch action, the numerical result showed that more arrangement of shear reinforcement can effectively increase the displacement ductility where arch action starts to dramatically decrease; smaller shear span to effective depth ratio, larger amount of tension reinforcement and higher axial compression load can reduce the displacement ductility where arch action starts to significantly decrease.

Chapter 5

In chapter 5, a hypothesis for the reason why arch action of RC member decreases due to cyclic loading was presented and discussed numerically. On the basis of the RC column studied in chapter 3, initial section crack was introduced in the same model, and the effect of section crack on shear strength and arch action was investigated by monotonic loading analysis using 3-D RBSM. The numerical result presented that the initial section crack located at the position 1.0d and 2.0d (d: effective depth of RC column) distance far away from the footing-column intersection can significantly reduce the shear strength and arch action, but the initial section crack located at the footing-column intersection has little reduction effect.

Chapter 6

Chapter 6 proposed an experimental method for introducing initial section crack into RC beam and investigated the effect of initial section crack on shear performance by

3-point loading test. Moreover, the shear loading test was simulated and the effect of initial section crack on the capacities of beam action and arch action were figured out. Both the experimental and numerical result showed that the initial section cracks at the position 1.0d distance far away from the loading point, 0.5 mm and 1.0 mm in width, can lead to evident shear strength degradation. Furthermore, it was confirmed that the shear strength degradation is caused by the degradation of arch action. Finally, the numerical local stress result presented that the initial section crack obstructs the transfer of compressive stress along beam axis, which is the essential factor for the degradation of arch action.

Chapter 7

Chapter 7 showed the result of monotonic loading analyses for RC beams with and without cut-off point in longitudinal rebar. Moreover, the shear resistance hysteresis were decoupled into the progresses of beam action and arch action. As a consequence, it was understood that the shear strength degradation caused by rebar cut-off point is attributed to the degradation of arch action. Additionally, the developments of local stress and strain along tension rebar for the two beams were surveyed, in order to find out the reason of arch action degradation due to rebar cut-off point. The result showed that the degradation of the capacity of arch action is originated from the relatively low upper limit of the combination load capacity in tension rebar, i.e. the force in tension rebar after yielding, for the rebar cut-off beam, which is attributed to the reduced number of tension rebar.

Chapter 8

Chapter 8 described the conclusions derived from this study and the recommendations for the future work.

This study contributes to a comprehensive understanding of shear failure after yielding (shear strength degradation) of RC member resulting from cyclic loading by numerical study for the analysis of shear resistance mechanism, i.e. beam action and arch action. Especially, it was clarified that the effect of section crack, which is regarded as a typical deformation behavior under cyclic loading, is an essential reason of arch action degradation. Since it is necessary to propose effective and applicable method for eliminating development of section crack and suppressing degradation of arch action in order to improve the shear performance of RC member withstanding seismic effect and cyclic loading, the future direction focusing on the shear component of arch action was pointed out.