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主 論 文 の 要 旨

論文題目　**EXPERIMENTAL AND NUMERICAL STUDY ON BOND STRESS AND SLIP RELATIONSHIP OF CORRODED REBAR**
(腐食した鉄筋の付着応力すべり関係に関する実験的及び数値解析的研究)

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論 文 内 容 の 要 旨

Rebar corrosion has been a wide-spreading problem among the RC structures during the serve life. As one of the most significant factor in the corroded RC member, bond deterioration between rebar and concrete directly threat the serviceability and safety of the degraded structure. In order to prolong the service life of the affected structures, it is important to estimate the residual strength and ductility of the RC member and implement necessary maintenance and rehabilitation. Hence, a comprehensive understanding of the effect of corrosion on bond deterioration is fundamental. However, the experimental and numerical investigation on this topic is still insufficient.

The first objective of this study is to demonstrate the synthesis effect of corrosion-induced crack and rusted rebar shape on bond-slip relationship, of which parameters including internal crack pattern, surface crack width and corrosion degree are investigated thoroughly. The second objective is to clarify the individual effects of corrosion-induced crack, corroded rebar shape and rust accumulation on bond-slip relationship. The third objective is to propose a simplified numerical model consisting of concrete, round rebar without modeling explicitly the details of rebar ribs and interface elements based on 3D RBSM to study the effect of corrosion-induced crack and its influential factors on bond degradation.

Chapter 1

This chapter is the introduction of this study, including the research background, a general review of related references, the study objectives and the organization of the dissertation.

Chapter 2

This chapter includes an experimental program on bond-slip relationship of corroded specimen with various concrete cover and side cover thickness. First, test procedure including accelerated corrosion tests and two end pull-out tests conducted in this study are explained. Second, bond-slip relationships accompanying with internal crack pattern subjected to corrosion and rebar pull-out are presented.

The effect of concrete cover on internal crack pattern agreed with the previous theoretical criterion based on C/D ratio. In addition, concrete side cover thickness did not largely influence the crack pattern induced by corrosion. Surface crack width developed corresponding to corrosion degree after 3-4% corrosion. Regardless of C/D ratios and concrete side cover, bond strength subjected to corrosion exhibited up to 20% increase with 3-5% corrosion, then deteriorated to 20% of the non-corroded bond strength after 10% corrosion. Bond degradation was proportional to the crack width development and a better correlation could be obtained compared to with corrosion degree; when crack width reached to 1.0mm, degradation of bond strength became nearly constant. C/D ratio and side concrete cover did not influence the dependency of normalized bond strength on corrosion degree and surface crack width. Moreover, the influence of corrosion degree on slip reduction could be confirmed. 75% reduction of slip was achieved with more than 10% corrosion. After the open of surface crack, slip directly degraded to around 0.05-0.1mm regardless of the concrete cover. No clear dependency of normalized slip on corrosion degree and surface crack width was found. Moreover, with the existence of corrosion-induced crack and corroded rebar shape with rust, a clear enhancement of initial stiffness and bond ductility was obtained.

Chapter 3

In this chapter, an experimental program studying the individual effects of corrosion-induced crack, corroded rebar shape and rust accumulation is proposed. Test series include normal corroded specimen, corroded rebar with & without rust in non-cracked concrete specimen. Moreover, corroded rebar shape with & without rust are both measured by laser scanning test. Corroded rebar shape obtained by laser scanning test showed that rebar corrosion causes the deterioration of relative rib area and rib height while enhances rib deviation regardless of the presence of rust. Clear correlation of bond strength against geometric indexes was confirmed. With the absence of corrosion crack, rust accumulation caused apparent enhancement of bond at small corrosion, while degradation induced by effect of corroded rebar shape regardless of the formation of rust was less than half of the case with corrosion crack at large corrosion degree. Within about 20% corrosion, the removal of rust from rebar was inconsequential to obtain the good bonding during the rehabilitation work. Moreover, corroded rebar shape did not cause clear degradation on slip at ultimate bond strength while rust accumulation induced a reduction tendency at large corrosion degree. Furthermore, accumulation of rust on rebar surface enhanced the adhesive and friction force, resulting in the increase in initial stiffness in specimen subjected to corrosion. With the absence of corrosion crack, bond ductility did not change from non-corroded case.

Consequently, corrosion-induced crack in concrete was clarified to be more dominant than rust and change of rebar shape in bond deterioration mechanism, which determined bond strength, slip and bond ductility.

Chapter 4

In this chapter, a numerical method based on 3D RBSM simulating the effect of corrosion-induced crack on bond behavior is presented. A three-layered model was proposed to consist of round rebar without detailed rib shape, concrete and interface where both corrosion-expansion model and shear transfer model are assigned.

Proposed numerical model was firstly validated to obtain reasonable accuracy of the bond performance with non-corroded specimen. Then the proposed model was validated to reproduce the bond deterioration caused by corrosion-induced crack considering rebar located at different position in concrete. Additionally, bond deterioration mechanism subjected to corrosion-induced crack was investigated basing on internal crack propagation and stress distribution in concrete. Results demonstrated that with the existence of corrosion-induced crack in the concrete cover, tensile stress and compression zone where shear stress transferred induced by slip does not generate in near to the concrete cover, whereas shifts towards concrete body with smaller area and magnitude. Bond deterioration mechanism was concluded to be a combined effect of degradation of ring-tension stress around crack and compressive stress near concrete cover.

Chapter 5

In this chapter, effect of corrosion-induced crack on bond degradation is further investigated numerically considering various concrete cover and side cover thickness, rebar diameter and corrosion expansion region.

The results showed that effect of rebar diameter does not influence the internal crack pattern but enhance the surface crack width with same corrosion degree; larger rebar diameter resulted in larger bond degradation with same corrosion degree; the discrepancies of bond degradation between different rebar diameters could be alleviated by the surface crack width. Besides, effect of concrete side cover caused different internal crack pattern and surface crack width; total surface crack width was indicated to be as important as corrosion degree in bond strength evaluation. Moreover, effect of concrete cover caused different internal crack pattern and surface crack width based on C/D ratio; with certain C/D ratio, the relationships between normalized bond strength and surface crack width were consistent regardless of the rebar diameters; as C/D ratio increased, the normalized bond strength decreased faster with the increase of both corrosion degree and surface crack width.

Chapter 6

This chapter includes the conclusions derived from this study and the recommendations for future study.

In the summary of significant findings in the dissertation, bond-slip relationship between rebar and concrete is influenced by rebar corrosion through degradation of ultimate bond strength, slip at ultimate bond strength and transforming in initial stiffness and bond ductility. The influence is basing on a combined mechanism of the presence of corrosion-induced crack and the rusted rebar surface. More importantly, as the dominant factor in bond deterioration mechanism, corrosion-induced crack is determined by a series of complex factors and some of them including concrete cover thickness, rebar diameter, C/D ratio, corrosion region were further studied experimentally and numerically. Conclusions derived above point out the well-defined significance of C/D ratio among other factors in bond deterioration and the close correlation between bond strength and surface crack width, which is a comprehensive and practical indicator in the evaluation of residual bond capacity in RC member subjected to rebar corrosion.

At last, recommendations for the future work are presented regarding experimental, numerical and analytical model for the evaluation of residual bond strength induced by corrosion-induced crack and corroded rebar shape.