Analysis of Concrete Cover Spalling due to Rebar Corrosion

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Abstract: This study examined the applicability of previously proposed corrosion expansion model on the base of rigid body spring method to model the concrete cover spalling, which is a part of research aiming at clarifying the mechanism of corrosion-induced cover spalling. It is also found that localized corrosion can result in the internal cracks developing diagonally to concrete surface and then a sudden spalling, which poses a remarkable threat to the safety of structure.

1. Introduction

The serviceability of ageing reinforced concrete structures is greatly affected by internal rebar corrosion as corrosion products of rebar occupy larger volume than original rebar, impose expansion pressure on surrounding concrete, and then induce concrete cover cracking and spalling. Although there are a number of researches focusing on cracking mechanism of the corroded structures, few of them are extended to cover spalling. However, it cannot be ignored since it's strongly related with the safety of structures in terms of the influences on human's safety.

The study currently conducted try to identify the influence factors of corrosion-induced cover spalling, specifically to clarify the relationship between localized corrosion and cover spalling. Here, the applicability of analytical method, which was based on Rigid Body Spring Method with corrosion expansion model, was verified by comparison with experimental results.

2. Outline of Analysis

2.1 Specimen

Three rebars were embedded into the concrete specimen with a compressive strength of 40MPa during experiment. The specimen dimension is shown in Fig.1. Part of the bottom of concrete specimen, which is marked in red in Fig.1, was in touch with salty water by the link of sponge in order to reach the state of localized corrosion. A DC power was used to carry out accelerated corrosion process and conduction time was determined based on Faraday's law. Three objective corrosion degree varying as 5%, 10% and 15% were studied in the test. After artificial corrosion process, the surface cracking map was monitored and then the specimen was cut in different positions, where the internal crack pattern was investigated. Fig.2 shows the distribution of corrosion degree along rebar. It can be seen that it is distributed in the shape of triangle and the part that was connected with sponge exhibits a higher corrosion rate.

For simulation, RBSM model corresponding to this specimen was established using Voronoi random polygons. It is noted that only one rebar was introduced into the model because the other two rebars were barely corroded and it can also reduce the computation burden.

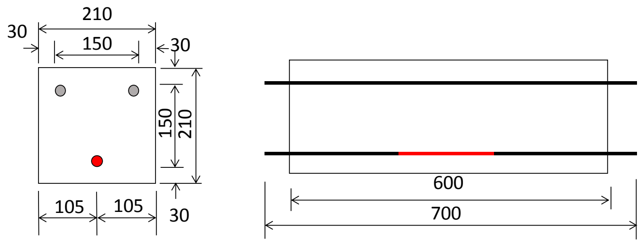
2.2 Corrosion Expansion Model

In previous study of our lab (Tran et al. (2011)), expansion of corrosion products inside concrete due to rebar corrosion was modeled by internal expansion pressure, which was simulated with increment of initial strain applied on the boundary between rust layer and rebar layer as determined by Eq. (1).

$$\Delta\sigma_{cor} = E_r\left(\Delta\varepsilon - \Delta\varepsilon_0\right) = E_r\left(\frac{\Delta U_{cor}}{H} - \frac{\Delta U}{H}\right) \quad (1)$$

Where E_r is elasticity modulus of corrosion product, ΔU_{cor} increment of real increase of rebar radius confined by surrounding concrete, ΔU free increase of rebar radius and H thickness of corrosion product layer. In addition, it was reported in the work of Yuan and Ji (2009) that the corrosion products distribute on the half circumference of rebar facing concrete cover. Hence, during simulation increment of initial strain was only applied over one-quarter of the model, which was also based on the distribution of corrosion degree as shown in Fig 2.

This model combined with RBSM method is appropriate to evaluate corrosion-induced cracking behavior of concrete cover and agrees well with accelerated corrosion test result (Tran et al. (2011)).



a) Section b) Side view

Fig. 1 Specimen dimensions

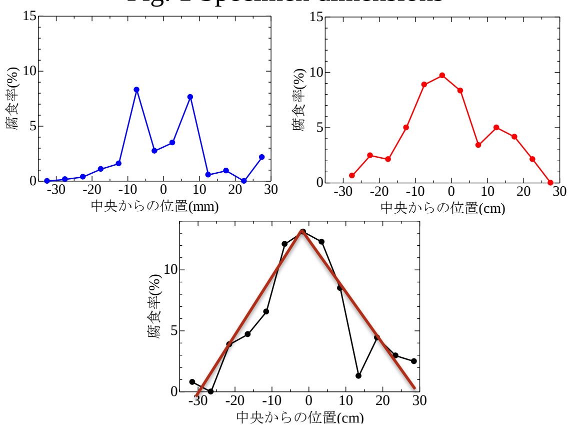


Fig. 2 Distribution of corrosion degree

3. Result and Discussion

It is observed that cover spalling occurs when practical corrosion degree reaches 12.5% at the center part for this specimen size. The comparisons between simulation and experimental results presented here account for two kinds of corrosion degree, a small corrosion degree of 4.84% and a large corrosion degree of 12.5% to illustrate the applicability of the numerical model.

3.1 Small corrosion degree

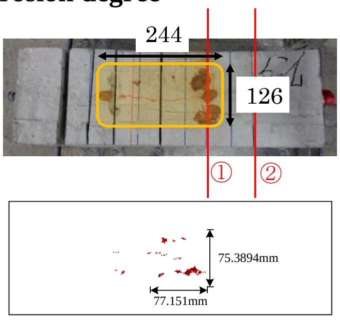


Fig. 3 Comparison of surface cracking map

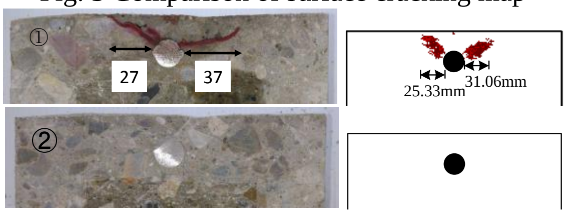


Fig. 4 Comparison of internal cracks

Fig. 3 displays the surface cracking map obtained from accelerated corrosion experiment and analytical method separately. The rust trace demonstrates the mostly cracked part, which is in agreement with the simulation result as shown in the figure below. Fig. 4 depicts the internal crack pattern at different positions, which are indicated in Fig 3. Meantime, the simulation results, in which a red sign represents cracks with a width larger than 0.3mm, are shown correspondingly. It is shown that the numerical method agrees with the experiment not only in the internal crack pattern but also in the length of lateral cracks.

It is proposed in the work of Tsutsumi et al (1996) that if the ratio of cover thickness to rebar diameter less than 1, internal cracks develop toward concrete surface diagonally. Comparatively, internal crack propagate respectively to sides and surface in the shortest path when this ratio larger than 1. Although the ratio of cover thickness to rebar diameter for studied specimens is larger than 1, the internal cracks propagate diagonally to concrete surface, which can be attributed to localized corrosion. It is worth noting that localized corrosion will result in the internal cracks developing to concrete surface and then a sudden cover spalling even if the cover thickness is considerably big. Besides, there are few cracks produced at the concrete surface, which reduces the accuracy of predicting cover spalling by monitoring surface cracking conditions.

3.2 Large corrosion degree

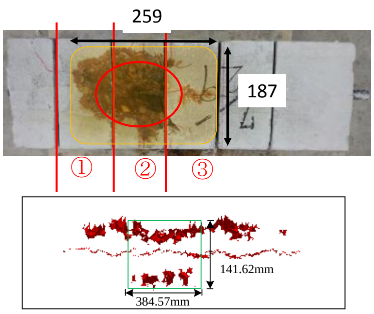


Fig. 5 Comparison of surface cracking map

Fig. 5 presents surface cracking under a corrosion degree of 12.5% for the center part of rebar. It is shown that a small part with an approximate area of 120cm^2 is dropped out of the specimen, which is indicated with a red circle in Fig 5. The green square marked in simulation result of Fig 5 gives an estimation of potential spalling area, which is a little larger than the experiment and need to be further examined.

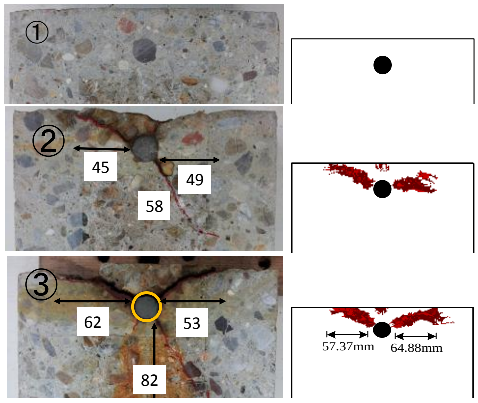


Fig. 6 Comparison of internal cracks

Fig.6 shows the internal crack pattern at three locations, which are marked in Fig.5. It is proved that current analytical model is capable of modeling the evolution of inside cracks resulted from local corrosion.

Consequently, it can be concluded that the corrosion expansion model owns sufficient accuracy to model the cover spalling caused by localized corrosion when the practical distribution of corrosion degree is introduced into the modeling.

4. Conclusion

Trough comparing the numerical results based on corrosion expansion model with experimental results in detail, the applicability of the analytical method proposed formerly is confirmed. Besides, it is found that localized corrosion will lead to the internal cracks propagate diagonally to concrete surface and finally spalling of concrete cover.

It is known that the crack development of concrete due to internal rebar corrosion is also related with the geometrical features of concrete specimen, such as the width of specimen. Further research is required to study the spalling phenomena of concrete slab due to localized corrosion. At present, the related experiment is being conducted to identify the mechanism of spalling.

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