RELIABILITY ASSESSMENT OF CRACKED RC BEAM BY CONSIDERING THE COUPLED EFFECTS OF CRACK DEVELOPMENT AND CORROSION INITIATION AND PROGRESSION

The University of Tokyo Regular Member ○Wang Tiao
The University of Miyazaki Regular Member Li Chunhe

1. INTRODUCTION

Reinforcement corrosion induced by chloride ingress is one of the major threats of reinforced concrete (RC) structures exposed to chloride attack. RC structure always cracks under external loading. These cracks provide additional paths of chloride ingression and facilitate the reinforcement corrosion. On the other hand, the degradation induced by corrosion in RC structure involves great uncertainties and randomness due to the variability in material properties, the variability in geometry and the random nature of the marine environment. JSCE proposed the performance-design approach of RC structure under chloride ingression. However, this approach does not consider the coupled effects of crack development and corrosion initiation and progression. The performance degradation is thus underestimated. This study thus proposes a reliability analysis system based on Monte-Carlo simulation, which considers coupled effects of crack development and corrosion initiation and progression. The corrosion failure possibility (CFP) of RC structure can be thus elevated.

2. RELIABILITY ANALYSES SCHEM

Fig. 1 illustrates the overall reliability assessment scheme of concrete beam subjected to flexure load. The inputs required in this scheme include the water-binder ratio, temperature, reinforcement properties, concrete strength, pH of pore solution, geometry of the concrete beam and the boundary conditions to which the concrete beam will be exposed during its life cycle.

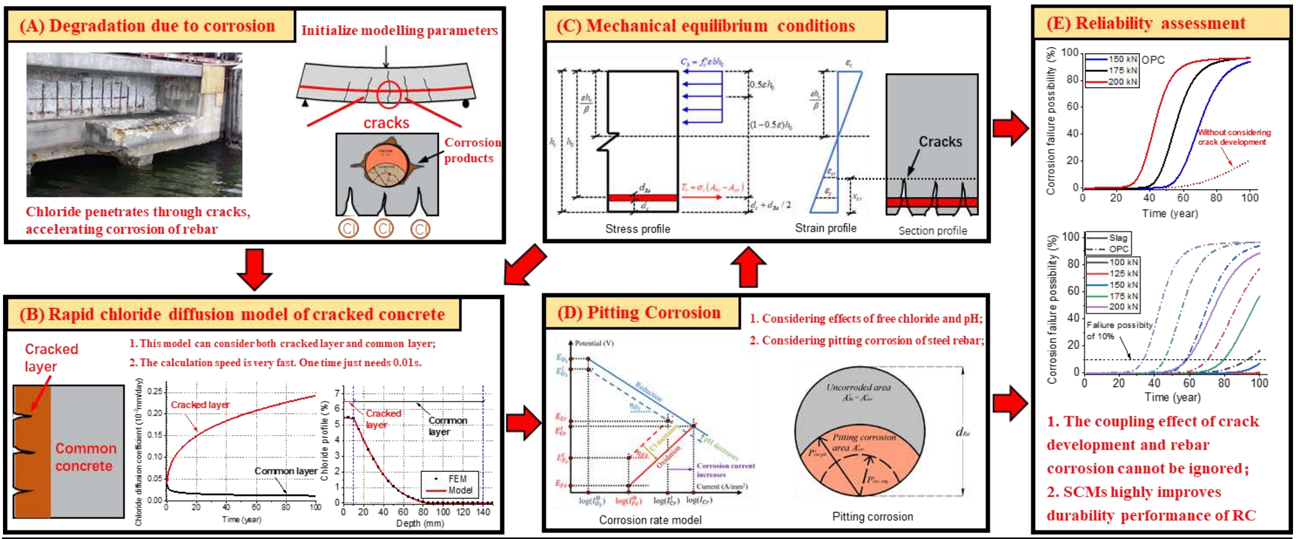

Fig.1 Reliability analysis scheme on corrosion failure time of RC beam under chloride ingression.

For each concrete beam in Monte-Carlo simulation, the chloride diffusion profile of cracked concrete is determined by rapid two-layer numerical approach (RNA) with crack geometries and chloride exposure conditions (Fig. 1B). The RNA has been verified for chloride diffusion progress of cracked concrete. The calculation speed of this approach is very fast. One step just needs 0.2s, which facilitates the Monte-Carlo simulation. More details can be found in the reference Wang et al. (2021a & b). With the free chloride content at rebar, the corrosion rate and pitting corrosion area are determined by corrosion rate model and pitting corrosion propagation model subsequently (Fig. 3D). The corrosion rate model is based on the model proposed by Maekawa et al (2008), which considers the pH effect and chloride content. The pitting corrosion model is adopted the pitting corrosion development model proposed by Stewart (2004). The corrosion area will send to mechanical analysis (Fig. 3C). The rebar stress and crack geometry (crack width and crack depth) will send to chloride diffusion model for next step analyses. These calculation procedures will be repeated step by step until the stress of steel bar is higher than its yielding strength.

3. ANALYSES RESULT

A concrete beam subjected 4-point load is taken as an example, which is illustrated in Fig. 2. The diffusion coefficient

Keywords: Corrosion failure possibility, RC structure, Corrosion, Crack development, Chloride
Contact address: Hongo 7-3-1, Bunkyo-ku, Tokyo, 113-8656, Japan, Tel: +81-3-5841-7498 E-mail: wang @concrete.t.u-tokyo.ac.jp

of the concrete substrate $D_{con}^{t_0}$ follows a lognormal distribution with a coefficient of variation (COV) of 0.2 at reference age 28day. Its mean value is taken as 0.672 mm^2/day. The time-dependency of the concrete substrate is described by a power function of Eq.1. α follows a normal distribution with a mean value of 0.15 and a COV of 0.2. The diffusion coefficient of cracked concrete is determined by JSCE code (i.e., Eq. (2)). The concrete cover depth follows a normal distribution with a mean of 100 mm and a COV of 0.15.

$$D_{con}^{t_i} = D_{con}^{t_0}\left(\frac{t_{st}+t_i}{t_0}\right)^{-\alpha} \tag{1}$$

$$D_{cr}^{t_i} = D_{con}^{t_i} + 3\left(\frac{\sigma_s^{t_i}}{E_s} + \varepsilon_{sh}^{t_i}\right)D_{cr,k} \tag{2}$$

where t_{st} is the initial time of chloride exposure, taken as 28day; $D_{con}^{t_i}$ is the chloride diffusion coefficient of uncracked concrete; $\sigma_s^{t_i}$ is the stress of rebar; E_s is elastic module of rebar; $\varepsilon_{sh}^{t_i}$ is the drying shrinkage of concrete; $D_{cr,k}$ is characteristic chloride diffusion coefficient of concrete crack (200 cm^2/year); and the superscript t_i means i^{th} step.

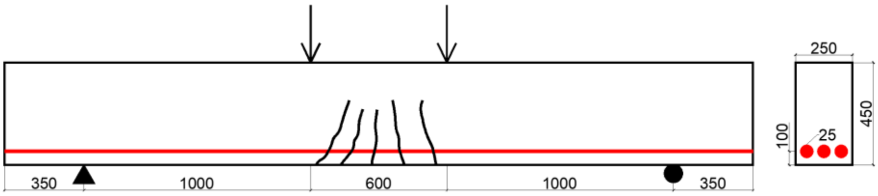

Fig.2 RC beam subjected to 4-point load.

Fig. 3 shows the loading effect on CFP of concrete beam. It also presents the CFP without crack development that the thickness of cracked layer is assumed to be a constant of 5mm. The CFP of concrete beam is 93.82% after 100 years when load is 150 kN. However, the CFP is only 10.20% without crack development. It shows that the CFP of RC structure will be significantly underestimated if the coupled effect of crack development and rebar corrosion is ignored.

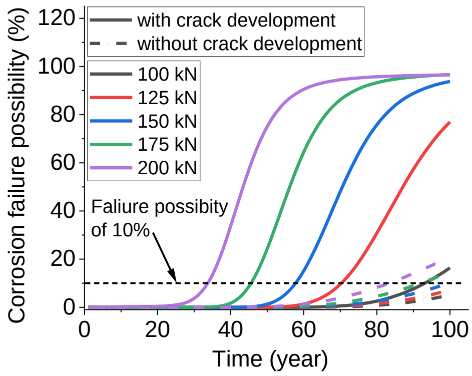

Fig.3 Effect of external load on corrosion failure possibility.

4. CONCLUSIONS

A reliability assessment system has been developed to predict the CFP of RC structure, which considers coupled effects of crack development and corrosion initiation and progression. Analyses results show that the CFP is significantly underestimated without considering external load and crack development.

ACKNOWLEDGEMENT

The authors are grateful for the financial support from Yoshida Award, Encouraging Prize (JSCE) and The Taisei Foundation (20020).

REFERENCES

T. Wang, J.-J. Zheng, J.-G. Dai, Analysis of time-dependent chloride diffusion in surface-treated concrete based on a rapid numerical approach, Structure and Infrastructure Engineering, (2021) pp.1-13. https://doi.org/10.1080/15732479.2021.1945113.

T. Wang, Y. Luan, A probabilistic approach for estimating corrosion possibility of reinforced concrete structure considering crack development, (2021). 4th Microstructure Related Durability of Cementitious Composites.https://repository.tudelft.nl/islandora/object/uuid%3Aaa027416-132c-46c9-a1eb-c8c06d6fdc0f

K. Maekawa, T. Ishida, T. Kishi, Multi-scale modeling of structural concrete, Boca Raton, FL: CRC Press, 2008.

M.G. Stewart, Spatial variability of pitting corrosion and its influence on structural fragility and reliability of RC beams in flexure, Structural Safety, 26 (2004) pp. 453-470. https://doi.org/10.1016/j.strusafe.2004.03.002