EVALUATION OF THRESHOLD OF CRACK WIDTH BASED ON CHLORIDE INGRESS INTO CONCRETE IN RC MEMBER BY NUMERICAL SIMULATION

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1. INTRODUCTION

RC structures are in general allowed to have flexural cracks under the service load. Hence, it is essential to restrict crack width to avoid steel corrosion. In the standard specification for concrete structures by Japan Society of Civil Engineering (JSCE), limitation of crack width is formulated as a function of thickness of concrete cover. Though this limitation of crack width has been proved adequate practically, its reasonableness has not been theoretically confirmed. Therefore, the purpose of this study is to investigate the influence of cover thickness and environmental action on limitation of crack width through numerical simulation, in which coupled transport model of moisture and chloride is employed.

2. METHOD OF NUMERICAL SIMULATION

2.1 Calculation of transport of moisture and chloride ions in cracked concrete

Transport of chloride ions in cracked concrete is calculated by two-dimensional analysis using coupled transport model for water and chloride ions[1]. Layout of a part of RC member with flexural crack analyzed in this study is shown in **Fig.1**, in which L is crack interval, w is crack width, c is thickness of concrete cover. Moisture and chloride ions are assumed to penetrate into concrete from the exposed surface and the crack surface.

In calculation of moisture transport, two different models are alternatively used depending on drying and wetting process. When concrete surface is exposed to the air, transport of water within concrete is calculated by diffusion model in nonsaturated concrete. When concrete surface directly contacts with liquid water, capillary suction takes place. Transport of liquid water from the boundary surface and within concrete is calculated by the capillary suction model in concrete instead of diffusion model. Flexural crack in RC member is modeled as spaces between parallel planes. When concrete surface directly contacts with liquid water, liquid water penetrates into crack by capillary suction. Thereafter, liquid water ingresses into concrete from both exposed surface and crack surface. The amount of penetrated water into concrete from the crack surface does not exceed the amount of water in crack. When all liquid water in crack has penetrated into concrete, liquid water penetrates into concrete only from the exposed surface. Transport of chloride ions in concrete pores is calculated with considering molecular diffusion of free chloride ions within liquid water phase and transport of liquid water, bulk mass flux of free chloride ions carried by capillary suction water, and phase transition between free and fixed chloride with cement hydrate in concrete.

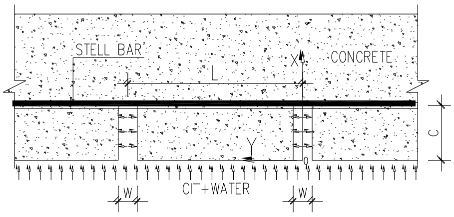

Fig.1 Layout of RC member with flexural crack

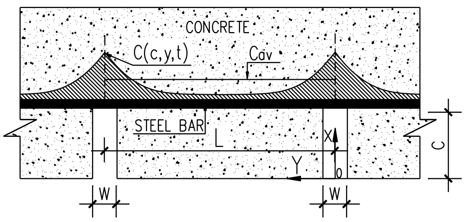

Fig.2 Determination of C_{av} by averaging method

2.2 Evaluation of average chloride content at reinforcing bar

Chloride content along the reinforcement in concrete $C(c, y, t)$ is obtained by numerical simulation. Average chloride content at reinforcing steel bar C_{av} is calculated by averaging $C(c, y, t)$ with respect to position y as:

$$C_{av} = \frac{1}{L}\int_0^L C(c,y,t)dy \tag{1}$$

3. LIMITATION OF CRACK WIDTH IN JSCE STANDARD SPECIFICATION

In the standard specification for concrete structures by Japanese Society of Civil Engineering (JSCE), the limitation of crack width is defined as following equation:

$$w_a = 0.005c \left(< 0.5\text{mm}\right) \tag{2}$$

where w_a is limitation of crack width, c is thickness of concrete cover.

4. NUMERICAL EXPERIMENT

4.1 Analytical cases

Table 1 shows experimental parameters and their variation examined in this study. Drying-wetting cycle is chosen as experimental parameter because it was considered for deterring limitation of crack width by JSCE (2002). Calculated cases are presented in Table 2.

Keywords: Limitation of crack width; Flexural crack; Chloride ingress; Numerical simulation
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Table 1 Experimental parameters and their variation

Experimental parameters	Variations
Concrete cover (c) (mm)	50, 80, 100
Drying-wetting cycle (tw) (length of once cycle is 7days)	wetting days: 0.1, 1, 2

Table 2 Calculated cases in numerical experiment

Cases	c(mm)	w (mm)	L (mm)	drying-wetting
1 to 8	50	0 to 1	400	6-1
9 to 15	50	0 to 0.5	400	6.9-0.1
16 to 21	50	0 to 0.5	400	5-2
22 to 31	80	0 to 1	400	6-1
32 to 40	100	0 to 1	400	6-1

4.2 Results and Discussion

(1) Influence of drying-wetting cycle

Fig.3 shows the relationship between calculated average chloride content along the reinforcing bar and crack width under various drying-wetting action. It is found in Fig.3 that the average chloride content along the reinforcing bar remarkably increases when crack width exceeds a certain crack width in every case. This crack width can be regarded as the limitation of crack width over which the risk of corrosion suddenly increases in terms of chloride ingress. It is found that analytically obtained limitation of crack width increases with increasing of wetting period. This is attributable to the fact that water penetration into concrete from crack surface increases with increasing of wetting period. However, analytically obtained limitation of crack width is smaller than that in JSCE specification, which is, for instance, 0.25mm when cover is 50mm. One of the reasons of this is that the limitation of crack width by numerical simulation is obtained under drying-wetting condition, which is regarded severe condition for corrosion.

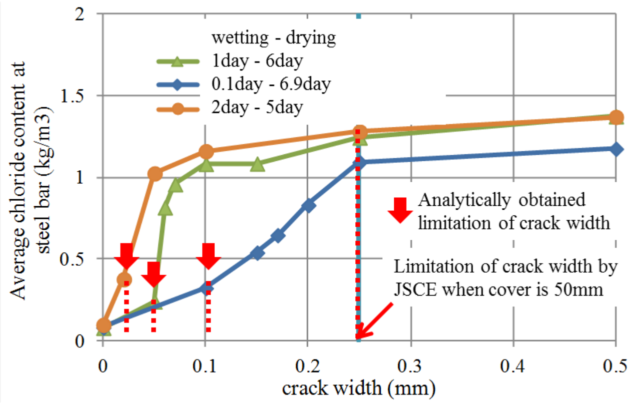

Fig.3 Relationship between C_{av} and crack width

(2) Influence of cover thickness

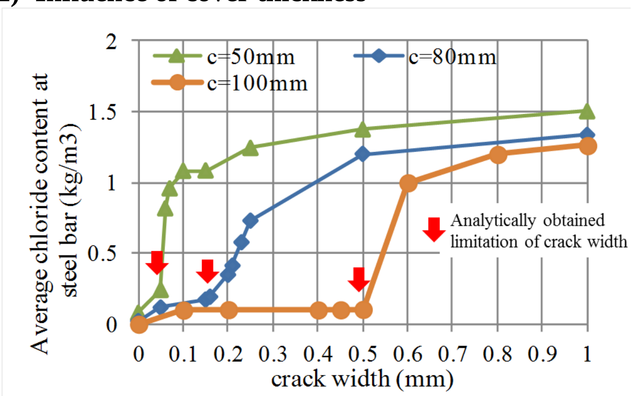

Fig.4 Relationship between C_{av} and crack width (1day wetting and 6days drying)

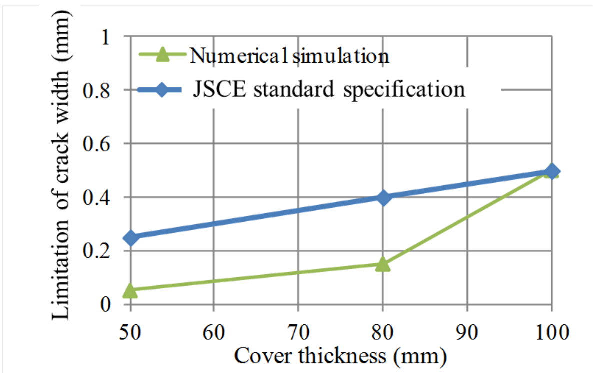

Fig.5 Relationship between limitation of crack width and cover thickness (1day wetting and 6days drying)

Fig.4 shows the relationship between calculated average chloride content along the reinforcing bar and crack width under 1day wetting and 6days drying. It is found that the average chloride content along the reinforcing bar remarkably increases when crack width exceeds 0.05mm, 0.15mm and 0.5mm in cases that cover thickness is 50mm, 80mm, and 100mm respectively. These limitations of crack width as a function of cover thickness are plotted in Fig.5. Limitation of crack width in JSCE standard specification is also plotted. Limitation of crack width evaluated by the two methods show same tendency; both increases with increasing of cover thickness. The difference between them is small when cover thickness is 100m, while it becomes greater when cover thickness is thinner. The reason of this is considered that the limitation of crack width by numerical simulation is only based on chloride ingress, while the limitation of crack width by JSCE is experimentally determined considering various influencing factors on corrosion in addition to chloride content. This should be more investigated in further study.

5. CONCLUSION

Analytically obtained limitation of crack width under drying-wetting condition becomes small when ratio of length of wetting period in one cycle increases. It increases with increasing of cover thickness. This tendency corresponds with limitation of crack width in JSCE standard specification.

REFERENCES

1) S. Kobayashi and T. Shimomura: *Numerical Analysis on Transport of Aggressive Materials and Corrosion of Steel Bars Concrete*, Proceedings of the Japan Concrete Institute, Vol.24, No.1 pp.831-836, 2002.6