

Drying Shrinkage Cracking in RC Wall (Crack Control Design)

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ABSTRACT: In the previous study, for the quantitative crack control design in the RC wall, the simple equations (crack width, number of cracks) based on the bond analysis was proposed, and these equations enabled a quantitative crack control design.

In this paper, the crack control design method by these equations was explained citing example.

Keywords: crack control design, RC wall, crack width, number of cracks

1. INTRODUCTION

Because cracks occurring in RC building cause corrosion of the reinforcing steel, lead to deterioration of the quality of building, and especially have a bad influence upon the appearance, the crack control is important. The cracks occurring in the wall of RC building usually occur due to the restraint of volume change induced by drying shrinkage. These cracks are controlled by a reduction of drying shrinkage, an increase of the reinforcing steel, and the control joint. However, because there is no definite method for the estimation of cracking due to drying shrinkage in RC wall, the quantitative design for crack control in RC wall can't be performed yet.

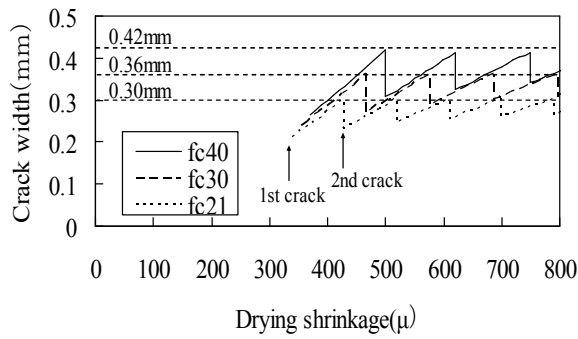
Accordingly, for the quantitative crack control design in the RC wall, Ohno, Y & Seo, T proposed the analytical method by bond analysis[1] and simple equations

(crack width, number of cracks)[2] based on the bond analysis, and the validity of these equations was verified by the experimental study and field study[2][3].

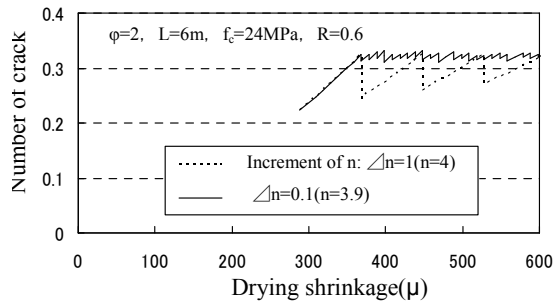
In this paper, the crack control design method by these equations was explained citing example.

2. ESTIMATION EQUATION

From parameter study by the bond analysis[1], it was confirmed that crack width is affected by concrete strength(f_c), reinforcement ratio(p_t), and bar size(D), and the number of cracks was affected by all parameters (concrete strength, reinforcement ratio, bar size, drying shrinkage (ϵ_{shn}), restraint ratio(R), length of RC wall(L), creep coefficient(ϕ)). Fig. 1 is an example of the result by bond analysis. The maximum crack width is almost constant



(a) Crack width



(b) Number of cracks

Figure 1: An example of analysis results

value, and this maximum crack width was used to propose the estimation equation of the crack width. The increment of $n=0.1$ was considered to investigate accurately the number of cracks.

The estimation equations of the crack width and the number of cracks proposed from the previous study[2] are as follows.

$$W = 0.0484 \cdot \left(\frac{f_c}{27} + 1 \right) \cdot \frac{K}{p_t^{1.79}} \quad (\text{mm}) \quad (1)$$

where,

$$K = 1.0(\text{D10}) = 1.33(\text{D13}) = 1.16(\text{D10, D13})$$

$$n = K_{P_t} \cdot K_L \cdot K_{f_c} \cdot K_{sh} \cdot K_{\phi} \cdot K_R \cdot K_D \cdot n_0 \quad (2)$$

where, $n_0 = 2.1$

Reinforcement ratio coefficient(p_t : %)

$$K_{p_t} = 4.69 p_t - 0.787 \quad (3)$$

Length of RC wall coefficient(L : m)

$$K_L = 0.957(L/6) + 0.027 \quad (4)$$

Concrete compressive strength coefficient(f_c : MPa)

$$K_{f_c} = -0.557(f_c / 27) + 1.547 \quad (5)$$

Drying shrinkage coefficient(ϵ_{shn} : μ)

$$K_{sh} = 0.003 \epsilon_{shn} - 0.82 \quad (6)$$

Creep coefficient

$$K_{\phi} = -0.36 \phi + 1.52 \quad (7)$$

Degree of restraint coefficient

$$K_R = 3.62R - 0.82 \quad (8)$$

Bar size coefficient

$$K_D = 1.00(\text{D10}), 0.76(\text{D13}), 0.88(\text{D10, D13})$$

3. CRACK CONTROL DESIGN IN RC WALL

Fig.2 shows the flowchart of crack control design in RC wall by the proposed equations(Eq.(1), Eq.(2)). The tensile stress of concrete(σ_c) due to the restraint of volume change induced by drying shrinkage is compared with tensile the strength of concrete(f_t)[4]. If σ_c is less than f_t , the crack doesn't form in RC wall, and this means the crack was controlled by reducing drying shrinkage. If σ_c exceed f_t , the crack control design is demanded.

In case of the crack control by the reinforcing steel, the crack width is calculated by Eq.(1), and this value is compared with the allowable crack width (0.3mm)[4]. If the calculation value exceeds the allowable value, increasing the reinforcing steel until the calculation value becomes less than 0.3mm, the crack control design is carried out.

In case of the concentration control due to the control joint, the crack spacing is determined by the number of cracks calculated by Eq.(2), and the control joint is installed in RC wall. Where, the ultimate creep coefficient between 2 and 3[5] can be used for the calculation of the number of cracks, and the estimation equation of

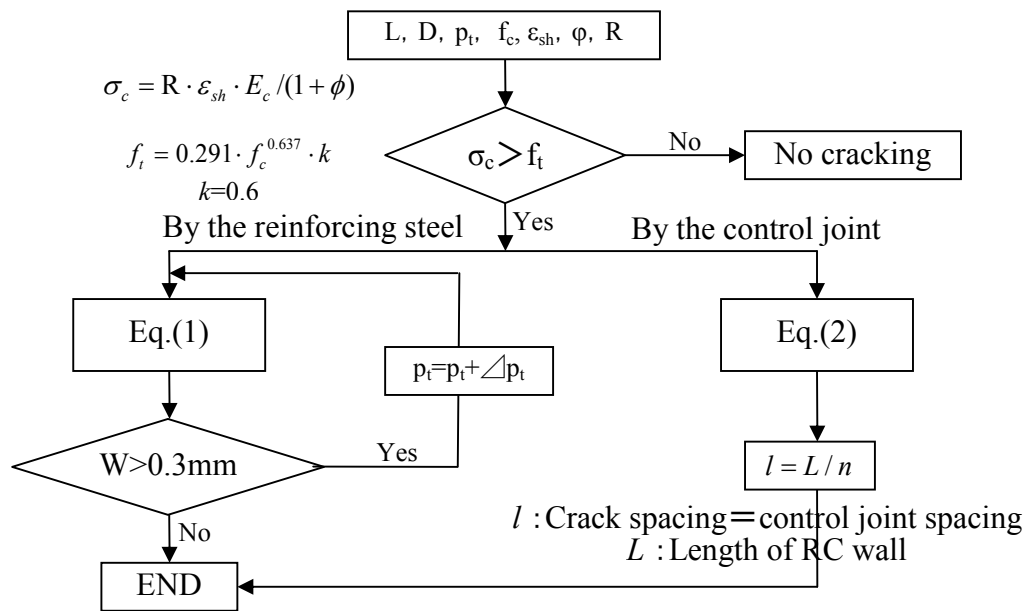


Figure 2: Flowchart of crack control design

drying shrinkage and creep coefficient can be also obtained by the equations proposed in ACI 209[6], CEB-FIP 1990[7], and elsewhere[4][8]. To consider the restraint ratio, the values between 60% and 70% for the first floor can be used, and the values between 40% and 50% for the over first floor can be used. These values are based on the FEM analysis[9].

4. EXAMPLE OF CRACK CONTROL DESIGN

Evaluate the crack performance of RC wall designed on the following condition, and execute the crack control design by the reinforcing steel and the control joint.

[Condition]

- * Length of RC wall(L): 6000mm,
- * Thickness of RC wall(t): 180mm
- * Main reinforcement: D10@200: p_t=0.4%
- * Concrete strength(f_c): 24MPa
- * Drying shrinkage(ε_{sh}): 700 μ
- * Creep coefficient(φ): 2.0
- * Restraint ratio(R): 0.5

① Estimation of crack occurrence

$$f_t = 0.291 \times 24^{0.637} \times 0.6 = 1.3 \text{ MPa}$$

$$\sigma_t = 0.5 \times 0.0007 \times 23004 / (1 + 2) = 2.68 \text{ MPa}$$

Here, λ: 0.6, E_c = 21000(f_c / 20)^{0.5}, φ=2.0
σ_t > f_t: Crack occurrence

② Crack control by reinforcing steel

In case of given condition

$$W = 0.0484(24 / 27 + 1)(1 / 0.4^{1.79}) = 0.47 \text{ mm}$$

$$W = 0.47 \text{ mm} > 0.3 \text{ mm} \text{ N.G}$$

Therefore, the reinforcement ratio over 0.4% is necessary for the crack control.

In case of D10@150(p_t=0.53%)

$$W = 0.28 \text{ mm} < 0.3 \text{ mm} \text{ O.K}$$

In case of D13@250(p_t=0.56%)

$$W = 0.34 \text{ mm} > 0.3 \text{ mm} \text{ N.G}$$

In case of D10,13@200(p_t=0.55%)

$$\text{Alternation placing of D10 and D13}$$

$$W = 0.3 \text{ mm} = 0.3 \text{ mm} \text{ O.K}$$

③ Crack control by control joint

The number of cracks is calculated by Eq.(2) from the given condition

$$K_{p_i} = 4.69(0.4) - 0.787 = 1.09$$

$$K_L = 0.957(6/6) - 0.027 = 0.98$$

$$K_{f_c} = -0.557(24/27) - 1.547 = 1.05$$

$$K_{sh} = 0.003(700) - 0.82 = 1.28$$

$$K_{\phi} = -0.36(2.0) + 1.52 = 0.80$$

$$K_R = 3.62(0.5) - 0.82 = 0.99$$

$$K_D = 1.0$$

$$n = 1.09 \times 0.98 \times 1.05 \times 1.28 \times 0.80 \times 0.99 \\ \times 1.0 \times 2.1 = 2.39 \cong 3.0$$

Therefore, the space of control joint becomes 2m. Fig. 3 shows the setting of control joint in RC wall.

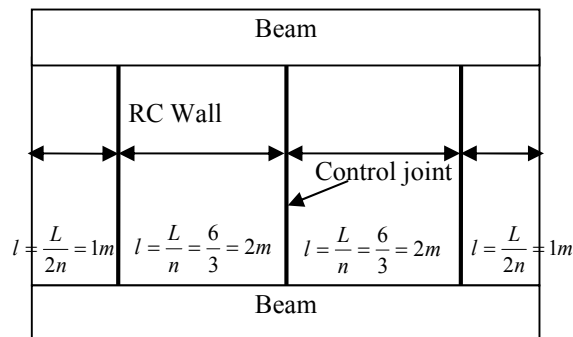


Figure 3: Setting of control joint

5. CONCLUSION

Simple equations (crack width, number of cracks) were proposed for the quantitative shrinkage crack control in the RC wall, and a quantitative crack control became possible by these equations.

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REFERENCES

- [1] Ohno, Y, Seo, T, Nakagawa, T. 2007. Estimation of Drying Shrinkage Cracking in Restrained Reinforced Concrete Member. Journal of AIJ. No 616. pp9~16. Japan.
- [2] Seo, T, Ohno, Y. 2008. Estimation Equation of Cracking due to Drying Shrinkage in Reinforced Concrete Wall. Journal of AIJ. No 626. Japan.
- [3] Seo, T, Nakagawa, T et al. 2007. Experimental Study on Crack Width of RC Wall due to Shrinkage, Proceeding of JCI. Vol 29. No 1. pp663~668. Japan.
- [4] AIJ. 2006. Recommendations for Practice of Crack Control in Reinforced Concrete Structures (Design and Construction).
- [5] Gilbert, R. 1992. Shrinkage cracking in fully restrained concrete members, ACI Structural Journal. Vol 89. No 2. pp141-149. U.S.A
- [6] ACI 209, Prediction of creep, Shrinkage, and Temperature Effects in Concrete Structures, ACI, Detroit, 1982.
- [7] COMITE EURO 1990. CEB-FIP Model Code 90. Thomas Telford.
- [8] AIJ. 2003. Shrinkage Cracking in Reinforced Concrete Structures (Mechanisms and Practice of Crack Control)
- [9] Suzuki, K, Ohno, Y. 1988. Degree of restraint of drying shrinkage in wall of concrete structure (estimated by FEM). Technical Papers of AIJ Kinki chapter. Vol 29. pp5~8. Japan.