The effect of temperature expansion on cracking behavior of slabs

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ABSTRACT: The current design standards refer to the necessity for expansion joint, there are no clear limitations as to the location and spacing of expansion joint. To find the effect of the rebar ratio, structural tests were performed on Samples with adjustments of the rebar ratio. As the rebar ratio increases, the average crack width decreases. The number of crack increase but the concrete crack width decrease. Also, comparing results of experiment with those of analysis, it is necessary to apply the concrete tensile strength, which reflects the contribution of the reinforcement ratio.

Keywords: Cracking, Concrete slab, Expansion, Rebar ratio, Temperature loading.

1 INTRODUCTION

Recently, as the space of architectural structures are getting longer and larger, expansion joint is increasingly applied to large-scale structures such as shopping malls and logistics centers. Expansion joint is a functional joint that is designed to absorb the deformation of a structure caused by temperature change, drying shrinkage, settlement, vibration, and so on (Klein et al., 2009). However, expansion joint complicates the process and delays the construction period. After the completion of construction, there is a problem of leakage of water and cracks of the structure due to expansion joint and it causes maintenance costs. So the use of expansion joint is minimized in the field (Iqbal, 2010; Saiyed et al., 2010; Shirke, 2010).

Although the current design standards refer to the necessity for expansion joint, there are no clear limitations as to the location and spacing of expansion joint. It is being designed depending on the intuition and experience of the engineer. There are many differences, but it is known that 150 ~ 200 ft (46 ~ 61 m) is appropriate in past cases. If the spacing of expansion joint is 200 ~ 300 ft (61 ~ 91 m), the deformation is 1 in (25.4 mm) or less (Fintel, 1985).National Academy of Sciences (NAS) is based on research and analysis studies and the allowable building length is 400 ~ 600 ft(120 ~ 180 m).

Structural tests are conducted on the set variables to examine the distribution of deformation, stress and cracks according to the temperature load effect. And the analytical modeling is verified through comparison with experimental results.

2 EXPERIMENTAL DETAILS

2.1 Variable Setting

The range is limited by the deformation of the structure due to the temperature change. Focusing on long-term temperature cracks, there is cracks caused by volume changes due to temperature changes and dry shrinkage, creep. Generally, it occurs within a year after construction or in a direction perpendicular to the long axis.

If the stress in the member is greater than the tensile strength of the concrete, it will cause concrete cracking. Structural problems may occur if the crack width in the member is larger than the allowable crack width (0.41 mm in ACI 318). In this experiment, the deformation due to the temperature load is replaced with the change of the actual member length. The tensile force is directly applied to the slab.

$$\varepsilon_T = \alpha\Delta T = \Delta L/L \qquad (1)$$

In $\alpha\Delta T$ is the strain due to temperature load. $\Delta L/L$ is the strain due to the actual member length.

2.2 Main parameters

The effect of the rebar ratio among various parameters of the concrete slab members was examined. The size of Samples is 1000 mm × 3000 mm × 150 mm (the short length × long length × thickness), the concrete compressive strength $f_c' = 24$ MPa, the steel tensile strength $f_y = 400$ MPa, both of the end of Samples are reinforced.

The concrete compressive strength at 28 days is about 20MPa and the modulus of elasticity is about 14.3 ~ 16GPa. The concrete splitting tensile strength

at 28 days is about 2 MPa, which is about 10% of the concrete compressive strength.

All Samples satisfied minimum rebar ratio ρ_{min} = 0.2% or more. It considers internal restraint according to the rebar ratio, crack delay and dispersion effect. Rebar yield strength is 482 MPa for SD400 D10, 507 MPa for SD400 D13 and the modulus of elasticity is 173 GPa, 185 GPa.

Table 1. Experimental parameters

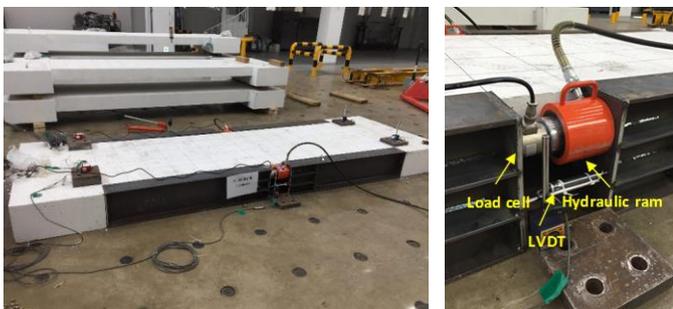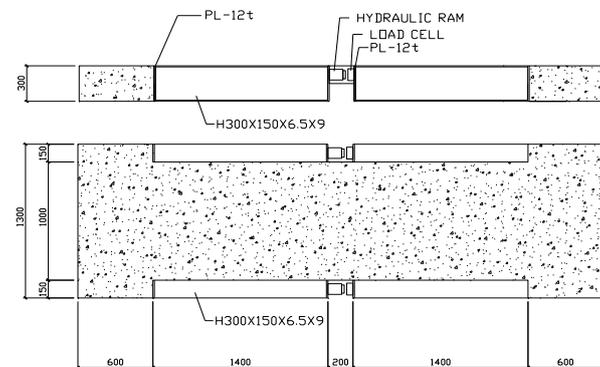| Sample	Parameter	Detail
1	reference Sample	D10@200 mm (ρ = 0.475%)
2	downer rebar ratio	D10@450 mm (ρ = 0.285%)
3	upper rebar ratio	D13@200 mm (ρ = 0.845%)
4	mixed rebar ratio	D10@200 mm(ρ = 0.475% in left) D13@200 mm(ρ = 0.845% in right)

Figure 1: Sample Details

3 EXPERIMENTAL RESULT

3.1 Sample 1 (Reference Sample)

Sample 1 is rebar ratio (D10@200, ρ = 0.475%) which is the reference Sample. Slab deformation occurred at slab stress of 3 MPa, which is 1.5 times greater than concrete splitting tensile strength (about 2 MPa). Bars at the center, end, and corner part were not yielded because the strain was less than the rebar yield strain (ε_y=0.0028), but the stresses at the ends and corners were measured to be larger than those at the center.

As the slab average strain increases, the number of crack increases. The measured crack width was less than the allowable crack width (0.41 mm, ACI 318). Considering that the final stress (4.61 MPa) is equivalent to ΔT = -30 °C, it is suggested that the member itself is not structural problem even when the reference Sample is in an extremely low temperature environment.

Initial cracks occurred at the end of the concrete at a stress (1.89 MPa) similar to concrete splitting tensile strength. As the load increases at final load, cracks are dispersed at the same position as the transverse reinforcement.

3.2 Sample 2

Sample 2 is rebar ratio (D10@450, ρ = 0.285%) which is downer rebar ratio than the reference Sample. Slab deformation occurred at a slab stress of about 1.5 ~ 1.6 MPa, and the maximum tensile strain ($\varepsilon_t{'}$=0.0002) of the concrete reached the splitting tensile strength.

When the slab stress is more than 3.21 MPa (corresponding to ΔT = -20 °C), the measured crack width was larger than the allowable crack width and the crack width increased sharply to 1.6 mm. This is 4 times the allowable crack width, which can lead to structural defects of members if the temperature change is dramatically large.

Initial cracks occurred at the end of the concrete at a stress (1.97 MPa) similar to concrete splitting tensile strength. Cracks were not dispersed in the longitudinal direction but concentrated on the initial cracks, which led to an increase in the crack width.

3.3 Sample 3

Sample 3 is rebar ratio (D13@200, ρ = 0.845%) which is upper rebar ratio than the reference Sample. Slab deformation occurred at 4 MPa, which is twice the concrete splitting tensile strength.

Considering that the final stress (6.84 MPa) is equivalent to ΔT = -43 ° C, the measured crack width was less than 0.2 mm and it was much less than the allowable crack width.

Initial cracks occurred at a stress more than twice as high as the splitting tensile strength of concrete, which is considered to be attributed to crack control. Cracks are distributed at the same position as the transverse reinforcement at final load.

3.4 Sample 4

Sample 3 is rebar ratio (D10@200, ρ = 0.475% in left

and D13@200, ρ = 0.845% in right) which is mixed rebar ratio than the reference Sample. Cracks were concentrated on the left side of the slab with relatively small stiffness up to 4.03 MPa (ΔT= -25 °C).

In case of the steel ratio of the slabs is overlapped, when the temperature is changed to the extreme low temperature environment or more, the cracks of the members having low stiffness exceed the allowable crack width and structural problems may occur.

3.5 Result of Samples

As the rebar ratio increased (ρ = 0.285% → ρ = 0.475% → ρ = 0.845%), the concrete slab stress increased until it reached the concrete maximum tensile strain. The rebar is contributes to the increase the tensile strength of the slabs, as well as the concrete.

In case Sample 2 (D10 @ 450) comparing with Sample 1 (D10 @ 200), the number of cracks decreased at the same stress in the slab. But, in case Sample 3 (D13 @ 200) comparing with Sample 1
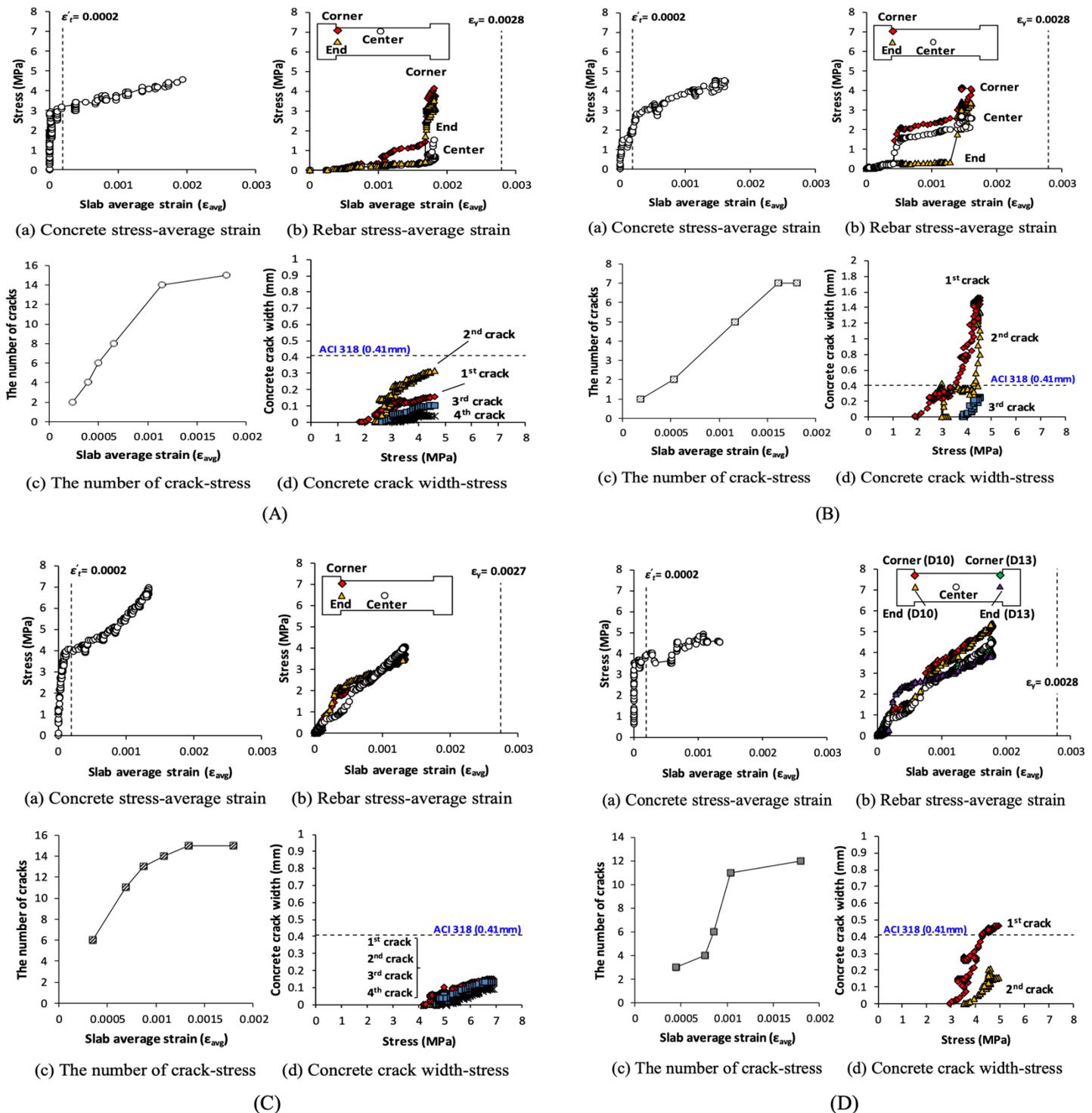

Figure 2: The experiment result, (A) Sample 1, (B) Sample 2, (C) Sample 3, (D) Sample 4

(D10 @ 200), the number of cracks increased similarly to the number of transverse reinforcement in the slab.

The average crack width is calculated as follows.

The average crack width = the slab average strain × the slab length / the number of crack

The allowable crack width is 0.41 mm under working load conditions in ACI 318. If the temperature load ($E\alpha\Delta T$) is replaced by the tensile force, the slab cracking behavior at the stress can be predicted. As the rebar ratio increases, the average crack width decreases. So it is very effective way to control the crack width. For the reference Sample, when the slab stress occur at least 4 MPa ($\Delta T = -25$ °C), it may cause structural problems beyond the allowable crack width.

4   ANALYSIS RESULT

4.1 Sample 1 (Reference Sample)

At $\Delta T = -10 \sim -12$ °C, the net principal tensile strain of the edge of the reference Sample increased sharply beyond the maximum tensile strain of concrete ($\varepsilon_t = 0.0002$), which is considered to be attributed to the tensile stress after the concrete cracking by the rebar. At $\Delta T = -13$ °C, the concrete crack width at the corner exceeded the allowable crack width.

4.2 Sample 2

At $\Delta T = -15$ °C, the net principal tensile strain was higher than 3 times the corner of reference Sample and 1.8 times the end of it. $\Delta T = -11 \sim -12$ °C, the concrete crack width at the corner and end exceeded the allowable crack width.

4.3 Sample 3

At $\Delta T = -15$ °C, the net principal tensile strain was less than 0.5 times the corner of reference Sample and 0.7 times the end of it. All sections of the slab did not exceed the allowable crack width until the temperature change (ΔT) reached –15 °C. It is very effective to increase the rebar ratio of the slab for the crack control according to the change to the extremely low temperature environment.

4.4 Sample 4

When the temperature changes ($\Delta T = -15$ °C), the net principal tensile strain is concentrated too much on the left side of the slab having low stiffness. The corner crack of the left side of the slab exceeds the allowable crack width, which occurred smaller than the temperature change comparing the reference Sample. Crack behavior may change due to stiffness differences of adjacent or connected members.

4.5 Result of Samples

As a result of the analysis, the peak stress occurred the splitting tensile strength of concrete. Comparing with the analysis results, the maximum slab tensile stress in experimental results was 1.5 times that of the Sample 1 (reference Sample), 1 times that of the Sample 2 (the downer rebar ratio Sample), and 2 times that of the Sample 3 (the upper rebar ratio Sample). It is necessary to apply the concrete tensile strength, which reflects the contribution of the reinforcement ratio. The minimum rebar ratio has no contribution to the concrete tensile strength. If it is more than that, the safety factor can be applied by substituting the coefficient.

The fracture aspect of the analysis results was confirmed to be similar to the actual slab cracking pattern in experiments. Cracks appeared mainly at the end and corner. In the Sample 4 (the mixed rebar ratio Sample), cracks concentrated on the left side of the slab with relatively low stiffness and it is same results in the analysis and experiment.
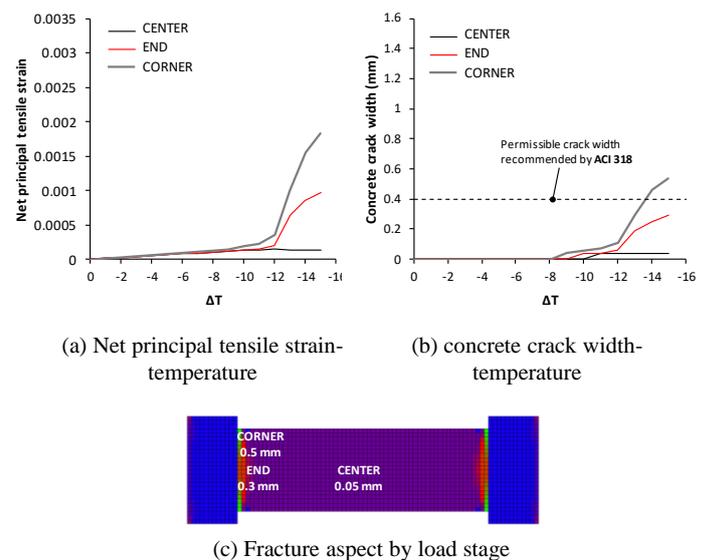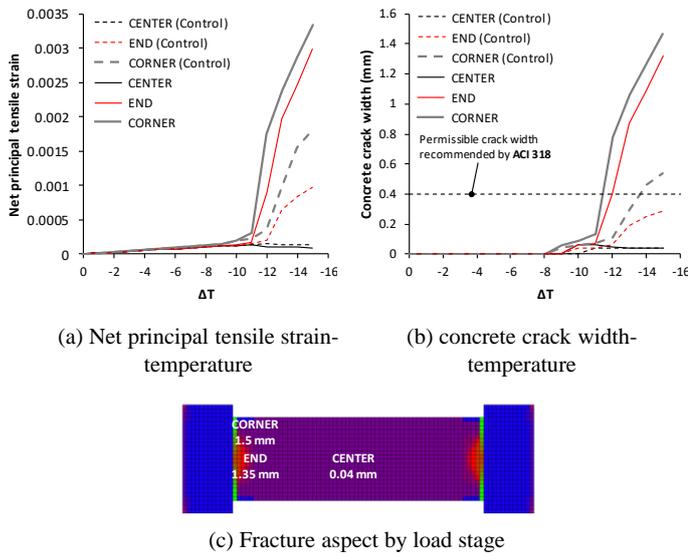

(a) Net principal tensile strain-temperature

(b) concrete crack width-temperature

(c) Fracture aspect by load stage

Figure 3: The analysis result (Sample 1)

(a) Net principal tensile strain-
temperature

(b) concrete crack width-
temperature

(c) Fracture aspect by load stage

Figure 4: The analysis result (Sample 2)

(a) Net principal tensile strain-
temperature

(b) concrete crack width-
temperature

(c) Fracture aspect by load stage

Figure 5: The analysis result (Sample 3)

(a) Net principal tensile strain-
temperature

(b) concrete crack width-
temperature

(c) Fracture aspect by load stage
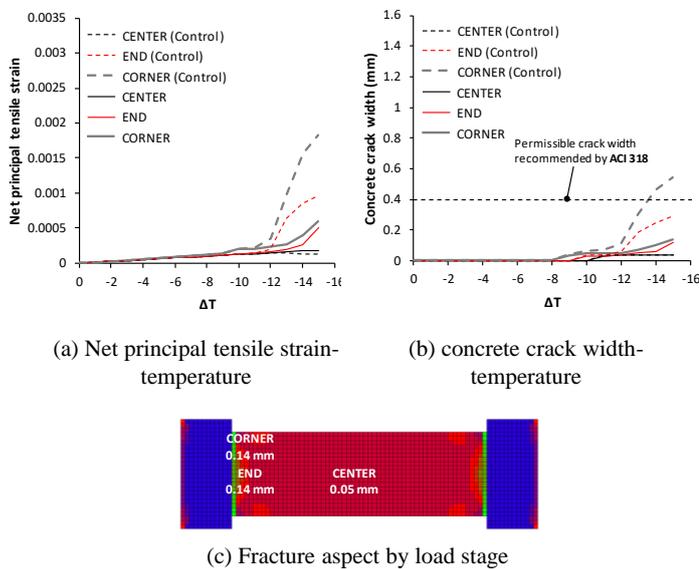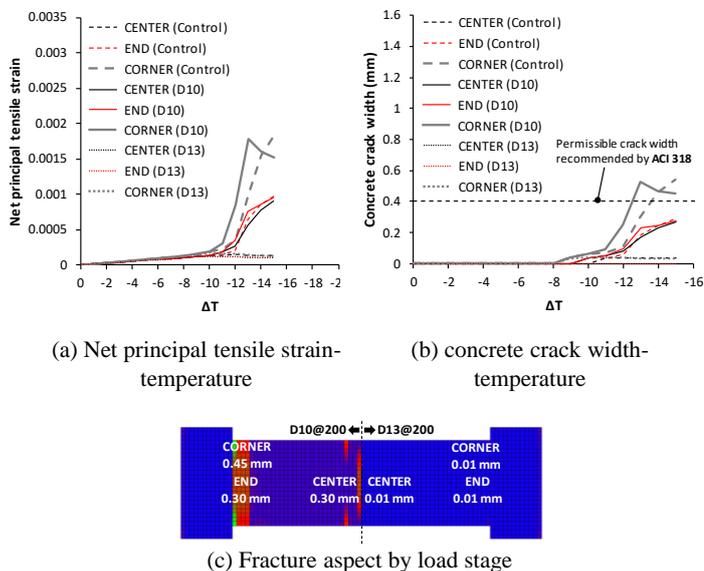
Figure 6: The analysis result (Sample 4)

5 CONCLUSIONS

The temperature analysis considering the use conditions is less conservative than the existing recommendation criteria, but the possibility of slab cracking is somewhat higher than the structure.

Although the temperature analysis showed more conservative results due to the use period of the structure, the thermal delay effect and the crack resistance depending on the details, it is more reasonable and practical than the unconditional expansion joint application according to the structure length from the design point of view.

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