[2118] 負の曲げモーメントを受ける鉄筋コンクリート隅角部の終局強度に関する一研究

A STUDY OF ULTIMATE STRENGTH OF REINFORCED CONCRETE CORNER CONNECTION JOINTS SUBJECTED TO NEGATIVE MOMENT

Virach RUNGROJSARATIS* and Tamon UEDA**

1. INTRODUCTION

In the design practice for reinforced concrete corner connection joints, it is desirable to avoid failure in the corner connection joints. Although there is the consensus for the corner connection joint subjected to negative moment (moment tends to close the corner) that all common reasonable reinforcing details give an acceptable performance (2), care for detailing such as bend radius of reinforcement should not be overlooked when high percentage of reinforcement is considered. Kemp et al's experiment (1) also showed that the premature splitting failure in the corner connection joint might occur as percentage of reiforcement was increased. To avoid splitting failure , Kemp had proposed equation for limiting steel content.

From Balint et al's tests (3), it was found that other than to limit the flexural steel content, to provide a sufficient size of bend radius of reinforcement in corner connection joint can prevent splitting failure of the corner. Current code provisions of either ACI (5) or JSCE (6) specify the limited bend radius of reinforcement in the function of bar diameter for preventing detrimental crushing of concrete inside the bend. The provisions seem to be inconsistent. For instance, it is easily understood when an extereme case of high strength of reinforcement is used. These provisions may not be able to deter premature failure of the corner. A study of reinforced concrete corner subjected to negative moment was done to provide a better understanding for prescribing an appropriate bend radius of reinforcement in the corner.

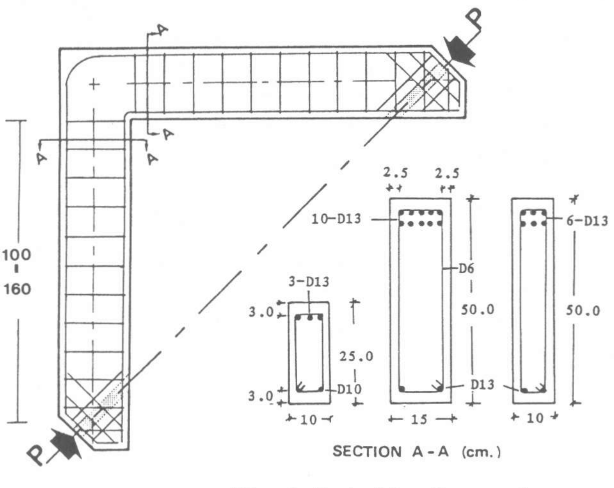

Fig.1 Detail of specimen

---

* Graduate student, Dept. of Civil Eng., Univ. of Tokyo.

** Asso. Prof., Dept. of Civil Eng., Univ. of Tokyo.

TABLE 1. DETAILS OF SPECIMEN

SPECIMEN	CROSS-SECTION cm.x cm.	BEND RADIUS cm.	ρ %	f'_c kg/cm²
RB1	10 x 25	6.5(5D)	1.727	267
RB2	10 x 25	9.0(7D)	1.727	412
RB3	10 x 25	13.0(10D)	1.727	260
RB4	15 x 50	13.0(10D)	1.860	385
RB5	10 x 50	13.0(10D)	1.727	241

NOTE: Using deformbed bar D13 (F_y =4415 kg/cm²,E_s =1.765X10^6 kg/cm²)
D = bar diameter
ρ = percentage of main reinforcement

2. OUTLINE OF TEST

5 specimens of L-shaped reinforced concrete structure, shown in Fig. 1, were conducted. The main parameters considered in this study were bend radius size of reinforcement, corner size and concrete strength. All specimens casted with mortar were kept a constant percentage of reinforcement. A simple and conventional corner reinforcing pattern, shown in Fig. 2, was arranged without an auxiliary reinforcement in the corner connection joint. The details of all specimens were given in Table 1. Negative moment was applied to the joint core by employing hydraulic jack and prestressing bar through the end of the adjoining members. According to the manner of loading, the state of stress acting on the joint core was symmetry. A combined axial, bending, and shear forces created the most critical situation for the corner connection joint. Behavior of joint core was studied by measuring reinforcement strain at the face of corner, at the begining of the bend and also diagonal compressive strain within the corner, given in Fig. 2.

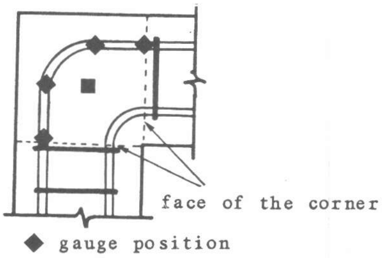

Fig.2 Reinforcing pattern and measurement location

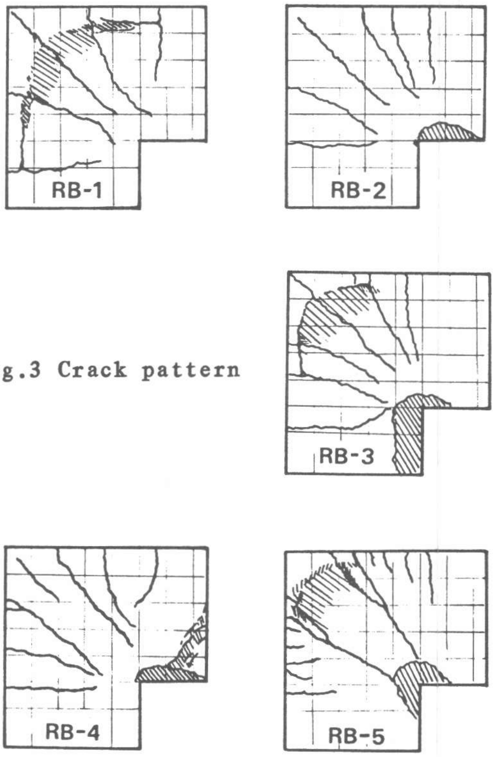

Fig.3 Crack pattern

3. TEST RESULTS

3.1 Crack Pattern : Figure 3. shows that the similar feature of crack pattern is observed in all tested specimens. Typical cracks in joint core are two flexure cracks at the face of corner, two inclined flexure cracks and probably one more of diagonal crack. The development of cracks were firstly generated at the face of corner and followed by inclined flexure cracks and diagonal crack respectively as load was increased. It is noted that the location from which inclined flexure crack generated along the outer face of corner depends on size of the corner connection. Approximately, this location from the face of the corner was 2/5 of corner connection size for small size of specimens (RB1, RB2, RB3) and 3/5 of corner connection size for large size specimens (RB4, RB5).

3.2 Diagonal Compressive Stress :

Based on the crack pattern observed in Fig. 3, the behavior of corner connection joint can be assumed to act as truss mechanism in which tension forces induced by reinforcement can balance compression force acting inside bent reinforcement by diagonal concrete strut. The simple idealization of joint behavior is shown in Fig. 4. Considering symmetric stress field in joint core which means

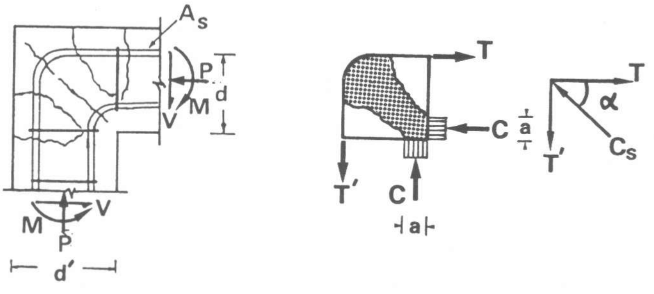

Fig.4 Idealized truss mechanism

$$T = T' , A_s = A_s', \qquad (1.a)$$

$$\alpha = \tan^{-1}(d/d') = \pi/4 \qquad (1.b)$$

and equilibrium of forces,the relation between diagonal compressive stress and reinforcement stress can be derived as follows.

$$\sigma_c = \sqrt{2}\ \rho(d/W)\ \sigma_s \qquad (2)$$

where W = efffective strut width,
σ_c = diagonal compressive stress,
σ_s = reinforcement stress,
ρ = reinforcement ratio (As/bd),
d = effective depth,
b = corner thickness.

From experimental result shown in Fig.5 ,it was found that concrete strut stresses computed from the model developed by Maekawa (4) and reinforcement stresses have the same linear relation except some data disturbed by existing of the diagonal crack. Based on Eq.2, the ratios d/W for all tested specimens become the same constant value. This implies that effective strut width depends linearly on size of corner connection when the results of specimen RB3 and RB5 are compared. The other results also show that the effect of bend radius on effective strut width seems to be small and can be neglected. By assuming d/W of 2.4 and substituting into Eq.2, the calculated diagonal compressive stresses for which tension stiffening (7) was included in the analysis of steel stress from given external load predicted well experimental results before yielding of reinforcement as shown in Fig. 6. Strut stress observed from Fig. 5 still increases after yielding of reinforcement. The reason of increasing strut stress may due to strain hardening behavior in reinforcement and reduction of effective strut width affected by decreasing of compressive depth (a), Fig. 4, at the inner of the corner.

3.3 Reinforcement Strain : The measured strain of reinforcement at the beginning of bend (ε_2) and at the face of corner (ε_1) are plotted in Fig.7. It was found that after inclined flexure crack, strain at the beginning of bend become larger than at the face of corner. The difference between these two strains became the more obvious as the larger moment was applied. The same characteristic was observed in all specimens. This might be due to the deformation of bar, like behavior of dowel action, at the existence of inclined flexure cracks and shifting of gauge position from the center of bar. Some features supported this reason were that effect of yielding strain at the beginning of bend (ε_2) did not affect ultimate flexural strength and load-relative deflection behavior of the corner connection joint, as shown in Fig. 8a. The ultimate flexural strength and load-deflection behavior are still governed by yielding of strain at the face of corner (ε_1).

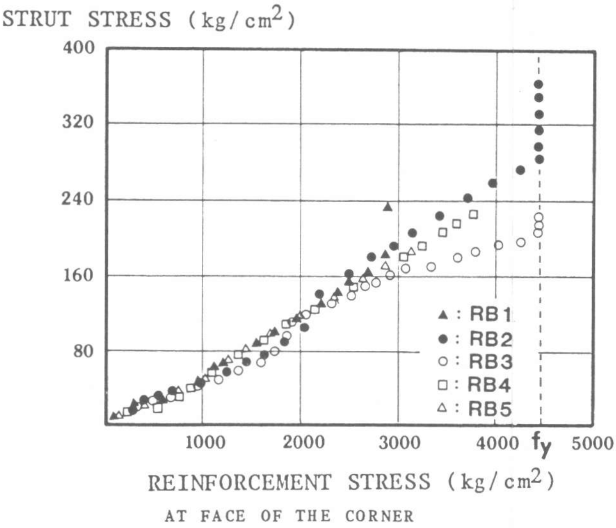

Fig.5 Relationship between reinforcement stress and strut stress

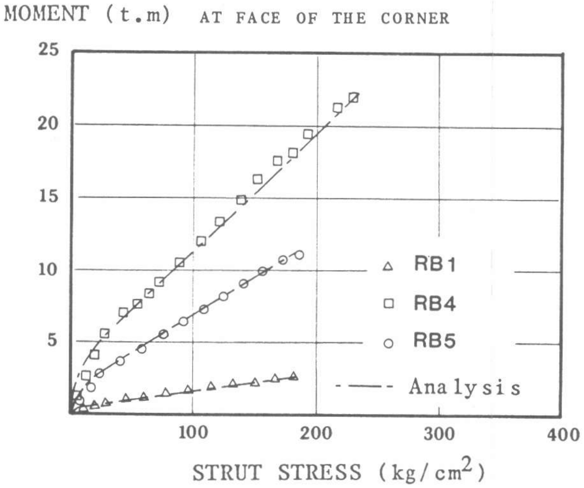

Fig.6 Comparison between analytical values and measuring results of strut stress

3.4 Failure Mode : Two distinguished failure modes, flexure failure and bearing stress failure, were observed in four specimens (RB1, RB2, RB3, RB5). Flexure failure which was caused by yielding of tensile steel and crushing of concrete at the face of corner is a failure type required for corner design. This type of failure found in specimens RB2 was ductile failure as shown in Fig. 8a. Bearing stress failure, sudden destructive failure shown in Fig. 8b, was caused by crushing of concrete around the bend of tensile steel and accompanied by spalling of concrete out of plane of the corner frame. Specimens RB1, RB3 and RB5 failed due to this bearing stress failure. However, specimen RB3 failed after yielding of

TABLE 2. TEST RESULTS OF ULTIMATE LOAD

SPECIMEN	Pu/test(kgs)	Pu/cal(kgs)	σ_c/f'_c	FAILURE MODE
RB1	3500	4713	0.681	BEARING
RB2	5427	5367	0.869	FLEXURE
RB3	4887	4907	0.869	BEARING
RB4	23000	25140	0.594	SHEAR
RB5	9200	12228	0.770	BEARING

NOTE: Pu/cal : Flexural ultimate load
σ_c : Diagonal compressive stress

reinforcement at the face of corner. It is noted that bearing stress failure also may occur in compression steel side. There was the sign of this failure in specimen RB5.

3.5 Ultimate Strength:The results of ultimate strength of tested specimen were given in Table 2. The observed of ultimate strength of specimens RB2 agreed well with principal requirement for design of corner. However, specimens RB1,RB3,RB5 did not. The strength of RB1,RB5 specimens were lower than the calculated strength (Pu/cal) of adjoining member. Although strength of specimen RB3 is equal to strength of adjoining member, however, the failure is rather brittle fashion as shown in Fig.8a, which is not required in design.

The results of specimen RB5 proved that code provisions of either ACI (5) or JSCE (6) which provide the limiting of bend radius size of reinforcement as 6D and 10D (D:bar diameter) respectively appear to be inadequate to preventing bearing stress failure mode

From the results of specimens RB1, RB3 and RB5 in Table 2., a localized bearing stress failure is not governed by strut stress (σc/fc) and it can be predicted that corner performance can be improved by increasing the relative bended size of reinforcement to corner connection size or concrete strength.

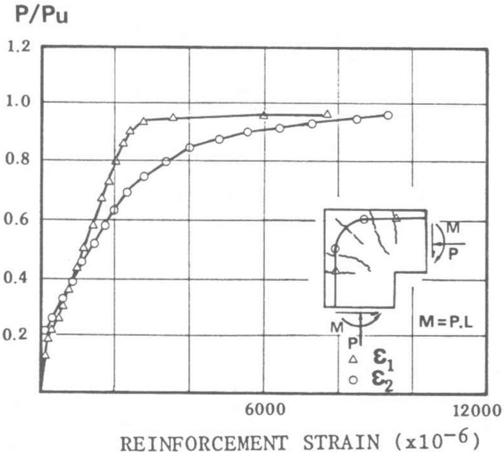

Fig.7 Comparison of reinforcement strain at the face of corner and at the begining of bend

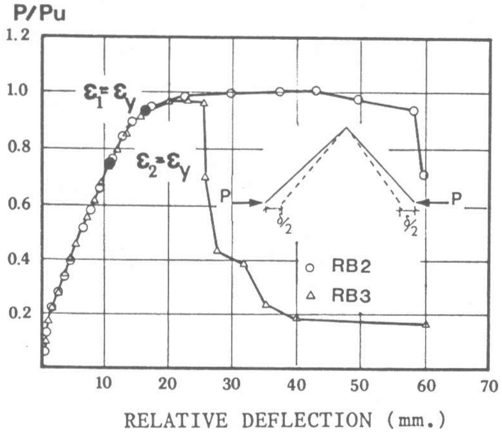

Fig.8a Load - relative deflection curve

4. CONCLUSIONS

Based on the test results, the conclusion related to behavior and strength of corner connection joint under negative moment can be summarized as follows

1. Truss mechanism formed in the corner connection joint and effective concrete strut width depended on corner connection size and depth of compression zone at the inner corner
2. Both ACI and JSCE code provisions for bend radius of reinforcement in the corner connection joint are not conservative
3. Increase in the ratio of bend radius of reinforcement to corner connection size and concrete strength can increase ultimate strength of corner connection joint caused by bearing stress failure mode.

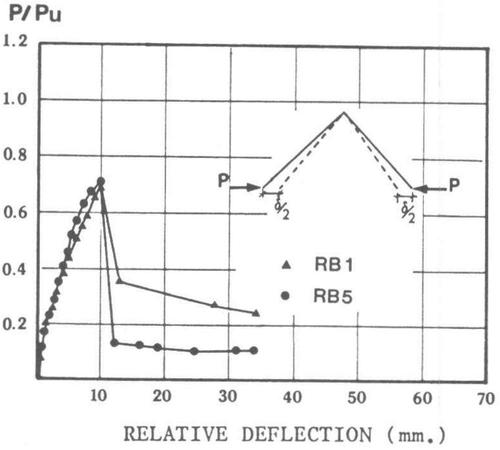

Fig.8b Load - relative deflection curve

REFERENCES

(1) Kemp,E.L. and Mukherjee,P.R.,"Inelastic Behavior of Concrete Knee Joints," The Consulting Engineer, Oct 1968, pp 44-48

(2) Mayfield, B., Kong, F.K., Bennison, A. and Davies, J.C.D.T.,"Effect of Detailing on the Behavior of Light-weight Concrete Corners," J. ACI, Vol 68, No. 5, May 1971, pp 361-372

(3) Balint, P.S. and Talor, H.P.J.,"Reinforcement Detailing of Frame Corner Joints with Particular Reference to Opening Corner," Technical Report, TRA 462, Cement and Concrete Association,Wexham Springs, Feb 1972,16 pp

(4) Maekawa,K. and Okamura,H.,"The Deformational Behavior and Constitutive Equation of Concrete Using the Elasto-Plastic and Fracture Model," J. of Faculty Eng.,Univ of Tokyo(B), Vol XXXVII, No. 2,1983

(5) "Building Code Requirements for Reinforced Concrete ACI 318-77," ACI Manual of Concrete Practice, 1983, pp 20

(6) "Recommendation for Limit State Design of Concrete Structures," Concrete Library International, No. 4, 1984

(7) Sivasubramaniyam, S.,"A New Model for Finite Element Analysis of Reinforced Concrete," Doctoral Dissertation submitted to Univ. of Tokyo, Dept. of Civil Eng.,1985