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Crack Growth In Concrete by Anchor Bolt

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1. INTRODUCTION

Anchor bolts embedded in a large concrete block subjected to tension loading will fail by pulling a cone out of the concrete providing the steel strength of the bolt is high enough. Several attempts have been made to understand the behavior of a circumferential crack forming this cone and crack growth of this failure mode.

Stone & Carino [1] have conducted the pullout test on enlarged scale (scale 12:1) of an anchor bolt with the micro strain gages being placed in the concrete. Eligehausen & Sawade [2] have carried out the pullout test an anchor bolt with a special strain gages were embedded in concrete and sound emission analysis method. The different results of both of these test on the load-crack growth behavior of concrete cone failure are indicated.

On the other hand the numerical analysis of Finite Element Method (FEM) were performed by Eligehausen et.al [2] and Maruyama K. et.al [4] indicated that for a relative crack length a/l $\fallingdotseq$ 0.43 $\sim$ 0.45 the maximum load is reached.

In order to observe the crack growth of failured cone of concrete of an anchor bolt in visual condition, the ink-ethanol liquid injection method has been used. The ink-ethanol liquid is used to observe and measure the crack growth of concrete cone failure of an anchor bolt at a certain load level. This method also is being developed on crack growth of concrete cone failure in fatigue loading of an anchor bolt.

2. EXPERIMENT

The properties of bolt and concrete block is summarized in Table-1. In this study the bolt was placed before pouring concrete and frictional resistance between concrete and bolt was eliminated by wrapping vinyl tape on bolt shank.

Figure-1 shows the schematic representation of test. Four pieces of 2 mm diameter of small plastic hose in four directions were attached at the head of bolt in order to get the ink-ethanol liquid through crack area. At a certain load level a different color of ink-ethanol liquid was injected to concrete by ink injection tool through a small plastic hose. After failure occurred the length of every color of ink-ethanol liquid area from the edge of the disk of bolt (crack was assumed initiates from the edge of the disk of bolt) and inclination angle (θ) were observed and measured.

Table-1. The properties of Bolt and Concrete block

The properties of Bolt		The properties of Concrete block	
1.Bolt Type	SCM 435 JIS B 1176	1. Dimension of Block	400 cm x 400 cm x 25 cm
2.Max.Tensile Strength	6300 kgf/cm^2	2. Nominal Compr.Strength	300 kgf/cm^2
3.Dia. of Bolt (Area)	20 mm (314.16 mm^2)	3. Actual Compr.Strength (ave.)	321 kgf/cm^2
4. Embedment length	5.5 cm	4. Split Tensile Strength (ave.)	25.6 kgf/cm^2

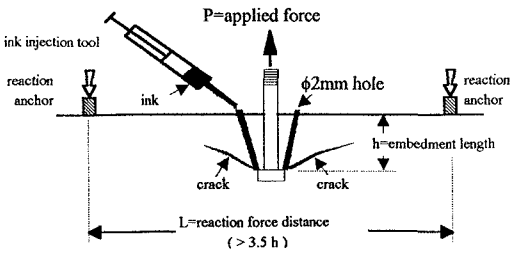

Fig.-1 Schematic representation of static pullout test

3. TEST RESULTS AND DISCUSSIONS

All data test are summarized in Table-2. Figure-2 shows a typical shapes of failured cone of concrete. The inclination angle between the failured cone and the surface of concrete ranged from 20 to 40 degree and the meanvalue is 24 degree. This seems to coincide the results by Maruyama K.et.al [3] which showed

the inclination angle of cone failure ranged from 20 to 40 degree and the mean value was 27 degree by undercut anchor bolts and a little difference is recognized the results by Eligehausen [2] which reported the mean value of inclination angle was 37.5 degree.

Table-2. Static Pull-out Test Results

Specimens no.	ST - 01	ST - 02	ST - 03
1. Maximum load (Pmax)	4.08 tf	4.15 tf	4.514 tf
2. Max. Displ. (δmax)	2.175 mm	1.3875 mm	1.990 mm
3. Mode of failure	cone failure	cone failure	cone failure
4. Inclination angle (θ)	19°21'20"25° 23°23'21"23°	23°29'19"20° 22°29'20"27°	20°18'21"44° 25°24'17"38°
5. Crack length at :			
a. 2.0 tf load's	not measured	no crack	no crack
b. 3.0 tf load's	not measured	2.5 cm	no crack
c. 3.5 tf load's	not measured	4.8 cm	2.0 cm
d. 4.0 tf load's	8.0 cm	7.9 cm	4.2 cm
e. 4.5 tf load's	- - - -	- - - -	7.8 cm

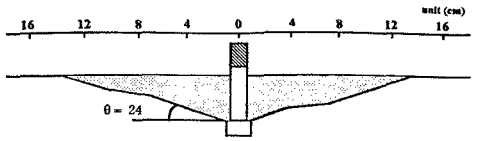

Fig.-2 A typical shapes of concrete cone failure

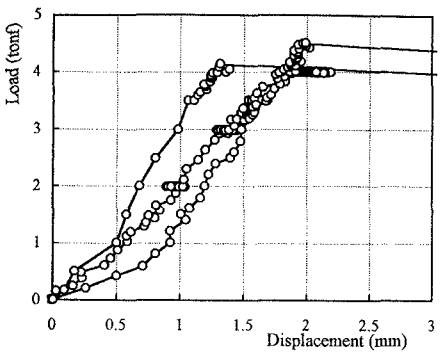

Fig.-3 Load-Displacement curve

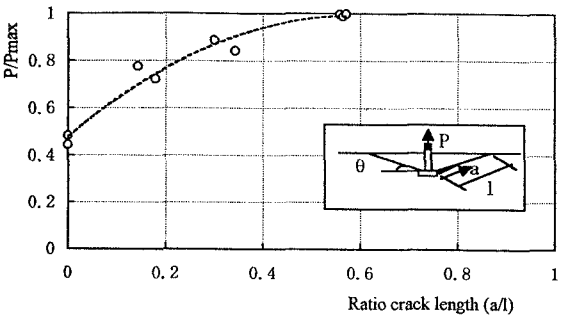

Fig.-4 Ratio crack length (a/l) as function of load

The load-displacement curves are shown in figure-3. Figure -4 shows the ratio of cracked surface to the total surface of the failured cone as a function of the load. From fig.-3 and fig.-4 the failure process was concluded as the following steps: (1) The circumferential crack near the edge of the disk of bolt initiates at the end of elastic response of concrete (in this case at about 50% of the maximum load); (2) The circumferential crack continues to grow in a stable manner with increase of load; (3) Near the maximum load the circumferential crack reached about 0.56 of the total failure cone length. This result was a little larger than the result by Maruyama K.et.al [4] which showed the ratio (a/l) of 0.43 by Linear Finite Element Method (LFEM) and the result by Eligehausen [2] of 0.45 by Non Linear Finite Element Method (NLFEM); (4) Shortly after passing the maximum load unstable crack grows fast and the concrete cone failure fully developed.

4. CONCLUSIONS

From this study the followings can be concluded

- The ink-ethanol injection method was developed to observe the load crack growth behavior of an anchor bolt. This method proved to trace the crack growth in concrete.

5. REFERENCES

[1] Stone.W.C and Carino.N.J,"Deformation and Failure in Large-Scale Pullout Tests", ACI Journal, Nov.-Dec., 1983,pp.501-513.

[2] Eligehausen R. and Sawade G."A fracture mechanics based description of the pull-out behavior of headed studs embedded in concrete".,Fracture Mechanics of Concrete Structures (From theory to applications) edited by L.Elfgren, Chapman and Hall Ltd, London , 1989,p.407.

[3] Maruyama K.et.al .,"Load-Bearing Mechanism of Undercut Type Fixings." Transactions of the JCI, Vol.12, 1990, pp.499-506.

[4] Maruyama K., Moriyama T., Shimizu K.,"Load-Bearing Mechanism of Post Anchor Bolt in Tension." Transactions of the JCI, Vol.13, 1991,pp.611-618.