論文報告集, Vol.18, No.2, 1996

論文 A Testing Method of Crack Growth in Concrete by Pull-out Test of Anchor Bolt

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ABSTRACT : Anchor bolts embedded in concrete structures subjected to tension loading will fail by pulling a cone out of the concrete providing the steel strength of the bolt is high enough. To observe the behavior of a circumferential crack forming this cone in visual condition the ink-ethanol injection testing method was introduced. In this method, by injection of ink-ethanol through narrow holes into a concrete specimen at a certain load level the internal circumferential crack forming the concrete cone failure is dyed.

KEYWORDS : concrete cone failure, ink-ethanol injection, circumferential crack.

1. INTRODUCTION

It is well known that one of the typical failure mode of anchor bolts embedded in concrete structures is concrete cone failure. This failure mode occurs providing the steel strength of the bolt is high enough. Various testing methods have been carried out to understand the behavior of a circumferential crack with this failure mode. Testing methods such as placement of strain gauges in concrete[1,2], acoustic emission analysis[2,3,4] have been done so far. However, different results are indicated and the crack growth mechanism of this failure mode is not well understood yet.

In order to observe the behavior of crack growth with this failure mode in visual condition,a testing method of the ink-ethanol injection was introduced. In this method, by injection of ink-ethanol liquid into a concrete specimen, the internal circumferential crack forming this concrete cone failure was dyed. This crack pattern was observed after the specimen failured.

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2. EXPERIMENT

2.1 SPECIMENS

The type of an anchor bolt is headed anchor which was placed in formwork before pouring concrete. The friction resistance between a bolt and the concrete was eliminated by wrapping vinyl tape on bolt shank. The shape of bolt is shown in figure-1 and in this experiment two types of diameter of bolt namely, 16 mm and 20 mm were used with the embedment lengths of 30 mm and 45 mm, respectively. The strength of bolt was chosen more than five times of the strength of concrete so that the concrete cone failure must occur. All properties of a bolt and the concrete block were summarized in Table-1.

Tabel-1 The properties of Bolt and Concrete Block

The properties of Bolt		The properties of Concrete Block	
1.Bolt Type	JIS B 118-1974	1.Dimension of Block	400x400x250mm
2.Max. Tensile Strength	1059 MPa	2.Nominal Compressive Strength	29.4 MPa
3.Diameter of Bolt	16mm & 20mm	3.Actual Compressive Strength (ave.)	36.5 MPa
4.Embedment length	30mm & 45mm	4.Splitting Tensile Strength (ave.)	2.6 MPa

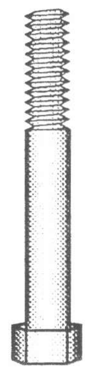

Fig.-1 Shape of Bolt

Figure-2 shows the concrete block specimen which has dimension of 400 x 400 x 250 mm. The concrete block used a high early strength cement with maximum of aggregate size and design slump value were 25 mm and 100 mm, respectively. The nominal compressive strength was 29.4 MPa. The compressive and tensile strength of concrete were obtained using cylinder specimens with dimension of ϕ100mm x 200mm.

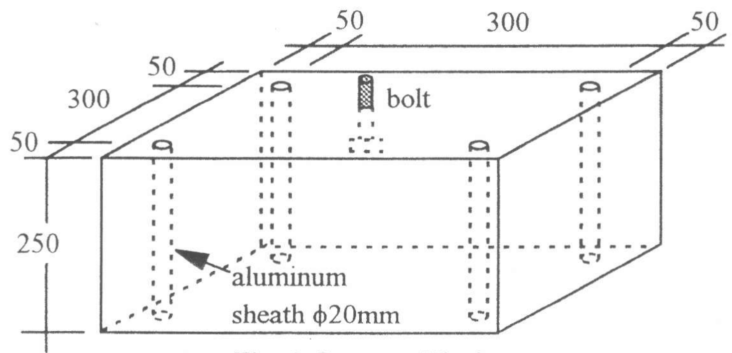

Fig.-2 Concrete Block

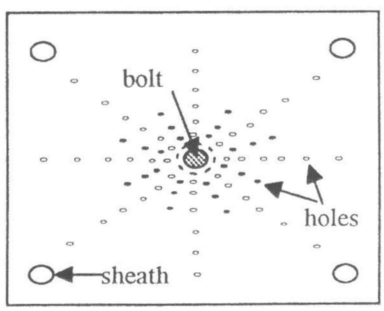

Fig.-3 Location of holes around of bolt

The locations of narrow holes around the bolt were shown in figure-3 which were made by placing a number of piano wires before casting the concrete. The diameter of holes was 1.2 mm and the length was about the same as the embedment length of a bolt. In this test two types of hole number were used namely 48 holes and 72 holes, respectively.

2.2 TEST PROCEDURE

Figure-4 shows the testing system of the test .The loading machine has a load cell of 49 kN capacity with the reaction frame and a control panel.The load and displacement data were monitored by a control panel and A/D converter. All measuring data were recorded and stored through a personal computer.

A schematic representation of the test is shown in figure-5. At a certain load from lower level up to near maximum the ink-ethanol was injected into the concrete through a number of holes. After failure occured the crack pattern which was dyed by ink was recorded in photograph, and using a scanner and computer calculation the area of crack was obtained. In order to eliminate the influence of compressive stress produced near the reaction points on the stress transfer mechanism, the distance between reaction points were designed more than six times of the embedment length as shown in figure-5.

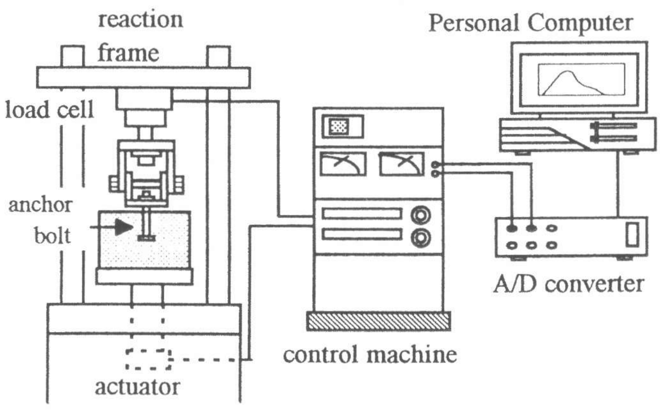

Fig.-4 Testing system

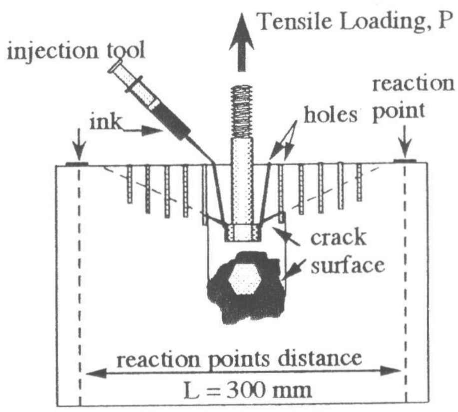

Fig.-5 Testing method

3. TEST RESULTS AND DISCUSSION

3.1 SHAPE OF CONCRETE CONE FAILURE

Twenty-eight specimens for both cases of embedment length were tested in this experiment. All specimens showed the concrete cone failure. Figure-6 show the failure cone shape for both types of embedment length. The inclination angle between a failure cone and the surface of concrete ranged from 15° ~ 35°, with average values of 24 ° and 28° for embedment lengths of 30 mm and 45 mm, respectively. The inclination angle tended slightly to increase with increased embedment length.

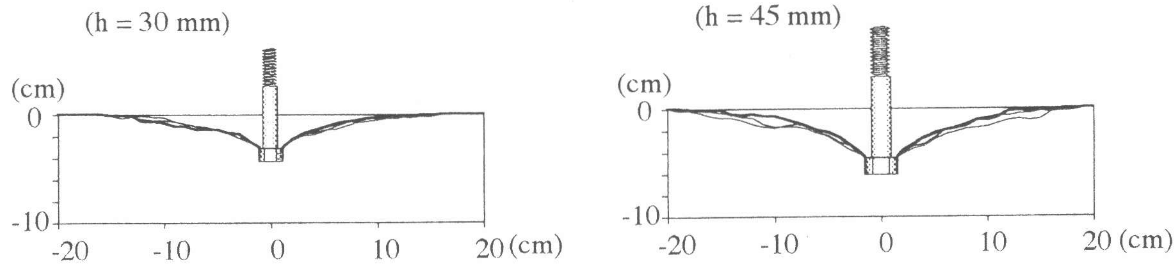

Fig.-6 The shape of failed concrete cone

3.2 LOAD-DISPLACEMENT CURVES

Load -displacement curves with and without holes are shown in figures-7 and 8. Figure-9 shows the influence of number of holes on the maximum load. From these figures, in general it can be seen that no significant effect of holes is observed on the load carrying mechanism of anchor bolts.

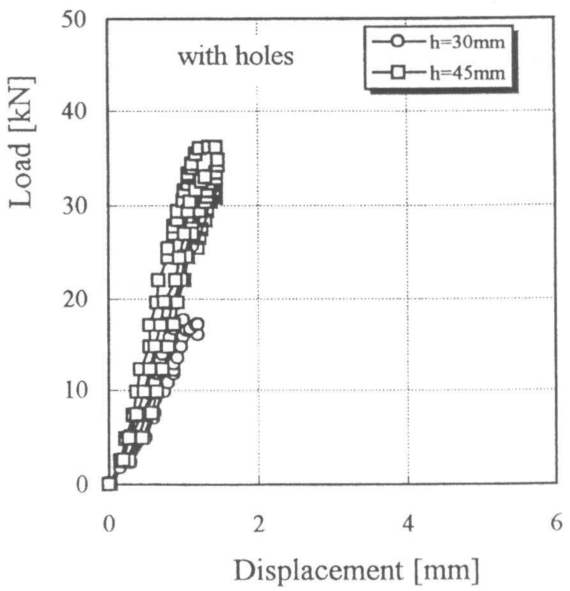

Fig.-7 Load-displacement curves (with holes)

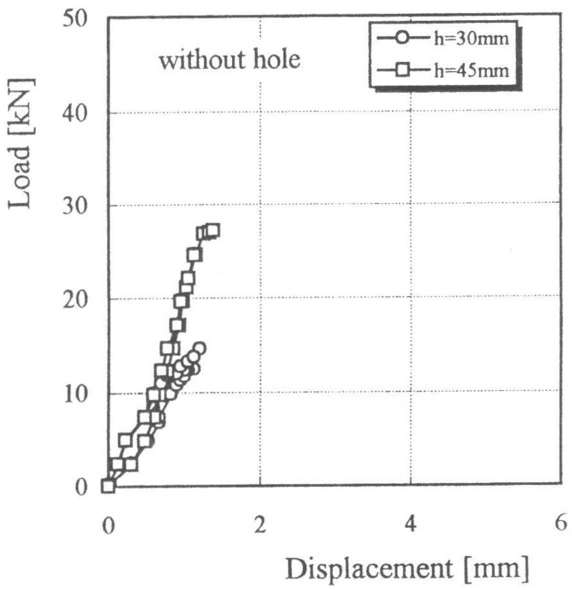

Fig.-8 Load-displacement curves (without hole)

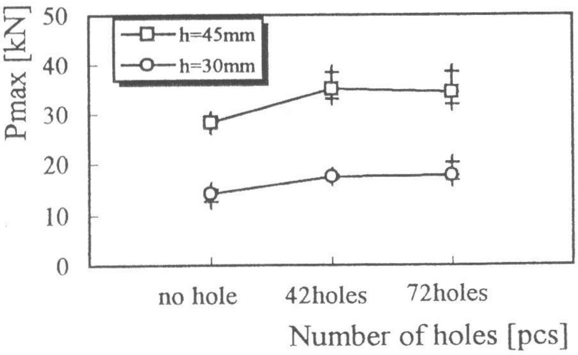

Fig.-9 Influence of holes to maximum load

3.3 MECHANISM OF CRACK GROWTH

A series of crack growth with increase of load for both cases of embedment length are shown in figure-10. No significant difference in crack growth mechanism can be recognized. In figures-11 and 12 the ratio of crack cone surface area to total cone surface area after failure is plotted as a function of the ratio of applied load to maximum load with comparison of the results of Eligehausen & Sawade[2]. Calculation by Linear Finite Element analysis is given as well. From these figures the crack growth mechanism could be summarized as the following steps :

a) Circumferential crack starts at an early loading level, about 10% of the maximum load near the head of the bolt. The distribution of crack is not necessarily identical around of the edge of bolt, but the crack initiates at someplace near the head of a bolt which has lowest tensile capacity.

b) Crack continues to grow with increase of applied load, but until 90% of the ultimate load this crack grows slowly and concentrates at near the edge of a bolt.

c) Near the ultimate load the unstable crack grows fast and the concrete cone failure fully developes.

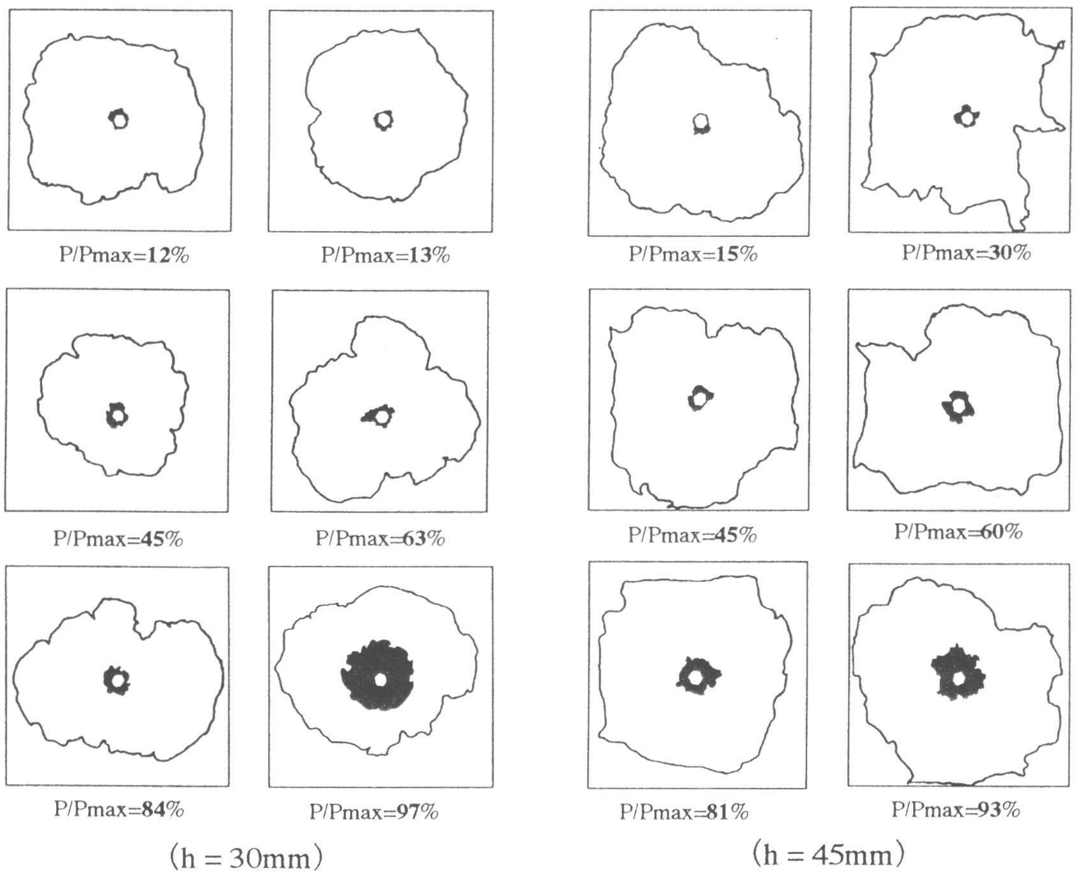

Fig.-10 Series of crack growth with increase of load

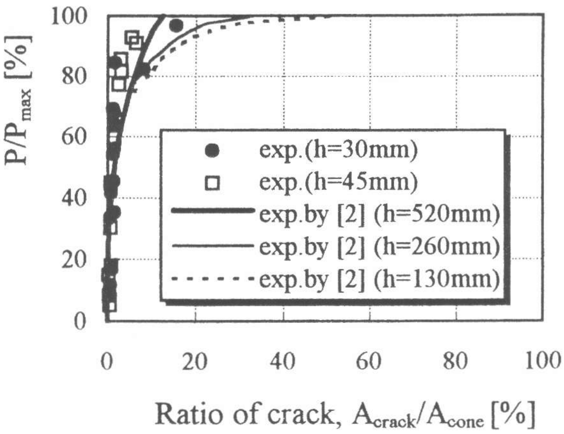

Fig.-11 Crack surface area and comparison with exp. by [2]

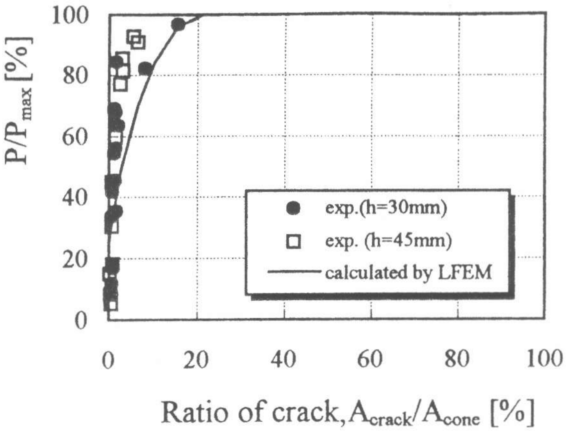

Fig.-12 Crack surface area and comparison with LFEM calculation

4. CONCLUSIONS

From this experiment the followings could be concluded :

1. Until about 90% of ultimate load the circumferential crack of concrete cone grows slowly and concentrates near the edge of a bolt.
2. A testing method by injection of ink-ethanol liquid to trace a crack growth in concrete could be proved effective.

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