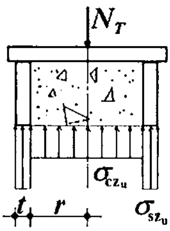


Figure 1

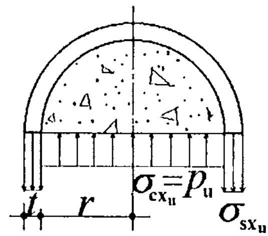
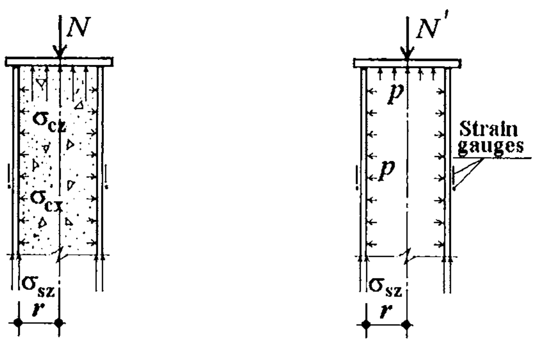


Figure 2



a) Concrete filled steel tube

b) Companion hydraulic specimen

Fig. 3—Resolutions of forces

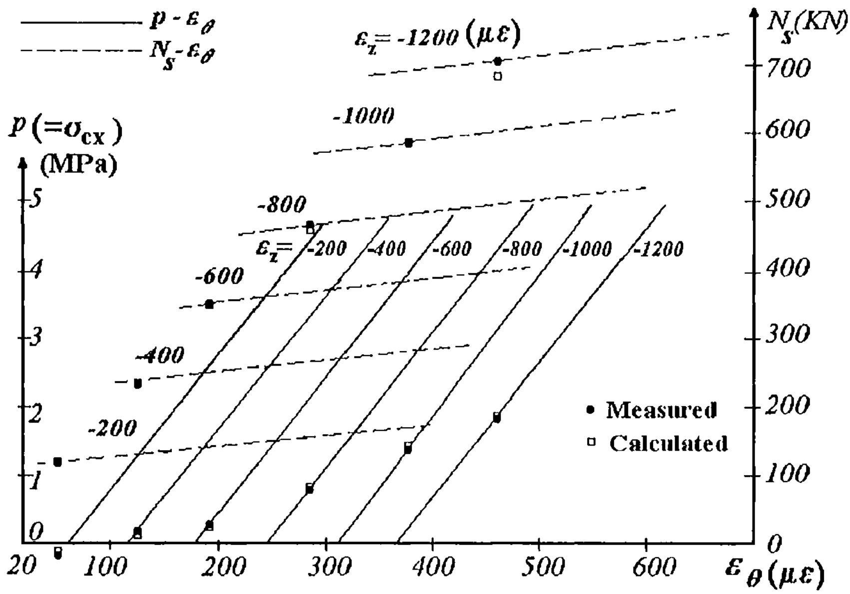
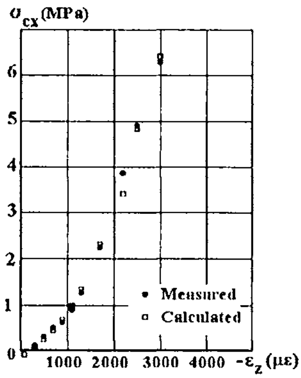
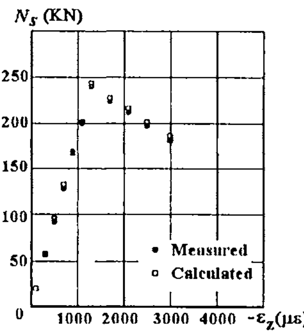


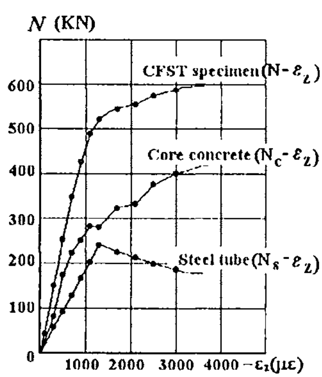
Fig. 4—The chart drawn according to the data of hydraulic specimen AH3



a) Confining stress versus axial strain relationship

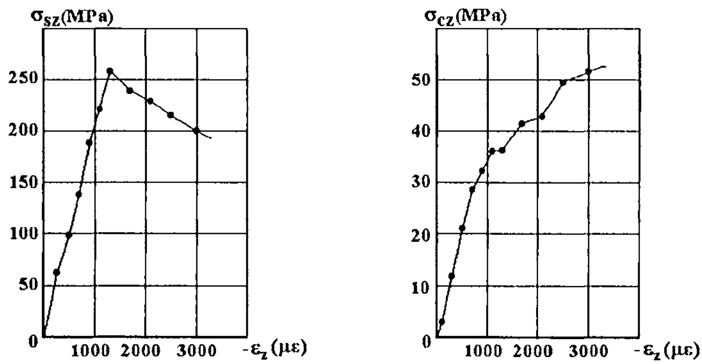


b) The vertical load upon steel tube versus axial strain relationship



c) The vertical load upon CFST, steel tube and concrete versus axial strain relationships

Fig. 5—The results of CC5 and CH2



a) The longitudinal stress in steel tube versus axial strain relationship

b) The average longitudinal stress in concrete versus axial strain relationship

Fig. 6—The results of CC5

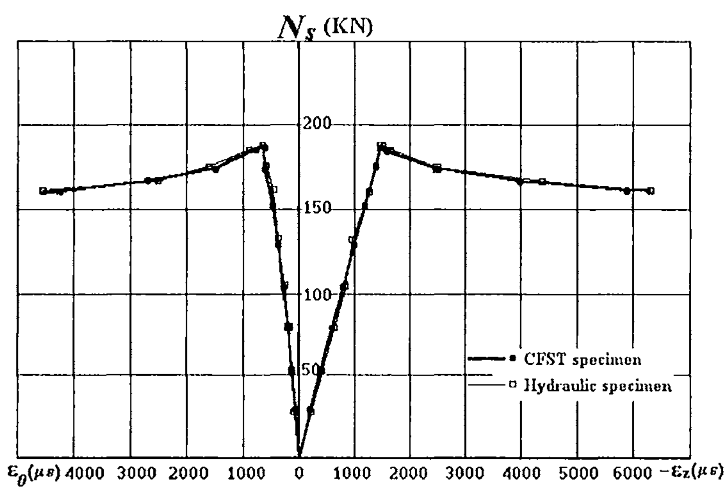


Fig. 7—The vertical load upon steel tube versus axial and hoop strain relationships of DC2 and DH1

Theoretical Evaluation of the Break Off Test for Concrete

by M. Wecharatana and A.P. Ranasinghe

Synopsis: The Break Off Test is a recently developed nondestructive test for concrete. Although many experimental investigations have been carried out on this test, no in-depth theoretical evaluation has been done. In this study the behavior of the break off test specimen is investigated and the theoretical basis of the test explored. Based on linear elastic fracture mechanics, a model to predict the strength - manometer reading relationship of the test is proposed and compared with experimental results with good correlation.

It was found that the ACI recommendation on the modulus of rupture (MOR) may be very conservative for certain members. The MOR of a rectangular beam is different from that observed from a circular cross section such as the break off test specimen. New MOR values are suggested for small rectangular beams and members with circular cross sections.

Keywords: Compressive strength; cracking (fracturing); crack width and spacing; flexural strength; fracture mechanics; models; nondestructive tests; stresses; tests; theories

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INTRODUCTION

Strength of concrete is normally measured using the standard 6"x12" cylinder or 6" cube. The measured compressive strength (f'_c) is commonly used for design. The accuracy of concrete strength is frequently challenged, particularly in large concrete structures where size effect of the test specimens is attributed for the differences. Many nondestructive tests were developed and in-situ evaluations of concrete strengths have been commonly carried out.

The two most common tests are the schmidt Hammer and the Windsor Probe. In recent years, it was obvious that these tests are inaccurate and unreliable. Large variations are frequently observed casting some doubts on the reported concrete strengths. It has been found that the Schmidt Hammer test results depend on the stiffness of concrete, characteristics of the near-surface layer, surface texture and wetness, aggregate type, orientation of hammer and type of cement (1). Windsor Probe test is strongly influenced by the type of aggregate, hardness of surface layer, orientation of probe and is useful in determining the relative quality of concrete rather than predicting the compressive strength (1). As the infrastructure decays, more and more nondestructive tests are required to evaluate the existing structures for their reliable serviceability. An urgent need arises to develop more reliable nondestructive tests for these applications.

A new nondestructive test called "Break Off Test" was recently developed in Norway to measure the compressive strength of concrete (2). The test consists of a small cylinder (2.17" in diameter and 2.76" in length), made by inserting a rubber sleeve in cast-in-place concrete or by coring into the existing structures. Figure 1 shows a schematic of the break off tester (3). A shear force is then applied by a hydraulic jack at the end of the cylinder until it ruptures. The applied force is measured by a pressure gauge (a manometer) where the break off number is read. The break off number was experimentally correlated with the measured compressive strength of concrete. Figure 2 shows the calibration chart provided by the manufacturer of the break off tester (3).

Although substantial amount of experimental investigations has been carried out on this test, no in-depth theoretical evaluation has yet been done to date. In this paper the behavior of the break off test specimen is investigated and the potential theoretical basis of this test configuration is established using fracture mechanics. It is expected that the results from this study will provide a justification for the standardization of the break off test.

The relationship between the manometer reading of the Break off tester and the applied force has been reported by Hashida et al. (4) as shown in Figure 3. Figure 4 shows a similar relation obtained by Dahl Jorgenson (5). It is seen that the load vs B.O. relation is as follows :

$$P = 3.81 (BO - 2.973) \quad (1)$$

where, P = Applied load in lbs
BO = Manometer reading in Bars

FRACTURE MECHANICS APPROACH

When uniaxial tension specimens fail, a reduction in strength is observed as microcracks develop and form into a single macrocrack. Based on this phenomenon Hillerborg et al. (6) in 1976, introduced the fictitious crack model (FCM). This model assumes that the fracture process zone (FPZ) at the tip of a crack is long and narrow. Figure 5 shows the terminology used in the fictitious crack model (7-9).

Gerstle et al. (10) have used the fictitious crack model to analyze reinforced and unreinforced concrete beams with rectangular cross sections in bending. The concrete members considered were without an initial crack. A finite element analysis has verified that their simplified assumptions are reasonable. Figure 6 shows the relationship between the normal stress and displacement which characterize the fracture process zone (10).

The break off test method assumes that the ultimate flexural strength of concrete is reached at the extreme outside fiber at the base of the Break off test specimen. The circular cross section restricts the ultimate fiber stress to a point, and a crack is initiated at this point (11).

Figure 7 shows an idealized and magnified deformed shape of the break off specimen used in this study. Two cases are considered: Case I, in which the fictitious crack has not yet opened far enough to relieve the normal stress at its mouth ($CMOD < COD_{cr}$), and Case II, in which $CMOD > COD_{cr}$.

The following assumptions made by Gerstle et al. (10) for beams with rectangular cross sections are assumed to be valid for the break off specimen with a circular cross section.

1. At a horizontal distance equal to the crack length a (See Figure 7) from the crack, plane sections of the beam remain plane after deformation (Bernoulli's beam assumption).
2. Fictitious crack surfaces remain plane after deformation.
3. Normal closing tractions acting on the fictitious crack follow the linear stress-COD curve shown in Figure 6.
4. Fiber bending stress in the concrete along the bottom of the beam is equal to the traction normal to the crack mouth at the bottom of the beam.
5. The concrete is linear elastic.

Normalization of Parameters

Using the stress distributions shown in Figure 7, the maximum moment capacity of the circular section was obtained. In order to achieve this and simplify the algebra, the parameters in Figures 6 and 7 are normalized as follows:

Geometric Parameters

Crack mouth opening displacement $C=\frac{CMOD}{COD_{cr}}$

Crack length A = a/D

Distance from crack tip to neutral axis S = s/D

Distance from neutral axis to top of beam T = t/D

Material Parameters

Two material parameters are needed here for concrete

a scale parameter for concrete $\beta = \frac{f'_t D}{E_c COD_{cr}}$

where f'_t represents the tensile strength and E_c is the Young's modulus of concrete.

a strength ratio $k = \frac{f'_t}{f'_c}$

where f'_c is the compressive strength of concrete.

Stress parameters

Stress at crack mouth opening $\sigma_{CMOD} = f'_t (1 - C)$

Stress in top fiber of beam $F = f/f'_t$

Applied moment $M = \frac{m}{f'_t D^3}$

where m is the internal resisting moment.

It should be noted that internal resisting moment is equal to the external moment created by external loads.