STRESS-STRAIN RELATIONSHIP FOR CONFINED CONCRETE UNDER CYCLIC LOADING AND STRAIN GRADIENT

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SUMMARY

This paper presents the results of tests made to study the stress-strain relationship for confined concrete with strain gradient under monotonic and cyclic loading. Five specimens were tested under combined axial load and flexure. First two specimens were tested under monotonic loading which was adjusted to produce a triangular strain distribution. The last three specimens were tested under cyclic loading. The validity of different analytical models proposed were checked using the test results.

INTRODUCTION

In the past 20 years considerable experimental research has been made to determine the stress-strain relationship for confined concrete. Most of the previous tests were carried out under uniaxial and monotonic loading. Semi-empirical models were developed using the available data from such tests. The main objective of the research program reported was to investigate the applicability of such analytical models when there is (a) strain gradient, (b) precracking and (c) load cycles causing strains in the reinforcement beyond yield strain. In the first phase of the program, which is reported in this paper, five specimens plus a pilot specimen were tested under combined axial load and flexure. Mainly three variables were studied; effect of strain gradient, effect of cracking and cyclic loading.

TEST SPECIMENS

The size of cross-section, amount and geometry of longitudinal and transverse reinforcement were identical in all specimens as shown in Figure 1. The specimens were scaled models of Toronto specimen 2A6-15 tested by Sheikh and Uzumeri[1] under monotonic uniaxial loading.

TESTING

Specimens 2 and 3 were tested under monotonic loading by applying a compressive load P_1 and an eccentric load P_2 as shown schematically in Figure 2(a). The details of this loading arrangement, which was designated as "basic loading" are shown in Figure 3. At each load increment P_2 was adjusted until the strain on the opposite face was zero or nearly zero. This type of a loading arrangement was previously used by Hognestad et al.[2]. Specimens 4, 5

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and 6 were cracked by introducing tension on the face where maximum compression occurs under "basic loading". Tension was introduced using three different types of load arrangement as shown in Figure 2(b), (c) and (d). The type of loading used for cracking each specimen is given in Table 1. After the preliminary loading, which caused tension cracking, basic loading was applied. The strain history for each specimen was different as shown in Figure 4. Under tension loading, tensile stresses in longitudinal reinforcement remained below the yield value except in specimen No. 6.

TABLE - 1

TEST RESULTS

Spm	Ldg Hst (*)	At Peak Load P_t (kN)	At Peak Load ε_{cc}	P_c/P_t for Gross Area: Hognes	Kent & Park	Modf K&P	P_c/P_t for Core Area: Hognes	Kent & Park	Modf K&P	Sheikh & Uzum
2	a	2300	0.0124	-	0.81	1.04	-	0.73	0.92	0.99
3	a	2100	0.0095	0.69	0.97	1.24	0.58	0.65	0.80	1.13
4	b+a	2010	0.0125	-	1.09	1.37	0.58	0.65	0.79	1.26
5	c+a	1800	0.0148	0.79	1.02	1.35	0.67	0.74	0.96	1.24
6	d+a	2000	0.0225	-	0.91	1.16	-	0.81	1.03	1.12

(*) Each letter corresponds to the loading pattern shown in Fig. 4.

Specimens were instrumented to measure the curvature and strains on the faces and at different locations on the longitudinal and transverse reinforcement. Since the strains on faces were important in controlling the loading and in determining the proporties of the concrete stress block, these were measured using three independant instrumentation; mechanical gages and clip gages mounted on longitudinal steel (gage length = 150 mm) and electrical strain gages located on the longitudinal reinforcement. Deflection was measured by tracing the displacement of specimen with respect to a piano wire stretched from one roller to the other. Rotations were measured by using a "rotation meter" atteched to the specimen at the midheight. Basic instrumentation, with the exception of electrical gages on transverse reinforcement, is shown in Figure 3.

TEST RESULTS

Strains, deflections and rotations were measured and recorded at each load increment until the peak load was reached. Since strain controlled loading was not possible, only a few readings could be taken after the load started to drop. The load history applied to each specimen, maximum total axial load reached and the corresponding concrete strains at the face are given in Table 1. In Figure 5 load cycles for each specimen are shown for basic loading only. In this figure variation of total load as a function of concrete strain at the most compressed face is demonstrated.

In Table-1 P_c/P_t ratios are also given. P_c (based on core & gross areas) was obtained from the strains measured using different analytical models(1) (2) (3) for concrete and P_t was the maximum measured load. The variation of this ratio is presented for specimens 3, 4, 5 and 6 in Figures 6, 7, 8 and 9. For each model, three curves are presented for the variation of P_c/P_t, (a) P_c based on gross area, (b) P_c based on core area, and (c) P_c considering gradual cover crushing. For Sheikh and Uzumeri model simply one curve is presented since the effective area to be used is defined in this model.

An examination of Figures 6, 7, 8 and 9 reveals that in general, better agreement is obtained with the test results using Sheikh and Uzumeri model or modified Kent and Park model based on core area. While modified Kent and Park model seems to underestimate the capacity, Sheikh and Uzumeri model appears to overestimate it especially at later load stages. Among the four analytical models used in this study, the one proposed by Sheikh and Uzumeri seems to be more consistent since P_c/P_t ratio remains almost constant at different strain levels. It should also be noted that when this model is used P_c/P_t ratio does not exceed 1.20 with the exception of specimen 4. Strain gradient, initial cracking and cyclic loading seem to influence the effectiveness of confinement and applicability of models derived from tests on uniaxially loaded specimens tested under monotonic loading.

CONCLUSIONS

From limited number of tests reported in this paper the following conclusions seem to be valid :

1. Effectiveness of confinement is influenced by initial cracking, strain gradient and cyclic loading.
2. For precracked specimens tested under repeated loading producing strain gradient, the model proposed by Sheikh and Uzumeri for confined concrete seems to overestimate, while the modified Kent and Park model seems to underestimate the capacity of the section.
3. While P_c/P_t ratio varies as a function of concrete strain when the first three models are used, this ratio remains almost constant when Sheikh and Uzumeri model is employed. Therefore this model seems to be more consistent than the others.

Further research is needed in this area.

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3. Park, R., Priestley, M.J.N., and Gill, W.D., "Ductility of Square-Confined Concrete Columns", Proceeding of ASCE, V. 108, ST4, April 1982, pp. 929-950.

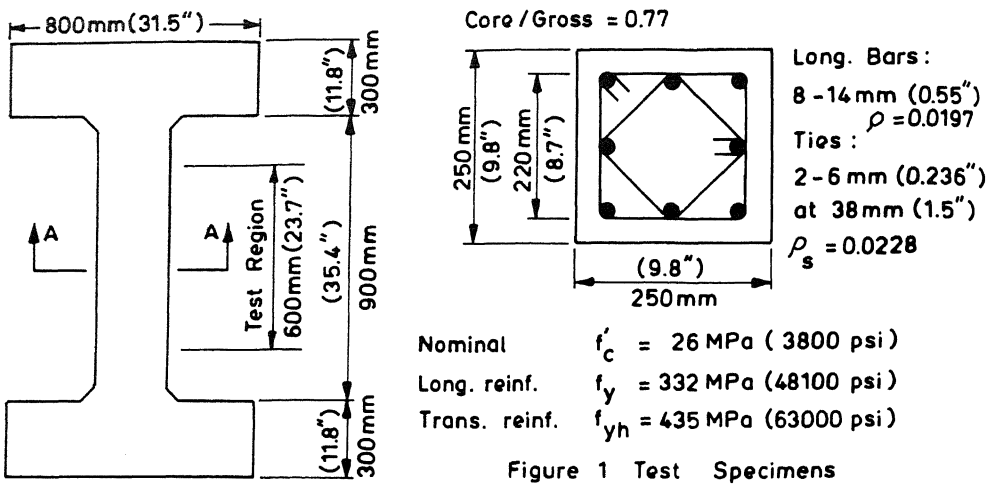
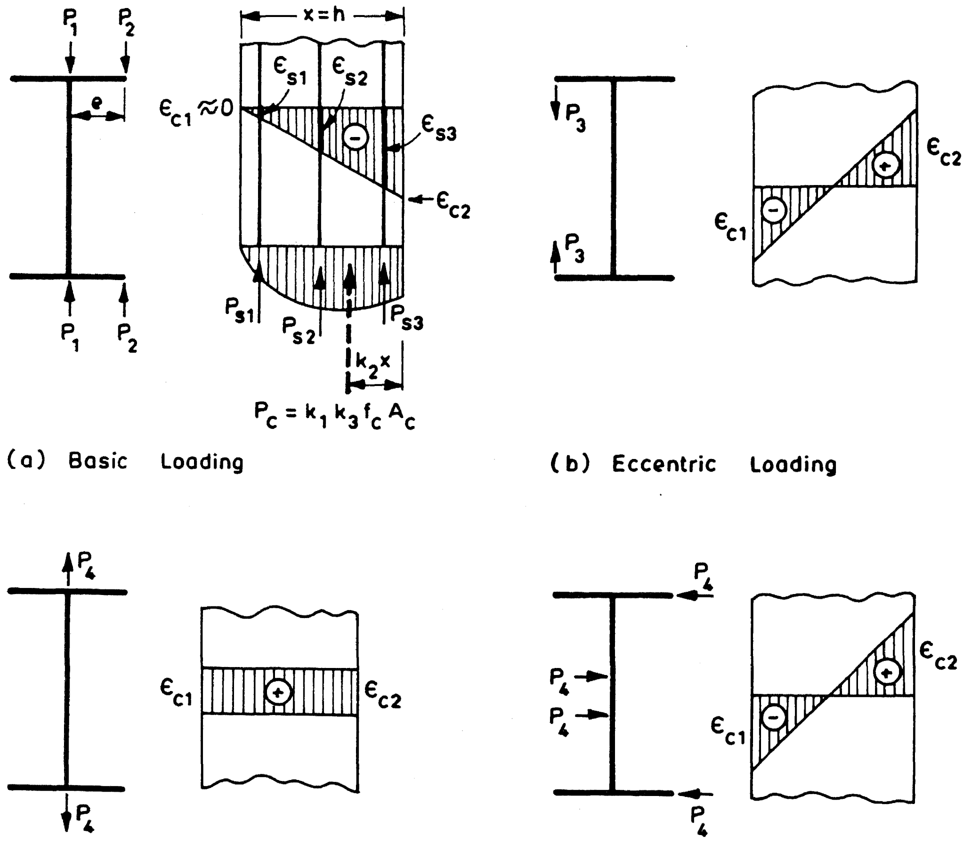


Figure 1 Test Specimens



(a) Basic Loading

(b) Eccentric Loading

(c) Direct Tension Loading

(d) Flexural Loading

Figure 2 Loading Patterns

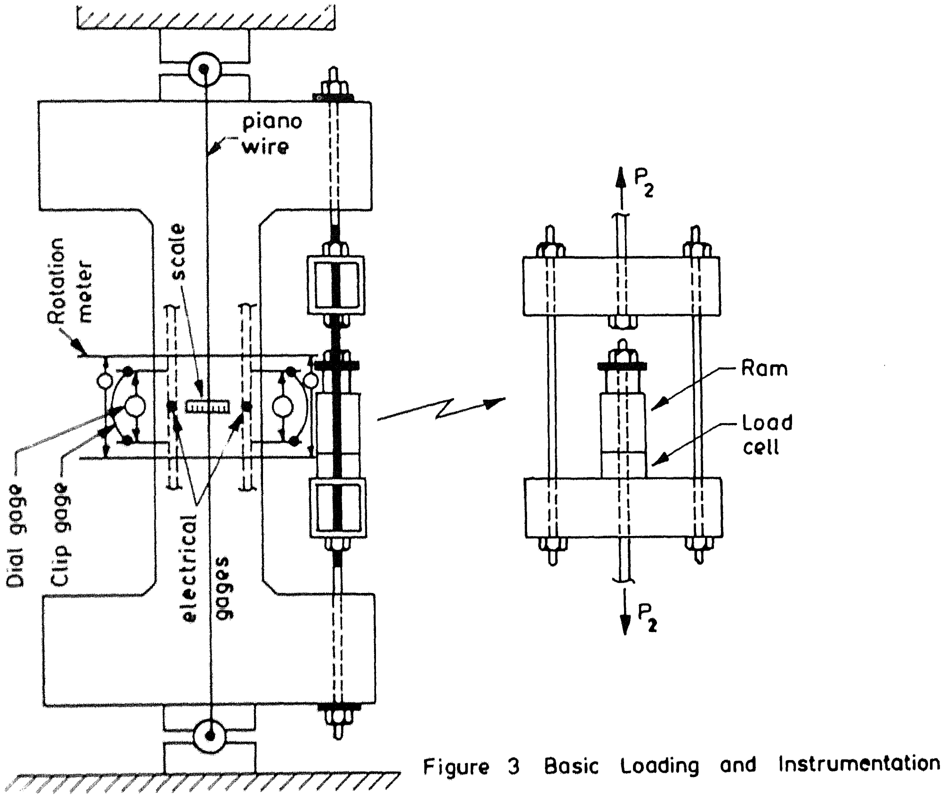


Figure 3 Basic Loading and Instrumentation

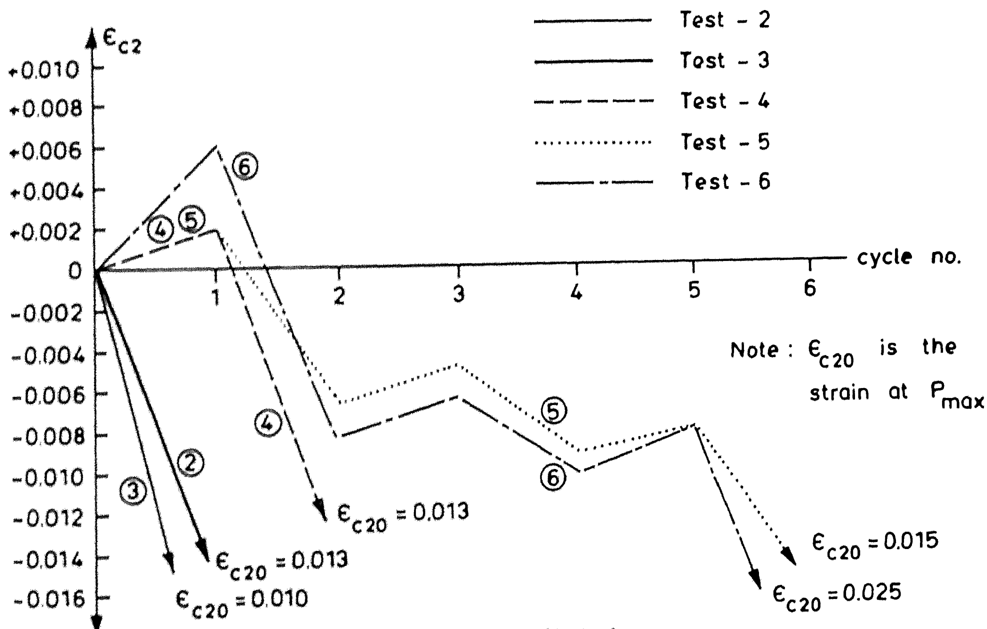


Figure 4 Strain Histories

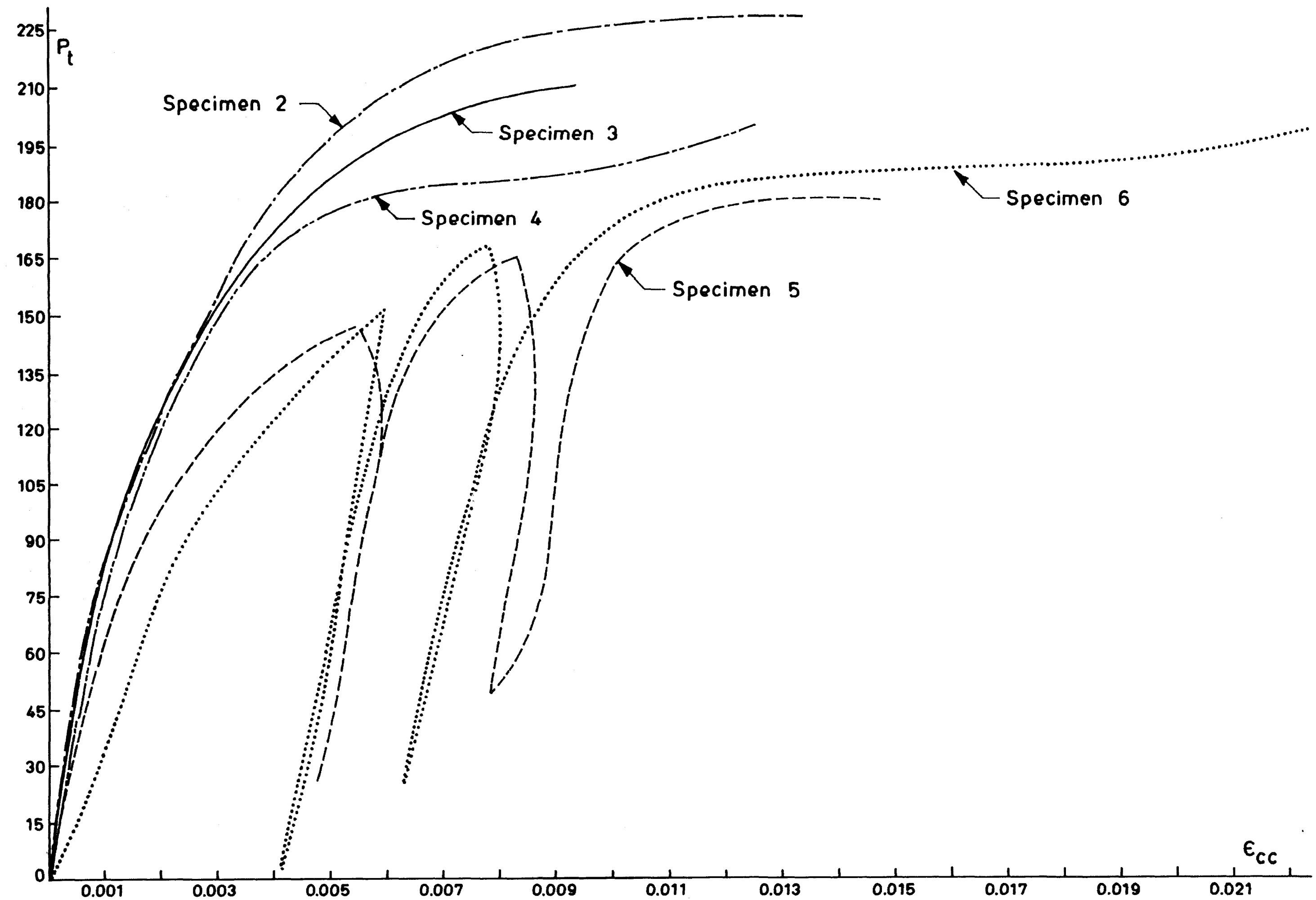


Figure 5 Measured Load - Strain Relationships

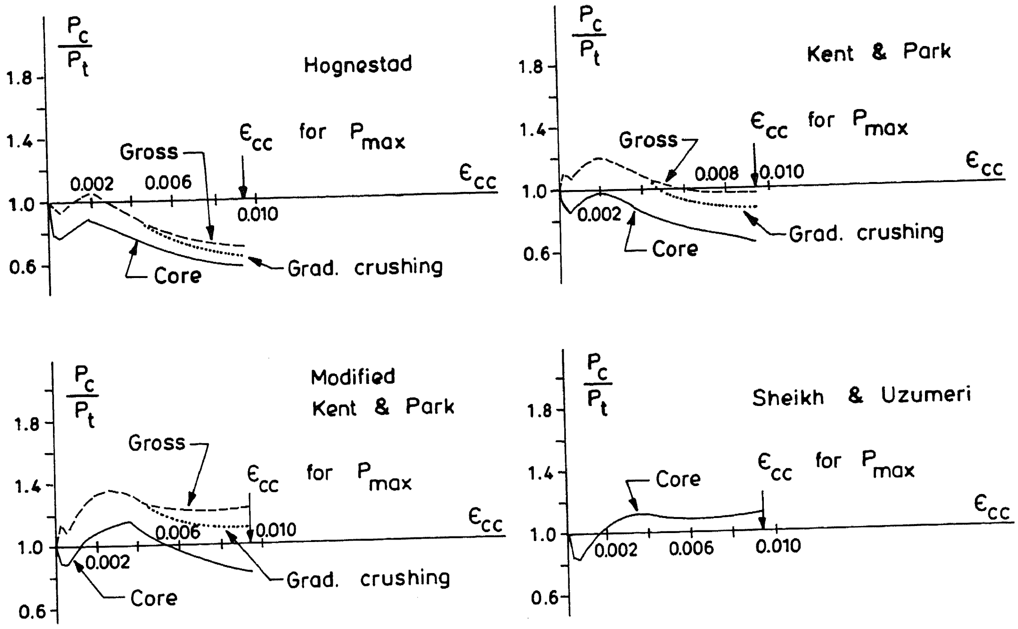


Figure 6 Specimen 3 Test Results

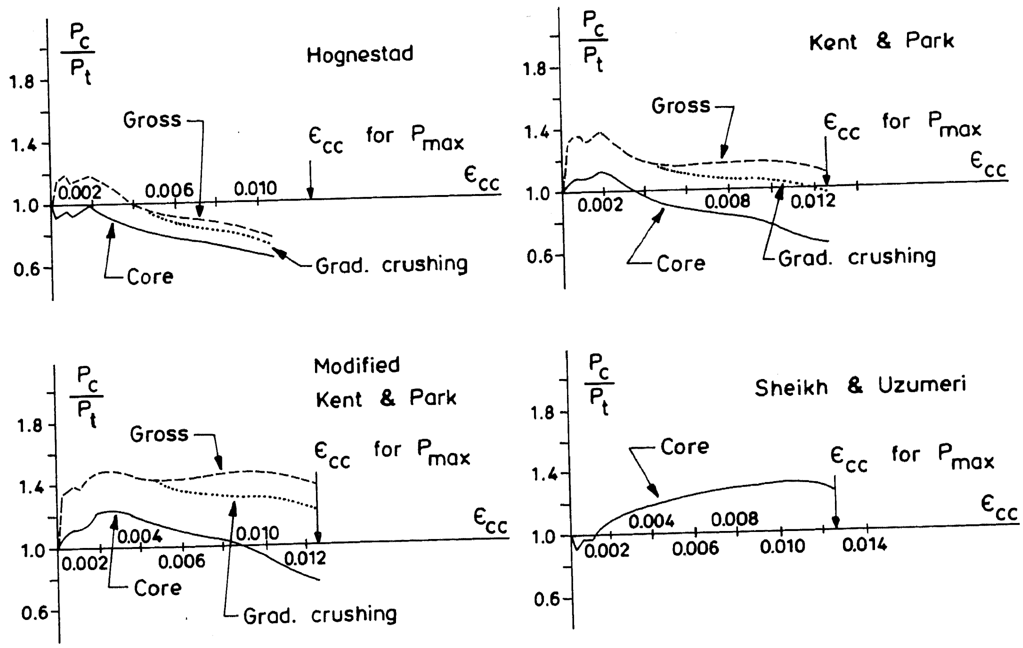


Figure 7 Specimen 4 Test Results

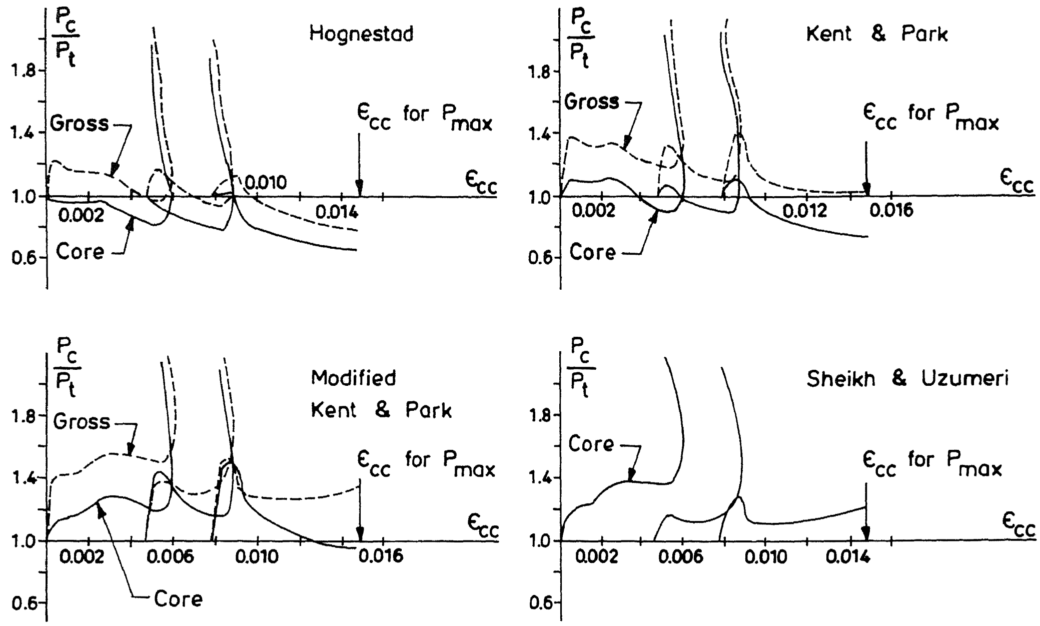


Figure 8 Specimen 5 Test Results

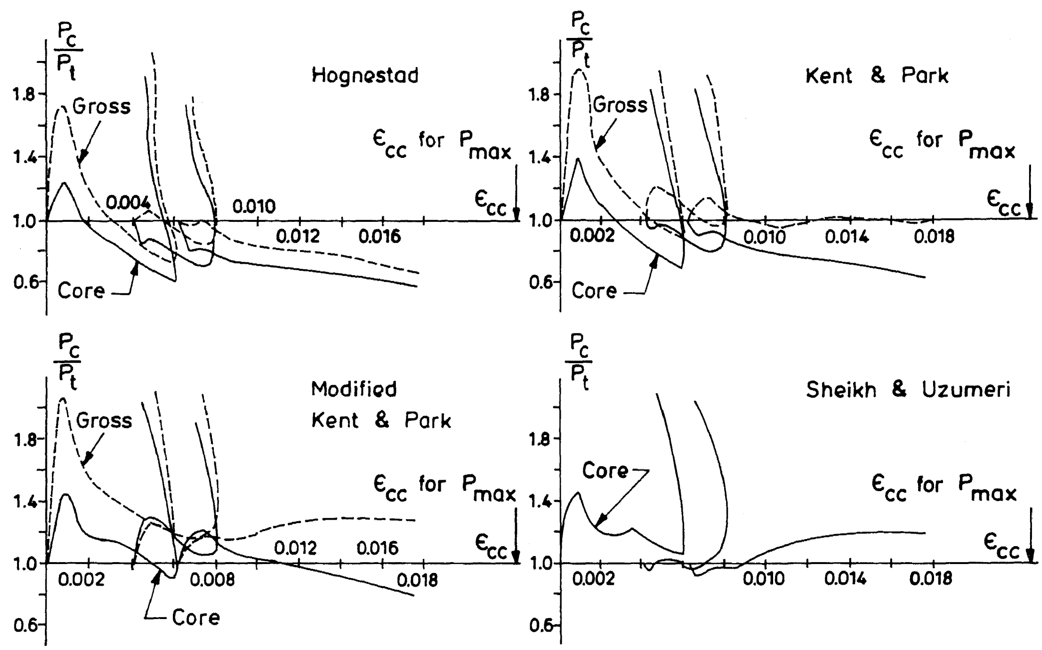


Figure 9 Specimen 6 Test Results