SIZE EFFECT IN AXIALLY LOADED REINFORCED CONCRETE COLUMNS

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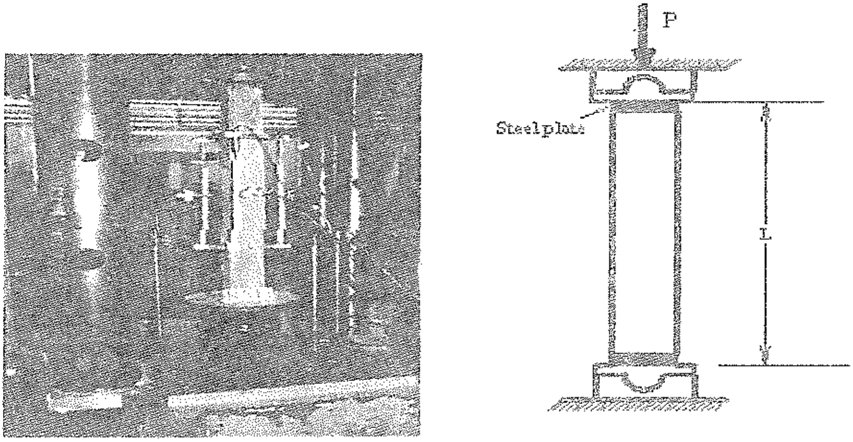
INTRODUCTION

Concrete structural design does not exploit the tensile carrying capacity of concrete and is still largely based on elasticity or plasticity theory which implies that geometrically similar structures of different size should fail at the same nominal stress. As this conservative design practice has proved successful, it might well be argued that there is no need to change it through the introduction of a general failure theory which not only involves energy failure criterion but also accounts for progressive failure in structures [1,2,3]

A theory of fracture mechanics applicable to quasi-brittle materials has been developed during the last decade or so[1,2] . A reasonable consensus has emerged among researchers during this period that the introduction of this theory into the design methodology of all concrete structures (which are likely to fail in a brittle manner) can lead to significant benefits[3,4]. It is known from experiments that the load-deflection diagram of concrete columns, even short ones in which the P-□ effect is negligible, exhibits post-softening behaviour. Hence, a size effect ought to exist. It will help, for example, in achieving uniform safety margins for structures ranging in size over several orders of magnitude to improve their reliability [4,5].

EXPERIMENTAL DETAILS

A schematic view of the test setup and the loading arrangement used in the experimental study are illustrated in Figure .1. The top and bottom ends of the columns were located in spherical seating supports, designed to reduce eccentricity of loading to a minimum,



Loading of specimens

Loading set up

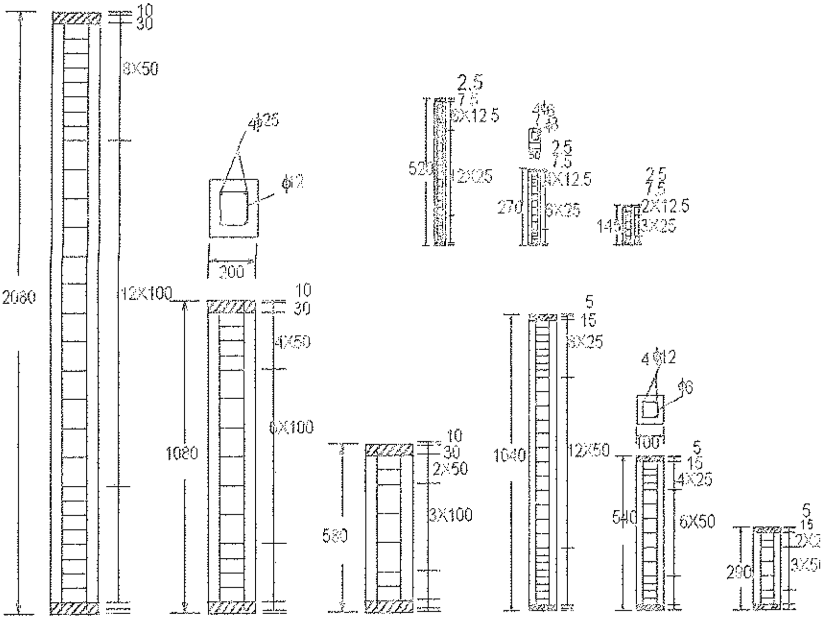
Figure 1. Test set up and Loading of specimens

The columns were of square cross-section with sides, D, of 50 mm, 100 mm and 200 mm. The maximum length of column which could be used in the study was determined by the available daylight in the testing machine used for the longest test specimens. Based on this limitation, the effective lengths corresponding to the largest cross section were 580, 1080 and 2080 mm, the effective lengths corresponding to the middle section size were 290, 540 and 1040 mm and the effective lengths corresponding to the smallest cross section were 145, 270 and 520 mm as detailed in Fig.2. The above combinations resulted in three slenderness ratios, □ of 9.7, 18.0 and 34.7 (where□ =L/r=L/0.3D). The columns in each group of the same slenderness ratio were geometrically similar.

Geometric similarity was maintained with the reinforcing bars, their locations and cover, as well as the diameter and spacing of the links. All these dimensions were scaled in proportion to the column dimension D. The diameters of the longitudinal reinforcing bars (d_b) were 6, 12 and 25 mm for the columns with D=50, 100 and 200 mm respectively. The corresponding link dimensions and spacing are detailed in Fig.2. The distance from the centre of the reinforcement to the edge of the column was D/4 in all cases.

The mix proportions (by weight) were 1:3.6:1.8::0.67 corresponding to cement. The maximum fine aggregate size was 5 mm and the maximum coarse aggregate size was 10 mm. The columns were cast in forms made of plywood with a smooth hard varnish-painted surface. The forms were stripped after one day. A total of 27 columns together with three companion 100 mm cubes (to evaluate 28 day compressive strength), cylinders of diameter 100 mm and length 200 mm (to evaluate splitting tensile strength were cast from the same batch, the testing programme extended over three days i.e. 28→30 days after casting. Care was taken throughout to ensure that all columns were correctly aligned between the platens of the testing machine.

Figure 2. Test columns for different size



The specimens were taken out of the water immediately pr to testing. Instrumentation was then completed and specime were prepared for testing. One type of failure mode w encountered. a brittle failure was observed, as the maximu load was reached, a fine network of vertical crack was visua observed, as loading proceeded, a wide vertical cra propagated and led to a sudden splitting of the specimen j after the peak load. A number of the columns broke approximately mid-length, as might be expected from buckli analysis. However, the small slender columns had a m variable location for failure with about half of them failing n the quarter-length and the other half at one end adjacent to either the upper or lower support.

TEST RESULTS AND DISCUSSION

The compressive strength and the splitting tensile strength results were obtained from the control specimens cast from the same batch of concrete are reported in Table 1. Three identical specimens were tested in all cases also the column test results are summarised in Table 2

Table 1. 28 Days concrete strength results

Days	*Compressive strength* *((N/mm^2)* *(V%)*	*Splitting strength* *((N/mm^2)* *(V%)*
28	34.43 (4.59)	3.52 (5.98

V% = Coefficient of variation

Table 2. Column test results,

a) Short Coolum

Column No	RS1	RS2	RS3	RS4	RS5	RS6	RS7	RS8	RS9
D(mm)	50	50	50	50	50	50	50	50	50
λ	34.7	34.7	34.7	18	18	18	9.7	9.7	9.7
Pu (kN)	98	104	107	110	101	106	85	76	88
σN (N/mm2)	39.2	41.6	42.8	44	40.4	42.4	34	30.4	35.2

b) Medium Column

Column No	RM1	RM2	RM3	RM4	RM5	RM6	RM7	RM8	RM9
D(mm)	100	100	100	100	100	100	100	100	100
λ	34.7	34.7	34.7	18	18	18	9.7	9.7	9.7
P_u(kN)	400	383	398	366	371	405	322	379	354
σ_N(N/mm^2)	40.0	38.3	39.8	36.6	37.1	40.5	32.2	37.9	35.4

c) Long Column

Column No	RL1	RL2	RL3	RL4	RL5	RL6	RL7	RL8	RL9
D(mm)	200	200	200	200	200	200	200	200	200
λ	34.7	34.7	34.7	18	18	18	9.7	9.7	9.7
P_u(kN)	1248	1308	1315	1306	1296	1411	1290	1263	1288
σ_N(N/mm^2)	31.0	32.7	32.9	32.7	32.4	35.3	32.3	31.6	32.2

Based on the size effect law proposed by Bazant[9] i which the nominal stress at maximum load, $\sigma_N = P/D^2$, is give by $\sigma_N = Bf_t`(1+\beta)^{-1/2}$ where $\beta = D/D_0$ with D=50, 100, and 20 mm in this study. $f_t`$ is the tensile strength of concrete and and D_0 are two empirical constants determined by linea regression analysis of the test results. The expressio $\sigma_N = Bf_t`(1+D/D_0)^{-1/2}$ can be rearranged as follows:

$$(f_t`/\sigma_N)^2 = 1/B^2 + D/B^2 D_0 \qquad (1)$$

The above equation is of the form Y= C + AX where Y $(f_t`/\sigma_N)^2$, X=D and the constants C and A are given by C=1/B and $A = C/D_0$. Since $\sigma_N$ and $f_t`$ are known for various values c D a plot of $(f_t`/\sigma_N)^2$ against D results in C and A bein determined from a regression analysis of the test results.

The expression for σ_N may also be rearranged as follows

$$\sigma_N/Bf_t` = (1+\beta)^{-1/2} = (1+D/B_0)^{-1/2} \qquad (2)$$

For very small test specimens, $D/D_0 << 1$ and hence σ_N $Bf_t`$ in which case strength theory of failure is dominant. Fc very large test specimens, $D/D_0 >> 1$ and hence $\sigma_N = Bf_t`(D/D_0$ $^{1/2}$ (or taking logarithms of both sides gives, $\log(\sigma_N/Bf_t`) = -1/$ $\log\beta$) in which case LEFM theory of fracture is dominant. Th intersection of strength theory and LEFM occurs whe $Bf_t`(D/D_0)^{-1/2} = Bf_t`$ i.e. when $D/D_0 = 1$ or $D = D_0$. The linea regression plots are presented in Figure 3 . whereas Figure shows such a relationship for the test results in log scale whic results a curve showing size effects, since the relationship is n along the horizontal strength curve. Comparing the size effe plots of different column slenderness shows that in the case the larger slenderness ratios, the behaviour

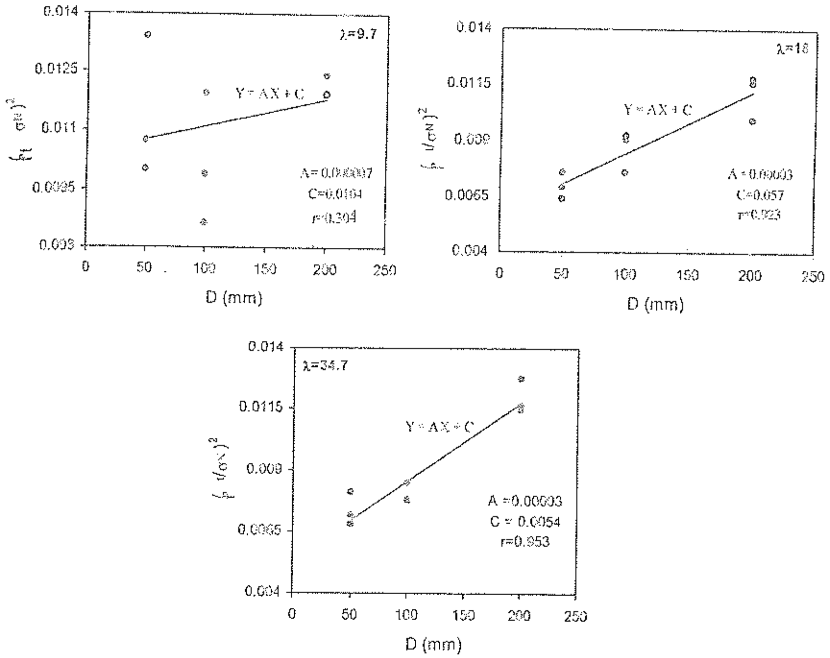


Figure 3. Linear Regression Plots

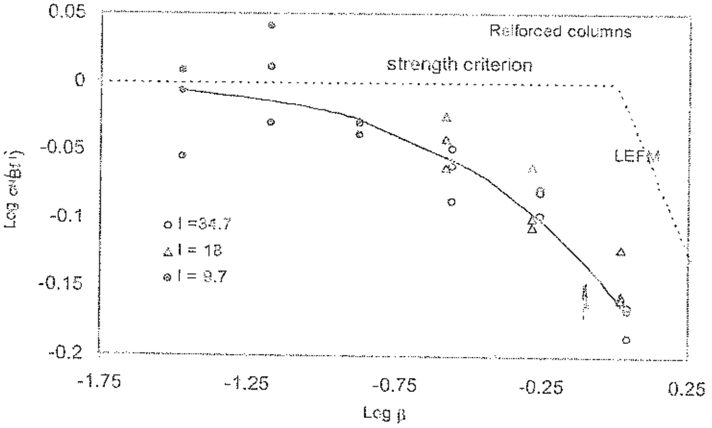


Figure 4 :- Size effect plot for various slenderness ratio

of the column is closer to the LEFM line, i.e. more brittl relative to the same specimen made of the small slendernes ratios for highest slenderness columns used in the study. Thi is to be expected, since a more slender column of the sam cross section stores more energy than a stockier.

CONCLUSIONS

The main conclusions to be drawn from this study are a follows:

1. The failure loads of the reinforced concrete columns o varying dimensions exhibit a size effect (which is no recognized by current codes). This conclusion indicates tha further research is required in this area.

2. The test results are in agreement with the proposed siz effect law of Bazant.

3. With increasing slenderness of columns, the size effec becomes more pronounced.

4. More localised failure is observed in columns with a hig slenderness ratio than in columns with a low slenderness ratio.

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