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DUCTILITY AND STRENGTH IN HIGH-PERFORMANCE LIGHTWEIGTH CONCRETE COLUMNS

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SUMMARY

The purpose of this study was to investigate the effect of key variables (the configuration of transverse reinforcement, the spacing of transverse reinforcement, the longitudinal reinforcement ratio), on the structural performance of high-strength lightweight concrete columns under monotonic eccentric loading. Using the test results, current EC2 predictions of 2nd order effects were checked in order to investigate the implication of the material properties on the design procedure.

INTRODUCTION

High-strength lightweight concretes tend to be more brittle under compressive loading, and display less post-peak deformability than normal weight concretes [1]. The above characteristics affect the structural response of members of various types and rises questions on seismic performance, within the inelastic range of deformations.

Experimental data on high-strength lightweight concrete columns behaviour can be found rarely in literature, especially on realistically sized columns, subjected to large inelastic displacement excursions.

A research program is being conducted by the University of L'Aquila in order to study various aspects of high-strength/high-performance lightweight concrete [2]. The purpose of this study is to develop more information on structural performance of high-strength lightweight concrete columns. Thirty-two columns were tested under monotonically increasing eccentric loading. The variables used in the test program were the percentage and configuration of transverse and longitudinal reinforcement and the initial eccentricities of loading. The results were compared with the column design procedure in Eurocode n.2 for predicting the 2nd order effects.

TEST PROGRAM

Test units

Thirty-two columns were tested under monotonic eccentric loading. The units dimensions and reinforcement details are shown in Fig.1. The experimental variables used in testing were the amount of transverse and longitudinal reinforcement. The letter (A, B, C) refers to the configuration of the transverse

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reinforcement, the first number (40, 50, 100) to the spacing in mm of transverse reinforcement, the second number (1, 4) to the longitudinal reinforcement ratio. In some units a third number (10) indicates that the ties of these units are made with Ø10mm instead Ø8mm steel bars.

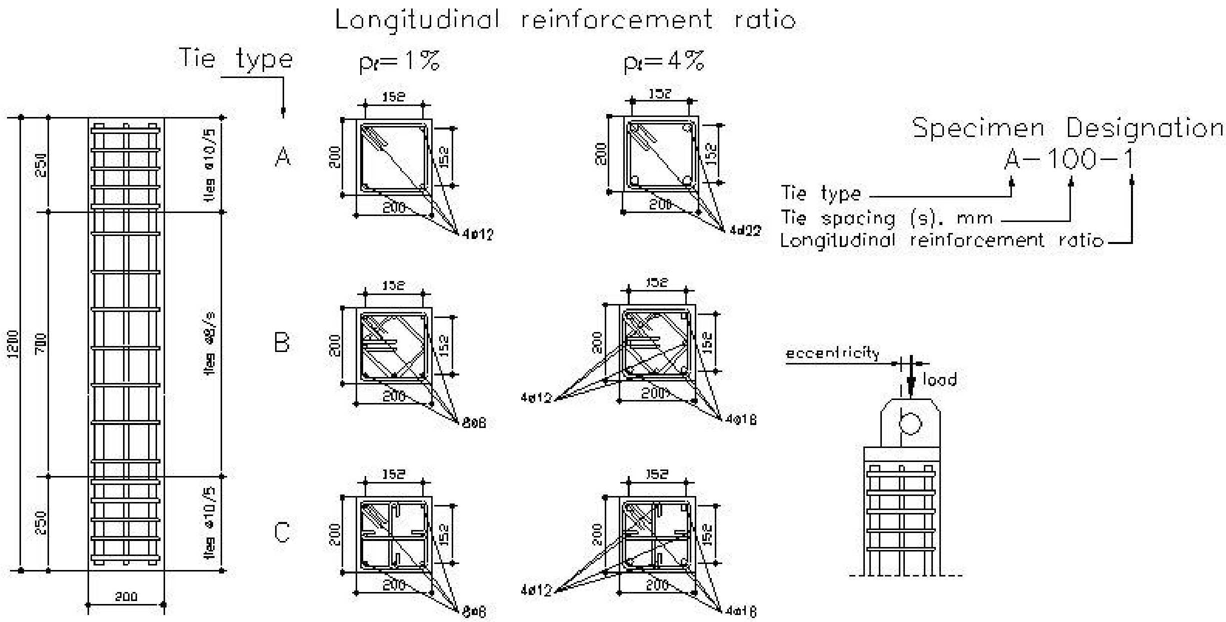

Fig.1: Dimensions and details of column test units.

Concrete

The lightweight concrete mixture was prepared in order to obtain an average compressive cylinder strength of about 60 MPa at 28 days of age. Portland cement, natural sand, silica fume and lightweight aggregate (expanded clay) from Italian source were used. The proportioning of the concrete mixture is summarized in Table I.

Table I: Mixture proportions and properties of freshly mixed lightweight concrete.

Portland cement 52.5R [(1)]	(kg/m^3)	500
Fine aggregate (0-2mm)	(kg/m^3)	378
Fine aggregate (0-4mm)	(kg/m^3)	278
Lightweight aggregate (2-10mm)	(kg/m^3)	522
Slurry (50%SF+50%water)	(kg/m^3)	100
Water	(kg/m^3)	130
Superplasticizer [(2)]	(l/m^3)	12
W/C		0.36
W/(C+SF)		0.33
Slump	(mm)	200
Unit weight	(kg/m^3)	1920

[(1)] Portland cement ENV197-1 CEM I 52.5R.
[(2)] Carboxilated acrylic ester copolymer.

The average compressive strength of concrete from cubic specimens (150×150×150mm) at 270 days of age was 61MPa.

Steel reinforcement

Deformed reinforcing bars (Feb44k Type, $f_{yk} \geq 430$MPa) were used for reinforcement. Table II shows the measured average properties of the reinforcing bars.

Table II: Measured properties of the reinforcing bars.

Bar size (mm)	8	10	12	18	22
Yield strength, f_y (MPa)	449	505	441	527	545
Ultimate strength, f_t (MPa)	596	628	578	644	659

Testing of units

The units were loaded using a monotonic eccentric load, incrementally applied under the deflection control to failure (Fig.1). The loading eccentricities were 35, 45, 60mm, these values were chosen in order to give a range of primarily compression failures. The minimum age at time of testing was 270 days. Important parameters during testing such as loads, lateral displacements at mid-height of each column, column curvatures, strains in the transverse reinforcement were continuously registered for each column. The curvatures were calculated over a length equal to the column depth (200mm) located at mid-height of each unit.

TEST RESULTS AND DISCUSSION

Load versus lateral displacement and moment versus lateral displacement measured during testing are shown in Fig.2. It can be seen that both the configuration and the spacing of the transverse reinforcement considerably influence the ductility of columns.

Table III shows the displacement ductilities ($\delta_{0.85}$) calculated for the units as the ratio of the lateral displacement ($d_{0.85}$) corresponding to 85 percent of the peak load reached just before the cover concrete spalling, over the lateral displacement corresponding to the peak load (d_0).

Table III: Displacement ductility.

Transverse reinforcement configuration	Spacing (mm)	Displacement ductility $\delta_{0.85}$ Longitudinal reinforcement ratio	
		$\rho_\ell = 1\%$	$\rho_\ell = 4\%$
A	50	1.9	2.4
	100	1.6	1.5
B	40	3.6	6.1
	50	3.1	5.1
	100	1.7	1.5
C	50	2.6	3.4
	100	1.6	1.8

In many of the tested units the drop in load once the cover softens was greater than 10% of the peak load. This trend was remarkable for the units having the configuration of the transverse reinforcement B and C.

Table IV shows the average rate of degradation of the load carrying capacity and the moment carrying capacity, that the columns experienced during testing. The rate of degradation was respectively calculated as $R_N = 0.15N_{peak}/(d_{0.85}-d_0)$ and $R_M = 0.15M_{peak}/(d_{0.85}-d_0)$. R_N resulted more pronounced in comparison with R_M The test results indicate that significant toughness enhancement can be achieved with proper configuration of the transverse reinforcement.

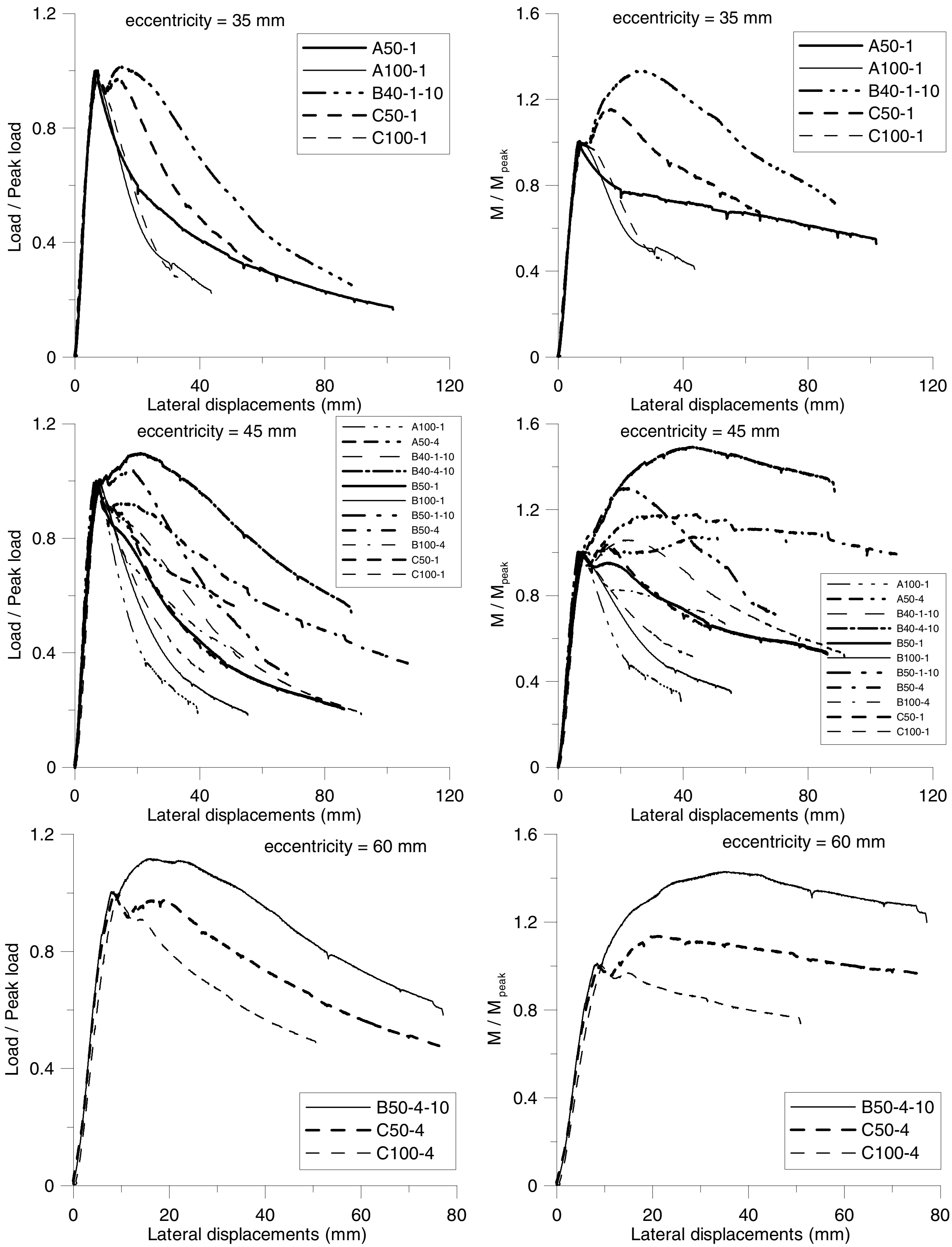

Fig.2: Load, moment versus lateral displacement.

Table IV: Strength degradation.

Transverse reinforcement configuration	Spacing (mm)	Rate of load degradation $R_N=0.15N_{peak}/(d_{0.85}-d_0)$ Longitudinal reinforcement ratio $\rho_\ell = 1\%$	$\rho_\ell = 4\%$
A	50	60.3	27.9
	100	64.1	71.1
B	40	16.6	6.1
	50	21.1	11.7
	100	49.7	67.1
C	50	19.6	12.7
	100	49.7	36.1

Transverse reinforcement configuration	Spacing (mm)	Rate of moment degradation $R_M=0.15M_{peak}/(d_{0.85}-d_0)$ Longitudinal reinforcement ratio $\rho_\ell = 1\%$	$\rho_\ell = 4\%$
A	50	1.0	---
	100	2.2	2.2
B	40	0.2	---
	50	0.3	---
	100	1.4	2.2
C	50	0.4	---
	100	1.4	0.9

Prediction of 2nd order effects

The high-strength lightweight concrete columns may be affect by 2nd order effects, which cannot be compensated by greater mechanical stiffness, because the modulus of elasticity is generally low (18000÷24000 N/mm^2). The 2nd order effects reduce the carrying capacity and the ductility capacity, negatively influencing the moment redistribution and the plastic damping of dynamic actions.

The test results were directly compared with the theoretical 2nd order effects prevision according to the approximated method (EN1992-1, 2nd draft EC2, section 5, clause 5.8.8.3, [3]). The method gives a nominal second order moment M_{II} based on a deflection, which in turn is based on an estimation curvature (1/r). M_{II} in the critical section of the column is calculated as $M_{II} = N(1/r)\ell_0^2/\pi^2$.

The theoretical relationships M versus 1/r given N, were calculated using the stress-strain models for the concrete and the reinforcing steel as shown in Fig.3. The calculations were made by using the actual material strength for concrete and for reinforcing steel. Different values were assumed for ε_{c1} and ε_{cu} in order to include the confinement effect (configuration A, $\varepsilon_{c1} = 3.3‰$, $\varepsilon_{cu} = 4.5‰$, configuration B, $\varepsilon_{c1} = 3.5‰$, $\varepsilon_{cu} = 5‰$, configuration C, $\varepsilon_{c1} = 3.5‰$, $\varepsilon_{cu} = 5‰$).

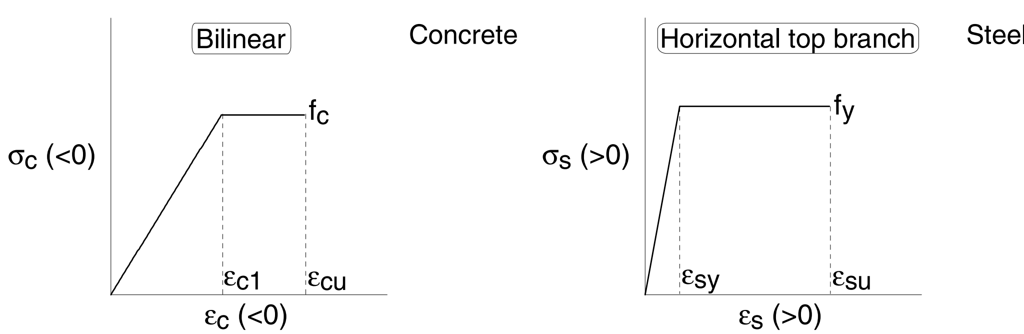

Fig.3: Stress-strain diagrams for lightweight concrete and for reinforcing steel.

The structural response in terms of load versus mid-height displacement (Fig.4) shows that the overall comparison of the theoretical previsions to the test results was quite good.

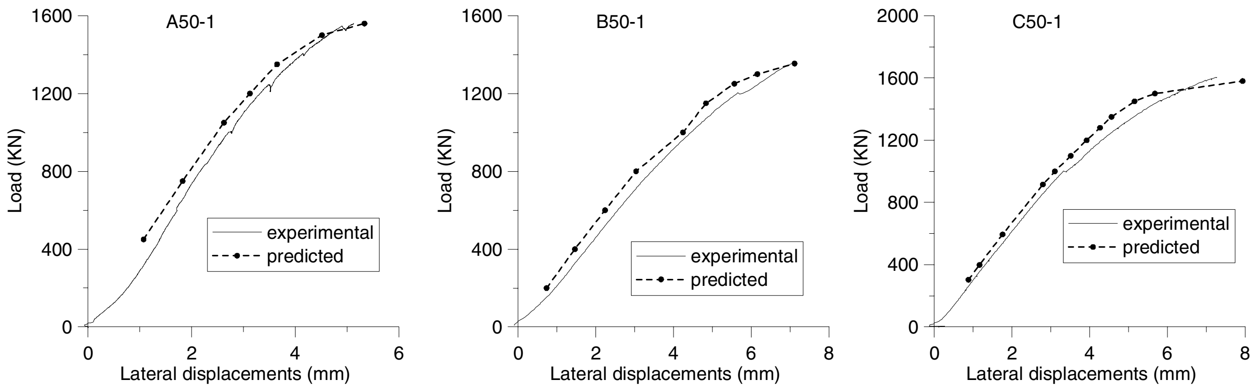

Fig.4: Load versus mid-height displacement.

CONCLUSIONS

The following conclusions can be drawn from this study:

- the use of transverse reinforcement configurations B and C resulted in a significant improvement in structural performance (ductility and load-carrying degradation),
- the design procedure of EC2 appears to be suitable for predicting the 2nd order effects of high-strength lightweight concrete columns.

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