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Effects of reinforcement continuity and homogeneity lacks on the behaviour of reinforced concrete columns subjected to transverse actions

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ABSTRACT: In this paper are presented the initial results of experimental tests conducted at the Dipartimento di Costruzioni, University of Florence, being part of a general program of research whose purpose is to investigate the effects of homogeneity and continuity lacks due to constructive modalities on seismic response of reinforced concrete structures. This work, in particular, gives suitable quantitative informations on the influence of variation of stirrups spacing and of longitudinal reinforcement bars overlapping on the mechanical characteristics (stiffness, strength, ductility and energy absorption) of reinforced concrete specimens simulating columns subjected to combined axial and transverse actions.

1 INTRODUCTION

Analysis of damages occurred on reinforced concrete framed structures during strong earthquakes points up the fundamental role played by columns to oppose seismic actions; on the other hand their performance, depending on mechanical characteristics, is very sensitive to homogeneity and continuity lacks. On the basis of these remarks, a general program of research has started at the Dipartimento di Costruzioni, University of Florence; it consists of two phases, the first one experimental, the other one of analytic modelling.

The purpose of the research is to evaluate the influence that continuity and homogeneity lacks - due to concrete casting and actual reinforcement distribution - can have on seismic response of columns, producing unexpected performance of overall structure with respect to prediction of usual modellings.

In particular, the research intends to investigate perturbations connected with the following aspects:

- reinforcement: a) variation of stirrups spacing
  b) longitudinal reinforcement overlapping
- concrete: c) recasting zones
  d) concrete components segregation

in the case of transverse actions, both of monotonic and cyclic type, with different amounts of axial load.

In this work are illustrated results relating to the first phase of research, the experimental one, concerning effects of reinforcement discontinuities. Adopted transversal loading was of monotonic type.

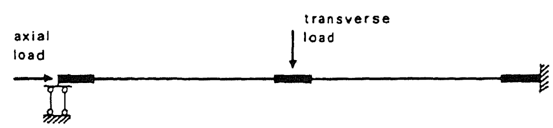

Figure 1. Theoretical scheme of test units.

2 DESCRIPTION OF TESTS

Test specimens consisted of two elements simulating lower floor columns of a multistory building, connected and restrained in a manner to realize, on the one hand, a geometric situation of fixed joint because of symmetry, and to average, on the other, results relating to two similar elements in the same test (Figure 1).

Three 1/3 scaled specimens have been tested:
- specimen A: characterized by uniform disposition of stirrups and longitudinal bars, specimen of comparison;
- specimen B: characterized by not uniform stirrups distribution along the member length, with a halved spacing close to nodal zones;
- specimen C: characterized by splice of longitudinal overlapping bars placed close to the central stub; lap length has been designed in conformity with italian regulations and according to several researchers advices, like Paulay (1982) and White-Gergely (1984).

Geometric dimensions and reinforcement details are illustrated in Figure 2. Longitudinal reinforcement consisted of 4 D8 mm bars, while transverse reinforcement consisted of closed D6 mm stirrups with overlapping 135 degrees hooks. All the bars were of deformed type.

Measured compressive strength of concrete

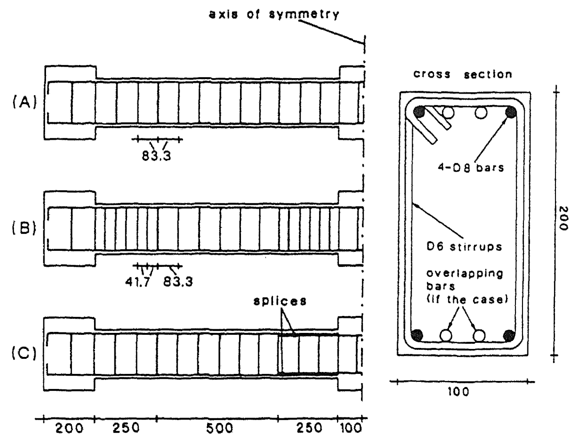

Figure 2. Geometric dimensions and reinforcement distribution of specimens.

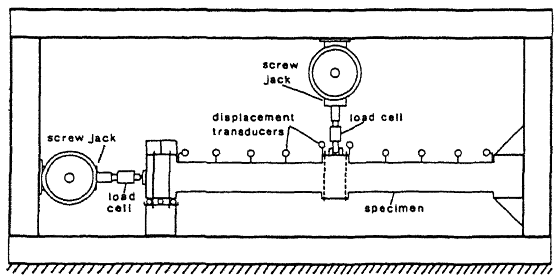

Figure 3. Test setup and loading arrangement.

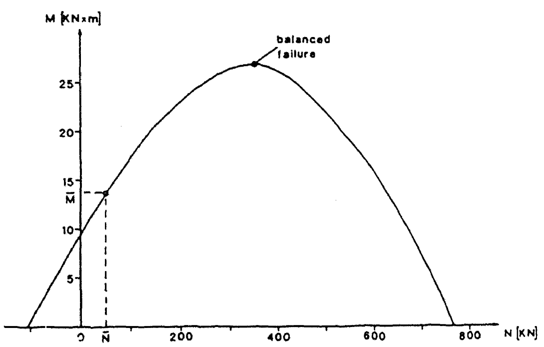

Figure 4. Theoretical interaction diagram for the tested R.C. columns ($\bar{N}$ = axial load of tests).

and yield stress of steel were, respectively, 39 MPa and 540 MPa.

Test setup and loading arrangement are illustrated schematically in Figure 3; 150 KN capacity screw-jacks were used to apply both the axial compressive force and the transverse action. The specimens were instrumented with

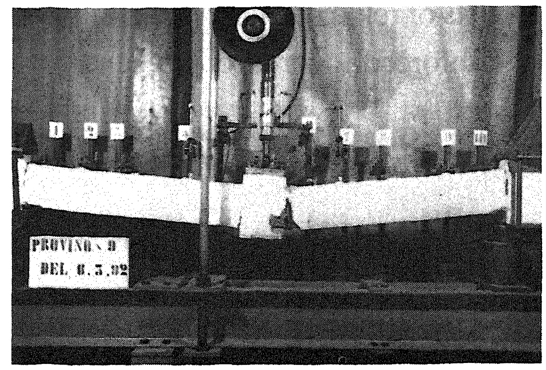

Figure 5. Failure mechanism of specimen B.

inductive and electric resistance transducers to measure lateral displacements at ten different locations. An automatic data acquisition system was used to record measurements carried out during the tests.

The axial load was kept constant during each test at a level of 50 KN, corresponding to approximately 25% of element allowable axial load (criterion usually adopted in high intensity seismic zones); the amount of axial load was then below the value corresponding to theoretical balanced point of section, in the zone of tension failure (Park-Paulay, 1975 and Giuffre'-Giannini,1983) (Figure 4).

Transverse load has been applied quasi-statically by controlled lateral displacement, following a monotonic history up to failure. Failure mechanism is shown, with reference to specimen B, in Figure 5.

3 RESULTS

Test results are shown in Figures 6, 7 and 8, where transverse load (F) versus displacement (δ) diagrams are plotted; on the curves the following characteristic points are emphasized:

- cracking point (CP)
- yielding point (YP)
- ultimate point (UP)

Secant stiffness $Kc = Fc/\delta c$ relating to CP and $Ky = Fy/\delta y$ relating to YP, strength Fmax, displacement ductility $\mu ka = \delta u/\delta y$, degradation index $\xi = (Fmax-Fu)/Fmax$ and energy absorption Eom relating to the three specimens are listed in table 1. Percent differences are related to values of specimen A.

A comparison of results of specimen A with those of B indicates that the different confinement characteristics do not influence load-displacement curves until yielding point; in fact, in this range, specimens A and B have a substantially analogous behaviour as testified by values of stiffness (Kc and Ky) and by amounts of first cracking and yielding loads (Fc and Fy). Beyond yielding point,

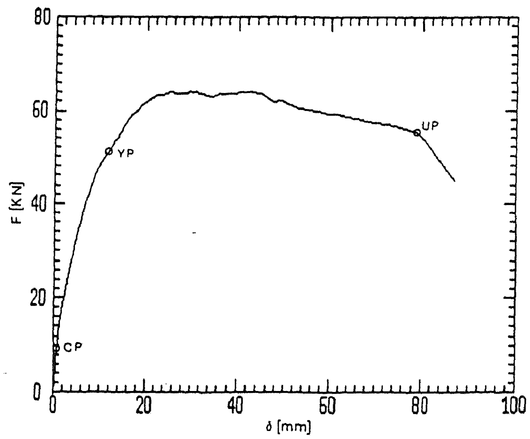

Figure 6. Load-displacement diagram: specimen A.

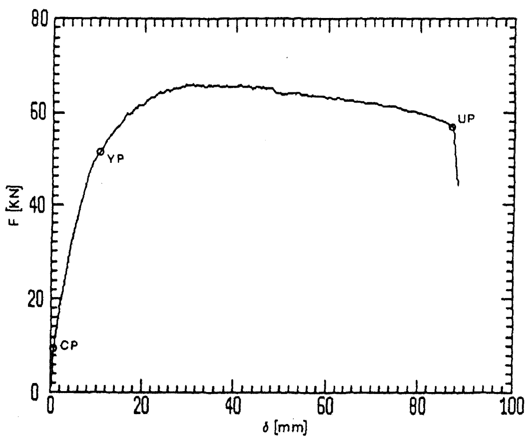

Figure 7. Load-displacement diagram: specimen B.

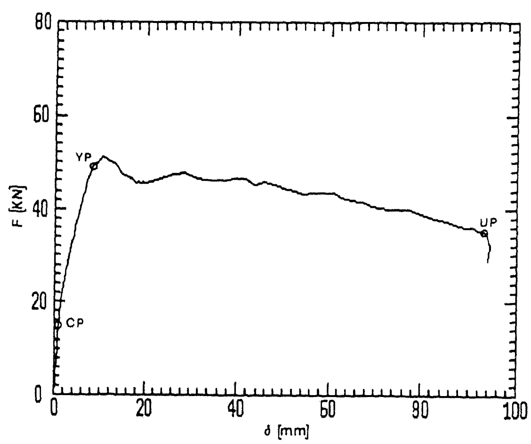

Figure 8. Load-displacement diagram: specimen C.

Table 1. Numerical test results.

specimen	Kc (KN/mm)	Ky (KN/mm)	Fmax (KN)	μka	ξ	Eom (KJ)
specimen A	12.7	4.46	64.4	7.10	0.166	4.59
specimen B	12.7 0%	4.91 +10.1%	66.1 +2.64%	8.30 +16.9%	0.145 -12.7%	5.13 +11.8%
specimen C	17.4 +37.0%	5.96 +33.6%	51.0 -20.8%	11.2 +57.3%	0.323 +94.6%	4.01 -12.6%

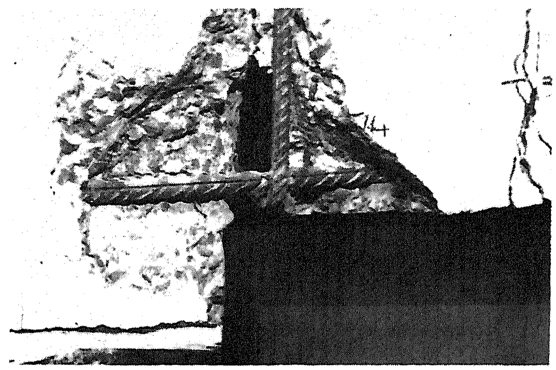

Figure 9. Detail of failure modality: specimen B.

moreover, it can be observed improvement due to closely spaced stirrups at the critical regions of specimen B, as testified by greater values of ductility factor and absorbed energy, with a lower strength degradation.

Figure 9 illustrates crisis modality of specimen B, characterized by breaking of bars in tension near the central stub.

Figure 10 shows how, in the case of specimen A, failure (near the central stub) is accompanied by compressed bars buckling, concrete crushing and transversal shifting phenomena.

Specimen C shows, with respect to specimens A and B, a greater stiffness in the initial phase of loading as well as a higher first cracking point. Beyond yield, reached at a load level very close to other specimens ones, a sudden decrease of strength happens due to onset of slippage of tensioned overlapping bars (Figure 11). In the post-yield phase specimen C performs, nevertheless, in an almost satisfactory manner as regards ductility, considering the greater, even if limited, strength degradation.

4 CONCLUSIONS

Analysis of experimental results leads to the following conclusions:

1. Closely stirrups spacing in critical regions of specimens (near nodes) produces an improvement of overall behaviour, as obtained by several experimental investigations (see,

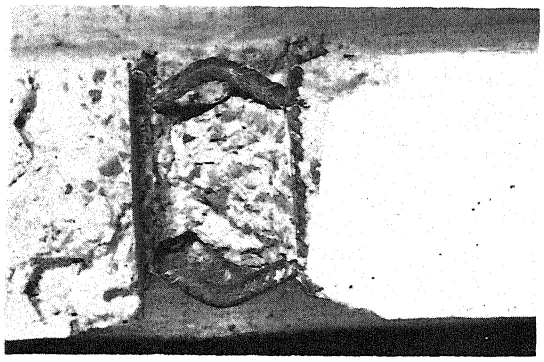

Figure 10. Detail of failure modality: specimen A.

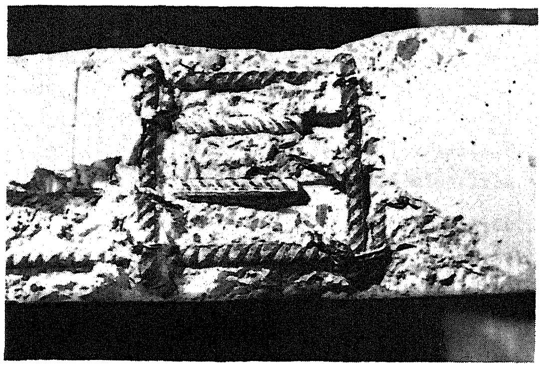

Figure 11. Detail of failure modality: specimen C.

among others, Atalay-Penzien, 1975 and Park-Zahn-Falconer, 1975). However, structural response in term of stiffness, strength, ductility and absorbed energy does not point out very substantial differences between specimens A and B, considered also the low amount of axial load.

2. Specimen C response, on the contrary, induces to consider with a particular caution presence of overlapping bars splices in critical regions of columns. In fact, stiffness increase in the elastic phase, due to a greater reinforcement concentration in the critical regions, could draw in these elements unexpected increase of stress; to such an increase corresponds a lower strength capacity if splice length is calculated conforming to current normative provisions.

Further indications will be furnished by means of experimental tests directed to investigate specimens behaviour in presence of reversed cyclic loading and for different amounts of axial load.

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