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SEISMIC BEHAVIOUR OF CIRCULAR COLUMNS: AN EXPERIMENTAL RESEARCH

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SUMMARY

An experimental investigation to determine the behaviour of reinforced concrete circular columns subjected to earthquake-type loading is presented.

Four full-size columns assembled to a cut down of beam were tested.

The experimental results showed a good harmony with a theoretical model. The tests also showed a significant and remarkable rotation of the column, around its longitudinal axis, when a considerable disaggregation of the concrete is reached: this fact must be correlated with the windup direction of the spiral.

The authors advice to adopt 50% right-hand and 50% left-hand spirals to prevent the tendency of the whole building to rotate.

INTRODUCTION

Reinforced concrete moment resisting frame buildings, during earthquake of moderate or strong intensity, are subjected to large inelastic deformations. The critical building members must therefore be designed and detailed to withstand large cyclic deformations without any significant loss of strenght and stiffness. In a frame, the columns constitute the most critical components because the collapse of buildings generally dipends on the failure of the columns. Infact, whereas beams and slabs generally do not fall down even after severe damages at plastic hinge positions, columns will rapidly collapse under their vertical loading once sufficient spalling has taken place.

The behaviour of structural r.c. elements, subjected to cyclic plastic deformations, has been object of remarcable attention in the last years;particularly the most investigated subject, both theoretically and experimentally, has been the behaviour of rectangular cross section columns. About circular columns, viceversa, the theoretical and/or experimental works are relatively insufficient.

The difference between rectangular and circular section elements is not very large. But some parameters such as the post-critical ductility and the collapse mechanisms are rather different; that is due to different geometry of reinforcement.

The present paper illustrates a comparison between the experimental and theoretical behaviour of four full-size circular columns, equal to those of a building to be used as a bank (1) (Fig.1), subjected to combined normal and flexural cyclic stress.

<u>Building description</u> This study has been carried out to chek the columns structural behaviour in a construction built in a seismic area.

(1) Branch of Banca Toscana in Ponte all'Ania, Garfagnana, Italy.

The building is located in a zone of the Italian territory subjected to high seismic risk. It has three stories, basement included. The building structure is constituted by reinforced concrete frames, placed along two orthogonal directions; the beams have rectangular section and the columns circular section. The beams and the columns are geometrically all equal among them, except the volumetric ratio of reinforcement. The slabs are constituted by reinforced concrete and hollow tiles mixed floor.

Fig.1 Branch of Banca Toscana in Ponte all'Ania.

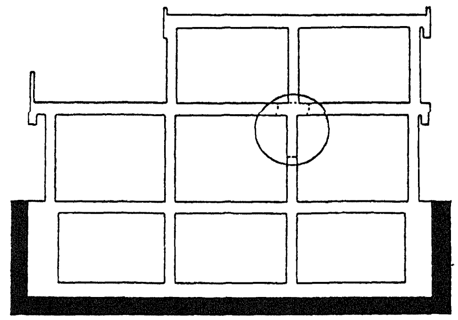


Fig 2 Frame of the structure

At first, the structure has been designed by the admissible stresses method. Then the theoretical determination of the structural behaviour in the elasto-plastic range was adopted to determine the overall ultimate strenght to strong earthquakes.

It was particularly necessary to verify if the collapse kinematisms of frames with circular columns reinforced by a continuos spiral stirrup were different from those of usual frames.

In order to verify the reliability of theoretical results we believed necessary to carry out adequate experiments on structural members (columns) in which the arising of remakable crumbling phenomena could cause the collapse of the building.

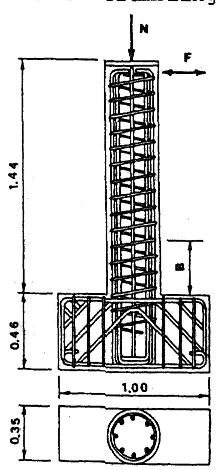


Fig.3 Tested specimen.

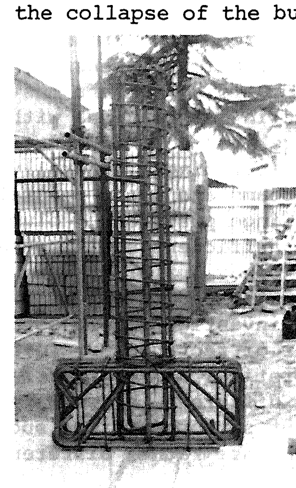


Fig.4 Specimen reinforcement.

Specimens A critical point of the structure is represented by the zone of the columns adjacent to the connection between columns and beams (Fig.2). Therefore the tested specimens were designed as shown in Fig.3 and 4.

As it can be observed, the specimens were formed by a full-size circular semi-column and a cut down of beam.

The reinforcement of the cut down of beam, because experimental requirements (anchorage of the specimens) was different from the actual one. On the contrary, the reinforcement of the semicolumn, constituted by 8∅20,was exactly equal to that of the columns of the building.

On the top, the column had square section to allow the connection with the two hydraulic actuators. Since this part was sufficiently far from the zone in which the plastic hinge occurs, we can reasonably beleve the results were not notably influenced.

Materials Tension tests on the reinforcements of the specimens have been carried out; the values of the measured parameters are reported in table I.

TABLE I

	∅ (mm)	f_{yk} (MPa)	f_{tk} (MPa)	A_5 (%)
Longitudinal bars	20	505	752	24
Spiral reinforcement	10	482	764	24

where:
- ∅ nominal diameter;
- f_{yk} yield stress;
- f_{tk} characteristic strength;
- A_5 rupture elongation on 5 diameters.

The characteristic cube strength, R_{ck}, of the concrete, resulted equal to 47 MPa.

Marks of the specimens The names adopted to distinguish the specimens follow a convention used previously for similar experiments too (Ref.1). They are like:

nBC20

where n is the serial number of the specimen, the second letter (B) shows that the test is made on the upper semicolumn , the third letter (C) indicates the shape of the column (circular) and, finally, the number 20 indicates the diameter of the longitudinal bars (mm).

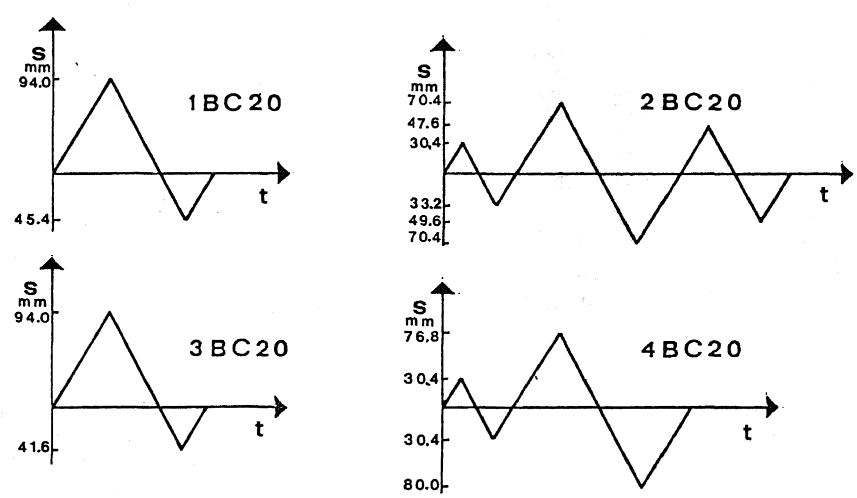


Fig.5 History of the transverse displacement.

Load history The specimens have been loaded by two double effect servo-controlled hydraulic actuators, which applied, respectively, a constant axial load and a transverse cyclic displacement, which varied during the tests. To be precise, the models 1BC20 and 2BC20 were subjected to a compression of 300 KN (constant during every test), while the specimens 3BC20 and 4BC20 were subjected to a compression of 150 KN.

The two adopted values (300 and 150 KN) approximately correspond to the maximum and minimum loads provided by the designer of the structure.

The history of the transverse displacement is shown in Fig.5. As it can be seen, the displacement history is composed by ramps; the displacement velocity was constant in all the tests.

Test setup and instrumentation The test setup was constituded by a steel frame to which the specimen were restrained; the two hydraulic actuators were restrained to the same frame by spherical hinges (Fig.6).

The actuators were worked by a electro-hydraulic MTS system. During every test, the following measures were collected:

- axial load, by a load cell in series with the actuator;
- transverse reaction of the specimen, by a load cell as above;
- transverse displacement, refferred to the restrainted base of the column;
- curvature of the part of the column adjacent to the fixed end, measured on two measurement bases, the lenght of which were 175 and 350 mm respectively (Fig.7);
- deformations of the steel and the concrete near the constrained zone by four strain gauges (two on the longitudinal bars and two on the concrete surface).

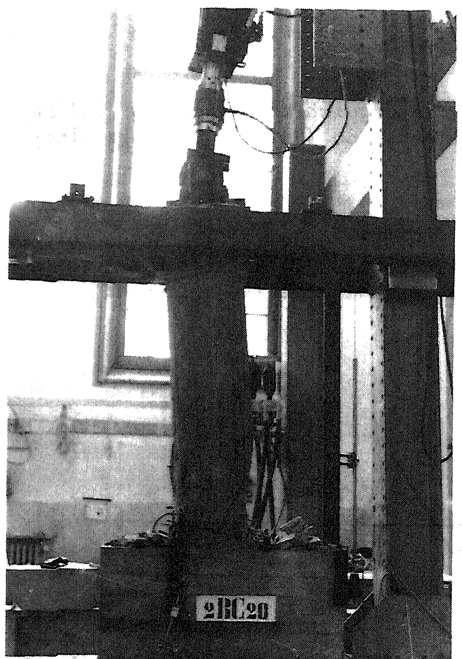


Fig.6 Test setup.

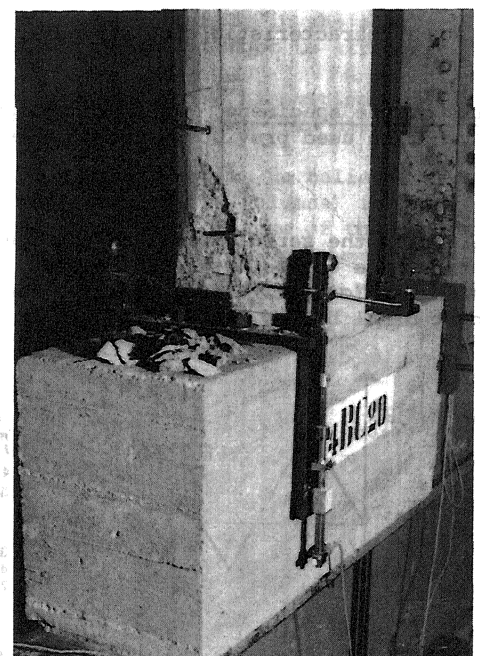


Fig.7 Device for curvatures measuring.

Experimental results Some of most significant experimental results are reported in table II. In the first column of the table is indicated the specimen name; in the second, the axial load N and in the third, the maximum bending moment; in the fourth column, the maximum deformation reached in the compressed concrete; in the fifth column, the maximum curvatures measured on two different bases (175 and 350 mm); in the sixth column, the percentage deviation between the measures on the two bases.

Some other results are reported in Fig.8.

TABLE II

(1) Specimen name	(2) N (t)	(3) M_{max} (KNm)	(4) Max. deformation in the concrete	(5) Max. curvatures (Rad/mm)x10^{-5}		(6) d (%)
				on 175 mm base	on 300 mm base	
1BC20	30	190	0.0041	29.8	19.8	50
2BC20	30	222	0.0041	-	-	-
3BC20	15	185	0.0033	32.0	19.2	66
4BC20	15	183	0.0032	25.4	15.7	62

Theoretical-experimental comparison The experimental results have been compared with the theoretical forecasts coming from a well known constitutive law (Ref.2). In order to consider the double efficiency of the spiral stirrup regarding to the concrete confinement, the parameter Z has been taken as it follows:

$$Z = \frac{1}{2} \frac{0.5}{E_{50u} + E_{50h} - 0.002}$$

where:

- $E_{50u} = \dfrac{3 + 0.002 f_c}{f_c - 1000}$
- $E_{50h} = \dfrac{3}{4} r_s \sqrt{\dfrac{b}{s_h}}$

- f_c is the cylinder strength of the concrete, equal to 0.85 R_{ck};
- r_s is the ratio between the volume of spiral reinforcement and volume of core;
- b is the perimeter of the confined core measured outside of the spiral;
- s_h is the pitch of the spiral.

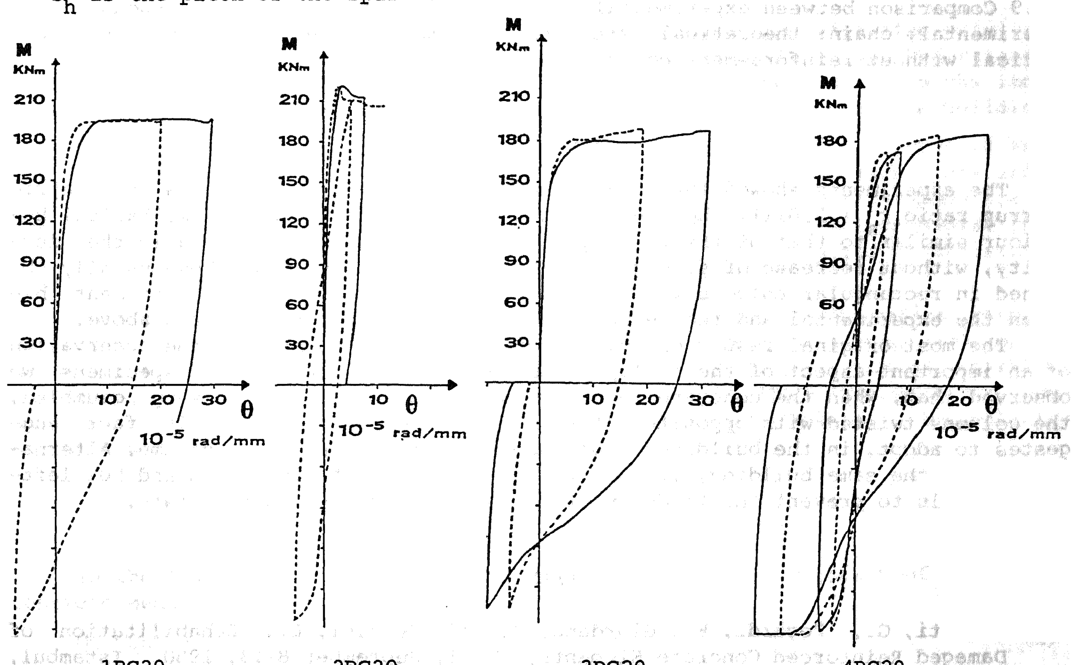


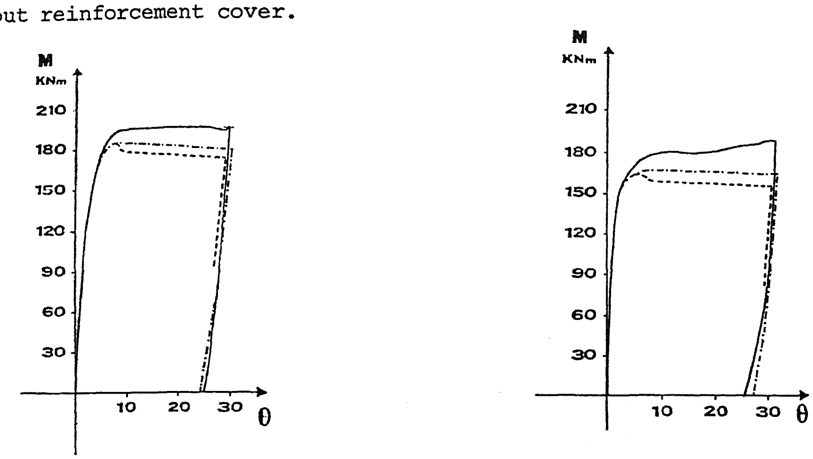
Fig.8 Relationship between the bending moment and the curvature (continuous line: 175 mm base; dashed line: 300 mm base).

To determine the section behaviour, we followed two different ways with and without the expulsion of the concrete outside the confined core.

Discussion of the results The experiments confirmed that the maximum allowable deformation in the concrete is about 0.004 also for circular colomns.

The Fig.8 shows the relationship of the bending moment in the constrained section as function of the curvature measured on two different bases. As we can observe, the different axial load (300 and 150 KN) does not influence sensibily the ductility values. Moreover,untill the reached curvature values, we did not observe no significant strength decreasing.

The Figs.9 (specimens 1BC20 and 3BC20) shows, only for the first semicycle, the comparison between the experimental and theoretical behaviour, calculated with and without reinforcement cover.



1BC20 3BC20

Fig.9 Comparison between experimental and theoretical behaviour (continuous line: experimental; chain: theoretical with reinforcement cover; dasced line: theoretical without reinforcement cover).

CONCLUSIONS

The experiments showed that the tested circular columns (with a volumetric stirrup ratio,r_s = 0.011), when subjected to cyclic stress, have a mechanical behaviour similar to that of the rectangular section columns. Particularly the ductility, without decrease of strength, reached values better than those usually obtained in rectangular columns with medium stirrup ratio. The good agreement between the experimental and theoretical results confirms what exhibited above.

The most original result of this experiment is represented by the observation of an important aspect of the collapse kinematic motion. In all the specimens we observed that, when the concrete in the constrained zone resulted very crumbled, the columns twisted with opposite rotation to that of the spiral. This fact suggestes to adopt, in the buildings, two opposite spirals in every column. Alternatively, in the same building, it is advisable to have 50% right-hand and 50% left-hand spirals to prevent the tendency of the whole construction to rotate.

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