COLUMNS WITH SPIRAL REINFORCEMENT UNDER CONCENTRIC COMPRESSION

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Abstract

The work is experimental and has to do with the behavior of circular cross-section (piles or columns) under axial compressive load. 10 column specimens having a diameter of 205mm and height 800mm were studied. The main parameters whose influence was examined are: (1) Spiral reinforcement ratio, (2) Density (step) of spiral reinforcement, (3) The ductility of spiral reinforcement, (4) The strength of spiral reinforcement and (5) Opportunities for improving the mechanical behavior (strength and ductility) of these components by using either special ties or fiber reinforced concrete. Using experimental results, stress-strain diagrams σ-ε are constructed from which interesting conclusions emerged.

Keywords: *Columns, Spiral reinforcement, Compression, Circular*

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1. INTRODUCTION

There is no mechanical property in which the columns of circular cross section with spiral reinforcement lag behind their counterparts rectangular ones. Their implementation in the areas of negligible seismic hazard is possible to achieve a reduction of the cross section due to significantly improved strength due concrete confinement stemming from the presence of spiral reinforcement. In earthquake zones, they exhibit their superiority thanks to their increased ductility. It is well-known the case of columns of Olive View Hospital which made history in the San Fernando earthquake of 1971 [1-3].

Some of the reasons that the columns in question account deprived, at least in our country, the spread they should be entitled to are constructional, e.g. the problem of their formwork or the construction of the spiral reinforcement. But today with the proliferation of one-use paper formwork and the possible standardization of metallic spirals, construction barriers are lifted and perhaps the only ones left from the obstacles is the lack of knowledge of the benefits and the momentum of the past that is certainly in favor of rectangular section columns.

The strange thing, however, is that the regulations do not give the proper attention to their design, especially the seismic design. E.g. there is no prediction for their check against shear. Also, if someone compares the related article &18.4.7 of a previous issue (1991) of the Greek Concrete Code [4] with the same article in the most recent version of the reformed Greek Concrete Code (2000) [5], he can observe a significant variation with respect to the minimum acceptable reinforcement ratio, which was equal to 2% in the older version compared to 1% in the new version. In the authors' opinion, this large difference can be attributed only to a lack of reliable knowledge.

A modern problem that its treatment is associated with the use of spiral reinforcement is the applications of high-strength concrete (HSC), i.e. improved concrete strength greater than the maximum specified quality (C50) of the Regulations [4-6]. More precisely, according to the literature, high strength concretes are characterized those possessing strength above 80 MPa. But it is known that as concrete strength increases the more brittle concrete becomes, respectively steel loses its ductility increased when its yield strength increases. In the concrete case, "drugs" are two: (a) Confinement using spiral reinforcement and (b) Adding fibers to the concrete (fiber concrete) uniformly distributed and randomly dispersed throughout its mass. Fig. 1 shows a gradual lifting of the brittleness of concrete by incorporating therein various percentages of steel fibers. Also Fig. 2 shows a further reduction of brittleness by applying varying degrees of confinement using spiral reinforcement. It is also observed in the latter case that while brittleness is reduced, concrete material strength significantly increases.

As is known, the brittleness of concrete, which is manifested by the steep slope of the downward branch of stress-strain diagram σ-ε, is due to the establishment of internal cracks between aggregates and hardened cement [7]; a phenomenon that results to an increase of the slope of the downward branch of the stress-strain diagram. The influence of confinement begins to manifest itself when internal cracking causes swelling of the material. For this reason, the spiral reinforcement shall not affect the rising branch of the stress-strain diagram σ-ε and its contribution is reflected therein, when load approaches the strength of the material. Improvement of concrete mechanical characteristics due to confinement in accordance with the rules of CEB is given in Model Code (1991) [8].

Finally, the primacy of circular cross-section columns with spiral reinforcement is not limited to the compressive axial stress state, but extends to other stress states, too, like bending and punching shear. This is due to the fact that the adverse effects of inclined seismic stress, which causes a significant reduction of the mechanical properties of seismic structural elements, such as strength, stiffness and energy absorption capacity, do not occur to circular columns. This advantage of columns of circular cross-section over the corresponding square ones covers the small difference in flexural strength (≈ 10%) observed between the two types of columns when they do not differ in: the longitudinal reinforcement, confinement reinforcement, core cross-sectional area, qualities of materials and axial loading (see Fig. 3).

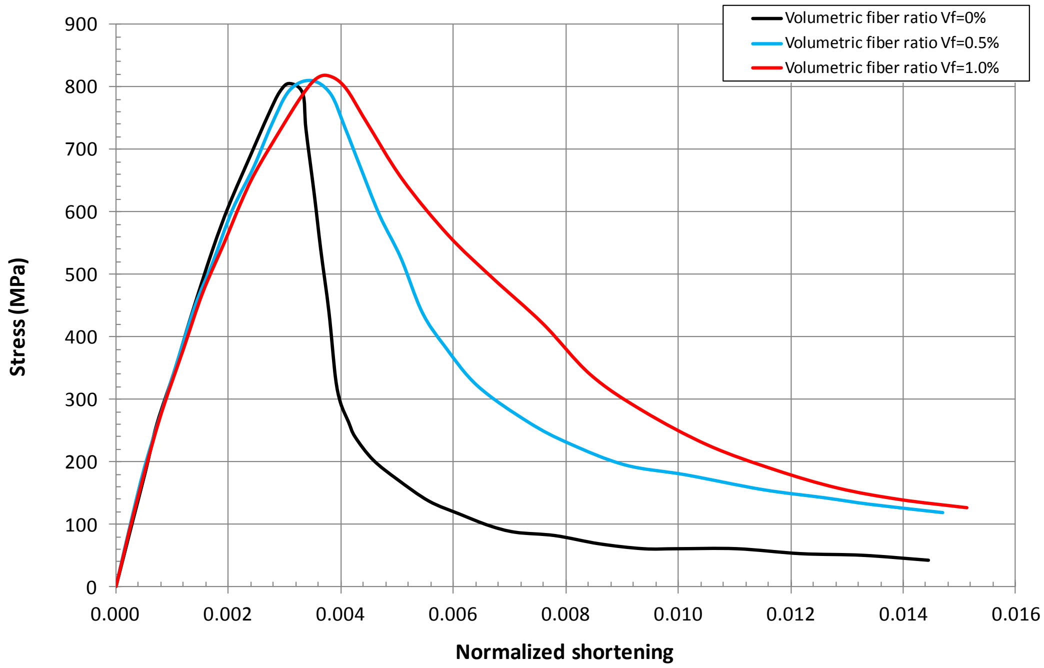

Fig. 1: Improvement of downward branch of concrete stress-strain diagram σ-ε by incorporating metal fibers in its mass

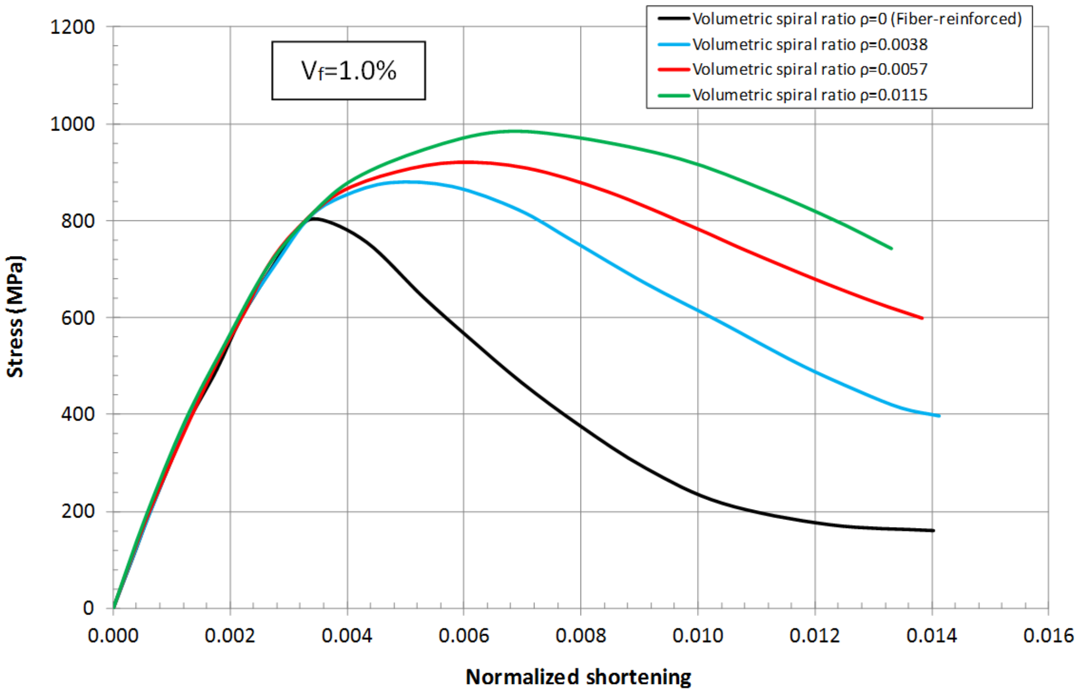

Fig. 2: Additional improvement in the mechanical behavior of fiber-reinforced concrete by confinement with the use of spiral reinforcement

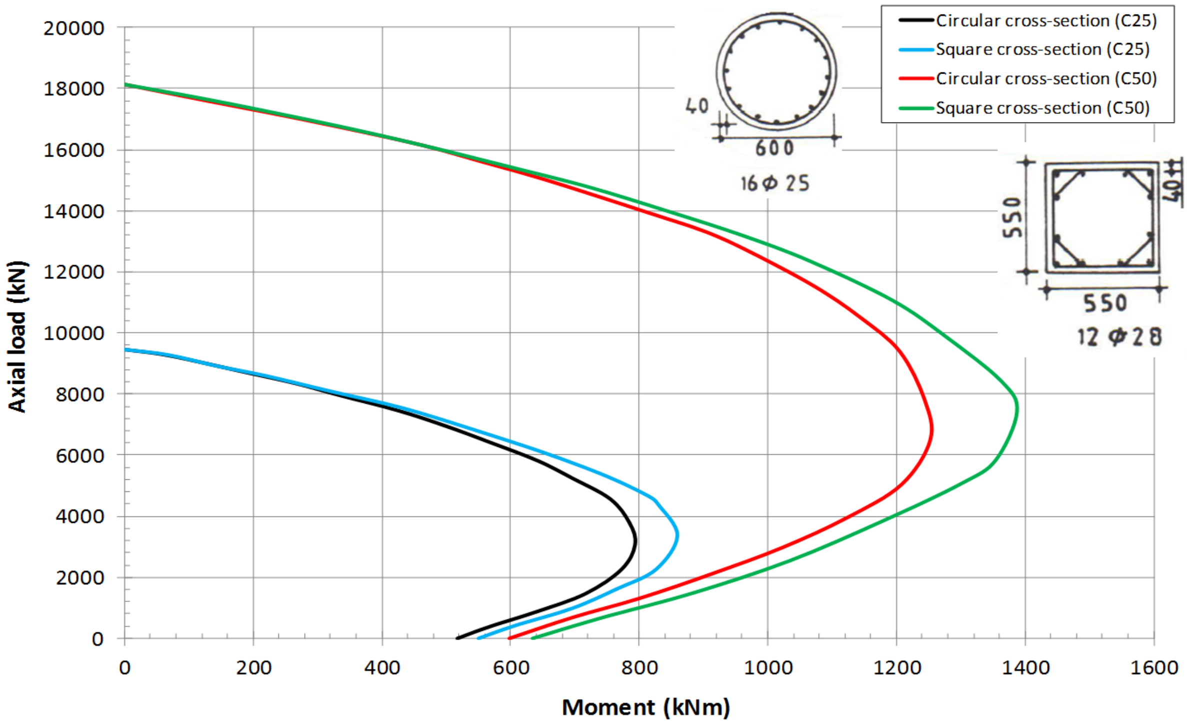

Fig. 3: Strength comparison of columns with square section and circular cross-section for two cases of concrete quality

2. EXPERIMENTAL INVESTIGATION

2.1 Objectives – Variables

The present study is part of research program that took place in the Laboratory of Reinforced Concrete and Masonry Structures at the Department of Civil Engineering of the Aristotle University of Thessaloniki.
Key objectives of the work are the following:

a) Consideration of the possibility of improving the results of confinement with various combinations of means.
b) Investigation of the influence of the ductility of steel on the results of confinement.

The parameters studied in this paper mainly refer to the characteristics of spiral reinforcement as:

a) The step of the spiral
b) The diameter of the spiral
c) The yield limit of the spiral
d) The ductility of the spiral

In the context of examining the possibilities of improving the results through appropriate combinations of spiral reinforcement with other ways of improving confinement, the following combinations of spiral reinforcement with other materials were tested:

a) Fiber reinforced concrete
b) Conventional ties

As mentioned in the introduction, the combination of spiral reinforcement and steel fiber reinforced concrete contributes effectively to the removal of brittleness of high-strength concretes [9-13]. The second way, however, which is easier to enforce arose from a real problem of a technical work which was built in the northern part of Greece. This project included pile-columns which were detailed with strong longitudinal reinforcement, but not sufficient spiral reinforcement. Against this background, the supervision of the project called for measures to complete the transverse reinforcement. Since, however, it was not possible to remedy the densification of already installed spiral reinforcement, it was envisaged the completion of the spiral reinforcement with conventional ties, which was easy to install as pairs of opposite stirrups (see Fig. 4).

The Supervision does not confine itself to the computational coverage of the "solution" in accordance with paragraph &18.4.4 of the Greek Concrete Code [5] and a further experimental investigation of the possibility of superposition of the two ways of confinement was attempted.

The parameters which remained unchanged in the specimens of this work are the quality of the concrete that was kept constant for all specimens, and the longitudinal reinforcement, which was absent from all specimens.

It is noted that three cases of spiral reinforcement step were examined, i.e. 20, 35 and 50mm. The middle of them meets the minimum requirement of the Greek Concrete Code [5], according to which the maximum step should not exceed 20% of the diameter of the core section (35 = 0.2 x 175). The other two values are symmetrical with respect to the previous one and the first one responds to strong confined columns while the third one is outside of the Code's limits [5].

Two diameters of spiral reinforcement were chosen in combination with one of the two main objectives of the research, which was the investigation of the influence of ductility of spiral reinforcement to the results of confinement. Diameters Ø4.2 and Ø5.5 were chosen, of which the first relates to steel practically having no ductility with failure strength equal to 800MPa while the second relates to ductile steel with failure strength equal to 475MPa. Stress-strain diagrams for the two kinds of steels are given in Fig. 5. Selection criterion for the diameters with the characteristics previously described was the same tensile capacity in both cases and the difference was that in one diameter (Ø4.2) there was no steel ductility, while in the other diameter (Ø5.5) there was available the ductility of steels characterized by the Code [5] as S400. Mechanical reinforcement percentages corresponding with steps s are calculated from the relationship $\omega_w = (4 \cdot A_s \cdot f_{ys}) / (D \cdot s \cdot f_c)$, where A_s is the area cross-section of the spiral, D the core diameter, s is the step of the spiral and f_{ys} and f_c are the strengths of materials. So for the three cases of steps equal to 20, 35 and 50mm, the corresponding mechanical reinforcement ratios were equal to 0.05, 0.03 and 0.02.

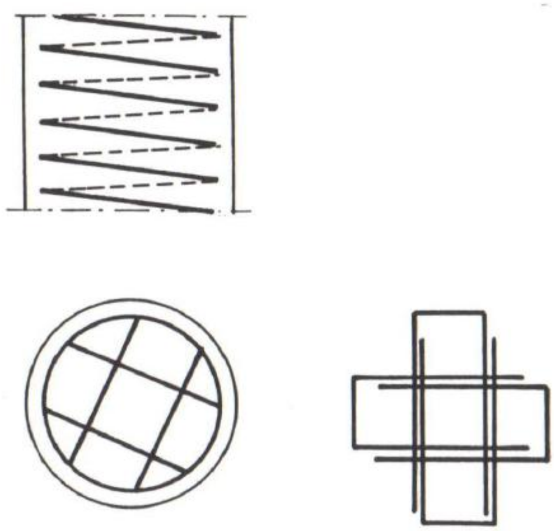

Fig. 4: Strengthening of confinement results by placing conventional ties

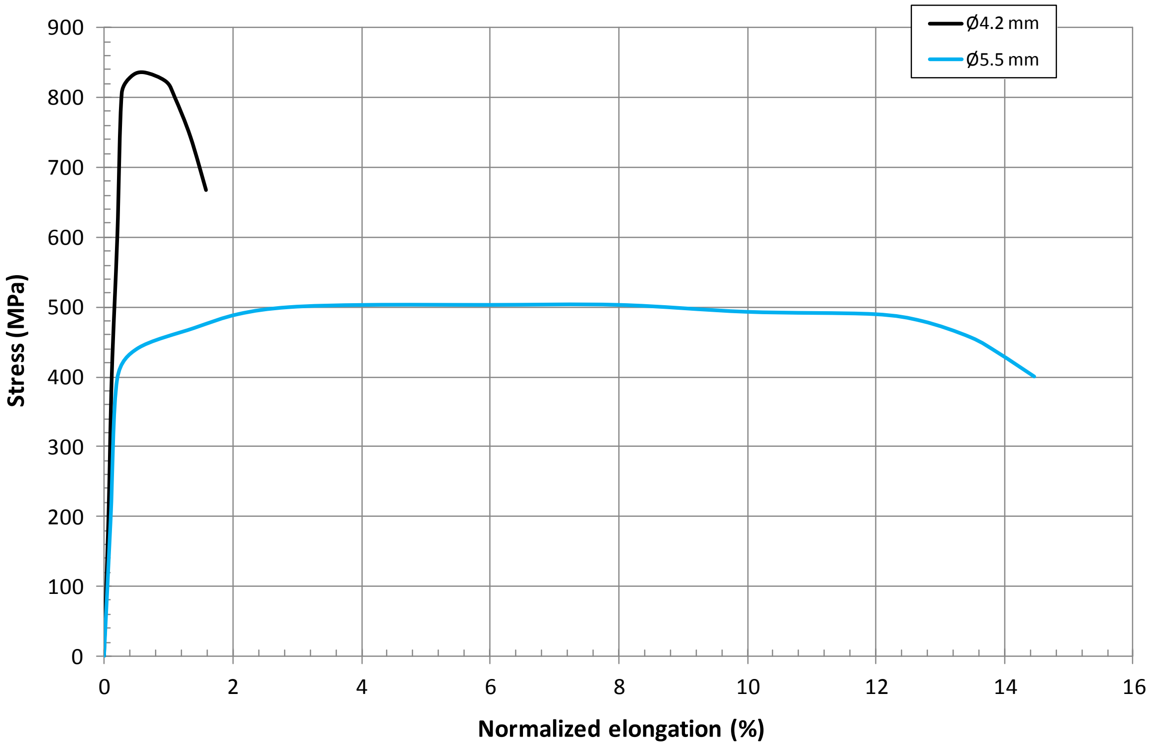

Fig. 5: Steel stress-strain diagrams σ-ε of specimens' spiral reinforcement

2.2 Specimens – Measurements

The work includes nine specimens of circular cross-section columns without longitudinal reinforcement and concrete quality around C25. Table 1 gives the characteristics of the specimens' spiral reinforcement. The last column of the table gives the additional ways of improving confinement, involving only the specimens 8 and 9. Conventional ties of specimen 8 have the cross form of Fig. 4. The diameter of the ties is Ø4.2 and distances between them equal to 35mm. Also, the fiber-reinforced concrete of specimen 9 has metal fiber content equal to V_f = 0.75% by volume. The fibers have an aspect ratio l / d = 60.

Test specimen 1 was constructed as unreinforced for comparison purposes and for assessing the contribution of spiral reinforcement to the improvement of the strength and confinement.

The dimensions of the specimens are given in Fig. 6 and their outside diameter is 205mm, their core diameters 175mm and their height 800mm.

The spiral reinforcement was constructed by means of a suitable drum. Drum diameter was smaller than the final diameter of the spiral to take account of the inevitable "fluff" after the drum.

At the end parts of the specimens, the pitch of the spiral reinforcement was condensed to 10mm to eliminate the impact of manufacturing defects in these critical areas, which (defects) could cause premature failure due to rupture phenomena.

Such spirals were placed also at the edges of the unreinforced specimen 1. Fig. 7 shows the spiral reinforcement of a specimen with the pitch inspissation at the ends.

The concrete specimens had maximum grain aggregates equal to 16 mm. The concreting of test specimens took place on a vibrating table together with six cylindrical specimens 15/30cm used for quality control of concrete. Concrete strength of 25MPa was found with the help of these control specimens. The maintenance of all specimens occurred within a water tank.

Once the specimens acquired the desired strength of 25MPa, they were placed on the load device (laboratory press). Afterwards, they underwent a gradual and relatively slow paced axial compressive load while at the same time, the shortening of specimen was recorded at load steps of 50kN (see Fig. 8).

Recording of shortening took place with the help of a suitable strain gauge of a large range. Based on the experimental results, stresses and strains of specimens could be calculated. In this way, for every test specimen, a stress-strain diagram σ-ε was constructed.

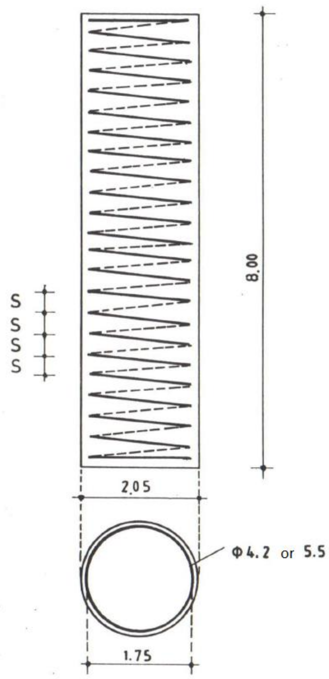

Fig. 6: Typical test specimen

Fig. 7: Typical specimens' spiral reinforcement

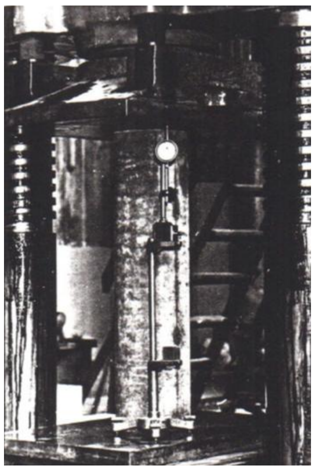

Fig. 8: Test setup

Table 1: Characteristics of specimens' spiral reinforcement

Specimen	f_c (MPa)	Spiral reinforcement						
		Ø (mm)	s (mm)	f_{ys} (MPa)	Ø (mm)	s (mm)	f_{ys} (MPa)	Additional confinement
1	25.5	-	-	-	-	-	-	
2	26.0	4.2	20	800	-	-	-	
3	25.0	4.2	35	800	-	-	-	
4	26.0	4.2	50	800	-	-	-	
5	25.5	-	-	-	5.5	20	475	
6	24.5	-	-	-	5.5	35	475	
7	24.0	-	-	-	5.5	50	475	
8	24.5	4.2	35	750	-	-	-	Ø4.2/35
9	26.0	4.2	35	750	-	-	-	Fiber-reinforced with V_f=0.75%

3. EXPERIMENTAL RESULTS

Fig. 9 shows the results of the present work in the form of stress-strain diagrams σ-ε for all specimens of this work. Diagrams reflect essentially the degree of confinement, developed according to the pitch, diameter, the strength and the ductility of the specimens' spiral reinforcement. Also, stress-strain diagrams σ-ε of the two specimens, in which confinement was achieved using two different means, display the degree of compatibility of these different means of confinement.

Specifically, as far as the behavior of the specimens during loading is concerned, it can be stated that:

a) Specimen 1, without spiral reinforcement, failed suddenly with the appearance of longitudinal cracks mainly. Failure stress of the unreinforced specimen, despite the expected influence of the size effect, did not differ from that of the control cylinders f_c = 25MPa.

b) The remaining specimens which had transverse spiral reinforcement showed peeling near the maximum failure load after which the downward branch of the diagram exhibited steep slope or softer slope depending on the developed confinement. Confinement also influenced the increase of failure load compared to the corresponding load of the unreinforced specimen. The maximum increase in resistance observed in densely reinforced specimens 2 and 5 was slightly greater than 40% of the strength of unreinforced specimen. But the calculation was based on the full cross-section of the unreinforced specimen and does not reflect the actual percentage of increase due to confinement, which underestimates. In the authors' opinion, the increase in strength due to triaxial stress should be calculated based on the core diameter D = 175mm and not the full diameter of 205mm. Therefore the maximum strength increase due to confinement is estimated over 50% of the unreinforced specimen's strength.

c) At specimens with strong confinement, the strain ε reached a value of 3.5% and despite this, the column was able to bear the service load according to the Code [5].

d) Failure occurred in the specimens (except from the unreinforced one) with bursting fracture of the spiral reinforcement. The first break of the spiral reinforcement occurred for very large strain (shortening) and was followed by other fractures adjacent to the first break point of the spiral. At specimen 2 after unloading, six breakpoints of spiral reinforcement were observed, all at the central region of the specimen.

The event of a failure in the reinforcement was accompanied by a negative jump in the strength of the specimen. Multiple fractures caused rapid deterioration of resistance and increased the slope of the downward branch in the stress-strain diagram σ-ε.

e) An impressive behavior was notice at specimen 8 with the mixed transverse reinforcement (ties and spiral). While specimens purely reinforced with spirals were deformed after rupture of the spiral unilaterally (usually swelling of the area of mass failure of spirals), the specimen in question exhibited no swelling tendencies despite multiple failures of its spiral reinforcement. This is due to the containment of the material which could not, like in the other cases, expand from the punched core, but retained in position from the intact ties of the "wound" region. It is noted that no snap of ties were observed in the specimen. Slips of anchorages in the concrete mass are suspected.

f) Specimen 9 having a mixed confinement reinforced constituted from spiral reinforcement and steel fibers showed no significantly increased resistance compared with specimens 2 and 5, but had significantly improved the downward branch of the stress-strain diagram σ-ε.

Fig. 10 shows typical failure modes of representative specimens of this work.

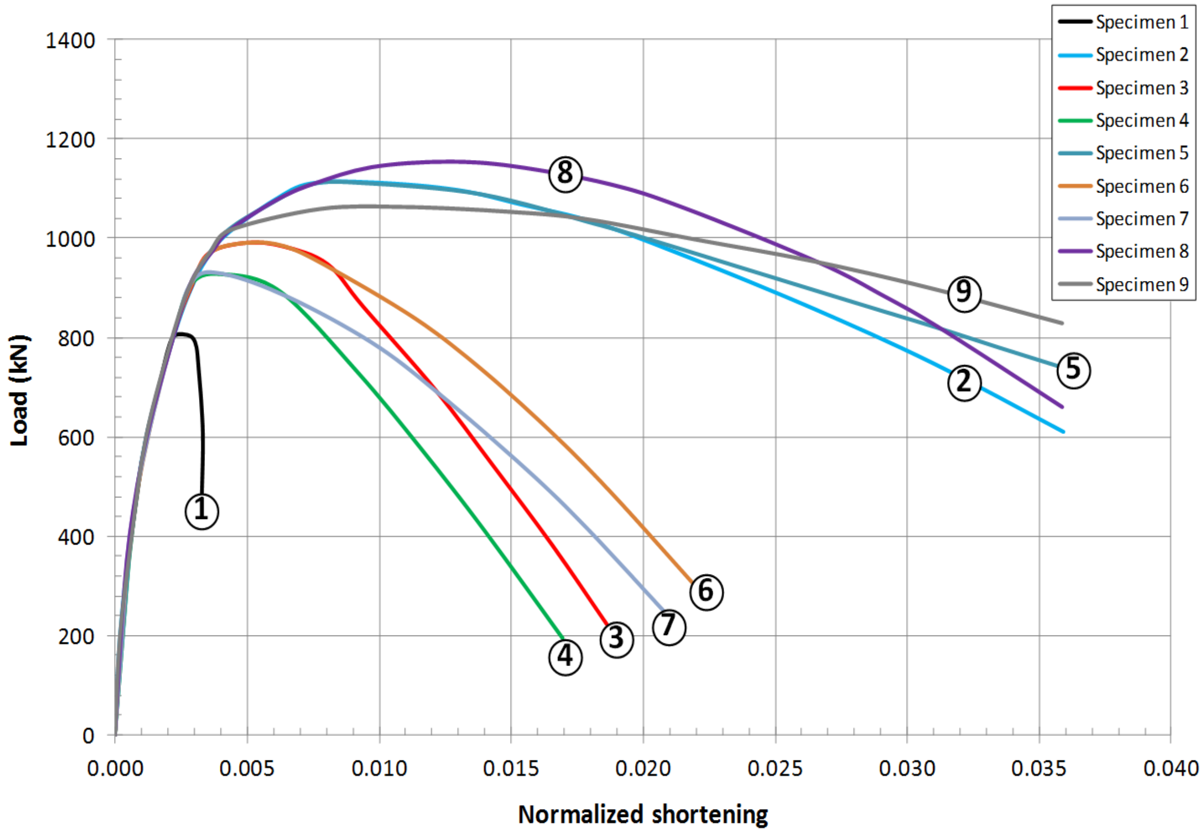

Fig. 9: Experimental results

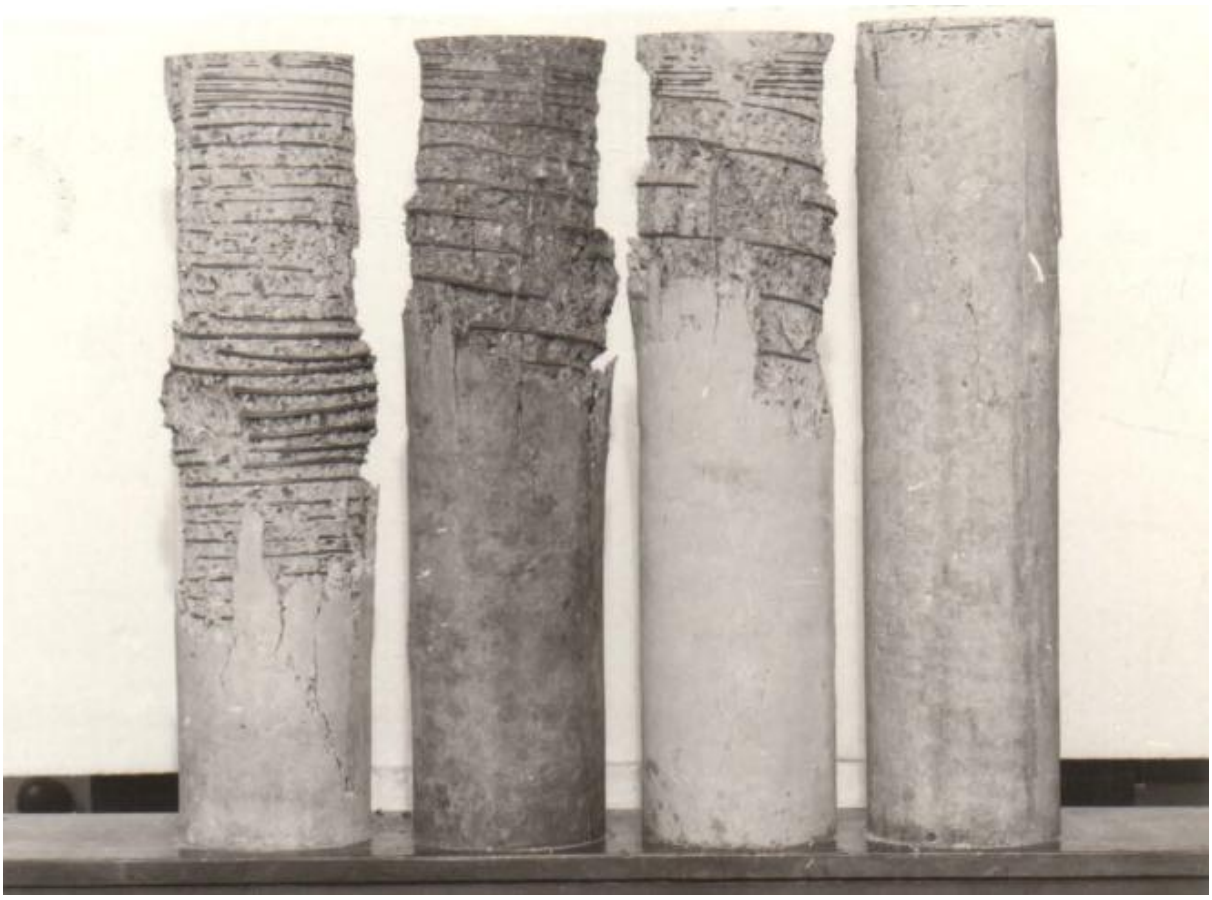

Fig. 10: Typical failure modes of specimens

4. CONCLUSIONS

The conclusions of this work can be summarized as follows:

1. The utilization of strong spiral reinforcement (ω_w = 0.05) achieves a significant increase in compressive strength of the columns, of the order of 50%, and a dramatic increase of failure strain, which is about tenfold.
2. Steels with high yield limit are particularly efficient as confinement reinforcements.
3. High ductility of confinement reinforcement improves the maximum value of strain (shortening) ε_{cu} of the stress-strain diagram σ-ε.
4. Application of mixed type of confinement reinforcement constituted from spiral reinforcements and conventional ties is a particularly satisfactory type of confinement, which additionally gives the structural component the ability to retain its shape and part of its resistance, even after multiple failures of the spiral reinforcement.

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