# Improving Seismic Safety of RC Elements by Using Advantages of Rectangular Spiral Stirrups

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**SUMMARY:**

In the last decades, the prescriptions for RC structural seismic design have produced minor improvements in the steel reinforcement technology. In the fabrication and handling of reinforcement, an important amount (30 to 65 percent) of the resources is dedicated to transversal reinforcement stirrups.
If the technology used in fabrication of steel cages for circular section concrete drilled piles would be applied to common rectangular section concrete elements, significant benefits shall be obtained. The principle of rectangular spiral stirrups implies a rectangular loop that is unfolded like accordion to obtain the steel transversal reinforcement.
The benefits of using these new stirrups include: consumption of less material (savings ranging from 6 to 14 percent); the mitigation of element's failure due to stirrup opening; increased productivity; increased rigidity of the reinforcement cage prior to concrete pouring; time and energy savings in production. For validation purposes, comparative analyses have been carried out with ATENA 3D.

*Keywords: transversal reinforcement, spiral, improved behaviour, material savings, comparative analysis*

## 1. INTRODUCTION

During the latest earthquakes in Europe, and world wide, many classes of reinforced concrete RC elements have suffered while the structures were exposed to seismic/dynamic loading.

Looking into the latest development of the seismic prescriptions, aiming to prevent severe damages of RC elements, it has been noticed that there is relatively little concern on the shape and optimal placement of steel reinforcement in these types of structural elements. Although significant achievements have been reached in structural design and building engineering, minor improvements can be identified for the steel cage reinforcement assembly in the last decades.

When considering the RC linear elements (girders and columns), an important amount of resources are dedicated to fabrication and handling of the transversal reinforcement (stirrups). For a RC structural element, depending on the design data, geometry and location, the resulting cost of transversal reinforcement may reach a percentage of 65 from the cost of entire reinforcement cage of that structural element. In most cases, the longest operation in reinforcement cage fabrication is represented by production and assembling of the stirrups.

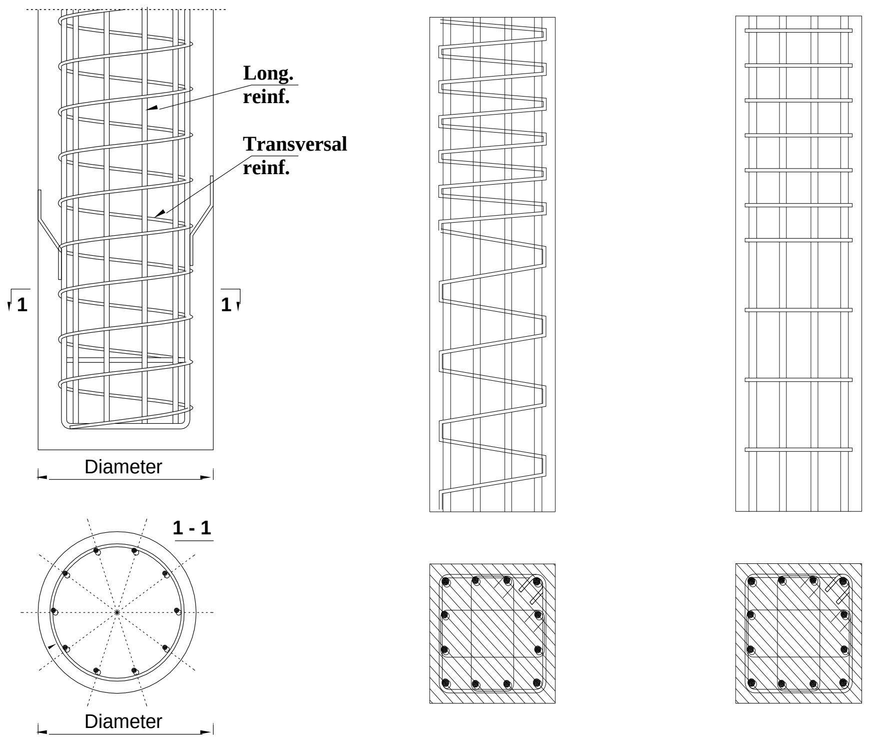
Significant benefits shall be obtained if the principles used in the fabrication of steel reinforcement cages for circular section concrete drilled piles will be applied to common rectangular section concrete elements. This paper deals with the advantages of using spiral stirrups in RC elements of constructions exposed to earthquakes. The constructive principle of rectangular spiral stirrups implies a constant section rectangular loop that is unfolded like accordion when used to obtain the steel cage reinforcement.

Several important structures collapsed due to stirrups opening when subjected to important seismic actions. This risk is minimized in the case of using spiral stirrups, since it consists of only one wire as transversal reinforcement, throughout the entire length of the element.

This paper is intended as a comparative study between usual stirrup elements, with anchorage end hooks, and rectangular spiral reinforcement. So, in order to obtain realistic data, identical assumptions and conditions will be considered for elements in both solutions.

## 2. ADVANTAGES OF USING RECTANGULAR SPIRAL STIRRUPS

The circular section concrete columns (or drilled piles) with spiral transversal reinforcement are easier to produce, require a shorter time to assemble, and when subjected to lateral loads the failure by stirrup opening is not an option. These advantages could be obtained for usual rectangular section by using the rectangular spiral reinforcement.




a. Circular column; b. Rectangular column with spiral stirrups (variable spacing) c. Rectangular column with usual stirrups (variable spacing).

**Figure 1.** Lateral views of steel reinforcement cage.

One of the main benefits when using rectangular spiral stirrups is material savings because there are not required end hooks for each section, in order to close the stirrup and ensure proper structural behaviour against stirrup opening.

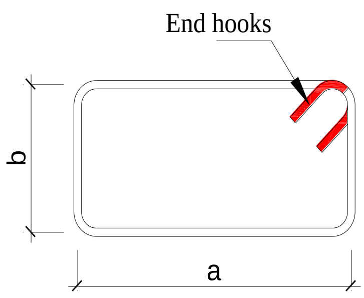
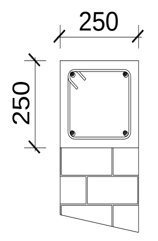
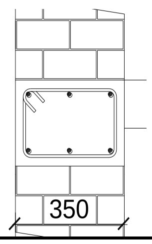
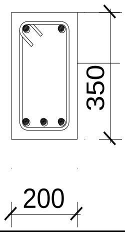
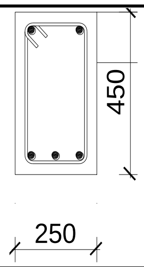
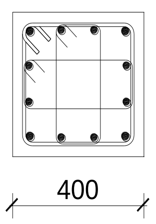


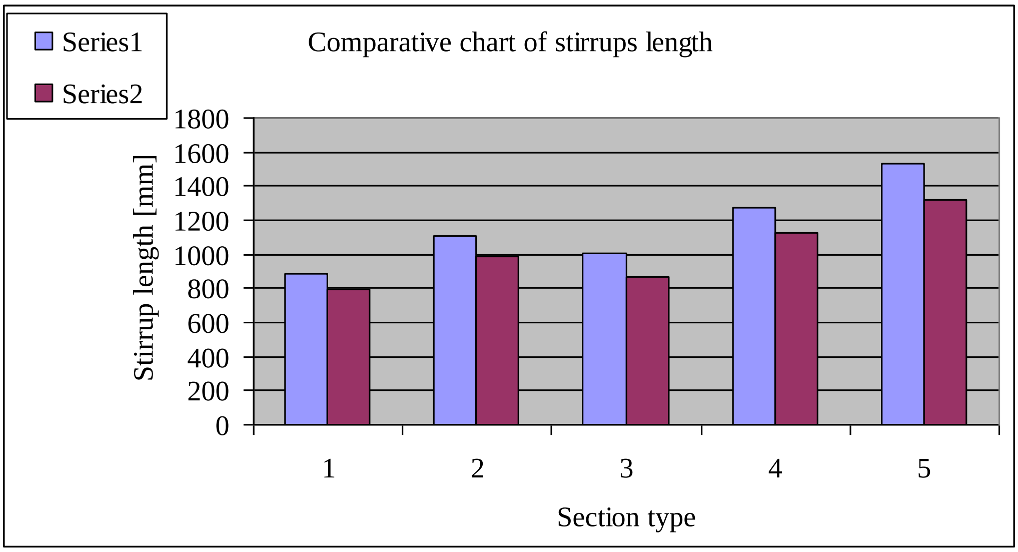

**Figure 2.** Main elements of a usual stirrup used in RC elements.

Further on this paper there will be comparative studies of various sections and dimensions of RC rectangular elements, based on total length of the stirrup, which consists on horizontal segments (a), vertical part (b) and anchorage end-hooks. In the same manner, the dimensions of the RC section will be referred as A and B.

**Table 2.1.** Data of the analysed sections of RC elements.

| |  |  |  |  |  |
|---|---|---|---|---|---|
| Element type | Flat (bond) beam | Flat (bond) beam | Beam | Girder | Column |
| Section size A x B [mm] | 250 x 250 | 350 x 250 | 200 x 350 | 250 x 450 | 400 x 400 |
| Stirrup dimensions a x b [mm] | 194 x 194 | 292 x 192 | 140 x 290 | 182 x 382 | 330 x 330 |
| Bar diameter Ø [mm] | 6 | 8 | 8 | 8 | 10 |
| Spacing [mm] | 200 | 200 | 150 | 100 | 100 |
| STIRRUP LENGTH [mm] | | | | | |
| Usual stirrups L1 | 890 | 1110 | 1010 | 1270 | 1530 |
| Rectangular spiral stirrups L2 | 796 | 987 | 870 | 1128 | 1317 |
| Length variation [%] (D/L1) | -10,56 | -11,08 | -13,86 | -11,18 | -13,92 |

Note: Usual stirrup length L1 is considered in accordance with minimal specifications of Eurocode 2.




Series 1 = usual stirrups
Series 2 = rectangular spiral stirrups

**Figure 3.** Comparative chart of stirrup lengths for the analysed sections of RC elements.
The data includes geometric characteristics of commonly used sections for concrete elements, containing the lengths of transversal reinforcement required for one section in usual and rectangular spiral stirrup solution.

**Table 2.2.** Characteristic stirrup lengths in accordance with EC2 for usual and spiral solutions.

| Stirrup perimeter *2(a+b)* [mm] | Transversal reinforcement bar diameter [mm] @ spacing [mm] | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Ø6 @ 200 mm | | | Ø8 @ 150 mm | | | Ø10 @ 100 mm | | |
| | Usual | [%] | Spiral | Usual | [%] | Spiral | Usual | [%] | Spiral |
| 500 | 614 | -14,1 | 527,4 | | | | | | |
| 600 | 714 | -13 | 621,1 | 718 | -13,5 | 621,1 | | | |
| 700 | 814 | -12 | 716,5 | 818 | -12,4 | 716,5 | 822 | -12,8 | 716,5 |
| 800 | 914 | -11,1 | 813 | 918 | -11,4 | 813 | 922 | -11,8 | 813 |
| 900 | 1014 | -10,2 | 910,2 | 1018 | -10,6 | 910,2 | 1022 | -10,9 | 910,2 |
| 1000 | 1114 | -9,5 | 1008 | 1118 | -9,8 | 1008 | 1122 | -10,2 | 1008 |
| 1100 | 1214 | -8,9 | 1106,2 | 1218 | -9,2 | 1106,2 | 1222 | -9,5 | 1106,2 |
| 1200 | 1314 | -8,3 | 1204,7 | 1318 | -8,6 | 1204,7 | 1322 | -8,9 | 1204,7 |
| 1300 | 1414 | -7,8 | 1303,4 | 1418 | -8,1 | 1303,4 | 1422 | -8,3 | 1303,4 |
| 1400 | 1514 | -7,4 | 1402,3 | 1518 | -7,6 | 1402,3 | 1522 | -7,9 | 1402,3 |
| 1500 | 1614 | -7 | 1501,4 | 1618 | -7,2 | 1501,4 | 1622 | -7,4 | 1501,4 |
| 1600 | | | | 1718 | -6,8 | 1600,5 | 1722 | -7,1 | 1600,5 |
| 1700 | | | | 1818 | -6,5 | 1699,8 | 1822 | -6,7 | 1699,8 |
| 1800 | | | | | | | 1922 | -6,4 | 1799,2 |
| 1900 | | | | | | | 2022 | -6,1 | 1898,6 |

The larger the section is, the smaller the influence of end hooks in total stirrup length is identified

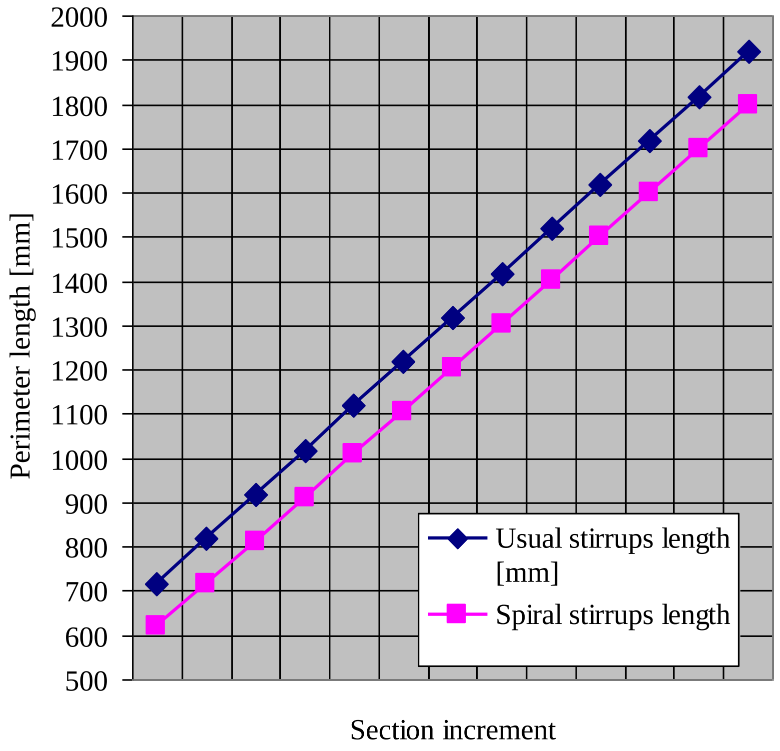



**Figure 4.** Length evolution for usual and spiral stirrup with identical perimeter.

As shown above, for RC elements sections commonly used in practice can be considered an amount of 10 percent in material savings (steel used as transversal reinforcement). This benefit does not have implication in poor structural behaviour or any other unwanted effects. The amount of material reduction is due to elimination of the end hooks.

Another advantage in using the spiral stirrup solution involves production resources management, as time and energy stored in the manufactured element. The classic stirrup requires a 5 point manufacturing, with a total of 540 degrees bending of wire. On the other side, the proposed solution of rectangular spiral stirrups implies only a 4 point and a total of 360 degrees of wire bending, which is less than 80 % than usual solution.

Better resource management conducts to fewer costs and less time to produce the same amount of transversal reinforcement.

Compared to the usual stirrup, the rectangular spiral can be obtained only by using dedicated equipment, since it is difficult to obtain more than 3 loops by simple man labour.

The assembly formed by longitudinal and rectangular spiral stirrups is more rigid prior to concrete pouring, due to diagonal like effect of the inclined transversal wire. This aspect provides better stability of steel cage before concrete reached its strength, thus avoiding deteriorations and miss positioning of reinforcement from man work or undesired actions. This aspect is also important in transportation and handling, since usual steel assembly needs to be straightened or repositioned after a few handling operations.

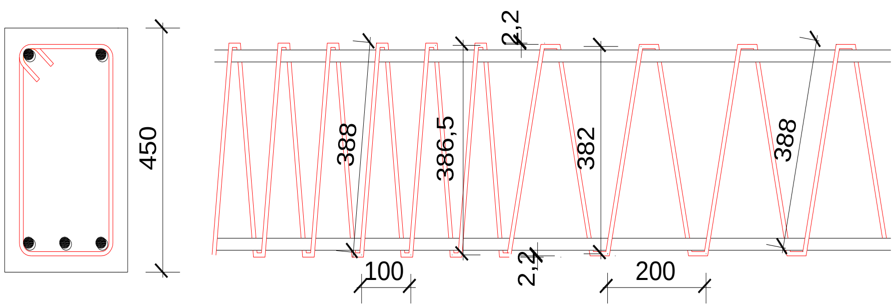



**Figure 5.** Rectangular spiral stirrups used on variable spacing.

Versatility of the stirrups is another appreciated characteristic of this proposed solution, since it can handle an important amount of variability in the spacing, without special preparations. For instance, it can be solved to cover various spacing values (e. g. 100 to 200 mm), without affecting stability or behaviour.

### 2.1. Technological aspects for rectangular spiral stirrups

Hence the segments of the spiral are inclined (on an angle that depends on the spacing between stirrups and stirrup sides), a slight increase in dimension will occur from the initial lengths *a* and *b*.

Considering *a* and *b* (**Fig. 2** and **6**) the length of segments in usual stirrup, and *a'* and *b'* the length of segments for spiral stirrup, on corresponding sides, by geometrical analysis can be written:

$$(a+b)^2 + (s/2)^2 = (a'+b')^2 \quad , \tag{2.1}$$

where *s* represents the spacing between consecutive stirrups.

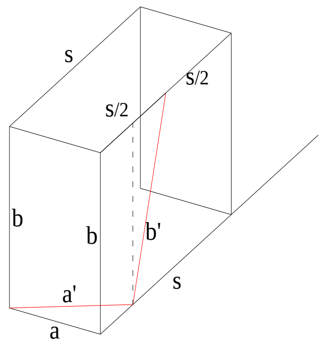



**Figure 6.** Geometric elements of proposed stirrups

In order to find *a'*, the required length of horizontal segment of spiral stirrup, by replacing *b'* in 2.1:

$$a'^2 = \sqrt{\frac{a^2 + 2 \times a \times b + b^2 + s^2/4}{1 + 2 \times b/a + \frac{b^2}{a^2}}} \quad , \qquad (2.3)$$

As a practical example, considering *a*=100 mm, *b*=200 mm and spacing *s*= 100 mm, the value for *a'* shall be 101,38 mm, with only a 1,4% increase from initial computing segment length.

If the slope of the stirrup would not be constant along the element, a residual torsional component in the bent wire shall produce rotation deformation of the entire assembly.

## 3. NUMERICAL SIMULATIONS AND RESULTS INTERPRETATION

In order to determine the structural behaviour of the proposed rectangular spiral stirrups, a series of analysis have been performed on the elements presented in Table 2.1. Dimensions, material, loading pattern, longitudinal reinforcement distribution and stirrup spacing were identical for the pairs of the analysed elements. The only difference in each pair of elements was the path of the transversal reinforcement. The tests have been carried out using the ATENA 3D software platform, developed by Cervenka. The analyses performed considered identical conditions (dimensions, materials, steel diameter, and load pattern) for each pair of RC elements.

The loading pattern was established to better isolate the shear effect in the element, in order to better observe the behaviour of the transversal reinforcement that is the subject of this paper. In order to avoid failure or excessive deformation due to flexure, the ends of the elements underwent imposed deformation in only one direction, the other being restricted. All elements have been subjected to imposed deformation, that incrementally conducts to failure level.

Finite element distribution and all other input data were maintained identical for the same element, changing only the stirrup.

After tests have been carried out, some remarks can be stated. For the analysed elements, the variation between the two sets of stirrups induced an evolution of less than 2%.

Tests showed that 4 out of 5 specimens had improved structural behaviour with spiral stirrups, showing increased (less than 2%) strength capacity and deflection stability.

Only one element, the flat/bond beam 250 x 250 mm, with stirrups of 6 mm spaced at 200 mm showed slight decrease (aprox. 1%) in strength capacity, most likely due to higher slope of the spiral stirrups.

**Table 3.1.** Comparative analysis on 200 x 350 mm RC beam with usual and proposed rectangular spiral stirrups

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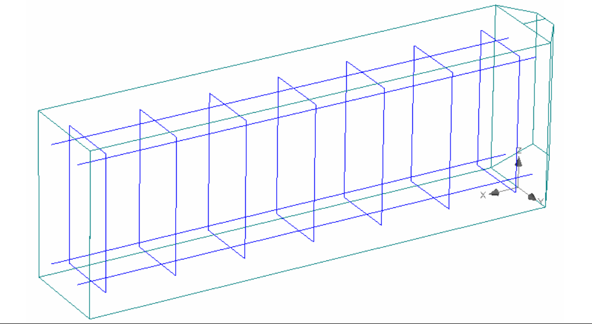
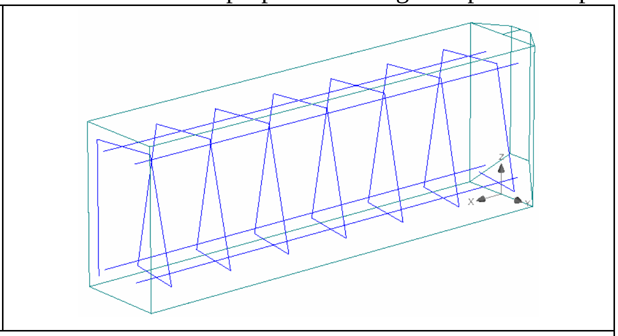
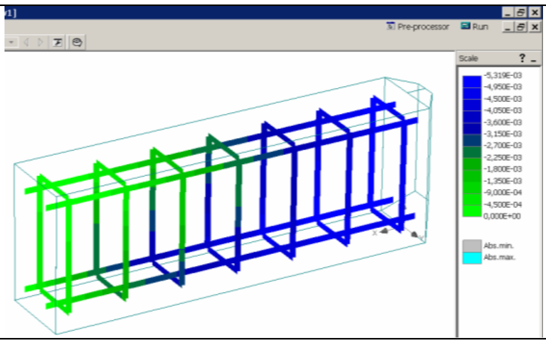
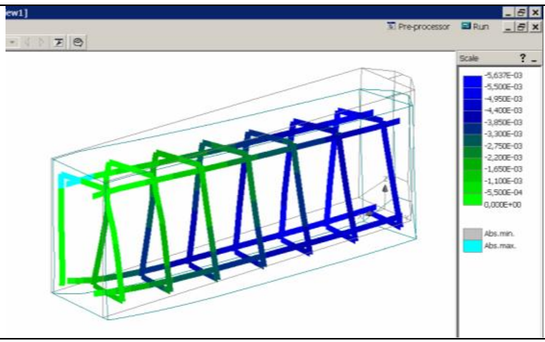
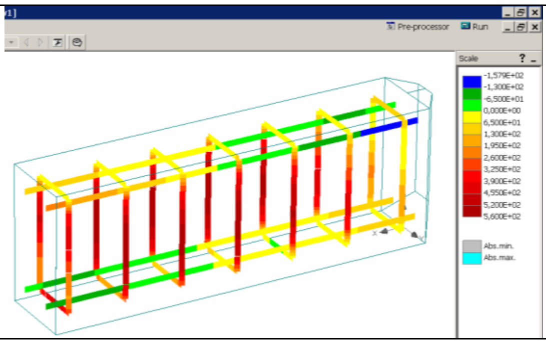
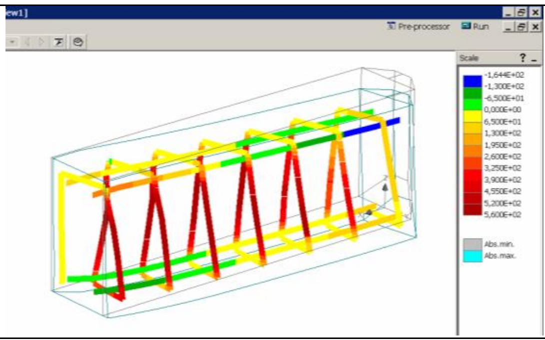
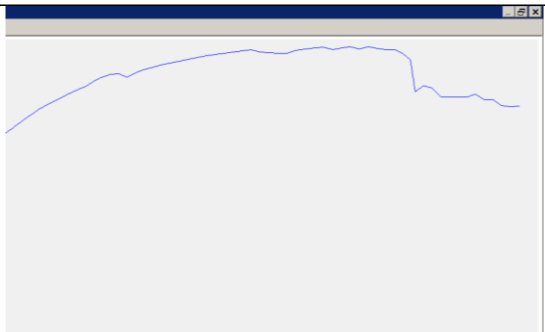
|---|---|
|  |  |
| Models of analysed elements | |
|  |  |
| Deformed view (vertical imposed displacement) | |
|  |  |
| Stress distribution in reinforcement elements | |
|  |  |
| Force-deformation behaviour curves | |

After performing the sets of numerical analysis, the proposed rectangular spiral stirrups can be considered a viable and advantageous solution as transversal reinforcement in rectangular RC sections.

Future work includes full scale tests and implementation of this solution in building industry.

Financial estimations showed that the gain that would be obtained by using this type of stirrups ranges between 2 and 5 euros/ sqm. of building floor surface, depending on the structural type used.

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