Shear capacity of RC rectangular beams with continuous spiral transversal reinforcement

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Abstract

In this study the behaviour of reinforced concrete beams with rectangular spiral reinforcement under monotonic loading is experimentally investigated. In this direction, three beam specimens with ratio $\alpha / d = 2.67$ were constructed and tested in monotonic shear loading. The first specimen had common stirrups, the second one spiral transversal reinforcement and the third one spiral transversal reinforcement with favourably inclined legs. Based on the experimental results and the behavioural curves of the tested beams it is deduced that the specimens with continuous spiral shear reinforcement demonstrated 15% and 17%, respectively, higher shear strength than the beam with closed stirrups. Further, the beam with spiral transversal reinforcement with favourably inclined legs exhibited enhanced performance and a rather ductile response whereas the other beams showed brittle shear failure.
Keywords: inclined reinforcement, shear beams, spiral reinforcement, tests.

1 Introduction

It is generally accepted that the use of continuous spiral reinforcement in reinforced concrete elements with cyclic cross section can substantially improve the strength and the ductility of the concrete and henceforth the total seismic response and capacity of the structural element [1, 2, 3, 4]. The extension of the use of continuous spiral reinforcement in elements with rectangular cross sections is a new promising technology that is estimated it can enhance the capacity and the performance of these reinforced concrete members [5, 6, 7].

In this paper, the shear performance of RC beams with rectangular cross section and continuous spirally applied transversal reinforcement is experimentally investigated. The effectiveness of the use of continuous spiral reinforcement with rectangular shape as shear reinforcement, in comparison to the use of common closed stirrups (see also Figure 1a) is examined. Two types of transversal spiral reinforcement are used and examined in this study.

The first one has the common form of spiral reinforcement with continuous rectangular spires as shown in Figure 1b. The inclined legs of the reinforcement of one vertical side of the web have opposite inclination to the legs of the other vertical side. This way, only the legs of the one side of the web are in favourable inclination for shear loading.

The second type of continuous reinforcement is an improved form of spiral transversal reinforcement (Figure 1c). The legs of the continuous reinforcement of both vertical sides of the web have the same inclination and two different parts of continuous reinforcement are placed in the shear spans of the beam in order all reinforcement legs to have favourable inclination for monotonic shear loading. In this way, along the entire length of the beam and in both vertical sides of the web, the inclined legs of the continuous reinforcement are approximately vertical to the potential shear cracking.

2 Experimental program

The experimental program includes 3 reinforced concrete beams with rectangular cross section and dimensions b/h = 200/300 mm. The total length of the specimens is equal to 1.84 m. Each beam comprises different type of steel shear reinforcement: (a) Beam B12-s has common closed stirrups, (b) common continuous spiral transversal reinforcement is used for the beam B12-sp and (c) continuous spiral transversal reinforcement with favourably inclined legs, as previous described, is used for the beam B12-spA.

The diameter of the steel shear reinforcement of the examined beams is equal to 5.5 mm. The spacing of the stirrups of the specimen B12-s and the spacing of the spires of the specimens B12-sp and B12-spA are equal to 120 mm. Thus, all the examined beams have approximately the same volume of shear reinforcement. All specimens comprise high volume of steel longitudinal reinforcement (2∅14 up and 4∅18 down) in order to avoid bending failure. Geometrical and reinforcement details of the tested beams are shown in Figure 2.

Mild plain steel with nominal yield strength equal to 220 MPa was used for the shear reinforcement of the beams whereas the steel of the longitudinal reinforcement is high bond steel with nominal yield strength equal to 500 MPa. Further, in order to determine the compressive strength of the concrete, supplementary compression tests of six 150×300 mm cylinders were also carried out. The mean value of the compressive strength of concrete was f_c = 28.5 MPa.

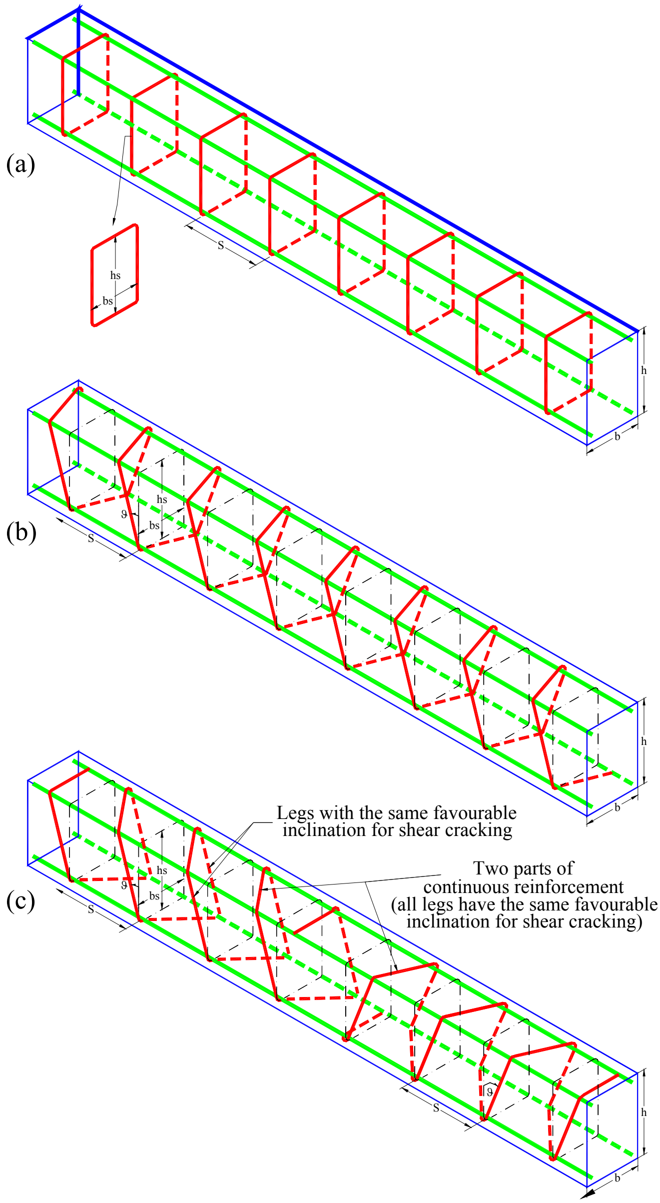
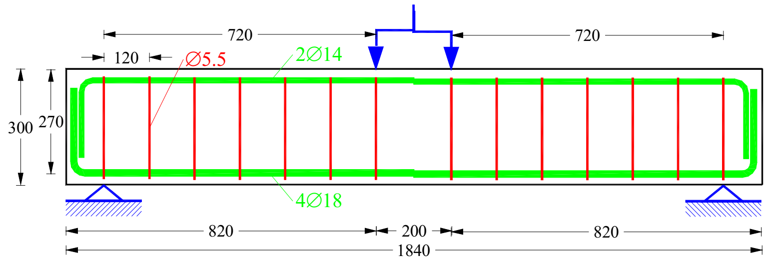
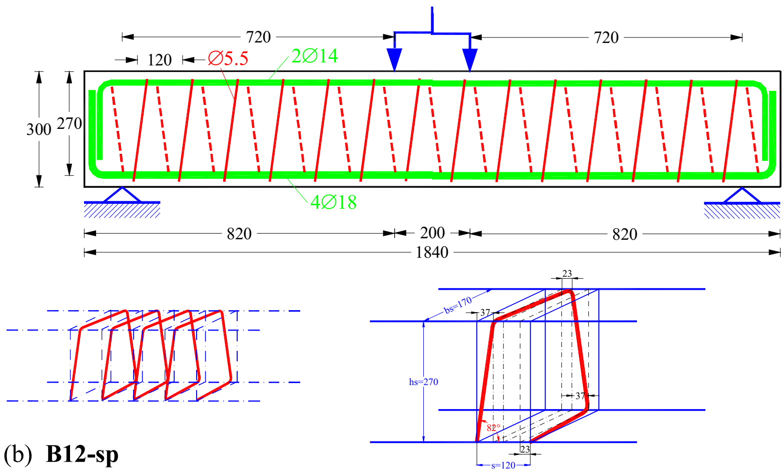


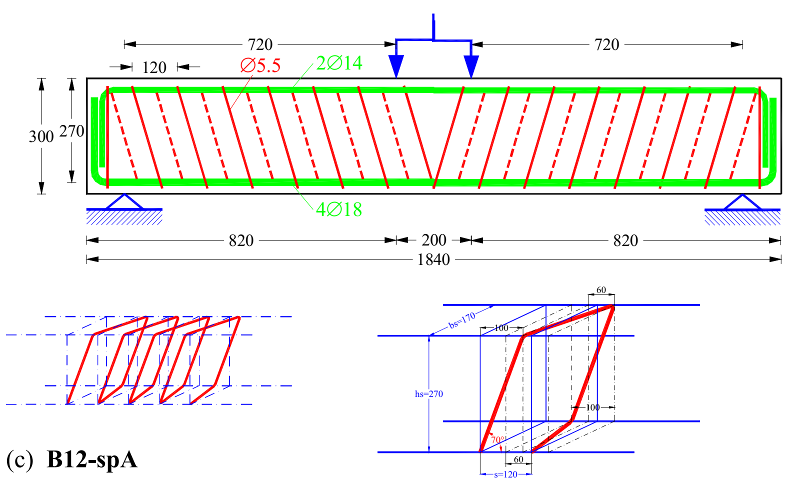
Figure 1: Examined types of shear reinforcement (a) common closed stirrups, (b) common continuous spiral reinforcement and (c) improved continuous spiral reinforcement.



(a) **B12-s**



(b) **B12-sp**



(c) **B12-spA**

Figure 2: Geometry and reinforcement details of the tested beams.

The beams were supported on two roller supports 1.64 m apart. The imposed loading was monotonic and applied in two points 200 mm apart, in the midspan of the beam, as shown in Figure 3 [8]. The length of the shear spans of the specimens was equal to $\alpha = 720$ mm. The load was imposed consistently in low rate and was measured by a load cell with accuracy equal to 0.05 kN. Midspan deflection of the tested beams was measured by a linear variable differential transducer (LVDT) with accuracy equal to 0.01 mm. Measurements for load and deflection were read and recorded continuously.

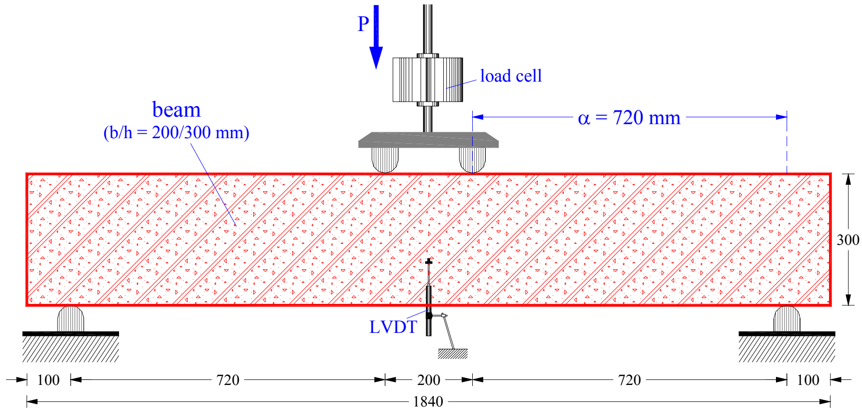


Figure 3: Experimental setup.

3 Test results and discussions

All tested beams exhibited shear failure. Shear diagonal cracks appeared in the shear span of the beams. Table 1 presents the volume of the shear reinforcement, the ultimate shear strength ($V_u = P_u / 2$) and the percentage increase of the shear strength due to the use of spiral shear reinforcement in comparison with the use of stirrups. Additionally, the entire shear response of the tested beams is presented in Figure 4 in terms of the total applied load (P) versus midspan deflection (δ) experimental curves.

Table 1: Test results.

Beam code name	ρ_w (%)	V_u (kN)	Increase of shear strength
B12-s	0.198	107.5	-
B12-sp	0.200	123.5	15 %
B12-spA	0.209	126.0	17 %

$$\rho_w = \frac{A_s}{s \cdot b \cdot \sin \vartheta}$$

where: b: the width of the beam
A_s, s: the area and the spacing of the shear reinforcement, respectively
ϑ: the inclination of the shear reinforcement to the horizontal axis of the beam

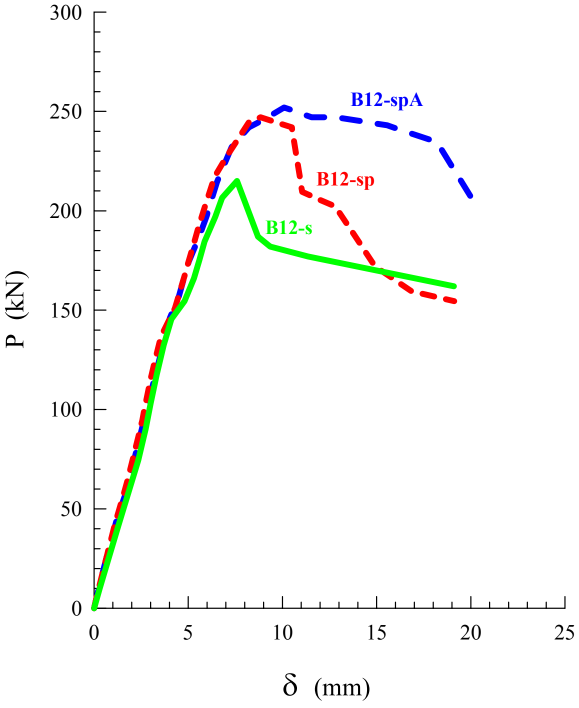
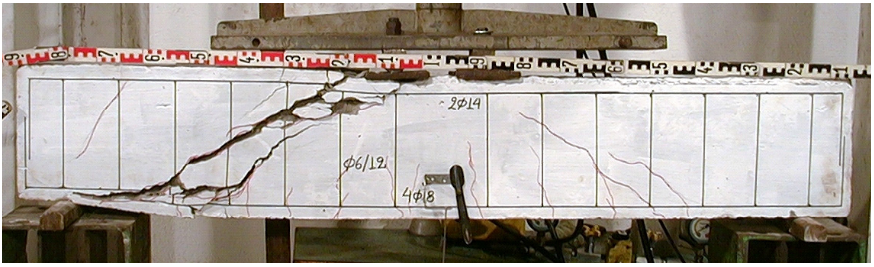


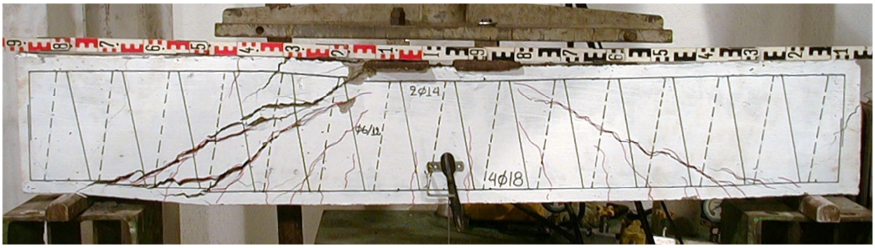
Figure 4: Experimental curves.

Based on the experimental results reported in Table 1 and presented in Figure 4 it can be deduced that the beams with continuous shear reinforcement (B12-sp and B12-spA) demonstrated higher shear strength than the beam with closed stirrups (B12-s). Further, based on the behavioural curves of the beams in Figure 4, it is proved that beams B12-s and B12-sp showed brittle shear failure whereas beam B12-spA with improved continuous reinforcement exhibited enhanced performance. It is mentioned that the beam B12-spA showed a rather ductile response since the load bearing capabilities after the ultimate load was remained high ($\geq 0.85P_u$) for deformation almost twice the yield deformation.

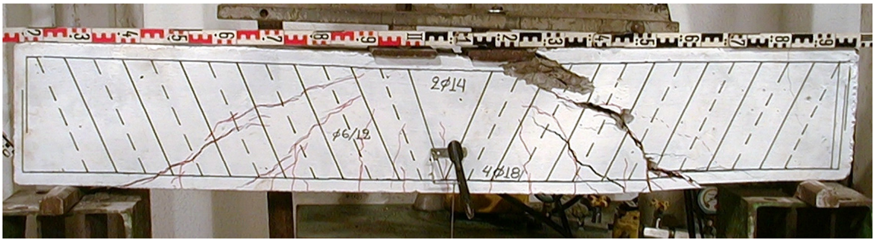
Crack patterns at failure of the beams are presented in Figure 5. In this figure it is shown that diagonal cracks appeared within the shear span of the tested specimens displaying this way the typical shear cracking patterns of beams with web reinforcement [9].



(a) B12-s



(b) B12-sp



(c) B12-spA

Figure 5: Failure modes.

4 Concluding remarks

The shear performance of reinforced concrete beams with rectangular cross section and continuous reinforcement is experimentally investigated. The effectiveness of the use of two different types of transversal continuous spiral reinforcement with rectangular shape as shear reinforcement, in comparison to the use of common closed stirrups is examined.

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Based on the experimental results and the behavioural curves of the tested beams it is deduced that the specimens B12-sp and B12-spA with continuous shear reinforcement demonstrated 15% and 17%, respectively, higher shear strength than the beam B12-s with closed stirrups. Further, beam B12-spA with spiral transversal reinforcement with favourably inclined legs exhibited enhanced performance and a rather ductile response whereas beams B12-s and B12-sp showed brittle shear failure.

References

[1] Park, R. & Paulay, T., Reinforced Concrete Structures, John Wiley & Sons, 1975.
[2] Saatcioglu, M. & Razvi, S., Strength and ductility of confined concrete, Structural Engineering, ASCE, 118(25), pp. 1590-1607, 1992.
[3] Sheik, S. & Toclucu, M., Reinforced concrete columns confined by circular spirals and hoops, ACI Structural, 90(5), pp. 542-553, 1993.
[4] Hellenic Aseismic Code 2000 (in Greek).
[5] Essawy, A.S. & El-Hawary, M., Strength and Ductility of Spirally Reinforced Rectangular Concrete Columns, Construction and Building Materials, 12(1), pp. 31-37, 1998.
[6] Karayannis, C.G., Sirkelis, G.M., Chalioris C.E. & Mavroidis, P.D., External RC Joints with continuous spiral reinforcement - Experimental investigation, Proc. of 14th Greek Concrete Conf., Vol. A, (in Greek), Kos, Greece, pp. 343-353, 2003.
[7] Karayannis, C.G. & Sirkelis, G.M., Response of columns and joints with spiral shear reinforcement, Proc. of 12th Int. Conf. on Computational Methods and Experimental Measurements (CMEM 2005), Malta, 2005.
[8] Karayannis, C.G. & Chalioris, C.E., Experimental Investigation of the Contribution of Bonded C-FRP jackets to Shear Capacity of RC Beams, Proc. of the Int. Symposia Celebrating Concrete: People and Practice, Vol. Role of Concrete in Sustainable Development, Dundee, Scotland, UK, pp. 689-696, 2003.
[9] Zararis P.D., Concrete Shear Failure in Reinforced Concrete Elements, Structural Engineering, ASCE, 122(9), pp. 1006-1015, 1996.