Response of columns and joints with spiral shear reinforcement

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Abstract

In this study the behavior of reinforced concrete members with rectangular spiral shear reinforcement under cyclic loading is experimentally investigated. In this direction two pairs of specimens are tested. The first pair of specimens comprises two exterior beam-column joints while the second one comprises two column specimens. The first specimen of each pair has rectangular spiral shear reinforcement whereas the latter has common stirrups. Both beam-column specimens have been suffered the same full cyclic deformation with increasing amplitude and 2 full cycles at every step. Also, both column specimens have been suffered the same increasing full cyclic deformation with 2 full cycles at every step. The results of the tested specimens reinforced with rectangular spiral reinforcement are compared with the results of the specimens reinforced with stirrups, in terms of maximum loading and energy absorption per step, and ductility capacity. From the observed responses of the tested specimens it can be deduced that the use of rectangular spiral reinforcement in the reinforced concrete members improved the seismic capacity of all the examined specimens.
Keywords: beam-column joints, columns, spiral shear reinforcement.

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 (Park and Paulay [7], Saatcioglu and Razvi [9], Sheikh and Toklucu [10]). International codes in these cases propose increased performance factors for the concrete confinement (ACI 318, EC8).

The extension of the use of continuous spiral reinforcement in elements with rectangular cross sections is a new promising technology that is believed it can improve the seismic capacity of structures.

It is generally acceptable that the beam-column joints and especially the external joints are critical regions for the total seismic response of reinforced concrete structures. Moreover, the behaviour of columns is also critical for the overall seismic capacity of structures. Thus, any improvement of the seismic properties of these members using the Rectangular Spiral Reinforcement (RSR) would be very interesting in terms of general reinforcing strategy and structural safety.

The response of beam-column joints depends on some different factors as the mechanisms of shear transfer, the concrete compressive and shear strengths, the confinement of the joint area, the anchorage type of the beam's longitudinal reinforcement etc (Paulay and Priestley [8], Karayannis et al [4], Karayannis and Sirkelis [3,5], Tsonos [11,12]). It is obvious that the improvement of the concrete response in terms of any of these factors would help to the improvement of the total seismic response of the joint. Considering that the application of the RSR could contribute to the improvement of the concrete properties it is expected to contribute to the total improvement of the response of the joints.

The scope of this study is the experimental investigation of the possibility of the improvement of seismic capacity of concrete members using continuous rectangular spiral shear reinforcement in the column and the joint body.

The results from the specimens reinforced with spiral reinforcement are compared with the results from specimens reinforced with stirrups, in terms of hysteretic response, ductility and energy absorption.

2 Experimental program

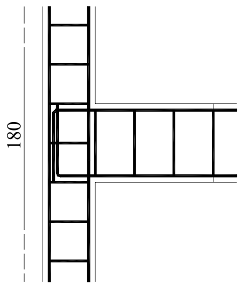
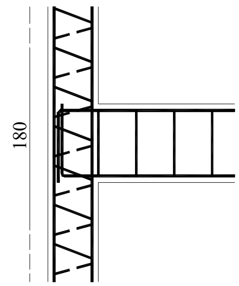
The experimental program comprises four specimens of concrete members sorted into two groups. The characteristics of all specimens are presented in Table 1 and Table 2.

The geometric characteristics of the specimens of Group A (Table 1) were the same for both specimens. The total column length was 180 cm and the column cross-section was 20×20 cm. The column's reinforcement was 4∅10. The column's shear reinforcement was ∅8/15.

The total beam length was 110 cm and the beam cross-section was 20/30 cm. The beam reinforcement was 4∅10 (2∅10 up, 2∅10 down). The beam's shear reinforcement was ∅8/15. The beam's reinforcement anchorage for specimens of Group A has the recommended by the code total length, but the anchorage had smaller straight part than the recommended one.

Specimens AJ1s and AJ1sp had 1 stirrup and one spiral step of Rectangular Spiral Reinforcement (RSR), respectively, as shear reinforcement in the joint area.

Table 1: Specimen characteristics of Group A.

<table>
<tr><th colspan="2">GROUP A
Beam – Column Specimens</th></tr>
<tr><td colspan="2">Column cross section 20x20 cm
Beam cross section 20/30 cm</td></tr>
<tr><td>Longitudinal bars : 4∅10
Shear reinforcement : ∅8/15</td><td>Longitudinal bars: 2∅10 Up, 2∅10 Down
Shear reinforcement : ∅8/15</td></tr>
<tr><td></td><td></td></tr>
<tr><td>Specimen AJ1s:
1 stirrup
∅8/15 in the joint body</td><td>Specimen AJ1sp:
1 spiral step
∅8/15 in the joint body</td></tr>
</table>

The concrete mean compressive strength for both specimens of Group A was f_c=32.8 MPa. Column axial load N_c equal to 70 kN was applied during the test in both specimens.

The geometric characteristics of specimens of Group B were the same for both specimens. The total column length was 340 cm and the column cross-section was 30×30 cm.

The column reinforcement was 6∅12 (3∅12 at each side). The total beam length was 90 cm and the beam cross-section was 20/30 cm (see also Table 2). The beam reinforcement was 6∅12 (3∅12 up, 3∅12 down). The column's longitudinal bars for specimens of Group B had the recommended by the code lap-splice length equal to 97cm for this case. Both specimens had column's shear reinforcement ∅8/10 at the critical region and ∅8/15 at the rest column's region.

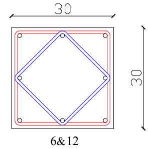
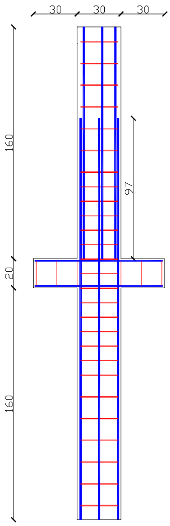
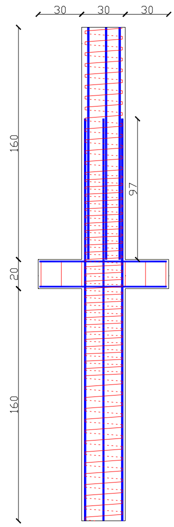
Specimens BJ1s and BJ1sp had stirrups and spiral steps of RSR, respectively, as shear reinforcement in the column.

The concrete mean compressive strength for both specimens of Group B was f_c=31.6 MPa.

2.1 Test ring and loading procedure

Test setup and instrumentation details for specimens of Group A are shown in Figure 1. Supports that allow rotation were used to simulate the inflection points assumed to occur at the mid-height of the columns in a laterally - loaded frame structure. Column axial load N_c=70 kN (≈$0.05A_cf_c$), was applied during the tests in all the specimens.

Table 2: Specimen characteristics of Group B.

GROUP B	
Column Specimens with cross section 30×30 cm	
Longitudinal bars : 6∅12 Shear reinforcement : ∅8/10 in the column's critical region ∅8/15 in the rest column's region	
	
Specimen B1s: Stirrups as shear reinforcement	**Specimen B1sp:** Spiral as shear reinforcement

The specimens were subjected to full cyclic deformations with increasing amplitude imposed near the free end of the beam (Figure 1) by a pinned-end actuator. Both specimens have been suffered the same increasing deformation with 2 full cycles at every step. Maximum displacements of beam's free end in the loading cycles were ±6mm, ±20mm, ±40mm and ±60mm for the 1st, 2nd, 3rd, and 4th loading step, respectively. The displacements of the beam's end were measured by a LVDT (Linear Variable Differential Transformer). LVDTs were also placed at each end of the column to check the supports during the tests.

Test setup and instrumentation details for specimens of Group B are shown in Figure 2. Supports that allow rotation were used to simulate the inflection points assumed to occur at the mid-height of the columns in a laterally - loaded frame structure.

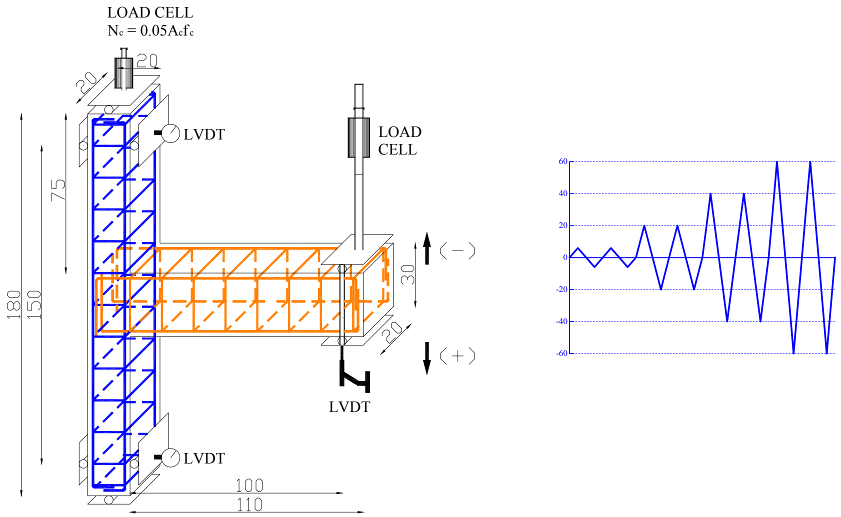


Figure 1: Test set up and loading history for Group A.

The specimens were subjected to full cyclic deformations with increasing amplitude imposed axial to the beam (Figure 1) by a pinned-end actuator. Both specimens have been suffered the same increasing deformation with 2 full cycles at every step. Maximum displacements in the loading cycles were ±8mm, ±15mm, ±30mm, ±55 and ±80mm for the 1st, 2nd, 3rd, 4th and 5th loading step, respectively. The imposed displacements were measured by a LVDT (Linear Variable Differential Transformer). LVDTs were also placed at each end of the column to check the supports during the tests.

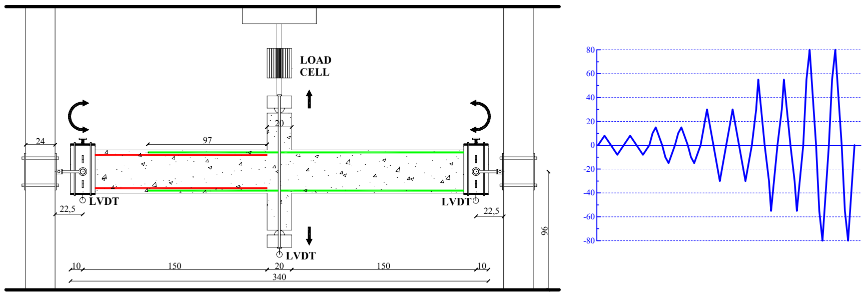


Figure 2: Test set up and loading history for Group B.

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3 Experimental results

3.1 Specimens of Group A

3.1.1 Specimens AJ1s and AJ1sp

Specimens AJ1s and AJ1sp had one stirrup and one spiral step of RSR as shear reinforcement in the joint body, respectively. Both were suffered a full cyclic increasing deformation with maximum displacements of loading steps equal to ±6, ±20, ±40 and ±60 mm.

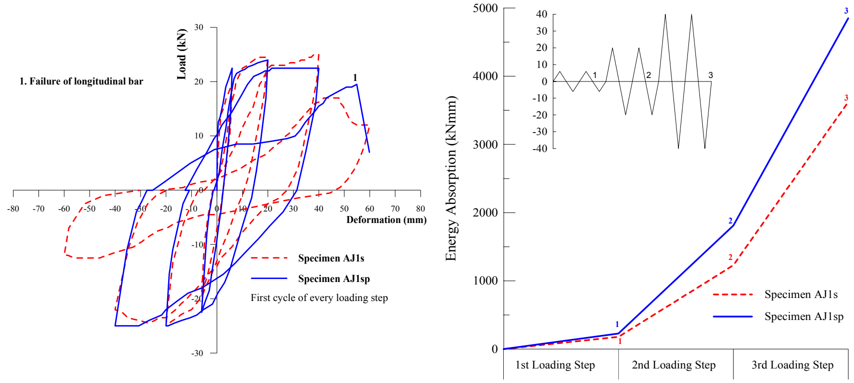

Figure 3: Hysteretic response and Energy absorption of specimens AJ1s and AJ1sp.

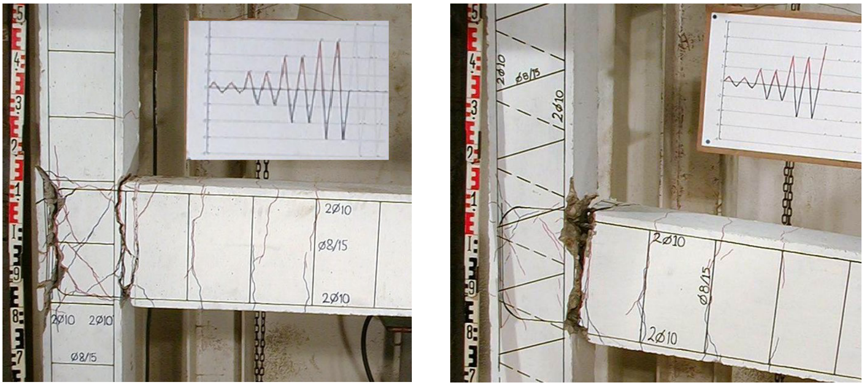

Figure 4: Final condition of specimens AJ1s and AJ1sp.

In specimen AJ1s the damage occurred at the joint area (Figure 4). The specimen kept its load carrying capacity until the fourth loading step at deformation equal to 60mm. At this deformation the back side of the joint area was cracked because of the internal push of the beam's reinforcement anchorage.

The behaviour of specimen AJ1sp was different than the behaviour of specimen AJ1s. The damage was localized from the beginning at the juncture of the beam to the column. There were no damages at the joint body (Figure 4). The specimen appeared a better behaviour in terms of energy absorption (Figure 3). Finally the damage remained only at the beam's critical region where the formation of a clear plastic hinge took place. When the deformation was equal to 60mm a failure of one longitudinal beam bar reinforcement occurred. Until the end of the loading procedure the joint body remained almost intact. This behaviour is considered as a desirable one since the damage appeared and remained outside of the joint body and had flexural characteristics. The hysteretic response of specimen AJ1sp was improved compared to the one of the specimen AJ1s by 34% in terms of energy absorption.

3.2 Specimens of Group B

3.2.1 Specimens B1s and B1sp

Both specimens B1s and B1sp were suffered a full cyclic increasing deformation with maximum displacements of loading steps equal to ±8, ±15, ±30, ±55 and ±80mm.

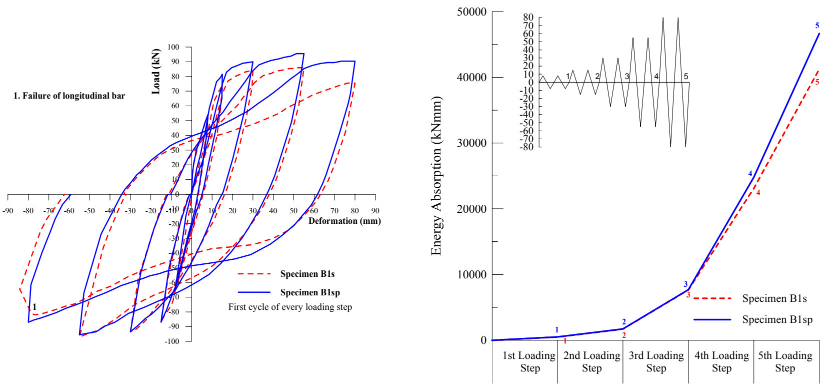

Figure 5: Hysteretic response and Energy absorption of specimens B1s and B1sp.

In specimen B1s the damages were localized at the column's critical region (Figure 6) with the formation of a plastic hinge. Major damages appeared at the critical region of the lower column. The specimen kept its load carrying capacity until the first cycle of the fifth loading step at maximum deformation equal to 80mm. At this deformation failure of one of the longitudinal bars occurred. At the next loading cycle three more longitudinal bars failed.

The behaviour of specimen B1sp was similar to the behaviour of specimen B1s for the first 3 loading steps whereas the observed behaviour was substantially improved in the last two loading steps comparing to the behaviour of specimen B1s of specimen with stirrups. The damages were localized at the column's critical region (Figure 6) with the formation of a plastic hinge. Major damages appeared at the critical region of the lower column. The specimen kept its load carrying capacity until the second cycle of the fifth loading step at maximum deformation equal to 80mm. At this deformation failure of three of the longitudinal bars occurred.

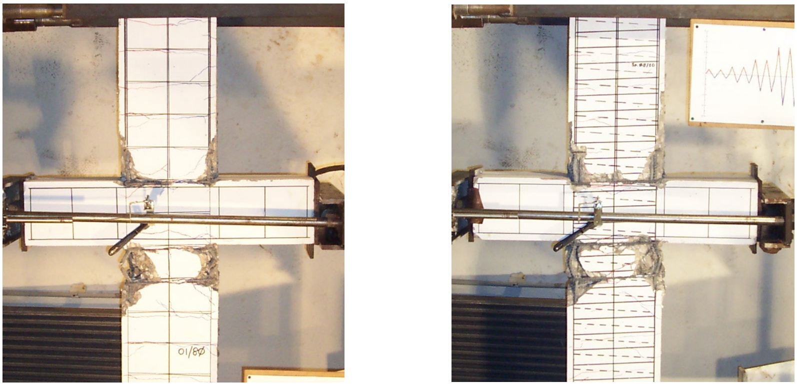

Figure 6: Final condition of specimens B1s and B1sp.

The hysteretic response of specimen B1sp (Figure 5) was improved compared to the one of the specimen B1s. The observed energy absorption of specimen B1sp was 11% and 21% bigger in the 4th and 5th steps, respectively, compared to the corresponding observed values of absorbed energy of specimen B1s. Finally, the response of specimen B1sp (Figure 5) was improved compared to the one of the specimen B1s by 13% in total in terms of energy absorption.

4 Conclusions

In this study results from specimens of concrete columns, tested in cyclic loading, reinforced with Rectangular Spiral Reinforcement (RSR) are compared with the results of similar specimens reinforced with typical stirrups equally spaced and tested the same way.

In specimen of Group A reinforced with stirrups (AJ1s) the damage was appeared and localized at the joint body. On the contrary in the specimen reinforced with RSR (AJ1sp) the damage appeared only at the beam's critical region with the formation of plastic hinge. This behaviour is considered as the best expected one since the damages remained outside of the joint body and had flexural (ductile) characteristics. Finally, the hysteretic response of specimen AJ1sp was improved compared to the one of the specimen AJ1s by 34% in terms of energy absorption.

The column specimens of Group B presented similar response. The damages were observed in the column's critical region with the formation of a plastic hinge. The hysteretic response of specimen B1sp (Figure 5) was improved compared to the one of the specimen B1s. The observed energy absorption of specimen B1sp was 11% and 21% bigger in the 4th and 5th steps, respectively, compared to the corresponding observed values of absorbed energy of specimen B1s. Finally, the response of specimen B1sp (Figure 5) was improved compared to the one of the specimen B1s by 13% in terms of energy absorption.

References

[1] Essawy A.S., El-Havary M., Strength and ductility of spirally reinforced rectangular concrete columns. Journal Construction and Building Materials, Vol. 12. No 1, pp. 31-37, 1998

[2] Karayannis C.G., Chalioris C.E., Sideris K.K., Effectiveness of RC Beam-Column Connection Repair Using Epoxy Resin Injections. Journal of Earthquake Engineering, Vol.2. No 2, pp. 217-240, 1998

[3] Karayannis C.G., Sirkelis G.S., Effectiveness of RC Beam-Column Connections Strengthening Using Carbon-FRP Jackets. 12th ECEE. Proc. in CD form, paper ref. 549, 2002

[4] Karayannis C.G., Sirkelis G.S., Chalioris C.E., Mavroidis P., External R.C. Joints with continuous spiral reinforcement. Experimental investigation. 14th Greek Concrete Conference, Vol. A, pp. 343-353, In Greek, 2003

[5] Karayannis C.G., Sirkelis G.S., Design parameters and response of external joints-Damage index and valuation of experimental results. 14th Greek Concrete Conference, Vol. A, pp. 332-342, In Greek, 2003

[6] Karayannis C.G., Sirkelis G.S., Chalioris C.E., Effectiveness of RC Beam-Column Connections Strengthening Using Carbon-FRP Jackets. 12th European Conference on Earthquake Engineering (12ECEE), Paper Ref.549, 2003

[7] Park R., Paulay T., Reinforced Concrete Structures. John Wiley & Sons. 1975

[8] Paulay T., Priestley M.J.N., Seismic design of reinforced concrete and masonry buildings. John Wiley & Sons, 1992

[9] Saatcioglu M., Razvi S., Strength and ductility of confined concrete. Journal of Structural Engineering ASCE, Vol. 118, No 25, pp. 1590-1607, 1992

[10] Sheik S., Toclucu M., Reinforced concrete columns confined by circular spirals and hoops. ACI Structural Journal, Vol. 90, No 5, pp. 542-553, 1993

[11] Tsonos A., Shear strength and hysteretic behaviour of exterior beam column connections. Proceedings of the 5th SECED Conference on European Seismic Design Practice - Research and Application, London, Proc. Balkema 553-559, 1995

[12] Tsonos A., Papanikolaou K., Post-earthquake repair and strengthening of reinforced concrete beam-column connections (theoretical and experimental investigation). Bulletin of the New Zealand Society for Earthquake Engineering, Vol. 36: 73-93, 2003