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Evaluation of Strength and Ductility of Cross Spirally Circular Reinforced Concrete Columns Using Experimental Results

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Abstract

This paper experimentally and investigates the behavior of reinforced concrete (RC) columns subjected to eccentric loading with experimental methods. The columns are reinforced and confined with cross spiral. The new confinement technique uses cross spirals to confine RC circular columns in order to enhance their strength and ductility. Eight RC circular columns subjected to load eccentricity with two different grades of spirals steel, two different volumetric ratio of confining spiral and two different positions of cross spirals are experimentally tested. The force, axial and lateral displacement and concrete strains in different locations are measured during the testing. The columns are 1000 mm long with two hunched heads of 500 mm height and 250 mm diameter.

Keywords: Cross Spirally Circular, Reinforced Concrete Columns , Ductility, Strength

1. INTRODUCTION

The effect of lateral reinforcement on strength and ductility of reinforced concrete (RC) columns has been studied. As a column is subjected to compressive loads, the concrete expands laterally. This expansion of concrete is resisted by the lateral confinement, which imposes confining stresses on the concrete. The effectiveness of this resistance to expansion is based on the method used to confine the concrete in the column. Currently, the use of spirals is the most common method of confinement. Through countless research studies, it was shown that spirals were the most effective means of lateral confinement for a column when large deformations (ductility) need to be achieved. Spiral reinforcement acts to resist the lateral expansion by applying a uniform pressure on the concrete core surrounded by the spiral. This uniform pressure significantly reduces the lateral expansion, which leads to significant strength and ductility enhancement. However, some limitations have been placed on lateral confinement to aid constructability and provide certain minimum levels of ductility. The ACI 318-08 concrete building code (ACI committee 318, 2008) recommends using spiral reinforcement to confine columns, especially in earthquake resistant structures where ductility is a very important issue. The ACI Committee 318 (2008) specifies a minimum allowable clear spiral spacing of 25 mm for constructability reasons, which may not be considered conservative and may show difficulty in the construction. The meanstioned code also specifies a maximum allowable clear spiral spacing of 75 mm, which may still show difficulty in the construction of large columns and long and slender piles. The construction of long and slender RC piles, where no visual inspection can be performed, can be very challenging if the spiral is closely spaced.

Hindi and Turechek (2006) tested 12 cantilever circular columns with two different lengths and several spiral spacing and patterns. The columns were subjected to constant axial load and reversed cyclic lateral displacement to study the influence of the new confinement technique on the lateral strength and ductility of circular columns compared to columns confined with conventional single spiral. Six of the columns (1000-mm high and 200 mm diameter) were designed to study the flexural behavior, and the other six columns (500-mm high and 200-mm diameter) were designed to study the shear behavior.

Hindi *et al*. (2005) tested the cross spiral idea in pure axial compression. The results gathered from those tests showed that when compared by volumetric ratios of lateral reinforcement, the regular and the cross spiral confinement method showed comparable results in strength and ductility. Also, when a column that had two spirals, each with a spacing of S, was compared to a column with a single spiral with spacing S, the strength was increased slightly while the ductility tended to increase dramatically. The proposed cross spiral confinement technique offers the same benefits as spiral confinement, but it also allows more flexibility to better fit the needs of the designer or contractor.

Havaei and Keramati (2009) tested fourteen circular RC columns under eccentric load. The results of their tests of the columns with the same volumetric ratio of confining spirals for regular and cross spiral with different eccentricities showed similar general performance but improved ductility, lower bending stiffness and lower moment capacity of cross spiral specimens with respect to regular ones. Columns with several configurations of lateral confinement have been tested by others (i.e., Saatcioglu and Grira, 1999; Lambert-Aikhionbare and Tabsh, 2001; Budek et al., 2002; Tanaka and Park, 1993; Kunnath and EL-Bahy, 1997; Turechek, 2006), including interlocking spirals, welded wire grids, high-strength and prestressed spirals, and fiber wrapping. The objective of this paper is to evaluate experimentally the strength and ductility of cross spiral circular reinforced concrete columns under eccentric loading using the new confinement technique. Eight reduced scale RC circular columns with two different grades spirals, two different volumetric ratio of confining spirals and two different positions of cross spirals under eccentric load were tested.

2. EXPERIMENTAL PROGRAM

Eight reduced-scale RC circular columns with cross spirals of two different grades, two different volumetric ratio of confining spirals and two different positions of cross spirals under eccentric load of e/D=1.0, ‘e’ as the eccentricity and ‘D’, the diameter of the specimen, were tested. The columns were constructed at Amirkabir University of Technology of Tehran, Iran, and tested at the structural laboratory Department of Civil Engineering. The tested portion of the columns had a clear height of 1000 mm with hunched heads of 500 mm height. The specimens were prepared, and tested under compression eccentric loading up to failure. The eight columns were cast in four sets of two different steel grades, volumetric ratio and spirals positions.

2.1. Specimen details

The columns considered in this research were built to a scale of 1:3, and only physical dimensions of the column and reinforcing steel were scaled. In order to investigate the proposed cross spiral confinement configuration behavior, two of the specimens were confined using cross spirals crossing at lateral faces (CSCL), two other specimens having cross spirals crossing the highly stressed tension and compression faces, i.e., 90° spiral rotation with respect to the first set (CSCLR), the other two sets with the same spiral shapes of the first two sets but having the amount of volumetric spiral ratio of twice the amount of preview two sets (CSCL-2ρ and CSCLR-2ρ). Table 1 summarizes the specimen labels and properties.

Table 1. Specimens details

Number	Exp. Code	Spiral Steel Grade	S*	ρ**	28 Day (f_c') (MPa)	Test Day (f_c') (MPa)
1	CSCL	G_1	150	0.0086	30.8	32.9
2	CSCL	G_2	150	0.0086	30.4	33.2
3	CSCLR	G_1	150	0.0086	30.6	32.9
4	CSCLR	G_2	150	0.0086	30.5	33.1
5	CSCL-2ρ	G_1	75	0.0172	30.9	33.3
6	CSCL-2ρ	G_2	75	0.0172	30.7	32.9
7	CSCLR-2ρ	G_1	75	0.0172	30.6	33.8
8	CSCLR-2ρ	G_2	75	0.0172	30.5	33.0

Each specimen was labeled using CSCL for cross spiral and CSCLR for cross spiral crossing at lateral faces, CSCLR for 90° spiral rotation of ρ equal to 0.0086 and CSCL-2ρ and CSCLR-2ρ of ρ equal to 0.0172. The numbers following the letters define the steel grades G_1 and G_2. The spiral spacing is 150 mm center to center for the first four specimens and 75 mm for the second four. Figure 1 shows a comparison between different cases cross spirals.

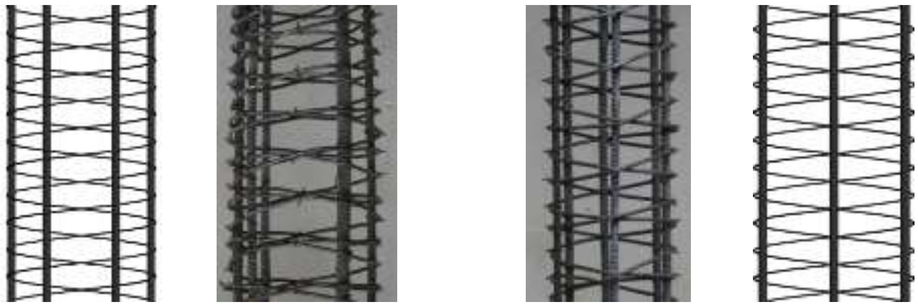


Figure 1 . Spiral comparison

The specimens had an overall diameter of 250 mm, which is one third of a typical column of 750 mm diameter. As shown in Figure 2, the distance (198 mm) center to center of the longitudinal rebars was kept constant for columns with cross spirals in order to make a fair comparison in terms of flexural capacity. This led to a minimum cover of 20 mm to the outer edge of the outer spiral for columns with cross spirals. The Specimens details for the cross spiral columns are show in Figure 2. The used reinforcements were tested at Strength of Materials Laboratory of Department of Mechanical Engineering of Amirkabir University of Technology. The stress-strain curves for the test material are shown in Figure 3. G_1 (f_y =323MPa) and G_2(f_y =435MPa) were used for spirals and G_3(f_y =335MPa) was used for all of longitudinal reinforcement.

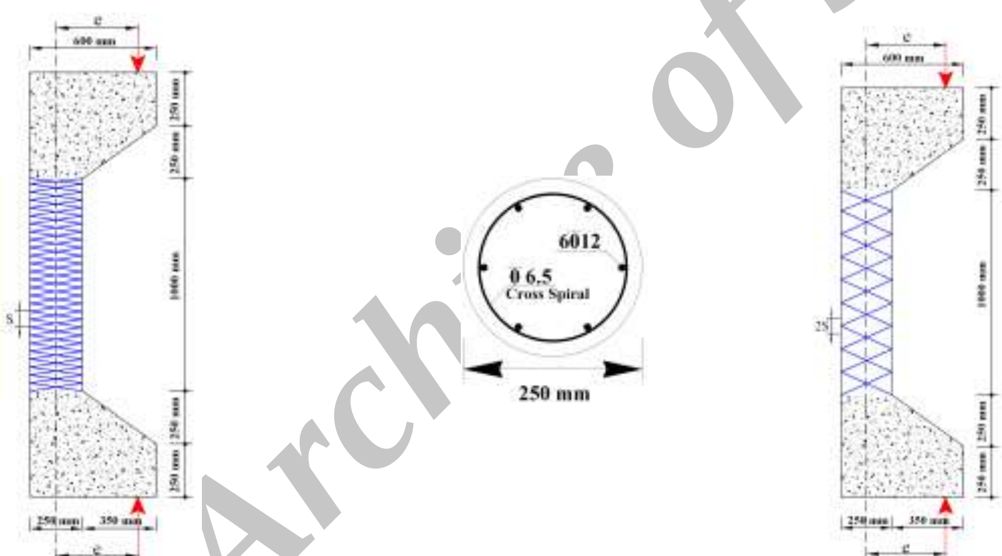


Figure 2. Specimens details.

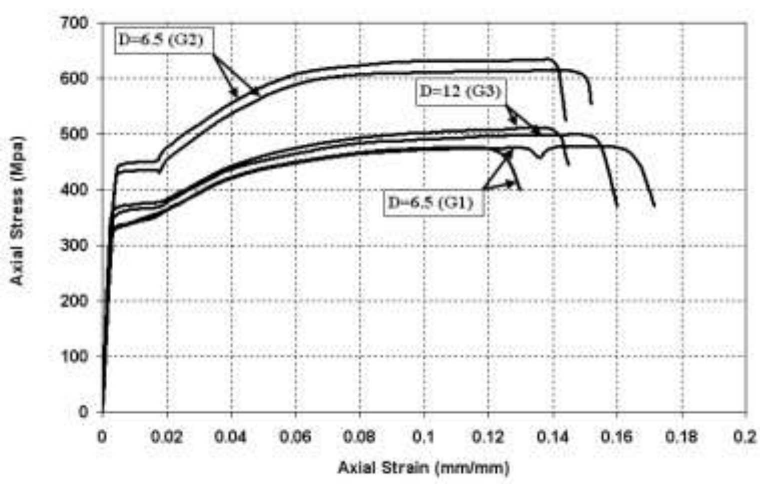
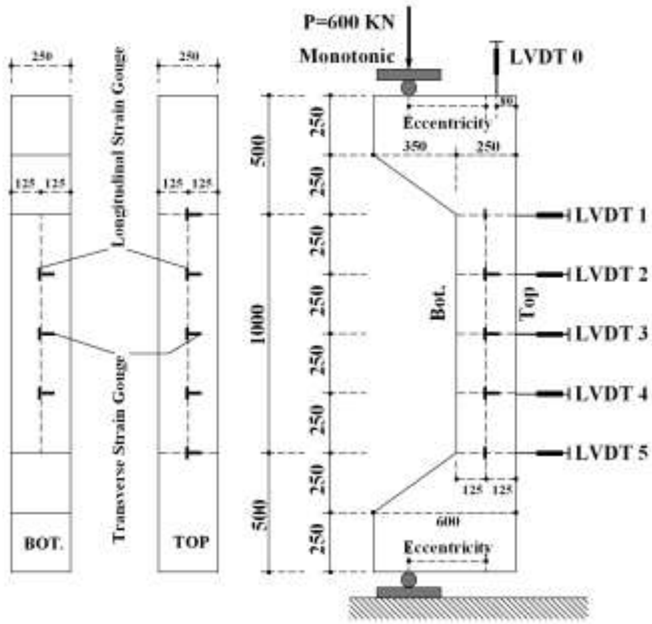


Figure 3. steel stress-strain curves

Each column had six $-\phi$ 12 mm deformed steel bars for longitudinal reinforcement. The longitudinal reinforcement ratio, for all columns was 0.014. The spiral spacing used is 150 mm for volumetric ratio equal ρ and 75 mm for volumetric ratio equal 2 ρ columns. The spiral was made of 6.5 mm diameter smooth bar. The transverse (confinement) volumetric reinforcement ratio, for volumetric ratio equal ρ columns was 0.0086 and for volumetric ratio equal 2 ρ columns was 0.0172. This ratio was calculated based on the columns concrete core measured to the outside edges of spirals. For columns confined, the concrete core was assumed to be the area surrounded by the average of the centerlines of the two spirals, which equals to the area surrounded by the outer diameter of the inner spiral, as shown in Figure 2. A ready-mix concrete with pea gravel was used for the specimens. For each column concrete, six standard cylinder specimens taken, three tested at 28 day and the other three tested at the test day (around 90 days). The average concrete strength are shown in table 1. Each column was outfitted with twenty-four PL-60-11(120$\pm$ 0.3Ω) TML Series precision strain gauges. Six of strain gauges were placed on the compression side, eight on the lateral and ten on the tension side of the specimen as shown in Figure 4.



a) compression side b) tension side c) lateral side

Figure 4 . Strain gauges and LVDT arrangement

2.2. Test setup and loading

The columns were tested by use of a hydraulic testing actuator at the Structural Laboratory of Department of Civil Engineering. The testing frame setup is shown in Figure 5. The Top head of the specimen is vertically adjustable and it is attached to an actuator, while the bottom head is fixed. The connections of two heads were prepared as a hinge connection with predefined eccentricity. The lateral stability of every specimen in and out of plane was fixed by appropriate steel elements to a rigid frame. Figure 4 shows the arrangement of (Linear Variable Displacement Transducer) LVDTs and strain gauges. A total number of six LVDTs and 24 strain gauges were used for every specimen. The specimens were tested using a 600-kN capacity compression actuator and the data were monitored using an automatic data collecting system. The Displacements and strains were monitored by a digital data logger system. The tests were continued up to failure under a monotonically increased load under a displacement control mode. The force, displacements, and strains data were obtained during the test and were filed by computer software.

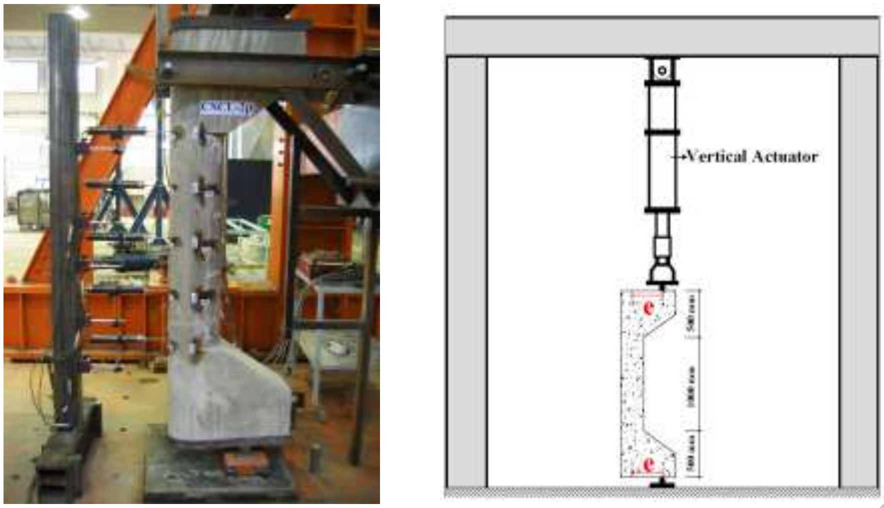


Figure 5. Test setup

3. EXPERIMENTAL RESULTS AND DISCUSSIONS

3.1. Overall Behavior

The behavior of the columns under eccentric loading had an overall similarity. At the early stages of loading of the specimens, the noise related to the micro cracking of concrete was obvious, indicating the start of stress transfer to the confined core. The maximum lateral deflection was seen at mid height of the specimen. The cracking, failure and fracture were gradual and began on tension face of the column. Concrete cracking progressed to up and down of the specimen. The fracture was initiated at mid height of the specimens up on reaching the column ultimate strength and decreasing of the jack applied load. Inspection of the fractured specimens showed yielding of longitudinal steel bar in tension face and buckling of longitudinal steel bar in the compression face of the columns. It was clearly observed the better performance of volumetric ratio equal 2 ρ columns to the volumetric ratio equal ρ columns, mainly on the crack width and spacings. Figure 6 shows the failure and fracture region of confined by volumetric ratio equal ρ and confined by volumetric ratio equal 2 ρ specimens.

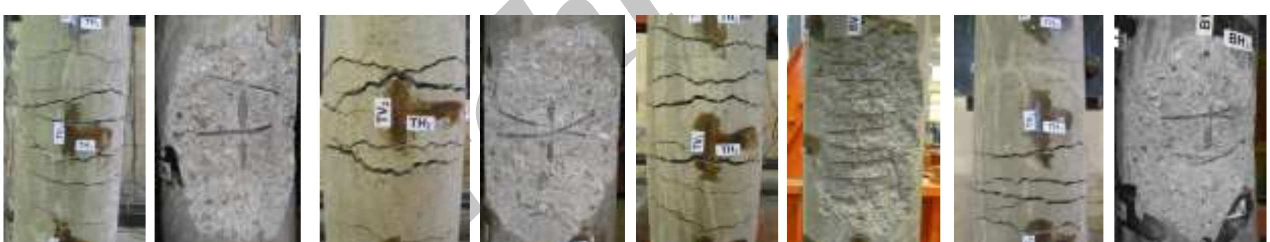
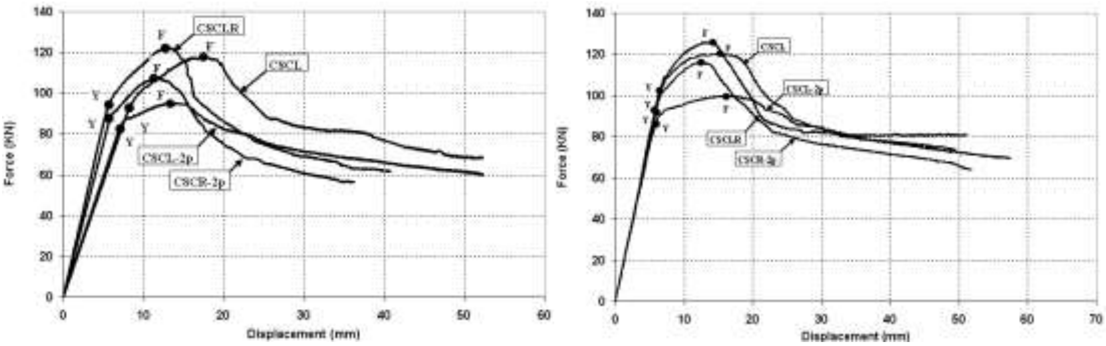


Figure 6. Column Failures

3.2. Load-Displacement Behavior

The load-displacement curves of specimens with 100% eccentricities are shown in Figure 7. The displacements were measured from load actuator. All specimens have an approximate linear behavior before yield point, Y. For example, for the specimen CSCL-1 with G_1 (f_y =323MPa), the tension side longitudinal steel bars are yielded at the force of 94.68 kN and a displacement of 8.52 mm. The first secant stiffness is equal to 11.11 kN/mm. After yielding of tension bars, the stiffness is decreased but the load capacity is increased to the point, F, where the compression reinforced buckles and forms a plastic hinge at the force of 117.56 kN and a displacement of 17.28 mm. All of the specimens have a similar nonlinear behavior based on Figure 7. The first part of all curves roughly is linear to yield point, Y, where the steel bars in tension edge are yielded. After the cover spalling, the spirally confinement are effectively activated, so second part of all curves have not enormous stiffness degradation. The second stiffness is improved with confined by volumetric ratio equal 2 ρ . The maximum load carrying of every specimen is achieving at confinement failure point, F.

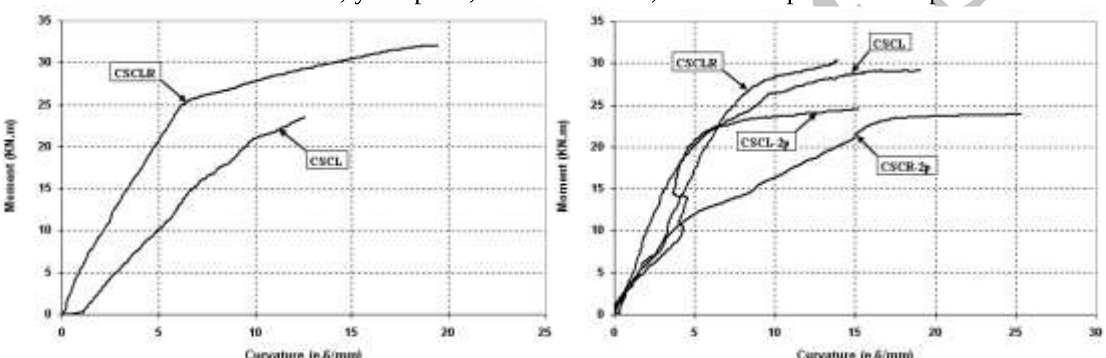


a) Steel type G_1 b) steel type G_2

Figure 7. Load-displacement behavior of specimens

3.3. Moment-Curvature Behavior

Figure 8 show the moment-curvature behavior of specimens at the mid height of the test length. The moments were calculated with multiplying the forces by the eccentricity. The curvatures were obtained with dividing the differential longitudinal strain of tension and compression edges per height of mid section (250 mm). It shows that the tested volumetric ratio equal 2ρ column have improved curvature capacities but lower bending stiffness and moment capacity with respect to volumetric ratio equal ρ columns. Table 2 shows the first stiffness, yield point, second stiffness, and failure point for all specimens.



a) Steel type G_1 b) steel type G_2

Figure 8. Moment-curvature behavior of specimens

Table 2. Experiment results

Specimen	First Stiffness (KN/mm)	Yield Point (Y)		Second stiffness (KN/mm)	failure point (F)	
		Force (KN)	Disp. (mm)		Force (KN)	Disp. (mm)
CSCL (G1)	11.11	94.68	8.52	6.80	117.56	17.28
CSCL (G2)	14.51	108.81	7.5	7.30	120.2	16.46
CSCLR (G1)	16.23	96.73	5.96	9.34	121.96	13.05
CSCLR (G2)	14.23	111.86	7.86	8.63	125.24	14.51
CSCL-2ρ (G1)	11.06	87.30	7.89	7.28	95.00	13.04
CSCL-2ρ (G2)	14.09	90.19	6.4	5.99	100.14	16.7
CSCR-2ρ (G1)	14.65	89.97	6.14	8.99	107.04	11.90
CSCR-2ρ (G2)	15.02	100.23	6.67	8.92	116.06	13.00

4. CONCLUSION

From the testing of 8 reinforced concrete columns with spiral volumetric ratio equal of ρ and 2ρ with steel grades G_1 and G_2, as recorded in the paper, the following conclusions were drawn:

(1) Considering the moment-rotation diagrams, it shows higher moment capacity of all specimens using spirals grade G_2 versus G_1.

(2) Considering the moment-curvature diagrams, it shows considerable improvement in specimens ductility using spiral volumetric ratio of 2ρ with steel grade G_2 versus ρ and G_1.

(3) Observation of specimens mode of failure indicated that breakdown of specimens was mostly due to insufficient moment resistance. In specimens with volumetric spiral ratio less than the ACI code limit, the failure due to insufficient confinement in addition to moment failure was also observed.

(4) The behavior and crack propagation pattern of the specimens showed that almost all of the cracks converged in the point of maximum curvature and diverged towards the tension zone with an inclination almost the same as spiral inclination.

(5) The results showed that the ductility of the specimens reinforced with cross spirals of steel grade G_2 increase about 13% versus G_1.

(6) Comparison of the tested specimens showed an improvement in ductility of about 19% of specimens with spiral volumetric ratio of 2ρ versus ρ.

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