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Numerical Analysis of Multi-spiral Confinement in Rectangular Columns

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Abstract: Appropriate design of confinement reinforcement in columns is basically critical for structures that need to persevere through strong earthquakes. This study presents the numerical analysis on multi- spiral confinement for rectangular reinforced concrete columns through investigation and assessment of various configurations in axial compression through the finite element analysis (FEA) method using ANSYS Software. Confinement designs, including conventional configuration and different multi-spiral configurations were evaluated in a series of axial compression loading. The outcomes show that the specimens with multi-spiral configurations exhibited higher compressive strengths and energy capacities than those with rectilinear conventional confinement designs. Among them, five spirals configuration showed better confinement and therefore, was chosen for additional study. A detailed parametric study was carried for 5S confinement designs. Test variables include spiral diameter ratio and center to center spiral spacing. The efficiency of multi-spiral confinement in rectangular columns was clear through this study.
Keywords: Confinement, Multi-spiral, Axial compression, FEA

1. Introduction

Conventional transverse reinforcement in columns consists of perimeter hoops and cross ties. Generally transverse reinforcement gives a combination of benefits for the strength of the column. It provides a passive confinement impact that increases the ultimate axial load. Confinement steel also provides columns with higher shear strength capacities as well as an increase in ductility. Conventional system accompanies a bunch of issues special to rectangular molded sections. Ordinary reinforcement performs ineffectively in distributing the lateral stresses attributable to the uneven nature of the layout of the lateral steel. Due to the extreme need for ductility and shear transfer in highly seismic areas, the amount of traditional rectilinear reinforcement can cause significant congestion. Another concerning issue with high lateral reinforcement designs is the extra time expected to form, install, and tie every perimeter hoop for every column.

The application of helical reinforcement in rectangular concrete columns is not normal because it creates an uneconomical design. So, the multi-spiral interlocking model which was invented by Yin et al. (2004) shows the importance of structural relocation in the construction industry.

With the improvement of technologies and Finite Element Techniques, it has become a practical method to contemplate RC structures. Kachlakev et al. (2001) uses ANSYS finite element methods to strengthen the RC beam by using FRP composites. A.I Karabinis et al. (2007) studied the reinforced column seismically strengthened by FRP Jacketing by using the finite element modeling. Pierre Labossiere et al. (2011) carried out a finite element analysis of columns confined by composite materials. They suggested models for predicting the ultimate load capacities of RC columns in addition to identification of stress and strain in the column during the loading process. Y Chen et al. (2011) studied the compressive behavior of columns confined by interlocking multi-spirals using finite element methods. Rajai Al-Rousan (2019) presents a three-dimensional finite element modeling for columns confined with CFRP composites. Investigated the compressive behavior of short columns confined by multi-spiral reinforcement by FEM using the stress-strain model of Mander et al. (1998). Wang et al. (2020) proposed a simplified finite element analysis method for the columns incorporated with the multi-spiral configurations.

In this study ANSYS finite element models were used to stimulate the compressive behavior of different column configurations. The analysis of columns with complicated configurations is not easy to carry out. So, the research presents a comparison study between the conventional column configuration with multi-spiral configurations using ANSYS software. Due to the better performance of five spiral configurations, a parametric study was carried out to understand the application of such configurations in real life.

2. Finite Element Analysis

2.1 Element Type

SOLID186 Element was used to model the concrete. It is a higher order 3-D, 20-node solid element that exhibits quadratic displacement behavior. The element is defined by 20 nodes having three degrees of freedom per node: translations in the nodal x, y, and z directions. The element supports plasticity, hyper elasticity, creep, stress stiffening, large deflection, and large strain capabilities. It also has mixed formulation capability for simulating deformations of nearly incompressible elastoplastic materials, and fully incompressible hyper elastic materials.

BEAM188 Element was used for steel section modeling. The element is a linear, quadratic, or cubic two-node beam element in 3-D. BEAM188 has six or seven degrees of freedom at each node. These include translations in the x, y, and z directions and rotations about the x, y, and z directions. A seventh degree of freedom (warping magnitude) is optional. This element is well-suited for linear, large rotation, and/or large strain nonlinear applications.

2.2 Material Properties

The finite-element study in this paper was conducted within the elastic range, only essential material properties were used. For both the longitudinal and transverse reinforcing steels, a Young's modulus, E_s of 200 GPa and a Poisson's ratio, μ_s of 0.3 were used for modeling. Also yield stress of steel was taken as 314MPa. The Poisson's ratio of concrete, μ_c of 0.2 was used in this study. The modulus of elasticity of concrete, E_c can be determined according to the formula suggested by IS 456:2000, as follows,

$$E_c=5000\sqrt{f_{ck}}$$

2.3 Finite Element Modelling

The ANSYS software is used to perform the analysis and to predict the axial compression behaviors of the columns incorporated with multi-spiral configurations. Due to the symmetry of the modeled structure, half of the column height was considered for the modeling, which will reduce calculation effort. Mesh convergence determination was also done. Boundaries were kept as effectively held in position at both ends, restrained against rotation at one end. Steel reinforcement modeling was done by adopting the discrete method.

2.4 FEA Validation

To verify the approach used in this study, a validation was conducted for the four spiral configured columns with different material properties. All rectangular columns were 1200mm in height and 600*600mm size. Fig.1 shows the comparison of results obtained from the test and analysis. The finite element analysis used to verify the approach showed a better agreement with the test results. Thus, concluding that the method is efficient for further study on numerical analysis and parameter study.

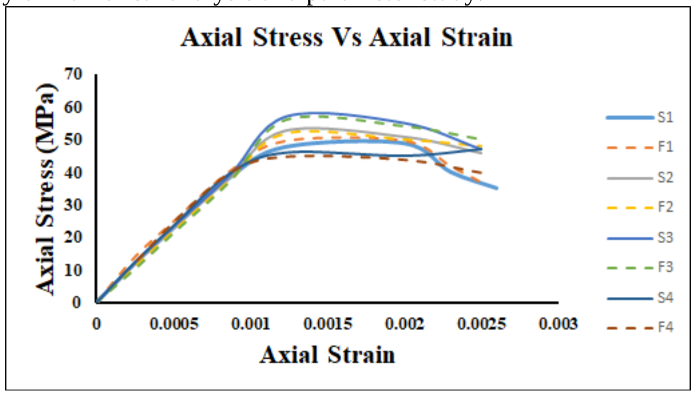

Fig.1 Axial stress Vs Axial strain

3. Results Analysis

3.1 Numerical Results

The Fig.2 shows the four configurations used to study which includes a traditional stirrup design (C), the combination of two spirals (2S), the combination of four spirals (4S) and the combination of five spirals (5S). Table 1 lists the geometrical and engineering properties used for the analysis. The vertical spacing of the confinement varies from 50 to 100 mm.

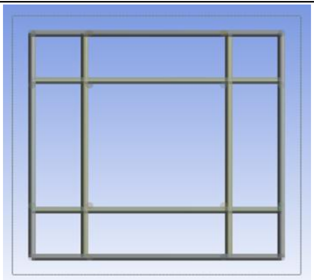

Fig.2.a C Configuration

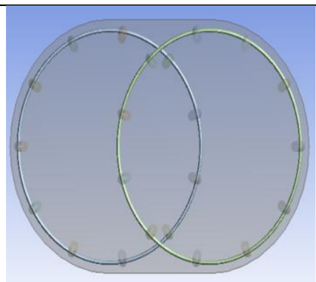

Fig.2.b 2S Configuration

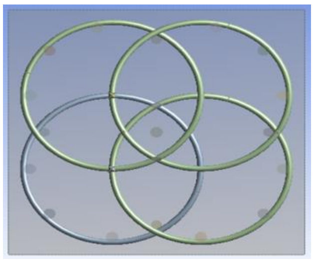

Fig.2.c 4S Configuration

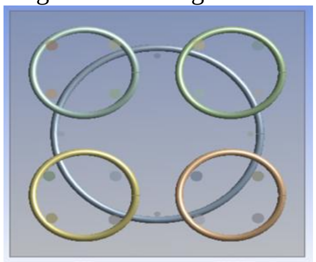

Fig.2.d Configuration

Fig.2 Different Confinement Configuration modelled in ANSYS Software

Table 1 Material Properties

Material Properties				
Cross section	Concrete f_{ck} (MPa)	Lateral Reinforcement		
		f_y(MPa)	Bar size (mm)	Spacing (mm)
C1	25	500	8	75
C2	25	415	8	75
C3	35	415	10	65
C4	65	500	8	75
4S1	25	415	8	75
4S2	25	415	10	75
4S3	25	500	8	65
4S4	35	415	10	70
4S5	25	415	10	75
4S6	65	415	8	75
5S1	25	415	8	75
5S2	25	415	10	75
5S3	25	415	S-8, L-10	65
5S4	35	415	8	75
5S5	65	500	10	65

5S6	65	415	S-8, L-10	65
2S	25	415	8	75
2S2	25	415	10	75
2S3	25	500	8	65
2S4	35	415	10	70
2S5	65	500	8	75

The size of all rectangular columns was chosen as 600*600*3000 mm while the oblong column as 610*915*3000 mm. Yield strength of longitudinal bars were given the same as the transversal bar. They were taken as 16-25 mm Ø. The four spiral configuration consists of four spirals interlocking with each other having a spiral diameter as 360 mm. The five spiral configuration has one large spiral with a spiral diameter of 420 mm which is interlocked by four small spirals with 210 mm spiral diameter at the corner of the large spiral perimeter. The two spiral configurations consist of two circular cages interlocking with each other having a spiral diameter of 540 mm. Fig.3 shows the comparison of stress Vs strain relationship of the four configurations. This figure shows the axial compression behavior of rectangular columns can be improved by using multi-spiral interlocking configurations. Also, oblong two spiral configuration is considered for the study to conform spiral configurations efficiency as compared with the rectangular columns.

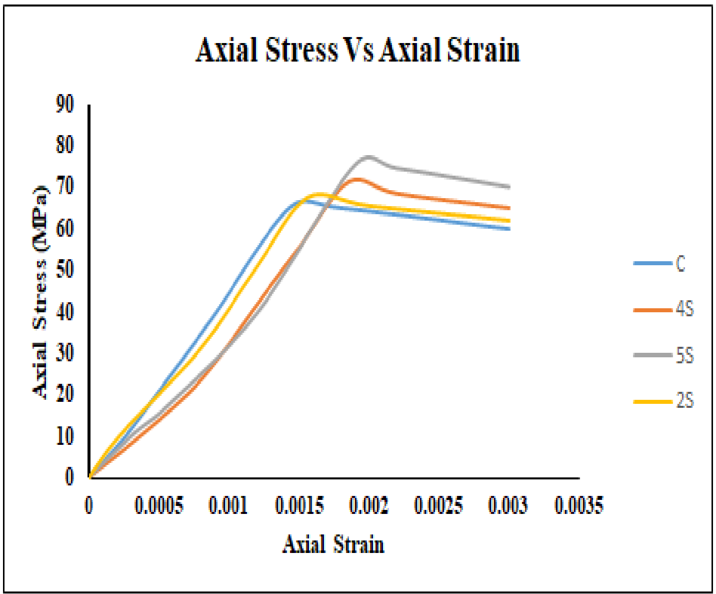

Fig.3 Comparison of configurations

4. Parametric Analysis of 5S Configuration

As compared with conventional column configuration with multi-spiral configurations, 5S shows better performance. Also, the small spirals at the corner can provide much more confinement along with keeping the vertical bars closer to the column perimeter. According to the better performance from the previous analysis, a detailed parametric study was carried out to understand the usage and application of multi-spiral configurations.

4.1 Effect of Large and Small Spiral diameter

To explore the impacts of the measure of large and big spirals on the compressive strength of confined concrete, the proposed strategy was applied to specimens with different ratios of large and small spirals for the five spiral arduous ratios. The diameter ratio, the ratio of large diameter to that with the diameter of small spirals was used to create the ratios. Therefore, the five diameter ratios were produced by keeping the spiral diameter of large spirals as constant while the small spiral diameter kept changing. The other properties of columns remain the same as those of the previous analysis. After the analysis it was found out that the confinement efficiency was reduced while the spiral diameter ratio decreased. According to the codal provisions the volumetric ratio for spiral hoop is inversely proportional to A_c/A_g. By comparing the analytical results obtained, the transversal reinforcement of each column was defined in terms of volumetric ratio according to IS 456: 2000. Hence with lower D_L/D_S ratios, the column gains better axial load carrying capacity. Thus, the confinement efficiency of the column increases with a lower spiral diameter ratio.

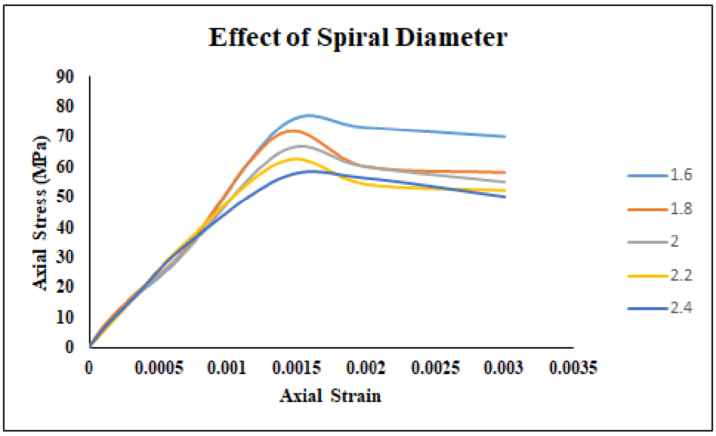

Fig.4 Comparison graph of Spiral Diameter Study

4.2 Effect of center-to-center spiral spacing

The center to center spacing of two interlocking spirals should have an important role in the design of configuration. The efficient transfer of shear forces from spirals to spirals need to take place for resisting the shear force. So, the study on the effect of spirals center to center distance is done. Fig.6.8 shows the Center-to-Center distance of 5S configuration. It is the vertical distance between the centers of two spirals, i.e.; large and small. It was understood that the c/c distance can be related to the large spiral radius the study was carried out for five c/c distance which was a set of multiplication of the large spiral diameter. According to the observed results, the center-to-center spiral spacing should be within 1R to 1.2 R, where R is the large spiral radius. After that the structure is showing reduction in axial load carrying capacity because, After the effective confinement, that can be provided by the interlocking region decreases, which further decreases the strength of the structure. In practical cases, there must be chances of separation of cages along with increase in c/c distance. Fig.5 shows the comparison graph of five specimen with different center to center spiral spacing.

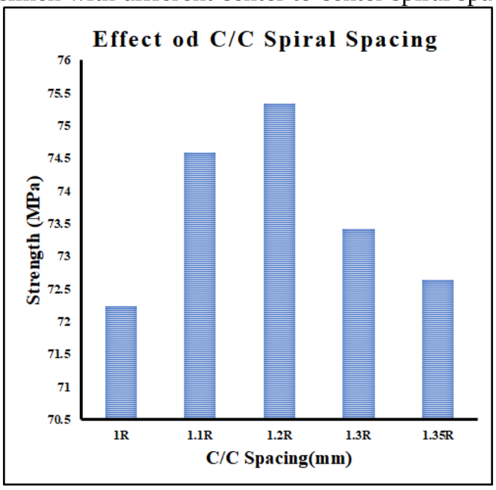

Fig.5 Comparison graph of C/C Spiral Spacing Study

5. Conclusion

In this research compressive behavior of rectangular columns incorporated with an interlocking multi-spiral configuration has been studied. Numerical results show better agreement with the experimental results under axial compression. It can be concluded that the multi-spiral columns perform better than traditional columns. The stress-strain relationship obtained from the analysis clearly states that the axial load carrying capacity of columns incorporated with multi-spiral configuration can be increased by 25% than the traditional columns. Also, the transversal steel required for the construction can be reduced by 30% by replacing the traditional columns with multi-spiral columns. By comparing the traditional columns and multi-spiral columns, the five spiral configurations exhibit superior confinement behavior. A parametric study was carried out for a better understanding of five spiral configurations. From the study, it was understood that, for the same amount of transversal reinforcement, the axial load carrying capacity of 5S is increasing with a lower spiral diameter ratio, where the ratio is considered as D_L/D_S. To achieve better confinement efficiency, closer spiral pitches and C/C spiral spacing of 1.2, Where R is the Large spiral radius, should be provided.

Acknowledgements

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