Investigation of the optimal design equation for stirrups used in ductile reinforced concrete columns

Abstract

One of the most important properties of concrete structures is their ductile behavior against earthquake. Ductility of a structure includes resisting relatively high plastic deflection without significant reduction of structure strength and absorption of earthquake energy through hysteresis behavior. Different design codes have considered requirements for ductility of various structural elements. The purpose of this study is to investigate the optimal design equation for stirrups used in ductile reinforced concrete columns. In this investigation, stirrupts for three types of columns including the circular column with 750 mm diameter and rectangular columns with dimensions 1000×1000 and 500×500 mm in medium and high ductility were studied. Also, two types of concrete strength 30 and 60 MPa were considered to evaluate the effect of concrete strength. The required stirrupts obtained from proposed equations were compared with IR code and ACI. Moreover, numerical simulation using ABAQUS software for aforementioned situations was performed. Finally, the results obtained from DBA and Vikor methods considering axial and rotational ductility, and cost showed that the proposed equations are the most optimal design equation in medium ductility. Also, the proposed equations are the best in high ductility when they were used to columns with concrete strength 30 MPa. In concrete strength 60 MPa, the equations suggested by ACI and IR code are the most optimum as they were applied to the circular column and the rectangular column with cross-section 1000×1000 in high ductility, respectively.

Keywords: Ductility, Stirrupt, reinforced concrete column, ABAQUS, DBA

1. Introduction

One of the most important properties of concrete structures is their ductile behavior against earthquake. Structures ductility includes resisting relatively high plastic deflection without significant reduction of structure strength and absorption of earthquake energy through hysteresis behavior. Different codes and requirements such as ACI318 [1] and IR code [2] have presented equations to determine the required stirrup for various ductility levels. Many researches have been conducetd to assess the ductility for reinforced concrete columns. Palter et al. [3] investigated the effects of concrete strength and transverse reinforcement on concrete beam column behavior. In another research, they also proposed models predicting the required stirrups for concrete with strength 120 MPa. Seismic behavior of circular and rectangular concrete beam column was studied by Li et al. [4]. The results of the research indicated that all specimens had highly ductile behavior. In this study, models have been proposed to determine the required stirrups for circular and square reinforced concrete columns in medium and high ductility levels. Then, a comparison has been performed between the proposed model with ACI and IR code requirements. Finally, DBA and Vikor methods [5] considering axial and rotational ductility, and cost are used to determine the most optimal design equation for different ductility levels.

2. Methodology

The proposed models of circular columns for medium and high ductility levels were presented in Eqs. (1) and (2), respectively:

$$\rho_s = 0.098 k_p (\frac{f_c'}{f_{yh}}) \qquad (1)$$

$$\begin{cases} k_p = \dfrac{P}{P_0} \\ P_0 = 0.85\left(A_g - A_{st}\right) f_c' + A_{st} f_y \end{cases}$$

$$\rho_s = 0.17 k_p \left(\frac{f'_c}{f_{yh}}\right) \tag{2}$$

$$\begin{cases} k_p = \dfrac{P}{P_0} \\ P_0 = 0.85\left(A_g - A_{st}\right) f'_c + A_{st} f_y \end{cases}$$

Also, the proposed models of square columns for medium and high ductility levels were presented in Eqs. (3) and (4), respectively:

$$\frac{A_{sh_y}}{c_y s} = 0.06 k_p k_n \left(\frac{f'_c}{f_{yh}}\right)\left(\frac{A_g}{A_{ch}}\right) \tag{3}$$

$$k_n = \frac{n_1}{n_1 - 2}$$

$$\frac{A_{sh_y}}{c_y s} = 0.09 k_p k_n \left(\frac{f'_c}{f_{yh}}\right)\left(\frac{A_g}{A_{ch}}\right) \tag{4}$$

$$k_n = \frac{n_1}{n_1 - 2}$$

The aforementioned models were compared with ACI and IR code requiremens. Also, DBA and Vikor methods considering axial and rotational ductility, and cost are used to determine the most optimal design equation for different ductility levels. The results are discussed in next section.

3. Results and discussion

According to DBA and Vikor methods, the proposed models are the most optimal design equations in medium ductility for circular and square concrete columns. Also, the proposed models are the most optimal design equations in high ductility for circular and square concrete columns with concrete strength 30 MPa. However, the equations of ACI and IR codes for circular and square columns with high ductility and concrete strength 60 MPa are the best design equations, respectively.

4. Conclusions

Based on the results, it can be concluded that the proposed models are able to suitably determine the required stirrups for reinforced concrete beam columns in medium and high ductility levels.

References

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