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Effect of rectangular spiral stirrup on bearing capacity of RC beams under cyclic loading

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ABSTRACT: Nowadays, civil engineers are looking for novel approaches to develop structural performance and the speed of building construction simultaneously. One of these approaches is using rectangular spiral stirrups instead of traditional stirrups in manufacturing of RC beams. Based on recent experimental studies, these beams have shown some advantages in performance when compared with beams reinforced by traditional stirrups and in some cases, the results were much better. In this study, at the first stage, two types of RC beams with rectangular spiral stirrup and traditional stirrups were simulated in the ABAQUS software and verified under monotonic loading. The shear capacity was measured and validation was performed based on the experimental force-displacement curves. Then, at the second phase of this research, another RC beam with traditional stirrups was simulated and was verified against push-over curves. Moreover, the force-displacement of monotonic loading and failure mode was obtained from an experimental study. Cyclic loading was applied to the beams with continuous rectangular spiral and traditional stirrups. Then, the performance of those simulations was compared by enveloping strength curves. But in the cyclic loading phase, in most cases, the performance of beams with these two transverse reinforcement methods was equivalent and in some cases, the traditional one was shown even better results.

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1. INTRODUCTION

Beams and columns are two important structural parts of each building and have significant effects on the behavior of a building. So, a lot of researches have been carried out until today in order to investigate the behavior of beams and columns. According to the studies conducted in recent years, the bearing capacity of the beams and columns can be significantly improved by using spiral transverse reinforcements in place of the traditional stirrups [1]. Moreover, the spiral stirrups are manufactured in the factory. So, when the spiral stirrups are used in any project, the construction time is reduced dramatically. Several researchers have investigated the effect of the rectangular and circular spiral stirrups (considering different configuration) on the behavior of reinforced concrete columns (bearing capacity and flexibility) under monotonic and dynamic loading [2- 5]. De Corte and his colleagues [6] investigated the effect of the rectangular spiral stirrups on the behavior of reinforced concrete beam. In their study, a four-point monotonic load was applied on the beam. The results obtained from their research indicated that the bearing capacity and ductility of RC beam with spiral stirrups were greater than the corresponding values of the RC beam reinforced with the traditional stirrups. Karayannis et al. [7] carried out experimental research for the investigation of the effect of the simple and advanced rectangular spiral stirrups on the behavior of RC beams under the four-point monotonic load. They concluded that when the spiral stirrup is used, both the shear capacity of the beam and its ductility are increased approximately as 22 and 200 percent, respectively. Maranan et al. [8] investigated the behavior of concrete beams transversely reinforced with rectangular GFRP composite spirals. They reported that when the GFRP spiral stirrup is used in a beam, the shear capacity of the concrete beam and its ductility are increased. The resistance of the links of the spirals against the shear diagonal cracks is the main reason for the increase of the shear capacity and ductility of the concrete beam [8]. Min Li and his coworkers [9] showed that the behavior of an RC beam under monotonic loading is completely different from its behavior when subjected to cyclic loading. They concluded that the bearing capacity of an RC beam under cyclic loading is lower than that of monotonic loading (roughly 10 percent). It necessitates that the behavior of RC beams with rectangular spiral stirrups should be investigated under cyclic loadings. A review of the literature indicates that there is a need for more investigations on this topic. Because, the majority of the researches carried out in this area, investigated the behavior of RC beams, experimentally. So, there is a lack of knowledge of stress and strain distributions in the beam with rectangular spiral stirrups. On the other hand, no research has been found in the case of the effect of the rectangular spiral stirrup on the behavior of an RC beam under cyclic loadings. The current

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research is carried out to respond to these needs.

In this regard, a finite element model of an RC beam with rectangular spiral stirrup was developed using ABAQUS CAE/6.14 commercial software. Then, monotonic and cyclic four-point loadings were applied to the model. A comparison has been made between the results obtained from the finite element model developed in this study and experimental available results found in the literature to prove the validity of the results of the developed model. The effect of the rectangular spiral stirrup on the behavior of concrete beam was then investigated comprehensively through performing a parametric study.

2. METHODOLOGY

Equations of the RC beam were modeled in the ABAQUS finite element software. The beam was simulated using C3D8R solid elements. This three-dimensional element has eight degrees of freedom. The transverse and longitudinal reinforcements were simulated as wire using T3D2 element. This bilinear element has two nodes. A bilinear elastoplastic material model was used to simulate the reinforcement's behavior. The modulus of elasticity and Poisson's ratio of the steel reinforcements were considered as 210000 MPa and 0.3, respectively. In the FE model developed in this study, concrete damage plasticity (CDP) behavior was used to model the behavior of concrete. Based on the ACI 318 [10], modulus of elasticity of the concrete () was considered as in which, stands for 28 days strength of the concrete. In addition, the Poisson's ratio of the concrete was taken as 0.2, uniaxial tensile and compressive behaviors of the concrete were considered in the model to define the concrete plastic behavior. The longitudinal and transverse reinforcements were assumed to be embedded within the concrete beam elements. The boundary and loading conditions were applied to the model. The flexural behavior of the beam was investigated under a linear monotonic four-point load. In addition, a cyclic four-point load was applied to the beam in order to investigate the effect of rectangular spiral stirrup on the flexural behavior of the beam.

3. VERIFICATION

Concerning the literature, there is no sign of investigation of the behavior of RC beam with rectangular spiral stirrup under cyclic loading; the verification of the model developed in this study was performed in two steps. At the first step, a comparison was made between the results obtained from the FE model and Karayannis et al. [7] experimental results. Moreover, the shear capacity of the concrete beam was calculated based on the ACI. The results obtained from the model developed in this study, those of Karayannis et al. and ACI ones are presented in Table 1. As can be seen from this table, there was a good agreement between the results obtained from the model and Karayannis et al. experimental results. In the second step of model validation, the behavior of the beam with traditional stirrup under cyclic loading predicted by the model was compared with the experimental ones of Min Li et al. [12]. The hysteresis diagrams obtained from the model and Min Li et al. experiment are shown in Figure 1. As illustrated in Figure 1, the results obtained from the models are in good agreement with the results measured and reported by Min Li et al. [12].

4. RESULTS AND DISCUSSION

A parametric study was also carried out in this study in order to investigate the effect of some parameters on the behavior of concrete beam (hysteresis curve and strength) under cyclic loading. The concrete compressive strength, diameter and spacing of transverse reinforcements, length and the cross-sectional area of the beam were changed through the parametric study. The results obtained from the parametric study indicated that when the concrete compressive strength considered as 30 MPa, the behavior of RC beam under cyclic loading is not affected by the spiral stirrup. In other words, in this situation, the behavior of the beam with spiral stirrup under cyclic loading is very close to that of the beam with the traditional stirrup. Moreover, as the spacing of the spiral increases, the bearing capacity of the concrete beam increases. In fact, when the spiral spacing is increased, the strength of the beam with spiral stirrup becomes greater than that of the beam with the traditional stirrup. When the characteristic strength of concrete is considered as 20 MPa, the strength of the beam with spiral stirrup is obtained very close to that of the beam with the traditional stirrup. As a conclusion, when the concrete strength is increased, the strength of the concrete beam with spiral stirrup is also increased. In the presence of concrete material with the strength of 20 MPa, as the spacing of the spiral stirrup increases, the flexural rigidity of the concrete beam with traditional stirrup under cyclic

Table1. Comparison of results for verification

Model Name	Vu, FE (KN)	Vu, EXP (KN)	Δpeak FE (mm)	Δpeak EXP (mm)	Error Vu (%)	Error Δpeak (%)
ST80	125	125.1	7.8	7.3	0.17	8.08
SP80	134.3	143.2	8.9	10.3	6.66	13.7
SPA80	135.4	150.0	11.1	11.1	10.8	0.72
ST120	105.9	107.0	7.6	7.6	1.14	0.66
SP120	119.9	124.5	8.8	8.8	3.9	0.45
SPA120	122.9	125.2	10.6	10.1	1.97	5.05

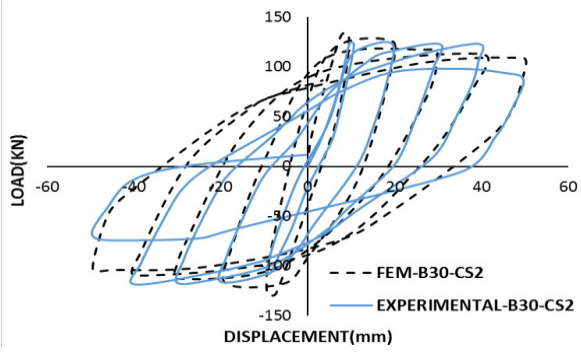

Fig. 1. Comparison between hysteretic loops

loading becomes greater than that of the beam with the spiral stirrup. The difference between the strength of the beam with spiral and traditional stirrups depends on the number of the cycles of the loading. As the number of cycles of the loading is increased, the difference is raised and reached 18 percent. The strength reduction of the beam with spiral stirrup is justified based on the reinforcement congestion. As the spacing of spiral stirrup is increased, the reinforcement congestion is decreased and subsequently, the concrete enclosure and beam strength are decreased. As the diameter of the rectangular spiral stirrups increases from 6 to 10 mm, the bearing capacity of the concrete beam is increased from 9 to 15 percent, roughly. Moreover, the ultimate strength of the concrete beam is increased up to about 60 percent, if the compressive strength of concrete is increased from 20 to 30 MPa. The length and cross-sectional area of the beam have no significant effect on the beam behavior reinforced by traditional and spiral stirrups under cyclic loading. In other words, as the beam length and cross-sectional area of the beam increases, the beam is failed by flexural mode instead of shear mode. Hence, the bearing capacity of the beam depends on concrete strength and longitudinal reinforcement. As the concrete strength is increased from 20 to 30 MPa, the strength of the beam is increased 30 percent, approximately.

5. CONCLUSIONS

Main results obtained from the current study lead to the following conclusions:

- Based on a comparison made between the results obtained from experimental and numerical studies, it can be deduced that the ACI-318 is conservative at predicting the ultimate shear strength. The nominal shear strength of the beam predicted by ACI-318 was 40 percent lower than those of the experimental and numerical works.

- According to the force-displacement curves obtained from the parametric study, when the concrete strength is considered as 30 MPa, the behavior of the beam with spiral and traditional stirrups under cyclic loading was the same. In other words, when the strength of the concrete is high, the spiral stirrup has no significant effect on the strength of the beam. As the concrete strength is decreased from 30 to 20 MPa, the behavior of the beam is affected by the transverse reinforcement. Hence, the strength of the beam with spiral stirrup is different than that of the traditional stirrup.

- The link of the advanced spiral stirrup was perpendicular to the crack line in the straight direction of the cyclic loading. But, in the reverse direction of cyclic loading, the link was parallel with the crack line. So the strength of the beam with advanced spiral stirrup was low.

- As the diameter of stirrup increased, the strength of the beam increased and the beam was fractured by shear mode. Moreover, as the spacing of the spiral was increased, the strength of the beam with spiral stirrup was decreased compared to the beam with the traditional stirrup.

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