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Improvement behavior of RC beams with continuous spiral stirrups under shear

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ABSTRACT

Reinforced concrete, RC beams subjected to shear failure which is the most unwanted failure mode due to speed progress is studied numerically. Therefore, the effective design of beams is necessary because of the sudden failure types of these beams in shear. The minimum shear reinforcement ratio of RC beams must be provided around the longitudinal rebars. Thus, the stirrups with different patterns have a significant benefit for improving the RC beam. In this paper, the performance of specimens with different spiral stirrups using ANSYS programs is investigated by comparing them with conventional stirrups of RC beams. One statement on the experimental results has been obtained from previous research Karayannis et al. [17]. The behaviors of these experimental beams are compared with finite element analysis of the identical beams. It is found that the behaviors of the experimental beam in comparison with the behaviors of the numerical beam are slightly different. Based on the FE analysis, the shear strength results demonstrated the mean accuracy and standard deviation of about 0.994 and 0.028, respectively, compared with the experimental test. Furthermore, the curve determined from FE analysis is consistent with the experiment data. The results give knowledge about the importance of spiral stirrups of the beam, and the most effective method among the investigated cases.

1. Introduction

Shear failure behavior is brittle due to the rapid breakdown of reinforced concrete beams [1]. It makes predicting the occurrence of shear failure is difficult due to low deformations. The use of stirrup correctly is necessary for buildings construction to ensure bending failure occurs before sudden shear failure. Therefore, it is necessary to discover more effective stirrup reinforcement methods for shear beams. Thus, stirrups with different patterns are a significant benefit [2]. The spiral reinforcement of seven small-sized RC beams enhances the ductility of the beam before shear failure occurs. mixed shear reinforcement of RC beam-column joints improved failure mechanisms and increased bearing compared to specimens with traditional stirrups [3].

Moreover, beams with spiral stirrups increased shear resistance and improved ductility and peak deformation compared to beams with commonly used stirrups [4]. Meanwhile, it is found that the use of spiral stirrups in place of conventional rectangular stirrups with the same amount in beams improves the beams' torsional ability and performance response [5]. So, to enhance constructability and cost, the structural performance of reinforced concrete columns was developed by using continuous hoops subjected to repeated loads [6]. Joshy and Faisal [7] have improved the shear capacity and ductility of 12 self-compacting concrete beams, and Corte and Boel [8] stated that the use of spiral stirrups instead of conventionally stirrups under the bending test. Also, Shataratet et al. recommended using spiral shear stirrups with an angle of about 80° to

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improve the ductility and shear behavior of the beams and reduce labor costs [9]. In addition, continuous spiral stirrups are recommended in the SCC beam at an angle of 85° regardless of the spacing between them. It enhances the shear capacity and reduces the construction cost [10]. Thus, it is found that few researchers use spiral stirrups rather than traditional vertical stirrups [11]. Since the shear failure mechanism is complex, the experimental test of beams underestimated the contribution of the stirrups but increased the contribution of the concrete component. In contrast to analytical methods, stirrups do not reach yield upon failure [12].
In general, structural analysis is very complex. Therefore, finite element analysis (FE) is used to simulate realistic problems of structures and obtain approximate solutions. Finite element analysis has been used widely by practicing engineers [13-16]. The finite element method can analyze the non-linearity of the behavior of the RC beams.

2. Research significance

ANSYS is commercial software for 1D, 2D, and 3D structure behavior analysis by geometric model properties, meshing the different shapes and post-processing. Thus, numerous engineering and scientific research use ANSYS interactive software to evaluate experimental results. In this paper, ANSYS software is used to study the performance of beams with different continuous spiral stirrups based on the experimental beam that has been obtained from previous research Karayannis et al. [17].

3. Numerical Analysis

The numerical analysis employed is finite element analysis of various engineering applications of ANSYS software.

3.1. Modeling

The modeling was performed by using ANSYS software for beams with various forms of conventional and continuous stirrups and then analyzing these models. Then, it was defined as geometric of concrete with both longitudinal and stirrups reinforcement details for the beam. Thus, analyzing results reveals the importance of spiral stirrups and the most effective ones for beams to support the literature survey.

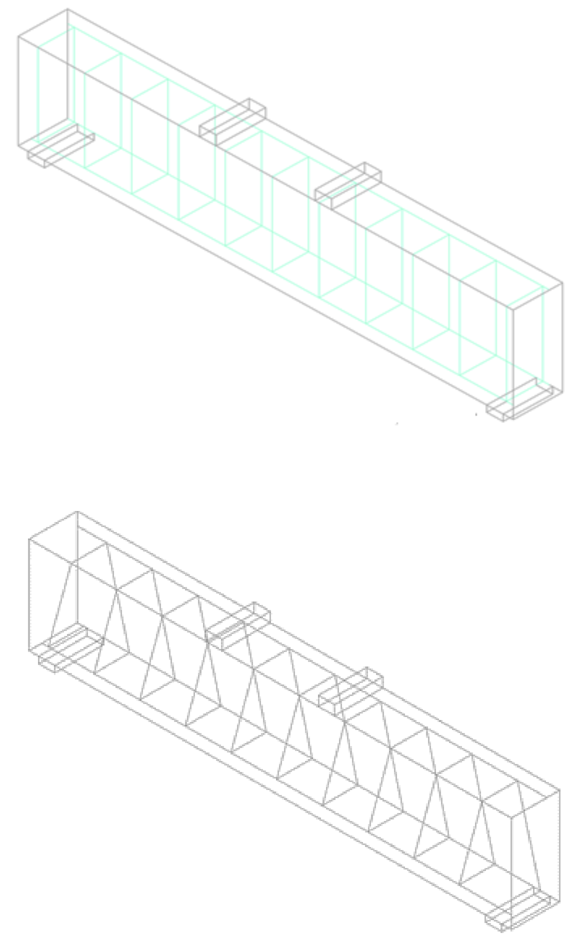

Figure 1. Traditional closed and spiral stirrups of beam B1 and B2

3.2. Details of beams

A numerical study includes three RC beams with a length of 1.84 m, a width of 200 mm, and a height of 300 mm (rectangular section). According to experimental research, the shear reinforcement of concrete beams has been represented by Karayannis et al. [17]. The beam B1 is with traditional closed stirrups (see Fig. 1) and beam B2 is reinforced with continuous spiral stirrups. The type of reinforcement of beam B3 is continuous spiral stirrups with inclined legs. The diameter of the stirrups is constant at 5.5 mm for all beams. The distance between the stirrups is 120 mm with a different pattern to obtain almost the same reinforcement ratio of the stirrups, approximately p=0.002. A new study is added to the numerical analysis by reducing distances between the stirrups to increase the percentage of shear stirrups. Therefore, the effect of the ratio of stirrups with different patterns has been studied to enhance the shear behavior of the specimens. Also, the effect of the grade of concrete strength on the shear strength has been studied.

3.3. Material properties

The steel reinforcement and concrete material properties by Karayannis et al. [17] have been used in Ansys software in accordance with the experimental results as listed in Table 1.

Table 1. Material properties of specimens

Concrete		Steel	
Tensile strength, (MPa)	02.85	Stirrup steel (MPa)	220
Compressive strength (MPa)	28.50	Longitudinal steel (MPa)	500
Young's modulus (GPa)	25.00	Young's modulus (GPa)	200
Poisson's ratio	00.20	Poisson's Ratio	0.3

3.4. Meshing and loading

The concrete and steel reinforcement were modeled in the Ansys program [18]. A quadrilateral mesh of concrete was used to obtain good results, as shown in Fig.2. The number of mesh elements and nodes are 9854 and 12728, respectively. The location of two-point loading with pinned supports on both ends of the model is represented. The applied loading was at two points with the distance between it 200 mm in the midspan apart of the beams. Meanwhile, the distance between two supports of the beam was 1.64 m apart. 3D spar elements represent the longitudinal and transverse steel reinforcement as link elements (see Fig. 3). Thus, the compatibility between practical and numerical data is achieved.

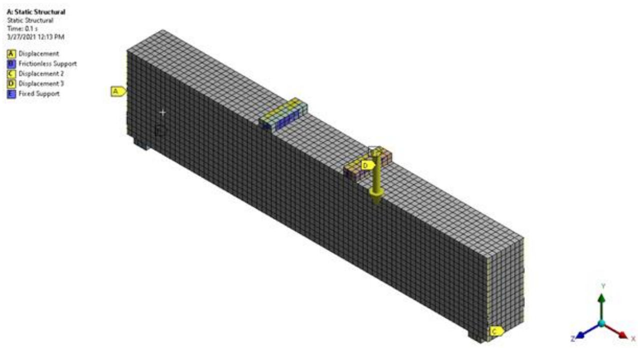

Figure 2. Quadrilateral mesh of concrete

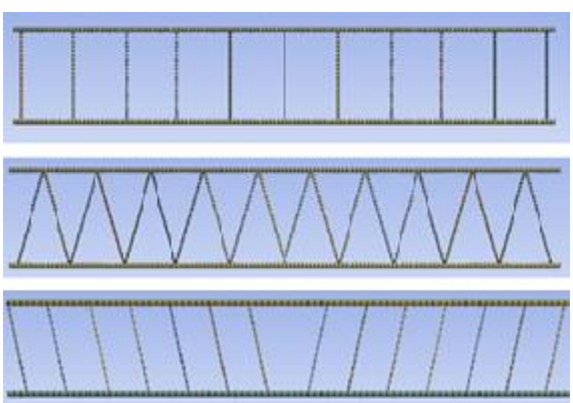

Figure 3. Link elements of different steel reinforcement

3.5. Linear analysis of specimens

This work uses the ANSYS program to perform a linear analysis of beams. The shear failure occurred after several attempts with maximum and minimum loading steps, leading to convergence failure at small loading increments.

3.6. Effect of stirrup ratio on shear behavior

In this paper, the numerical results have been verified by comparing them with experimental results in the literature reviews. Table 2 presents a numerical and experimental comparison of the shear strength of specimens with different types of spiral and closed stirrups. The numerical data analysis indicated shear failure for all beams consistent with the experimental data analysis. In addition, the results revealed that the shear strength of spiral reinforcement beams is higher than a conventional beam. Fig. 4 shows the

4. Results and discussions

In this section, load-deflection curve of the beam has been obtained by numerical analysis. In started, the high-resolution FE analysis is compared to the experimental beams. Then, the load-deflection curves defined from the FE analysis are less inconsistent with experimental curves after the cracks of the beam occurred because the perfect bond between beam components (steel reinforcement and concrete material) led to FE results having more stiffness. In general, the diagonal shear stress appeared in beams. According to the behavior of the curves of specimens, the results reveal that the spiral stirrups have higher shear strength than closed stirrups. This information agrees with Karayannis C. G. et al. [17]. In general, the behavior all curves of the beams B2 and B3 with continuous shear reinforcement showed that the shear strength is higher than the specimen B1 with stirrups closed. Moreover, the performance of specimen B3 showed more ductility improvement than the other beams on shear failure as compatible with experimental results Chalioris CEand Karayannis CG. [19].

Table 2. Comparison between numerical load and experimental load of beams [17]

Beam	Cracking load (EXP)	Cracking load (ANS)	Ultimate load (EXP)	Ultimate load (ANS)	Difference Cracking load	Difference Ultimate load
B1	148	135	215	210	1.096	1.024
B2	150	135	247	250	1.111	0.988
B3	150	135	252	260	1.111	0.969
			Mean		1.106	0.994
			Standard deviation		0.009	0.028

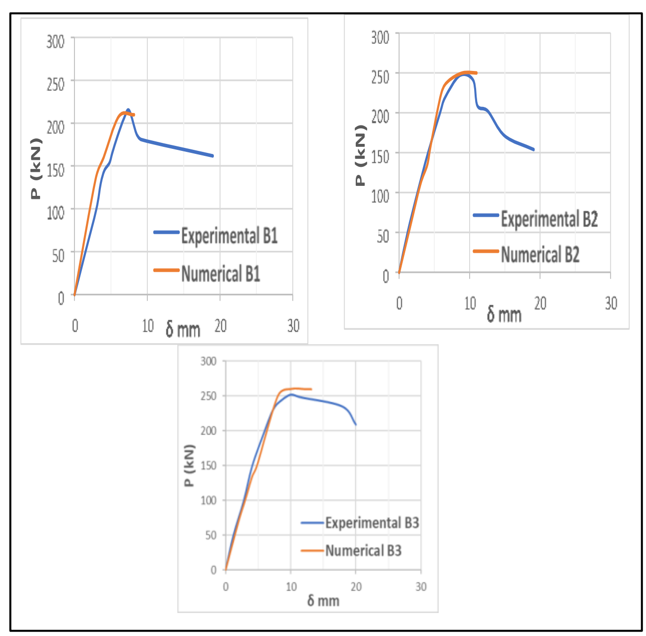

Figure 4. The load-defection of the beam with different pattern stirrups

4.1. Shear patterns

The finite element analysis was performed to predict crack development in concrete beams. ANSYS records a shear stress during the loading phases. The result of all beams appeared failure shear. In the beginning, no cracks of all beams were observed, and the behavior was essentially linear until the first crack was obtained. Thus, propagation of diagonal shear stress was observed in these beams. New diagonal cracks appeared with increasing loads, as the number of cracks increased parallel to the primary cracks until the final load. Thus, one crack developed significantly from the other cracks resulting in sample failure. For beams with different stirrup patterns, FE showed that the diagonal shear stress appear in concrete under the point loading toward the supports of the beam. So, beams with spiral stirrups have shear failure because enough longitudinal steel in the flexure area led to incline cracks appearing in concrete faster. For Example, Fig. 5 shows crack patterns deformation in concrete and steel on beam B2 at failure. Diagonal shear stress appeared within the shear test. As a result, the beam reinforcement pattern led to the typical shear patterns Shatarat et al. [10].

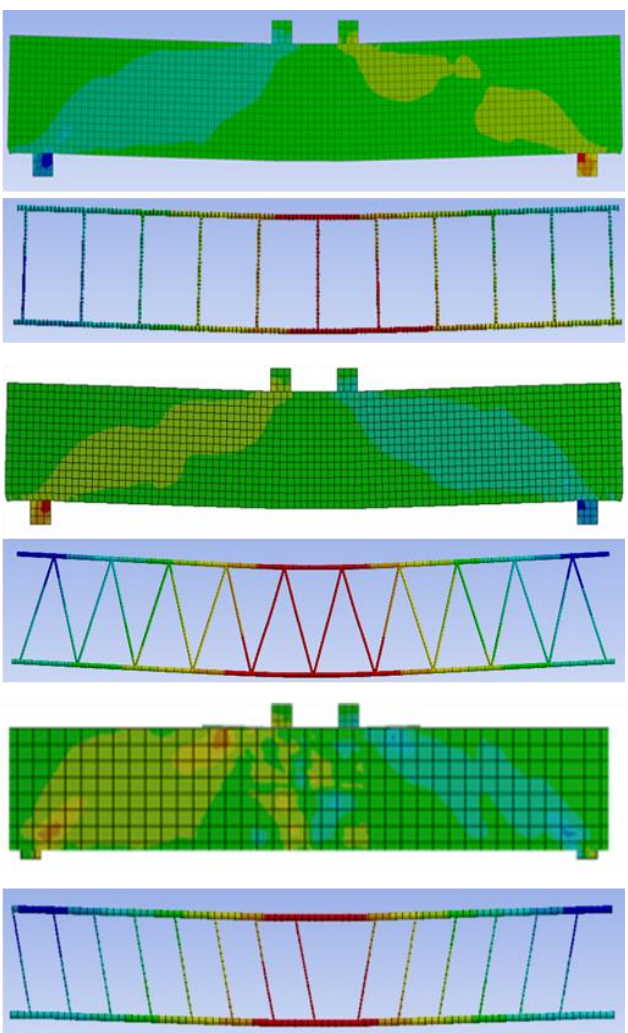

Figure 5. Shear patterns in concrete and steel of beams B1, B2 and B3 at failure.

In this section, some numerical parametric study is included, like compressive strength of concrete and ratio of spiral reinforcement on shear strength. For getting more information, the impact of concrete strength on the shear strength has been studied. Therefore, the compressive strength of concrete is increased from f'c to 1.5 f'c and 2f'c MPa for beams B1, B2 and B3, respectively. For beam B3, the numerical result indicates the appreciable increase in shear strength of beams of about 21 % and 39% with an increased grade of concrete from 1.5 f'c and 2 f'c, respectively. Also, it is noticing the shear strength response of all beams is better, as indicated in Fig. 6.

Figure 7 presents the shear strength of specimens with spiral stirrups reinforcement distances equal 120, 100, and 80 mm. The effect of the increased ratio of spiral stirrups on the shear capacity of specimens is about 5%, while the change distance between spiral stirrups is from 120 mm to 80 mm. The shear behavior of the RC beams depends on the shape of reinforcement of the stirrups. It also depends on the concrete strength by comparing different shapes of spiral stirrups in RC beams with conventional stirrups.

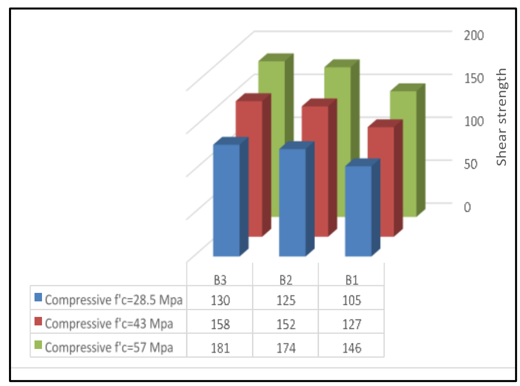

Figure 6. Effect compressive concrete on different pattern stirrups of beams

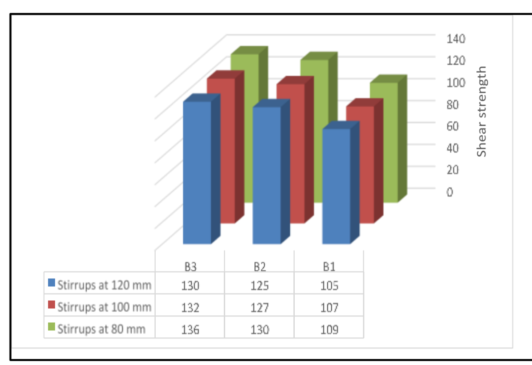

Figure 7. Effect ratio of stirrups on different pattern stirrups of beams

5. Conclusions

In this paper, the shear performance of traditional and continuous spiral reinforced concrete beams is investigated. These beams are analyzed using the ANSYS program and compared with the practical results from previous research. Numerical analysis indicted that the increasing in the grade of concrete to 1.5fc and 2fc led to increase the shear strength of the beam by about 21% and 39% respectively. The effective ratio of spiral stirrups by the less distance between stirrups from 120 to 80 mm is increased the shear strength of the beam by approximately 5%. The spiral stirrups configurations improved failure mechanisms and shear response compering with the same beam with conventional stirrups. The beam with spiral transverse reinforcement is enhanced performance and ductility response. Meanwhile, the beam with conventional stirrups showed the failure of the brittle shear. The numerical result is indicated the appreciable increase in shear capacity of all specimens with a high grade of concrete. The effect of the decreased distance between spiral stirrups on the shear capacity of specimens is low.

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