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Behavior Of Recycled Concrete Beams With Openings In Shear Region: Experimental And Numerical Study

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Abstract :
The current paper presents an experimental and numerical investigations to study the shear behavior of simply supported natural and recycled coarse aggregate concrete beams. A total of eight beams using two different types of aggregate ‘‘natural and recycled” were cast and tested. The beams were divided into two groups, the first group consists of four solid beams, while the second one consists of four beams with openings in the shear zone. The beams were subjected to a symmetric two-point loads for this purpose, four different replacement ratios of natural coarse aggregates (NCA) by recycled coarse aggregates (RCA): 0% (reference mix), 25%, 50%, and 100%. Subsequently, Numerical results were compared with the experimental ones to check the validity of the model. Afterward, a total of 18 numerical models were conducted to study the different parameters that not covered by the experimental program such that, shape of openings, dimension and location of openings along the shear span. The results indicated that compressive, tensile, and flexural strengths decreases as the recycled coarse aggregate increase. It was found that the shear behavior and the shear strength of the RCA beams were very similar to that of the corresponding natural aggregate concrete beams. The experimental results showed that a reduction in the shear strength of RC beams with openings ranged between 22 % and 30% in comparison to the corresponding control beam without opening.
Keywords: *Recycled Coarse Aggregates, R.C. beams, Opening, Shear, ANSYS*

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I. Introduction

The manufacture of concrete requires the use of significant amounts of cement and aggregates. The negative environmental impact of the production of these ingredients from nonrenewable sources led to a global interest in finding alternative sources. The use of recycled cementations materials has increased significantly. The use of recycled alternatives aggregates to the normal concrete aggregate has also been explored on a wide scale as it can lead to considerable savings in natural resources, landfills, and energy. Concrete that is produced using RCA is commonly referred to as recycled concrete aggregate. Japan was the first country interested in the study of RCA concrete. Kasai [1] and Mukai and Kikuchi [2] released the criteria for RCA concrete. Adnan et al (2007), [3], Malesev et al, [4], and .B. Singh et al [5] investigated experimentally the effects of various percentages of Recycled Coarse Aggregate (RCA) on the mechanical properties of Concrete. The study shows that the use of recycled concrete aggregate (RCA) can lead to a reduction of compressive strength. Choi Et Yun [6] investigated the shear behavior of reinforced recycled aggregate concrete beams without shear reinforcement. The variables in the test program were replacement rate of recycled aggregate and shear span-to-depth ratio. This work compared the experimental results with results obtained using current code equations found in the American Concrete Institute (ACI) 318 [7] and equations proposed in the study. This research had found that the current code equations can adequately predict the shear strength of recycled coarse aggregate concrete beams and possibly can be applied for the use of recycled aggregate in structural elements. Aly et al [8] studied sixteen beams to investigate the effect of RCA ratios, the shear span to depth ratios and the effect of different locations and reinforcement of openings on the shear behavior of the tested specimens. Test results indicated that the ultimate shear strength of beams with RCA is very close to those with natural aggregates indicating the possibility of using RCA as partial replacement to produce structural concrete elements. Khaldun Rahal [9] studied shear strength of recycled aggregates concrete a twenty-seven push-off specimens were tested to assess the effects of replacing part or all the coarse aggregates with recycled aggregates. It was observed that 20% and 50% replacement caused only a 7% reduction in the normalized shear strength. However, full replacement caused a 29% reduction. Ignjatovic´ I., et al [10] studied the shear behavior of RCA concert beams with and without shear reinforcement. It was found that insignificant difference in the shear behavior and the shear strength of the beams made from natural or recycled aggregate. Reis N., et al, [11] carried out experimental, numerical and analytical investigations on punching shear behavior of recycled coarse aggregate concrete slabs. Francesconi L., et al [12] presented the results of an experimental study of the influence of using RCA on the punching shear strength of RC slabs.

Limited studies have covered the topic of reinforced concrete recycled beams with openings. In this research, an experimental program, as well as the analytical method, will be carried out to study the shear behavior of RCA beam with openings. The effect of the size, shape, and position of the openings with various ratios of RCA, will be investigated.

II. Experimental program

All experimental program were carried out at the concrete research laboratory of the “Faculty of Engineering, Fayoum University”. A detailed description of the experimental work is introduced in this research:

i- Materials Used

The materials used in the preparation of the test specimens are Portland Cement (CEMI 42.5 N), normal drinking tap water, admixtures (addicrete BVF) for high workability, anatural sand as fine aggregate, and Natural and Recycled coarse aggregate. Two types of steel reinforcement were used. The first type with grade (28/45) was used with Ø 6 mm diameter as stirrups, where the second one was high-yield strength deformed bars with grade (40/60) used with Φ10 mm and Φ 12 mm diameter as top and main bottom reinforcement respectively.

ii- Mixtures Proportions

Four groups of concrete mixes, NCA and RCA were produced. NCA mixes were used fully natural aggregate as coarse aggregate in the concrete mix. Meanwhile, RCA mixes were used Recycled Aggregate as partially or fully replacement of natural aggregate as coarse aggregate. These mixes were designed according to the approximate design method. The concrete mixtures were prepared with a water-cement (w/c) ratio of 0.47. Addicrete (BVF) is used as a superplasticizer with 2% as a percentage of the mixture cement content. The combination in concrete mixes after this will be called as M1 (0%), M2 (25%), M3 (50%), and M4 (100%). Table 1 shows the mix proportions of the concrete. The properties of fresh and hardened NAC and RAC, based on average values for three tested specimens are presented in Table 2.

Table 1 Concrete Mixtures Proportions

MIX	Natural Aggregate (%)	Recycled Aggregate (%)	Cement (kg)	Sand (kg)	NCA (kg)	RCA (kg)	Water (kg)	add.BVF (kg)
M1 (0%)	100	0	375	613.3	1226.6	0	176.25	7.5
M2(25%)	75	25	375	613.3	919.92	306.6	176.25	7.5
M3(50%)	50	50	375	613.3	613.3	613.3	176.25	7.5
M4(100%)	0	100	375	613.3	0	1226.6	176.25	7.5

Table 2 Properties of fresh and hardened concrete.

Mix	Fresh concrete tests			Hardened concrete tests (MPa)		
	slump	compact factor	flow test	compressive Strength	tensile strength	flexure strength
M1	175 mm	0.92	148 mm	42.30	3.53	140.30
M2	160 mm	0.89	133 mm	41.42	3.07	119.81
M3	150 mm	0.88	104 mm	39.15	2.87	102.97
M4	143 mm	0.83	115 mm	33.34	2.56	93.24

III. Description of Tested Beams

The experimental program was conducted on eight beams divided into two groups with and without openings. The first groups consist of four beams without openings, while the beams in the second group consist of four beams with two rectangular openings of dimensions 100*200 mm. One in each shear region at 350 mm far from the support and were placed symmetrically about the mid-point of the beam. In each group, one beam made from different concrete types: 0%, 25%, 50%, and 100% replacement ratio of coarse aggregates. Dimensions of all specimens were 2000 mm length with 1800 mm effective length, 120 mm width, and 250 mm height. A clear cover of 15 mm was preserved at the top and bottom of the beam whereas a clear cover of 10 mm was preserved on the beam’s vertical sides. The reinforcement was three longitudinal bars with 12 mm diameter in the bottom and two longitudinal bars with 10 mm diameter at top, and the stirrups were 6 mm diameter spaced at 150 mm center to center. No additional reinforcement was used around the openings to simulate the sawn-up situation. Fig. 1 shows the dimension and reinforcement details of the test specimens.

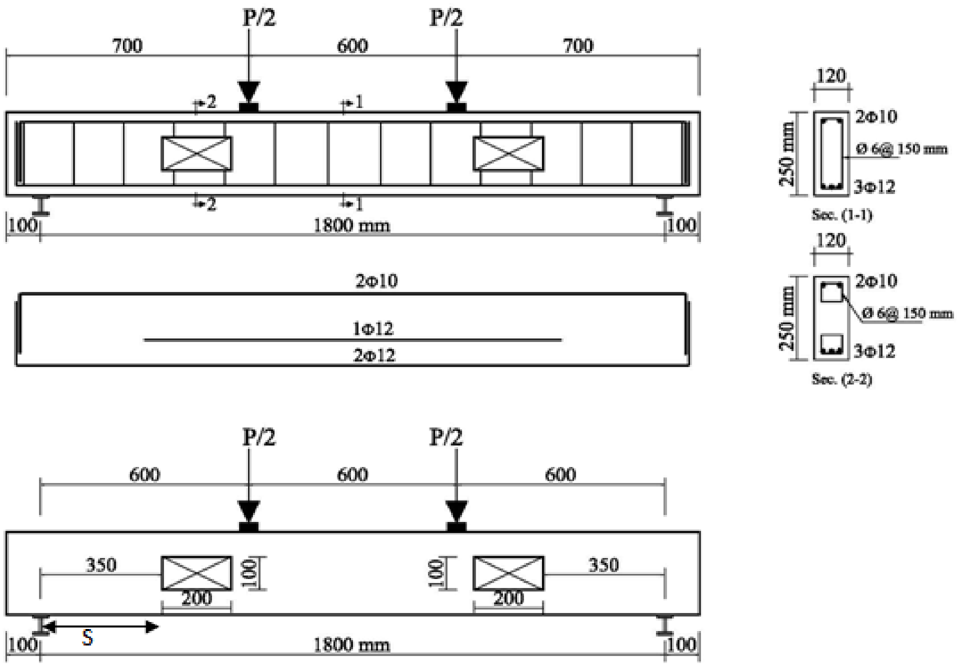

Fig. 1 Geometry and cross sections of tested beams (Unit: mm)

iii- Test Setup

All the specimens were simply supported with an effective span of 1800 mm and tested under the effect of asymmetric two point loads applied at the third points of the beam span. One LVDT with 100 mm was used and located at the bottom face of the specimen at the mid-point of the beam span. Fig.2 shows the experimental test setup.

Fig. 2 Experimental test setup

IV. Numerical simulation using Finite Element (FE) method

Numerical simulation usually provides a powerful tool for performing various investigations in a very small time and an extremely low cost compared to the experimental tests. In order to check the validity of the FE models, their results must be reliable and have an acceptable agreement with the experimental results. In order to predict the complete response of reinforced concrete beams such as; displacements, strains and stresses distributions, ultimate shear loads and failure modes, and cracking patterns, a three-dimensional nonlinear finite element model using ANSYS 14.5 [13]. In this model, nonlinear constitutive models of concrete and reinforcement are considered. Concrete is modeled using a solid element, SOLID65, which has 8-nodes and three degrees of freedom at each node and which is capable of cracking in tension and crushing in compression.

The shear-transfer coefficients for open and closed cracks have been set to 0.4 and 0.9; respectively. The main and web reinforcements are modeled using LINK180 bar element within the concrete SOLID65 one.

iv- Numerical Modeling of Beam and Boundary conditions

After constructing a model with volumes, areas, lines and key points, a finite element analysis requires meshing of the model. The model is then divided into a number of small elements, and after loading, stress and strain are calculated at integration points of these small elements. In the current study, a displacement control incremental loading was applied at two symmetrical concentrated loads. Total displacement was divided into a series of displacement steps. Newton–Raphson equilibrium iterations provide convergence at the end of each displacement increment within tolerance limits. The automatic time stepping in the ANSYS program predicts and controls load step sizes for which the maximum and minimum load step sizes are required. Table 4 shows the material properties of the elements. Fig 3 represents the numerical finite element model of studied beams with and without openings.

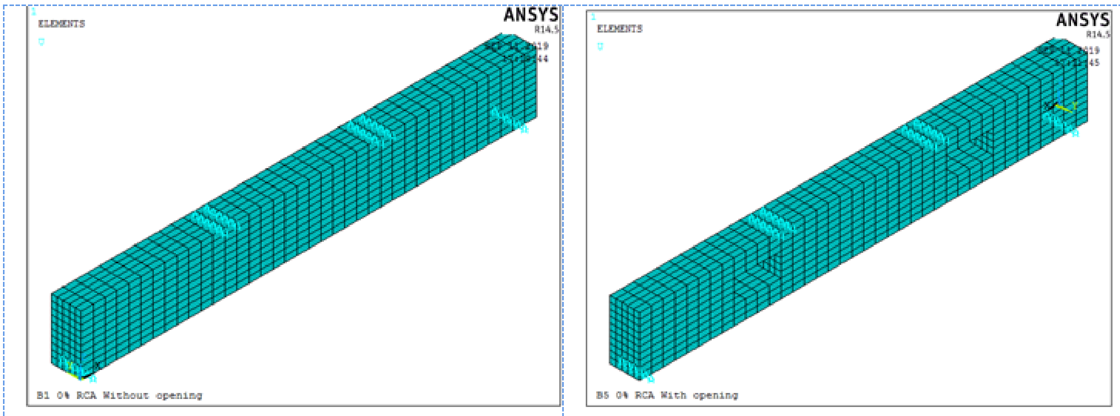

Fig. 3 Finite Element Models

V. Parametric Study

Verified models were used to investigate the variables not considered by the experimental program. A three-dimensional finite-element program 'ANSYS' was used for the numerical analysis of 18 beams. Three main variables will be studied: the opening size, percentage of RCA and position of opening. In this numerical analysis, three ratios of opening size (100*100, 100*200 and 100*300), two different percentages of RCA % (0 and 100), and three different positions of opening from support (150, 250, and 350) mm. The description of the suggested extra models is listed in Table 3.

Table. 3 Description of proposed extra Models

Group	Model	Opening size (mm)	RCA %	Position of Opening from support (S) (mm)
Group 1	B1, B2, B3	100x100	0	150, 250, 350
Group 2	B4, B5, B6	100x100	100	150, 250, 350
Group 3	B7, B8, B9	100*200	0	150, 250, 350
Group 4	B10, B11, B12	100x200	100	150, 250, 350
Group 5	B13, B14, B15	100x300	0	150, 250, 350
Group 6	B16, B17, B18	100x300	100	150, 250, 350

VI. Results And Discussion

The results obtained from the test specimens and numerical model are discussed in the following sections. The load versus the deflection values, failure load, and crack pattern were observed and post cracking stiffness and ductility ratio were calculated.

i- Results of Experimental Program

Load- Deflection Relationships

Figures 4 shows a comparison between the applied loads and the corresponding central deflection curves of the test specimens. The deflection and the load-carrying capacity indicated that the percentage of RCA causes a slight decrease in ultimate loads at the same deflection value for beams without openings, the ultimate load decrease from 98.7 kN to 94.0 kN with percentage 4.7%. Otherwise, in the case of the beam with openings, the percentage of RCA causes a significant decrease in ultimate loads, the ultimate load decrease from 76.2 kN to 66.1 kN with a percentage 13.25%.

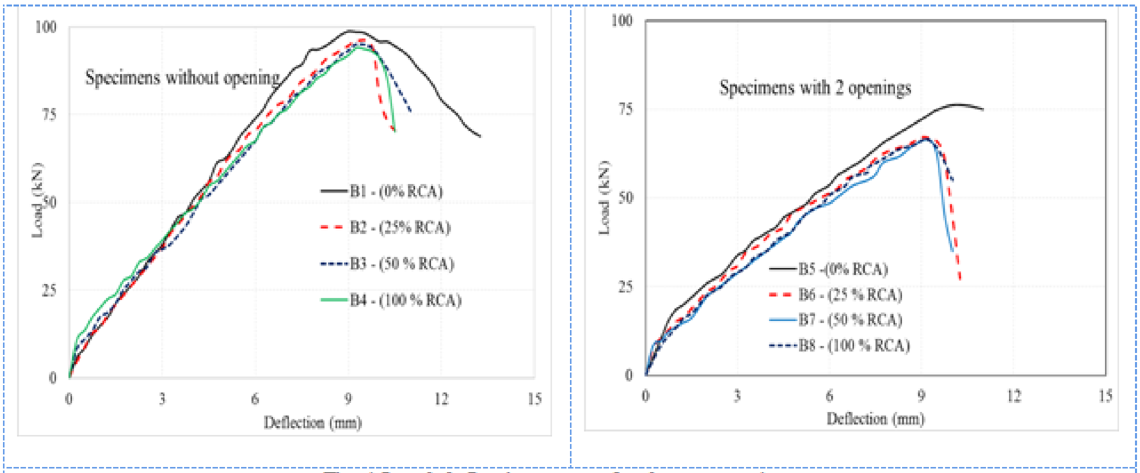

Fig. 4 Load-deflection curves for the test specimens

Ultimate Load, Ductility, and Post cracking Stiffness.

The experimental results of the test specimens such that ultimate loads, 1st cracking loads, ultimate deflection, yield deflection, ductility and post cracking stiffness are listed in Table 4. Its clear that the ultimate load capacity decrease by a percentage of 22.3 %, 30.0 %, 29.3 % and 29.6 % for 0%, 25%, 50 % and 100 % of RCA respectively for the corresponding two beams with and without openings. Otherwise, there is no significant difference (4.7%) in the ultimate load values for the beam without opening while there is a significant difference (13.25%) for the same type of beam with openings. The results showed that the 1st cracking loads for beams with openings smaller than that of the solid beams, as well as the effect of changing RCA percentage decrease the value of 1st load crack to 33.3% for beams without openings and to 14.3% for beams with openings. For all test specimens, there is slightly changed in ductility and post cracking stiffness values of the same type of beams (with or without openings).

Table. 4 Summary of test results.

Specimens	Ultimate Load Pu (kN)	1 st cracking Load (kN)	Ultimate Deflection δu (mm)	Yield Deflection δy(mm)	Ductility δu/δy	Post cracking Stiffness (kN/mm)
B1	98.7	78	9	8.05	1.12	10.78
B2	96.1	75	9.25	8.28	1.12	9.37
B3	95.3	68	9.25	8.8	1.05	9.75
B4	94.0	52	9.25	8.63	1.07	9.24
B5	76.2	49	10	9.35	1.07	6.61
B6	67.1	45	9	8.15	1.10	6.34
B7	66.5	43	9.25	7.85	1.18	6.03
B8	66.1	42	9.25	8.15	1.13	6.16

Cracking Pattern and Mode of Failure

Fig. 5 shows the cracking patterns of the test specimens after the completion of the test. It can be observed that all the test specimens failed in shear failure mode. The first crack occurs in the constant shear region. It, in general, occurs in the shear span of the beams and it is a shear crack (diagonal cracks). Cracking increases with increasing the loads and have appeared on the tension side of the beam accompanied by vertical cracks. In the case of the beams with opening, the crack pattern was diagonal and propagated from the corner of the opening to the edge of the beam. Spalling of concrete was seen on the surface of the beam and increased gradually until the load approached almost its ultimate value.

Fig. 5 Crack pattern for the tested beams

ii- Comparison between Experimental and Finite Element Results.

Fig. 6 shows a comparison between the load-deflection relationship for experimental and numerical results. The ultimate load and deflection for both experimental and FE results are summarized in Table 5. The average percentage between experimental results to numerical results in the ultimate load is 95%, while it is 89.1% for ultimate deflection. It can be seen that the numerical results are in good agreement with the experimental ones and the finite element modeling is quite accurate in representing the best specimens. The nonlinear numerical analysis shows close behavior with those obtained from the experimental study. The comparison between the experimental results with the finite element models shows that both models are in good agreement with each other, and shows the compatibility between are two solutions. Thus the developed finite element model can be used successfully to extend the work for studying the behavior of RC beams with and without openings using different percentages of RCA. Fig. 7 shows crack patterns obtained from numerical models, all cases were nearly identical as obtained from experimental tests.

Table 5. The ultimate load and deflection for both experimental and FE results

specimens	Experimental		Numerical		Exp to Num %	
	Ultimate Load (NK)	Def.mm)	Ultimate Load (NK)	Def.mm)	Load	Def.
B1	98.7	9.0	99.5	10.7	99.2	84.4
B2	96.1	9.3	99.4	11.2	96.6	82.9
B3	94.1	9.3	98.9	11.4	95.2	80.9
B4	94.0	9.3	97.9	10.7	96.0	86.3
B5	76.2	10.0	77.8	10.8	97.9	92.8
B6	67.1	9.0	75.6	10.8	88.8	83.5
B7	66.5	9.3	72.0	9.5	92.4	97.4
B8	66.1	9.3	70.2	8.8	94.2	104.6
				average	95.0	89.1

Fig. 6 comparison between experimental and finite element results

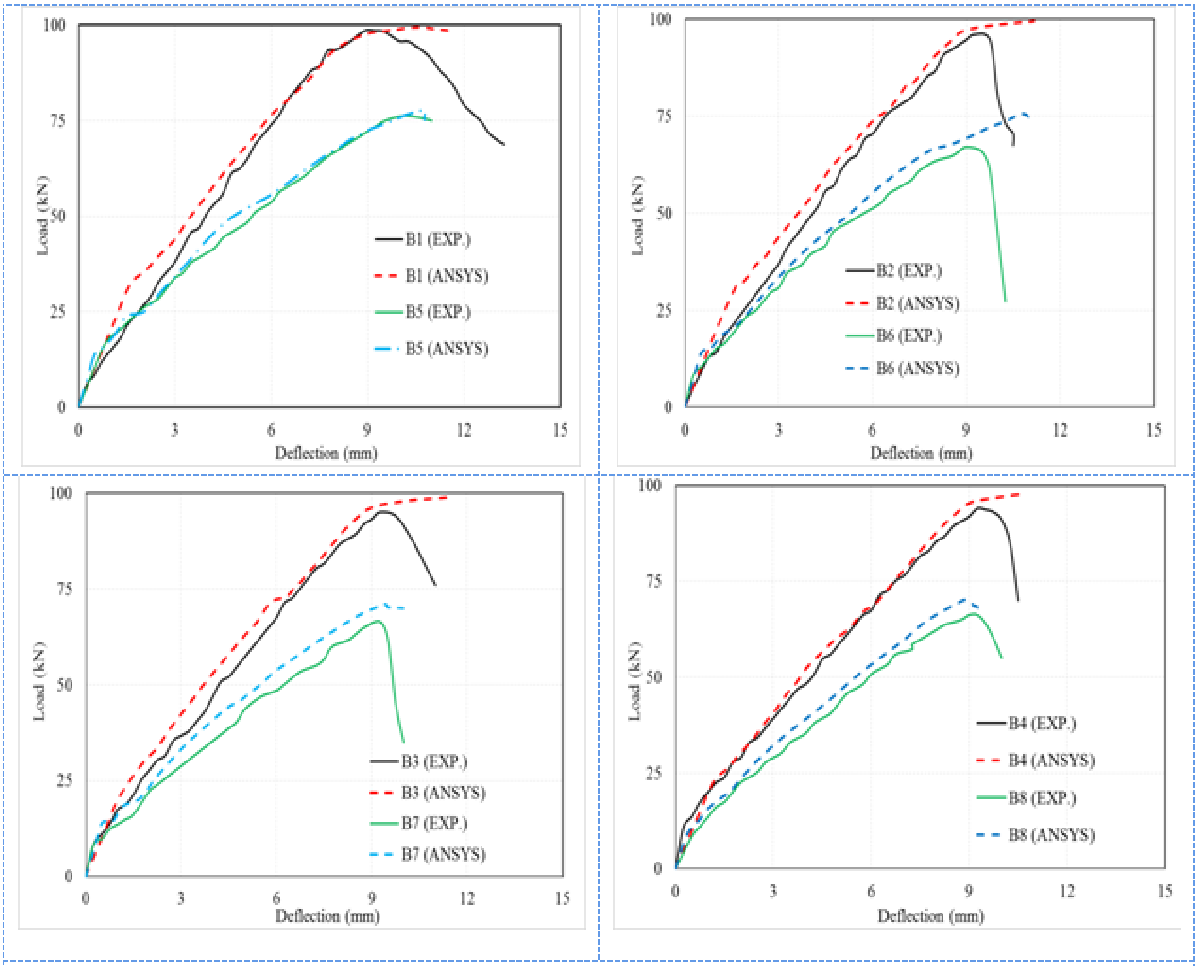

Fig. 6 comparison between experimental and finite element results

iii- Parametric Study Results

Fig. 8 shows the load-deflection relationship at the middle point for numerical models. The summary of numerical results is listed in Table 6. The ultimate shear strength is considerably increased as distance S increased for all groups, on the other hand, increasing the percentage of RCA from 0% to 100% causes decreasing in the ultimate shear strength capacity. Table 6 shows ultimate loads, ultimate and yield deflection, the ductility and post cracking stiffness of the suggested numerical models. The results show that as opening size increase from 1:1 to 1:3 as the ultimate loads decreases from 96.1 KN to 47.9 kN with a decreasing percentage equal 50% to 0% RCA, while it decreases from 87.1 kN to 36.8 kN with decreasing percentage equal 58% for 100% RCA. The results show also as the increasing distance of opening from support causes increasing the percentage of ultimate loads by 3.5%, 8.9% and 47.0% for 0% of RCA and 3.5%, 16.2% and 36.1% for 100% RCA due to change of opening size by 1:1, 1:2 and 1:3 respectively. Due to increasing opening size, there is slightly change in ductility values (8% for RCA=0% and 10.4% for RCA=100%), while due to changing location of opening from support the ductility values slightly change (13% for RCA=0% and 9% for RCA = 100%). At the same location of the opening , post cracking stiffness was affected due to change the opening size from 100*100 to 100*200 by 36% and from 100*100 to 100*300 by 70% for RCA = 0%, while the values will be 41%, 58% in the same order for RCA= 100%.

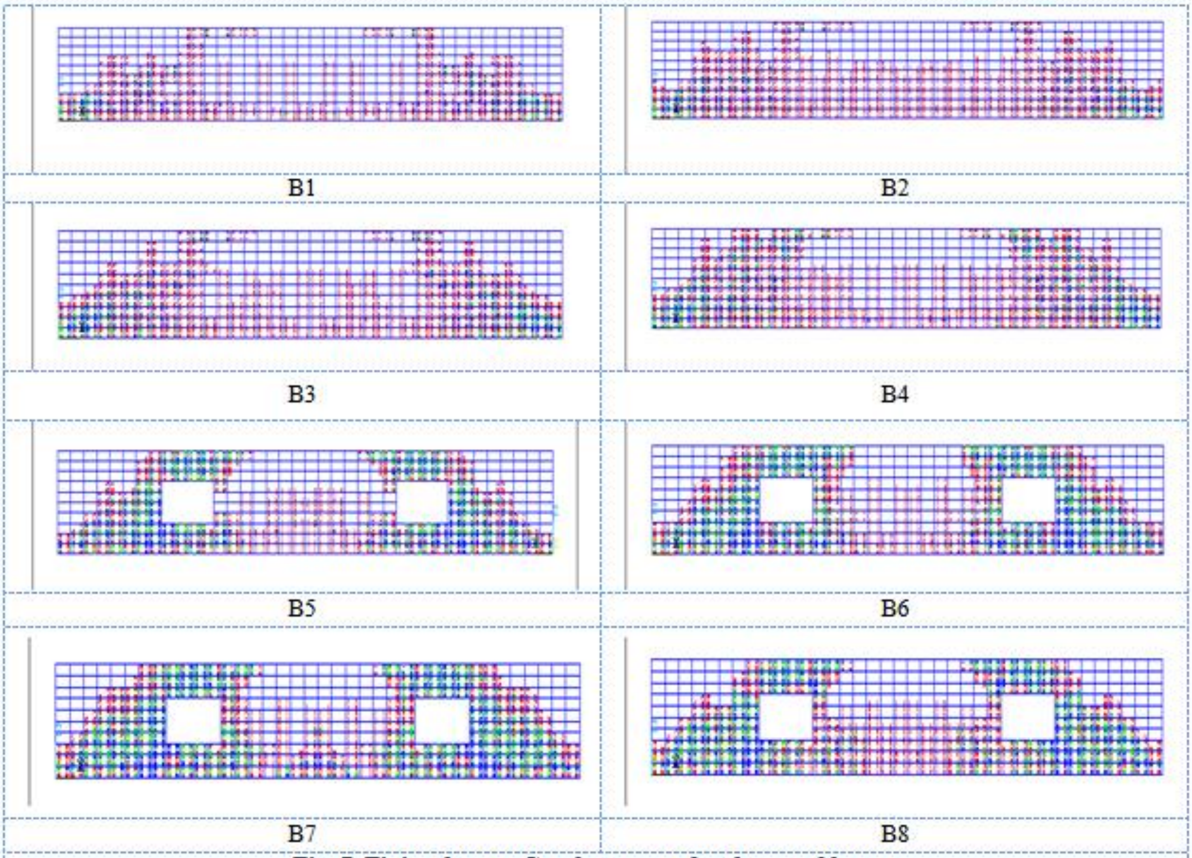

Fig. 7 Finite element Crack patterns for the tested beams

Table 6: Summary of finite element results

Specimens	Ultimate Load Pu (kN)	Ultimate Deflection δu (mm)	Yield Deflection δy(mm)	Ductility δu/δy	Post cracking Stiffness (kN/mm)
B1	96.10	14.5	9.60	1.51	6.42
B2	98.50	14.40	10.20	1.41	6.54
B3	99.50	14.20	10.80	1.31	6.73
B4	87.70	11.70	9.00	1.30	7.67
B5	89.70	11.22	9.20	1.22	7.73
B6	90.70	11.00	9.30	1.18	7.94
B7	71.40	13.90	9.93	1.40	4.11
B8	74.10	12.52	9.80	1.28	4.32
B9	77.80	10.77	8.50	1.27	5.12
B10	60.40	12.60	9.60	1.31	4.49
B11	65.90	12.66	9.90	1.28	5.21
B12	70.20	8.80	7.90	1.11	6.32
B13	47.90	12.60	8.30	1.52	1.94
B14	50.70	11.50	7.80	1.47	2.77
B15	70.40	11.40	9.20	1.24	3.78
B16	45.63	10.66	6.62	1.61	3.19
B17	51.22	9.80	5.88	1.67	3.76
B18	61.73	8.82	5.84	1.51	5.22

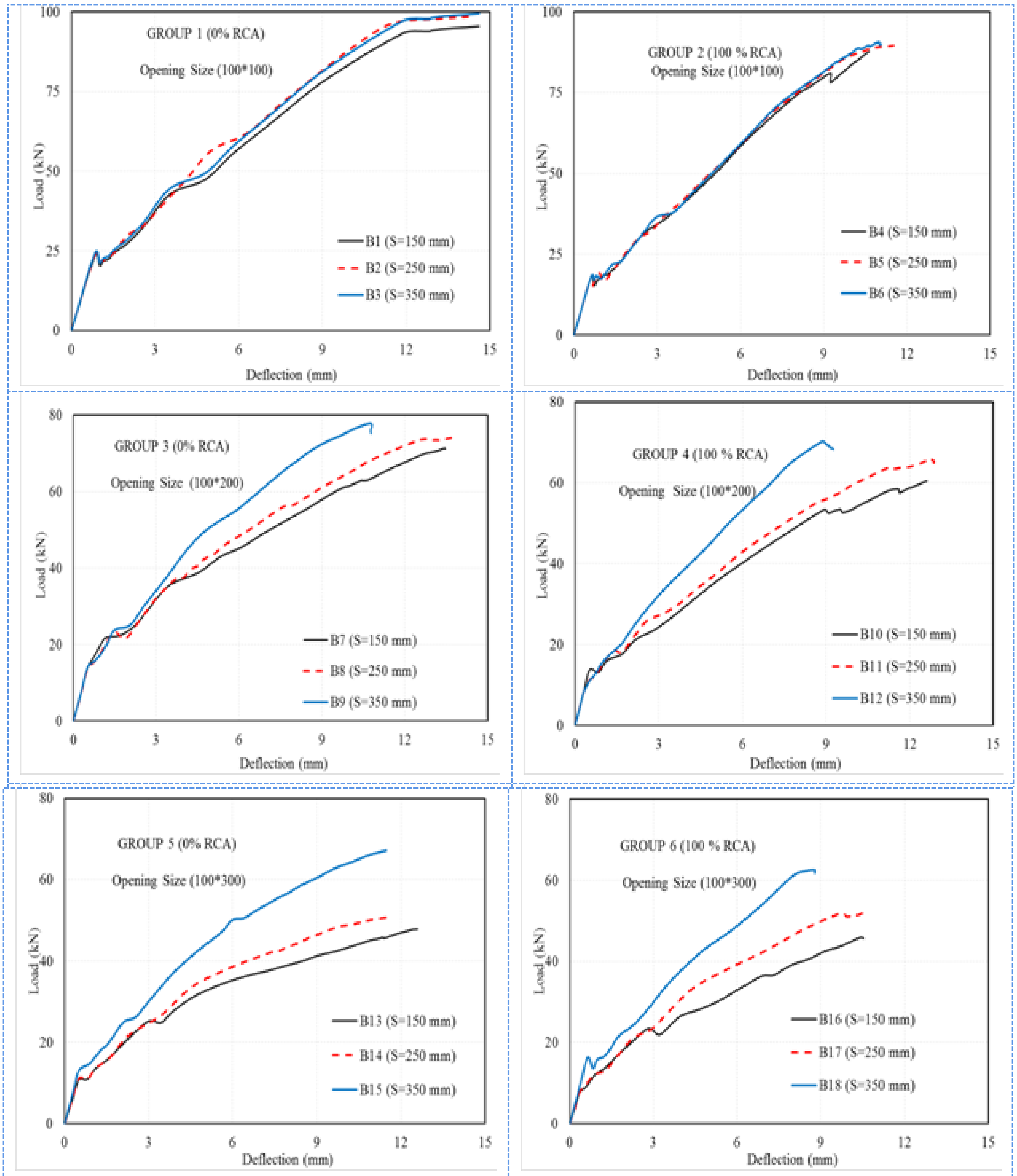

Fig. 8 Load- deflection curves for finite element models

VII. Conclusions

This study investigated experimentally and numerically the shear behavior of recycled coarse aggregate concrete (RCA) beams with and without openings. Based on the presented results, the following conclusions are obtained:

1. Increasing the recycled coarse aggregate replacement ratios led to a significant reduction in the compressive, the spilt tensile, and flexural strengths of the concrete cubes and cylinders.
2. Shear failure modes of RCA beams did not differ from the cracking morphology and crack propagation of NCA beam, but a slightly different angle and shape of the shear crack was observed in 50% RCA beams compared with the NCA beam.
3. Replacement of natural coarse aggregates with recycled ones did not cause any negative effect on the shear capacities, post cracking stiffnesses, and ductility's of the test specimens without openings. Differences in

normalized shear capacities of beams with 0%, 25%, 50% and 100% of RCA were limited to 5% for the solid beams. While the first shear cracks for the solid beams decreases as the recycled coarse aggregate percentage replacement increases.

4. The presence of openings at the shear region in the beam may extremely reduction in the shear strength, the first shear crack, and post cracking stiffness of the member and changes the failure mode from flexural yielding to brittle shear failure.
5. R.C beams with the length of an opening of 33% of the total shear span exhibit reduction in its shear strength by about 30% based on the experimental results.
6. The presence of opening produces earlier cracks at the opening location.
7. For the test specimens with openings, a diagonal shear failure occurred at corners of tension zones of opening, before the yielding of the longitudinal rebars.
8. The obtained numerical results of reinforced concrete beams demonstrate that the variation in the opening length has a significant effect on the shear capacity. The shear strength and stiffness of a beam decrease with increasing opening length.
9. Based on the Finite element results, the shear strength of R.C beams with small openings is increased with increasing the opening distance from the support. For the beams opening dimension (100*100) located completely at the shear region, the beams may be assumed to be a solid web beam.
10. Generally, the theoretical results obtained using the finite element analysis are in good agreement with the experimental values. An excellent correlation between numerical and experimental load-deflection curves was recorded.

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