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Bearing Capacity of Sustainable Self-Compacting Concrete Walls

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Abstract

The experimental program includes testing thirteen wall panels divided into five categories; every group comprises three specimens. The first group explains the aspect ratio (AR) effect with three values (0.5,0.625 and 0.75). The increase in AR results in a decrease in the ultimate load and an increase in the lateral displacement. In the second group, the slenderness ratio (λ) is investigated by the ratios (11.43, 13.33, and 16). The maximum load increases and the displacement decreases as it decreases. The third and fourth groups clarify the opening's effect (dimensions and locations). The results indicated a decrease in failure load and displacement as the size of the opening increases and as it approaches the edges. So, the largest load and displacement were when the opening was 15x25 cm at the center. The last group had the same details as the first group's samples, but these were tested in a two-way manner that caused a rise in the loading capacity by 15%.

Keywords: Aspect ratio; One-way action; Opening; Slenderness ratio; Two-way action.

1. Introduction

A wall is characterized as a vertical load-bearing structure with a length exceeding its depth [1]. The fortified concrete walls, formerly employed to protect against external elements and classified as non-load-bearing walls, neglect the strength of the walls as a structural element. This oversight was primarily due to early concrete codes that prescribed very low operational design stresses and the limited research on these components. force-bearing concrete walls primarily support vertical loads that exert downward pressure on the upper section of the wall [2]. The factors that affect the final strength of the RC walls are boundary conditions, aspect ratio, slenderness ratio, and openings. Boundary conditions have a principal effect on construction behavior and failure modes. The first type of boundary condition is one-way action (OW), which consists of walls that are restrained at both ends, upper and lower sides. This type of wall is found in tilt-up or bending constructions and causes walls to produce a single out-of-plane curvature corresponding with the loading direction. In experiments described in the literature, peripheral restraining was considered as a pin connection that restricted movement in both directions. Tests of OW walls typically show that a lateral principal crack has developed along the center of the wall [3]-[6]. The second type of boundary condition is two-way action (TW), which is restrained on three or all sides. Such constrained structural elements are usually present in intractable structures and distort in both the horizontal and vertical axes; they behave as simple support slabs transversely loaded. The restrictions by all sides are designed to prevent movement and rotation. Restraints can raise the ultimate strength of the wall and reduce the wall's deformation [7]-[10]. Many studies demonstrated that the failure load is related to eccentricity, slenderness (λ), and aspect ratio (AR). Generally, the high slenderness walls are the least load-bearing, low-slenderness walls can collapse by crumpling in the compression face and bending in the other face, whereas walls with a high slenderness ratio (λ) can also buckle. In all current experimental tests, a brittle mode of failure has been recognized in both scenarios [9]-[13]. Doh and Fragomeni revealed that walls made of high-strength concrete displayed a more dramatic loss of strength with increasing slenderness than walls made of normal concrete [10]. Saheb and Desayi showed that the loading ability is decreased by 35% and 37% for OW and TW walls, respectively, when the slenderness ratio (λ) is increased from 9 to 27 [9],[11]. The loading capacity of RCW is also sensitive to AR. Experimental research shows that the load-carrying capacity of regular-strength RCW panels diminished with an increase in aspect ratio (AR), but lateral displacement (LS) exhibited an inverse relationship. [14],[15]. The same conclusion was obtained for geopolymer RCW [16], at AR less than one. The side constraints boosted ultimate strength by up to 29% and 68% at AR more than one [9]. A wall's ultimate load capacity is much lower when openings are present compared to a comparable solid wall [17][21]. Although the cracking loads for OW walls are less than TW, the openings refute the gain of restraints on all edges. On the other hand, it's noted that large increases in final capacity might be made by taking side restrictions into account [21]. The early failure of the beam or column that surrounds the openings has an effective role in the final load. Though they are investigating the same parameter (the impacts of restrictions on opening walls), it is thought that the disparities between the aforementioned research can be clarified in the context of the various designs and opening sizes that they examined. It is also unclear if the lateral restraints were successful in exerting the needed effect. Among the factors that affect the final capacity are the materials added to concrete, such as high reactivity attapulgite (HRA). Substituting Iraqi clays for cement may diminish both the expenses and the environmental repercussions of cement production. There are several studies related to the use of this material in the concrete mix. This study offers different percentages of HRA utilised as a substitute: (0-20)%. The test results indicate that a 10% is the optimal ratio, [22]. In a separate investigation, HRA was utilised to create a lightweight LWSCC, with an optimal HRA content of 10%. This resulted in an enhancement of both the compressive load and splitting tensile strength compared to the original mixture, yielding values of 10.0%, 12.1%, 11.1%, and 12.4% for compressive load, and 12.0%, 18.2%, 16.6%, and 16.2% for splitting tensile strength, respectively, at 7, 28, 56, and 90 days. Consequently, attapulgite is suitable for the fabrication of LWSCC. [23]. Various percentages of attapulgite were utilised, namely 0%, 4%, 8%, 12%, and 16%, as substitutes for cement. The results demonstrate that the incorporation of attapulgite improved the properties of the concrete. Overall, all concrete mortar mixtures formulated with varying amounts of attapulgite exhibited satisfactory mechanical qualities. [24]. This claystone can also be used as an alternative to fine or coarse aggregate in order to produce lightweight concrete [25],[25]. The present work studied the effects of aspect ratio, slenderness ratio, size of openings, location of openings, and boundary condition with Self-compacted Concrete (SCC) wall samples that contain attapulgite (ATP) as a partial replacement of cement.

2. Method and Materials

After conducting several tests, the mix was found to be compliant with the specifications for self-compacting concrete mixes [26]. Clay was used after being crushed and ground into a fine powder, and calcined for thirty minutes at 750 degrees Celsius to be an effective pozzolanic material, where a ratio of 10% was used as a substitute for cement. [22] for preparing the final mixture for pouring concrete wall samples. The second stage involves examining thirteen samples divided into five groups, each including three specimens, to assess the effects of the five variables on SSC wall samples. The variables are:

1. The aspect ratios are 0.50, 0.6250, and 0.750, corresponding to dimensions (L, H, T) of 80x40x5 cm, 80x50x5 cm, and 80x60x5 cm, respectively. The slenderness ratios (H/t) are 16, 13.33, and 11.43, associated with dimensions (L, H, T) of 80x50x5 cm, 80x50x6 cm, and 80x50x7 cm, respectively. Size of openings: presence of opening at center with three sizes (15x25, 20x30, 20x40) cm, and as a ratio of wall area is (9.375%, 15%, 20%) respectively.
2. Location of openings; presence of opening at (center, centerline near edge, corner), in addition, the boundary condition by testing three samples in two-way action.

2.1 Concrete constituents and Steel reinforcement

2.1.1 Concrete constituents:

In this investigation, the materials used are: the ordinary Portland cement type (I), sand, coarse aggregate with a particle size of 5-14 mm, limestone powder, superplasticizer, and high-reactive attapulgite. The materials comply with the Iraqi standard specifications [27]-[29].

2.1.2 Steel Bars

Steel reinforcements are welded together to form a mesh. The bar has a diameter of 6 mm, a yield strength (fy) of 445 MPa, and is designed with a center-to-center spacing of 100 mm in both directions and a concrete cover of 15 mm, as shown in Fig. 1.

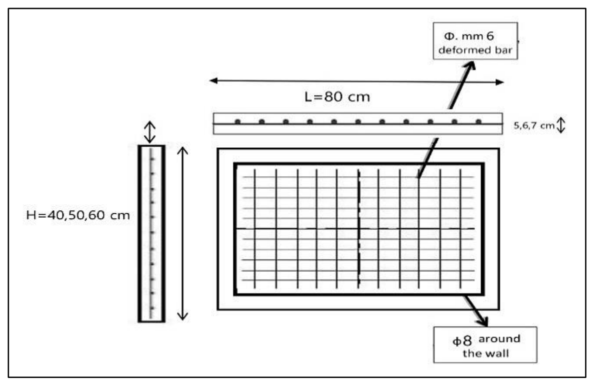

Figure 1. Arrangement of Reinforcement in Panel

2.2 Abbreviated Naming of Wall Specimen

The panels can be designated as follows:

W: Denotes the Wall.

X1: Denotes the type of restriction (O & T) one and two -way action respectively

X2: This refers to the quantity of items in each group.

Each parameter is assigned to one group.

(AR, λ, SO, LO and BC) (1, 2, 3, 4, and 5) respectively.

X3: Denotes the number of samples within the groups. The complete details of the wall samples are presented in Table 1.

Table 1: The wall samples details

NO.	Symbol	L	H	T	No. Group	Parameter value
1	WO11	80	40	5	AR (1)	0.5
2	WO12	80	50	5	AR (1)	0.625
3	WO13	80	60	5	AR (1)	0.75
4	WO21	80	50	5	λ (2)	16
5	WO22	80	50	6	λ (2)	13.33
6	WO23	80	50	7	λ (2)	11.43
7	WO31	80	50	5	SO (3)	15X25
8	WO32	80	50	5	SO (3)	20X30
9	WO33	80	50	5	SO (3)	20X40
10	WO41	80	50	5	LO (4)	At center
11	WO42	80	50	5	LO (4)	C.L near edge
12	WO43	80	50	5	LO (4)	At corner
13	WT51	80	40	5	BC (5)	Two way
14	WT52	80	40	5	BC (5)	Two way
15	WT53	80	40	5	BC (5)	Two way

2.3 Concrete Mix

In this study, many experimental mixtures were designed to obtain a self-compacted concrete that complies with the requirements of SCC, which must satisfy the criteria for filling capacity, segregation resistance, and passing ability, and required compressive strength [26]. Mix Proportion for SCC is shown in Table 2.

Table 2. Proportions of self-compacted Concrete Mix.

Test	Property	Unit	Result	Range [29]
Slump Flow	Filling-ability	mm	776	650-800
V-funnel	Segregation resistance	Sec	8.4	6-12
L-Box	Passing ability	%	0.98	0.8-1.0

2.4 Properties of Fresh Concrete

All the characteristics of SCC are tested by (slump flow, V-funnel, and L-box) tests. The Test Results of Fresh SCC are explained as shown in Table 3.

Table 3. Tests Results of Fresh SCC

Material	Proportion
Cement	315 kg/m^3
Fine aggregate	788 kg/m^3
Coarse aggregate	890 kg/m^3
Limestone	150 kg/m^3
Attapulgite	35 kg/m^3
Water	170 kg/m^3

2.5 Characteristic of Hardened SCC

The tests of hardened SCC are shown in Table 4.

Table 4: Characteristics of Hardened SCC

Compressive Strength (fc_u)	40.806 Mpa
Modulus of Rupture (f_r)	5.11 Mpa
Splitting Tensile Strength (f_{ct})	4.6 Mpa
Modulus of elasticity (E_C)	28650 Mpa

2.6 Evaluation Protocol

The specimens were fixed as shown in Fig. 2. A force of 2 kN T was applied to fix the plates to the supports, followed by a gradual increase in the applied loads of 10 kN at a loading rate of 1.5 kN/s until failure occurred. The increasing loads allowed for the documentation of all load values along with the corresponding lateral deflections.

Figure 2. Wall samples under testing

3. Results and Discussion

This section elucidated the correlation between load capacity and lateral displacement for studied parameters (AR), (λ), (SO), (LO), and (BC), in addition to the ductility index (Δ u /Δ y) for all RCW specimens, which is shown in Table 5.

Table 5. ductility index of RCW specimens

Symbol	No. Group	$\Delta_{u\ (mm)}$	$\Delta_{y\ (mm)}$	Δ_u/Δ_y
WO11	AR (1)	2.89	1.022	2.827
WO12	AR (1)	3.68	1.86	1.97
WO13	AR (1)	4.08	1.84	2.217
WO21	λ (2)	3.68	1.86	1.97
WO22	λ (2)	2.77	1.29	2.147
WO23	λ (2)	2.03	1.05	1.93
WO31	SO (3)	3.23	1.9	1.7
WO32	SO (3)	2.78	1.626	1.7
WO33	SO (3)	2.21	1.11	1.99
WO41	LO (4)	2.78	1.626	1.7
WO42	LO (4)	3.1	1.7	1.82
WO43	LO (4)	1.66	1.06	1.56
WT51	BC (5)	2.54	0.84	3.02
WT52	BC (5)	3.17	1.34	2.36
WT53	BC (5)	3.26	1.55	2.1

3.1. Effect of Aspect Ratio

Fig. 3 illustrates the correlation between loading capacity and lateral displacement as influenced by aspect ratio (AR), whereas Fig. 4 depicts the fracture pattern of the group.

The following observations can be made:

a. The load capacity of RCW samples increases when the aspect ratio (AR) decreases from 0.75 to 0.5.

b. The augmentation of ultimate loads is approximately 10%, 15.91%, and 27.5% for the reduction of AR from (0.75 to 0.625), (0.625 to 0.5), and (0.75 to 0.5), respectively.

c. A reduction in lateral displacement correlates with a decline in AR results. When AR is decreased from (0.75 to 0.625), (0.625 to 0.5), (0.75 to 0.5), the lateral displacement decreases by about (9.8%,21.46%,29.16%), respectively.

d. The lower AR means a decrease in height and the stability of other dimensions, and this results in a decrease in lateral displacement. Also, the number and width of cracks decrease during the loading process, and this makes the wall panel maintain the highest possible stiffness. In addition to that, the value of AR (0.625) represents the optimum ratio to gain the largest possible amount of loading capacity; the gain of increasing AR after (0.625) is considered small and negligible.

e. Cracks number and their length increase and approach the center zone with increasing AR.

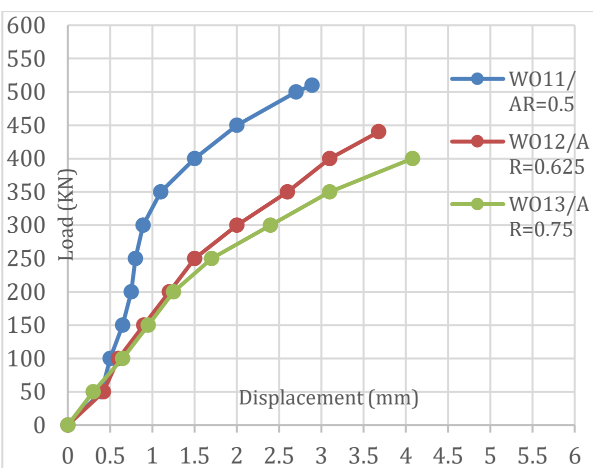

Figure 3. Influence of (AR) on the connection between Ultimate Load and Lateral Displacement

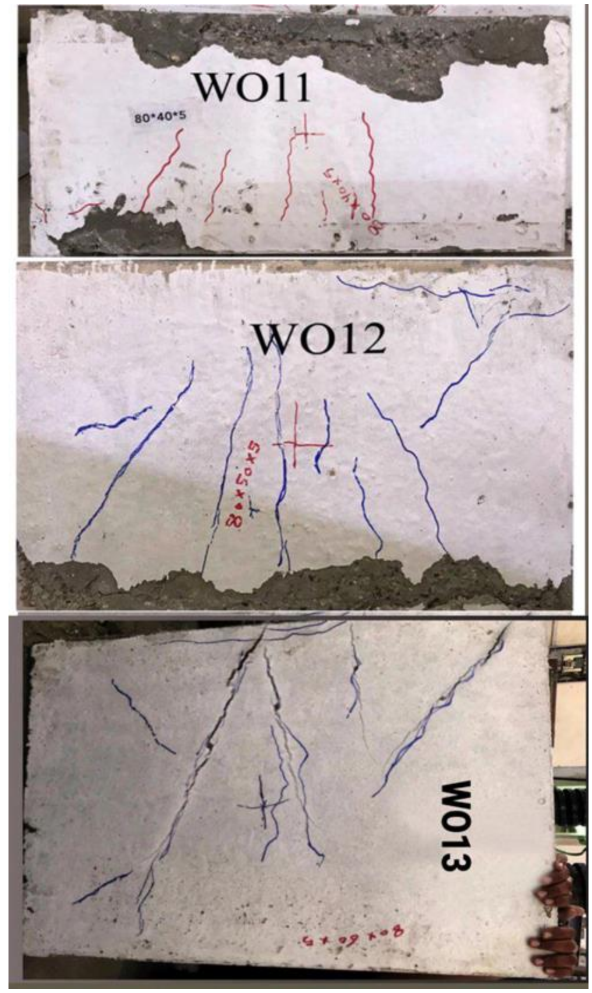

Figure 4. Crack pattern of the first group

3.2. Slenderness Ratio

a. Fig. 5 and Fig. 6 illustrate the correlations among load capacity, displacement, and fracture mode. It is evident that the ultimate strength diminishes as the ratio of (λ) increases, and in self-compacting concrete, the ultimate load also decreases with an increase in the ratio of (.λ)

b. An increase in lateral displacement correlates with an increase in (λ). The lateral displacement increases by roughly 36.45%, 32.85%, and 81.28% when λ is raised from 11.43 to 13.33, from 13.33 to 16, and from 11.43 to 16, respectively.

c. All samples in this group failed due to bearing rather than bending. Augmenting thickness diminishes the slenderness ratio, hence mitigating the cracks linked to the loading process, resulting in a more brittle failure.

d. Cracks are more numerous and widespread as the slenderness ratio increases

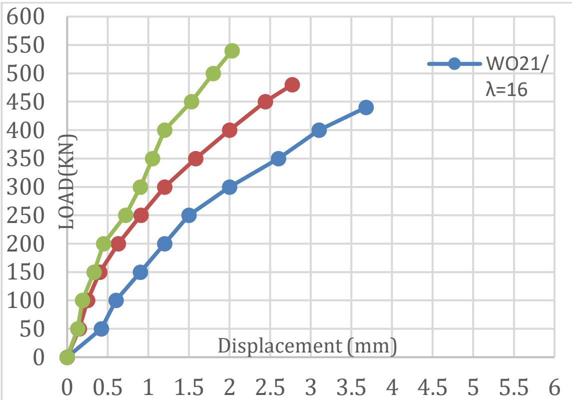

Figure 5. Impact of Slenderness Ratio (λ) on Ultimate Load and Lateral Displacement

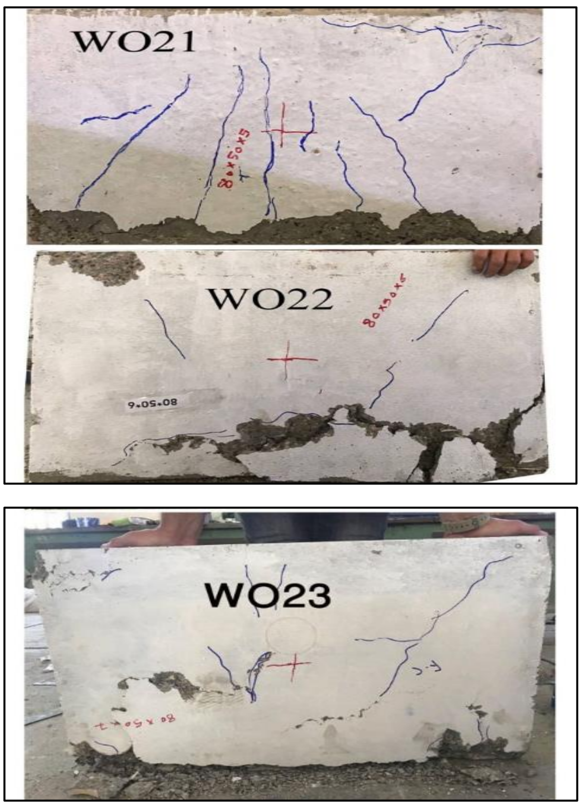

Figure 6. Crack pattern of the second group

3.3. Size of Openings

The effect of the size of openings (SO) is shown in Fig.7 and Fig. 8, which show the crack pattern of the group.

a. The loading capacity of the RC wall specimen drops by rising in (SO) from (15X25 to 20X40).

b. The decrease is about 10.52 %, 14.7%, and 23.68% for an increase in (SO) from (15X25 to 20X30), (20X30 to 20X40), and (15X25 to 20X40), respectively, for the final load for SCC wall

c. The reduction in lateral displacement is accompanied by an increase in the size of openings (SO). When (SO) increased from (15X25 to 20X30), (20X30 to 20X40), and (15X25 to 20X40), and for displacement, the decrease was approximately 19.39%, 20.86%, and 31.88%, respectively.

d. The cracks spread around the corners of the openings and follow the path closest to the corners of the sample, so the larger the size of the openings, the faster the failure.

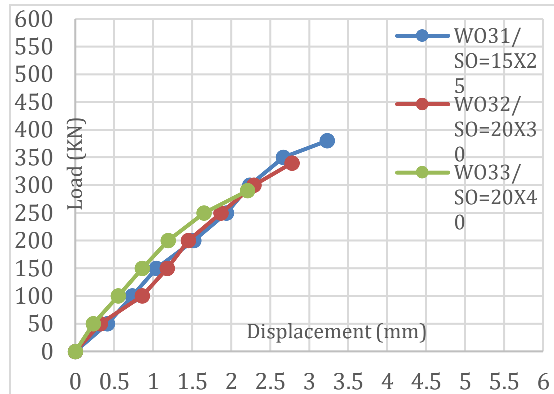

Figure 7. Opening's size (SO) effect on Ultimate load and Lateral Displacement.

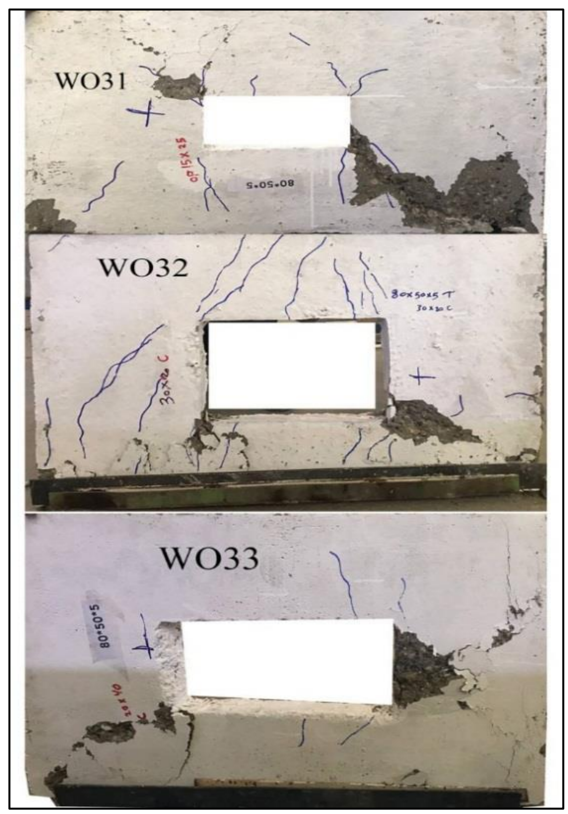

Figure 8. Crack pattern of the third group

3.4 Location of Openings

The Effect of the location of openings (LO) on ultimate load and lateral displacement is shown in Fig.9 and Fig.10, which show the crack pattern of the group. It can be noticed that the following:

a. The loading capacity of the RC wall specimens was affected by changing the location of the opening (LO) at the center (C), centerline near the edge (C.L ng), and at the corner (CR).

b. The reduction of final load for SCC wall specimens is about 11.76 %,10%, and 20% when the location of the opening changes from (C to C.L ng), (C.L ng to CR), and (C TO CR), respectively.

c. The change in lateral displacement that accompanies the difference in opening location for SCC wall panels is about 11.51 % increasing when the location of the opening changes from (C to C.L ng), 46.45% decreasing when the change from (C.L ng to CR), and 40.28% decreasing for the change from (C to CR), respectively.

d. The hole of the corner has less bearing and more cracking, unlike what it was in the middle, due to the decrease in the failure path from the corners of the holes to the corners of the sample. The arch action is the main reason due to the tangential force that occurs on the sides of the openings.

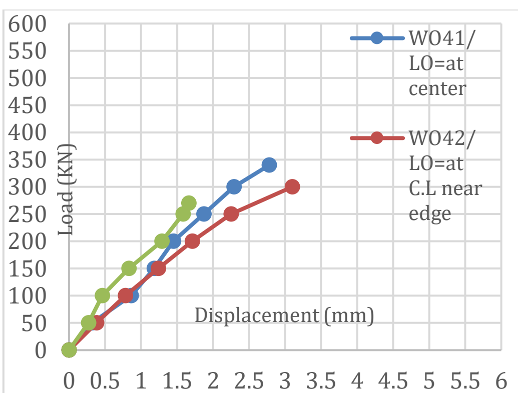

Figure 9. Effect the location of openings (LO) on the ultimate load and the lateral displacement

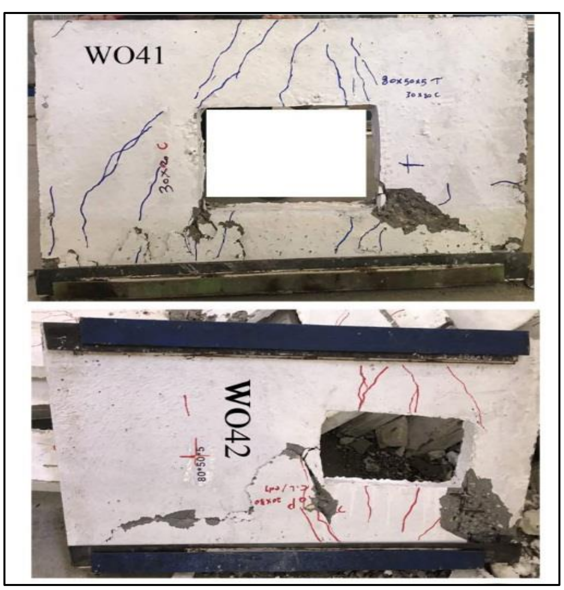

Figure 10. crack pattern of the fourth group

3.5. Boundary Condition

Figures 11 and 12 show the crack pattern of the group. It can be seen (For two-way action only):

a. The maximum strength of the wall specimen diminishes as the aspect ratio (AR) goes from 0.5 to 0.75.

b. The enhancement in ultimate capacity for the SCC wall specimen when there was a reduction in aspect ratio (AR)

c. The reduction in AR values correlates with a decrease in lateral displacement for the SCC wall specimen. The reduction in lateral displacement is around 22.08% when the aspect ratio (AR) decreases from 0.75 to 0.5, and about 2.76% when it decreases from 0.75 to 0.625.

Additionally, Figs. 3, 4, 11, 12 disclose the subsequent consequences (one-way and two-way actions):

a. The load capacity of the wall rises with two-way motion compared to one-way action; nevertheless, lateral displacement decreases correspondingly.

b. The enhancement in the ultimate load due to two-way action support is approximately 7.84% at an aspect ratio (AR) of 0.5, 11.36% at AR of 0.625, and 15% at AR of 0.75. The decrease of lateral displacement by two- way action was about 12.11%, 13.86%, and 20.09% when the AR was equal to 0.5, 0.625, and 0.75, respectively.

c. The increase of AR results in an increase in lateral displacement for (one or two) way action. Constraints on all sides prevent bending, so the sides are free of cracks and are abundant in the middle, with a change in the shape of these cracks due to the concentration of stresses.

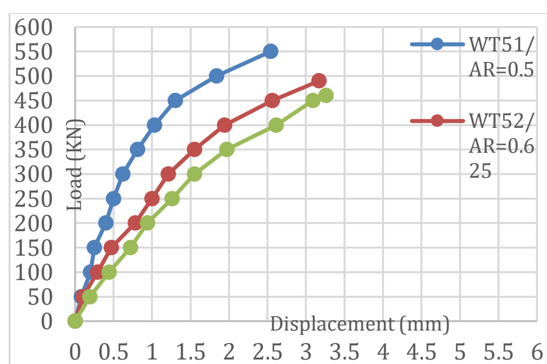

Figure 11. Effect of Boundary condition (BC) on Ultimate load And Lateral Displacement

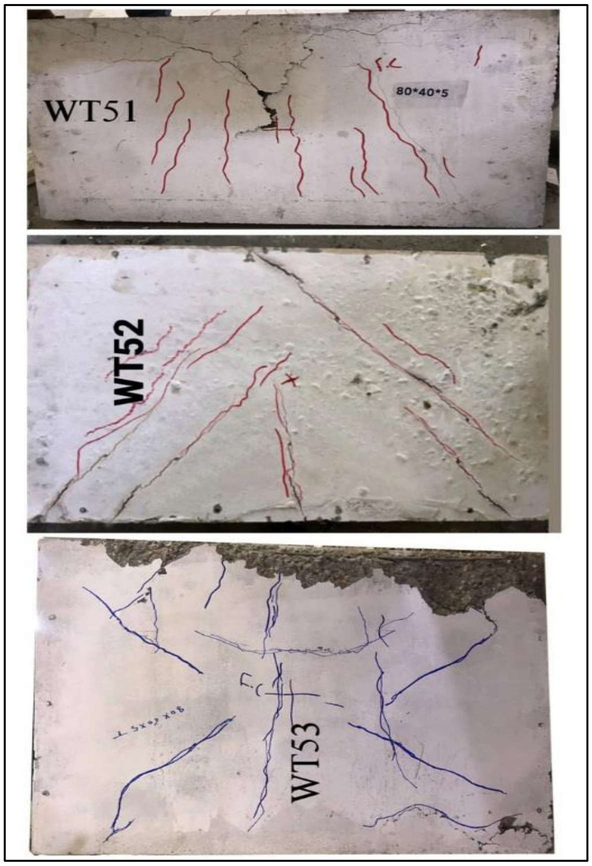

Figure 12. crack pattern of the fifth group

4. Conclusion

The lower the value of AR and λ, the greater the loading capacity and the lower the lateral displacement and the number of cracks as well, because failure tends to be brittle failure and vice versa. The value of AR (0.625) represents the optimum ratio to gain the largest possible amount of loading capacity; the gain of increasing AR after (0.625) is considered small and negligible. As for walls with openings, there is a clear and sharp decrease in the final load of RCW samples with increasing opening dimensions. Also, the opening's location has a considerable influence on the final load, failure behavior, and the load transfer mechanism. When the openings were located at the center, it was the point farthest from the edges and therefore had less impact than the others. The opening located at the corner had the most effect, had the least load, and failed the quickest because it was located near two edges. Ultimately, in instances of unidirectional or bidirectional support, comprehensive support from all sides (in the case of bidirectional support) alleviates the bending at the lateral edges of the walls, postponing the bending and failure process, thereby enhancing load-bearing capacity relative to slabs with unidirectional support. Stresses are concentrated in the core region, resulting in compressive failure instead of bending, as demonstrated in one example.

Author Contribution Statement

Akhlas Hashem: performed the practical part, represented the results graphically, and analyzed them. Wissam Kadhim and Luma Abdul Ghani formulated the research problem and oversaw the results of this study. Results of the final manuscript were discussed by all authors.

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Conflict of interest

The authors certify that there is no conflict of interest related to this article's publication.

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