Capacity of Self Compact Concrete Walls Using Attapulgite as A Partial Replacement of Cement Under One Way and Two Way Action Restriction

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قدرة الجدران الخرسانية المدمجة ذاتيا بًاًستخدام الأتابولجيت كبديل نسبي للسمنت تحت تقييد في اتجاه واحد وفي اتجاهين

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Abstract

This investigation about the structural performance of sustainable self-compact concrete walls exposed to eccentric axial regularly dispersed loading, including the effect of aspect ratio (AR) and slenderness ratio (λ) by one-way and two-way action. The experimental program includes testing ten wall panels, the eccentricity of the loading system equivalent to one-sixth of depth. These wall panels are separated into four groups, each one consisting of three specimens. first and second groups clarify the aspect ratio (H/L) effect. The results indicated for decreasing AR from (0.75 to 0.625), (0.625 to 0.5), and (0.75 to 0.5), the increase of final load is about 10 %, 15.91%, and 27.5%, also the decreasing of lateral displacement is 20.1%, 21.4%and 29.2% respectively for one-way action. The increase in final capacity 6.52 %, 12.24%, and 19.56%. also about 2.76%,19.87% and 22.08% decreasing in lateral displacement for two-way action respectively. third and fourth groups for the effect of slenderness ratio (λ) which decrease from (16 to 13.33), (13.33 to 11.43) and (16 to 11.43), The increase of final load is about 9.09 %, 12.5%, and 22.73% for one way and 6.12%, 9.62%, and 16.3% for two-way action respectively. Also when raised (λ) from (11.43 to 13.33), (13.33 to 16), and (11.43 to 16), the increase in lateral displacement is approximately (36.45%, 32.85%, and 81.28%) for one way action, and (36.76%, 25.29% and 71.35%) for two way action respectively.

Keywords: Attapulgite; Aspect ratio; Slenderness ratio; One-way action and Two-way action

المستخلص

هذا البحث يدور حول الأداء الإنشائي للجدران الخرسانية المستدامة ذاتية الر ص والمعرضة لأحمال محورية لامركزيةموزعة بانتظام بما في ذلك تأثير نسبة العر ض إلى الارتفاع (AR) ونسبة النحافة(λ) من خلال العمل في اتجاه واحد وفي اتجاهين. ويتضمن البرنامج التجريبي اختبار عشر لوحات جدارية، تعادل انحراف نظام التحميل سدس العمق. يتم تقسيم هذهالألواح الجدارية إلى أربع مجموعات، تتكون كل منها من ثلاث عينات. توضح المجموعتان الأولى والثانية تأثير نسبةالعرض إلى الارتفاع (H/L). أشارت النتائج إلى انخفا ض AR من (0.75 إلى 0.625)، (0.625 إلى 0.5)، (0.75 إلى0.5)، وبلغت زيادة الحمل النهائي حوالي 10%، 15.91%، 27.5%، كما بلغ انخفاض الإزاحة الجانبية 20.1% و21.4%و29.2% على التوالي للعمل في اتجاه واحد. الزيادة في السعة النهائية 6.52%، 12.24%، 19.56%. كما انخفض بحوالي 2.76% و19.87% و22.08% في الإزاحة الجانبية للعمل في الاتجاهين على التوالي. أما المجموعة الثالثة والرابعة لتأثيرنسبة النحافة (λ) والتي انخفضت من (16 إلى 13.33) و(13.33 إلى 11.43) و(16 إلى 11.43)، وبلغت زيادة الحمل النهائي حوالي 9.09%، 12.5%، 22.73%. في اتجاه واحد و6.12% و9.62% و16.3% في الاتجاهين على التوالي. وأيضا عند رفع (λ) من (11.43 إلى 13.33)، (13.33 إلى 16)، و (11.43 إلى 16)، فإن الزيادة في الإزاحة الجانبية تبلغ تقريباً (36.45%، 32.85%، 81.28%) للحركة ذات الاتجاه الواحد، و (36.76%، 25.29%، 71.35%) للعمل في الاتجاهين على التوالي.

الكلمات المفتاحية: أتابولجيت؛ نسبة الابعاد؛ نسبة النحافة؛ الاسناد في اتجاه واحد؛ الاسناد في اتجاهين.

1. Introduction

Concrete is one of the most widely used and durable building materials. It provides sufficient strength to bear loads and is resistant to external conditions. It comprises different constituent materials with significantly different properties that complement each other. One type of concrete is self-compacting concrete SCC, which is defined as concrete that must meet the requirements of Passing and flow ability, Segregation resistance, and attaining complete compaction with the weight of one's own body alone, independent of external compaction. Moreover, it can be filled in small places with reinforcement steel, eliminating the need for external compaction equipment according to EFNARC (2005). Concrete in general, has unique and qualitative properties, and the presence of cement as its main component is considered one of its most important properties. So, Large quantities of tons of cement are produced annually, and in addition to being expensive, cement also pollutes the environment by emitting a lot of carbon dioxide during production; for this reason, there are many research directions on the production of concrete using sustainable alternatives that limited the use of cement. The first part of this research is about the production of sustainable self-compacting

concrete SSCC, which includes the properties of SCC in addition to containing a sustainable material with a partial or complete replacement of one of its components.

2. Related Research

There is a group of research on the production of this type of concrete SSCC, one of them (Ofuyatan, *et al.*, 2021) about SCC with silica fumes as a cement substitute by the extents of 0%, 15%, 25%, and 35% of volume. Results for compressive strength at 21 Days (kN/mm2) were 39.24, 34.42, 25.10, and 20.60, respectively. This study's evaluation of a variety of qualities relevant to concrete production employing silica fumes as a substitute for cement proved successful. In another study (Hilal, *et al.*, 2020) investigate the initial and final performance of SCC prepared by coal ash besides fly ash (CA&FA), each one alone a fractional exchange of cement. mixtures done with 0%, 10%, 20% and 30% (by weight) of cement. The findings indicated that the CA had detrimental effects on the fresh characteristics of SCC. However, the outcomes still align with the fresh SCC's requirements. also has significantly increased SCC's durability and water absorption. versus the addition of FA. (Younis Khudair, *et al.*, 2020) used recycled glass powder (RGP) as a partial alternative to cement, the test findings showed that increasing the amount of cement replaced with RGP generated a modest reduction in passing ability while maintaining flow ability and improving segregation resistance. The resulting mixes' mechanical characteristics improved up to a 30% replacement level. (Kumar, *et al.*, 2020) used the metakaolin and plastic fiber substitute the cement in the SCC mixture; metakaolin with 20% constant replacement and plastic fiber ratio are 0%, 0.25%, 0.5%, 0.75%, and 1%, respectively with metakaolin. The research result demonstrated that with the inclusion of plastic fiber, SCC's ability to fill and pass is reduced, but the characteristics are not significantly altered. The parameters of hardened SCC demonstrate that both substances have an effective role in the strength of SCC. In another study, high reactivity attapulgite (HRA) was used to produce lightweight LWSCC by (Abbas, *et al.*, 2016); optimum content of HRA used 10%, causing growth in compression load also splitting tensile value as compared with the original mixture (10.0%, 12.1%, 11.1%, and 12.4%) and (12.0%, 18.2 %,16.6%, and 16.2%) respectively with 7, 28, 56 and 90 days. for this, the attapulgite is appropriate to contribute to the production of LWSCC. Also, (Qassim & AL-Saraj, 2021) found that HRA with silica fume has a significant improvement in the properties of concrete and its resistance to shear stresses, as the axial load improves the shear capacity and reduces the shear failure in the (LWSCC). The Iraqi clay (Attapulgite) has been processed to pozzolanic material HRA. The possibility of replacing the Iraqi clays with cement can reduce the cost and the impact of cement manufacturing on the environment. In the study of (Zghair, *et al.*, 2022), three percentages of HRA were used as a replacement: 0, 10, and 20 % by weight of cement. The test result shows that the10% of HRA is an optimum ratio, which increases the compressive strength compressive strength. (Abdulrasool, *et al.*, 2023) used different percentages of attapulgite, including 0%, 4%, 8%, 12%, and 16%, in replacement of cement. The findings indicate that using attapulgite enhanced the compressive strength by 9% and 8% for flexural strength. In general, all concrete mortar mixes that were prepared with different attapulgite percentages result in acceptable mechanical properties. (Abdulrasool, *et al.*, 2022) used Attapulgite fine aggregates (AFA) in place of two different amounts of normal sand. To examine the effectiveness of internal wet curing, AFA has been proven to be beneficial for internal treatment. It has been discovered that enhancing the properties of highperformance concrete properties with 20% AFA results in low internal stress and a noticeably higher compressive strength. Research is ongoing in this field, as industrial and plastic wastes, and even natural plant wastes, are used as sustainable materials. In any case, concrete gains strength over time and has a long service life. So, it is considered the most suitable material to be the basic component in building structural elements; one of the most important elements is walls. Reinforced concrete walls (RCW) were previously utilized to guard against the outside environment. They were regarded as non-load-bearing walls, without taking into account the wall's strength as a structural component. this is because the early published concrete codes had very low operating design stresses, and little study of these components was conducted. Concrete load-bearing walls that principally sustain vertical loads that operate downward on the upper region of the wall may experience weak-axis bending due to the eccentric behavior of the applying axial vertical load, according to (James & James, 2011). The wall is defined as a vertical load-bearing element with a length greater than four times its depth in clause 1.3.4.1 of Part 1 of British Code 8110 from 1997, which differentiates walls from columns. RCW has become as popular today as the traditional structural elements such as beams, slabs, and columns. whether they are walls restricted from two directions (one-way action) or all sides (two-way action). This is what will be studied in our research using a sustainable, selfcompacting mixture that includes attapulgite as a relative alternative to cement.

3. Materials and Methods

3.1 Material properties

In this investigation, the materials used are:

3.1.1. Cement

In this investigation, ordinary Portland cement (OPC) type (I) is utilized. which conforms to **IQS No.5/1984**

3.1.2. Fine Aggregate (sand)

Natural sand was utilized as a fine aggregate for SCC mixtures with specific gravity (2.56) and modulus of fineness (2.6). By the requirements of Iraqi standard **(IQS) No.45/1984 zone** (2).

3.1.3. Rough Aggregate (gravel)

The largest size of gravel is (12 mm) with specific gravity (2.7), which is used in the SCC mix. Accordance with Iraqi Specification **(IQS) No. 45/1984**.

3.1.4. High Reactive Attapulgite:

This particular clay, which appears as bluish-green and grey claystone in the Al-Najaf and Karbala districts, after breaking up the large stones into smaller pieces with a hammer, attapulgite can be made by burning it for half an hour at 750°C in an electric oven after ground it into tiny bits to become a fine powder. for this investigation, the properties of attapulgite powder comply with **ASTM-C618** (Table, 1).

Table 1. Chemical analysis of Attapulgite

Oxide Composition	Oxide content (%)
SiO_2	50.82
Al_2O_3	11
Fe_2O_3	6.455
TiO_2	1.019
CaO	22.78
MgO	6.942
SO_3	1.211
Na_2O	2.531
K_2O	2.302

3.1.5. Superplasticizer S.P

Water Reducing Admixture of superbly Water Reducing. Layda's superplasticizer is designed for the production of an SCC mix.

3.1.6. Limestone Powder

Limestone was used during this work, and it is a common addition to self-compacting concrete. Limestone, a white powder, is locally called (AlGubra). Limestone is used as a filler material to improve certain properties, as compared to cement.

3.2. Steel reinforcement properties

Steel bars, welded with each other to become a mesh located by the center of the specimen's width with a 15mm concrete cover (use one layer of reinforcement due to limited thickness). The bar's diameter (6mm) was designed with (100mm) c/c spacing in both directions. also, an (8mm) steel reinforcement is positioned around the mesh to brace or guard the wall's edges and strengthening, as shown in Figure (1) and Table (2)

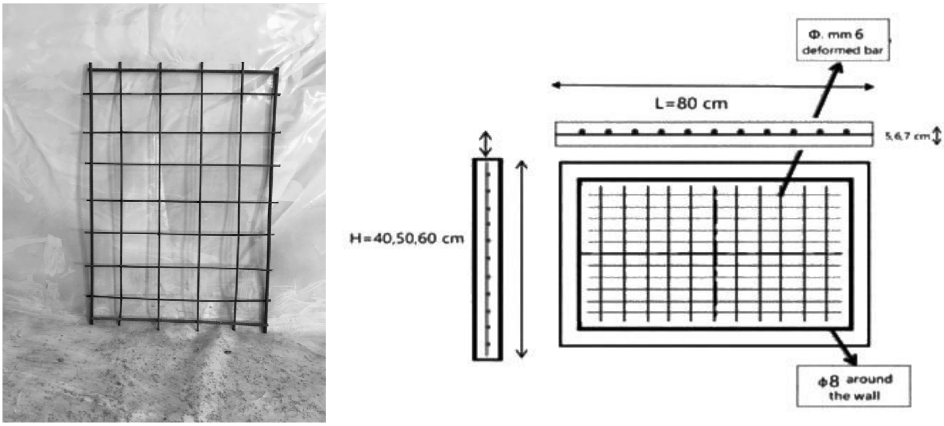

Figure (1) Steel reinforcement of wall panel

Table 2. The reinforcement mesh specification*

Property	Diameter 6 mm	Diameter 8 mm
Yield stress	**MPa**	**515MPa**
Ultimate strength	**MPa**	**MPa**
Elongation %	**4.905**	**11.78**
Location with mesh	**(10*10) cm (C/C)**	**Around mesh**

*** Each value is an average of three specimens, by ASTM A615-86**

3.3 Concrete Mix

The first part of the experimental program includes a set of trial mixtures to get the desired characteristics of the SCC mix. Where the mixture is chosen that is compatible or commensurate with the standard properties of SCC by conducting the standard cone test and V funnel test, according to (**EFNARC 2005**), and then pouring the mixture into six cubes of size (10x10) cm and 3 prisms (10x50) cm to measure the compressive and tensile strength,

respectively. This procedure or method is adopted for each mixture until the required properties are reached. After obtaining the mixture with the required properties of SCC, four mixtures with different proportions of attapulgite clay 0%, 10%, 15%, and 20% as a partial replacement of cement. as shown in Tables (3&4). The mixture with a ratio of 10% attapulgite is chosen to be the control mixture because at this replacement percentage the highest pozzolanic activity occurred, so it consumed more $Ca(OH)_2$ to produce more cement gel, thereby the voids between discrete cement and micro-cracks was reduced. because it is a good percentage as a relative substitute for cement, and the decrease in compressive strength is not significant, so it is suitable for pouring RCW samples. The proportions of the final mix are shown in Table (5). The second part of this work study includes testing ten opening RCW samples which are separated into four groups, each one containing three specimens to examine the effects of the following variable of SSCC wall samples.

1. Aspect ratio (AR): The magnitudes of aspect ratio (H/L) are (0.5, 0.625, 0.75)
2. Slenderness ratio (λ): The values of slenderness ratio (H/t) are (16, 13.33, and 11.43)
3. Boundary condition (BC): all specimens are tested by one-way and two-way action

Table 3. Results of Trials Mixes of SCC with (0,10,15,20) % of Attapulgite

Self-compacting Concrete Mix	SCC With 0% ATP	SCC With 10% ATP	SCC With 15% ATP	SCC With 20% ATP
Compressive Strength of SCC for 7 days (MPa)	35.133	32.2	24.566	22.033
Compressive Strength of SCC for 28 days (MPa)	41.866	40.806	32.75	30.21

Table 4. Results of Trials Mixes of SCC with (0,10,15,20) % of Attapulgite

Self-compacting Concrete Mix	SCC With 0% ATP	SCC With 10% ATP	SCC With 15% ATP	SCC With 20% ATP
Modulus of rupture of SCC for days 28 (MPa)	7	7.6	6	5.4

Table 5. Proportions of SSCC Mix.

Material	Cement	Sand	gravel	limestone	Attapulgite	water
Proportion	315 kg/m^3	788 kg/m^3	890 kg/m^3	150 kg/m^3	35 kg/m^3	170 kg/m^3

4. Characteristics of Hardened SSCC

The tests of mechanical properties of hardened SCC mixes include the compressive, Flexural, Tensile strength, and modulus of elasticity as illustrated in Table (6).

1. Compressive Strength: Three cubes with (10) cm agreement with **B.S:1881: part116:1989**
2. Splitting or indirect tensile strength test is carried out on three cylinders of (10x20cm) by **ASTM C496/C 496M-17**.
3. Flexural strength (modulus of rupture) is tested by three prisms (10x10x50cm) with **ASTM C78-15**.
4. static modulus of elasticity is obtained by testing a 150x300 mm cylinder to get the statically elastic modulus according to **ASTM C469/C 469M –14**.

Table 6. Characteristics of Hardened SSCC.

Compressive Strength (fc_u)	40.806 Mpa
Modulus of Rupture (f_r)	7.65 MPa
Splitting Tensile Strength (f_{ct})	5.11 MPa
Modulus of elasticity (E_c)	28650 MPa

5. Abbreviated naming of Wall Specimen

Panels are naming as (W x1 x2 x3), where:

W: Indicates to the Wall.

X1: Indicates the type of restrain (O= one-way action or T= two-way action).

X2: Indicates the number of the group, a group for each parameter

X3: Indicates to numerous samples within the groups.

The full information of the wall samples is shown in Table (7) and Figure (2)

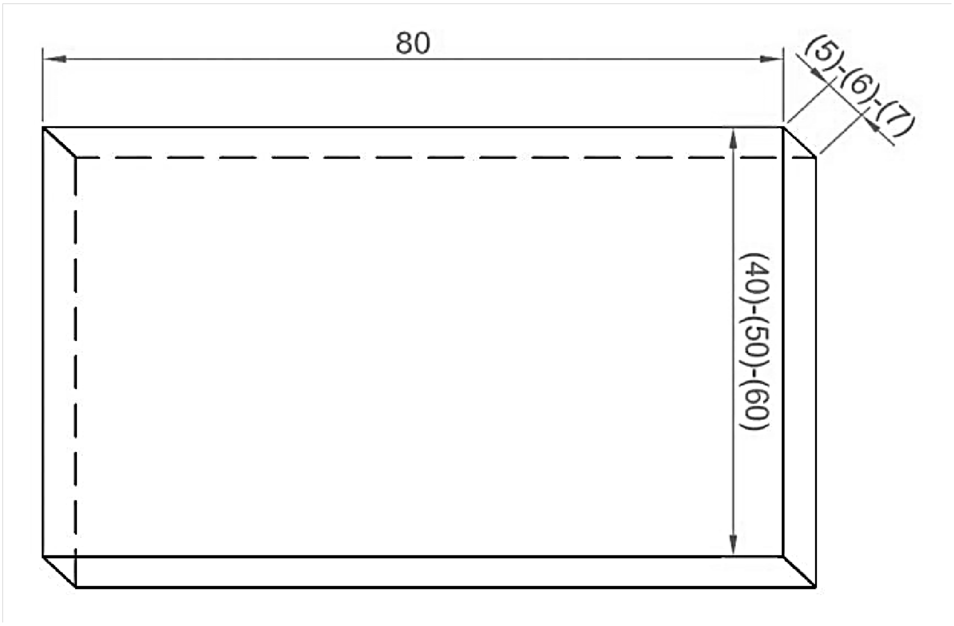

Figure (2) Wall samples configuration

Table (7) The full information of wall samples*

NO.	Symbol	L	H	T	NO.GROUP	BC
1	WO11	80	40	5	AR (1) = 0.5	one-way
2	WO12	80	50	5	AR (1) = 0.65	one-way
3	WO13	80	60	5	AR (1) = 0.75	one-way
4	WT21	80	40	5	AR (2) = 0.5	Two-way
5	WT22	80	50	5	AR (2) = 0.65	Two-way
6	WT23	80	60	5	AR (2) = 0.75	Two-way
2	WO31	80	50	5	λ (1) = 16	one-way
8	WO32	80	50	6	λ (1) = 13.33	one-way
9	WO33	80	50	7	λ (1) = 11.43	one-way
5	WT41	80	50	5	λ (2) = 16	Two-way
7	WT42	80	50	6	λ (2) = 13.33	Two-way
10	WT43	80	50	7	λ (2) = 11.43	Two-way

*All dimension by cm unit

6. Testing Procedure

After preparing the testing device, the samples were installed and locked by upper and lower supports to be examined one after the other. Leveling the samples to achieve the orthogonally of specimens with applied load which done by t/6 eccentricity. The dial gauges are positioned in the middle for solid walls and at a quarter of distance for opening walls to measure the lateral displacement corresponding with applied loads. Each test begins with application of around (2KN) to seat panels with supports, then the applied loads are gradually increase by 10 (KN) until failure. Gradual loads allow us to record all values of loads with lateral deflection that get with it. as shown with Figure (3) below.

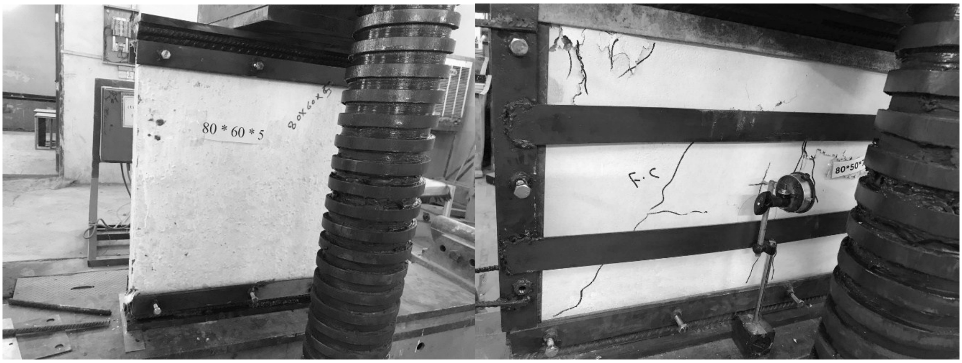

Figure (3) Wall samples under testing

7. Result and Discussion

The following parameters are studying on the structural behavior of SSCC wall panels

1. Aspect Ratio effect by one-way action

For one-way action only, the relation between loading capacity and lateral displacement under the effect of aspect ratio (AR) is shown in Figure (4), and figure (8) show the crack pattern of this group.

From figures can be noticed the following:

a. The loading capacity of RCW specimens drops with increasing of AR from (0.5 to 0.75).

b. The increase of final load is about 10 %, 15.91%, and 27.5% for decreasing AR from (0.75 to 0.625), (0.625 to 0.5), and (0.75 to 0.5) respectively.

c. For SCC wall specimens, increasing lateral displacement is accompanied by an increase in AR findings. When AR is increased from 0.5 to 0.75 and from 0.625 to 0.75, the lateral displacement increases by about (41.176%) and (10.87%), respectively. When AR is increased from 0.5 to 0.625, the lateral displacement increases by about (27.3%).

d. The increase in height (H) is what causes this decrease in ultimate strength

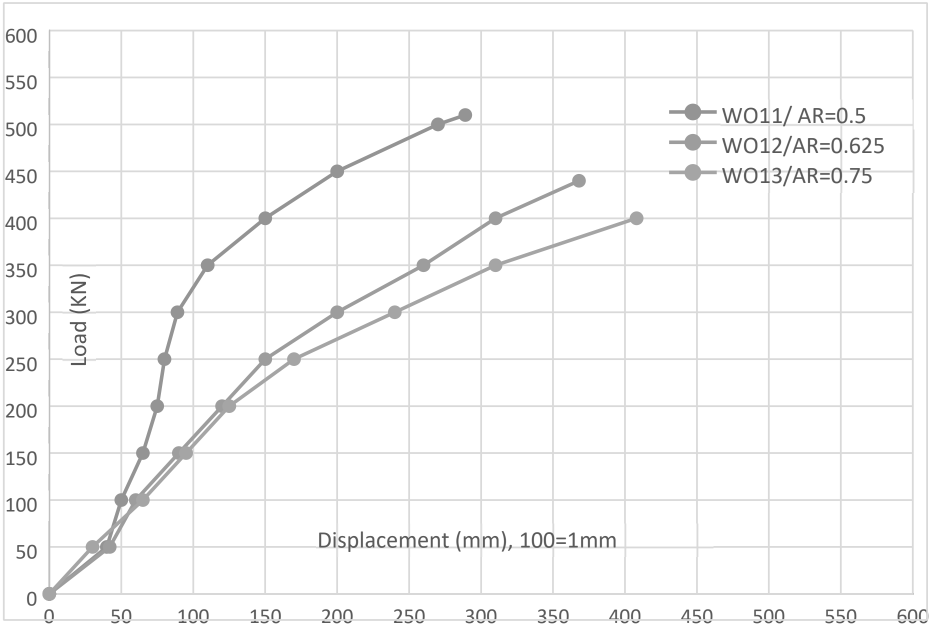

Figure (4) Aspect Ratio (AR) effect On Ultimate load And Lateral Displacement

2. Aspect Ratio effect by two-way action

For two-way action only, the relation between loading capacity and lateral displacement under the effect of aspect ratio (AR) is shown in Figure (5), and figure (9) show the crack pattern of this group.

From figures can be noticed the following:

a. The wall specimen's maximum strength falls as AR increases from (0.5 to 0.75).

b. The increase in final capacity for SCC wall specimen is about 6.52 %, 12.24%, and 19.56% for decreasing AR from (0.75 to 0.625), (0.625 to 0.5), and (0.75 to 0.5) respectively.

c. The decreasing of AR results accompanies a decrease of lateral displacement for the SCC wall specimen. The decrease in lateral displacement is about (22.08%) when AR decreased from 0.75 to 0.5 and about (2.76%) when decreased from 0.75 to 0.625, also the decrease in lateral displacement about (19.87%) for AR decreased from 0.625 to 0.5.

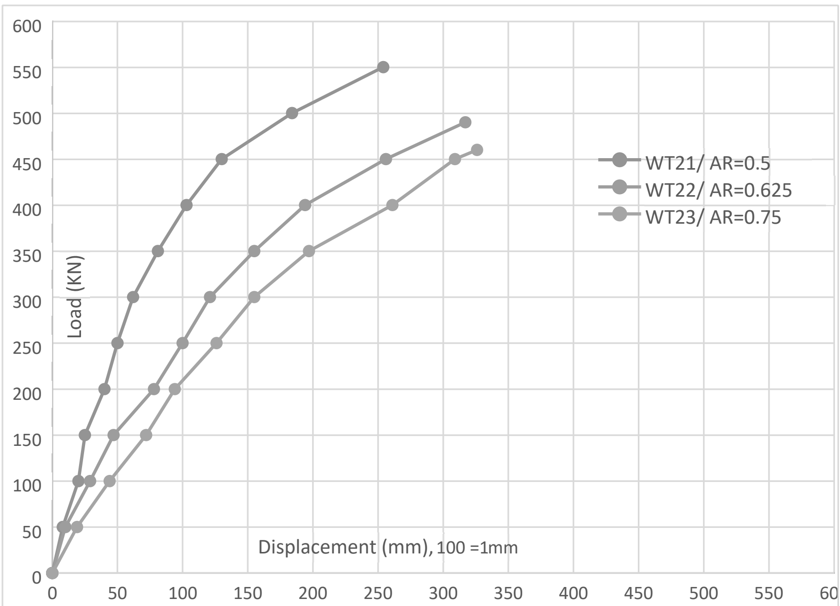

Figure (5) Aspect Ratio (AR) effect On Ultimate load And Lateral Displacement.

Furthermore, Figures 4 and 5 reveals the following results (One-way and two-way action):

a. The loading capacity of the SCC wall panel increases by two-way action as compared with one-way action, but the lateral displacement decreases on the contrary.
b. The increase in ultimate load for SCC wall panels for change from one-way to two-way action was about 7.84% at AR=0.5, 11.36% at AR=0.625, and 15% at AR=0.75.
c. The decrease of lateral displacement as follow, When AR=0.5 the decreasing is about 12.11%, AR=0.625 decreased by 13.86% and when AR=0.75 decreased by 20.09%. The increase of AR results in an increase in lateral displacement for SCC wall specimens whether it is (one or two) way action.

3. Slenderness Ratio effect by one-way action

For one-way action only, the relation between loading capacity and lateral displacement under the effect of the Slenderness ratio (λ) is shown in Figure (6), and figure (10) show the crack pattern of this group.

From figures can be noticed the following:

a. The RC wall specimen's maximum strength falls as (λ) rises from (11.43 to 16).
b. The increase of final load for the SCC wall specimen is about 9.09 %, 12.5%, and 22.73% for a decrease in (λ) from (16 to 13.33), (13.33 to 11.43) and (16 to 11.43) respectively.
c. For SCC wall specimens, an increase in lateral displacement is accompanied by an increase of (λ). When raised (λ) from (11.43 to 13.33),

(13.33 to 16), and (11.43 to 16), the increase in lateral displacement is approximately (36.45%, 32.85%, and 81.28%) respectively.

d. All the samples of the group failed by bearing, not bending. Increasing thickness reduces the slenderness ratio and thus reduces the cracks associated with the loading process, and failure becomes more brittle.

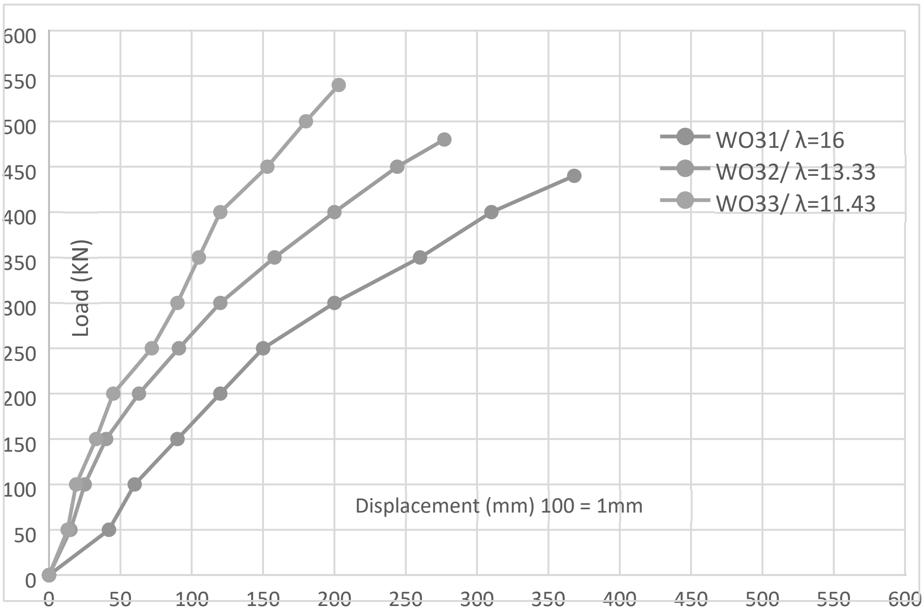

Figure (6) Slenderness Ratio (λ) effect On Ultimate load And Lateral Displacement.

4. Slenderness Ratio effect by two-way action

For two-way action only, the relation between loading capacity and lateral displacement under the effect of Slenderness ratio (λ) is shown in Figure (7), and figure (11) show the crack pattern of this group.

From figures can be noticed the following:

a. The RC wall specimen's maximum strength falls as (λ) rises from (11.43 to 16).

b. The increase of final load for the SCC wall specimen is about 6.12 %, 9.62%, and 16.3% for a decrease in (λ) from (16 to 13.33), (13.33 to 11.43) and (16 to 11.43) respectively.

c. For SCC wall specimens, a decrease in lateral displacement is accompanied by a decrease of (λ). from (16 to 13.33), (13.33 to 11.43), and (16 to 11.43). the decrease in lateral displacement is approximately (20.2%, 26.9% and 41.64%) respectively.

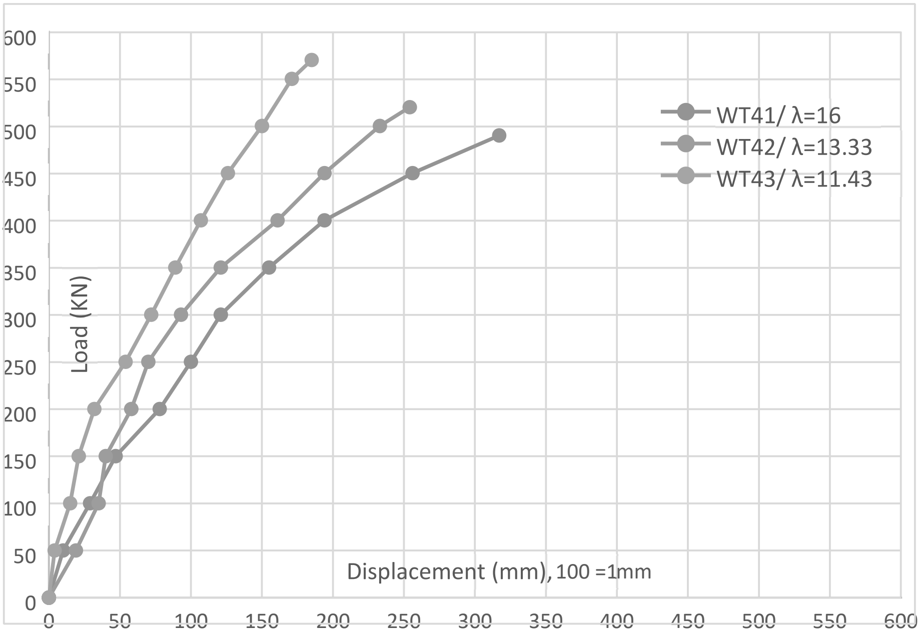

Figure (7) Slenderness Ratio (λ) effect On Ultimate load And Lateral Displacement.

Furthermore, Figures 6 and 7 reveal the following results (one-way and two-way action):

a. The loading capacity of the SCC wall panel increases by two-way action as compared with one-way action, but the lateral displacement decreases on the contrary.

b. The increase in ultimate load for SCC wall panels for change from one-way to two-way action were about 11.36%, 8.33%, and 5.55% at (λ) =16, 13.33, and 11.43 respectively.

c. The decrease in lateral displacement is as follows, 13.85%, 8.66%, and 8.86% at λ=16, 13.33, and 11.43 respectively. The increase of (λ) results in an increase in lateral displacement for SCC wall specimens whether it is (one or two) way action.

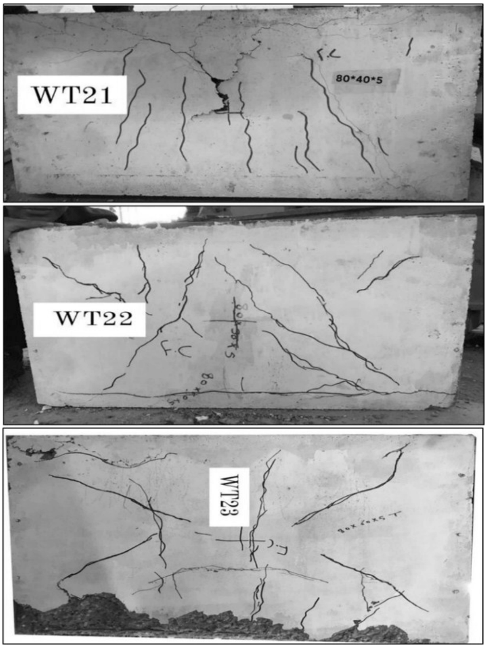

Figure (8) Crack pattern of first group

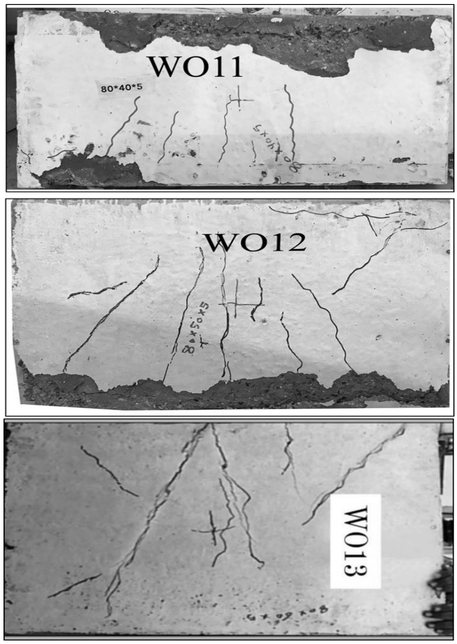

Figure (9) Crack pattern of second group

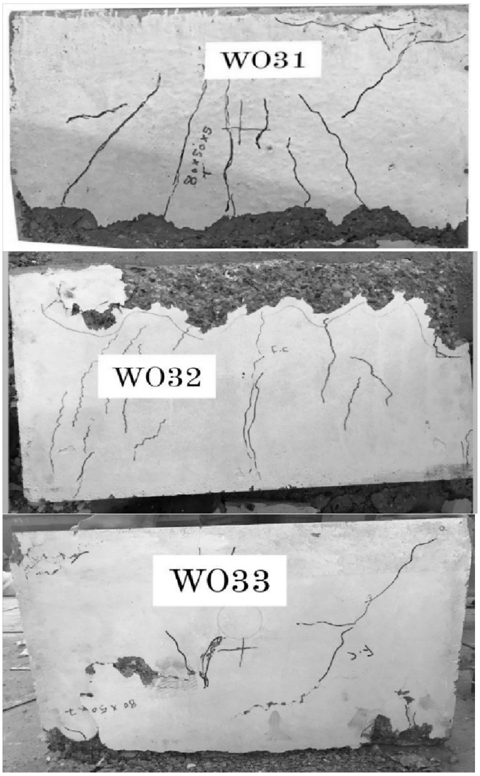

Figure (10) Crack pattern of third group

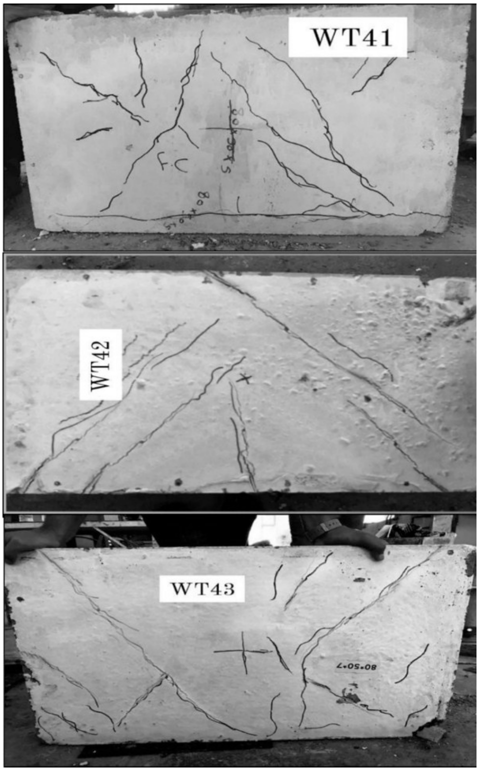

Figure (11) Crack pattern of fourth group

8. Conclusion

From this research work the experimental result refer to inversely proportional of aspect ratio (H/L) and slenderness ratio (H/T) to the load capacity of RCW samples which decrease with increasing the wall height (H), or decreasing wall thickness (T), both of these factors affect the ultimate load and failure mode, decreasing of aspect and slenderness ratio leading to tendencies of failure by crashing, also decrease in width, numerous of cracks and lateral displacement. Finally, the case of ends one way or two-way action, the support from all sides had a greater load capacity, in addition to the decrease in lateral displacement as compared to the uniaxial support because it delays the bending and failure process by stopping the bending at the side margins of the walls. This gain in load capacity and decrease in lateral displacement that achieved by the lateral restraints increases with increasing of aspect ratio (AR) and decreasing in slenderness ratio (λ). Overall the two-way action prevents the bending that occurs at the side edges of the walls and thus delays the process of bending and failure. The stresses are concentrated on the central region, and thus tends to crushing failure, not bending, as is the case in one way.

Abbreviations

ATP: attapulgite

AR: aspect ratio

BC: boundary condition

C.L: centerline

OW: One-way action

RCW: Reinforced concrete wall

SCC: Self-compacting concrete

SSCC: sustainable Self-compacting concrete

TW: Two-way action

λ: slenderness ratio

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