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STRUCTURAL BEHAVIOR OF MODIFIED REACTIVE POWDER AND REACTIVE POWDER CONCRETE WALL PANELS SUBJECTED TO AXIAL DISTRIBUTED LOADING

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Abstract:
This study presents an experimental investigation of behavior of concrete wall panels subjected to axial distributed loading, also evaluates the effect of slenderness ratio(H/t) ,and concrete strength on lateral deflection and behavior of concrete wall panels. The experimental program includes testing eight concrete wall panels hinged at top and bottom with free sides, by applying distributed load. These panels divided in to four groups, the first group with normal strength concrete, the second group with high strength concrete, the third group with modified reactive powder concrete (MRPC) and the fourth group with reactive powder concrete (RPC). Each group consists of two panels, one with slenderness ratio H/t=20 and the other with H/t=14. The obtained results indicates that as the concrete strength of wall panels increase, the behavior of the panels tends towards the brittle failure , also the results shows that the lateral deflection of the panel increase as the slenderness ratio (H/t) increase. The failure load for panels with RPC mix is greater than the failure load for panels with normal, high strength, MRPC mixes by about 96%, 39% and 17% respectively for (H/t=20).The failure load for panels with RPC mix is more than the failure load for panels with normal, high strength, MRPC mixes by about 98%, 36%, 16% respectively for H/t=14. The mode of failure for all panels was buckling failure and the line of failure lies near the center of the panel.

Keywords: *wall panel, reactive powder concrete , axial distributed loading*

الخلاصة:
يتضمن هذا البحث يتضمن دراسة تصرف الجدار اللوحي الكونكريتي تحت تاثير حمل محوري منتشر .ايضا يتضمن دراسة تأثير نسبة النحافة و مقاومة الانضغاط للكونكريت على الانحراف الجانبي و على سلوك الجداراللوحي الكونكريتي . تضمنت الدراسة العملية اختبار ثمانية نماذج من الجدار اللوحي مثبتة من الاعلى والاسفل بمسند يسمح بحرية الحركة للجوانب ، تحت تأثير الحمل المحوري المنتشر. قسمت هذه النماذج الى اربعة مجاميع ،المجموعة الاولى تتضمن نماذج تكون فيها الخرسانة المستعملة ذات مقاومة انضغاط اعتيادية ، المجموعة الثانية تكون فيها الخرسانة المستعملة ذات مقاومة انضغاط عالية ، المجموعة الثالثة تحتوي على خلطة خرسانية المساحيق الفعالة المعدلة MRPC . المجموعة الاخيرة تحتوي على خلطة الخرسانة ذات المساحيق الفعالة (RPC) . كل مجموعة تتضمن نموذجين الاول يكون ذا نسبة نحافة (H/t=20) والثاني يكون ذو نسبة نحافة (H/t=14) .النتائج المستخلصة من الدراسة العملية تبين انه بزيادة مقاومة الانضغاط لخرسانة النموذج يكون الفشل باتجاة الفشل الهش. ايضا تبين النتائج ان الانحراف الجانبي لكل نموذج يزداد بزيادة نسبة النحافة (H/t). حمل الفشل بالنسبة للنماذج ذات الخلطة الخرسانية (RPC) هو اعلى من حمل الفشل للنماذج ذات الخلطة الخرسانية الاعتيادية المقاومة و عالية المقاومة و النماذج ذات الخلطة (MRPC) بنسب ٥١%، ٧٢% و ٨٥% على التوالي وهذا بالنسبة للنماذج ذات نسبة النحافة (H/t=20) ، اما بالنسبة للنماذج ذات نسبة النحافة (H/t=14) فان حمل الفشل بالنسبة للنماذج ذات الخلطة الخرسانية (RPC) هو ايضا اعلى من حمل الفشل للنماذج ذات الخلطة الخرسانية الاعتيادية المقاومة و عالية المقاومة و النماذج ذات الخلطة (MRPC) بنسب ٥٠%، ٧٣%و ٨٦% على التوالي.

لجميع النماذج المفحوصة كان الفشل هو فشل انبعاج و فيها خط الفشل يكون قريب من مركز النموذج.

1. Introduction

Reinforced concrete walls are widely used as structural elements in locations where they are subjected to axial loads and end moments., and appear as integral components in box frames, folded plates, box girders, box culverts, tee beams, etc[1].

In the past, concrete walls were designed in most structures for protection against the external environmental conditions with little consideration for the capability of the wall as a structural member. This approach was mainly due to mainly due to published concrete codes[1].

Over the years, reinforced concrete walls have gained greater acceptance, by practicing engineers, as load-carrying structural members. This acceptance is due to the increased research undertaken on concrete walls and the subsequent increase in allowable design stresses incorporated in various current concrete codes.

1.2. Types of wall panels:

1.2.A: Concrete Wall Panel:

Reinforced concrete wall panels are commonly used as structural elements subjected to flexural-compression loads[2].

1.2.B: Tilt-Up Panels:

The system tilt-up is basically the construction of concrete walls on a flat level floor that serves as a mold, using a release agent that prevents the joining of two surfaces. The walls are self-supporting, allowing the construction of large spans of up to 25 m, without the use of pillars[2].

1.2.C: Sandwich Panel:

Walls may be built of prefabricated panels that are considerably larger in size than unit masonry and capable of meeting the requirements of appearance, strength, durability, insulation, acoustics, and permeability. Such panels generally consist of an insulation core sandwiched between a thin lightweight facing and backing[2].

1.2.D: Ferrocement wall panel:

Ferro cement primarily consists of cement – sand mortar matrix and steel wire mesh reinforcements. The layers of wire mesh are placed parallel and close together across the thickness of a thin element and embedded in mortar. When additional steel rods are used for reinforcement, the material is sometimes referred to as reinforced ferrocement[3].

1.3. Behavior of wall panels 1.3 under axial compression loads:

The ultimate strength and behavior of a structure usually depends on their geometry, material properties, support conditions and applied loading. Only from a good understanding of these factors one can satisfactorily develop a specification for the design of wall panels(4). In comparison with other dimensions, the thickness of the wall is small, which introduces the slenderness effect, leading to problems of stability. Also depending on the relative ratio of height to length, the behavior of a wall panel under load would vary from a short, wide compression member to a deep, narrow member. When concrete wall panels are slender, they become susceptible to buckling under axial compression loading. These panels can provide two types of curves depending on the bond of their edges. Slender panels restricted at the top and bottom, with vertical sides free, such panels behave in (one-way action) depicted by uniaxial curvature in the direction of loading (as shown in Figure1.a) .The other type of curvature appear in panels restricted at all sides, where biaxial curvature (two-way action) will occur in the directions parallel and perpendicular to that of loading .(Figure 1.b) shows a typical example of two-way action on a wall loaded axially(4).

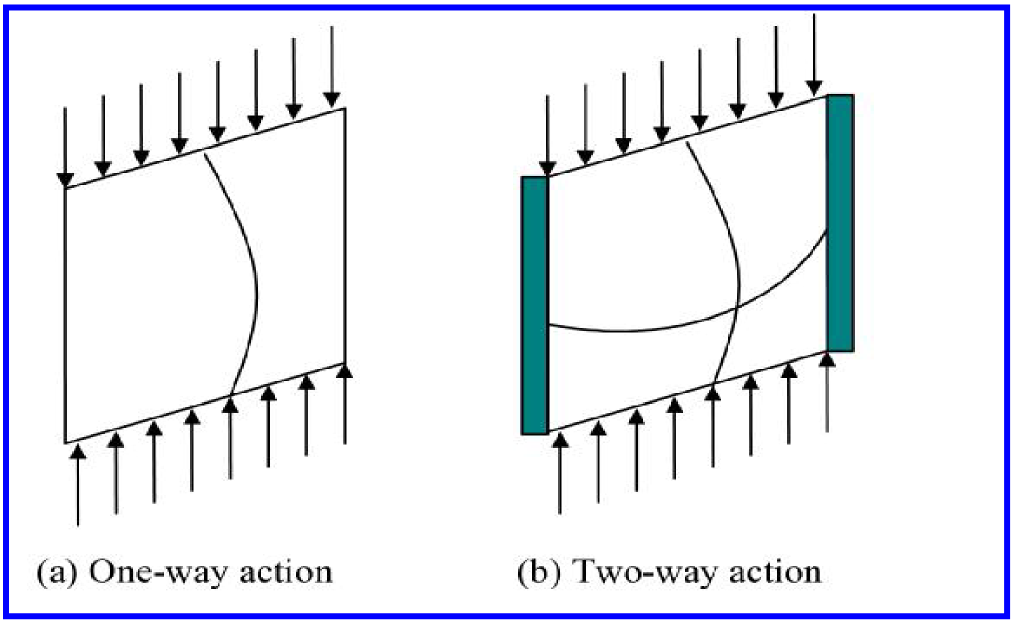


Figure (1)Wall with or without side's supports

1.4. Reactive Powder Concrete:

The term of Reactive Powder Concrete (RPC)has been used to describe a fiber-reinforced , super plasticized, silica fume-cement mixture with very low water-cement ratio (w/c)characterized by the presence of very fine quartz sand instead of ordinary aggregate. In Modified Reactive Powder Concrete a natural aggregate was used to replace the fine sand and/or part of the cementitious binder(5).

Both the original and modified RPC perform better in terms of higher strength and lower drying shrinkage or creep strain when they are steam cured rather than cured at room temperature .this improvement was related to a more dense microstructure of the cement matrix , particularly in the RPC specimens steam cured at $160^0C^{(5)}$.

2. Experimental Work:

The plan of the experimental work consists of casting and testing eight wall panels, divided in to four groups, the first group of normal concrete strength , the second group of high strength concrete , the third group of modified reactive powder concrete and the fourth group of reactive powder concrete .each group includes two wall panels (first panel with dimensions of(700*500 mm) and wall thickness of (35mm), while the second panel with dimensions of (700*500 mm) and wall thickness of (50mm), as shown in Fig (2).

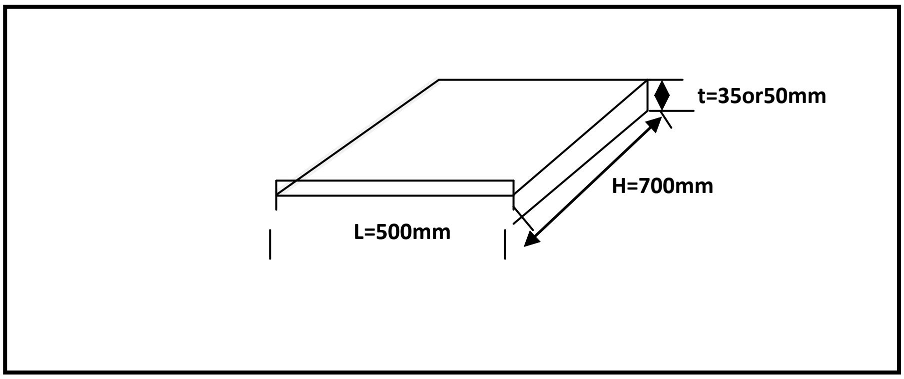


Fig. (2) Dimensions of wall pane

All concrete wall panels were reinforced with one layer of a plain steel welded mesh, consisting of 4 mm diameter bars with spacing of 90 mm c/c, placed centrally through the panel thickness. The vertical and horizontal reinforcement ratios, ρv and ρh, were both 0.0032 for all panels, satisfying the minimum requirements of the American Concrete Institute Code (ACI 318-08). The yield strength was determined from tensile test at the Structural Lab. of the College of Engineering of AL-Mustansiryia University. The average yield stress was 390 MPa.

2.1. Materials:

Optimum proportion must be selected according to the mix design methods, considering the characteristic of all materials used. The main properties of these materials are as follows:

2.1. A. Cement:

ordinary Portland cement type (I) is used. The chemical composition and physical properties of the cement used are shown in Table (1) and (2) complying with the Iraqi standard specification.

2.1. B. Fine Aggregate:

AL-Ukhaidher natural sand is used which has fineness modulus of (2.6), bulk specific gravity of (2.58)and sulfate content (SO_3%)of (0.09%) by sand weight. Table (3) shows its grading.

2.1. C. Coarse Aggregate:

Crushed gravel from AL-Nibaee with maximum size of (14mm) is used. The bulk specific gravity of this aggregate is (2.64) and its grading is shown in Table (4)

Table (1) Chemical composition of cement

Compound Composition	*Chemical Composition*	*Percentage by Weight*	*Limits of IOS No. 5/1984*
Lime	CaO	63.47	--
Iron oxide	Fe_2O_3	2.85	--
Alumina	Al_2O_3	5.46	--
Silica	SiO_2	19.5	--
Magnesia	MgO	2.44	<5
Sulphate	SO_3	2.11	<2.8
Lime saturation factor	L.S.F	0.80	0.66-1.02
Loss on ignition	L.O.I	3.12	<4
Insoluble residue	I.R	0.73	<1.5
Main Compounds			
Tricalicum Silicate	C_3S	57.11	--
Dicalicum Silicate	C_2S	16.23	--
Tricalicium Aluminate	C_3A	3.29	--
Tetracalicum Aluminoferrite	C_4AF	13.23	--

Table (2) Physical properties of cement

Properties	*Test Results*	*Limits of IOS No. 5/1984*
Fineness using blaine air permeability apparatus (cm2/ gm)	3100	>2300
Setting time using Vicat,s Method		
Initial (min)	160	>45min
Final(hrs:min)	4:25	<10 hrs
Soundness using Autoclave Method	0.19%	<0.80%
Compressive strength for cement mortar cube (70.7 mm)at:		
3 days	31.2	>15
7 days	34.0	>23

Table (3) Grading of fine aggregate

No.	*Sieve Size (mm)*	*Passing by Weight %*	*Limits of IOS No. 45/1984(Zone 3)*
1	4.75	92.50	90-100
2	2.36	83.75	85-100
3	1.18	63.84	75-100
4	0.60	35.84	60-79
5	0.30	15.84	12-40
6	0.15	0.64	0-10

Table (4) Grading of coarse aggregate

No.	*Sieve Size (mm)*	*Passing by Weight %*	*Limits of IOS No. 45/1984*
1	14	100	90-100
2	10	74.5	50-85
3	5	3.50	0-10

2.1.D. Admixture:

For the production of RPC and MRPC mixes, super plasticizer (high rang water reducing agent) based on poly carboxylic ether is used. One of the new generation of polymer based super plasticizer designed for the production of SCC Glenium 51 is used, the normal dosage for Glenium 51 is (0.5-0.8) L/ 100 kg of cement mass. Dosages outside this rang are permissible subjects to trial mixes. Glenium 51has been primarily developed for the applications in the ready mixed concrete industries where the highest durability and performance are required. The typical properties are shown in Table (5) that is added to achieve flow ability.

Table (5) Typical properties of Glenium 51*

No.	*Main Action*	*Concrete Super Plasticizer*
1	Color	Light brown
2	pH. Value	6.6
3	Form	Viscous liquid
4	Chlorides	Free of chlorides
5	Relative density	1.08-1.15gm/cm^3@25^{o}C
6	Viscosity	128±30cps@20^{o}C
7	Transport	Not classified as dangerous
8	Labeling	No hazard label required

*Provided by the manufacturer

2.2. Concrete Mixing Procedure:

The mixing procedure is an important thing to obtain the required workability and homogeneity. A horizontal rotary mixer of (0.3 m^3) capacity is used and the following sequence is adopted after a number of trial mixes has been done.

2.2. A. Material Properties of NSC:

Group one consist of normal strength concrete and material properties is shown in Table (6).

Table (6) Mix proportion of normal concrete

Mix designation	*w/c Ratio*	*Mix Properties (kg/m³)*					*Steel Fiber kg/m³*
		Water	Cement	Sand	Gravel	SP	
NSC	0.3	135	450	600	1150	6.75	-

2.2. B. Material Properties of HSC:

Group two consist of high strength concrete and material properties ispresented in Table (7).

Table (7) Mix proportion of high strength concrete

Mix designation	*w/c Ratio*	*Mix Properties (kg/m³)*					*Steel Fiber kg/m³*
		Water	Cement	Sand	Gravel	SP	
HSC	0.37	170	450	780	885	14.5	-

2.2 .C. Material Properties of RPC and MRPC:

As mentioned before group three and four consists of modified reactive powder concrete and reactive powder concrete. Properties of the two mixes are summarized and presented in Table (8).

Table (8) Mix proportion of MRPC and RPC

Mix designation	*w/c Ratio*	*Mix Properties (kg/m³)*						*Steel Fiber kg/m³*
		Water	Cement	Sand	Gravel	Silica Fume	SP	
MRPC	0.22	205	933	539	489	234	12.7	187
RPC	0.23	215	933	1030	--	234	12.7	187

The properties of steel fiber used in MRPC and RPC are shown in Table (9) .

Table (9) Properties of steel fiber *

Property	*Density Kg/m³*	*Ultimate Strength MPa*	*Modulus of Elasticity MPa*	*Average length mm*	*Normal Diameter mm*	*Aspect Ratio(L/d)*
Specification	7860	1130	$200*10^3$	250	0.4	625

*Provided by the manufacturer

2.3. Mixing, Casting and Compaction Procedure:

Horizontal rotary mixer of 0.3 m^3 capacity was used for mixing. Before using the mixer any remained concrete from a previous batch is cleaned off. Initially, coarse and fine aggregates are washed to remove any clay particles and then, all quantities are weighed and poured into the mixer and mixed before adding the water, then adding 50% of the water and mixed again, and then adding the remaining water gradually to the mixture, and the total time of mixing was (8-10 min).

Before pouring the fresh concrete in the formwork, steel reinforcement meshis placed carefully in the formwork as shown in Fig (3b), the formwork then placed on a vibrator table. Fresh concrete is placed in two equal layers, each layer is compacted by the vibrator table for a period about (20 - 40 sec). After the top layer has been compacted, it is smoothened and levelled with the top of the formwork by using a steel trowel. After finishing the procedures of casting , compacting and finishing the surface of the specimens, the specimens have been covered by nylon to prevent evaporation of water from fresh concrete .After 48 hours, the specimens were period of 28 days. After the end of curing period, the specimens are removed from the water, and kept for two days in the air to allow for drying. The main testing machine is a universal testing machine available in the Structural Lab. in Civil Eng. Dept. College of Eng. of AL-Mustansiryia University as shown in Fig.(3a) The panels are tested by this machine after making some arrangement to simulate the support condition for the panels. Cubes are also tested by this machine.

a) Universal testing machine b) steel reinforcement

Fig. (3) Universal testing machine and steel reinforcement

2.4 . Test Rig Set-Up:

The test rig in the case of axially loaded walls (hinged at top and bottom) must satisfy two main conditions. Firstly, the supports of the wall panel to be tested must be allowed to rotate freely, while at the same time they should not move or deflect laterally. Secondly, the axial load must be uniformly distributed across the length of the test panel. Each top and bottom hinged support conditions is simulated by attaching a 32 mm diameter high strength steel rod on a channel of size (C50 mm × 3 kg/m) and welded very well for a length of rod and channel 1.0 m to ensure that the panels will be within the length of the channel. Two high strength steel rods of12 mm then attached and welded very well to either flange of I-steel section to make a suitable guide for the steel rod of 32 mm that attached to the channel. This operation was made very carefully and with high accuracy to ensure a straight lines and no gaps allowed to be within the support and welding. Details of the simply supported top hinged edge are shown in Fig. (4).

The two I-sections fixed to the test machine by many clamps tightly, top and bottom taking care with the straightening of the two I-sections. After the test rig has been fixed, the panel fixed to the top and bottom hinge supports, leveling the panel to ensure the perpendicularity of the panel and applying the load to the failure of the panel.

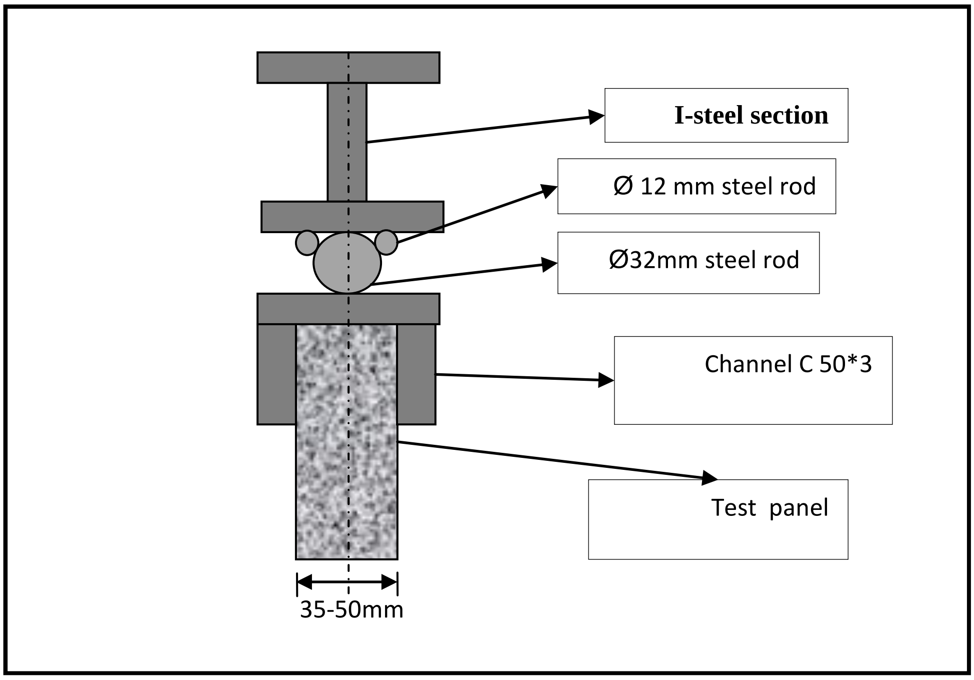


Fig. (4) Detail of Supports used in this work

2.5. Compressive Strength Test:

The average of three(150×150×150 mm) cubes were used to estimate the compressive strength of concrete). Test results are given in Table (10).

Table (10) Compressive Strength Results

Group	*Cube strength (Mpa)*
NSC	30.2
HSC	69.5
MRPC	100
RPC	128

3. Results and Discussion:

The concrete wall panels are divided in to four groups each group consist of two panels. the first croup of normal strength concrete, the second croup of high strength concrete , the third croup of MRPC and the fourth group of RPC. The results discusses the deflection behavior of the panels , the effect of compressive strength verse the failure load and the crack patterns and the failure mode of the panels.

Fig.(5), Fig (6), Fig (7) and Fig. (8) shows the lateral deflection for panels with normal, high strength, MRPC and RPC respectively .Fig. (9) and Fig. (10) shows the lateral deflection for panels with slenderness ratio (H/t=20) and (H/t=14) respectively.

Fig. (11) shows the failure load verse the compressive strength(normal, high strength, MRPC and RPC) for the panels with slenderness ratio (H/t=20) and (H/t=14).

Cracks occur in panels when the stresses exceed the tensile strength of concrete.
Excessive cracking and wide deep cracks affect durability can lead to corrosion of reinforcement although strength may not be affected. Cracking load is that load at which the first visible surface crack is seen by the naked eye on the surface of the wall. Although great care was taken in marking the first visible crack, the values of the cracking loads are still approximated and do not necessarily represent the load at which the actual cracking of concrete had started. This is because the crack at the beginning is tiny and cannot be seen until it grows up.

The cracking process of the concrete wall panels due to applied loads was studied from the experimental work. Fig (12), and (13) shows photographs of wall panels after failure has occurred

The cracking loads corresponding to the appearance of first crack and failure loads recorded are given in Table (11).

Table (11) The Cracking and Failure Loads

Panel	*Panel with normal concrete*	*Panel with high strength concrete*	*Panel with MRPC*	*Panel with RPC*

Cracking load(KN)	H/t=20	H/t=14	H/t=20	H/t=14	H/t=20	H/t=14	H/t=20	H/t=14
	60	70	70	100	100	150	150	200
Failure load(KN)	H/t=20	H/t=14	H/t=20	H/t=14	H/t=20	H/t=14	H/t=20	H/t=14
	178	197.5	250	287.5	297.5	337.5	348	392.5

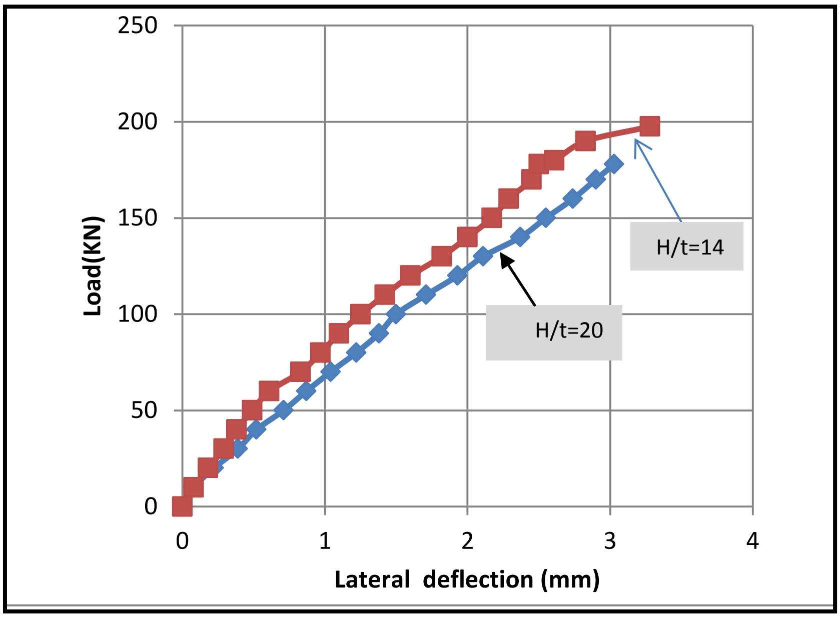


Fig.(5) Lateral deflection for panels with normal strength concrete

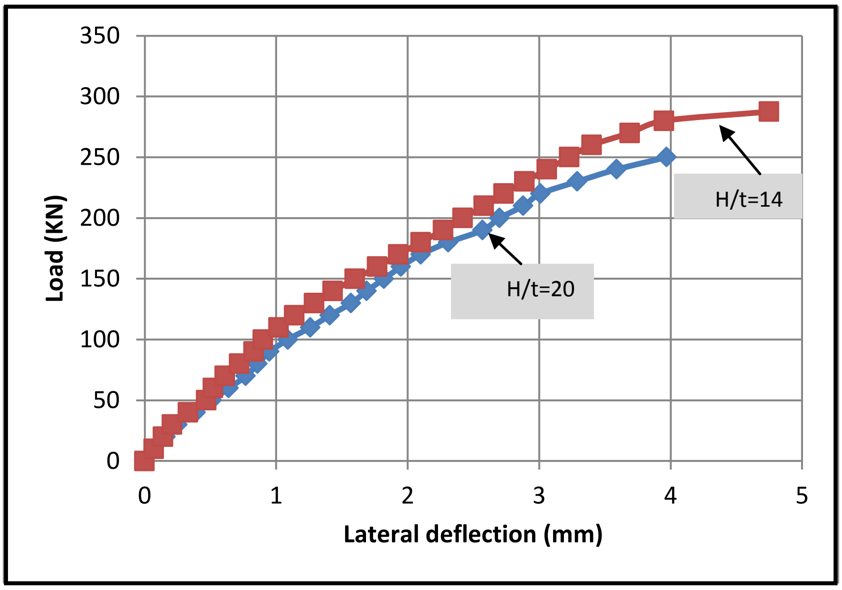


Fig.(6) Lateral deflection for panels with high strength concrete

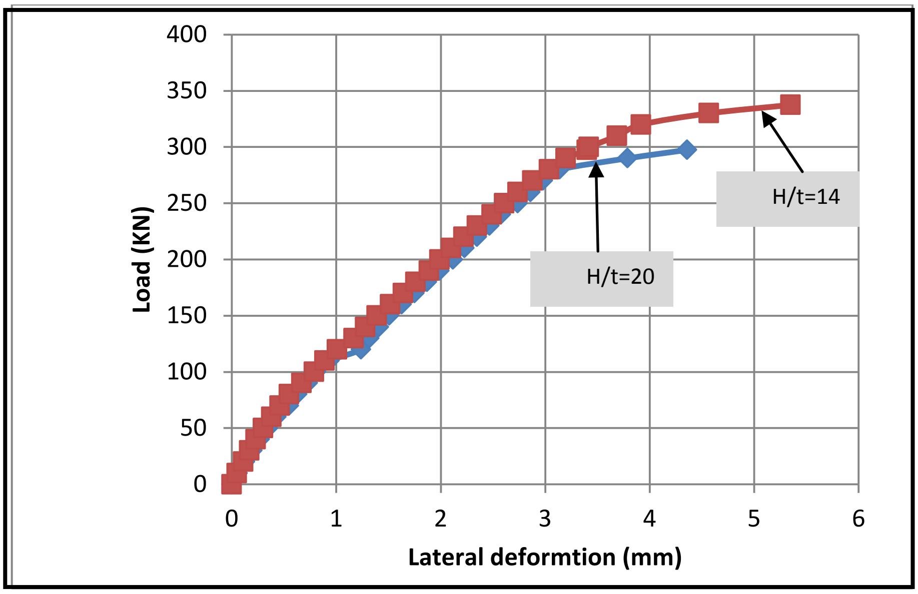


Fig.(7) Lateral deflection for panels with modify reactive powder concrete (MRPC)

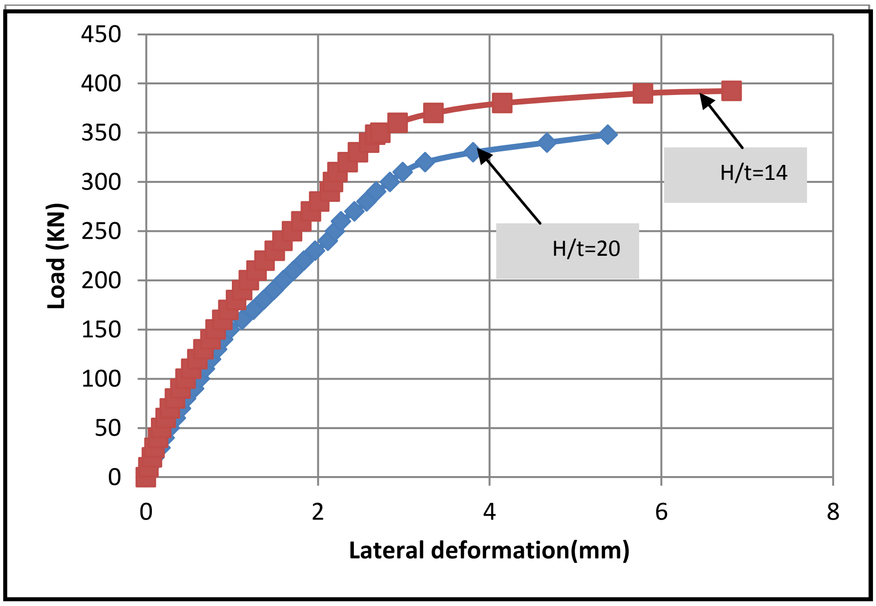


Fig.(8) Lateral deflection for panels with reactive powder concrete (RPC)

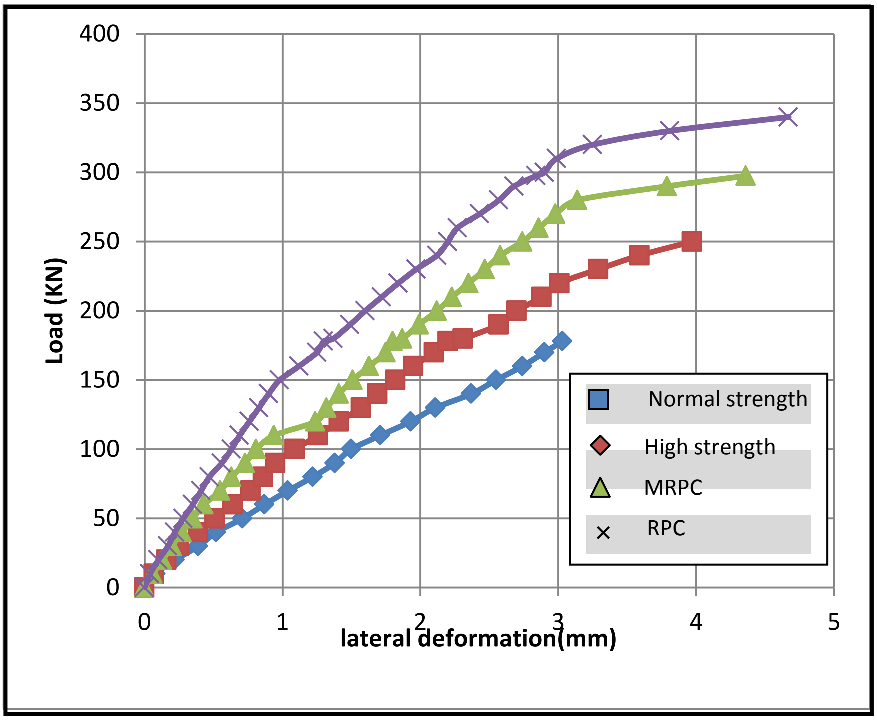


Fig.(9) Lateral deflection for panels with slenderness ratio (H/t=20)

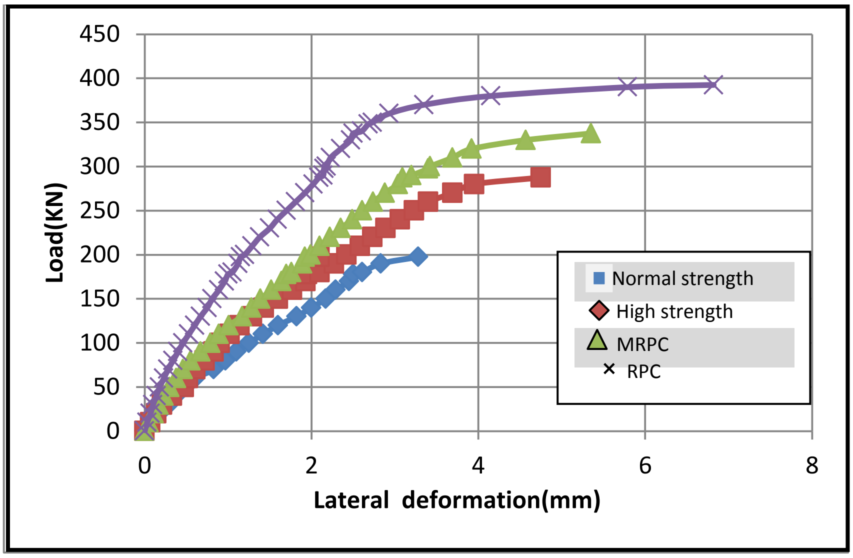


Fig.(10) Lateral deflection for panels with slenderness ratio (H/t=14)

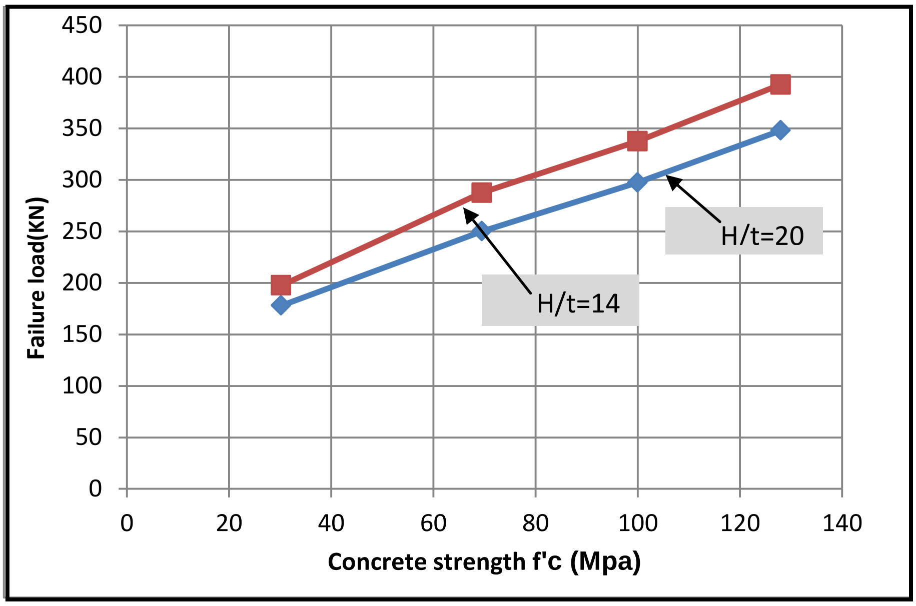


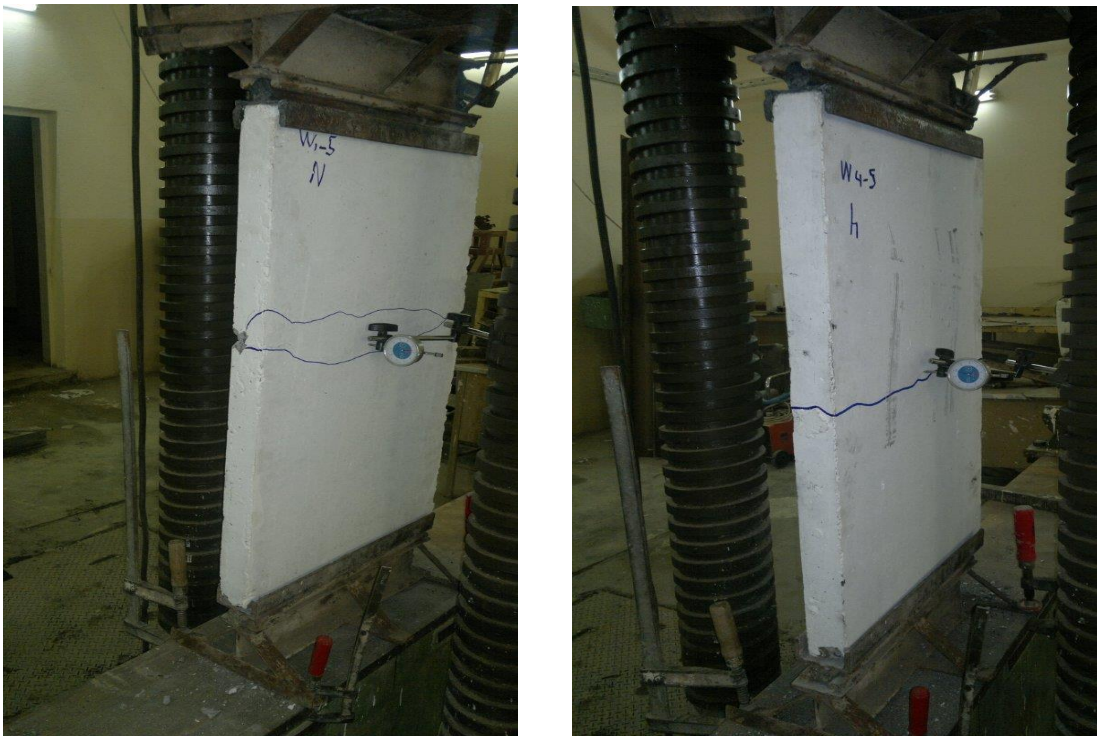
Fig.(11) Effect of concrete strength f'c on failure load for panels with normal, high strength, MRPC and RPC

a) Normal strength concrete

b) High strength concrete

c) MRPC d) RPC

Fig(12)Crack pattern for panels with H/t=20



a) Normalstrength concrete b) High strength concrete

c) MRPC d) RPC

Fig(13)Crack pattern for panels with H/t=14

The Fig.(5) which represents wall panels with concrete strength (f'c=30.2Mpa) and different slenderness ratio , shows that the wall exhibited a ductile failure behavior. This was reflected in the continually increasing values of the deflections as the test loads approached failure.

For panel with slenderness ratio (H/t=20) (t=35mm), show linear curve up to failure load, while panel with slenderness ratio (H/t=14) (t=50mm), show linear curve and then followed by nonlinear trend with lateral deflections increasing rapidly as failure was approached.

The lateral deflection for panel with (H/t=20) is more than the lateral deflection for panel with (H/t=14) by about 19%at the same applied load. The failure load for panel with (H/t=20) is less than the failure load for panel with (H/t=14) at about 10%.

Fig (6) represents wall panels with concrete strength (f'c=69.5Mpa) and different slenderness ratio, shows that the wall exhibited brittle failure behavior , this was reflected in high slope of the curves. A reason for this is the high strength of concrete for this group of panels. The two curves show linear behavior followed by nonlinear behavior up to failure. The lateral deflection for wall with (H/t=20) is more than the lateral deflection for wall with (H/t=14)by about 12% at the same applied load. While the failure load for wall with (H/t=20) is less than the failure load for wall with (H/t=14) by about 13%.

For Fig. (7) which represent wall panels with concrete strength (f'c=100Mpa) and different slenderness ratio , shows that the wall exhibit more brittle failure behavior. The two curves show linear behavior followed by nonlinear behavior up to failure. At linear part for the curves there is no big different in lateral deflection at the same applied load, while in nonlinear part the lateral deflection for the wall with(H/t=20) is more than the lateral deflection for wall with(H/t=14) by about 21% at the same applied load and the failure load for wall with (H/t=20) is less than wall with (H/t=14) by about 12%.

Fig.(8) which represent panels with concrete strength (f'c=128Mpa) and different slenderness ratio, shows that the wall exhibit more brittle failure behavior than the curves in Fig (7).Both curves shows linear behavior followed by nonlinear behavior up to failure. The lateral deflection for wall with (H/t=20) is more than the lateral deflection for wall with (H/t=14) by about 27% at the same applied load, and the failure load for wall with (H/t=20) is less than wall with (H/t=14) by about 12%.

Fig.(9) and Fig.(10) shows the lateral deflection verse the applied load curves for walls with normal, high strength, MRPC and RPC concrete mixes at slenderness ratio (H/t=20) and (H/t=14) respectively.

In general from Fig.(5,6,7,8,9,10) the lateral deflection for wall panels with slenderness ratio (H/t=20) was more than the lateral deflection for wall panels with (H/t=14) for the same applied load. This lead to conclude that the panels with high slenderness ratio exhibited more lateral deflection.

Also from figures above the large difference between the slop of the curves and the higher slope of the curves indicates the wall panels with higher strength concrete and its clearly noticed that the difference in lateral deflections for the same load was large. This means that the panels of high strength concrete will behave in brittle type of failure.

Fig (11) show that the relation between concrete strength (f'c) and failure load look like a linear relation for panels with (H/t=20) and (H/t=14). Also show that the failure load for panels with (H/t=20) is less than for panels with (H/t=14) by about 10% at (f'c =30.2 Mpa), and the difference between failure load increase by about (12%) as the (f'c) increase to (128Mpa).

For panels with (H/t=20) and (H/t=14) , the large difference between failure load for panels with RPC mix and other panels can be regarded to the materials used in RPC mixture when only fine materials used and this give better homogeneity when only very fine sand is present and then to more effective bond strength between cement matrix.

Also the presence of steel fiber in the mixture of MRPC and RPC and the ability of fiber to absorb large amount of energy before failure make the failure load for panels with MRPC and RPC higher than the failure load with normal or high strength concrete.

From photos in Fig.(11) and Fig.(12) , show that the type of failure was buckling failure. It is obvious that the line of failure lies near the center of the panel except the panel with (RPC mix and H/t=14mm), the line of failure lies above the center of the panel.

Conclusions:

Depending on the test results of the experimental program, the following conclusions are obtained:

1- The structural behavior and lateral deflections of concrete wall panels depends on slenderness ratio (H/t) and concrete strength.
2- As the slenderness ratio increase, the lateral deflection increase.
3- As the concrete strength of wall panel increase, the structural behavior of the wall panels tends towards the brittle failure.
4- The failure load for tested panels with RPC mix is greater than the failure load for tested panels with normal concrete mix by about 96% and 98% for slenderness ratio H/t=20 and H/t=14 respectively.

5- The failure load for tested panels with RPC mix is greater than the failure load for tested panels with high strength concrete mix by about39% and 36% for slenderness ratio H/t=20 and H/t=14 respectively.

6- The failure load for tested panels with RPC mix is greater than the failure load for tested panels with MRPC mix by about 17% and 16% for H/t= 20 and H/t=14 respectively.

7- The mode of failure for all tested panels was buckling failure and the line of failure lies near the center of the panel.

4. References

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