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STRUCTURAL BEHAVIOR OF REINFORCED CONCRETE VIERENDEEL TRUSS TO USE IN PRECAST CONSTRUCTION

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Abstract: This paper present an experimental investigation of structural behavior of Vierendeel Truss use instead of bearing wall in precast construction. The experimental program contains casting and testing (8) R.C wall panels specimens with opening with right angle corner, the dimension of opening (300*350*75) mm which it is length, width and thickness respectively . The dimension of the R.C wall panel specimens were (1000*750*75) mm which they are length, width and thickness respectively and all the specimens contain nib (cantilever) portion (100*60*75) mm length width and thickness respectively. In this study the main variable is the type of concrete and the compressive strength. The wall panel specimens were test with uniformly distributed load with an eccentricity of (67.5) mm chosen by the researcher. the specimens were simply supported to represent the supports of the truss. The wall panels were divided into (2) groups, the first group is normal strength with (4) specimens and the second group is reactive powder concrete (4) specimens. The failure load, load – deflection curves and crack pattern were studied. All the panels were deflected in single curvature in the vertical direction of loading. The presence of opening lead to decrease in strength, opening causes concentrated stress at the corners of opening and initiated the cracks and failure.

Keywords: *Reactive powder concrete, Normal Strength Concrete, Vierendeel Truss.*

التصرف الانشائي لمسنمات فرنديل للخرسانه المساحيق الفعاله، الخرسانه العاديه المستخدمه بدلا عن الجدران الكونكريته المسلحه في البناء الجاهز

الخلاصه: تتضمن هذه الورقه على دراسه التصرف الانشائي لمسنم فرنديل المكون من الخرسانه المسلحه (خرسانه المساحيق الفعاله والخرسانه الاعتياديه المقاومه) المستخدم في الابنيه الجاهزه. البرنامج العملي لهذه الدراسه تتضمن صب و فحص (8) نماذج من الجدار الخرساني المسلح الحاوي على فتحات قائمه الزاويه، ابعاد الفتحات (300*350*75) ملم (الطول،العرض و الارتفاع) بالتسلسل. ابعاد نموذج الجدار الخرساني المسلح (1000*750*75) ملم وتمثل هذا الابعاد الطول، العرض ، السمك وكذلك تحتوي النماذج على جزء ناتئ ابعاده (100*60*75) ملم وتمثل هذه الابعاد الطول ، العرض والسمك بالتسلسل. المتغير الرئيسي لهذه الدراسه هو نوعيه الخرسانه و مقاومه الانضغاط. النماذج تم فحصها بواسطه تسليط حمل منتظم مع مسافه تبعد عن المركز حوالي (67.5) ملم (تم اختيارها من قبل الباحث). النماذج مسنده اسناد بسيط حيث ان هذا الاسناد يمثل اسناد المسنم. عينات الجدار مقسمه الى مجموعتين، المجموعه الاولى هي خرسانه اعتياديه المقاومه و تتضمن اربع نماذج. اما المجموعه الثانيه هي خرسانه المساحيق الفعاله و كذلك تتضمن اربع نماذج.حمل التشقق الاولي و حمل الفشل، مخططات الحمل مع الهطول و كذلك شكل الفشل تمت دراسته. جميع النماذج حصل فيه تقعر احادي المحورفي الاتجاه العمودي للتحمل. وجود الفتحات يؤدي الى تركيز الاحمال في اركان الفتحات مما يؤدي الى بدأ تكون التشققات والفشل.

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1. Introduction

1.1. *Viernedeel Truss*

A Vierendeel truss is hyper static frame composed of a series of rectangular or trapezoidal panels without diagonal members. These types of frames depend on the rigidity of joints for stability. This type of trusses do not have the usual triangular voids which used in pin joint, rather employing rectangular opening with rigid connection in the elements, which unlike conventional truss must also substantial bending forces. Vierndeel frames are usually subjected to bending while the individual members in it are subjected to bending moments and shear force in addition to direct tension of compression. Viernedeel frames used in structural when the free space between top and bottom chord is required [1].

Vierendeel truss offers some esthetic qualities, has simple details because of the limited number of members at a joint, is easier to form and place and can be pre-cast or cast in place. Figure (1) shows different types of Vierendeel truss and applications.

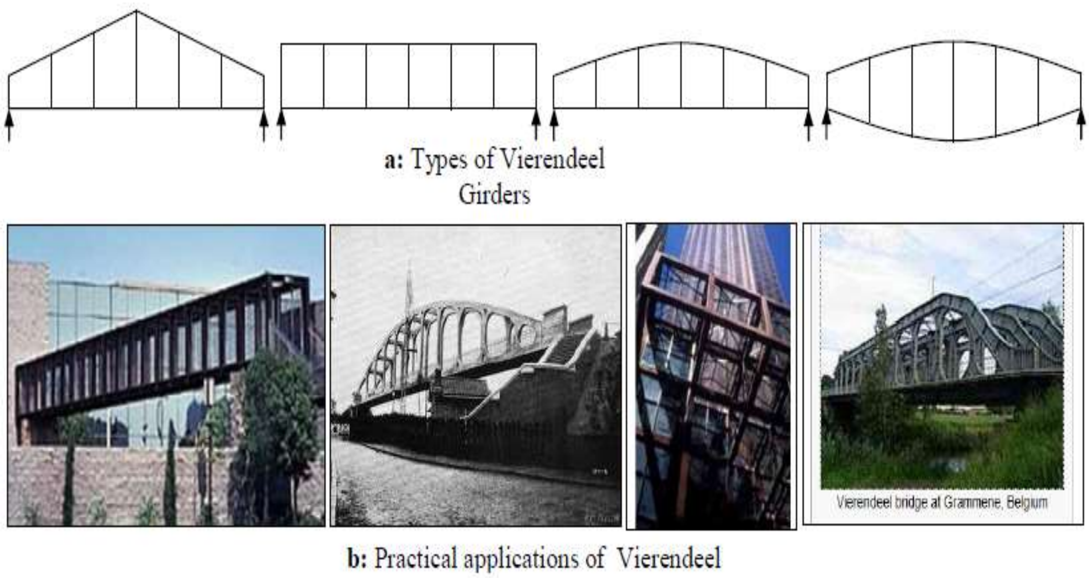


Figure1. (a, b)Different Types of Vierendeel Truss and its application

1.2. *Reactive Powder Concrete*

Reactive powder concrete (RPC) is one of the latest and most important development in concrete technology, it has superior mechanical properties such as; high strength, high ductility, high durability, limited shrinkage, high resistance to corrosion and abrasion and improvement in tensile cracking resistance, post cracking strength, ductility and energy absorption capacity [2].

RPC is a mixture of cement, silica fume, fine sand, high range water reducer, water and steel fibers without coarse aggregate to enhance the homogeneity [3].

Owing to the fineness of silica fume and the increased quantity of hydraulically active components, it has been called reactive powder concrete [4].

2. Materials

Normal strength concrete contain the main compound of mixture which it is cement, fine aggregate and coarse aggregate and water. RPC is a mixture of cement, silica fume, fine sand, high range water reducer, water and steel fibers without coarse aggregate. The materials were satisfying according to Iraqi specifications and ASTM.

3. Mix Proportion

All the mix proportion was selected according to the previous researchers with some modification for R.P.C mix [5, 6].

3.1. *Normal Strength Concrete Proportion*

Normal strength concrete which was represented by the first group of wall panels' specimen with mix proportion listed in table (1).

Table1. Shows the proportion of Normal Strength Concrete

Group No.	*Cement* *Kg / m^3*	*Sand* *Kg /m^3*	*Gravel* *Kg / m^3*	*Water* *Lit / m^3*
1	400	600	1200	200

3.2. *Reactive Powder Concrete*

Reactive powder concrete was represented by the second group of wall panels specimen with mix proportion listed in table (2).

Table2. Shows the proportion of Reactive Powder Concrete

Group No.	*Cement Kg / m^3*	*Sand Kg/ m^3*	*Silica Fume %*	*Super-plasticizers %*	*Steel Fibers %*	*W/C ratio*
2	1000	1000	15	6	1	0.25

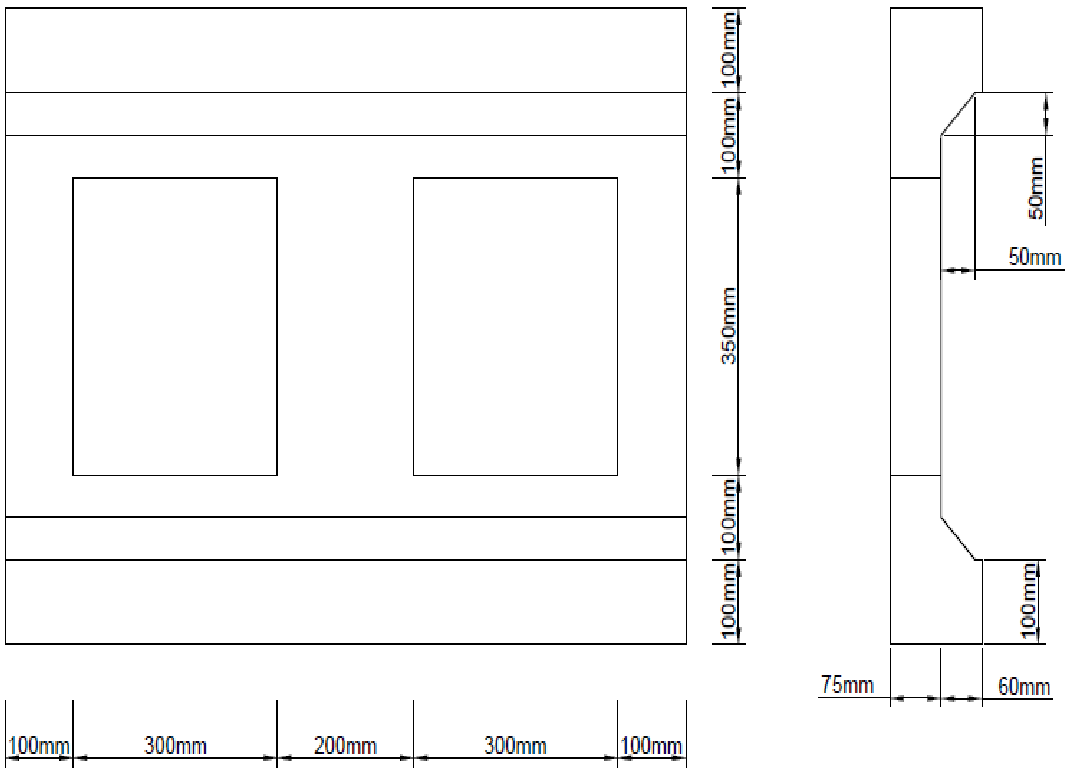
Silica fume by wt. = 150 kg/m^3
Super-plasticizer by wt. = 69 lit/m^3

4. Panel Designation and Dimensions

Panels are designated as (Wx1-x2); the number (x1) refers to the number of group. Group one was for the normal strength concrete and group two was for the reactive powder concrete. The number (x2) refers to the number of the specimen within the group. Table (3) shows the dimensions and designation of panels. The tested wall panels were designed to have appropriate dimensions that can be manufactured, handled and tested as easy as possible. The panel dimensions were (1000 *750 * 75) mm as length, width and thickness respectively, and contain a nib portion on the edge in one direction which dimension was (1000 * 100 * 60) mm and these were inclined inside the panel. The wall panel also contains two opening with dimension of (350 * 300 * 75) mm with right angles. Figure (2) shows the dimensions of wall panel's specimens.

Table3. Wall panels Designation and Dimensions

Group No.	*Wall Panels*	*Length mm*	*Height mm*	*Thickness mm*
Group 1	W1-1	1000	750	75
	W1-2	1000	750	75
	W1-3	1000	750	75
	W1-4	1000	750	75
Group 2	W2-1	1000	750	75
	W2-2	1000	750	75
	W2-3	1000	750	75
	W2-4	1000	750	75



(a) (b)

Figure2. (a) Front view of Wall Panel Dimensions
(b) Side view of Wall Panel Dimensions

5. Steel Reinforcement

All the (8) wall panels specimen were reinforced with (8mm) as main reinforcement for the beam and columns and for the cantilever portion, and (6 mm) for both ties and stirrups. The reinforcement used in these wall panels was satisfying the minimum required ratio of ACI- code318-08 [7]. Figure (3) shows the steel reinforcement and sections of the reinforcement of the specimens.

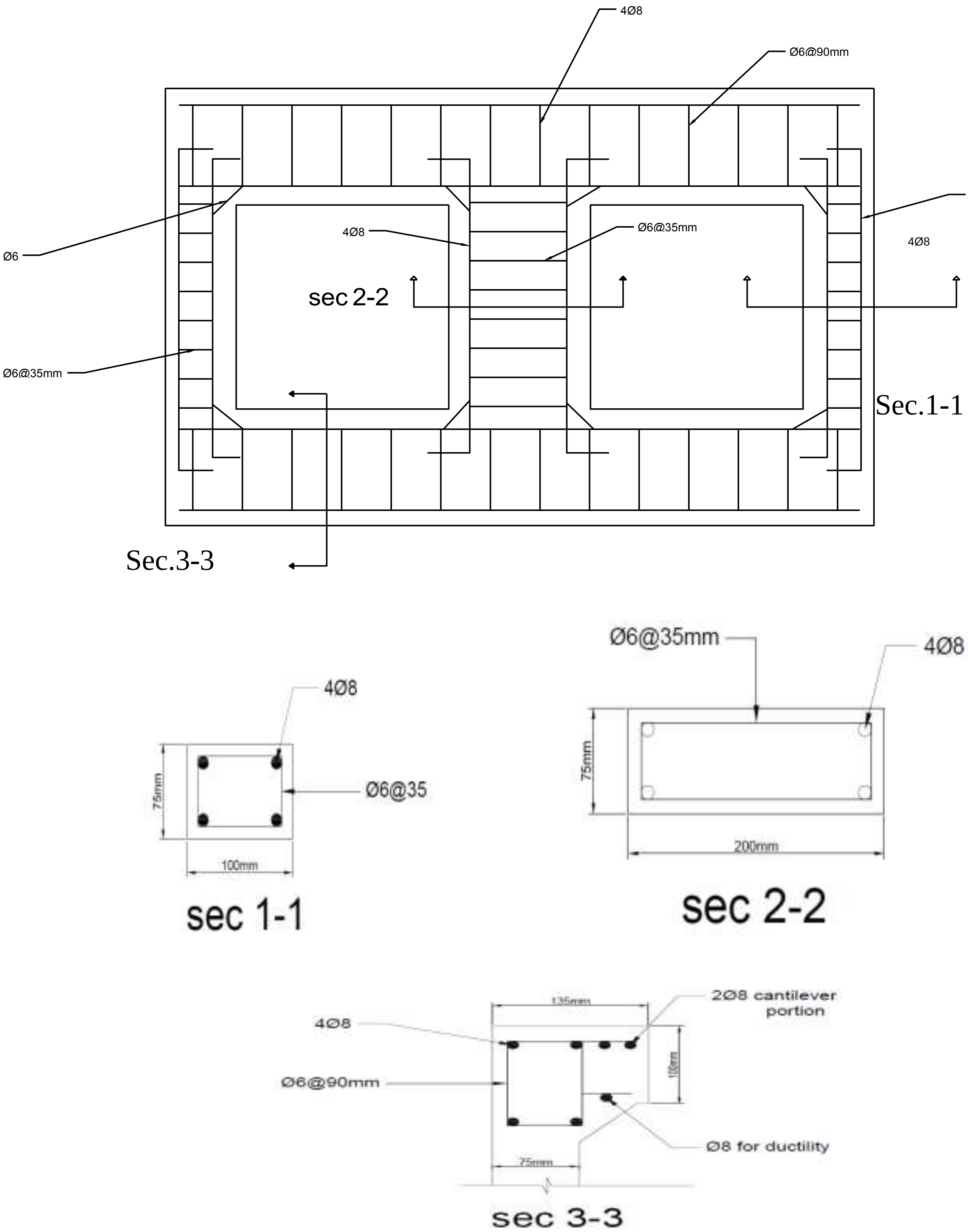


Figure3. Reinforcement of the R.C Wall Specimens

6. Mixing, Casting, Compaction and curing

A horizontal rotary mixer of 0.19 m^3 capacity was used for mixing. Before using the mixer for any type of concrete any remained concrete from a previous batch is cleaned off. The form work was were cleaned and their internal surfaces were oiled one day before casting to prevent adhesion to concrete after hardening. Before mixing, all quantities were weighed and packed in a clean container. Before casting the fresh concrete in the formwork, steel reinforcement is placed carefully in the formwork and checked the spacing (concrete cover) between the form-work and the reinforcement. All the materials were weighted and then added to the mixer and then casing into the form work and the compaction were applied only to the normal strength concrete by using vibrating rod, The purpose from this is to faire the air bubble in the mix and to forbidden the void from happen. After (2) days the form work were opened and the specimens were covered with saturated bags known commercially as jnfaas.

7. Testing

The preparation before testing includes painting all the specimens with white paint in order to make the cracks clear and apparent. The main testing machine is a universal testing machine (8551 M.F.L system) available in the Structural Lab, Department of Civil Engineering, Faculty of Engineering, Al-Mustansiriyah University. The panels are tested by this machine after making some arrangement to the supports and measure the span between supports and marking the required eccentricity and put the frame which is used to apply uniform line load and attach all the dial-gauges as shown in figure (4). The compressive strength were test by using this device, the average of (3) cylinders (150*150*300) mm were recorded in table (4). Figure (5) shows the testing machine and testing of R.C wall panel specimen.

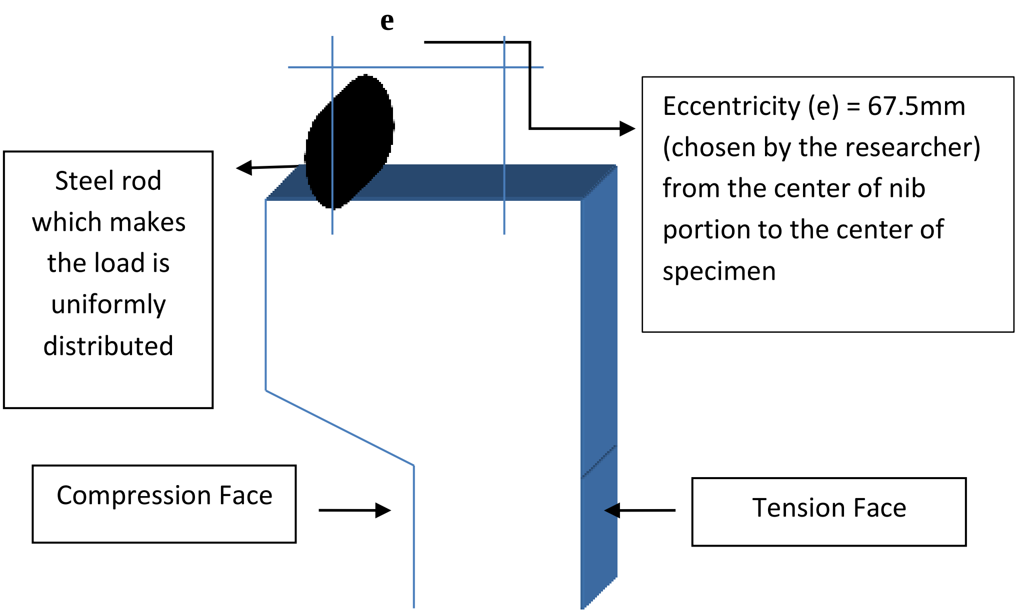


Figure 4. Applying load on specimen with eccentricity

(a) (b)

Figure5. (a) Testing machine (b)Testing of R.C Wall Panel Specimens

Table4. Compressive Strength

Type of concrete	*fc' (MPa)*
Normal Strength Concrete	26.2
Reactive Powder Concrete	112

8. Cracking load

Any prominent crack in R.C units greatly detracts from the appearance. Excessive types of cracking affect durability and can lead to corrosion of reinforcement although strength may not be affected [8].

Cracking load (first crack load) is that load at which the first visible surface crack is seen by the naked eye on the surface of the wall, ultimate load is the maximum load capacity of the specimen can reach before its failure .Table (5) shows the first crack load and ultimate load and the ratio between them.

Table 5. First crack, Ultimate load and ratio between them

Group	*Wall panel*	*First crack load (Pcr) kN*	*Ultimate load (Pu) kN*	*Pcr/Pu*100%*
Group One	W1-1	82.5	232.5	35.4
	W1-2	105	175	60
	W1-3	90	192.5	46.7
	W1-4	95	210	45.23
Group Two	W2-1	210	395	53.16
	W2-2	165	342.5	48.17
	W2-3	100	412.5	24.24
	W2-4	92.5	402.5	22.98

From the above values shown in table 5, it can be concluded that:

1- The cracking load (first crack load) of N.C are about (36-60) % of the failure load (ultimate load). The cracking load of R.P.C are about (23-54) % of the failure load.

2- The ultimate load for R.P.C is about (41-53) % more than N.C.
3- N.C shows less value of failure load (ultimate load) than R.P.C.
4- R.P.C shows high value of the failure load (ultimate load) than N.C, this is because the existences of silica fume and a steel fiber in the mixture and that shows ductile failure behavior and improvement in performance.
5- The addition of silica fume and very fine sand in R.P.C led to make the mixture dense and improve it is behavior in response to load.

9. Cracking Pattern

The crack patterns observed on the tension and compression face of the wall panels. All these photographs are taken for the panels after failure of these panels and marking the visible crack with colored lines as can as possible. The cracks were observed in tension and compression faces of the specimens. Figure (6) to figure (9) represent the crack pattern for N.C group. Figure (10) to figure (13) represent the crack pattern for R.P.C group. Where (a) represent compression face and (b) represent tension face.

(a) (b)

Figure 6. (a, b) Crack pattern for W1-1

(a) (b)

Figure 7. (a, b) Crack pattern for W1-2

(a) (b)

Figure 8.(a, b) Crack pattern for W1-3

(a) (b)

Figure 9.(a, b) Crack pattern for W1-4

(a) (b)

Figure 10.(a, b) Crack Pattern for W2-1

(a) (b)

Figure 11.(a, b) Crack Pattern for W2-2

(a) (b)

Figure 12.(a, b) Crack Pattern for W2-3

(a) (b)

Figure 13.(a, b)Crack Pattern for W2-4

For figures (6, 7, 8 and 9) which represent N.C group, it can conclude that:

1-The strength is less than with comparing with other group.

2-The cracks in the tension face are less than R.P.C. Cracks in tension face of columns of the specimens are non-straight. The cracks in the columns are more than the upper and lower chords. In the lower chord, the flexural cracks appeared before and then shear cracks appeared after the continuity in loading.

3- The reason for cracks in tension face of columns is the bending moment formed due to eccentric axial load and the cracks increases with the increasing of load.

4- Cracks in the compression face of specimens appeared in the upper chord and started from the corner between the columns and upper chord and with 45', this is due to concentrating the stress at corners of the opening.

For figure (10, 11, 12 and 13) which represent R.P.C group, it can conclude that:

1- The strength is more than the N.C group.

2- The cracks in the tension face are more than N.C group.

3- The cracks in the columns is more and had different sizes some were tiny and small and some is large, and the cracks is non-straight. The cracks in the columns are more than the upper and lower chords. In the lower chord, flexural cracks appear before the shear cracks.

4- Steel fibers arrest the crack and prevent the crack from progress.
5- The reason for cracks in tension face of columns is the bending moment formed due to eccentric axial load and the cracks increases with the increasing of load.
6- Cracks in the compression face of specimens appeared in the upper chord and started from the corner between the columns and upper chord and with 45'; this is due to concentrating the stress at corners of the opening.

10. Deflection Characteristics

Graphically, shows the load versus deflection profiles for N.C, R.P.C. During the test, the applied load and the corresponding deflections, at center of the lower chord, at the center of the middle column and at the bottom edge of the specimen and at mid of the opening were recorded using dial gauges (accuracy 0.01mm). All the tests are carried out under the condition of load control of 10kN increments.

At the beginning of each test, a small load is applied (about 2kN) to seat the supports and loading system, then the load is released and reloading is carried out in an rate with an increment of 10kN. Figure (14) shows the position of dial gauge. Figure (15) shows the curves of load deflection relation where the dial gauge is located at the center of lower chord, Figure (16) shows the curves of load deflection relation where the dial gauge is located at the center of middle column, Figure (17) shows the curves of load deflection relation where the dial gauge is located at the edge of the specimen for recording the longitudinal displacement (Slipping), Figure (18) shows the curves of load deflection relation where the dial gauge is located at the center of the opening.

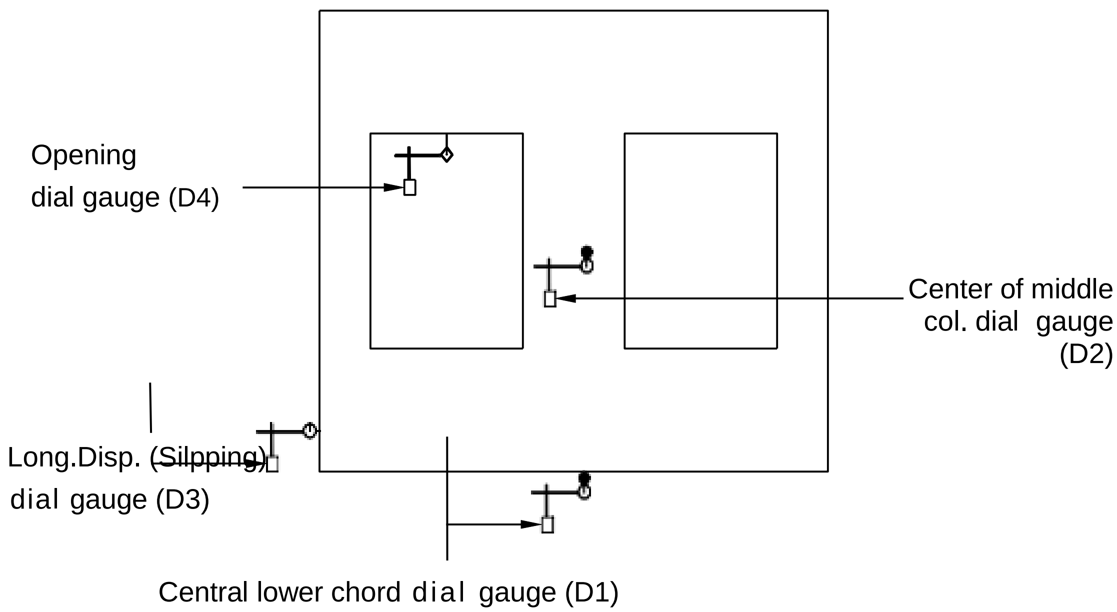


Figure 14. Dial gauges position

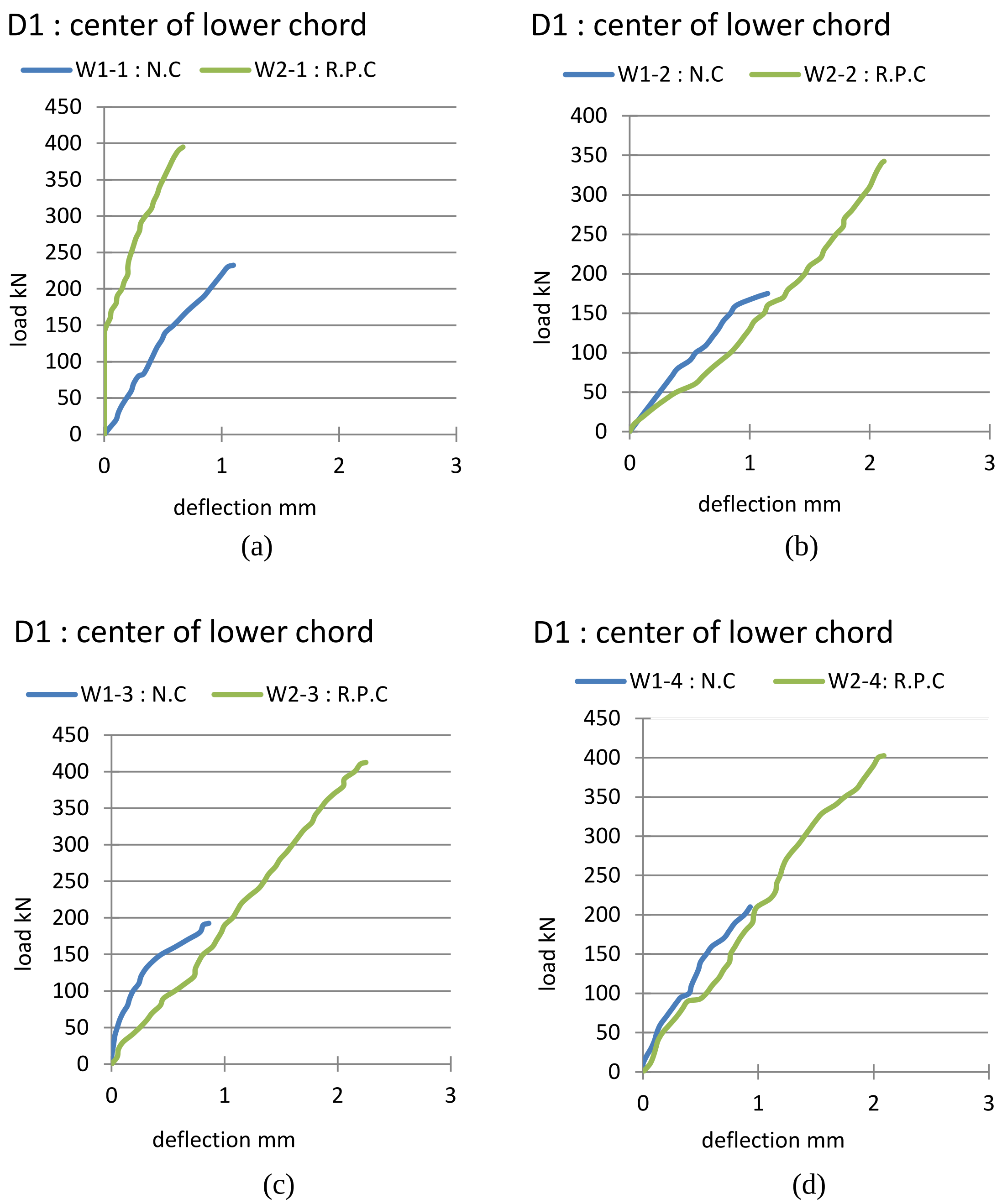


Figure 15. (a, b, c and d) shows the deflection at center of lower chord

For figure (15 a) W1-1&W2-1 shows linear curves and also W2-1 show linear curve but with small value of deflection compared with the W1-1

For figure (15 b) W2-2 shows linear curve and exhibited more ductility than W1-2. W2-2 shows high value of deflection.

For figure (15 c) W1-3shows linear curve but after the first crack load the curve change its curvature to non-linear.W2-3 shows linear curve and ductile failure behavior.

For figure (15 c) W1-4, W2-4 shows non- linear curves and W2-4 exhibited ductile behavior more than the others.

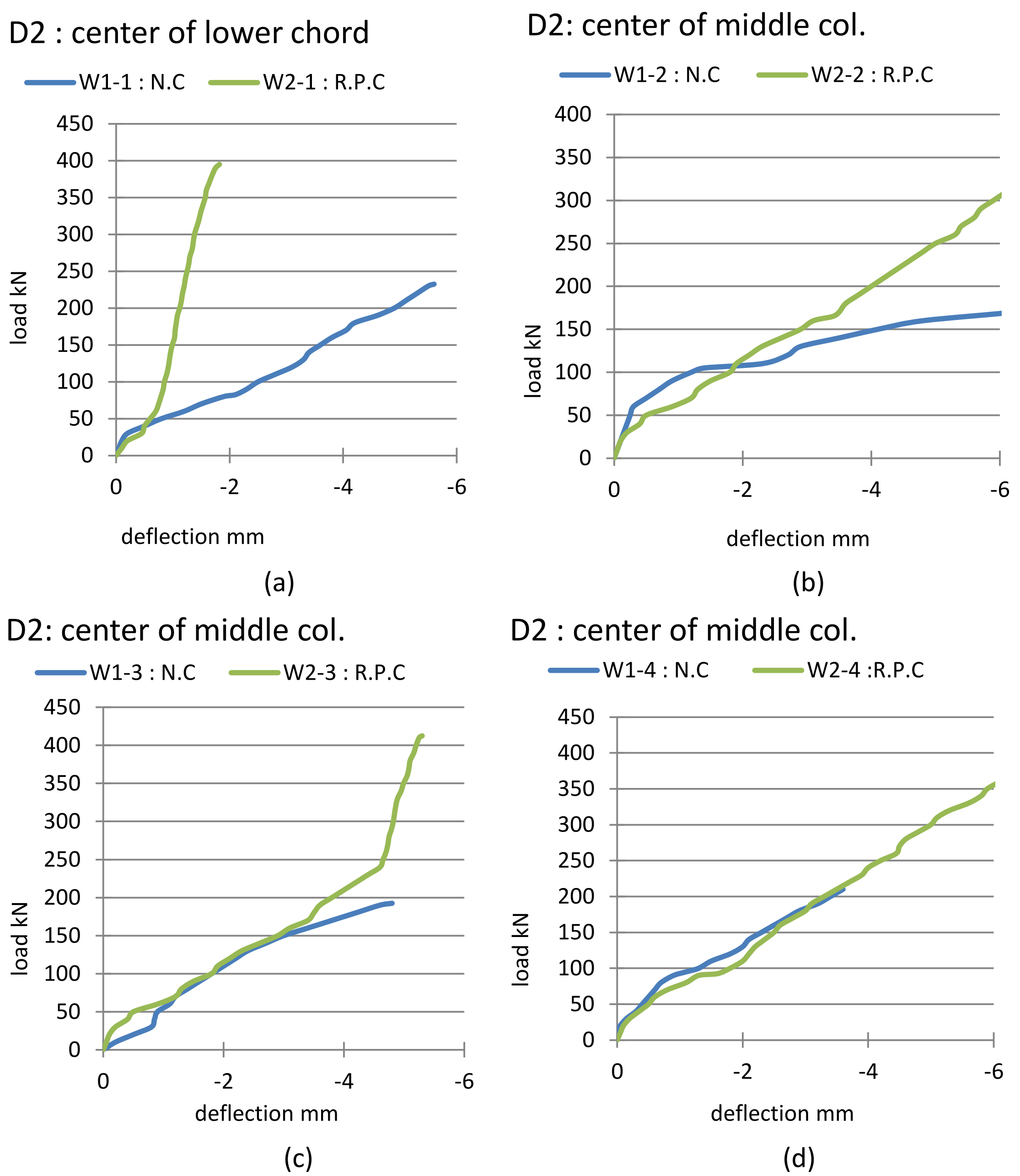


Figure 16. (a, b, c and d) shows the deflection at center middle col.

For figure (16 a) W1-1&W2-1 shows linear curve at beginning of test. W2-1 shows nonlinear curve and less deflection.

For figure (16 b) W1-2&W2-2 shows linear curves at beginning of test and then change its curvature after this point. W2-2 exhibited ductile behavior.

For figure (16 c) W1-3, W2-3 shows non- linear curve till failure but W2-3 at load about (250 kN) it change it is curvature severely and exhibited more ductility than other.

For figure (16 d) W1-4, W2-4 shows non- linear curves after the beginning of test. W2-4 exhibited ductile behavior reflected on the continuity of deflection value

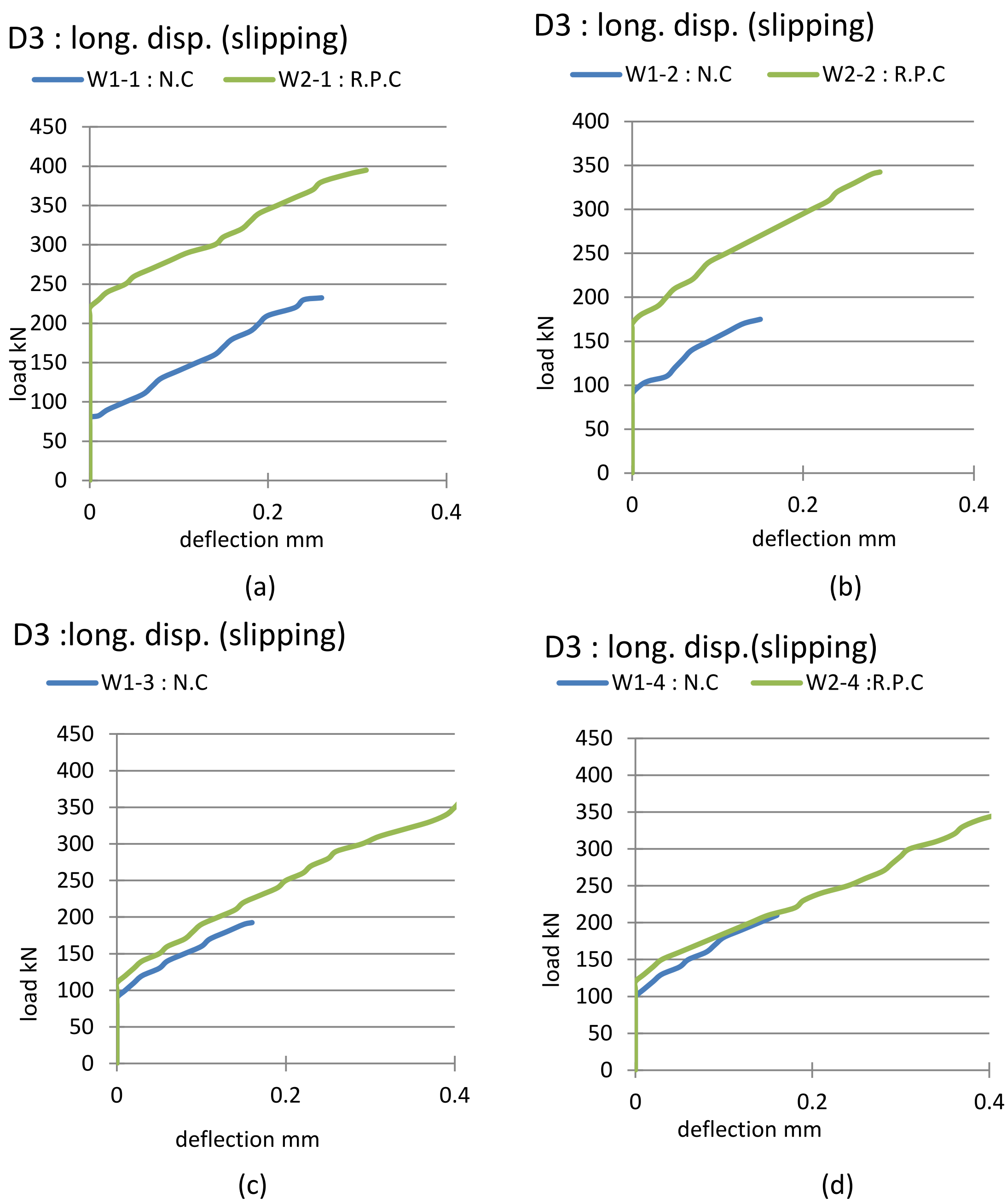


Figure 17. (a, b, c and d) shows the deflection at edge of specimen

For figure (17 a) W1-1, W2-1shows relatively linear curves and the dial gauge started to move after loading passes the first crack load. W2-1shows high value of slipping (long. Displacement). W1-1 failed before W2-1.

For figure (17 b) W1-2, W2-2 shows relatively linear curves. W2-2shows high value of slipping (long. displacement) due to high strength. Slipping started relatively after the first crack.

For figure (17 c) W1-3, W2-3 shows relatively linear curves. W2-3shows high value of slipping (long. displacement), which started relatively after the first crack happened.

For figure (17 c) W1-4, W2-4 shows relatively linear curves. W2-4shows high value of slipping (long. Displacement, which started relatively after with the first crack occurs.

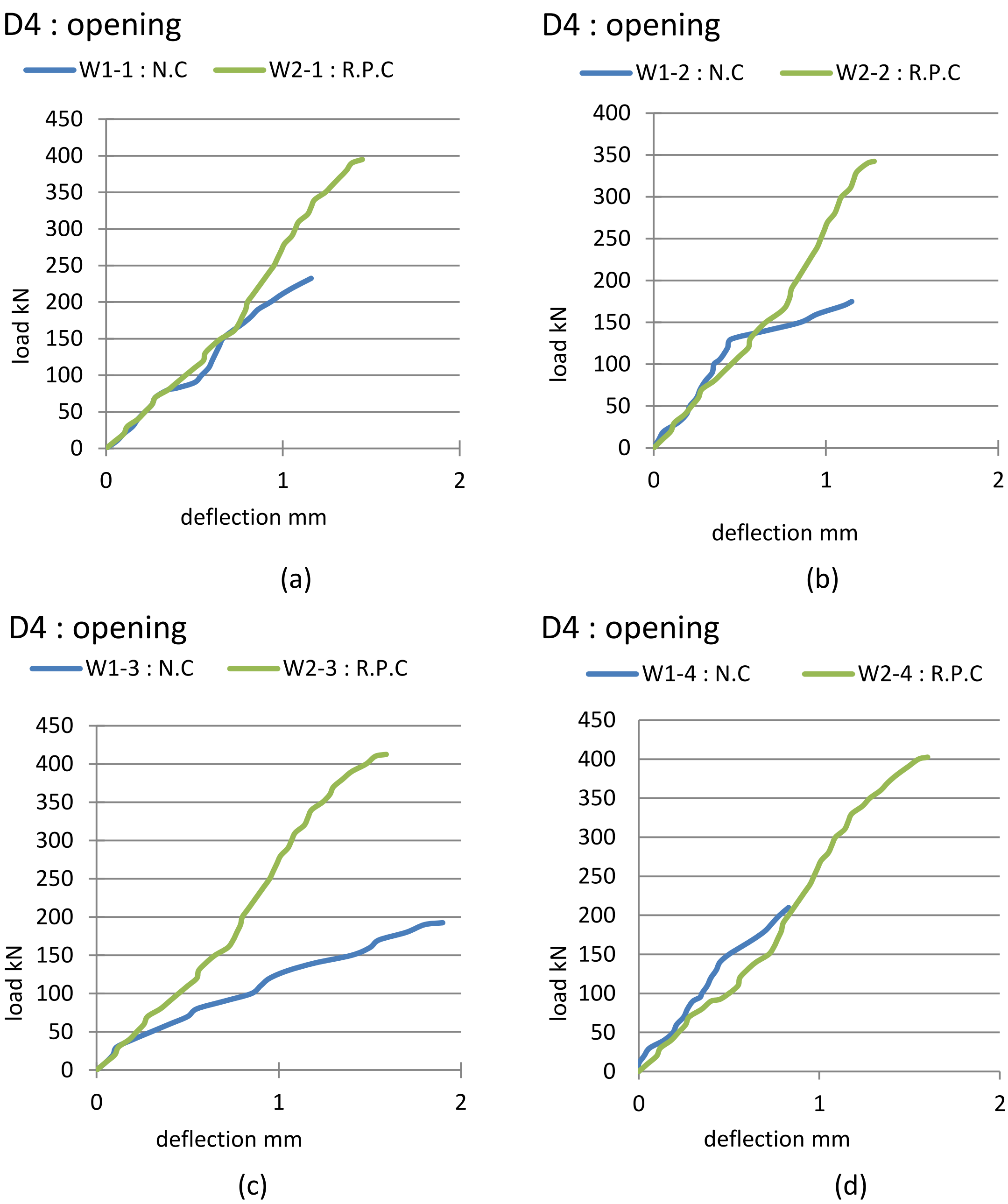


Figure 18. (a, b, c and d) shows the deflection of the opening

For figure (18 a) W1-1 shows relatively linear curve and after point of (100 kN) it change its curvature. W2-1 shows relatively linear curve and exhibited ductile behavior this reflected on the continuity of deflection.

For figure (18 b) W1-2 shows linear curve at the beginning of loading and then change its curvature, W2-2shows relatively linear curves and W2-2 shows high ductility.

For figure (18 c) W1-3&W2-3 shows linear curve at beginning of loading and then changed its curvature. W2-3 shows high strength.

For figure (18 c) W1-4, w2-4shows non- linear curves, W2-4 exhibited ductile failure behavior.

11. Mode of Failure

The modes of failure of R.C concrete wall specimens tested under axial eccentric distributed line load are:

1. W1-1, W1-2, W1-3and W1-4Cracking and crushing and bending in upper chord.
   W2-1, W2-2, W2-3and W2-4 Cracking and bending in upper chord
2. The panels were deflected in single curvature in vertical direction until the failure of specimens due to eccentric load applied.
3. Bending in the upper chord due to eccentric load and thus the columns were subjected to uniaxial action and this led to the curvature of columns (buckling).

12. Conclusions

From the previous paragraphs we concluded the followed:

1. The strength and the carrying load capacity for R.P.C. is more than N.C.
2. The cracking load (first crack load) of N.C are about (36-60) % of the failure load (ultimate load). The cracking load of R.P.C are about (23-54) % of the failure load.
3. The ultimate load of R.P.C group is more than the ultimate load for N.C for about (41-53) %.
4. The ratio of f'c between R.P.C and N.C is about (76) %.
5. R.P.C show high value of the failure load (ultimate load) than N.C and, this is because the existences of silica fume and a steel fiber in the mixture and that shows ductile failure behavior.
6. The addition of silica fume and very fine sand in R.P.C led to make the mixture dense and improve it is behavior to load and durability.
7. The main failure of the specimens were at joint between the upper chord and columns and the concrete is cracked and crushed in the compression face.
8. Cracks in tension face of columns of the specimens, and the cracks are non-straight. The cracks in the columns are more than the upper and lower chords.
9. In the lower chord, the flexural cracks appeared before and then shear cracks appeared after the continuity in loading.
10. The lower chord work as tension member and this lead to that the specimen work as truss and this is why the dial gauge which used in the bottom edge of the specimen (long. Displacement) recorded value of deflection.
11. The reason for cracks in tension face of columns is the bending moment formed due to eccentric axial load and the cracks increases with the increasing of load.
12. Cracks in the compression face of specimens appeared in the upper chord and started from the corner between the columns and upper chord and with 45', this is due to concentrating the stress at corners of the opening.

13. Abbreviations

R.C	Reinforced Concrete
ACI	American Concrete Institute.
R.P.C	Reactive Powder Concrete
N.C	Normal Strength Concrete
Dx	D: Dial gauge, x: number of dial gauge
Long. Disp.	Longitudinal Displacement
Wx1,x2	W: Wall Panel, x1: Number of Group, x2: Number of wall panel
Pu	Ultimate Load
Pcr	First Crack Load
Kg	Kilogram
lit	liter
m3	cubic meter
kN	Kilo newton

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