Experimental Investigation of High Strength Precast Reinforced Concrete Walls used (Vierendeel Truss Form)

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Abstract. This paper presents an experimental investigation to study the behavior of Vierendeel Truss used 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 the opening (300*350*75) mm which it is length, width, and thickness. The dimension of the R.C wall panel specimens was (1000*750*75) mm which they are length, width and thickness respectively and all the specimens contain 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 tested with uniformly distributed load with an eccentricity of (67.5) mm. The specimens were simply supported to represent the supports of the truss. The wall panels were divided into (2) groups, the first group is reactive powder concrete with (4) specimens and the second group is high strength self-compacted concrete with (4) specimens. The failure load, load–deflection curves crack pattern was studied.

All the panels were deflected in single curvature in the vertical direction of loading. Opening causes concentrated stress at the corners of opening and initiated the cracks and failure.

1. Introduction

1.1 Vierendeel Truss
In 1896 professor Arthur Vierendeel developed a rigid frame having rigid joints, this frame comprising from upper and lower chord with vertical members between the top and bottom chords. A Vierendeel truss is hyper static frame composed of a series of rectangular or trapezoidal panels without diagonal members. These types of frames depending on the rigidity of joints for stability. This type of trusses does not have the usual triangular voids which used in a pin joint, rather employing rectangular opening with a rigid connection in the elements, which unlike conventional truss must also substantial bending forces. Vierendeel 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. Vierendeel frames used in structural when the free space between the 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 (2) shows different types of Vierendeel truss and applications.
1.2 Self-Compacted Concrete

Self-compacting concrete (SCC) is a highly flow-able, non-segregating concrete that can spread into place, fill every corner of the formwork, and encapsulate the reinforcement without any mechanical consolidation or compaction and characterized by high resistance to segregation. SCC has also been described as self-placing concrete, and self-leveling concrete, which are all subsets of SCC. [2, 3]

Self-compacting concrete consists of the same components as conventionally vibrated normal concrete, which are cement, aggregate, water, and admixtures. However, the high amount of super-plasticizer for better workability, the high powder content as "lubricant" for the coarse aggregates [4].

1.3 Reactive Powder Concrete

Reactive powder concrete (RPC) is one of the latest and most important developments 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 [5]. 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 [6]. Owing to the fineness of silica fume and the increased quantity of hydraulically active components, it has been called reactive powder concrete [7].

2. Materials

RPC is a mixture of cement, silica fume, fine sand, high range water reducer, water and steel fibers without coarse aggregate. Self-compacted concrete contains the main compound of the mixture which it is cement, fine aggregate, and coarse aggregate and water but an amount of super-plasticizer which named commercially as Glenium 51 to enhance the workability. The materials were according to Iraqi specifications.

3. Mix Proportion

All the mix proportion was selected according to the previous researchers.

3.1. Reactive Powder Concrete

| Group No. | Cement Kg / m³ | Sand Kg/ m³ | Silica Fume % | Super-plasticizers % | Steel Fibers % | W/C ratio |
|-----------|----------------|-------------|---------------|----------------------|---------------|-----------|
| 3         | 1000           | 1000        | 15            | 6                    | 1             | 0.25      |

Silica fume by wt. = 150 kg/m³
Super-plasticizer by wt. = 69 lit/m³
3.2 High Strength Self-Compacted Concrete Proportion

Table 2. Shows the proportion of Self-Compacted concrete.

| Group No. | Cement Kg/m³ | Sand Kg/m³ | Gravel Kg/m³ | Silica Fume Kg/m³ | Superplasticizer Lit/m³ | Water Lit/m³ |
|-----------|---------------|------------|--------------|-------------------|-------------------------|---------------|
| 2         | 450           | 860        | 790          | 50                | 20                      | 150           |

4. Form Work

The form work used for casting the concrete of the wall panels was fabricated from rectangular timber planks named commercially as ply-wood with (20) mm thickness, this used for the bottom and opening. For the side of the form was made from the type of timber named commercially as jam. The sides of the form work were connected by screws, and these were connected with the bottom face by screw also, and the openings were connected by screws to the bottom face. Figure (2) shows Form work of the R.C Wall Panel Specimens.

Figure 2. Form work of the R.C Wall Panel Specimens.

5. Panel Designation and Dimensions

Panels are designated as (Wx1-x2); the number (x1) refers to the number of the group. Group 1 was for the normal strength concrete; group 2 was the high strength self-compacted concrete; group 3 was for the reactive powder concrete. The number (x2) refers to the number of the specimen within the group. Table (3) shows the group 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 cantilever portion on 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 a dimension of (350 * 300 * 75) mm with right angles. Figure (3) shows the dimensions of the wall panel’s specimens.
Table 3. Wall panels Designation and Dimensions.

| Group No. | Wall Panels | Length mm | Height mm | Thickness mm |
|-----------|-------------|-----------|-----------|--------------|
|           |             |           |           |              |
| Group 1   | W2-1        | 1000      | 750       | 75           |
|           | W2-2        | 1000      | 750       | 75           |
|           | W2-3        | 1000      | 750       | 75           |
|           | W2-4        | 1000      | 750       | 75           |
| Group 2   | W3-1        | 1000      | 750       | 75           |
|           | W3-2        | 1000      | 750       | 75           |
|           | W3-3        | 1000      | 750       | 75           |
|           | W3-4        | 1000      | 750       | 75           |

6. Steel Reinforcement
All the (8) wall panels specimen were reinforced with (8mm) as main reinforcement for the beam and columns and 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- code [8]. Figure (4) shows the reinforcement of the specimens.

Figure 3. Wall panel dimensions.  
Figure 4. Reinforcement of the R.C. wall specimens.

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.in Civil Eng. College of Al-Mustansiriya University as shown in figure (5). 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. The compressive strength was test by using this device, the average of (3) cylinders (150*150*300) mm was recorded in Table (4).
Figure 5. Testing of R.C wall panel specimens.

Table 4. Compressive Strength.

| Type of concrete | f’c MPa |
|------------------|---------|
| Reactive Powder Concrete | 112 |
| High Strength Self-Compacted Concrete | 70.2 |

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. [9]. 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 Ultimate load and ratio between them.

| Group | Wall panel | First crack load (Pcr) | Ultimate load (Pu) | Pcr/Pu*100% |
|-------|------------|-------------------------|--------------------|-------------|
| Group 1 | W2-1       | 92.5                    | 267.5              | 34.57       |
|        | W2-2       | 92.5                    | 262.5              | 35.23       |
|        | W2-3       | 95                      | 202.5              | 46.91       |
|        | W2-4       | 72.5                    | 157.5              | 46.03       |
| Group 2 | W3-1       | 210                     | 395                | 53.16       |
|        | W3-2       | 165                     | 342.5              | 48.17       |
|        | W3-3       | 100                     | 412.5              | 24.24       |
|        | W3-4       | 92.5                    | 402.5              | 22.98       |

9. Cracking Pattern
The crack patterns for typical specimens observed on the tension and compression face of the wall panels. All these photographs are taken for the panels after the 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.
10. Deflection Characteristics
Graphically, shows the load versus deflection profiles for R.P.C, S.C.C. During the test, the applied load and the corresponding deflections, at the mid center of the lower chord, the mid center of the middle column and the bottom edge of the specimen and 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 a rate with an increment of 10kN. Figure (15) shows the positions of dial gauges.
Figure 8. The position of dial gauges.

Figure 9. D1: centre of the lower chord.
Figure 10. D2: centre of the lower chord.
Figure 11. D3: long. Disp. (slipping).

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

1. Cracking and crushing and bending in upper chord
   - W1-1, W1-2, W1-3and W1-4 Cracking and bending in upper chord
   - W3-1, W3-2, W3-3and W3-4.
2. The panels were deflected in single curvature in the vertical direction until the failure of specimens due to the 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. Conclusion

- The cracking load of S.C.C is about (35-47) % of the failure load. The cracking load of R.P.C is about (23-54) % of the failure load.
- R.P.C show the high value of the failure load (ultimate load) than S.C.C; this is because the existences of silica fume and a steel fiber in the mixture and that shows ductile failure behavior.
- The addition of silica fume and very fine sand in R.P.C led to make the mixture dense and improve it is a behavior to load.
- For S.C.C specimens, the main failure of the specimens in this group is at the joint between the upper chord and columns. The concrete is cracked and crushed in the compression face. For R.P.C specimens, the main failure of the specimens in this group is at the joint between the upper chord and columns. The concrete in this point shows different behavior that in the S.C.C which the concrete in these specimens is cracked with little crushing of concrete because of the existence of steel fibers in the mixture. The steel fibers arrest the crack and enhance the ductility.
- Cracks in tension face of columns of the specimens and the cracks are non-straight. The crack in the columns is more than the upper and lower chords.
- In the lower chord, flexural cracks are appeared during the test and before the shear cracks appeared.
- 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.
- 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 the load.
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.

It should know that the panel W2-4, the frame during loading failed before it reaches its ultimate load.

References

[1] Raju, N. K., "Advanced Reinforced Concrete Design", CBS Publishers &distributers, First Edition, PP. 360, 1986.
[2] ACI Committee 237R-07, "Self-Consolidating Concrete”, Copyright by the American Concrete Institute, Farmington Hills, MI., First Printing, PP. 30, April, 2007.
[3] Neville, A.M., “Properties of Concrete”, Fifth and Final Edition, Wiley, New York and Longmont, London, PP.844, 2010.
[4] Dehn, F., Holschemacher , K. and Weihe D., "Self-compacting Concrete (SCC) – Time Development of the Material Properties and the Bond Behavior", The Laboratory for Combustion and Energy Research (LACER) No. 5, pp.115-123, 2000.
[5] Richard, P.and Cheyrezy, M., "Reactive Powder Concrete with High Ductility and 200-800 MPa Compressive Strength", ACI, SP144-24, pp. 507-518, 1994.
[6] Raj , J. and Jeenu, G., "Flexural Behavior of UHPC-RC Composite Beams", Proceedings of International Conference on Technological Trends (ICTT), College of Engineering, Trivandrum, India, 5 pp, 2010.
[7] Sadrekarimi, A., "Development of a Light Weight Reactive Powder Concrete", Journal of Advanced Concrete Technology, Japan Concrete Institute, Vol.2, No.3, pp.409-417, October 2004.
[8] ACI 318-08, "Building code requirement for reinforced concrete", American Concrete Institute, USA, 2008
[9] Macginley, T.J. and Choo, B.S., "Reinforced Concrete Design Theory and Examples ", Taylor & Francis e-Library, Second Edition, 2003.