

Structural Behavior of Hollow Reinforced Concrete Beams: A Review

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ARTICLE INFO

Article history:

Received 31 August 2020

Accepted 2 November 2020

Keywords:

Hollow beams; Sustainability; Concrete reduction; CO₂ emission; Structural behavior

ABSTRACT

This paper reviews some experimental and numerical results about the hollow reinforced concrete beams (HRCB). Any subtraction in concrete quantity within the structural members without a considerable lack in load carrying capacity represents a common research trend nowadays due to the decrease in sections dimensions, reinforcing steel and lateral inertia forces in severe earthquakes as well as the sustainability gain for the resulting inhibiting of CO₂ emission. In addition, the possibility of passing the electrical and mechanical facilities comprises another good feature of such type of structural members. During the traditional beam design process, the tension concrete is considered as strain transfer agent and do not have any role for structural resistance. As a result, longitudinal holes can be made within this area to produce the hollow reinforced concrete beams (HRCB). In this paper some remarkable research works are summarized with the most important conclusions within this field.

1. Introduction

As a matter of fact, concrete has a relatively high specific gravity, as a consequence, most of the dead weight that carried by the reinforced concrete structural member is the self-weight. This represents a rather bulky and heavy loads to the foundations. In this way, practices like using light weight concrete and suitable cross sections like I and U beams represents a good solution.

In addition, the facility functional performance and users' comfort of many services within civil engineering projects require engineering divisions. Such divisions are usually containing ducts, pipes and wires which are of plumbing, electrical and cooling / heating systems. More precisely, when these services are congested in one place or linked to zones out of building edges, many shortcomings are becoming serious like aesthetic lake and

long-term performance due to the environmental exposure.

On the other hand, many of civil engineering structural designers do not consider this issue in their design, so, seeking for a good suitable alternative solution is very justified to overcome the relevant problems. As a consequence, the researchers are motivated to include such members in their scientific programs [1].

In addition, there are many modern needs in reinforced concrete buildings have to be achieved simultaneously within the same structural members as well as the structural integrity. The hollow reinforced concrete beam (HRCB) is a representative example within this context, such beam is usually constructed by making a longitudinal hole and casted in site or pre casted. This study introduces a brief review about the past experience studies which included such type of beams.

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DOI: 10.24237/djes.2020.13411

2. Research significance

The proper implementation of hollow reinforced concrete beams is a very important issue in the civil engineering construction for both strength and service ability requirements, moreover, increasing the reliable experimental experience about such type of structural members is very useful and justified.

Due to all above, designers, organizations and authors are still having many reasons to understand the performance of such type of beams, therefore, this study attempts to view the current state of art about this field.

2.1 Advantages of HRCB

The following are some advantages of using HRCB:

1. Presence of holes means that many facilities can be pass through it and be protected against enviromental exposure.
2. A considerable amount of concrete volume can be subtracted.

As a result of facilites wire removal, a good aesthetic level can be reached.

3. Scientific research data for HRCB

As a matter of fact, the recent contributions discussed the matter of HRCB structural behavior with respect to load deflection curves and the consequent load carrying capacity as well as the first cracking loads. It is argued that any new innovation within this field of research cannot be done without a comprehensive review about this field, thus the following are the most known scientific experience within the scope of HRCB:

Altun, et al., (2006) [2] concluded that the steel fiber reinforced box section beams can be used effectively as an alternative to solid section reinforced concrete especially for large – span structures. That contribution established such conclusion based on the fact that the reduction in dead weight will be shown as reduction in static moments and the relevant earthquake loads on structural members.

The sections details of Altun, et al. experimental program is shown in Fig. 1.

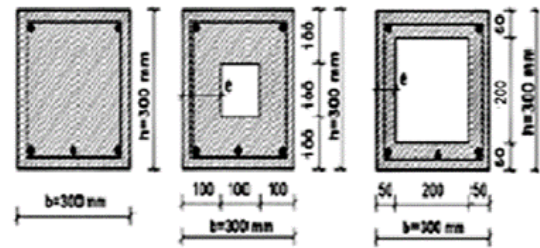


Fig 1. Section details of HRCBs box beams [2]

An experimental curve was presented to correlate the ratio of (actual ultimate load) / (theoretical ultimate load) and the ratio of (wall thickness)/ (beam height) for the steel fiber reinforced concrete (SFRC) box beams as shown in Figure (2).

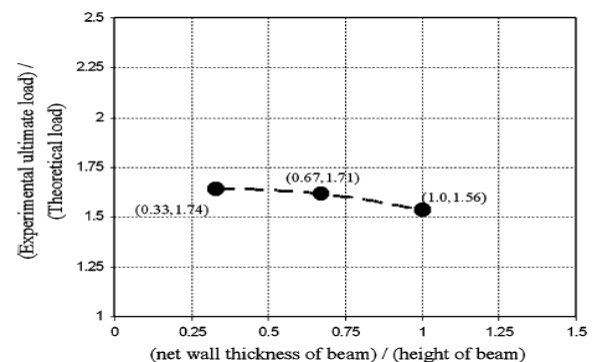


Fig 2. The correlation of (experimental ultimate load)/ (theoretical ultimate load) with the ratio of (net wall thickness)/ (outer beam height) [2]

In addition, the average reduction in ultimate load capacity and the calculated concrete reduction by volume are listed in Table 1.

Table 1 Box HRCBs results summary [2]

Type of Beam	Ultimate load capacity decrement	Concrete reduction per unit length
100 x 100 mm hole	1%	11.11%
200 x 200 mm hole	29%	44.44%

Alshimmeri and Al-Maliki, (2014) [3] deduced experimentally that increasing the shear reinforcement reduces the relevant deformations for each stage of load especially at initial stages. Such reinforcement enabled the concrete cover spalling down to be avoided if its quantity is doubled.

The implemented experimental program was devoted to rectangular HRCB under partially distributed load. The dimensions are shown in Figure (3).

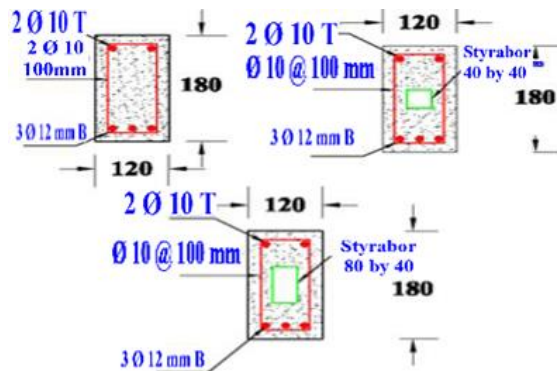


Fig 3. Section details [3]

Moreover, the reported decrement in the ultimate load capacity and the calculated concrete reduction by volume are listed in Table 2. The case of avoiding compressive concrete spalling out is shown in Figure (4).

Table 2 Results summary of HRCBs [3]

Type of Beam	Ultimate load capacity decrement	Concrete reduction per unit length
40 x 40 mm hole	37.14%	7.4 %
40 x 80 mm hole	58.33%	14.8 %



Fig 4. Double quantity shear reinforcement specimen (Concrete cover spalling down are avoided) [3]

Joy and Rajeev (2014) [4] figured out that the HRCBs with hollow axis illustrate flexural behaviour similar to the conventional beams. That conclusion was established due to the low loss levels in ultimate load capacity as shown in Table 3.

The conducted experimental research was devoted investigate the effect of circular holes to rectangular HRCBs, the holes were made my installing PVC pipes along the entire beam

length with 40 and 50 mm in diameter respectively as shown in Figure (5).

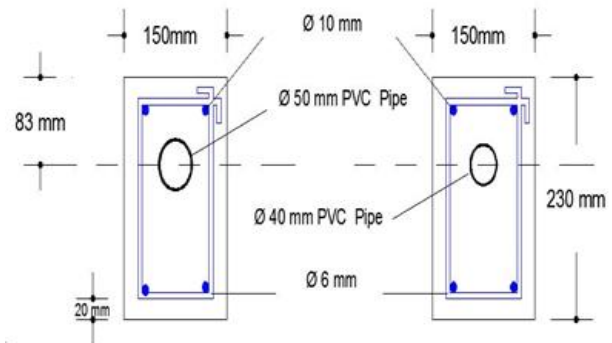


Fig 5. Section details of HRCBs [4]

Additionally, the loss in ultimate load capacity and the calculated concrete reduction by volume are listed in the results summary in Table 3.

Table 3 Results summary of HRCBs [4]

Type of Beam	Ultimate load capacity decrement	Concrete reduction per unit length	First crack load decrement
40 mm diameter	2.64 %	3.6 %	6.52 %
50 mm diameter	3.54 %	4.6%	7 %

Manikandan, et al., (2015) [5] concluded that the deflection at yield and ultimate stages are similar for circular hole HRCBs and solid section beams while the rectangular HRCBs illustrated lower levels of such behaviour.

The section dimension was (150 x 200) mm and the rectangular hole was (64 x 70) mm while the circular hole was of 70 mm in diameter as shown in Figure (6).

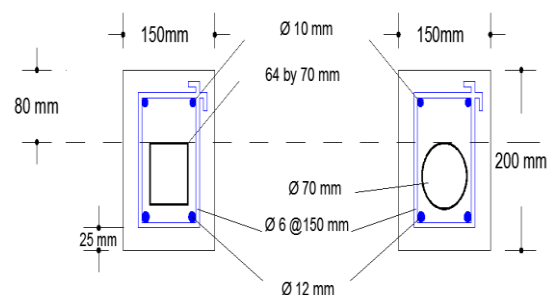


Fig 6. Section details of HRCBs [5]

However, the reported decrement in the ultimate load capacity and the calculated concrete reduction by volume are listed in Table 4. The load mid span deflection response is shown in Figure (7).

Table 4 Results summary of HRCBs [5]

Type of Beam	Ultimate load capacity decrement	Concrete reduction per unit length
Rectangular	14.93 %	6.96 %
Circular	14.72 %	2.6 %

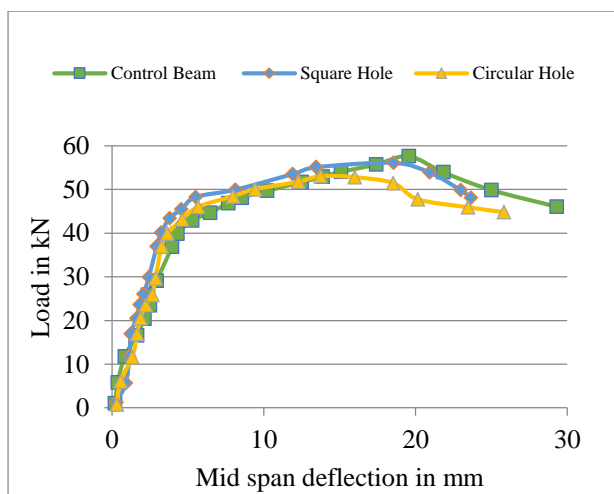


Fig 7. Load – Mid span deflection of HRCBs [5]

Varghese and Joy (2015) [6] deduced that the optimum depth of hollow core is 160 mm from extreme fiber of compression which is just below the neutral axis. The sections dimensions were (200 x 300) mm. Additionally, the depths of holes centre lines were taken as 120, 160, 200 and 240 mm from extreme fiber of compression and the holes as shown in Figure (8).

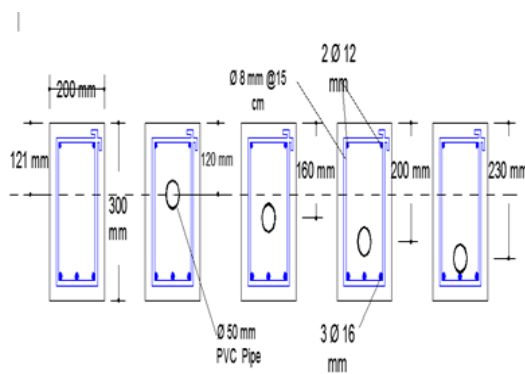


Fig 8. Section details of HRCBs [6]

Accordingly, the calculated concrete reduction by volume level was 3.27 %. The reported ultimate load capacity is listed in Table 5.

Table 5 Results summary of HRCBs [6]

Type of Beam	Ultimate load in kN
Reference	224
Depth of hole = 120 mm	251
Depth of hole = 160 mm	271
Depth of hole = 200 mm	254
Depth of hole = 240 mm	251

Jabbar, et al., (2016) [7] inspected the effect of transvers openings presence to the structural response of HRCBs numerically. ABAQUS software was used to implement a three-dimensional finite element analysis. The selected section had dimensions of (600 x 600) mm as shown in Figure 9.

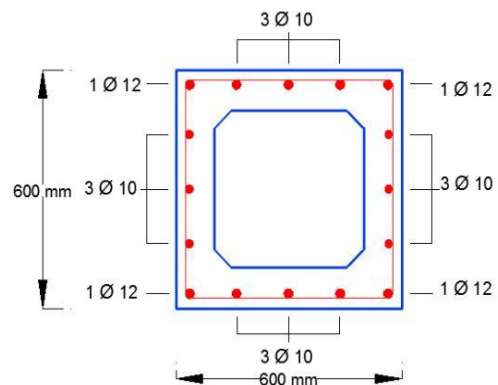


Fig 9. Section details of HRCBs [7]

Moreover, the transvers openings within the same beams were taken as (100 x 100) mm, (200 x 200) mm and (300 x 300) mm as shown in Figure (10).

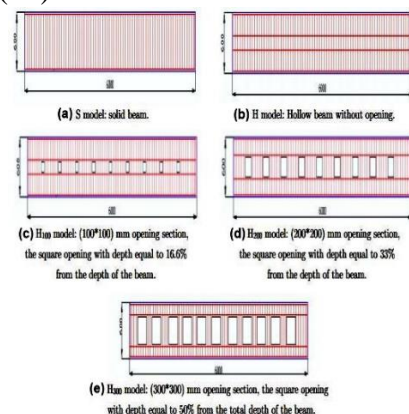


Fig 10. Transvers details of HRCBs [7]

In addition, the behavior of beams with transvers openings was compared both to solid reference beam as well as to hollow beam without transvers openings. However, the reported ultimate load capacity is listed in Table 6.

Table 6 Results summary of HRCBs [7]

Type of Beam	Loss in ultimate load
Without transvers openings	24.8 %
Transvers openings of x (100 x 100) mm	24.2 %
Transvers openings of x (200 x 200) mm	30.5 %
Transvers openings of x (300 x 300) mm	49 %

Soman and Anima, (2016) [8] stated that there is no significant reduction in load capacity can be observed if the circular hole made immediately under the natural axis. The section dimensions were (150 x 200) mm and the holes sizes are 25, 50 and 75 mm respectively as shown in Figure (11).

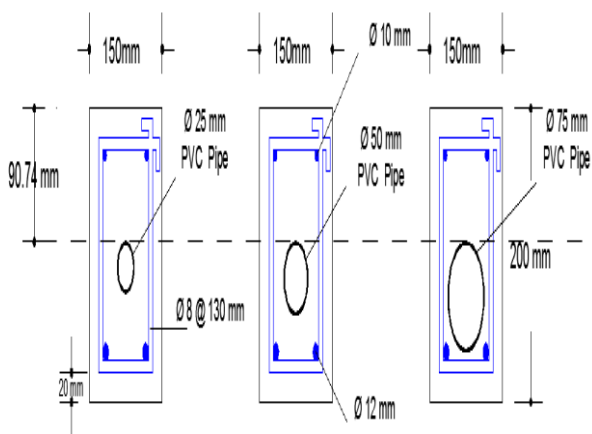


Fig 11. Section details of HRCBs [8]

It is observed through that study that there is an increase in the ultimate load capacity for all hollow beams if compared with the reference beam due to the mechanical properties of PVC pipes. The reported increment in the ultimate load capacity and the calculated concrete reduction by volume are listed in Table 7.

Table 7 Results summary of HRCBs [8]

Type of Beam	Ultimate load capacity increment	Concrete reduction per unit length
Hole diameter = 25 mm	20.14 %	4 %
Hole diameter = 50 mm	88.34 %	8 %
Hole diameter = 75 mm	42.88 %	16 %

Abdul Jabbar, (2017) [1] conducted an experimental program in term of HRCBs strengthened by carbon fibre polymer (CFRP) in order to investigate the effect of transverse openings. All the beams were of (150 x 250) mm and the longitudinal holes were of (50 x 50) mm and more than one longitudinal position was tested as shown in Figures (12, 13 and 14).

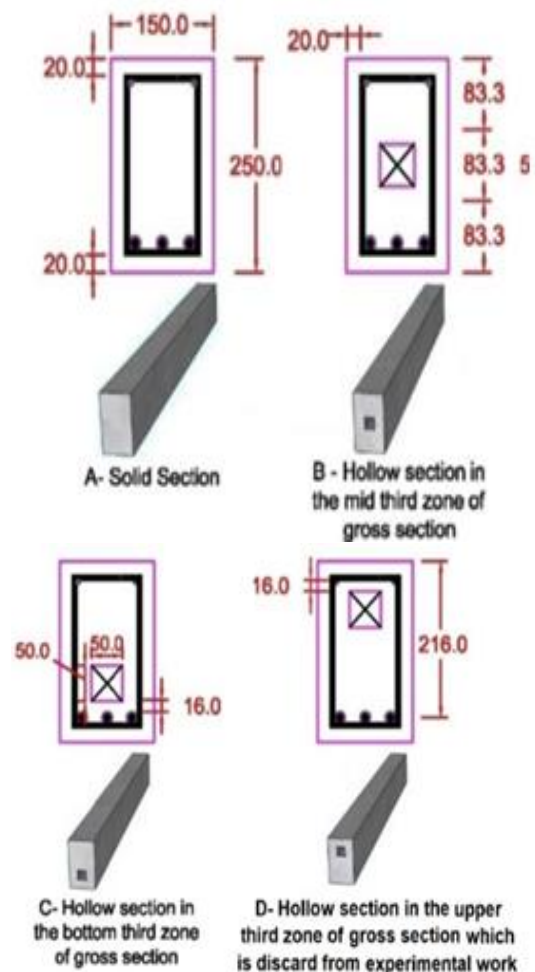


Fig 12. Beams dimensions of HRCBs [1]

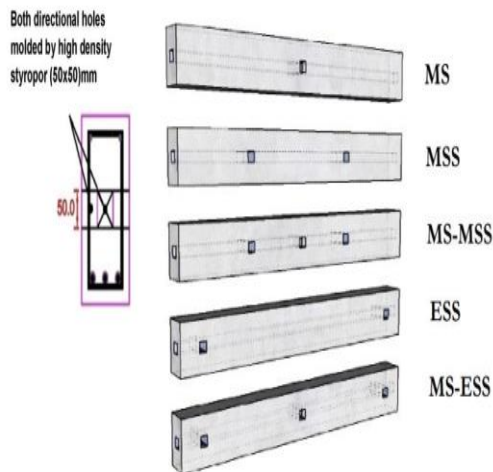


Fig 13. Different holes fashions of HRCBs [1]

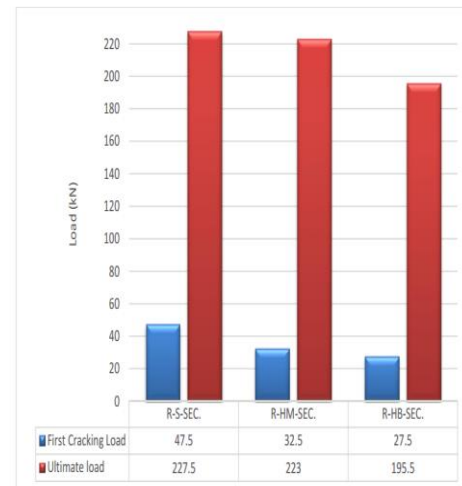


Fig 15. The effect of longitudinal holes to Ultimate and first crack load of HRCBs [1]

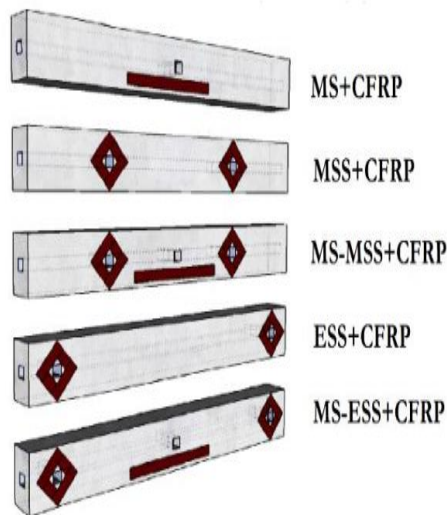


Fig 14. Different CFRP fashions of HRCBs [1]

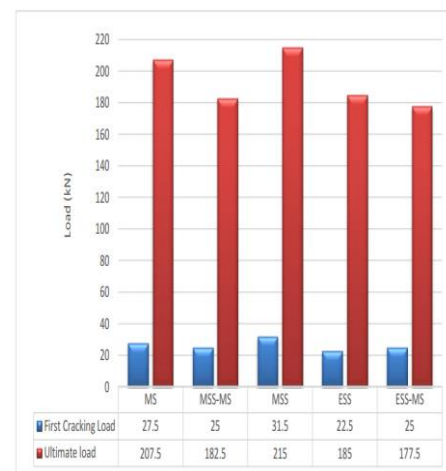


Fig 16. The transvers holes effect to Ultimate and first crack load of HRCBs [1]

The results revealed that the mid and bottom holed beams showed a reduction 2 % to 14 % in ultimate load capacity as shown in Figure (15). Additionally, such capacity is increased 3.16 % by the presence of two transvers holes at span thirds as shown in Figure (16). The beam that has two ends that strengthened by CFRP illustrated an increment of 6.12 % of such capacity as shown in Figure (17).

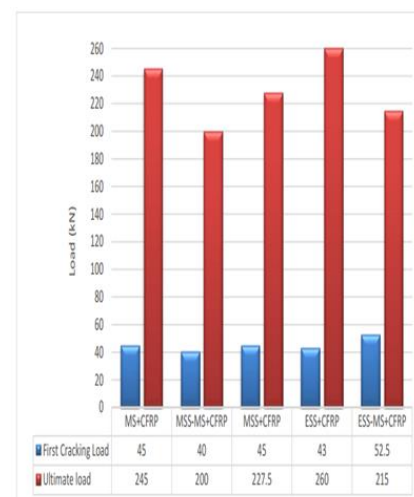


Fig 17. The CFRP strengthened transvers holes effect to Ultimate and first crack load of HRCBs [1]

Abdul-Razzaq, et al., (2017) [15] deduced that the flexural behavior of deep beams with openings are highly dependent upon interruption degree of compressive strut as a strengthening technique. The cross section of all tested specimens was of (100 x 400) mm while the span length was 1000 mm. The web openings were square, circular, and rectangular. Figure (18) shows the circular openings beams with and without strengthening while Figure (19) shows the results of that group of beams.

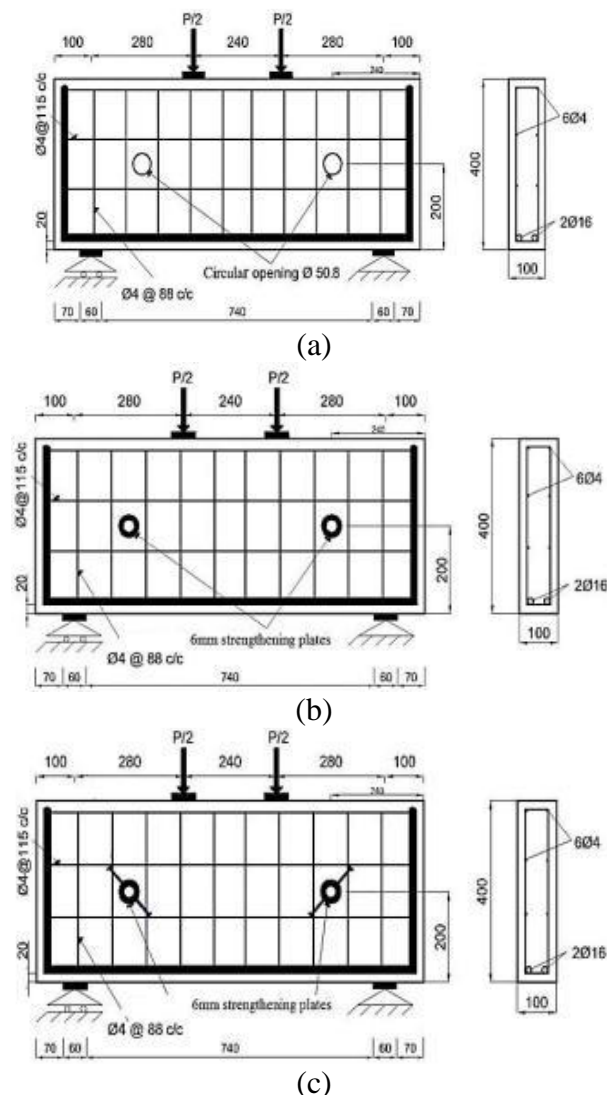


Fig 18. Details for the circular openings [15]: (a) beam with unstrengthened circular openings. (b) beam with circular openings strengthened via plates. (c) beam with circular openings strengthened via plates and studs

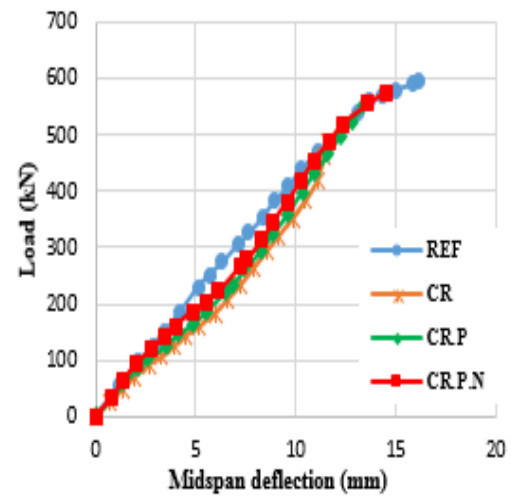


Fig 19. Results summary for the circular opening's beams [15]

Parthiban and Neelamegam, (2017) [9] investigated the effect of circular holes numbers to the rectangular HRCBs structural behavior. The holes made were 1 hole of 50 mm diameter, 2 holes of 25 mm in diameter and 3 holes of 12 mm in diameter while section dimensions were (150 x 200) mm as shown in Figure (20).

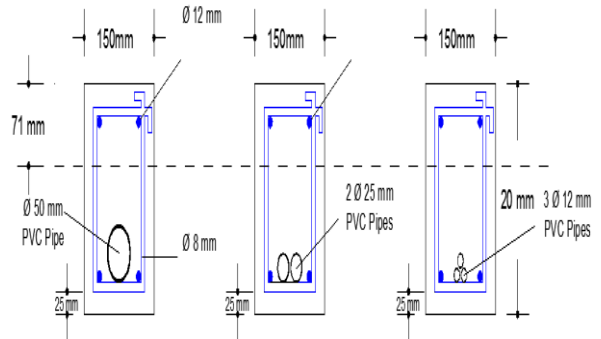


Fig 20. Section details of HRCBs [9]

Furthermore, the calculated concrete reduction by volume were 6.54, 3.27, 1.13 % and. The reported ultimate load capacity is 49, 88, and 70 % as listed in Table 8. It is believed through that study that such reduction in ultimate load capacity is the stress concentrations in the remaining concrete section and the lack in flexural rigidity.

Table 8 Results summary of HRCBs [9]

Type of Beam	Ultimate load capacity in kN	First crack load in kN	Concrete reduction per unit length
Control beam	113	70	/
1 hole of 50 mm in diameter	70	49	6.54 %
2 holes of 25 mm in diameter	128	88	3.27 %
3 holes of 12 mm in diameter	113	70	1.13 %

Abdul-Razzaq and Abdul-Kareem, (2018) [16] concluded that flange circular single opening within T beams has the maximum decrease in ultimate load capacity. The beams have an overall depth of 300 mm, an effective flange width of 390 mm and a 130 mm web width while the length was 2500 mm. Figure (21) shows the details of the single opening beam while Figure (22) shows the load – strain diagram of that beam.

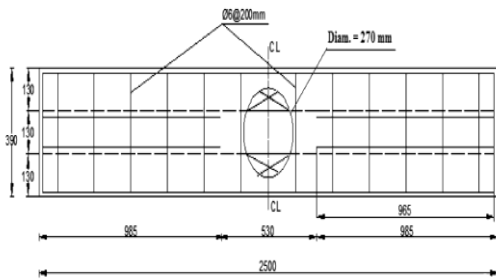


Fig 21. Single opening flange specimen details [16]

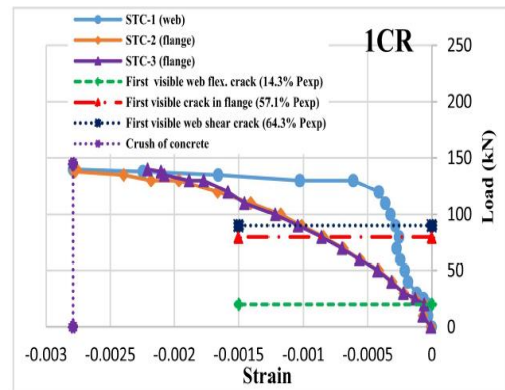
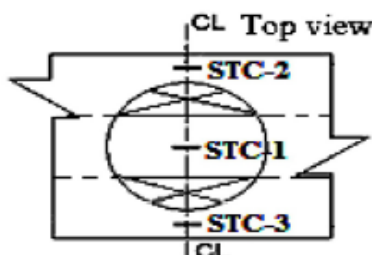


Fig 22. Single opening flange specimen results [16]

Murugesan and Narayanan, (2018) [10] implemented an experimental program to investigate the deflection diagram of rectangular HRCBs with different diameters and holes depths. All beams were of (150 x 250) mm while the diameters taken were 25, 40 and 50 mm and the depth of the circular holes center were taken as 45, 55, 65 and 180 mm below extreme fiber of compression as shown in Figure (23).

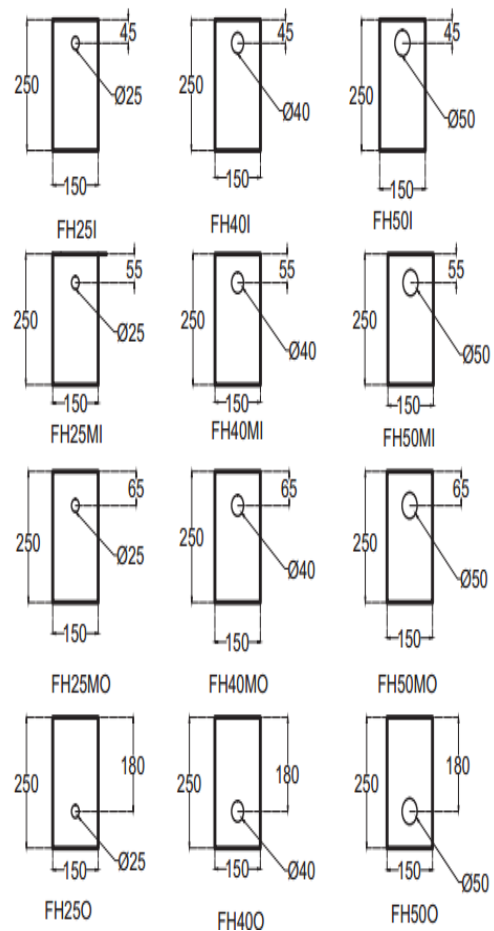


Fig 23. Section details of HRCBs [10]

More precisely, the reported reduction in concrete volume were 1.31, 3.35 and 5.23 % respectively, the structural behavior was characterized with respect to load mid - span curves, the deflected shapes of beams and a relation between two values, the first was the ratio of the deflection of hollow beams to that of solid $\frac{\delta}{\delta_s}$ and the other was the product of hollow portion area (A_h) by the distance from support to point load (a').

The results of that research program reveals a distinct behavior in load deflection curves, such behavior summarized by a linear portion of these curves at the first stage of loading till the first crack load (point A), then the curves illustrate curveliner behavior (point B) as shown in Figure (24). While Figure (25) shows the relation between δ / δ_s versus $A_h \times a'$ discussed above.

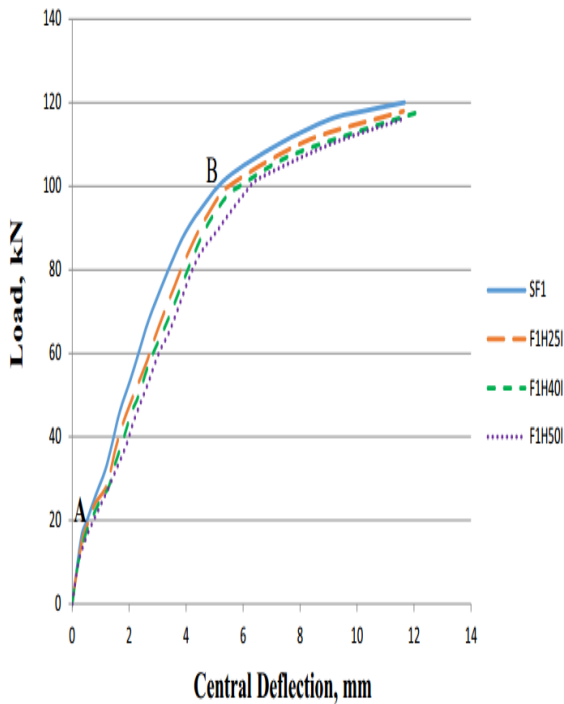


Fig 24. Deflection curve of HRCBs [10]

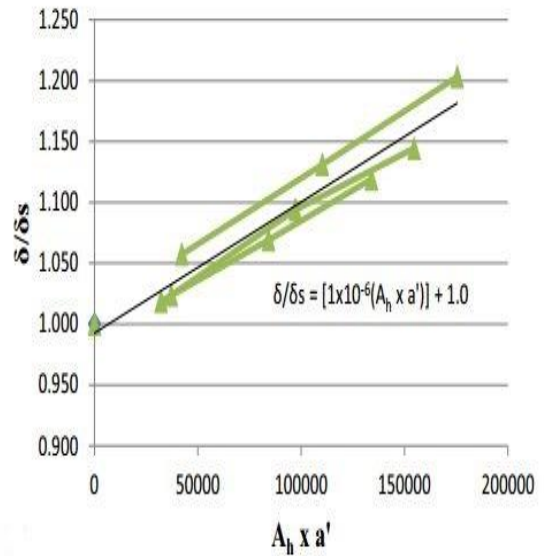


Fig 25. Results of HRCBs [10]: relation between δ / δ_s versus $A_h \times a'$

Sariman and Rahil (2018) [11] investigated the structural performance of HRCBs of apparent and neutral Tee section, the holes were made by installing 50 mm PVC pipes longitudinally along the entire length of beams as shown in Figure (26). It is deduced through that study that the stiffness of the neutral T beam is better than the apparent T beam.

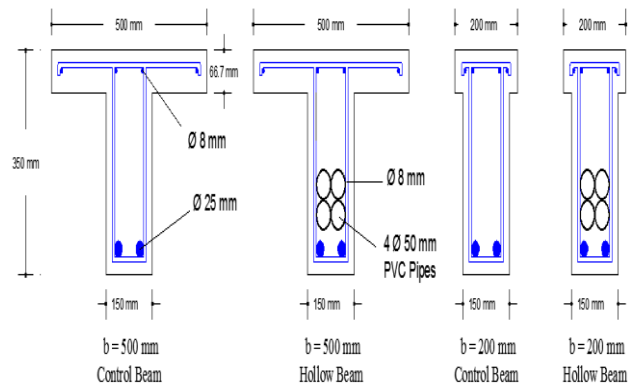


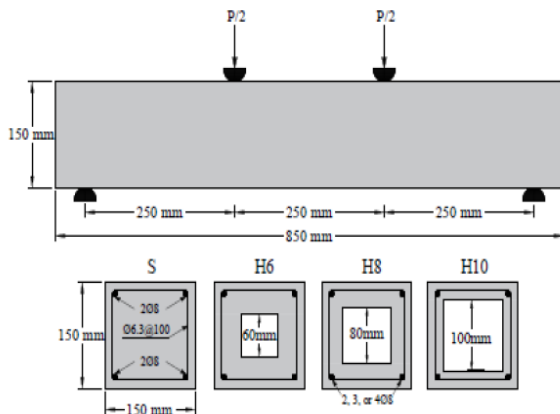
Fig 26. Section details T HRCBs [11]

Moreover, the reported decrement in the ultimate load capacity and the calculated concrete reduction by volume are listed in Table 9.

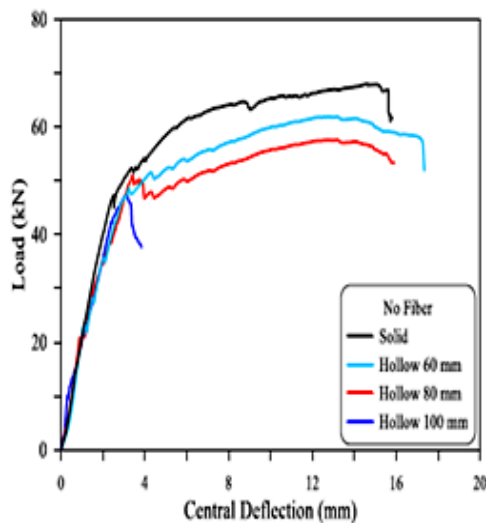
Table 9 Results summary of T HRCBs [11]

Type of Beam	Ultimate load capacity decrement	Concrete reduction per unit length
Apparent	1.71 %	10.36 %
Neutral	1.55 %	14.07 %

Abbass, et al., (2020) [12] implemented an experimental program to investigate the behavior of rectangular high strength HRCBs. Section dimensions were (150 x 150) mm and the holes dimensions (60 x 60) mm, (80 x 80) mm and (100 x 100) mm as shown in Figure (27). The relevant concrete reduction was 16, 28.4 and 44.4 %.

**Fig 27.** Beams details [12]

The results of intended study showed that the peak load and yielding increased as the size of holes decreased as shown in Figure (28).

**Fig. 28.** HRCBs results [12]: Load – central deflection

4. Conclusion

The following conclusions can briefly summarize as bellow:

1. In general, the presence of longitudinal holes within the reinforced concrete section causes a consequent increase in flexural performance.
2. The relevant lack in flexural performance are represented by the lack in ultimate load capacity, early cracks propagation and / loss in stiffness and ductility.
3. The stiffness of the neutral T beam is better than the apparent T beam.
4. It is deduced that making longitudinal hole just below the neutral axes of beams is the best choice for implementing such structural members.
5. Most of the recent research contributions were devoted to rectangular HRCB and it is suggested that scientific contributions should be directed to Tee HRCBs..
6. There is a noticeable lack in the literature about HRCB Tee sections.
7. The structural behavior of HRCB is characterized mostly with respect to first crack load levels, ultimate load capacities, and the load -mid span deflection behavior.
8. It is also recognized that a few research was devoted to propose regressive formulas to correlate the main component of HRCB and its structural behavior criterions.
9. It is argued that another research should be conducted in term of numerical modeling to investigate the structural behavior of HRCB.

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