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Effects of Longitudinal and Transverse Direction Opening in Reinforced Concrete Beam: The State of Review

Dinesh KannaM[1], Arun M[2]

[1]UG Student and [2]Associate Professor,
Department of Civil Engineering, PSG Institute of Technology and Applied Research,Coimbatore - 641 062, Tamil Nadu, India.

arun@psgitech.ac.in

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Abstract The implementation of hollow cores in beams is getting popular nowadays because of its practical advantages. The reduction of disadvantages in the beams with an opening is based on the engineers' knowledge and practical experiences too. Most of the researchers have started to learn about the hollow beams and also, the strengthening of these beams. Based on the reviews on various journals in the field of hollow beams, this article investigates the effect of shape, size, and position of opening and reviews the strengthening of hollow beams. Finally, it brings a judgment with the suggestions to provide hollow beams and the future scope for the research in the area of hollow beams.

Keywords size of opening; shape of opening; longitudinal and web opening; reduced stiffness; strengthening of beams.

1.INTRODUCTION

Millions of Reinforced Concrete (RC) components are being built in the construction industry all over the world every year. The basic amenities and additional facilities of water supply and sewage services, electricity, telephone and air conditioning vents are to be provided in the structures. In the modern construction era, the provision of opening is unavoidable to accommodate these essential utilities in RC beams at longitudinal and/or transverse directions. The provision of opening in beams will result in the reduction of self-weight of beams. Consequently, the prerequisites size of other structural members that support these beams will be reduced, leading to the saving in the construction materials and cost (Arun Murugesan and ArunachalamNarayanan [37,38]. Many researchers have reported on the behavior of steel beams, composite beams, and pre-stressed beams with openings in the transverse direction. A lot of research works have been taken in the area of RC beams with openings in the longitudinal and transverse direction. The majority of the work focuses on the strength characteristics and behavior of beams with openings in terms of Flexure, Shear, Flexure-Shear, Pre-cracking, and post-cracking deflection, crack width, external and internal strengthening separately with various types of loading condition. This paper explores the effect of opening, optimum shape, size, and position of the opening in reinforced concrete shallow beams without strengthening, various strengthening techniques preferred by different authors.

2.EFFECTS ON SHAPE OF THE OPENING

M.A. Mansur and Kiang-Hwee Tan [35] considered the most common simple shapes as openings from the study of Prentas. H. Madkour [31] has found that the reduction in ultimate loads and increased deflection, when the openings of large rectangular shapes located in shear zones. BengiAykac et al., [10] have compared their experimental results with another research consisting of triangular openings. The results indicated that the beams with circular openings have more load carrying capacity than square and triangular openings under all types of tensile reinforcement groups (lightly, moderately, and heavily reinforced). J.H. Ling et al., [30]said that the beams with circular openings offer 8% higher strength than the square openings. SoroushAmiri and Reza Masoudnia [9] analyzed the effects of opening on the behavior of concrete beams and their results showed that the circular openings had achieved 9% more ultimate load carrying capacity while compared with equivalent square opening. They reported that because of the existing corners in the square openings, the reduction of ultimate load carrying capacity is increased more than the circular openings. Saeed Ahamed Al-Sheikh [7] compared the reduction in ultimate loads between the various shapes of openings in beams and said that the reduction of the circular, square and rectangular openings are about 1%, 19%, and 23% respectively, and the reduction in load capacity between circular and equivalent square opening is about 8%. When the rectangular and square opening of the same height is compared, the results show that the Rectangular opening had a reduction in ultimate load of 3 - 4% more when compared to square opening.

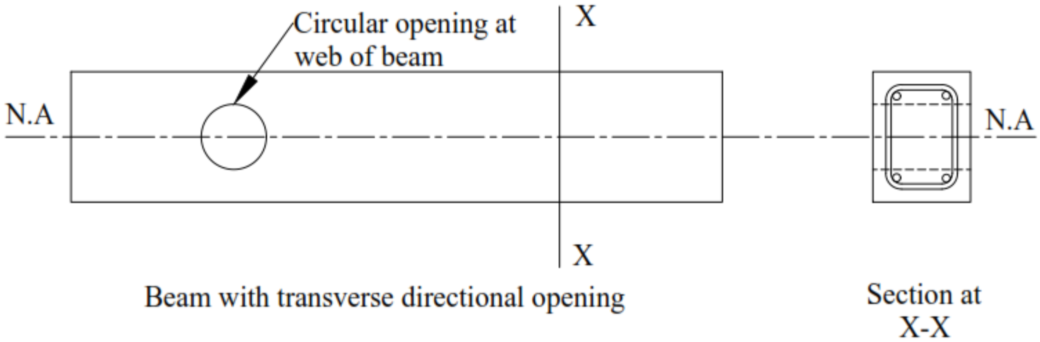


Figure 1. Beam with transverse opening

G. Balaji and R. Vetturayasudharsanan [11] investigated RC beams with circular openings and concluded that the Hollow beams had better ductility and less deflection at yield stage than control beams. Jain Joy and Rajesh Rajeev [28] recommended that the beams having longitudinal circular hollow core sections carried more loads because it avoids sharp edges. Jeyakumar et al., [27] said that the beams with circular openings had 9.58% more strength than beams with square openings. S. Manikandan et al., [33] experimentally investigated and observed that the hollow beams with circular openings had the same similarities of control beams in the ductility behavior, deflection at yield and flexural strength characteristics. Saif A Hassan et al., [24] concluded that the failure mode changes with respect to the position and number of openings because of the provision of circular opening.

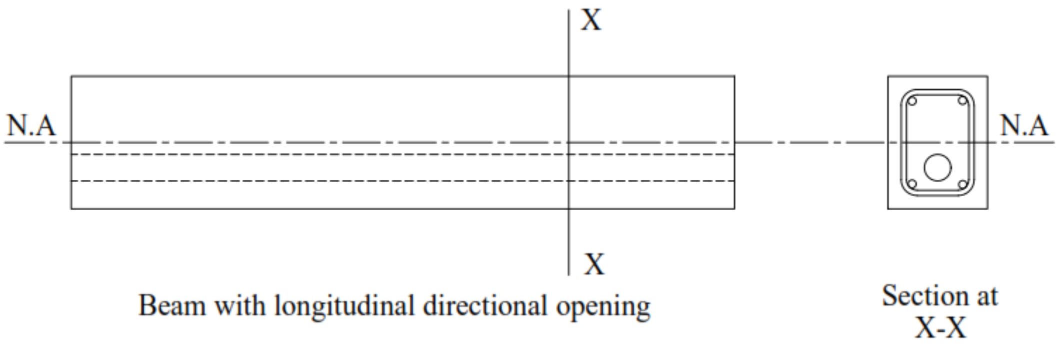


Figure 2. Beam with longitudinal opening

3.EFFECTS ON SIZE OF THE OPENING

M. A. Mansur and Kiang-Hwee Tan[35] and Saeed Ahamed Al-Sheikh[7] haveclassified the beams which are having the opening depth/diameter less than or equal to 0.4D (D – overall depth of beam) as termed as small openings. JavadVaseghiAmiri and MortezaHosseinAlbygie[8] said that when the opening diameter exceeds 1/3rd the depth of the member, it causes greater reduction in the serviceability of the beam. Eventually J.H. Ling et al., [30] reported that the reduction of beam strength was about proportion to the opening size. The beam lost approximately one-third of its strength when the opening size reached one-third of beam height. The beam lost one-sixth of the strength as the opening size was one-sixth.

M. A. Mansur [36] categorized with the type of failure that the size of the openings which allows the beams to maintain the beam type behavior are termed as small openings and others are large openings. When the size of opening lies between 30% and 40% of the overall depth of the beam, there will be a shift from Beam type behavior to frame type behavior. Therefore, it is recommended to determine the size of the opening between the above-mentioned ranges to conveniently apply the simple beam theory.

J.H. Ling et al., [30] recommended that when the opening height should not exceed 0.2 times the beam depth and the opening length should be limited to 0.05 times the beam length. While exceeding this limit, the beam strength was more severely affected. They also concluded that the opening size should not exceed 0.25D maintain at-least 80% beam performance. Ihsan A.S. Al-shaarbaf et al., [6] had concluded that the increase in the opening length and depth of opening results in a substantial decrease in the ultimate load. As well as H. Madkour [31] said that, under non-linear characteristics of the hollow beam, increasing the opening height causes the increased deflection and decreased ultimate load. SoroushAmiri and Reza masoudnia[9] concluded the results more distinctly that there is no effect when the beam had the opening with a diameter of less than 0.48D. Subsequently, and S. Naganathan et al., [3] have reviewed and suggested that the depth of openings can be taken up to 0.5D and further recommended that when the openings become multiple openings can be used with a minimum space of 0.5D between two adjacent openings.

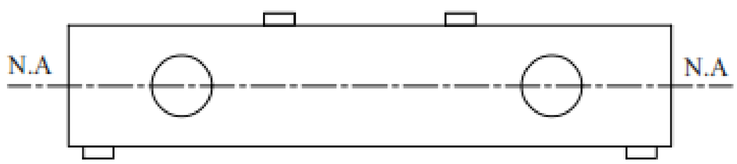
For hollow beams with longitudinal openings, Jeyakumar et al.,[27] have reviewed and reported that there was no effect on the ultimate load capacity when the circular opening size is less than 0.44D. The ultimate load capacity is reduced to 34.29% when the circular opening diameter is more than 0.44D. AhamadJabbarHussainAlshimmeri and Hadi Nasir Ghadhban Al-Maliki[1] have made a statement that the presence of hollow recess. In the RC beams had reduced the load carrying capacity and increased the deflection with respect to the increased the size of the square and rectangular openings up to 58% and 75% respectively when compared to solid beam for same applied load. Nasr. Z. Hassan et al., [24]has reported that the use of PVC pipe in the tension zone had no significant influence if the diameter of the pipe is less than 0.25b at two studied locations (160 mm and 180 mm from the top of the beam) where (b) is the breadth of the beam.

Arun Murugesan and Arunachalam Narayanan [38] and H. Madkour (2009)concludedthe provision and increment of opening will reduce the moment of inertia of the beam which leads to the reduction of lever arm distance between T_u and C_u. This reduction ultimately causes the decrement in first crack load and ultimate load.SherinKurikesu and Abhirami S [29]had analysed the geo-polymer concrete beams with longitudinal openings and concluded that the geopolymer beams with a hollow-core of 32 mm ф have more load carrying capacity, bending stress, shear force, less deflection than Geopolymer concrete solid beams. G. Balaji and R. Vetturayasutharsanan [11] has investigated the flexural hollow beams with 63.5mm ф (for single opening), 32.5mm ф (for double openings) circular PVC pipes and G.I. pipes, and concluded that the flexural behavior of hollow beams with double openings had considerable reductions in the behavior when compared to the beams with single opening and the concrete in beams can be removed upto 17.5% in the tension zone. Sallal R. Abid et al., [2]had dealt with the flexural behavior of HSC beams with different size reductions and said that the size reduction of 16% in the beams recorded the strength more than that of solid beam.

4.EFFECTS ON POSITION OF THE OPENING

JavadVaseghiAmiri and MortezaHosseinalibygie [8]observed that the position of opening has an effect which cannot be considered for the serviceability of the beam. But the openings can be placed in the mid of shear span, not close to the supports. Saeed Ahamed AL-Sheikh's [7] report opposes the results of JavadVaseghiAmiri and MortezaHosseinalibygie [8]by reporting that the beams with openings at shear zone had more reductions than the openings located above the supports and at the flexure zone. M. A. Mansur [35]recommends that the provision of openings entirely within the tension zone causes no change in the load carrying mechanism under pure bending. Fouad el Ame et al.,[16] reported that the provision of openings in the bottom chords with a diameter of circular opening less than 40% of the beam's effective depth brings no significant changes in terms of ultimate load capacity or first crack instant. When the openings are located in compression fibers, the behavior of the beam becomes more brittle with less plastic deformation. Besides the concrete in the upper fibers undergo extensive damages and the beam cracks more than usual. When the depth of the openings is equal to or greater than 0.4d, the type of failure changes from a beam type failure to frame type failure that occurs suddenly without significant previous signs.

J.H. Ling et al., [30]recommended for the shallow beams, openings should avoid the regions with maximum displacement and shear. Also, the opening affects the beam stiffness more significantly when it is placed at the mid-span, where the moment is predominant. For a higher beam capacity, the opening should avoid the beam mid-span and the support, where the maximum moment and shear occurs. It should avoid the potential pathway of the first crack and the critical shear crack. Thus the opening could be placed somewhere between the mid-span and shear regions.When increasing the opening size at support affected the beam ductility more significantly than the mid-span. S.C. Chin et al., [13,14]has investigated for a large square opening and placed the opening in the shear region (0.5d from support) and observed a brittle shear failure. Ihsan A.S. Al-shaarbaf et al., [6] concluded that the load capacity is decreased when the applied load to the nearest end of the opening decreases. SoroushAmiri and Reza masoudnia [9]have recommended that the adequate concrete in compression chord with proper shear reinforcement is required to obtain an ultimate flexural strength.



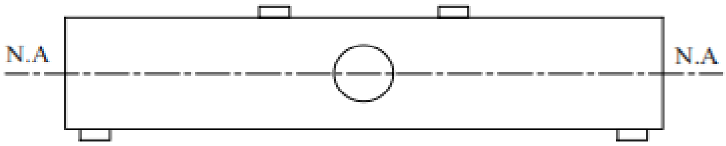


Figure3. Optimum position of opening in web of beams

Nilesh H. Saksena and Patel P G [43]concluded that the provision of opening at L/4 distance had more reductions than the openings provided at L/2 distance, which has no effect. Jain Joy and Rajesh Rajeev [28]said that the presence of a hollow circular PVC pipe instead of concrete in the low stressed zone has not caused a significant reduction in strength of reinforced concrete beams SoroushAmiri and Reza Masoudnia[9]have reviewed researches from various authors and said that the opening position should not be positioned not more than half of the depth of beam from the supports or from the load point.

Kamal GhamryMetwally et al., [42]discussing the position of rectangular web opening, as the relative influence of bending moment compared to that of shearing force increases as the opening is shifted away of the nearest support, the first crack appeared in beams with the opening located near the support faster than that in beams with the opening located away from the support. End openings resulted in an average reduction of 80% and 82% in the beam's cracking failure loads respectively relative to the corresponding beams without opening. This reduction slightly decreased when opening shifted away from the support and became about 70% to 65% respectively, and they also said that for the beams with a central opening, the crack pattern was similar to that of beams without opening. YaarubGatiaAbtan and HussainDhafer Abdul Jabbar [22] havestudied BLTO models (Beams with longitudinal and transverse opening) and concluded that the hollow core at 0.5D had no effect and it is considered as the optimum hollow core section. Stefee S.R and Ravi .C [46]has concluded with the optimum depth of web opening at the below neutral axis is 100 mm (from top) for the beam depth of 150 mm.

For longitudinal openings, Manikandan S et al., [33]have observed that introducing opening at a tension zone of size up to 25% had non-considerable reductions. Arun Murugesan and Arunachalam Narayanan [37,38]have concluded thatit is better to provide the openings below the stress block than other positions and when the distance between the center of opening and centroid of beam decreases the moment of inertia and leads to the reduction of cracking moment of resistance. Dhinesh N. P and Satheesh V. S [15]had reported that when the depth of opening is increased, it affects the ultimate load carrying capacity and deflection. Parthiban N and Neelamegam M[39]have observed that the presence of PVC pipes instead of concrete in the low stressed zone, increases the strength of RC beams up to 21%. Nasr. Z. Hassan et al., [24]has concluded that the best location to install PVC pipes in a reinforced concrete beam is 0.53d from top of sectionaway from the tension reinforcement to avoid brittle shear failure.

SherinKurikesu and Abhirami S[29] concluded that increasing the size of opening with pipe at neutral axis had not much difference in the flexural capabilities. YaarubGatiaAbtan and HussainDhaferAbdulJabbar [22] have studied with BLTO models and concluded that the presence of hollow-core led to decreased load resistance which also had lower value when hollow-core approaches tension or compression zone. They observed that more depreciation in the ultimate load and first crack load if the hollow core was found in the tension zone or compression zone. Saif A Hassan et al., [25]had concluded that the openings should not be placed near the supports and the failure mode changes with respect to the position and number of openings.

5.EFFECT OF OPENING IN RC BEAMS

M. A. Mansur [35] reported that under service loads, provision of opening causes reduction in stiffness which led to the excessive deflection, redistribution of internal forces and moment in continuous beams. Ihsan A.S. Al-Shaarbaf et al., [6] concluded that openings in a RC beam alters the beam behavior from simple to complicated. H. Madkour[31], Ibrahim

H. Elkersh et al., [19] and S. Naganathan et al., [3]observed that the diagonal cracks will be formed at earlier stage when the openings provided in the web of the beams and it reduces the shear capacity of the beam, due to the discontinuity created in the flow of stresses because of the openings. BengiAykac et al., [10] predicted that if the diagonal reinforcement is not provided then the top and bottom chord will act separately due to the opening. Saif A Hassan et al., [25] have observed that provision of opening in the existing beams is not recommended because it leads to the reduction in beam stiffness and the section will fail without indication.
Luis Herrera et al., [26]concluded that the specimen with web opening had comparable ultimate capacities to that of the specimen without opening with only a 15% decrease in compression and a 21% decrease in tension capacity. Fouad el ame et al., [16]reported that beams with opening size of less than 0.4d (d-effective depth of beam) exhibit a ductile behavior and beams with 0.4d or greater openings exhibit a brittle behavior. J.H. Ling et al.,[30] concluded that the stiffness was significantly affected by the size and the position of opening. If the size of the opening is about d/3 will affect the 36 % of stiffness of the beam. Stefee S.R et al., [46]have observed that the crack width is larger in beams with openings than solid beams and exceeds limitations of crack width irrespective of the size of openings and location. The opening reduces the cost of construction, providing opening does not require any skilled laborers, it also reduces the height of the ceiling, which leads to saving the overall height of the building. J.H. Ling et al., [30]reported that the shear crack occurred at around the same time regardless of the size, location of the opening. From Gajipara J.M et al., [20]under pure cyclic torsion, the torsional flexibility of the beam is governed by the longitudinal reinforcement and the post cracking deflection is governed by both the longitudinal and shear reinforcements. When most of the authors recommend hollow RC beams for the beams under torsion, this conclusion from Gajipara J.M et al., [20]improves the usage and improvement of RC hollow beams under torsion.
For longitudinal openings in the RC beam, A.S. Alnauimi et al., [4]have experienced that the failure load is closer to design loads with ductile nature for the tested beams. Ali Said Alnuaimi et al., [5]observed that the hollow beams had more displacement measured because the solid beams are likely to carry more loads. They recommend hollow beams when the torsion is predominant for the same reinforcement. Nibin Varghese and Anup Joy [47]have observed from the results of their research that all partially replaced beams (concrete in various zones are partially replaced by PVC pipes) had less deflection behavior than control beams at the safe load. Manish Kumar et al., [34]has observed that when increasing the difference in grade of concrete in hollow heterogeneous beams, the deflection is reduced. (Beams partially replaced by a different grade of concrete, below neutral axis).

6.SUGGESTIONS PROVIDED TO AVOID OR REDUCE THE EFFECT OF OPENING

- A separate simplified, empirical design procedure can be adopted for the design of beams with openings. If this fails, either the FEM or Strut &Tie procedure can be adoptedas an alternative practical solution. (Kamal GhamryMetwally et al., [42])
- In the case of openings in the existing beams, the strengthening can be done by,
  - Steel plates
  - Fiber reinforced polymer materials
  - CFRP sheets
  - Additional reinforcement (Nazar K. Oukali [41])

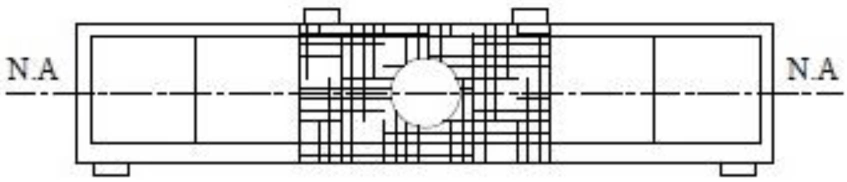


Figure 4. Provision of FRP sheets around the opening

- In order to reduce the effect of opening under strengthening category, it is recommended to use CFRP or FRP laminations to regain its half of design structural capacity (S.C Chin et al., [13,14]).
- FRP provides resistance against failure and increases the load carrying capacity of the beams(K.M. El-Sayed et al., [18]). CFRP sheets provide durability against corrosion to the concrete (Nazar K. Oukali [41]).
- The orientation of AFRP (Aramid fiber reinforced polymers) enhances the shear strength of the RC beams and the efficient angle of installation is 60° to the axis of the beam. (Bashir H. Osman et al., [40])

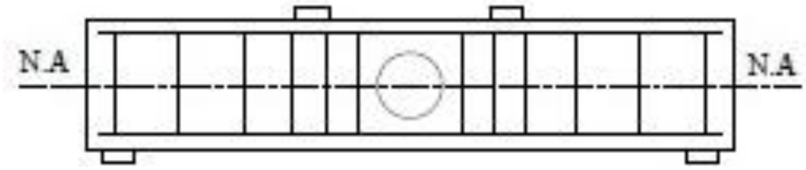


Figure 5. Provision of additional shear reinforcement

- Based on the usage of materials,
  1. Adopt an increased amount of shear reinforcement (Hadi Nasir Ghadhban Mohammed Al-Miliki [23])
  2. Special type of reinforcements can be provided around the opening in the form of
     - additional stirrups above and below the opening.
     - extra stirrups at both sides of the opening
     - longitudinal reinforcement in the top and bottom chords. (Kamal GhamryMetwally et al., [42])
  3. To reduce the area of concrete in the tension zone upto 25%, it is recommended to use G.I. pipes instead of PVC pipes (G. Balaji and R. Vetturayasudharsanan. [11])
  4. The flexural strength of RC beams having opening depends upon either the yielding of steel in tension or crushing of concrete in compression zone (Marta Slowik [45])
  5. When the opening is away from the load point, the additionally provided reinforcements will take the stress concentration around the opening. (Siddhalingesh B Kudatani et al., [44])
  6. Usage of diagonal reinforcement provides not only the shear resistance but also the flexural strength, stiffness and ductility to the RC beams with openings. (BengiAykac et al., [10], JavadVaseghiAmiri and MortezaHosseinalibygie [8]and J.H. Ling et al., [30])
  7. The increase in strength of concrete is more effective to improve the serviceability of the beams with larger openings. (JavadVaseghiAmiri and MortezaHosseinalibygie [8])
  8. Providing the reinforcement at the opening led to an increase of the load to initiate the shear crack by 20% and a substantial increase in the load for the crack to reach the opening.
  9. Strengthening using External Prestressing Technique (EPT) enhances the torsional capacityand also, improves the ductility behavior. (Abd El-HakimKhalil et al., [17])

7.CONCLUSION

The effects of opening either transverse direction or longitudinal direction in reinforced concrete beams by various authors have been studied. Based on the vigorous effort made in this area the following conclusionsare drawn:

1. It could be concluded that the usage of circular-shaped openings is more effective than other shapes of openings since it avoids sharp edges which are subjected to high-stress concentration while loading.
2. It is recommended to have a circular opening less than 0.55D of the beam for web opening. For longitudinal opening; the size of the opening to be restricted within 0.5D of the beam. The other shapes of web opening; Increase in size of opening decreases the mechanical properties of the beam, and it leads to the change in the mode of failure.
3. It can be concluded that, for web opening in RC beams, the optimum position to have a opening at mid-depth and the center between the support and load point to reduce the changes made in the beam due to opening.
4. When the opening location moves towards the point of application of load or towards the support, there will be an occurrence of reduction in its load-carrying capacity.
5. The optimum position to provide a longitudinal opening in the RC beam is just below the neutral axis. If the opening moves into the compression zone or tension zone, then the reduction in the structural capacity of RC beams will occur.
6. It is proposed to select the strengthening materials based on the purpose, availability, cost, availability of skilled labor and time.
7. It is desirable to work on the following field to elevate this work to the next level.
    - Performance of different types of concrete in the field of hollow beams
    - Investigation of different strengthening materials and techniques to reduce the deflection
    - Behavior of hollow RC elements under earthquake forces.

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