EFFECTS OF CIRCULAR OPENINGS IN RC DEEP BEAMS AT TOP OF SHEAR SPAN NEAR SUPPORT

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ABSTRACT

Opening is very important in structures in order to allow for the passage of conduits and also for mechanical purposes. There are various shapes of opening available with different dimensions of the openings. The presence of opening in the web can bring advantages in terms of minimizing the cost of the construction, however it may result into many problems which will cause cracking and deflection in the beam. Very limited studies have been done on deep beams with circular web opening. Therefore, this study was conducted in order to study the effects of circular opening due to the different sizes of opening located near the point load. In this study, the sizes of the circular opening considered were ∅150 mm, ∅200 mm and ∅250 mm. All beams of identical cross section of 100 mm x 500 mm and 1200 mm in length with circular opening of different sizes were provided. The beams were tested under four-point bending until failure. The results concern in this study were load deflection behavior, crack pattern and also failure mode. The presence of openings in the beams causes a reduction in the strength of the beam. The ultimate load of CB, BCO1, BCO2 and BCO3 were 42.97 kN, 46.59 kN, 30.55 kN and 27.99 kN respectively. Solid control beams and beams with circular openings failed due to shear. Increase in the opening size causes the cracks to be more severe. The increase in the diameter of openings disturb the load path transfer. In addition, providing openings of ∅200 mm reduces the strength by 28.90% and openings of ∅250 mm decreases the strength of the beam by 34.86%. Therefore, it can be concluded that increasing the size of openings causes a reduction in the strength of the beam.

ABSTRAK

Pembukaan atau lubang adalah sangat penting dalam struktur untuk membolehkan laluan konduit dan juga untuk tujuan mekanikal. Terdapat pelbagai bentuk pembukaan dengan dimensi yang berbeza. Kehadiran pembukaan di web boleh membawa kebaikan dari segi mengurangkan kos pembinaan, walaubagaimanapun ia boleh mendatangkan berbagai masalah kepada sifat atau tingkah laku rasuk yang mana boleh menyebabkan keretakan dan lenturan pada rasuk. Kajian yang sangat terhad telah dilakukan ke atas rasuk dalam dengan pembukaan web bulat. Oleh itu, kajian ini dijalankan untuk mengkaji kesan pembukaan bulat yang berbeza saiz pembukaan terletak berhampiran titik beban. Dalam kajian ini, saiz pembukaan bulat yang diambil kira adalah ∅150 mm, ∅200 mm dan ∅250 mm. Semua rasuk mempunyai keratan rentas yang sama iaitu 100 mm x 500 mm dan 1200 mm panjang dengan pembukaan bulat dengan saiz yang berbeza. Semua rasuk telah diuji di bawah empat titik lenturan sehingga gagal. Keputusan yang diambil kira dalam kajian ini adalah graf beban dan lenturan, corak retakan dan juga mod kegagalan. Kehadiran pembukaan pada rasuk menyebabkan pengurangan dalam kekuatan rasuk. Beban muktamad CB, BCO1, BCO2 dan BCO3 adalah 42.97 kN, 46.59 kN, 30.55 kN dan 27.99 kN. Rasuk kawalan dan rasuk dengan pembukaan bulat gagal oleh retakan ricih. Penambahan saiz pembukaan menyebabkan retakan menjadi lebih teruk. Peningkatan dalam diameter pembukaan mengganggu pemindahan laluan beban. Di samping itu, bukaan ∅200 mm mengurangkan kekuatan rasuk sebanyak 28.90% dan bukaan ∅250 mm mengurangkan kekuatan rasuk sebanyak 34.86%. Sebagai kesimpulan, peningkatan saiz bukaan menyebabkan pengurangan kekuatan rasuk.

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LIST OF SYMBOLS

∅	Diameter
L	Effective span
D	Overall depth
d_1	Distance between the center of opening to the center of support
d_2	Distance between center of opening to the bottom of the beam
M_u	Global moment
V_u	Global shear
n/a	Not applicable

LIST OF ABBREVIATIONS

RC	Reinforced concrete
IS	Indian standard
BS	British standard
CB1	Control beam 1
CB2	Control beam 2
CB3	Control beam 3
BCO1	Beam with circular openings (∅ 150 mm)
BCO2	Beam with circular openings (∅ 200 mm)
BCO3	Beam with circular openings (∅ 250 mm)

CHAPTER 1

INTRODUCTION

1.1 BACKGROUND OF STUDY

Reinforced concrete deep beams are widely used as transfer girders in offshore structures and foundations, walls of the bunkers and load bearing walls in buildings. In fact, deep beams are very useful in tall buildings or also known as high rise buildings. In the offshore gravity type structures, deep beams also act as a transferring and supporting elements. The presence of web openings in such beams is frequently required to provide accessibility such as doors and windows or to accommodate essential services such as ventilating and air conditioning ducts. Enlargement of such openings due to architectural or mechanical requirements and a change in the building's function would reduce the element's shear capacity, thus rendering a severe safety hazard.

Usually, pipes and service ducts are placed below the beam soffit and will be covered by suspended ceiling which will create a dead space. However, by passing ducts trough the transverse openings in the floor beams will lead to a reduction in the dead space which may resulted into a more compact design. Openings may be of different shapes and sizes depending on the purpose of providing the opening. Reinforced concrete deep beams with openings have complex stress and as investigated in the past research, the opening location, size and also shape have much effect on the structural strength of the deep beam. Various shapes are available, however the most common one is rectangular and circular openings.

1.2 PROBLEM STATEMENT

A large number of studies have been performed regarding the effects of opening on the T-beams, precast beams and deep beams, but very limited data have been reported on deep beams with circular web opening. Because of the limited depth of the rectangular reinforced concrete (RC) beams, introducing an opening in these beams is very significant. As a result of these particular arrangements of building services, the storey height of the building can be minimized and this will help to save the cost for material and construction.

The presence of opening in the web of RC deep beam may resulted in many problems in the beam behaviour such as excessive cracking and deflection and also reduction in the beam capacity. This is due to the sudden changes in the sectional configuration which causes the opening corners subjected to high stress concentrations which may lead to cracking unacceptable from durability and aesthetic viewpoint.

1.3 OBJECTIVES OF THE STUDY

The objectives of this research are:

i. To determine the load-deflection behaviour of RC deep beams with circular openings
ii. To determine the crack pattern behaviour of RC deep beams with circular openings
iii. To identify the effects of circular opening due to the sizes and opening location

1.4 SCOPE OF THE STUDY

This research focuses on the effects of various diameters of circular opening on the behaviour of reinforced concrete deep beams located near the point load. The sizes of circular openings considered in this study were ∅150 mm, ∅200 mm and ∅250 mm. This research was conducted to study the behaviour of RC deep beams with circular opening provided near to the loading point. All beams have an identical cross section of 100 mm x 500 mm and 1200 mm in length with circular opening with different sizes provided. All the beam specimens were tested under four-point bending using Magnus Frame of 300kN until failure. All the beams were tested to determine the effect of opening due its sizes and location. The results such as crack pattern, failure mode and load deflection behaviour were recorded during testing.

1.5 RESEARCH SIGNIFICANCE

Many experimental works have been conducted on RC deep beams with squares and rectangular openings (Khalaf (2006), Maaddawy and Sherif (2009), Chin *et al.* (2012), Mohamed (2013)). Limited data have been reported on the behaviour of RC deep beam with circular openings. Therefore, this research provides an experimental study on the behaviour of RC deep beams with the provisions of circular openings of various sizes.

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

Generally, beam is a structural elements which is able to withstand the load applied on it by resisting bending. Beams are usually being characterized by referring to the shape of the cross-section, length and also the material. There are various types of beam such as deep beam, T-beam and also precast beam. However, this study focuses on the behaviour of RC deep beam with openings. The presence of openings are often required in beams for various purposes such as to accommodate air conditioning and ventilation ducts. The behaviour of RC deep beam is significantly different from the beams of normal proportions in which deep beams requires a special considerations in the design, reinforcement and analysis (Niranjan and Patil, 2012).

2.1.1 RC Deep Beam / Solid Beam

Various types of beams are available for construction purposes. Most reinforced concrete beams are in rectangular cross section and in the construction of modern buildings, the most common types of beams used are RC deep beams. It has mostly been applied in the high rise buildings. According to IS-456 (2000) clause 29, simply supported beam is classified as a deep beam when the ratio of the effective span, L to overall depth, D is less than two. When the ratio of L/D is less than 2.5 for continuous beam, then the beam is classified as deep beam.

Beam is classified as a deep beam if the beam have a larger depth in relation to spans. Deep beam differ with normal beam in which they are most likely to have strength controlled by shear rather than flexure. In addition, deep beams have been widely used as transfer girders in offshore structures as well as foundations. Moreover, the failure behaviour of deep beams is significantly not the same from the one which are shallow due to the geometry and load transfer mechanism.

Kani (1967) reported that the existence of strong size effect on the ultimate shear strength of RC beams in which about 40% of the strength reduction was observed when the beam depth was increased from 300 mm to 1200 mm. Besides, Shioya *et al.* (1989) also claimed that about 25% reduction of shear strength was observed when the depth of the beam was increased from 1200 mm to 3000 mm. In addition, Niranjan and Patil (2012) conducted a study on the analysis of RC deep beam by finite element method. The details of their study is as shown in Figure 2.1. Niranjan and Patil (2012) reported that through the finite element analysis conducted, flexural strain and stress of deep beams is not linear is confirmed.

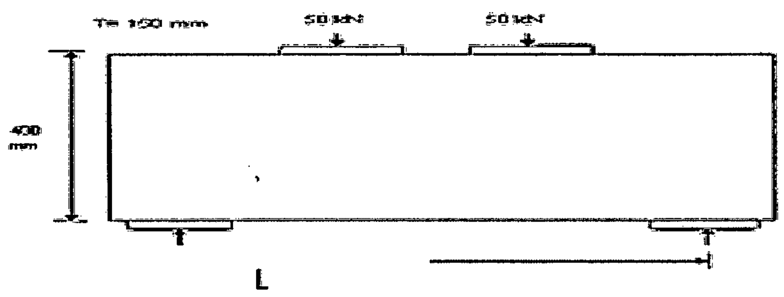

Figure 2.1: Deep beam with two point loading

Source: Niranjan and Patil (2012)

2.1.2 RC Deep Beams with Opening

Nowadays, especially for high rise and multi storey building, RC deep beam with opening is the most preferable type of beam used due to numerous advantages provided by RC deep beam with web opening. In addition, different types of openings are available such as square, rectangular and circular. It can be classified into two categories which are large and small openings. According to Mansur and Tan (1999), circular, square and nearly circular in shape openings, if the depth or the diameter of the openings is less than 40% of the overall beam depth, the openings may be considered as small openings. Openings are required for various purposes and hence the opening sizes may vary depending on the use of the opening.

It is often necessary to have a network of pipes and ducts in order to accommodate essential services such as electricity and air conditioning conduits. Due to the aesthetic reasons, the networks and ducts are usually being placed below the beam soffit and covered by a suspended ceiling. Deep beam is usually found in tall buildings, offshore structures and also in the foundation systems. By placing opening in the deep beam, this help to facilitate the passage of utility pipes and service ducts.

However, the presence of openings in the beams will lead to many problems concerning the structural strength of the beam. By passing the service ducts through transverse openings in the floor beams as depicted in Figure 2.2, will indirectly lead to the more compact design by means of reducing the dead space. This will minimize the required storey height and as a result this situation will lead to the major cost saving.

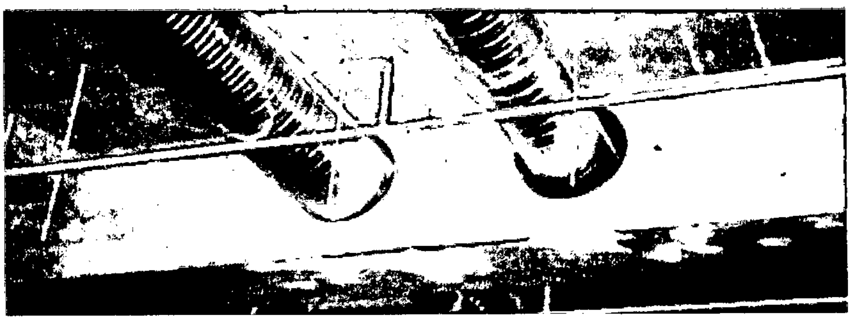

Figure 2.2: Concrete beams with circular opening

Source: Amiri *et al.* (2011)

2.2 OPENINGS

Web openings are varied depending on the purpose of the use. Condition of the beam will also be affected by the openings with factors such as shapes, sizes and also location.

2.2.1 Shape of Opening

Shapes of opening are one of the factors which affect the shear strength of the beam. It is found out that, the use of circular opening has advantages over using square opening regarding the structural strength of the beam (Alsaeq, 2013). Saksena and Patel (2013) also mentioned that the most common types of openings being provided in beams are circular and rectangular openings.

Different researchers have different point of view and as for Somes and Corley (1974) and Mansur *et al.* (1996), a circular opening is considered as a large opening when the diameter is more than 0.25 times the depth of the web. This is because, as the size of opening increases, the strength of the beam is reduced. Saksena and Patel (2013) mentioned in their research that the increase in the diameter of opening will cause the change in the pattern of cracks and the type of failure will change from flexural failure to beam type shear failure.

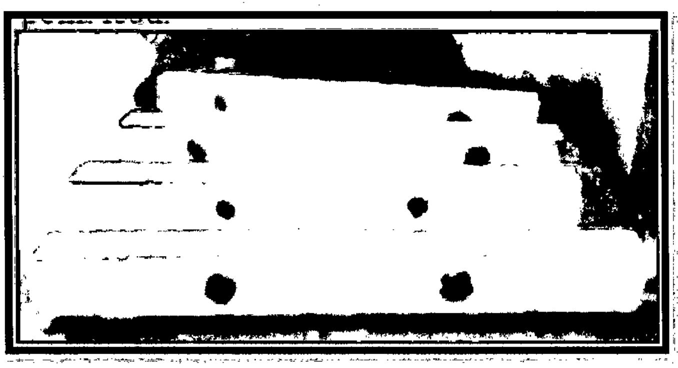

Figure 2.3: Circular openings provided in RC beams

Source: Saksena and Patel (2013)

Research conducted by Mansur and Tan (1996) proposed a simple design procedure for reinforced concrete beams with large web openings. In their research, it can be concluded that the openings provided should be lesser than one-half of the beam depth. In addition, it is found that the openings should be provided in order to provide sufficient concrete area for the chord in order to develop the ultimate compression block in flexure.

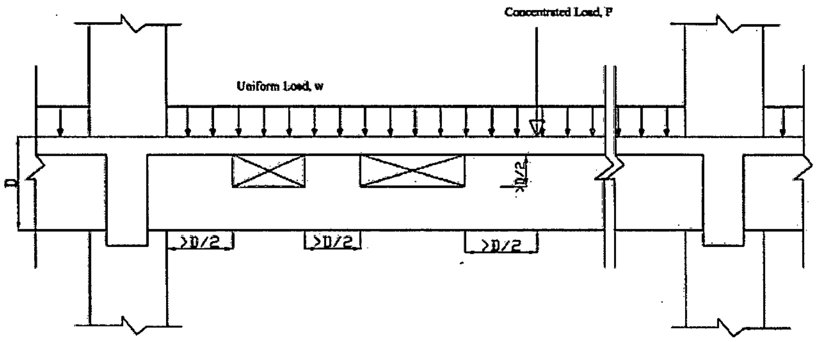

Figure 2.4: Guidelines for location of the web openings

Source: Mansur and Tan (1996)

Aykac *et al.* (2013) conducted a studies on nine rectangular RC beams being tested until failure in order to study the effects of web openings on the flexural behaviour of RC beams. They provided regular square and circular web openings in their studies. Based on their research, it was found that circular openings give lesser effect on the structural strength of the beam compared to the regular square openings. This is due to the lack of sharp corners in the circular openings which lead to the decrease in the stress concentration around the openings.

2.2.2 Location of Opening

Referring to the research done by Alsaeq (2013), the opening location has a greater effect on the structural strength on the beam if compared to the opening shape. Alsaeq (2013) conducted a study on beam with square openings in which due to symmetry, only half of the beam is considered as shown in Figure 2.5. In his study, he alters the location of the openings by changing the values of d1 and d2. Based on the results obtained in his study as depicted Figure 2.6, he also reported that when the opening is placed near the upper corners of the deep beam, it will helps to double the strength of the beam. Furthermore, as mentioned by Mansur and Tan (1996), the openings provided should be placed at the sufficient depth in which it should not be located more than one-half of the beam depth from supports or concentrated loads in order to provide efficient shear reinforcement.

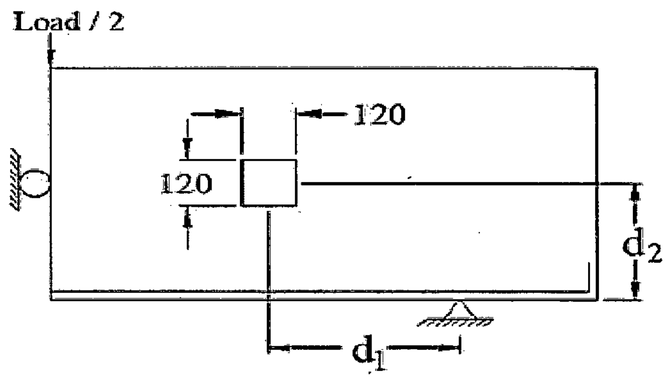

Figure 2.5: Half of the beam is considered due to symmetry

Source: Alsaeq (2013)

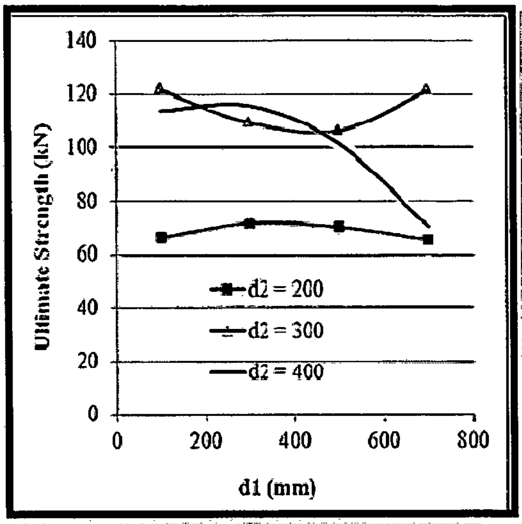

Figure 2.6: Ultimate strengths for beams with square openings

Source: Alsaeq (2013)

Saksena and Patel (2013) claimed that openings may be of different sizes and shapes, however, the openings are usually located near the supports where shear is said to be predominant. In addition, they also recommend that openings should be placed on concrete beams in order to provide chords with a sufficient concrete area so that the ultimate compression block in flexure can be developed. Indirectly, this will provide a sufficient depth so that an effective shear reinforcement can be provided. Research conducted by Mansur (1998) proved that the presence of opening in beams will represents a source of weakness in which the failure plane will passed through the opening unless the opening is placed at a distance which is consider very close to the supports. In addition, Ashour and Rishi (2000) tested continuous RC deep beams with small and large rectangular web openings. Based on their research, it was found that the load capacity reduces due to the provision of openings decreases as the openings are located closer to the end supports.

2.3 BEHAVIOUR OF RC DEEP BEAM WITH OPENING

The behaviour of RC deep beam with opening are different if compared to the deep beam without web opening in which Mansur *et al.* (1992) mentioned that due to the reduction of the cross sectional area of the beam, the behaviour of the beam will change from a simple behaviour to a more complex behaviour. Referring to the experimental work on various sizes of beams without shear reinforcement conducted by Kani (1967), the size of the beam greatly affects the ultimate shear strength of RC beams with openings in which a total of 40% of reduction of the strength was observed when the beam depth was increased about 900 mm from 300 mm to 1200 mm.

RC deep beams with web opening has various advantages in which by the presence of openings it will allow services or access to pass through. Moreover in deep beams, opening is usually desired for things such as windows and doors. As a result of having openings in deep beams for utilities to pass through, there will be reduction in the height of the building storey. However, the reduction in the story heights in buildings may result in too many problems in the beam behaviour such as a reduction in the beam stiffness which will finally lead to the excessive cracking and deflection of the beam.

According to Mansur (2006), this is due to the changes experienced in the sectional configuration and as a result, the corners of the opening are subjected to high stress concentration that will lead to cracking. Indirectly, excessive deflection will occur in which the stiffness of the beam are reduced. He also claimed that beam may fail in two distinctly different mode as depicted in Figure 2.7 which is beam-type failure and frame-type failure. As for beam-type failure, the failure plane will pass through the center of opening. Frame-type failure occurs as a result of formation of two independent diagonal cracks at the top and bottom chord of opening.

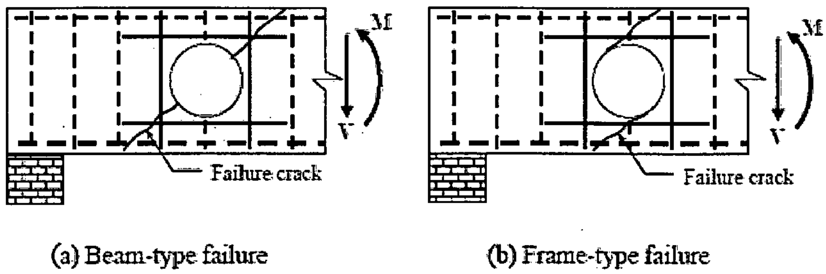

Figure 2.7: Modes of shear failure for RC beam with web opening

Source: Mansur (2006)

Moreover, Mansur (2006) mentioned that for circular, square and nearly square in shape openings will be consider as a small openings if the depth or the diameter of the opening is in a realistic proportion to the beam size. In this case, the mode of failure remains essentially the same with the mode of failure for solid beam without opening. Mansur (2006) claimed that the existence of opening will produce a disturbance in the normal flow of stresses and therefore will lead to the stress concentrations and an early cracking around the opening area. He proposed that a sufficient quantity of reinforcement should be provided in order to control the crack widths and to prevent any possible premature failure of the beam.

Study conducted by Mansur *et al.* (1991) reported that deeper openings lead to both early cracking and early yielding of reinforcement. Thus, the stiffness of the beam decreases. It was found that the ultimate load decreases as the opening depth was increased. The results of Mansur *et al.* (1991) study shows that an increase in the opening depth from 140 mm to 220 mm lead to a reduction in the ultimate load from 240 kN to 180 kN. In addition, Yoo *et al.* (2003) conducted a study on reinforced and prestressed concrete deep beams with various web openings. They concluded that for deep beam with web openings, diagonal cracks generally appeared at the top and bottom corners of the web openings propagating towards the support and loading points as depicted in Figure 2.8.