FEM ANALYSIS (3D) OF REINFORCED CONCRETE BEAM WITH OPENINGS

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ABSTRACT

Concrete beam with openings usually use to provide building services, such as conduits and pipes to pass through the beam so that the layout on water reticulation and electrical system will be more systematic. It also provide the ease of maintenance on building utility and reduces the financial during construction of high-rise building. However, beam with opening experience great losses of load capacity. In order to regain such losses, the strengthening method is investigated so that the strength of the concrete beam will be able to cover to the maximum. In this study, the behavior of the openings were investigated in terms of load-deflection, crack pattern and stress distribution. The simulation of strengthening concrete beam with openings by using CFRP laminates were conducted on RC beam with openings. There were three different types of beam that was analyzed in this study, which were solid RC beam, RC beam with openings and the strengthening RC beam with openings by using CFRP laminates. They were modelled using finite element software, ANSYS 12.0 in three degree of freedom. The location of the openings distinguished into zero distance, 140 mm and 280 mm from the supports. The beams were analyzed under four points loading. The result from numerical analysis was compared with the experimental result. The un-strengthened RC beams were found out that the beam reduced the ultimate load capacity at about 67 – 80% of the control beam. When the location of the opening was shifted further away from the support, the beam experienced less reduction of the ultimate load of the solid beam. Thus, the critical location of the opening was concluded at the face of the support. However, whenever the CFRP was installed around the opening region. The beam was able to fortify and regained at about 34 – 44% of ultimate load of the solid beam. Even though the beam was applied with CFRP laminates, they eventually failed on the shear zone. In conclusion, this research was able to prove that the beam was fortified by the CFRP strengthening method. A good agreement between numerical result and experimental result in literature was obtained based on the load-deflection relationship.

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LIST OF SYMBOLS

b_w	=	Web width
d	=	Effective Depth
d_o	=	Diameter of opening
A_v	=	Area of vertical legs of stirrups per spacing
s	=	Spacing
f_{yv}	=	Yield strength of stirrups
$(N_u)_t$	=	Stress Resultant
Vc	=	Shear capacity of solid concrete without shear reinforcement
f_c'	=	The concrete compressive strength
ρ	=	The longitudinal tensile steel reinforcement ratio
$\frac{a}{d}$	=	The shear span to effective depth ratio
A_{eff}	=	The effective area of the concrete cross-setion
E_c	=	Elastic Modulus
f_c'	=	Uniaxial Compressive Strength
f_t	=	Uniaxial Tensile Strength
ε_1	=	The strain value corresponding to $0.3{f_c}_1'$
ε_0	=	The ultimate strain value

CHAPTER 1

INTRODUCTION

1.1 BACKGROUND

The installation of the building services is needed in every building and these services play an important role for the structures so that the system can be maintained from time to time. In order to ease the installation of the services, concrete beam with opening is provided so that the services such as conduits, PVC pipes and other more, can pass through easily. These concrete beams usually will be used for high-rise building, where the pipe will be having difficult on installation, so concrete beam with opening will be able to ease the installation. It also helps to ease the maintenance of the building service as there will be avoid drilling through the hole of the beam in order to fix the water pipe that passes through the concrete beam.

However, concrete beam with opening will be experiencing reduction of the shear strength. Mansur (1998) suggested that the strengthening method of the opening was by reinforcing with the diagonal bar which also known as web reinforcement. Amiri and Reza (2011) conducted the opening effect on behavior of concrete beams without additional reinforcement in opening with the opening of circular and square shape, while Saksena (2013) simulated the effect of the circular opening on the behavior of concrete beam without additional reinforcement in opening region. As well as, Majeed (2011) had conducted experimental and numerical study of the effects of creating openings in existing RC beams and strengthening with CFRP. Chin (2013) also simulated reinforced concrete beams with openings by strengthening with CFRP laminates. In this study, it aimed to conduct simulation on the behavior of the reinforced concrete with opening by using ANSYS 12 computer program to check out the strength of the beam with and without the CFRP laminates in 3 dimensional.

1.2 PROBLEM STATEMENT

Based on the literature that had been conducted regarding the behavior of RC with openings, there were still many issues that can be discussed. RC beam with opening will be experiencing the reduction of strength. This mainly due to the square opening, the sharp edges of the opening undergoes more stress. It also reduced the stiffness of the opening due to the decrease in volume of RC beam. The shear cracks tend to form around the region of the openings and allowable deflection of RC beam decreases. Thus, strengthened method was required to provide in order to regain the strength of the RC beam with openings.

1.3 OBJECTIVE

The main objective of this research is to understand the behavior of the reinforced concrete beam with opening via ANSYS 12: The sub-objectives are as follows:

- To determine the behavior of RC beams with opening on un-strengthened and strengthened CFRP laminates in term of load-deflection, crack pattern, stress and strain distribution and failure mode.
- To determine the effects of square opening and location at 0d, 0.5d and d from the support
- To study the effective strengthening configuration of CFRP laminates in RC beams with openings
- To compare the result obtained in three dimensional with the experimental results from the literature.

1.4 SCOPE OF WORK

The scope of the research was to simulate simply supported reinforced concrete beam in three dimensional with square openings loaded with four point bending by using ANSYS 12 software. The beam was tested to failure under four-point loading so that the result will be able to obtain. Through software, load-deflection curve, stress, strain and the crack pattern was able to obtain. The test perimeter of the research was analyzed by using the cross sectional of 120 mm x 300 mm and length of 2000 mm for all beams. Furthermore, the effective length for the beams was 1800 mm and the effective depth will be at 280 mm. As for the reinforcement steel bar, it will be installed with 2H10 at top and 2H12 at bottom for all seven beams. The shear link will be using H6 with 300 mm center to center. The opening will be identical dimension of 210 mm x 210 mm square shape for other six concrete beams and there is one control beam which is without any opening. The location of the opening will be 140 mm, 280 mm and 420 mm from the support. Each location of opening will be tested with and without CFRP laminates. While, the compressive strength of the concrete was 35 MPa with the Poisson ratio of 0.2 and young modulus, E is $3x10^9$.

1.5 SIGNIFICANT OF RESEARCH

This research can be provided with an understanding on the behavior of RC beam with openings and the strengthening method on RC beam with openings was determined. Through this research, M&E engineers will be able to know the installation through the concrete beam avoiding the critical location for the beam when opening is required. Since ANSYS is promising software on modeling the concrete beam with opening. It also enable to strengthen the RC beam with CFRP laminates during analysis in ANSYS. The geometrical model on CFRP configuration was able to done easily through ANSYS. At the same time, engineer able to make reasonable decision at the same time shorten the procedure to test out the detailed analysis of beam with opening and strengthen method.

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

The purpose of literature review was done to know the reason on having concrete beam with openings and also to find out the behavior of the reinforced concrete beam with opening. Since the RC beams with opening were experienced reduction in strength, there were several ways to regain the strength of the structural member which were reported and conducted by researchers.

Nowadays, modern building is having more essential utilities like electrical cabling network, water supply system, and ventilation system. These pipes and duct were usually placed beneath the concrete beam and thus they created dead load on the structural member as they designed to have longer distance to reach the designated place. However, concrete beam with opening was the solution by decreasing the dead load on the building while giving a compact design for the structural. For aesthetic purpose, RC beam may needed to design with an opening. Thus, researcher was needed to test the capacity of the concrete beam so that the members will not be experiencing failure. In small building, the openings may not be significant. But in multistory building, the cost saving in term material and installation period for building utilities will be obvious as the length of the piping system will be in staying in a straight line instead of circulating around the building. The overall load on the foundation was decreased and lead to the foundation to be smaller.

In the past, there were also varieties of strengthening method in order to regain the strength capacity of the reinforced concrete beam with openings. Before starting the research, the method of the past researcher conducted on concrete beam with opening will act as a reference so that the gap of the research will be able to identify through this chapter. Each different type of samples, such as the shape and location of the openings that had been conducted by research was reviewed through this chapter.

2.2 THE EFFECT OF OPENINGS ON RC BEAM

In this sub chapter, the effect of the opening on concrete beam was reviewed in terms of different type of size and location.

2.2.1 Shape

There was various shape and size of the opening on concrete. However, different types of shape and different size will influenced the behavior of the reinforced concrete beam greatly. The most common openings that apply on practical are the circular opening and the square openings. Figure 2.1 shows that the different type of shape that apply on reinforced concrete beam:

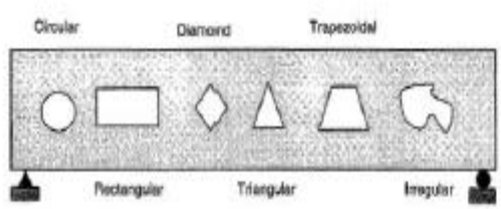


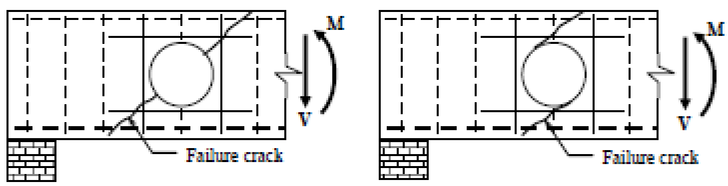
Figure 2.1: The shape of the openings (Prentaz, 1968; Mansur & Tan, 1999; Chin, 2013)

2.2.1.1 Circular Opening

RC beam with circular openings will definitely experience reduction in strength, but when the opening get even larger, the reduction of the strength will even more. Thus, the relationship of the diameter of the opening and the reduction in strength of the reinforced concrete beam was observed in linear increment. When the opening presence on the RC beam, the ultimate strength of the RC beam was expected at about 12.5% of the reduction comparing with the normal concrete beam. The location of the openings influenced the ultimate strength of RC beam. When location of the opening get nearer toward the support of the beam, the ultimate strength of the reinforced concrete beam will reduced greatly. (Javad & Morteza, 2004). Based on Rezwana et. al. (2014), the circular opening will gradually reduce the strength of the concrete beam as the size of the opening increase. They mentioned that the circular opening with diameter less than 44 % of the depth of beam was considered as small opening. These RC beam with small circular opening was analyzed with reduction at about 2% of the solid beam. If the circular opening was smaller, which diameter was 24 % of the depth of the beam, it was concluded that the opening had no effect on the concrete beam. As the diameter of the opening reached 48 % of the depth of beam, the load capacity of the RC beam was reduced at about 34 % of the solid RC beam. While RC beam with opening was observed to have the same properties as solid RC beam under the condition of the depth or the diameter of the openings is less than 40% of the overall concrete beam depth. Once this situation occurred, the opening was considered as small openings and the analysis of the beam should be following the same action and result as that of the solid reinforced concrete beam. (Mansur, 2006). Accordingly to Saksena (2013), he claimed that the circular opening with diameter less than 55% of the depth of the beam without any reinforcement in the opening zone and was placed at the center of the beam had no effect on the ultimate strength of the beam. Whenever diameter of openings increased, the beam was experienced 52% of reduction in strength comparing with the solid concrete beam. However, the small opening on RC beam only obtained small reduction in load capacity of the concrete beam when comparing solid reinforced concrete beam. Circular opening also reduced the stiffness of reinforced concrete beam and this lead to diagonal crack around the opening and which caused the load capacity drop about 37.57% comparing with normal concrete beam. (Kumar et al, 2013).

2.2.1.2 Web Reinforcing For Circular Openings

When come to circular opening, there were two types of shear crack; beam-type failure; Figure 2.2 (a) and frame-type failure; Figure 2.2(b) and these two types of failure will be needed to use web reinforcement differently. (Mansur, 1998)



(a) Beam-type Failure (b) Frame-type Failure

Figure 2.2: The type of failure at small openings (Mansur, 1998)

2.2.1.3 Beam-Type Failure For Circular Openings

According to (Mansur, 1998), beam type failure mostly occurred when the crack occurs at a diagonal of 45 degree, which the crack was transverse through the center of the opening (Figure 2.2 a.). This meant by the crack failure was similar with the solid reinforce concrete beam. Suggested by ACI Code (1995), the shear resistance of the concrete V_c with the presence of the small opening will used this Eq. (2.1) to obtain:

$$V_c = \frac{1}{6}\sqrt{f'_c}\, b_w(d - d_o) \qquad \text{Eq. 2.1}$$

whereby, b_w = web width; d = effective depth; and d_o = diameter of opening.

After knowing the shear resistance of the concrete, the shear strength of the reinforcement, V_s was needed to calculate by using such Eq. (2.2) to obtain:

$$V_s = \frac{A_v f_{yv}}{s}(d_v - d_0) \qquad \text{Eq. 2.2}$$

whereby, A_v = area of vertical legs of stirrups per spacing, s = spacing, f_{yv}=yield strength of stirrups.

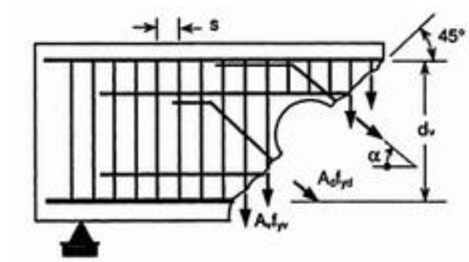


Figure 2.3: Shear resistance that is provided by the shear reinforcement bar (Mansur & Tan, 1999)

Once both values of $V_{c\ \text{and}}$ V_s acquired, the amount of the web reinforcement to carry the factored shear through the center of opening was calculated in the usual method. The amount of the distance should be contained within $\frac{(d_v - d_o)}{2}$, or preferable to lump together on the side of the opening so that the reinforcement will be strengthen enough to prevent shear crack from happening. (Mansur & Tan, 1999)

2.2.1.4 Frame-Type Failure For Circular Openings

In Figure 2.2 (b) shows that the frame-type failure occured mainly due to the two different diagonal crack, which each one of the corner that separated by the opening behaving independently. This will lead to the frame-like crack. Since both top and bottom acting differently, the design reinforcement for this failure mode will be treated independently, as suggested by Mansur (1998).

In order to fulfill the design method, the free-body diagram of Figure 2.4 is considered. It showed that the moment at the center of the opening is resisted due to the bending that compressive and tensile stress resultant combination acting top and bottom of the opening. The stress resultant was obtained by using Eq. (2.3):

$$(N_u)_t = \frac{M_u}{(d-\frac{a}{2})} \qquad \text{Eq 2.3}$$

After knowing the factored shear and axial forces, the member of each different crack could be independently design for shear resistance by using the conventional procedure when designing normal reinforced concrete beam. (Mansur & Tan, 1999).

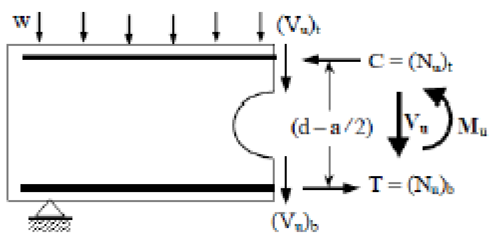


Figure 2.4: Free body diagram at beam opening (Mansur & Tan, 1999)

2.2.1.5 Square and Rectangular Openings

Unlike circular, square openings possess sharp edges which caused even more reduction of load capacity of the concrete beam. When square opening placed on the concrete beam, it was to be found that the load carrying capacity reduces to 45% to 70% compare to the solid concrete beam (Suresh & Angeline, 2014). As the width of the opening continues to increase further up to 10% of the depth of the beam size, the flexure crack will formed in the first stages. If the width of the opening goes beyond 10%, the beam will failed due to diagonal shear crack (Daniel & Revathy, 2014). There was also some evidence that show the square opening will experienced diagonal crack around the corner of the square opening and will extended toward the location of support and loading which cause beam toward failure (Pimanmas, 2010). Figure 2.5 shows the square opening experienced shear failure. This diagonal crack pattern was due to the extreme shear deformation as the tension on the edge experiences high stress concentration (Aykac et al, 2013).

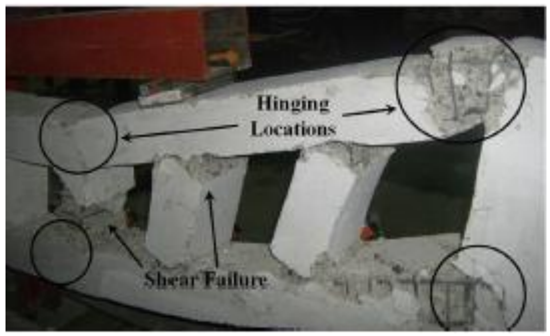


Figure 2.5: Failure mechanism of beam with square openings (Aykac et al, 2013)

There were some claimed that whenever there was RC beam with small opening, the load was observed to be transferring through the opening toward the support from the location where the load applied. While, concrete beam with large opening would behaved differently compare with small opening. Instead of the load applied transferred through the opening toward the support, the load was observed as it transferred through top and bottom side of the opening due to the length of the opening. Thus, large opening was observed to be having more negative effect on the concrete beam comparing with small opening. Therefore, higher stress concentration would see at the top and bottom of the opening as the load applied increases (Torunbalci, 2011). As for large opening on RC beam in flexure zone, the effect of ultimate strength was not as critical as RC beam with opening at shear zone. Whenever RC beam with opening at center of the beam, the result was obtained to be reduce at about 4.8 % of the ultimate strength when comparing with solid RC beam. This mainly due to the reduction of volume in concrete beam and caused the yield strength of the concrete beam to reduce. Thus, it was observed that the opening in flexure zone was slightly influenced the strength of the beam (Singh & Shafiq, 2014)

2.2.1.6 Reinforcing for Sharp Edges Openings

When designing shear reinforcement for concrete beam, the concrete shear resistance was needed in order to decide the amount of shear reinforcement. In order to know the concrete shear resistance, the formula of shear capacity of solid concrete beam without any shear reinforcement was used, which is Eq. 2.4 that derived by Zsutty (1971)

$$V_c = 2.14\ (f_c' \rho \frac{d}{a})^{\frac{1}{3}} (A_{eff})\ , \frac{a}{d} \geq 2.5 \qquad \text{Eq 2.4}$$

$$V_c = 5.35\ (f_c' \rho)^{\frac{1}{3}} (\frac{d}{a})^{4/3} (A_{eff})\ , \frac{a}{d} < 2.5 \qquad \text{Eq 2.5}$$

Whereby, Vc is shear capacity of solid concrete without shear reinforcement

f_c' Is the concrete compressive strength

ρ Is the longitudinal tensile steel reinforcement ratio

$\frac{a}{d}$ is the shear span to effective depth ratio

A_{eff} is the effective area of the concrete cross-setion

When estimating the shear capacity of a solid concrete, A_{eff} was just the cross-sectional area of the concrete beam. However, solid concrete beam presence with a square opening, the effective area would take as A_{eff} = width of beam x the difference of the depth between total depth and effective depth of the beam. Since the square opening experienced diagonal crack, the stress concentration factor was recommended to used ɳ = 2 for designing the sharp corner of the openings. Thus, the design of the amount used for shear reinforcement at the sharp corner must be twice the larger than the shear force in order to fulfill the stress concentration factor. (Maaddawy & Ariss, 2012; Mansur & Tan 1999). However, there was also a claim that the web opening around the region of the opening able to provide ultimate strength of the RC beam. When web opening that does not interfere compression struts between the load and support point, the load capacity was only reduced at about 6 – 8% % of the concrete beam. However, the design of web opening that crosses compression strut should avoided as it reduced the load capacity of the beam to approximately of 35% of the solid RC beam (Mohamed et. al., 2014).

2.3 LOCATION

When the opening is placed at the center of the beam had no effect on the ultimate strength of the beam. For openings that placed at one quarter of span of the beam, the beam was observed that at about 52% of reduction in strength comparing with the solid concrete beam. As the distance between the opening and the support was shorter, the RC beam was experienced more reduction in strength of the reinforced as the first shear crack mostly will be occurs near the support. (Ahmed, 2014; Javad & Morteza, 2004). As for semi-circular beams with opening at mid-span, the ultimate load of the beam was reduced to about 35% of the ultimate load that control semi-circular beam. However when opening was located outside both support of the beam, the ultimate load capacity of the beam was less effected as the cracks mostly occur within both support of the beam (Ali & Hemzah, 2014). Accordingly to Saksena 2013, the best portion to provide opening in beam was the center of the beam as it was almost no effect on the ultimate load of the RC beam. Figure 2.6 shows the comparing of the beam in terms of different location of the opening on RC beam. However when opening was provided at the distance of one quarter of the depth, the beam was reduced at about 52 % of the load capacity when comparing to solid beam. As the opening get nearer to the support point, which was L/8 of the depth of the beam, the reduction of the ultimate strength decreased at least 62 % of the solid beam.