STRENGTHENING OF REINFORCED CONCRETE DEEP BEAMS HAVING LARGE SQUARE OPENINGS IN SHEAR ZONE WITH CARBON FIBER REINFORCED POLYMER (CFRP)

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ABSTRACT

Typically, the reinforced concrete (RC) deep beam with large openings are facing some severe problems such as the interruption of natural load transfer by concrete struts acting in compression which can cause an intensive reduction in strength; and the clearly visible cracks in serviceability conditions. The CFRP has become an alternative solution to this issue and being extensively used as an external reinforcement to resolve the strength requirements in structural systems due to extremely strong yet light weight, outstanding fatigue properties, excellent corrosion resistance and easy yet efficient application on concrete. This experimental study is focuses on the investigation of the effect of CFRP wrap in strengthening RC deep beams with large square openings located in shear zone. Three approaches are under consideration; the first is the determination of natural load transfer in normal deep beam without opening, the second is the large square openings in deep beam without CFRP strengthening, and the third is the large square openings in deep beam with CFRP attached around the openings. A total of four RC deep beams which included a solid RC control beam, a deep beam with two large square openings, and two beams with two large square openings strengthened by using CFRP strips in different strengthening configurations, were tested to failure under four point loading to determine the relative structural behaviour such as ultimate load, failure mode, crack patterns, and load deflection behaviour. All RC deep beams were designed in a dimension of 120 x 600 mm and 2400 mm in length. The width and height of large square openings were in a dimension of 270 x 270 mm and located 300 mm from the edge of the deep beam. The loading point and support were located at 800 mm and 300 mm from the edge of the deep beam, respectively. RC deep beam with large square openings, US-BSO was significantly reduced the beam capacity by 61.76 % as compared to solid control beam, CB. However, the RC deep beam with large square openings strengthened by CFRP strips wrapped in U-shaped, SU-BSO has increases the beam capacity by 62.77 % compared to US-BSO. From the results obtained, it was found that the most effective CFRP strengthening method for RC deep beam with large square openings was U-shaped, which recovered the beam capacity up to 62.24 % as compared to solid control beam.

ABSTRAK

Biasanya, konkrit bertetulang (RC) rasuk dalam dengan bukaan besar menghadapi beberapa masalah yang teruk seperti gangguan pemindahan beban semula jadi oleh tupang konkrit bertindak dalam mampatan yang boleh menyebabkan pengurangan intensif dalam kekuatan; dan keretakan jelas kelihatan dalam keadaan kebolehgunaan. CFRP telah menjadi penyelesaian alternatif kepada isu ini dan sedang meluas digunakan sebagai tetulang luar untuk menyelesaikan keperluan kekuatan dalam sistem struktur disebabkan oleh berat amat kuat lagi cahaya, ciri-ciri keletihan yang luar biasa, ketahanan kakisan yang sangat baik dan permohonan lagi berkesan mudah pada konkrit. Kajian eksperimen adalah memberi tumpuan kepada penyiasatan kesan pembalutan CFRP dalam mengukuhkan RC rasuk dengan bukaan persegi besar yang terletak dalam zon ricih. Tiga pendekatan termasuk dalam pertimbangan; yang pertama ialah penentuan pemindahan beban semula jadi dalam rasuk dalam normal tanpa pembukaan, kedua adalah bukaan persegi besar dalam rasuk mendalam tanpa pengukuhan CFRP, dan yang ketiga adalah bukaan persegi besar dalam rasuk dalam dengan CFRP dilampirkan di sekitar bukaan. Sebanyak empat RC rasuk dalam yang termasuk RC rasuk kawalan pepejal, rasuk yang mendalam dengan dua bukaan persegi besar, dan dua rasuk dengan dua bukaan persegi besar diperkukuhkan dengan menggunakan jalur CFRP dalam konfigurasi pengukuhan yang berbeza, telah diuji dengan kegagalan di bawah empat mata loading untuk menentukan kelakuan struktur relatif seperti beban muktamad, mod kegagalan, corak retak, dan tingkah laku beban pesongan. Semua rasuk dalam telah direka dalam satu dimensi 120 x 600 mm dan 2400 mm panjang. Kelebaran dan ketinggian bukaan persegi besar mempunyai dimensi 270 x 270 mm dan terletak 300 mm dari tepi rasuk dalam. Titik memuat dan sokongan terletak pada 800 mm dan 300 mm dari tepi rasuk dalam, masing-masing. RC rasuk dalam dengan bukaan persegi besar, US-BSO telah dikurangkan dengan ketara keupayaan rasuk oleh 61,76% berbanding rasuk kawalan pepejal, CB. Walaubagaimanapun, rasuk dalam dengan bukaan persegi besar diperkukuhkan dengan jalur CFRP dibungkus dalam berbentuk-U, SU-BSO mempunyai meningkatkan keupayaan rasuk oleh 62.77% berbanding US-BSO. Daripada keputusan yang diperolehi, kaedah CFRP yang paling berkesan untuk mengukuhkan RC rasuk dalam dengan bukaan persegi besar adalah berbentuk U, keupayaan pulih rasuk sehingga 62,24% berbanding rasuk kawalan pepejal.

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LIST OF SYMBOLS

%	Percentage
mm	Millimeter
N/mm^2	Newton per millimeter square
MPa	Mega Pascal
l_o	Clear span
l_e	Effective span
a	Shear span of beam
P_u	Ultimate load
P_y	Yield load
δ_u	Ultimate deflection
δ_y	Yield deflection

LIST OF ABBREVIATIONS

a	Shear span (horizontal distance between support and loading point)
ACI	American Concrete Institution
ASTM	American Society for Testing and Materials
BS	British Standard
BSO	RC deep beam with square openings
C	Mid shear span
CFRP	Carbon fiber reinforced polymer
d	Effective depth of the beam
FRP	Fiber reinforced polymer
h	Depth of the beam
LVDT	Linear variable displacement transducer
OPC	Ordinary Portland Cement
RC	Reinforced concrete
SS	Surface strengthening
SU	Strengthening with U-wrap
US	Un-strengthened
UMP	Universiti Malaysia Pahang

CHAPTER 1

INTRODUCTION

1.1 RESEARCH BACKGROUND

In the construction of modern building structures, reinforced concrete (RC) deep beams are often used as primary load transferring elements, such as transfer girders, pile caps and shear wall. Nowadays, the use of deep beams has increased rapidly especially at the lower levels in tall buildings for both residential and commercial purposes due to their convenience and economical efficiency. A deep beam or transfer girder is commonly used when there is a lower column on the exterior façade needed to be removed due to architectural purposes. According to the Building Code Requirements for Structural Concrete (ACI 318-08) published by American Concrete Institute (ACI), deep beam can be defined as a beam in which either clear span is equal to or less than four times the overall member depth or concentrated loads are within a distance equal to or less than two times the depth from the face of support. Large openings through structural members are often required for mechanical and electrical conduits, such utility pipes and ducts are essential to accommodate part of the indispensable services as well as for the means of passageways like doors and hallways in the buildings (ACI Committee 318, 2008). Openings are classified as small or big openings and the best position of the opening is depended on its size (Chin et al, 2011). There is no clear-cut demarcation line or without any definition to classify the size of the opening, whether large or small. However, an opening may be considered as small opening if the depth to diameter of the opening is in realistic proportion to the beam size, about equal to or less than 40% of the overall beam depth. Large openings usually interrupt the natural load path and restrain the load transfer by concrete struts in the deep beams, causing a sharp decrease in strength and serviceability (Mansur, 2006). Normally in practice, the openings are located near the supports where shear is predominant. If the openings are located between the loading point and the support, the flow of force transfer will be disrupted and the load-carrying capacity of the deep beams will be significantly reduced. Web openings can be found to have various shapes, such as square, circular, rectangular, diamond, triangular, trapezoidal and even irregular shapes. Nevertheless, the circular and square openings are the most general in used practically.

Necessity of strengthening of RC deep beams with large openings is majorly depends on the types of construction of opening in RC deep beam, whether pre-planned or post-planned. Strengthening of RC deep beams with opening is not necessary if the opening is designed as built or pre-planned, since the location and sizes of the opening were specified and sufficient reinforcement is provided during design phase and construction of the deep beam. However, for a post-planned opening in RC deep beam, strengthening of RC deep beam is required to ensure sufficient shear capacity to prevent structural failure. Internal strengthening in deep beam with opening is commonly defined in situation where the upper and lower chords of opening are provided by longitudinal reinforcement whereas surrounding of the opening is strengthened by diagonal reinforcement (Mansur and Tan, 1999). For post-planned opening case, the opening has to be constructed in an existing RC deep beam by hand tool drilling technique. There might be some difficulties during the process of creating service utility pipes and ducts (Tamer and Sherif, 2009). Therefore, it is necessary for the deep beam’s opening to be strengthened externally with the external reinforcing material. Steel plates is the most common external reinforcing material, but fiber reinforced polymer (FRP) system seems to become the favourite in many construction industry currently. The FRP reinforcing system consists of choices of glass fibers, carbon, and aramid, the advantages and disadvantages will be discussed in the nest chapter (Haider, 2014).

Many literature and reports have been done on the effectiveness of CFRP strengthening system in provided external reinforcing to the structural members. The experimental results show that the shear capacity of solid RC beams without web openings is increase significantly. The researchers discovered that the beam’s shear span to depth ratio, internal shear reinforcement ratio, and the total amount of externally bonded CFRP sheets are the factors in effecting the gain in the shear capacity in solid RC beams (Chen and Teng, 2003) (Khalifa and Nanni, 2002). The results determine a fact that when the internal shear reinforcement ratio increases, the gain in the shear capacity after externally bonded with CFRP will decrease. Improvement and strengthening in shear capacity of RC beam with openings by using externally bonded reinforcement FRP system has become a focus point in the industry (Bousselham and Chaallal, 2006). Previous experimental results provide some precious data and evidences on improvement of weakness of laying a web opening in RC beam by using CFRP strengthening system. There are plenty of researches findings specify the potential of externally CFRP strengthening system in increasing the shear capacity of RC beams with web openings (Abdalla et al, 2003).

In this paper, reinforced concrete deep beams containing large openings are treated separately. Based on the research work reported in the literature, an attempt has been made to give a comprehensive treatment of openings under shear compression, addressing the major issues concerning structural design. It has been shown that the design of beams with large openings can be further simplified by maintaining its rationality and upholding construction economy.

1.2 PROBLEM STATEMENT

Reinforced concrete deep beams are widely used in both commercial and non-commercial buildings. The creation of a web opening in reinforced concrete (RC) deep beams is frequently required to allow accessibility for utility services such as electricity and air conditioning conduits, especially for the post-planned building services. The web openings' size is categorized as small or large opening, which is differentiate based on the depth-to-diameter of the opening. The behaviour of the RC deep beams in terms of load-deflection and crack patterns would be affected by the characteristics of the openings created on the beam, such as openings' shapes, sizes and locations on the beams. Creation of large opening would alter the building's function and thus, the structural strength of the building could reduce as well as resulted in sever safety hazard. From the previous studies, the existence of web opening causes several issues, especially reduction in beam strength, beam stiffness, cracking and deflection. However, the weakness of existence of web opening in RC deep beams can be solved by the externally strengthened method such as carbon fiber reinforced polymer (CFRP). Hence, further studies in the field of strengthening of RC deep beams with openings are necessary, in order to maximize the usage of RC deep beams with web openings. Differences of failure mode of the RC deep beams with openings, whether with or without CFRP strengthening is needed to be identify in order to determine the feasibility of the strengthening method for RC deep beams with openings.

1.3 RESEARCH OBJECTIVES

The general objectives of this study are to develop a rational physical reinforced concrete deep beam with large square-shaped openings with regard in experimental testing of beam capacity with or without reinforced of carbon fiber reinforced polymer (CFRP) wrap.

(i) To study the behaviour of the RC deep beam with openings under two circumstances; the first circumstances is the RC deep beam without CFRP strengthening, the second circumstances is the RC deep beam with CFRP strengthened in shear, in terms of load-deflection behaviour and crack patterns.

(ii) To determine the effects of the shape and size of openings for the RC deep beam.

(iii) To identify the most effective strengthening method from the strengthening configurations.

1.4 RESEARCH SCOPE

The behaviour of RC deep beams with large square openings strengthened by CFRP is the main scope of this experimental study. A total of four (4) RC deep beams were designed as simply supported and tested to failure under four-point loading test. Four (4) RC deep beams with dimension of 120 mm x 600 mm and a total length of 2400 mm length were prepared. A solid RC deep beam without opening is named as CB, which is functioned as control beam or a reference of the study. Conversely, the remaining beams were designed to have large square openings with dimension of 270 x 270 mm in width and height, respectively. The two large square openings section was designed to be located at the top of the shear span and at the face of support. The supports are located at 300 mm from both edges of the deep beams whereas the loading points are located at 800 mm from both edges of the deep beam. The shear span-to-depth ratios, a/h is standardized at 0.83 (a= 500 mm; h= 600), in order to ensure the deep beams to be fail in shear zone. Different externally bonded CFRP strengthening configurations were used to investigate the beam capacity reduction percentage and recovery percentage of the deep beam. The results of this study are in terms of load-deflection behaviour and crack patterns. The CFRP used in this experimental study is named SikaWrap-300C whereas an epoxy resin which known as Sikadur-330 was used in the process of dry application of the CFRP. The CFRP used to apply on the RC deep beams around the openings was cut into different size of strips according to the dimension of the area applied. All the CFRP strips were applied in ninety-degree (90°) vertical alignment in order to resist the natural load path of diagonal cracks within the shear zone.

1.4 SIGNIFICANCE OF RESEARCH

From the previous literature reviews, most researches show that the beam capacity of the reinforced concrete (RC) deep beams is reduced with the existence of the web openings. A good deal of studies and researches have been done regarding to the openings in deep beams in the last past few years. As the people realized the usage of deep beams increases, it becomes vitally important to study the behaviour of these beams in different circumstances. There are some main factors included in the issue stated in previous research such as concrete strength used, shear span-to-depth ratio of the beams, cross-sectional properties, configuration and type of web reinforcement, size, shape and location of web opening. Therefore, this research would provide the experimental results and information towards the behaviour and ultimate capacity gained of RC deep beam with opening strengthened by different configuration of CFRP. At the same time, this study also compensates the loss of deep beams' shear strength caused by creation of large openings. Last but not least, highest effectiveness percentage or most effective CFRP strengthening configuration would be provided thru this study, thus it can be used in future construction industry. The results and conclusions are intended to be useful for further structural engineering practice.

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

Deep beam is defined as the beam in which a significant amount of the load is transferred to the supports by a compression thrust joining the load and the reaction. . According to the Building Code Requirements for Structural Concrete (ACI 318-08) published by American Concrete Institute, a beam is classified as a deep beam for flexural if the beam's clear span/ beam's effective depth ratio is less than 1.25 for simply supported beams and 2.5 for continuous beams whereas deep beams is defined for shear if the beam's clear span/ beam's effective depth ratio is less than 5 for simply supported beams loaded on one face and supported on the opposite face so that compression struts can develop between loads and supports. However, there is another way to define deep beams which is the beams' clear spans equal to or less than four times the overall member depth; or regions loaded with concentrated loads within twice the member depth from the face of the support.

Web openings are generally introduced to accommodate building services such as air-conditioning ducts and electrical cables to save space, as these would otherwise be located below or within the deep beam. An opening produces geometric discontinuity within the beam as well as internal reinforcement and affects the nonlinear stress distribution over the depth of the beam. The creation of web openings decreases the ultimate strength capacity of a deep beam that can be attributed to the reduction of concrete mass acting in compression, and the opening acting as a stress raiser for shear crack propagation. This is particularly apparent when the opening is located along the critical load path of a deep beam.

2.2 STRENGTH AND BEHAVIOUR OF REINFORCED CONCRETE SOLID DEEP BEAM

Many researchers have analyzed the behaviour of reinforced concrete deep beams either in high or normal strength concrete with and without web openings. However, most of the researches have been carried out primarily focused on simply supported solid deep beams with various loading conditions.

According to An-Najjar (2005), when there is a significant amount of load in deep beam is transferred to supports by a compression thrust joining the load and the reaction. This will catalyse the compression in the diagonal direction to combine with the tension along the beam bars constitutes the basis for the strut-and-tie model. The tied arch action yielded also known as the force-transferring mechanism of deep beams. Two typical failure factors of a deep beam are either devastating of a compression strut or loss of a beam bar anchorage.

For the most part, deep beams are controlled by shear, rather than flexural. A significant amount of compressive forces are directly carried to supports by tied arch action. However, in practice tensile cracks develop in most deep beams between one-third and one-half of the ultimate loads. Thus, tension reinforcement rules the design of the deep beams. Since the main loads and reactions act in the plane of the member, a state of plane stress in the concrete can be calculated approximately.

The shear strength of deep beams is controlled by the following basic parameters: the effective span of beam (*l*e), width of beam (b), effective depth of beam (d), shear span of beam (a), cylinder compressive strength of concrete (f_{cd}), yield strength of vertical steel (f_{yv}), yield strength of horizontal steel (f_{yh}), reinforcement ratio of total horizontal tensile steel (ρ_t), reinforcement ratio of horizontal steel (ρ_h), and reinforcement ratio of transverse steel (ρ_v).

Furthermore, more parameters showed that they are also critical in deep beam behaviour such as size of bearing and loading areas, and anchorage of longitudinal steel into supports. Results have shown that in practice vertical shear reinforcement is more effective compared to horizontal shear reinforcement. Crack patterns in deep beam are mostly vertical or follow the direction of the compression trajectories, with the beam almost shearing off from the support in a total shear failure. Thus, in the case of deep beams, horizontal reinforcement is needed to resist the vertical cracks throughout the height of the beam, in addition to vertical shear reinforcement along the span. To resist the high tensile stresses at the tension regions of the deep beam, it is needed to concentrate horizontal tensile reinforcing bars in the lower zone. The allowable concrete shear resistance of the deep beam is higher than of ordinary beam because of the greater effective depth/ span ratio.

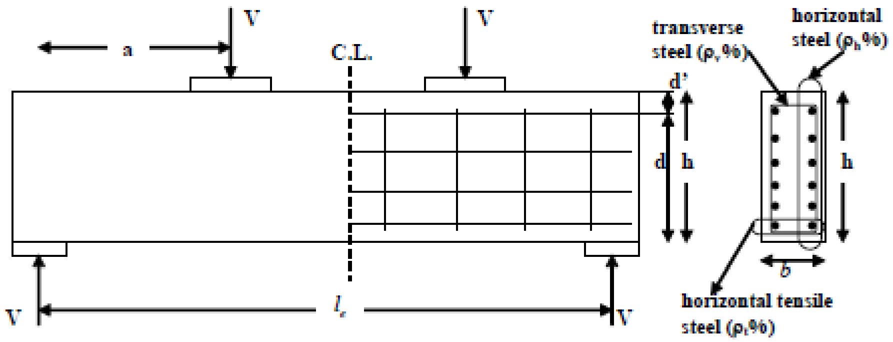

Figure 2.1: Basic parameters of simply supported deep beam for shear strength prediction: Deep beam (left); and Cross section (right)

Source: An-Najjar (2005)

2.3 STRENGTH AND BEHAVIOUR OF REINFORCED CONCRETE DEEP BEAM WITH WEB OPENINGS

Compared to solid deep beams, there has been little work done with reinforced concrete deep beams with web openings. Typically, large openings through structural members are necessary for building services such as mechanical and electrical conduits, or even for means of passageways. Besides, web openings in deep beams may be desired for windows and doors, or for passage of utility lines and ventilation ducts. Reduction in building storey height may occur to allow openings in deep beams for the transition of these utilities. The current study mainly focuses on the ultimate strength and behaviour of deep beams with web openings, more in depth discussions are devoted to this aspect.

Campione and Minafo (2012) studied the behaviour of reinforced concrete deep beams with web openings and low shear span-to-depth ratio. A total of twenty reinforced concrete small-scale deep beams with or without openings were casted and tested in flexure under four-point loading. The tested beams had a small shear span-to-depth ratio in order to stress the shear behaviour, different reinforcement arrangements, and web opening positions. The load was carried to the specimen with bearing plates having the same side length as the beam and connected to a device to measure the middle deflection of the beam. The experimental results show that the effect of the opening depends on its position in the beam; and the effect of the presence of reinforcement due to its arrangement. Afterwards, an analytical model is proposed to predict the shear strength and corresponding deflection of deep beams with openings. The results are compared with a non-linear finite element analysis and it shows a good agreement.

Lee (2008) studied on "Shear Strength of Reinforced Concrete Continuous Deep Beams with Web Opening" to predict the shear strength of the reinforced concrete deep beam regarding to various location. There are total of 5 deep beams with circular web opening casted and tested in the laboratory. The results showed that the specimens with web opening, whose diameter is 0.3 times of depth, have about 87-92 % of test result of shear strength of the specimen without web opening. Generally the slope of load-displacement curve is steeper in the span with opening than in the span without opening.

2.4 EFFECTS OF OPENING

2.4.1 Size of Opening

According to Hafiz (2014), studied on "Effects of Opening on the Behaviour of Reinforced Concrete Beam" to analyze the failure mode of size of opening by using finite element software ANSYS 10.0. The outcomes of the test show that beam of circular opening with diameter less than or equal to 44 % of the depth of the beam, without any special reinforcement in opening zone, behave similar to the beams without opening, mode of failure is flexure at mid-span, maximum compressive stress of the concrete occur at top of the beam for the ultimate load and tensile stress of the longitudinal reinforcement reaches to its yield stress before reaching to the ultimate stage of the beam. Conversely, for beam circular opening with diameter more than 44 % of the depth of the beam, without any special reinforcement in opening zone, reduces the ultimate load capacity of the reinforced concrete rectangular beams by at least 34.29 %, mode of failure is shear at the opening region, maximum compressive stress of the concrete occur at the opening region of the beam for the ultimate load and tensile stress of the longitudinal reinforcement reaches to its yield stress before reaching to the ultimate stage of the beam. It can be concluded that the circular opening has more strength than equivalent square opening with difference of 9.58 % in ultimate load capacity.

According to Amin, et al. (2013), studied on "Effect of Opening Size and Location on the Shear Strength Behaviour of R.C Deep Beams without Web Reinforcement" to study the effect of 3 different sizes of square web opening created on 3 locations of the R.C. deep beams without web reinforcement, hence, the opening size and location were the main factors in the current work. The finding of research was using the finite element non-linear analysis created by Ansys + CivilFEM. The results showed that sharp reduction in the ultimate shear was the consequence by creating an opening at the beam's shear zone, about 53.6 %. The results also showed that larger the openings, greater the reduction of ultimate shear capacity of the beam. Square openings with dimensions 0.45 h x 0.45 h make the average reduction in shear stress about 45.78%; whereas square openings with the dimensions 0.30 h x 0.3 h having the average reduction in shear stress of 28.2%; but the openings' size of 0.15 h x 0.15 h showed less effect in shear reduction, where the average reduction in shear stress is 11.55 %. It is found that the reduction of ultimate shear will be decreased with the decrease for the size of openings.

2.4.2 Shape of Opening

Haider (2013), studied the effects of the opening shape and location on the structural behaviour of reinforced concrete deep beam with openings, but the opening size remain unchanged. In this study, software ANSYS 12.1 is used to carry out the nonlinear finite element analysis. The ultimate strength of reinforced concrete deep beam with opening obtained by ANSYS 12.1 shows fairly good agreement with the experimental results, with a variance difference of less than 21 %. The present work concludes that the opening location has mu effect on the structural strength than the opening shape. The test results show that by using a circular opening instead of a square opening, which is similar in size, will increase the strength of the beam by 19 %.Introducing reinforcement bars around both the square and circular openings may increase the ultimate strength of the beam for up to 48 %. The Haider's research result showed that the best shape for the opening, in the deep beam considered, is the narrow rectangular with the long sides extended in the horizontal direction. But, deep beam with narrow rectangular opening is not suitable to be used in practical cases. However, deep beam with circular opening has more advantage over square opening, regarding the structural strength of the beam.

2.4.3 Location of Opening

Based on Son (2002) researched on "Design of reinforced concrete deep beams with openings and carbon fiber laminate repair", a total of five series beams (12 RC deep beams) consist of different opening in his study to determine the effect of location of opening in reinforced concrete deep beam. Series 1 is the solid beam without opening which act as the control parameter of this research; the remaining four series is classified in deep beams with variation opening location such as opening at bottom center and opening at center of the deep beam. The experimental results show that the location of the opening is a major factor influencing behaviour of the deep beam. When the opening did not interrupt the natural load path of the beam, it behaved like a solid deep beam. The beams with opening that interrupted the natural load path will failed by shear failure over the opening.

Haider (2013), studied on "Enhancing the Structural Behaviour of Reinforced Concrete Deep Beams with Openings", the effects of the opening shape and location on the structural behaviour of reinforced concrete deep beam with openings were determined without changed in the opening size. It was concluded that placing the openings near the upper corners of the deep beam may double the strength, and the use of a rectangular narrow opening, with the long sides in the horizontal save up to 40% of structural strength of the deep beam.

According to Amin, et al. (2013), studied on “Effect of Opening Size and Location on the Shear Strength Behaviour of R.C Deep Beams without Web Reinforcement” to study the effect of 3 different sizes of square web opening created on 3 locations of the R.C. deep beams without web reinforcement. The findings showed that the location of openings has great effect towards the structural strength of the deep beam. The effect is the largest when opening is created at shear zone where sharp reduction in the ultimate shear was determined. However, opening at mid-span location showed less effect and the ultimate shear increases with decrease for the size of openings. It found that when opening is located at the supports, the average reduction in shear stress is 23.93 % but the mid-span location showed the minimum effect where the average reduction in shear stress is 8 %.

2.5 FIBER REINFORCED POLYMER (FRP)

2.5.1 Introduction of FRP

Generally, there are several common types of high strength non-metallic fibres, also known as fiber reinforced polymer (FRP) such as carbon, glass and aramid fibres, encapsulated in a polymer matrix in the form of wires, bars, strands or grids. The FRP have shown great potentials and functionality in reinforcement for concrete, particularly where durability is of main concern. Nowadays, FRP have been used as one of the structural reinforcement materials and also for bridge construction materials such as bridge decks. FRP can play an important role in strengthening and retrofitting of degraded or strength deficient existing structures. Despite of its light-weight, remarkable high strength and high corrosion resistance, FRP presents an attractive material for structural rehabilitation. Furthermore, FRP strengthening makes very little changes to the dimension of the existing structural member due to its form of thin sheets.

Islam (2005), studied on “Shear Strengthening of RC Deep Beams using Externally Bonded FRP systems” to study the shear strengthening of reinforced