EXPERIMENTAL STUDY ON THE BEHAVIOUR OF REINFORCED CONCRETE DEEP BEAMS WITH LARGE CIRCULAR OPENINGS STRENGTHENED USING CFRP

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ABSTRACT

This experimental research was conducted to study the behaviour of unstrengthen RC deep beams with openings and strengthened using Carbon Fiber Reinforced Polymer (CFRP). Strengthening configuration of CFRP-wrap used in this study were U-wrap and surface-wrap which applied with one layer of CFRP and in vertical alignment (90°). Four RC deep beams which included a solid control beam, a beam with two large circular openings, beams with two large circular openings strengthened using U-wrap and surface-wrap were tested to failure under four-point loading. All the beam specimens were in a dimension of 120 x 600 mm and 2400 mm in length. The support and loading point were located at 300 mm and 800 mm from the edge of the RC deep beams, respectively. Circular openings was designed with a standard of 0.45h which considered as large circular openings in a diameter of 270 mm that located 435 mm from the edge of the RC deep beams. Shear span-to-depth ratio (a/h) in this study was 0.83 in which the distance between the loading point and the support was 500 mm in order for the beam specimens to fail in shear region. RC deep beam with large circular openings, NS-BCO greatly reduced the beam strength, approximately 51.20 % as compared to the control beam. On the other hand, RC deep beam with circular openings strengthened using U-wrap, UW-BCO increases the beam strength up to almost 85.0 % as compared to NS-BCO. Hence, the most effective strengthening method was U-wrap, UW-BCO which re-gained the beam strength up to 90.28 % as compared to control beam.
ABSTRAK

Kajian eksperimen telah dijalankan untuk mengkaji tingkah laku bertetulang rasuk yang mendalam konkrit yang tidak diperkukuhkan dengan pembukaan dan diperkukuhkan menggunakan Serat Karbon Mengukuhkan Polimer (CFRP). Konfigurasi pengukuhan CFRP-meledingkan yang digunakan dalam kajian ini adalah U-meledingkan dan permukaan-meledingkan yang ditampal dengan satu lapisan CFRP dan dengan penjajaran menegak, (90°). Empat bertetulang rasuk yang mendalam konkrit adalah termasuk rasuk kawalan pepejal, rasuk dengan dua pembukaan bulat besar, rasuk dengan dua pembukaan bulat besar diperkukuhkan menggunakan u-meledingkan dan permukaan-meledingkan diuji dengan kegagalan di bawah empat mata muatan. Semua spesimen rasuk berada dalam dimensi 120 x 600 mm dan 2400 mm dalam panjang. Sokongan dan muatan titik terletak 300 mm dan 800 mm dari tepi bertetulang rasuk yang mendalam konkrit, masing-masing. Pembukaan bulat direka dengan taraf 0.45h yang dianggap pembukaan bulat yang besar dalam garis pusat 270 mm yang terletak 435 mm dari tepi bertetulang rasuk yang mendalam konkrit. Rentang ricih nisbah kedalaman (a / h) dalam kajian ini adalah 0.83 di mana jarak antara titik beban dan sokongan adalah 500 mm supaya spesimen rasuk gagal di rantau ricih. Bertetulang rasuk yang mendalam konkrit dalam dengan pembukaan bulat besar, NS-BCO dikurangkan kekuatan rasuk, kira-kira 51.20% berbanding dengan rasuk kawalan. Sebaliknya, bertetulang rasuk yang mendalam konkrit dengan pembukaan bulat diperkukuhkan menggunakan U-meledingkan, UW-BCO meningkatkan kekuatan rasuk sehingga hampir 85.0 % berbanding dengan NS-BCO. Oleh itu, kaedah pengukuhan yang paling berkesan adalah U-meledingkan, UW-BCO dengan pengembalian kekuatan rasuk hampir 90.28% berbanding dengan rasuk kawalan.
# TABLE OF CONTENTS

<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>SUPERVISOR’S DECLARATION</td>
<td>ii</td>
</tr>
<tr>
<td>STUDENT’S DECLARATION</td>
<td>iii</td>
</tr>
<tr>
<td>ACKNOWLEDGEMENTS</td>
<td>iv</td>
</tr>
<tr>
<td>ABSTRACT</td>
<td>v</td>
</tr>
<tr>
<td>ABSTRAK</td>
<td>vi</td>
</tr>
<tr>
<td>TABLE OF CONTENTS</td>
<td>vii</td>
</tr>
<tr>
<td>LIST OF TABLES</td>
<td>x</td>
</tr>
<tr>
<td>LIST OF FIGURES</td>
<td>xi</td>
</tr>
<tr>
<td>LIST OF SYMBOLS</td>
<td>xv</td>
</tr>
<tr>
<td>LIST OF ABBREVIATIONS</td>
<td>xvi</td>
</tr>
</tbody>
</table>

# CHAPTER 1     INTRODUCTION

1.1 Background of Study 1
1.2 Problem Statement 3
1.3 Research Objective 4
1.4 Scope of Study 4
1.5 Research Significance 5

# CHAPTER 2     LITERATURE REVIEW

2.1 Design Standard for Dimension of RC Deep Beams 6
2.1.1 Building Code Requirements for Structural Concrete (ACI 318-83) revised 1986 and New Zealand Standard Code (NDS-3101-2006) 6
2.1.2 Canadian Code (CAN3-A23.3-M84) 7
2.1.3 Draft Eurocode & CEB-FIP Mode Code 7
2.2 Openings 8
2.2.1 Shape of Openings 8
2.2.2 Size of Openings 9
2.2.3 Location of Openings, Loadings and Supports 10
CHAPTER 3 METHODOLOGY

3.1 Overview 23
3.2 Materials Characteristics 23
  3.2.1 Reinforcement Steel Bars 23
  3.2.2 Concrete 24
  3.2.3 CFRP and Epoxy Resin 25
3.3 Specimen Details 27
  3.3.1 Arrangement of Reinforcement Steel Bars 27
  3.3.2 Strengthening Configuration of CFRP-Wrap 28
3.4 Preparation of RC Deep Beams 30
  3.4.1 Formworks for 4 RC Deep Beams 31
  3.4.2 Reinforcement Steel Bars for 4 RC Deep Beam 32
  3.4.3 Large Circular Openings for 3 RC Deep Beams 33
  3.4.4 Preparation Work before Concreting and Curing 34
  3.4.5 Concreting, Casting and Curing Process 35
  3.4.6 Dismantle of Formworks and Preparation Work before Four-Point Loading Test 37
3.5 Laboratory Testing 39
  3.5.1 Slump Test 40
  3.5.2 Concrete Compression Test 41
  3.5.3 Four-Point Loading Test 43
3.6 Research Flow Chart 45

CHAPTER 4 RESULTS AND DISCUSSION

4.1 Overview 47
4.2 Slump test 47
4.3 Concrete Compression Test 47
4.4 Behaviour of Load-Deflection Curve 49
  4.4.1 CB 51
  4.4.2 NS-BCO 52
  4.4.3 UW-BCO 53
4.4.4 SS-BCO 54

4.5 Four-Point Loading Test 55

4.5.1 Crack Patterns and Failure Modes 55
  4.5.1.1 Control Beam (CB) 55
  4.5.1.2 RC Deep Beam with Circular Openings (NS-BCO) 57
  4.5.1.3 RC Deep Beam with Circular Openings Strengthened Using U-Wrap (UW-BCO) 59
  4.5.1.4 RC Deep Beam with Circular Openings Strengthened Using Surface-Wrap (SS-BCO) 60

4.6 Ultimate-Load Capacity 62

4.7 Summary for Effective Strengthening Method 64

CHAPTER 5 CONCLUSION AND RECOMMENDATIONS

5.1 Overview 66

5.2 Conclusion 66

5.3 Recommendations 67

REFERENCES 68

APPENDICES 70

A Concrete Compression Test Results 70

B Control Beam (CB) Data 71

C RC Deep Beam with Circular Openings (NS-BCO) Data 72

D RC Deep Beam with Circular Openings Strengthened Using CFRP (UW-BCO) Data 73

E RC Deep Beam with Circular Openings Strengthened Using CFRP (SS-BCO) Data 74
# LIST OF TABLES

<table>
<thead>
<tr>
<th>Table No.</th>
<th>Title</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>3.1</td>
<td>Test that conducted in this experimental study</td>
<td>40</td>
</tr>
<tr>
<td>3.2</td>
<td>Test matrix</td>
<td>40</td>
</tr>
<tr>
<td>4.1</td>
<td>Data of yield point, yield deflection, ultimate load and ultimate</td>
<td>50</td>
</tr>
<tr>
<td></td>
<td>deflection for 4 RC deep beams</td>
<td></td>
</tr>
<tr>
<td>4.2</td>
<td>First visual cracking load (kN), ultimate-load capacity (kN) and</td>
<td>55</td>
</tr>
<tr>
<td></td>
<td>failure modes</td>
<td></td>
</tr>
<tr>
<td>4.3</td>
<td>Reduction, increases and re-gained strength of beam specimens</td>
<td>63</td>
</tr>
<tr>
<td>Figure No.</td>
<td>Title</td>
<td>Page</td>
</tr>
<tr>
<td>-----------</td>
<td>-----------------------------------------------------------------------</td>
<td>------</td>
</tr>
<tr>
<td>2.1</td>
<td>a) Beam 4. 110 mm (0.55D) openings at L/4 distance and b) Beam 5. 90 mm (0.45D) openings at L/4 distance</td>
<td>9</td>
</tr>
<tr>
<td>2.2</td>
<td>a) Beam 2. 110 mm (0.55D) openings at L/8 distance and b) Beam 3. 90 mm (0.45D) openings at L/8 distance</td>
<td>10</td>
</tr>
<tr>
<td>2.3</td>
<td>Typical specimen details (unit: mm)</td>
<td>11</td>
</tr>
<tr>
<td>2.4</td>
<td>Specimen 4</td>
<td>12</td>
</tr>
<tr>
<td>2.5</td>
<td>Load-deflection curve of specimen 4</td>
<td>12</td>
</tr>
<tr>
<td>2.6</td>
<td>Crack patterns and failure mode of control beam</td>
<td>13</td>
</tr>
<tr>
<td>2.7</td>
<td>Specimen 9 after testing</td>
<td>14</td>
</tr>
<tr>
<td>2.8</td>
<td>Load-deflection curve for specimen 9 and 10</td>
<td>14</td>
</tr>
<tr>
<td>2.9</td>
<td>Test Results</td>
<td>15</td>
</tr>
<tr>
<td>2.10</td>
<td>a) Failure mode A and b) Failure mode B</td>
<td>16</td>
</tr>
<tr>
<td>2.11</td>
<td>Internal strengthening for pre-planned openings of RC deep beam with openings</td>
<td>17</td>
</tr>
<tr>
<td>2.12</td>
<td>Details of specimens</td>
<td>18</td>
</tr>
<tr>
<td>2.13</td>
<td>CFRP strengthening scheme</td>
<td>19</td>
</tr>
<tr>
<td>2.14</td>
<td>Failure modes of the CFRP-strengthened beams</td>
<td>20</td>
</tr>
<tr>
<td>2.15</td>
<td>Strengthening configuration of C-cfrp-f</td>
<td>21</td>
</tr>
<tr>
<td>2.16</td>
<td>Failure mode of C-cfrp-f</td>
<td>22</td>
</tr>
<tr>
<td>3.1</td>
<td>Reinforcement steel bars of T10, T16 and R6</td>
<td>24</td>
</tr>
<tr>
<td>3.2</td>
<td>All RC deep beams were cast with same batch of ready-mix concrete</td>
<td>25</td>
</tr>
<tr>
<td>3.3</td>
<td>Spacer block</td>
<td>25</td>
</tr>
<tr>
<td>3.4</td>
<td>Carbon fiber-reinforced polymer (CFRP)</td>
<td>26</td>
</tr>
</tbody>
</table>
3.5 Sikadur 330 of component A and B
3.6 Arrangement of reinforcement steel bars from AutoCAD software
3.7 Arrangement of reinforcement steel bars from experimental works
3.8 a) Front view of UW-BCO b) Back view of UW-BCO c) Front view of SS-BCO and d) Back view of SS-BCO
3.9 a) Strengthening configuration of U-wrap for UW-BCO and b) Strengthening configuration of surface-wrap for SS-BCO
3.10 a) Plywood and b) Woods (1 x 2 inch)
3.11 Bend saw machine
3.12 Completed formworks for 4 RC deep beams
3.13 Progress of cutting reinforcement steel bars by using steel cutting machine
3.14 Completed reinforcement steel frame
3.15 Formworks with circular polystyrene that a) before concreting and b) after concreting
3.16 a) Silicon glue and silicon glue gun and b) Edge of formwork sealed with silicon glue
3.17 Formworks with reinforcement steel frames and circular polystyrenes which applied with oil and silicon glue a) Control beam b) RC deep beam with circular openings
3.18 Concreting works with a) vibrating the concrete and b) smoothing the concrete surface
3.19 Curing process of 4 RC deep beams
3.20 Dismantle of formworks
3.21 RC deep beams with white paint, grid line and strain gauges a) CB and b) NS-BCO
3.22 Step of applying CFRP and epoxy resin a) Grinding, sandblasting and cleaning b) 1 part of component B with 4 part of component A (Sikadur 330) c) Mixed uniformly to
formed epoxy resin and d) Applying of CFRP and epoxy
42 resin to the concrete surface

3.23 Cubes with 150 mm x 150 mm x 150 mm (width x height x length) 42

3.24 Concrete compression test that tested with compression machine 43

3.25 Four-point loading test a) In UMP (NS-BCO) and b) In UiTM (CB) 44

3.26 Methodology chart 45

4.1 Types of slump 47

4.2 Slump test 47

4.3 Type of failure mode for concrete compression test 48

4.4 Cubes after concrete compression test a) C1 (3 days) b) C4 (7 days) c) C7 (14 days) and d) C12 (28 days) 48

4.5 Graph of sample age (days) versus M35 concrete cube compressive strength (N/mm²) 49

4.6 Load-Deflection Curve of CB 51

4.7 Load-deflection curve of NS-BCO 52

4.8 Load-deflection curve of UW-BCO 53

4.9 Load-deflection curve of SS-BCO 54

4.10 Failure mode of CB 56

4.11 Diagonal cracks that appeared on left view of the CB a) Front view of CB and b) Back view of CB 57

4.12 Failure mode of NS-BCO 58

4.13 Diagonal cracks appeared on NS-BCO a) Right view of NS-BCO and b) Left view of NS-BCO 58

4.14 Failure mode of UW-BCO 59

4.15 CFRP with epoxy resin that peeling off with concrete from UW-BCO a) Front view and b) Back view 60
<table>
<thead>
<tr>
<th>Section</th>
<th>Description</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>4.16</td>
<td>Diagonal cracks on front view of SS-BCO a) front view b) left view and c) right view</td>
<td>61</td>
</tr>
<tr>
<td>4.17</td>
<td>Diagonal cracks on back view of SS-BCO a) Back view b) Left view and c) Right view</td>
<td>62</td>
</tr>
<tr>
<td>4.18</td>
<td>Comparison of load-deflection curve</td>
<td>64</td>
</tr>
</tbody>
</table>
LIST OF SYMBOLS

\( l_0 \)  Clear span
\( \Theta \)  Diameter
\( l \)  Effective span
\( \delta_u \)  Ultimate deflection
\( P_u \)  Ultimate load
\( \delta_y \)  Yield deflection
\( P_y \)  Yield load
<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>a</td>
<td>Shear span (Distance between support and loading)</td>
</tr>
<tr>
<td>ACI</td>
<td>American Concrete Institute</td>
</tr>
<tr>
<td>AFRP</td>
<td>Aramid fiber-reinforced polymer</td>
</tr>
<tr>
<td>B</td>
<td>Bottom of shear span-near loading point</td>
</tr>
<tr>
<td>BCO</td>
<td>RC deep beam with circular openings</td>
</tr>
<tr>
<td>C</td>
<td>Mid of shear span</td>
</tr>
<tr>
<td>CAN</td>
<td>Canadian</td>
</tr>
<tr>
<td>CFRP</td>
<td>Carbon fiber-reinforced polymer</td>
</tr>
<tr>
<td>d</td>
<td>Effective depth</td>
</tr>
<tr>
<td>FRP</td>
<td>Fiber-reinforcement polymer</td>
</tr>
<tr>
<td>FS</td>
<td>FRP strengthening</td>
</tr>
<tr>
<td>H or h</td>
<td>Depth</td>
</tr>
<tr>
<td>I.S.</td>
<td>Indian Standard</td>
</tr>
<tr>
<td>LVDT</td>
<td>Linear Variable Displacement Transducer</td>
</tr>
<tr>
<td>NDS</td>
<td>New Zealand Standard</td>
</tr>
<tr>
<td>NS</td>
<td>No strengthening</td>
</tr>
<tr>
<td>OPC</td>
<td>Ordinary Portland Cement</td>
</tr>
<tr>
<td>RC</td>
<td>Reinforced concrete</td>
</tr>
<tr>
<td>S</td>
<td>Satisfactory failures</td>
</tr>
<tr>
<td>SS</td>
<td>Surface strengthening</td>
</tr>
<tr>
<td>T</td>
<td>Top of shear span-near support</td>
</tr>
<tr>
<td>U</td>
<td>Unsatisfactory failures</td>
</tr>
<tr>
<td>UMP</td>
<td>Universiti Malaysia Pahang</td>
</tr>
<tr>
<td>UiTM</td>
<td>Universiti Teknologi Mara</td>
</tr>
<tr>
<td>------------</td>
<td>---------------------------</td>
</tr>
<tr>
<td>UW</td>
<td>U-wrap</td>
</tr>
</tbody>
</table>
CHAPTER 1

INTRODUCTION

1.1 BACKGROUND OF STUDY

In this 21st century, we realised that traditional methods are replaced by modern method from time to time and become more friendly use. Reason is the modern method have more advantaged then traditional method. In civil engineering field, there have been a trend that RC deep beams with openings are implanted for ease the installation of building services. The difference between RC beam and RC deep beam, is the depth of RC deep beam can be comparable with its own length but the dimension of RC beam is not limited. RC beam/deep beam can be classified into simply supported beam and continuous beam that based on the design standard, same goes with its own dimension. Function of the RC beam and RC deep beam are the same, which are to transfer the load that applied on itself to the column. Application of RC deep beam are normally for tall building structure (floor diaphragms, shear walls, wall footings, transfer gird & pile caps) and offshore structure.

Building services are installed through the RC deep beam with openings. RC deep beam with different shape of openings are for different kind of building services. As an example, circular openings are for the installation of piping, ducts, computer networks, telephone circuits and power cable. Moreover, Mansur & Tan (1999) state that square and rectangular openings are for air-conditioning services. Behaviour of RC deep beam such as stiffness, ultimate load capacity, first cracking, cracks pattern, failure mode and load-deflection curve are affected with openings through itself.
Openings can be classified into two that are pre-planned openings and post-planned openings. This both method can leaded to major cost saving for the construction project in the end. Pre-planned openings is which the shape, location and size of openings are decided on the design stage before the RC deep beams are constructed to formed the structural building. During the design stage, internal strengthening is the best choice to strengthen up the RC deep beams with openings. As for the post-planned openings, drilling process is conducted for the RC deep beam to have openings. This method usually applied on reconstructed and newly constructed structural building which involved relocation of building services. In this situation, external strengthening is commonly used to strengthen up the RC deep beams with openings, since it is not economical and kind of costly to reconstruct the whole structural building.

Advantages of pre-planned openings and post-planned openings have the same advantages that are headroom can be reduced by passing the piping and ducts utility through the RC deep beams with openings instead of hanging its down below the RC deep beam which are covered by ceiling causes increases of headroom; Cost saving can be done at the cost of installation building services with reduced the length of piping and ducts by passing through the RC deep beams with openings. Moreover, major cost saving and improvement on structural capacity by frame supports undergoes gravity loading & seismic excitation can only be done in pre-planned openings. These openings reduced the headroom, height of the building and faintly in weight of concrete beams which bring to such advantages.

This experimental study is based on the pre-planned openings. Hence, the RC deep beams with large circular openings must apply external strengthening. External strengthening can be classified into traditional method and modern method. Referring to the traditional method, steel plate can be installed on to the RC beams by adhesive bonding and bolted construction. This can increases the serviceability & ultimate load capacity of the RC beam section and available for maintenance & inspection. Disadvantaged of using steel plate as external strengthening are taking part of corrosion that become heavy when come in bigger size and need specialized in handling & installation.
After FRP is invented and proved that it can increases the strength of RC beam through previous experimental researches, it have replaced the steel plate to become a modern method. FRP can be classified into CFRP, GFRP and AFRP that contains carbon fibers, glass fibers and aramid fiber which the products come in the form of sheets, laminates, wraps and strips. The application for the CFRP is mainly on active strengthening to withstand the loads are constantly loaded; For GFRP is on passive strengthening to resist the seismic wave that transfer from earthquake, explosion and volcano eruption; AFRP can be applied in the field of blast mitigation and prevent bridge columns from collapse due to impact of vehicles. Thus, according to the applications of FRP the most suitable used for external strengthening in RC deep beams with openings is CFRP. The advantages of using CFRP are good in long-term behaviour, fatigue behaviour, alkali resistance & wear behaviour, resist to corrosion, light in weight and have high tensile strength & deformation capacity. Here come the disadvantages of CFRP that are cost for installation of CFRP is expensive and degradation is occurred when expose to high temperature.

1.2 PROBLEM STATEMENT

Experimental study on behaviour of RC deep beams with openings have been widely carry out under condition such as with difference shape of openings, size of openings and location of openings. There are merely data and result collect regarding the experimental study on behaviour of RC deep beams with large circular openings strengthened using CFRP. RC deep beam is come with restrict in depth which the openings of larger circular shape on it affect the behaviour of RC deep beam that causes the beam on failure mode and lead to structural building failure. This experimental study is related to the post-planned openings for the installation of building services. Normally, large circular openings are for the passes of utility pipe and ducts which are bigger in size through the RC deep beam. Openings causes reduction of RC deep beam in stiffness and ultimate load capacity that lead to exorbitant cracking and deflection. According to Campione & Minafò (2012), the failure mode was confirmed when the cracks started at the mid shear span and propagated to become two diagonal cracks which appeared between the curve contour of the circular openings and the edge of base plates. Problems can be solve by strengthen the openings region on the RC deep beam with difference
arrangement and configuration of CFRP wraps which have the ability to regain the beam strength.

1.3 RESEARCH OBJECTIVE

The main purpose of this experimental study is to study the behaviour of RC deep beams with large circular openings. Objectives of this experimental study are stated as below:

i. To determine the behaviour of RC deep beams with large circular openings (without CFRP and strengthening using CFRP wrap) in terms of load-deflection behaviour, crack pattern and failure mode.

ii. To identify the effects of openings in terms of size, shape and location.

iii. To identify the most effective strengthening configuration using CFRP in RC deep beams with openings.

1.4 SCOPE OF STUDY

The scope of this experimental study is to study the behaviour of RC deep beams with large circular openings strengthened using CFRP. Rectangular RC deep beams that are simply supported with total of 4 are tested to failure mode under four-point loading. Those 4 RC deep beams are cast into solid RC deep beam (act as a control beam), RC deep beam with large circular openings and 2 RC deep beams with large circular openings strengthened using CFRP. Large circular openings with diameter of 270 mm and the supports are located 300 mm start from both edge of the RC deep beam. In order to have failure mode on shear region instead of flexural region, the point loads are located a = 500 mm from the both supports by taking the formula of shear span-to-depth ratios, a/H = 0.83. External strengthening by using difference arrangement and configuration of CFRP are to determine the percentage of the beam strength regain. Dry application method have been used to applied the CFRP (Sikawrap-300C) after the mid-viscous Sikadur-330 resin have been applied uniformly on the surface of RC deep beams that need to be strengthened with thickness of 3 mm. All rectangular RC deep beams have the identical dimension of width (120 mm), depth (600 mm) and length (2400 mm). Data and
results are collected to analyse the ultimate load capacity, load-deflection, crack patterns and failure mode of each RC deep beams. Hence, comparison can be made between each other.

1.5 RESEARCH SIGNIFICANCE

Data and results of ultimate load capacity, load-deflection, crack patterns and failure mode are gained from this experimental study. Based on this data and results, the location of openings on RC deep beam by drilling process on reconstructed and newly constructed structural buildings should be avoided on shear region that near to the column (act as supports) which have the highest percentage in reduction of beams stiffness, ultimate load capacity and strength. On this experimental study, circular openings are used because it is the most utilisable shape that used in building services that applied in all the tall buildings. Moreover, large circular openings are for the installation of pipes, ducts and power cables that bigger in diameter. Since, RC deep beams with openings cause reduction in beams stiffness, ultimate load capacity and strength, external strengthening using CFRP wrap is applied. When facing this problems in real case, engineers can used the most effective method to strengthen up the RC deep beams with large circular openings because the installation of CFRP is expensive.
CHAPTER 2

LITERATURE REVIEW

2.1 DESIGN STANDARD FOR DIMENSION OF RC DEEP BEAMS

RC deep beam is a beam which have a dimension that in depth which bigger than the regular beam and may corresponding with its own length. Functions of the RC deep beam are to transferred and withstand loads which are higher than the capable of regular beam. Normally, the application of RC deep beams are on tall building structures and offshore structures. As an example: floor diaphragms, shear walls and wall footings who act as the load which sit on the RC deep beams for it to carried and transferred load to the columns; In foundation, RC deep beams act as a transfer girder between pile caps to connected all the pile caps together. A foundation are formed and to transfer load to the piles who hold on to the soil. Design standard for dimension of RC deep beams can be based on Building Code Requirements for Structural Concrete (ACI 318-83) revised 1986, Canadian Code (CAN3-A23.3-M84), CIRIA Guide 2 (1977), Indian Standard Code (I.S.-456-2000), New Zealand Standard Code (NDS-3101-2006) and Draft Eurocode & CEB-FIP Mode Code.

2.1.1 Building Code Requirements for Structural Concrete (ACI 318-83) revised 1986 and New Zealand Standard Code (NDS-3101-2006)

Based on Kong (2002) and Kore & Patil (2013), RC deep beam can be classified in to simply supported beam & continuous beam. Those beams are designed to test on shear strength & flexural strength. The loads are applied on the top surface of the RC deep beam with supports at the bottom. According to Building Code Requirements for Structural Concrete, the design standard for dimension of simply supported beam and
continuous beam on shear strength come with formula of clear span, $l_o$ over effective depth, $d$ smaller than 5.0. For flexural strength, the formula for simply supported beam and continuous beam are different with $l_o / h$ smaller than 1.25 and $l_o / h$ smaller than 2.5.

On the other hand, the formula for designed the dimension of RC deep beam under New Zealand Standard Code can be tested for both shear strength and flexural strength. The formula is $l_o / d$ smaller than or equal to 3.6 for both simply supported beam and continuous beam are listed in.

2.1.2 Canadian Code (CAN3-A23.3-M84)

Canadian Code and Building Code Requirements for Structural Concrete have similar formula on design standard for RC deep beam on flexural strength test. For the shear strength, the distance from the load applied to the support must be smaller than 2d in order to have more than 50% of shear occurs at the supports. This ensured RC deep beam tested to fail in the shear mode that based on the shear-span over depth ratios concept listed in Kong (2002).

2.1.3 Draft Eurocode & CEB-FIP Mode Code

Design standard for dimension of RC deep beam did not stated in the Draft Eurocode but it referred to the design standard of CEB-FIP Mode Code in the book of Kong (2002). CEB-FIP Mode Code can be tested on both shear strength & flexural strength with $l_o / h$ smaller than 2.0 (simply support beam) and $l_o / h$ smaller than 2.5 (continuous beam).


Kong (2002) and Kore & Patil (2013) stated that RC deep beam which are simply supported beam and continuous beam can be categorized by the formulas of effective span, $l$ over depth, $h$ smaller than 2.0 and 2.5. The value of effective span must be chosen from which the value is smaller with the distance between center of supports or 1.15 times
the clear span. Differences between CIRIA Guide 2 & Indian Standard Code and Building Code Requirements for Structural Concrete & Canadian Code are:

- The formulas under CIRIA Guide 2 & Indian Standard Code can be used to design dimension of RC deep beam that tested on shear strength & flexural strength but formulas by Building Code Requirements for Structural Concrete & Canadian Code can only tested on flexural strength.
- There are slightly difference between the formulas of (CIRIA Guide 2 & Indian Standard Code) and (Building Code Requirements for Structural Concrete & Canadian Code) are the clear span changed to effective span.

2.2 OPENINGS

The trend of this few years on the design of concrete structure is RC deep beam with openings. Openings can be classified into pre-planned openings and post-planned openings which openings are through the RC deep beams for the installation of buildings services. Advantages of the openings are to ease the installation of building services that in turn come with financial saving. In balance, openings also bring negative impact that stiffness and ultimate load capacity of RC deep beams can be reduced or affected due the shape of openings, size of openings and location of openings. Location of loading and support also play importance part in controlling the shear span-to-depth ratio (a/H) which causes the RC deep beam to be failed in shear region or flexural region.

2.2.1 Shape of Openings

Shape of openings through the RC deep beam are mainly depend on the type of building services. There are many shape in this world but the shape of openings for building services that come in usable are circular, square and rectangular. As stated in Chin, Shafiq, & Nuruddin (2011), building services such as installation of piping, ducts, computer networks, telephone circuits and power cables are suitable for circular openings. Moreover, square and rectangular openings are normally for air-conditioning services only.
2.2.2 Size of Openings

Saksena & Patel (2013), Pimanmas (2010) and Somes & Corley (1974) reported that the size of circular openings can be classified as large when the diameter of circular bigger than the value of 0.25h. Based on Figure 2.1, different diameter of circular openings (0.55h and 0.45h) under L/4 distance from the support are tested on shear region. The test showed that 0.55h of circular openings decreases 52% of strength as compared to the solid RC deep beam; 0.45h of circular openings decreases 21% of strength as compared to the solid RC deep beam.

![Figure 2.1: a) Beam 4. 110 mm (0.55D) openings at L/4 distance and b) Beam 5. 90 mm (0.45D) openings at L/4 distance](image)

Source: Saksena & Patel (2013)

El Maaddawy & Sherif (2009) conducted a studies on thirteen RC deep beam with rectangular openings with/without CFRP strengthening. They have provided 3 size of rectangular openings that are 150 mm x 150 mm, 200 mm x 200 mm and 250 mm x 250 mm. The size of the openings are getting bigger determined by the ratio of openings size over depth which are 0.3, 0.4 and 0.5. Based on the RC deep beams with openings, 21% of average ultimate load capacity is reduced for openings size from 150 mm to 200 mm. As for openings size from 150 mm to 250 mm, the results showed that 51% reduction of average ultimate load capacity is occurred.
2.2.3 Location of Openings, Loadings and Supports

RC deep beam is tested to fail on shear region under four-point loadings with loadings applied on top surface of the RC deep beam and supports at the bottom. Referring to the research done by Saksena & Patel, (2013) the location of circular openings are placed on a distance from the support with L/2, L/4 and L/8 as shown in Figure 2.1 and 2.2. The results indicated that circular openings (0.55h and 0.45h) with L/8 distance decreases 62% and 31.82% of strength as compared to solid RC deep beam. Moreover, circular openings (0.55h) with L/2 distance (centre span of the beam) showed that no effect on ultimate load capacity as compared to solid RC deep beam.

![Beam 2. 110 mm (0.55D) opening at L/8 distance](image)

![Beam 3. 90 mm (0.45D) opening at L/8 distance](image)

**Figure 2.2:** a) Beam 2. 110 mm (0.55D) openings at L/8 distance and b) Beam 3. 90 mm (0.45D) openings at L/8 distance

Source: Saksena & Patel (2013)

For the location of loadings and supports, the distance between loading and support with rectangular openings is ranged with low shear span-to-depth ratio ($a/H$) between 0.5 and 2.0 stated in Campione & Minafò (2012) and Kong (1970). Experimental research done by Campione & Minafò (2012) are RC deep beams with circular opening located within the shear span and mid–span section. Shear span-to-depth ratio, $\frac{a}{H} = \frac{131.6}{480} = 0.27$ where shear span is the distance between loading and support as shown in Figure 2.3. The low shear span-to-depth ratio is to ensure that the RC deep beam with opening are tested to fail on shear region instead of flexural region. For circular opening placed at