FLEXURAL STRENGTHENING OF BEAMS WITH LARGE OPENING IN CRITICAL BENDING ZONE (STATIC CONDITION)

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CERTIFICATION OF APPROVAL

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By

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A project dissertation submitted to the
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Approved by,

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UNIVERSITI TEKNOLOGY PETRONAS
TRONOH, PERAK
JAN 2010

CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the originality of the work is my own expect as specified in the references and acknowledgements, and that the originality work contained herein have not been undertaken or done by unspecified sources or persons.

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(PREETPAL KAUR A/P RAGBIR SINGH)

ABSTRACT

This research study was conducted to investigate the flexural strengthening of concrete beams with large opening using CFRP strips. The principal focus was given to determine the effects of the circular and square shape of openings. The amount and configuration of CFRP strips was determined based on the failure behaviour of the corresponding beam without strengthening. The amount of opening (circular and square) was kept as 8% - 10% of the beam elevation. The circular opening caused about 3.5% load capacity loss as compared to the solid beam and square opening resulted in about 22% loss of capacity. After applying CFRP on the circular opening beam; the capacity was obtained as 64% higher than the capacity of the solid beam. Whereas with square openings; CFRP application increased the capacity by 14% with respect to the solid beam. After applying CFRP on the circular opening beam; the capacity was obtained as 67% higher than the capacity of the circular opening beam without CFRP strips. Whereas with square openings; CFRP application increased the capacity by 11% with respect to the square opening beam without CFRP strips.

ACKNOWLEDGEMENTS

I would like to thank and express my highest appreciation to the various people involved greatly towards making my final year project a successful and valuable one. First and foremost, I would like to thank my supervisor, Assoc. Prof. Dr. Nasir Shafiq for actively participating in universities' final year project. . I am also deeply grateful for his advice, encouragement and patience throughout the duration of the project carried out. Second, I would like to thank my graduate assistant, Miss Chin (PHD student) who found time in a very busy schedule to give me guidelines and answer my questions. Her effort in properly defining my scope of work as well as training plan and schedule has really inspired me. Her guidance throughout the lab work has helped me tremendously in completing the tasks encountered. Third, I would like to thank Mr Johan and Mr Hafiz (Lab Technicians) for their backing, attention, time and sharing their technical knowledge with me in answering my many questions. I have very much benefited from their professional and personal advice. Fourth, I would like to thank Miss Kirijaa, my project mate for helping me throughout my project carried out. She has been very kind and generous in giving her help. She also did bare with me in the hard labour during testing and casting the beams. Finally, I am sincerely grateful to my beloved parents for their financial and emotional support during carrying out my project.

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CHAPTER 1

INTRODUCTION

1.1 BACKGROUND

In the construction of modern buildings, tall buildings, and other industrial structures pipes and ducts are installed to accommodate essential services such as water supply, sewerage, air conditioning, electricity, telephone, and computer network. These pipes and ducts usually run vertically and horizontally. The horizontal layout of pipes and ducts run under the ceiling, which sometimes penetrated through RC columns [7]. It is obvious that the inclusion of openings in RC beams cause it become weak in load resistance due to shear and bending moment depending upon the size, shape and location of the openings.

The beam may also have excessive deflection under service load that is due to reduction of beam stiffness and also result in a considerable redistribution of internal forces and moments in a continuous beam. If the beam is provided with special reinforcement insufficient quantity, then the strength of the beam may be reduced to a critical degree. The openings in the beams may be different in shapes and sizes. Prentzas (1968), in his extensive experimental study, considered openings of circular, rectangular, diamond, triangular, trapezoidal and even irregular shapes. Among all these openings the most common ones are circular and rectangular. Circular openings are used to accommodate service pipes, such as for plumbing and electrical supply.

Rectangular openings are used for air conditioning ducts that are in rectangular shape. The corners of the rectangular openings are rounded off to reduce possible stress concentrated at the sharp corners. This will improve the cracking behaviour of the beam in service. Mansur and Hasnat (1979) have defined openings circular, square or nearly square in shape as small openings, whereas, according to Somes and Corley (1974), a circular opening may be considered as large when its diameter exceeds 0.25 times the depth of the beam web. Therefore, by referring Somes and Corley study the beams in this research is classified as large openings because the openings diameter is 230mm for circular or 210mm X 210mm for rectangular and it exceed the 0.25 times the depth of the beam web.

The carbon fibre reinforced polymer (CFRP) is one of the reinforced materials that are widely used for repairing all kind of RC structures. The CFRP is used as external reinforce to the concrete members, which is different from other reinforced material that is used to reinforce the concrete members internally. The CFRP is needed in upgrading and strengthening of structural capacity. It is mostly used in the bridge construction. CFRP strips are lighter, non-corrosive, and less intensive than the application of the steel plate or exterior post-tensioning. These strips are proven method of providing structural strengthening to structural elements. The lightweight of CFRP strips can provide ten times the tensile strength of steel. The capability of the CFRP to carry loads in tension can be used to strengthen against flexural, shear or compression, depending on how the CFRP strips are oriented to the longitudinal reinforcing steel. Steel has superior qualities in terms of strength and compatibility with concrete where steel is an effective concrete reinforcement. However steel is highly susceptible to oxidation when exposed to chlorides. Factors such as insufficient cover, poor design or workmanship, poor concrete mix and aggressive environment can break down the protection layer and may lead to corrosion of the steel rebars.

This study is focused to determine the flexural strengthening of reinforced concrete beams that are applied by CFRP strips and has large opening in the middle of the beams. To proceed with this project, the research will be carried out to investigate the effects of circular and square shaped opening in the critical bending zone of beam and to develop the strength in the beam, CFRP strips are used. This study is carried out by testing and doing experiments on the various kind of opening (circular and square) in beams with CFRP strips as a strengthening tool. After the experimental process is done the result is gathered and compared to obtain solution to this study. In **Figure 1.1** show the picture of a cracking pattern of beam under bending stress.

Figure 1.1: Cracking Pattern of Beams under Bending Stress

1.2 PROBLEM STATEMENT

To provide the opening of desired shape, size and location in a RC beam is always an issue between structural and M&E engineer. Sometimes M&E engineer has to change the complete layout of the ducting system because the required openings are not prevalent into the structurally appropriate locations. For example they may fall at the location of maximum bending moment. To overcome such problem an engineering solution through research activities is needed that can allow the flexibility to M&E engineer to layout the ducting system with an optimum option.

1.3 OBJECTIVE

The two main objectives of this study are:-

- to determine the effects of circular and square shaped opening provided in the critical bending zone in terms of capacity loss,
- to develop a strengthening technique using carbon fiber reinforced polymers (CFRP) that can ensure the return of the lost capacity by providing about 8% of opening.

1.4 SCOPE OF STUDY

This study can be divided into 3 section which are literature review section, experimental or testing section and data analysis section. In the literature review section, it shows the research about the properties of the CFRP strips and the advantages using CFRP strips. The literature review consist the theory and previous project that used the CFRP strips. In the experimental or testing section, the flexural capacity test's data and procedure by using self straining loading frame machine is shown. The test will require reinforced concrete beams with circular and square openings that are applied by CFRP strips. Five beams of concrete strength fcu=+/- 35Mpa are cast and subjected to bending forces to obtain the design with the highest recovered bending capacity. For the data analysis section, the data of the results are compared and discussed for the different kind of openings. The openings are circular with 230mm diameter and square with 210mm X 210mm cross section. The data is then analysed and discussed in order to present the test result of this study. To obtain a mix design with the concrete strength fcu=+/- 35Mpa, 15 cubes of 100mm X 100mm were cast and test. These cubes were test on different days (after 3 days, 7 days and 28 days). The concrete strength fcu value obtained on the 28^{th} is used as the reference design concrete strength. 3 cubes were test on the 3^{rd} day, 3 cubes were test on the 7^{th} day and 9 cubes were test on the 28^{th} day.

CHAPTER 2

2.0 LITERATURE REVIEW

For several decades Fiber Reinforced Polymeric (FRP) is a kind of polymer besides CFRP which is widely used in the aerospace industry. Recently both FRP and CFRP are becoming popular in the construction industry for strengthening purpose. This is due to CFRP has the advantages of compositing materials such as immunity to corrosion, a low volume to weight ratio, a high strength to weight ratio, and unlimited delivery length (in sheet form), thus eliminating the need for joints. The usage of CFRP is proved to be an effective means of improving, upgrading and also strengthening reinforced concrete beams. This CFRP is improving the efficiency of construction work. This is due to CFRP is applied externally to the reinforced concrete beam. The reinforced can only be applied internally in the beam. By using conventional method the beam has to hack the reinforced before the reinforced can apply internally in the beam. This will create problem in wasting money as it has to rectify the structurally deteriorated or functionally obsolete reinforced concrete beam.

Strengthening of concrete beams for bending with CFRP sheets is the method being used to study the arrangement of CFRP sheets which results in the highest bending carrying capacity for beams with large openings. Large openings in the middle of the beams with 8%-10% of the web area of the beam, shows a massive loss in bending strength of the beam. By placing in CFRP strips it will increase the bending strength in the beam. In this final year project, the composite material used for the strengthening purpose CFRP was chosen due to its various advantages. The following are some advantages of using CFRP for bending strengthening in the critical bending zone of the beam with large opening:

i. Tailorability; the CFRP sheets can be arranged to the loading condition to optimize the performance.
ii. It has a low weight which reduces transportation expenses and allows for some prefabrication that consequently reduces time at the job site.

iii. CFRP does not have a yield limit and more or less elastic up to failure.

iv. High elastic modulus and high strength in both tension and compression

The strongest and stiffest reinforcing fibers for polymer composites are carbon fibers. The most commonly used are glass fibers. These fibers are made of pure carbon in form of graphite and the fibers are low in density. These fibers also have a negative coefficient of longitudinal thermal expansion. These carbon fibers are very expensive and can give galvanic corrosion in contact with metals. Therefore they are generally used together with epoxy where high strength and stiffness is required. Generally, there are eight possible failure modes in CFRP strengthened reinforced concrete beams. Not all of this eight failure modes were observed in pervious researches or applications. For a simply supported reinforced concrete beam strengthened by CFRP the following four modes will most likely occur:

i) CFRP rupture in tension zone

ii) Concrete crush in compression

iii) Delamination between CFRP and concrete

iv) CFRP peeling off in curtail zone resulting from a combination of shear and tensile stresses in the plane of the longitudinal steel bars.

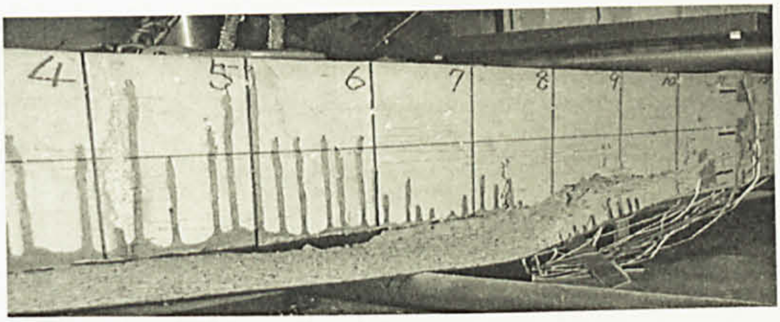


Figure 2.1: Peeling of CFRP

Figure 2.2: Delamination between CFRP and Concrete

A research on the difference behaviour of CFRP and steel reinforced beam was carried out by Muhammad Masood Rafi, Ali Nadjai, Faris Ali and Didier Taalamona [1], shows that the behaviour between CFRP and steel reinforced beam similar in many aspects. The numbers of cracks with equal average crack spacing at failure were developed in both types of beams. Beam reinforced with steel failed by steel yielding and beam reinforced by CFRP failed by concrete crushing as per design. This research also shows that the beam reinforced with CFRP deflected more than the beam reinforced with steel. However, after yielding of steel the rate of deflection in beam reinforced with steel is more than beam reinforced with CFRP. This research was carried out by casting 4 beams with the length of 2m and the cross-sectional was 120mm X 200mm. Each of the beams was reinforced with two longitudinal bats on the tension face (CFRP bars for CFRP reinforced beams and steel bars for steel reinforced beams). 20mm concrete cover was used all-around the beams. For all the beams the area and nominal yield concrete of the compression steel and nominal concrete strength were kept constant. The beams were left for air-drying and for each beam 4 cubes were cast for testing.

Another research on behaviour of CFRP strengthened the reinforced concrete beams with and without end anchorage provided at the ends of CFRP strips on the tension face of the beams which was carried out by C.-T. T. Hsu, W. Punurai, H. Bian and Y. Jia [2]. This research shows that CFRP strips that are externally epoxy bonded to the tension face of the beam is an effective technique to repair and retrofit the reinforced concrete beams under both monotonic and cyclic loads. Ductility of a CFRP strengthened beam is adequate if the beam is properly designed or anchored for under-reinforced concrete section. Besides that for any over-reinforced beams the CFRP strengthened beams with and without end anchorage do not improve both the flexural strength and ductility as compared to the control beam. For this research 12 beams were cast to test the flexural strength of the beams. The variables include different beam spans, cross-sectional, steel ratios, with or without CFRP and with or without end anchorage. The beams were divided into two categories, 6 beams for under-reinforced section beams and 6 beams for over-reinforced section beams.

A research done by Tom Norris, Hamid Saadatmanesh, Member, ASCE, and Mohammad R. Ehsani, Member, ASCE [3] on behaviour of damaged or under-strength concrete beams retrofitted with thin CFRP sheets. It shows that the CFRP sheets can increase the strength and stiffness of the existing concrete beam when bonded to the web and tension face. The direction of the reinforcing fibers is related to the magnitude of the increase and the mode of failure. CFRP sheets are placed perpendicular to cracks in the beams which largely increase the stiffness and strength in the beam and a brittle failure occurred due to concrete rupture as a result of stress concentration near of the CFRP. This shows that flexural or shear cracks in the beam were repaired. CFRP sheets which are placed obliquely to the cracks in the beam cause a smaller increase in strength and stiffness. This cause the beam to failure in ductile and preceded mode by warning signs such as snapping sounds or peeling of the CFRP. This research was done by casting 19 beams concrete beams which was applied with CFRP sheets at the tension flange and web. These beams were loaded to failure. Every beam had a cross-section of 127mm X 203mm. 13 beams were over-reinforced for shear by increasing the spacing of stirrups. These beams were reinforced in the manner to prevent shear failure and to isolate the flexural behaviour from shear behaviour. The 19 beams were cast for length of 2.44m and were simply supported. These beams were loaded at the quarter points to provide a region of constant moment and no shear in the centre of the beam.

Riyadh Al-Amery and Riadh Al-Mahaidi [4] also carried a research on the coupling of shear-flexural strengthening of RC beams. This research shows that CFRP strips enhance the shear strength of the concrete beam and contributes, compositely with the steel stirrups to the shear resistance. Besides that by using CFRP strips occurrence of debonding failure is prevented. This is done by providing an extra anchorage mechanism for the CFRP sheets. This CFRP strips also reduces the interface slip between the CFRP and the concrete section significantly. CFRP strips reduces one tenth of the slip values. This will enhance the composite action between the concrete beam and CFRP sheets leading to almost full composite state. Finally CFRP also increase the flexural strength up to 95% when this CFRP strips are used as anchor. If CFRP sheets are used alone, it will increase the flexural strength by 15%. The dominant mode of failure observed in the beams with straps is a ductile flexural failure with excessive yielding of internal steel prior to the rupture of CFRP sheets and crushing of the concrete. This research was carried out by casting 6 reinforced concrete beams with various CFRP retrofitting schemes. One of these beams was kept as a control beam for comparison and was kept without retrofitting. All the others beams were provided with either CFRP sheets for flexural strengthening or with coupled CFRP sheets and strips for overall strengthening. 2 of the beams were tested in four-point bending over a total span of 2.3m and a shear span of 700mm. The other 4 beams were tested in three-point bending. This intended to increase the applied moment at the critical section of the beam. These beams have a width of 140mm, depth of 260mm and the CFRP strips of 50mm wide one layer with a complete loop of 75mm overlapping. These strips were spaced 200mm along the beam span. The CFRP sheets are three layers applied centrally in a wet lay up process along bottom surface of the beams having a width of 100mm and a length of 200mm.

In conclusion all the researcher have proof that the CFRP strips increase the strength of the beam even if there is opening in the beam. CFRP not only increases the strength of the reinforced structure but also increases ductility and other aspects as explained above. This final year project is also using CFRP strips to increase the strength of the concrete beam in large opening beams so that it won't failure under critical bending zone. The openings will in circular and square in shape with 10%-20% of the web area from the overall area of the beam.

CHAPTER 3

3.0 METHODOLOGY

The methodology is divided into several parts which are literature review and information gathering, mixing and sampling fresh concrete and casting and curing cubes and beams. In literature review section, information regarding the failure of beam with large opening, properties of CFRP, bending moment in the beam and the failure under static condition is gathered by referring to respective books, journals and thesis developed by internal and external parties. The other two methods are experiments or testing carried out in the lab by referring the lab manual. The beam dimensions are large and special form-work is made to cast the concrete beams as the beams have large openings. The three experiments that are explained are done by referring the lab manual. In this research 5 beams with the following criteria would be tested for bending and is shown in **Table 3.1** below:

BEAM NO	1	2	3	4	5
CFRP strengthening	No	No	No	Yes	Yes
Shape of Opening	None	Circular (Φ230mm)	Square (210 X210mm)	Circular (Φ230mm)	Square (210 X210mm)
Spam of Beam (mm)	1800	1800	1800	1800	1800
Design Strength (Mpa)	+/- 35	+/- 35	+/- 35	+/- 35	+/- 35
Number of openings	0	1	1	1	1
Location of opening	-	Center of the beams	Center of the beams	Center of the beams	Center of the beams

Table 3.1: Criteria's for 5 Test Beams

Before carrying any lab experiment the mix design of the cubes is done. Firstly, a trial mix is to be carried out for the concrete of design strength +/- 35Mpa. Next, the mix design is calculated and amount of cement, coarse aggregates and fine aggregates are identified. Also, the moisture content of the aggregates is to be identified as drier aggregates absorb more water with could affect the water cement ratio. The quantity of water required is also calculated. The following steps are to be done before the beams can be cast:

1. Mixing and sampling of concrete (Trial Mix) to obtain optimum strength development of concrete in 28days.
2. The form work (non-permeable material) for the beam with opening is to be constructed according to the planned dimensions.
3. Reinforcement bars to be bent and installed as per design.
4. The design mix after the trial mix is batched to make test beams
5. Making of test beams (5 Nos)

3.1 MIXING AND SAMPLING FRESH CONCRETE [9]

Objective: Mixing and sampling fresh concrete in the laboratory (as recommended by BS 1881: Part 125: 1986)

Apparatus: A non-porous timber or metal platform, a pair of shovels, a steel hand scoop, measuring cylinder and a small concrete mixer

Procedure:

a) The quantities of cement, sand and course aggregate is weighed to make 1:2:4 concrete mix at water ratio of 0.6
b) Hand Mixing
   I. Cement and sand is mixed until uniform on the non-porous platform
   II. Coarse aggregate is poured and mixed thoroughly until uniform.
   III. Water is added to a hole formed in the center. The mixture is mixed thoroughly for 3 minutes or until the mixture appears uniform in color.

c) Machine Mixing

I. The concrete mixer is wet

II. The aggregate is poured and mixed for 25 seconds

III. Half the water is added and mixed for 1 minute and left for 8 minutes

IV. The cement is added and mixed for 1 minute

V. The remaining water available is added and mixed for 1 minute

VI. The machine is stopped and hand mixing is done to ensure homogeneity

VII. The concrete is poured onto the non-porous surface.

3.2 MAKING AND CURING CUBES AND BEAMS [10]

Objective: To cast and cure beams of given mix (as recommended by BS 1881: Part 111: 1983)

Apparatus: Form work for the test beams and 150mmX150mmX150mm moulds.

Procedure:

a) The inner faces of moulds will be brushed with oil and the screws tightened.

b) The mould is filled with concrete layers in 50mm deep layers approximately

c) Each layer is tamped 25times with the square face steel 25times for test cubes. It is ensured that the tamping passes through each layer.

d) After the top layer has been tamped, the surface of the concrete is struck off level with the top of the mould with a trowel.

e) Using a nail, the top surface of the concrete test cube is used to indicate the number and date of casting

f) The moulds are covered with polythene sheet or damp cloth to prevent evaporation and kept in the curing room for 24 hours.

g) After 24 hours, the concrete specimen is removed from the moulds and stored in the curing tank until they are to be tested at a temperature of 20 +/-5° C.

h) The preferred ages for testing are 3, 7, 28, and 56 days.

i) 12 specimens are made for each mix.

Note: The similar procedure is adopted for the casting of test beam using form works

3.3 TESTING 15 CUBES TO OBTAIN THE STRENGTH OF THE CONCRETE

A lab test was carried out at the concrete lab to test 15 cubes. The purpose of this test was to obtain the strength of the concrete after 28 days of curing. The expected concrete strength, fcu is 35+/- 5Mpa. These 15 cubes were design based on the trial mix ratio of cement, sand and gravel of 1:2:4 and water ratio of 0.5. For one cube by referring to the ratio, the amount of 100% OPC cement is 300kg/m^3, sand is 700kg/m^3, gravel is 1250kg/m^3 and water content is 150kg/m^3. These cubes dimension are 100mm x 100mm x 100mm. Therefore, for 15 cubes the amount of 100% OPC cement is 5 kg, sand is 11.5 kg, gravel is 20.5 kg and water content is 2.5 kg. The gravel size is 10mm. The cubes were cast using the concrete mixer machine and this concrete mixture were place into the 100mm x 100mm x 100mm moulds. 15 moulds were used to place the mixture. All the steps as explained above in the concrete mixing by machine are followed. A poker was used to apply vibration to the mixture in the mould. Three layers of mixture were place in the each mould and poker was used to vibrate after each layer was place. The vibration was only given for 2 seconds. It cannot be more than 2 seconds as it will enhance watering and segregation in the mixture. This will give wrong result later when tested under compression test. Then the cubes were left one day in the mould to harden. The next day, the moulds were open and the cubes were place in water for curing purpose. After that on the 3rd day three cubes were test on compression test. Then the other three cubes were test on the 7th day. The rest nine cubes were test on the 28th day. All the results were taken and the average value was taken as references. The major purpose of this cube testing is to find out the concrete strength, fcu on the 28th day. The concrete strength, fcu supposedly should be 35+/-5Mpa and this was achieved in this experiment.

3.4 CASTING 5 CONCRETE BEAMS WITH LARGE OPENING IN THE MIDDLE

In this research, the bending moment loss due to the large web opening is to be studied. By using CFRP it can be determined how much strength the beam regained even though there are large opening in the beam. As CFRP is an expensive material, the significance of using CFRP to regain the strength should be relatively feasible to be implemented in the industry. Five beams were cast to test the strength of the beams. Where two of these beams have circular openings (210mm diameter) in the middle of the beam and the other two has square openings (230mm X 230mm) in the middle of the beam. The fifth beam was solid beam where there was no opening in the beam. The concrete strength, fcu is 35+/- 5Mpa. All these 5 beams were cast following the lab manual and the steps are explained above. The beams have 2T12 rebar as the bottom and 2T10 rebar at the top of the beam. These rebars act as the main bars in the beams. The beams also have stirrups of R6 rebar with spacing of 300mm center to center. The beams were cast using the ready mix concrete with the strength of 35Mpa. The concrete cover used is 10mm top and bottom. First the formwork of the beams was prepared following the dimension of the beams. The dimensions of all 5 beams are 2000mm X 300mm X 120mm. For the square opening of the beam, wooden framework can be used to ensure the hollow section is maintained during casting. As for the circular opening, the hollow section can be maintained by using a pipe of external diameter Φ230mm. Form work must be applied with grease before the pouring of concrete. When the formwork for all the beams is done, with all the rebar and stirrups are placed as designed, the ready mix concrete is poured in the formwork. A poker was used to apply vibration the mixture in the formwork. Three layers of mixture were place in the each formwork and poker was used to vibrate after each layer was place. Poker vibrators to be used to ensure air is not entrapped and to avoid honeycomb in the concrete. However, the vibrator should not be used too long (more than 1 minute) which could lead to bleeding and segregation problems in the concrete later on. The top layer should not be vibrated, and surface to be finished. Then the concrete were left for three days in the formwork to harden. After three days, the formwork of the beams was open and the beams were place at the corridor of the lab for curing purpose by water. The beams are big in size and there are no curing tanks that are enough for these beams. Therefore the beams were cover with sacks and water daily. The functions of the sacks are to keep water so that the beams won't be over dried and to avoid surface cracks at the surface of the beams. After 28 days these beams was ready to be tested. The beams are tested using the self straining loading frame machine. The solid beam is tested first. Then the beams with the circular and square opening in the middle are tested. The CFRP is pasted based on the crack pattern that is obtained from the circular and square opening beams. This will increase the strength of the other two beams with circular and square opening. Finally the results and the graphs are compared so that this project achieves its objective. Below are some brief explanations on how the beams casting procedure and pictures:

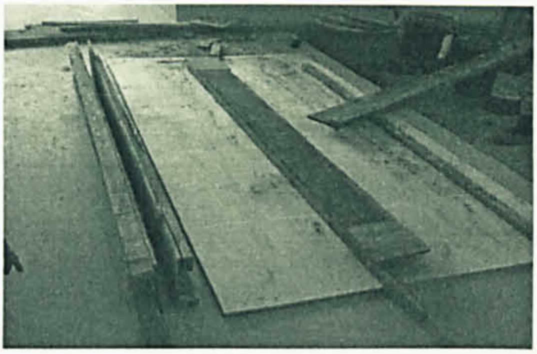


Figure 3.4.1: Ply wood and used form work from previous castings reused to construct the form work of required dimension to avoid wastage.

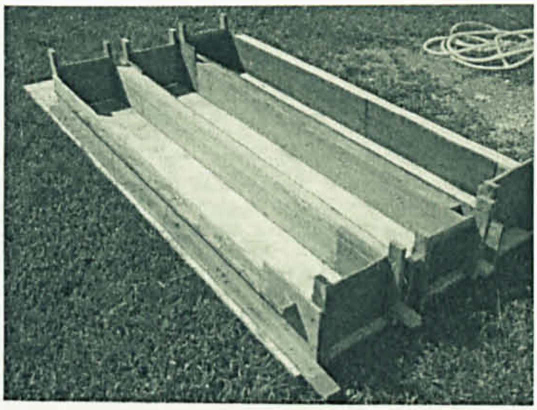


Figure 3.4.2: Completed form work of 3 beams to be cast on 1 plywood

Figure 3.4.3: Cutting of steel reinforcement bars (Y10 and Y12)

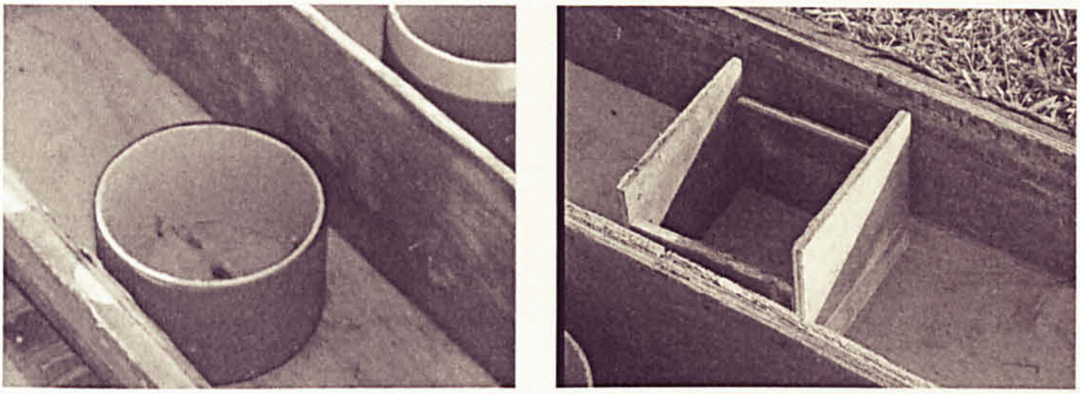


Figure 3.4.4: Special opening created at critical bending zone with Φ230mm for the circular opening and 210mm X 210mm for the square opening. The square opening was made using the spare wood and the circular opening was prepared using PVC pipes cut to the required size and depth. As the exact size of opening of the PVC pipe was not available at the market, the PVC size slightly smaller was glued with a rubber sheet with thickness sufficient to add the lack of opening size of the PVC to make Φ230mm.

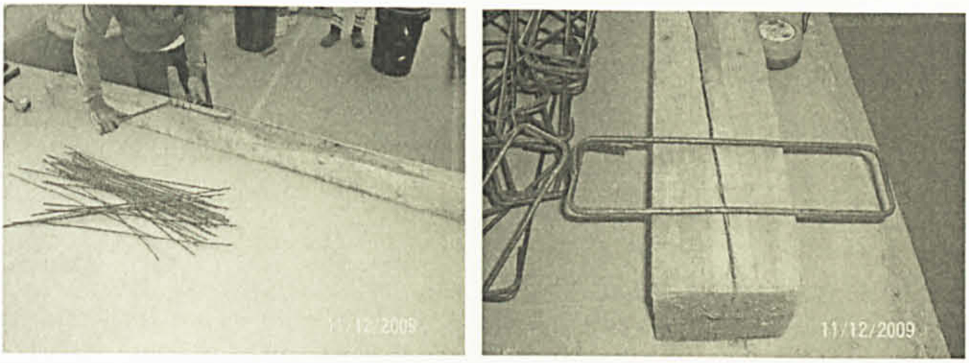


Figure 3.4.5: Bending of R6 links (Φ 6mm) with dimension 3"x 11" or 76mmX 280mm.

Figure 3.4.6: Steel Reinforcement bar bending activity (Y10 and Y12). Bars are bent about 3.5"

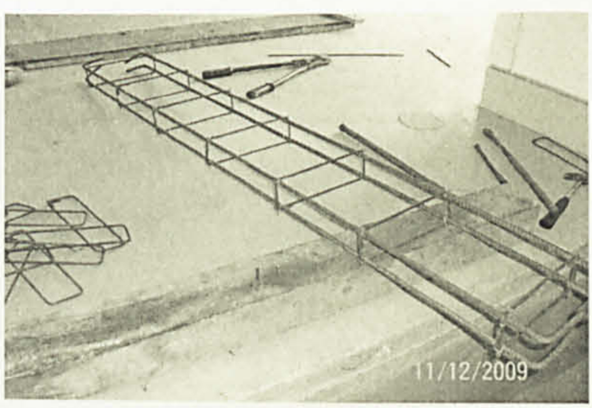


Figure 3.4.7: Completed steel reinforcement bars and the rebars are tying using the steel wires

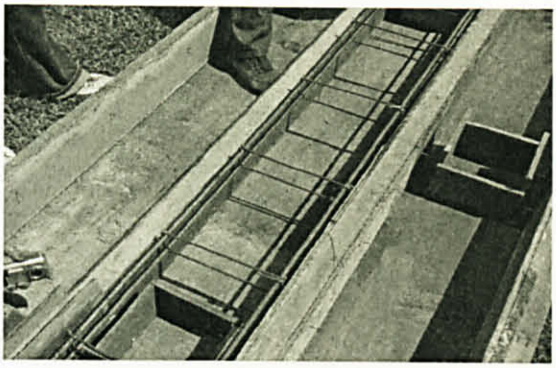


Figure 3.4.8: Placing Reinforcement bars into form work

Figure 3.4.9: Pouring Concrete into form work

Figure 3.4.10: Concreted Beams to be cured for 28 days by using wet sacks to avoid rapid heat loss which could lead to cracking.

CHAPTER 4

4.0 RESULTS AND DISCUSSION

From this final year project the knowledge or information that shall be gathered at the end of the study is the bending strengthening of concrete beams with large openings. The following objective or information shall be obtained from this project in the result and discussion section:-

i. The compressive strength of the concrete using Portland Cement (OPC) for the tested beams.
ii. The bending capacity of the beams with and without large opening which is tested.
iii. The difference in loss of bending capacity of beam using square and circular openings and beam without opening.
iv. The strengthening capacity of Carbon Fibre Reinforced Polymer and the ultimate arrangement of CFRP to optimize the regain of lost bending strength due to large openings.

4.1 COMPRESSIVE STRENGTH OF CONCRETE

A lab test was carried out at the concrete lab to test 15 cubes. The purpose of this test was to obtain the strength of the concrete after 28 days of curing. The expected concrete strength, fcu is 35+/- 5Mpa. These 15 cubes were design based on the trial mix ratio of cement, sand and gravel of 1:2:4 and water ratio of 0.5. For one cube by referring to the ratio, the amount of 100% OPC cement is 300kg/m^3, sand is 700kg/m^3, gravel is 1250kg/m^3 and water content is 150kg/m^3. These cubes dimension are 100mm x 100mm x 100mm. Therefore, for 15 cubes the amount of 100% OPC cement is 5 kg, sand is 11.5 kg, gravel is 20.5 kg and water content is 2.5 kg. The gravel size is 10mm. On the 3rd day three cubes were test on compression test. Then the other three cubes were test on the 7th day. The rest nine cubes were test on the 28th day. The concrete strength, fcu supposedly should be 35+/-5 Mpa and this was achieved in this experiment. The concrete strength increases as the day increases. The optimal day is on the 28th day, where on this the concrete will be fully hardened. The results are shown in the **Table 4.1.1** a graph is plotted in **Figure 4.1.1** to show the relation of the increasing concrete strength as the day increases.

Days	Cube	Compressive Strength (N/mm^2)	Average Stress (N/mm^2)
28	1	34.89	35.573
	2	35.01	
	3	34.5	
	4	34.05	
	5	36.81	
	6	36.83	
	7	36.55	
	8	36.89	
	9	35.54	
	10	35.04	
	11	36.21	
	12	34.69	
	13	35.5	
	14	36.03	
	15	35.06	

Table 4.1.1: Compression Test Result for 15 Cubes

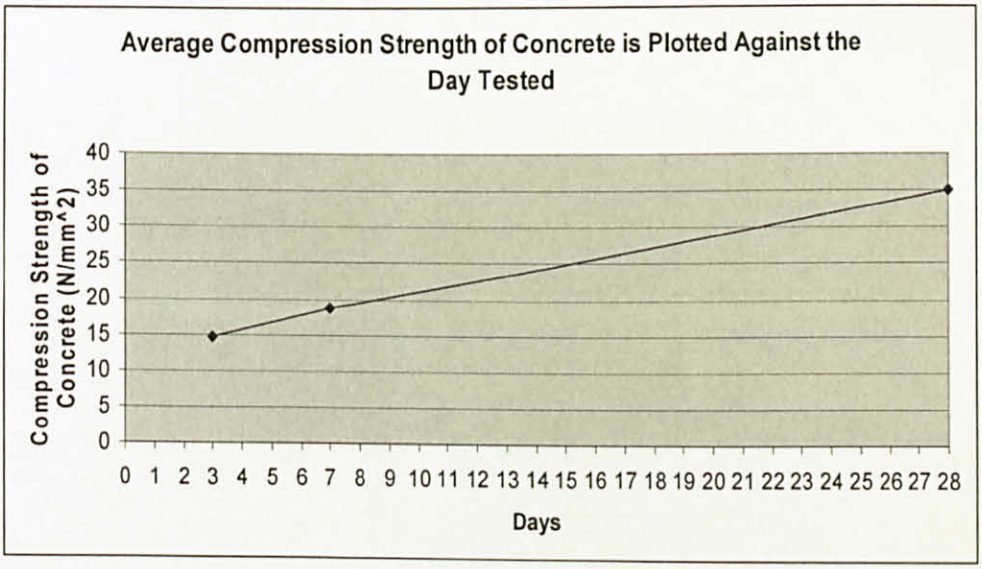


Figure 4.1.1: Average Compression Strength of Concrete increases as the Day Increases

4.2 REINFORCEMENT BAR DIMENSIONS

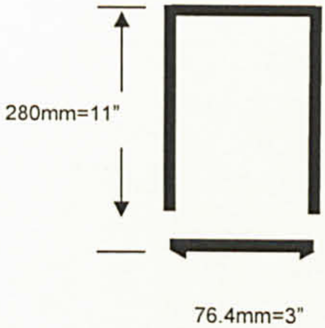


Figure 4.2.1: Cross Section Dimension of Beam Reinforcement

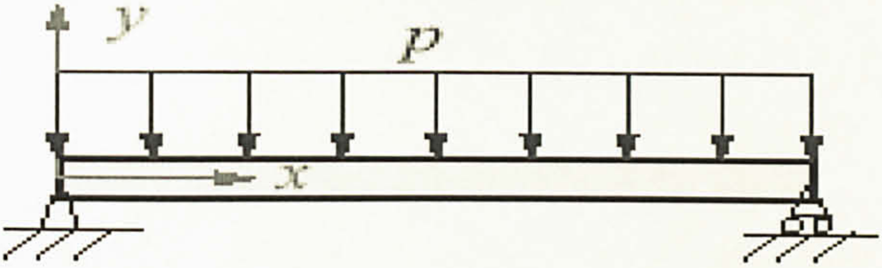


Figure 4.2.2: Simply Supported Beam with Uniform Load

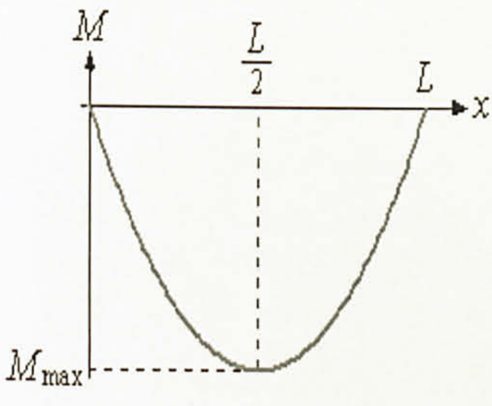


Figure 4.2.3: Moment Diagram (Beam without opening)

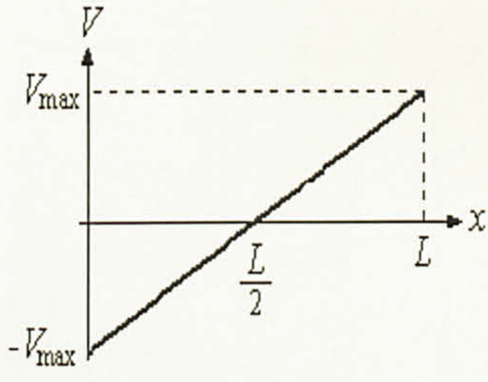
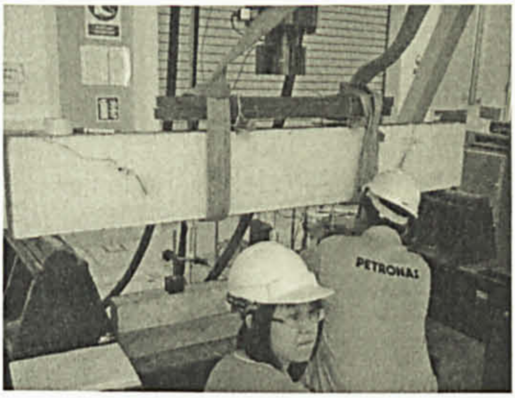


Figure 4.2.4: Shear Diagram (Beam without opening)

The **Figure 4.2.1** shows the cross section of the beam which is reinforced. The **Figure 4.2.2** shows the load distribution on the beam during the load is applied on the beams.

The load is distributed equally throughout the beam. The load is applied by using the self straining loading frame machine. **Figure 4.2.3 and 4.2.4** shows the maximum and minimum value of shear and bending moment in a beam. It shows that the beam undergo maximum bending moment at the center and maximum shear at the ends. It also shows that minimum bending moment occurs at the ends and minimum shear at the center of the beam. The beams are cast with circular and square opening in the middle. This opening is allocated at the maximum bending moment zone. It also shows that the beams are weak in the center due to bending failure. Therefore if proves that this project is done to achieve the maximum strength in the beam by using CFRP.

4.3 STATIC LOAD TEST OF CONTROL BEAM AND BEAMS WITH LARGE OPENING IN WEB AT CRITICAL BENDING ZONE (CIRCULAR AND SQUARE OPENING OF BEAMS WITHOUT CFRP STRENGTHENING)



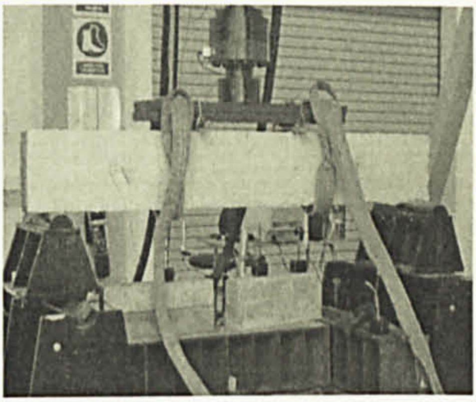


Figure 4.3.1: Preparation for static load for control beam using the self straining loading frame attached to a dynamic actuator (500kN) simply supported.

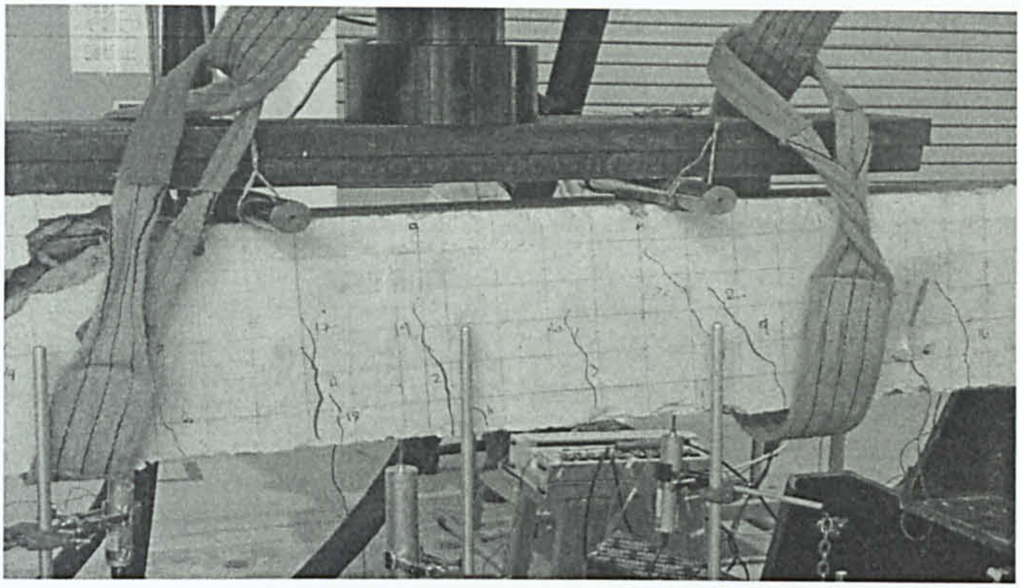


Figure 4.3.2: Crack pattern of control beam subjected to static load.

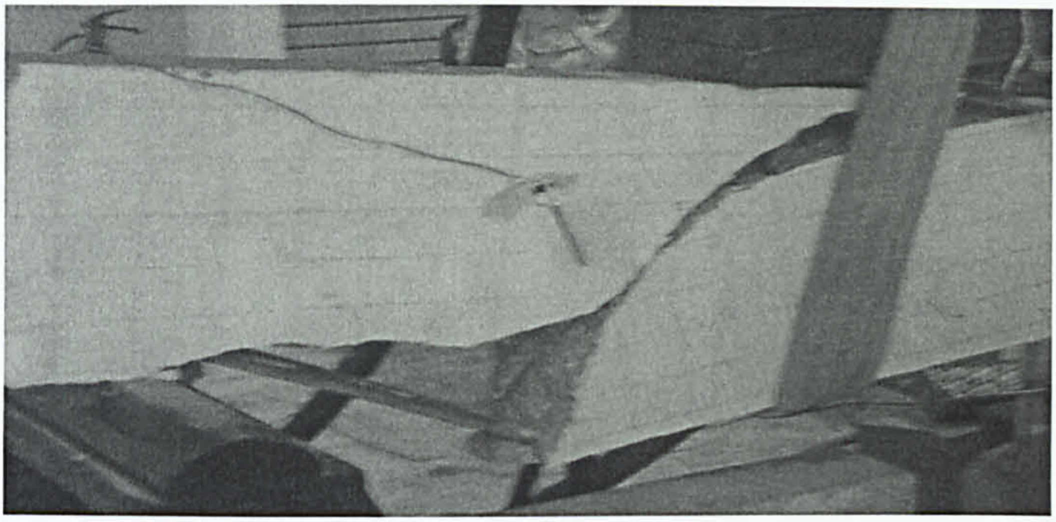


Figure 4.3.3: Failure of control beam at support by shear failure. Bottom Reinforcement Bar (Y12) bent.

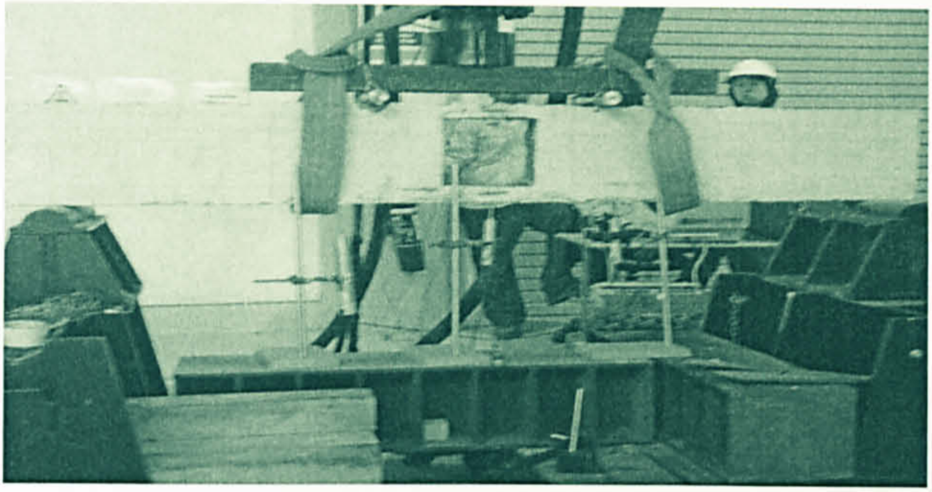


Figure 4.3.4: Preparation for static load for beam with large square opening in critical bending zone using the self straining loading frame attached to a dynamic actuator (500kN) simply supported.

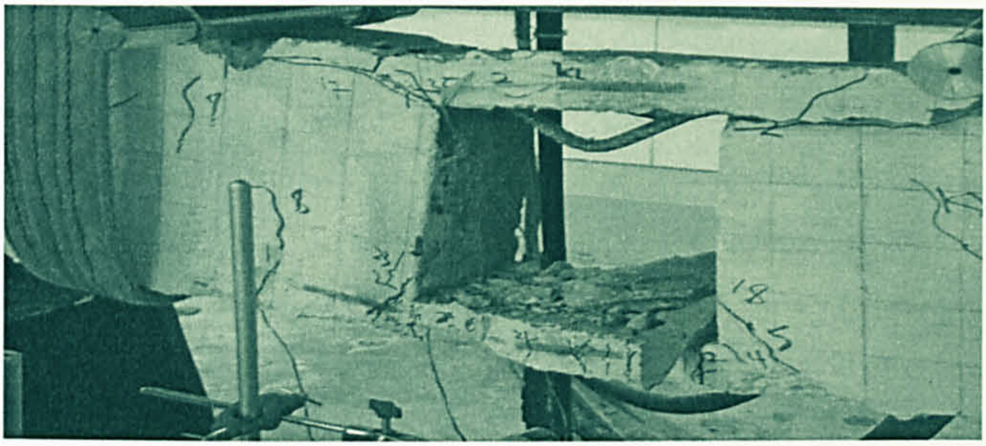


Figure 4.3.5: Failure of beam with large square opening at the center of the beam.

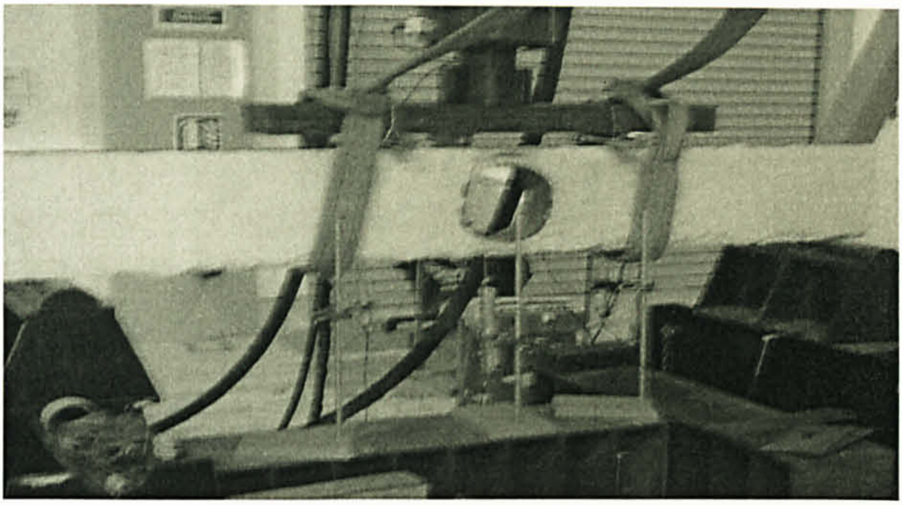


Figure 4.3.6: Preparation for static load for beam with large circular opening in critical bending zone using the self straining loading frame attached to a dynamic actuator (500kN) simply supported.

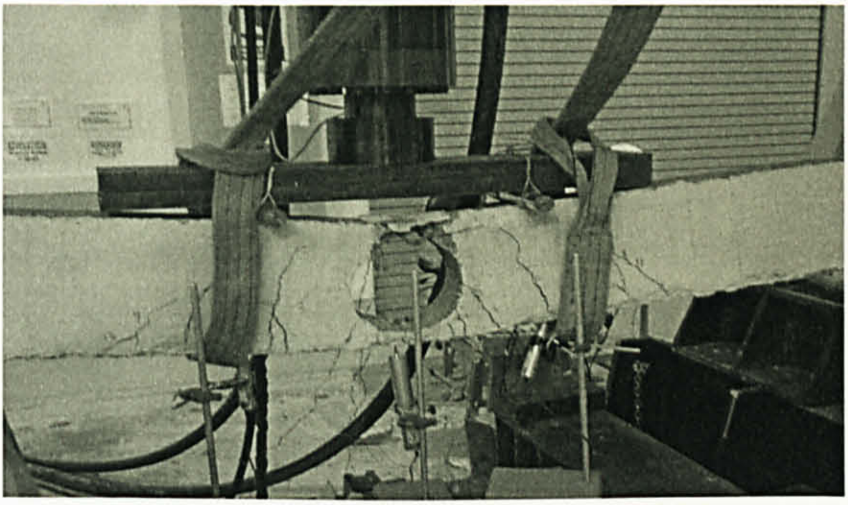


Figure 4.3.7: Failure of beam with large circular opening at middle of the beam

Figure 4.3.8: Beam with large square opening at middle of the beam pasted with CFRP Strips

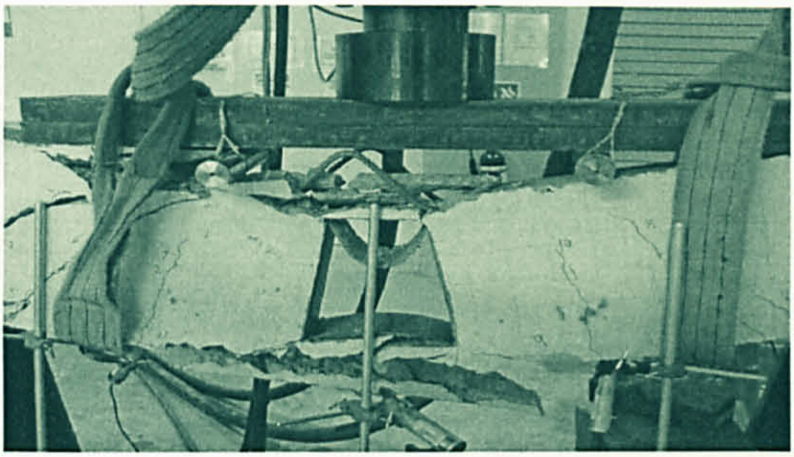


Figure 4.3.9: Failure of beam with large square opening at middle of the beam pasted with CFRP strips

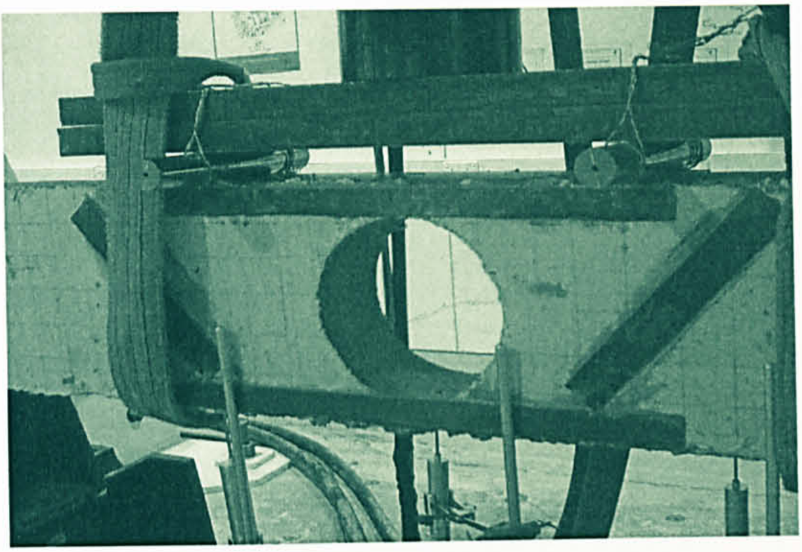


Figure 4.3.10: Beam with large circular opening at middle of the beam pasted with CFRP strips

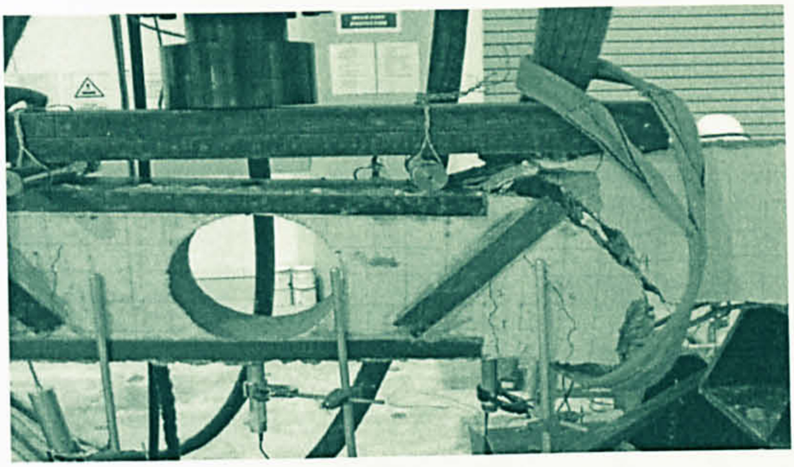


Figure 4.3.11: Failure of beam with large circular opening at middle of the beam pasted with CFRP strips

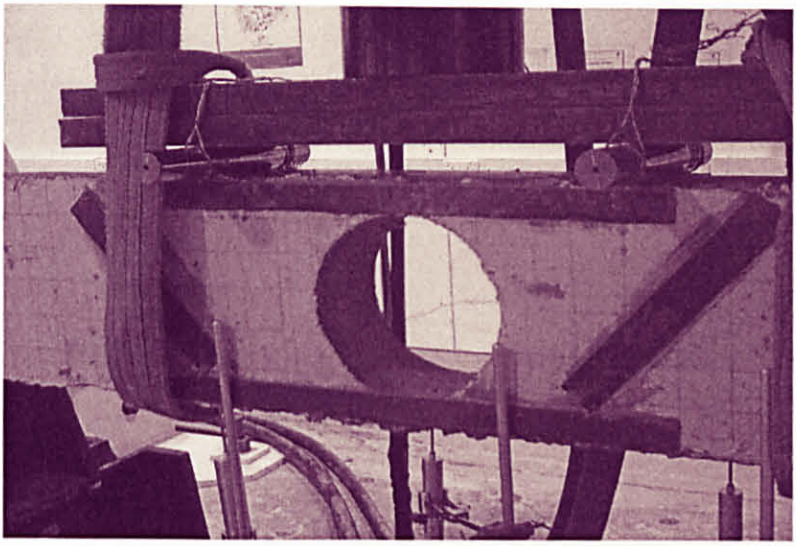


Figure 4.3.10: Beam with large circular opening at middle of the beam pasted with CFRP strips

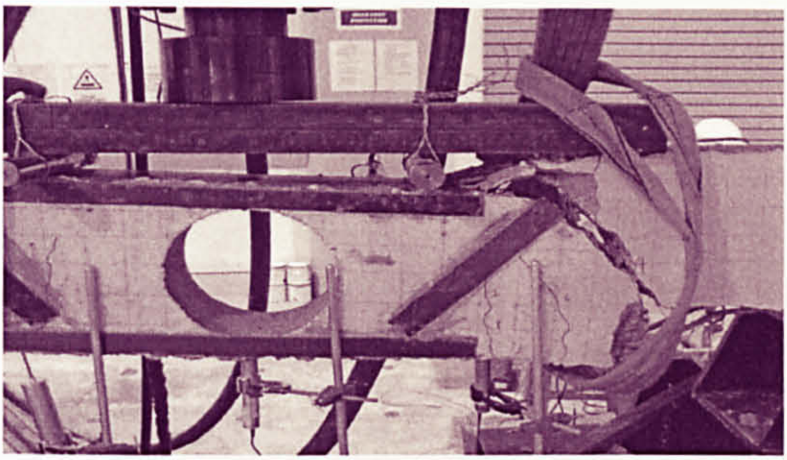


Figure 4.3.11: Failure of beam with large circular opening at middle of the beam pasted with CFRP strips

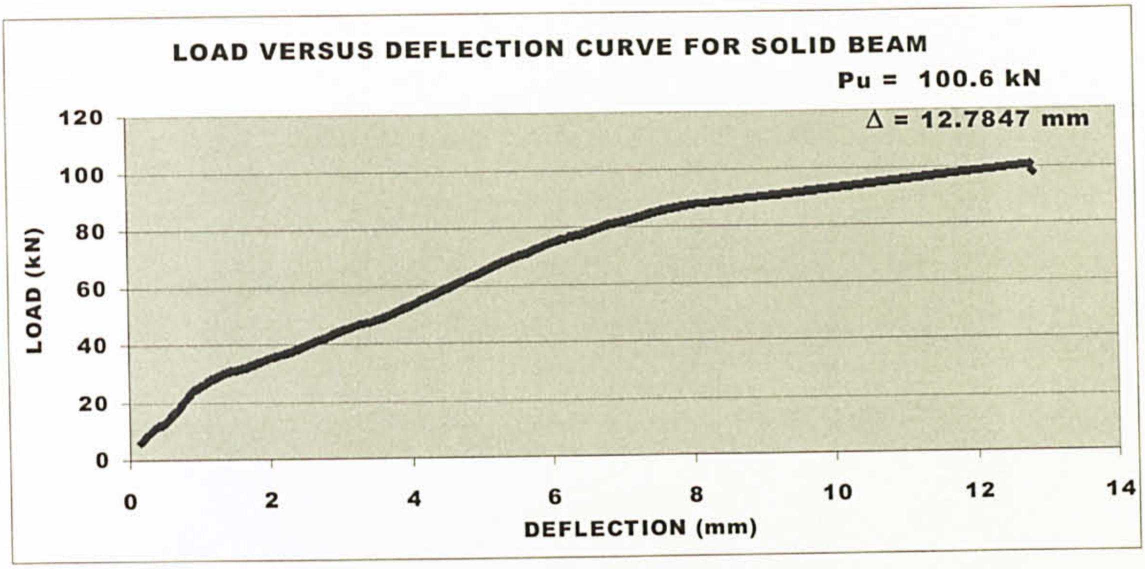


Figure 4.3.12: Graph plotted to show load versus deflection curve for solid beam

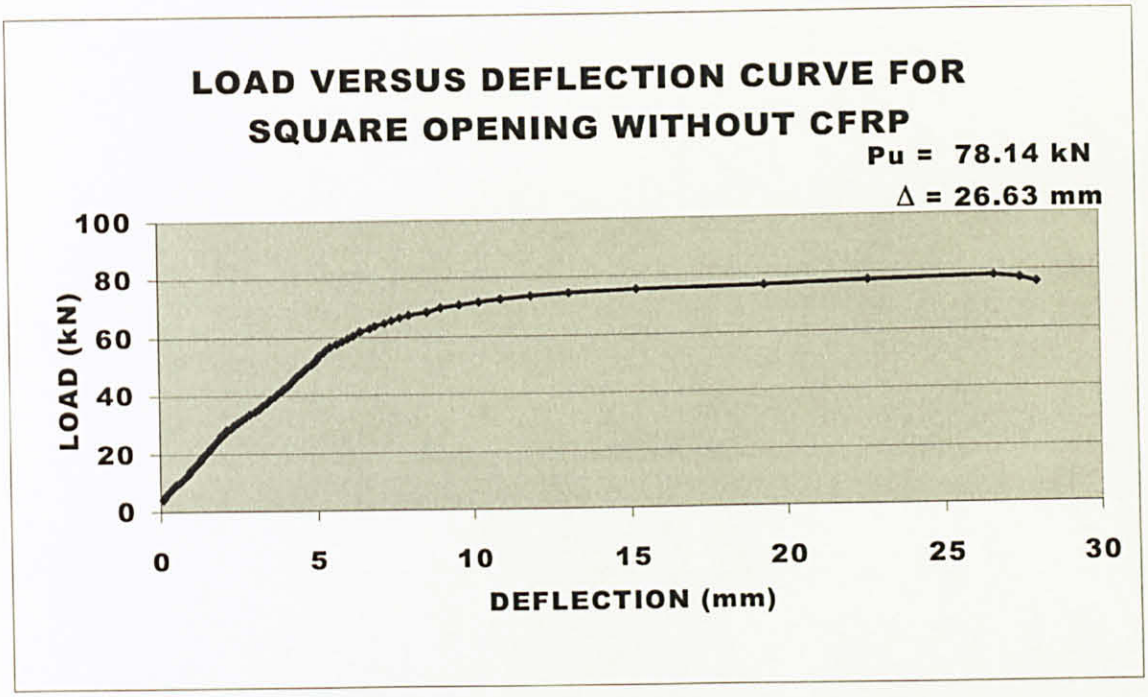


Figure 4.3.13: Graph plotted to show load versus deflection curve for square opening without CFRP strips

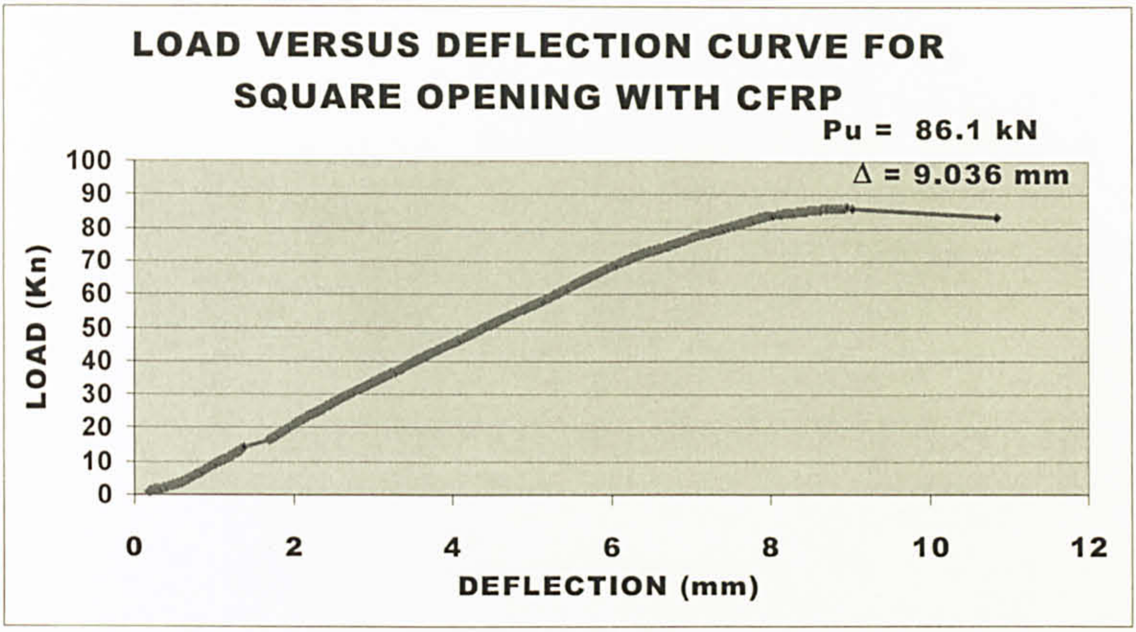


Figure 4.3.14: Graph plotted to show load versus deflection curve for square opening with CFRP strips

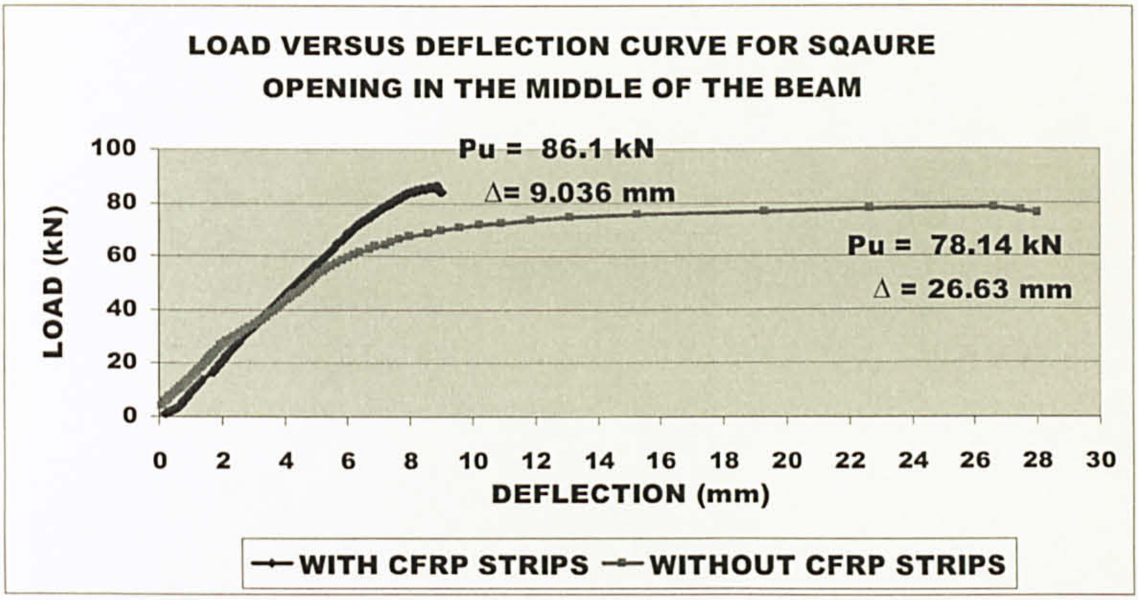


Figure 4.3.15: Graph plotted to show the comparison of load versus deflection curve for square opening without and with CFRP strips

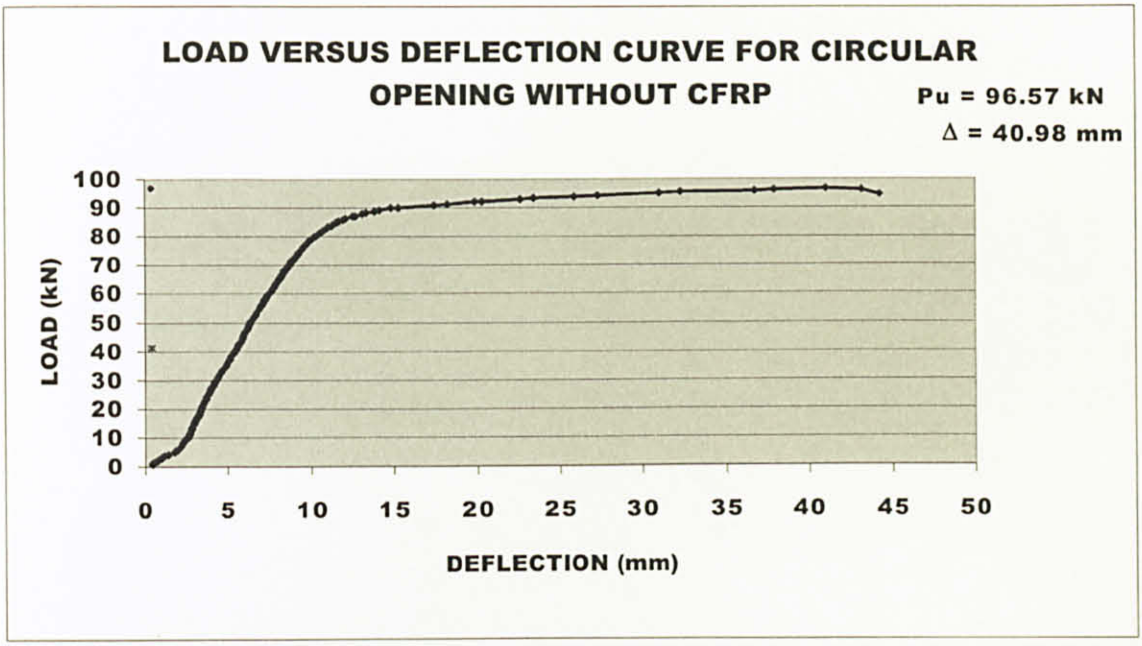


Figure 4.3.16: Graph plotted to show load versus deflection curve for circular opening without CFRP strips

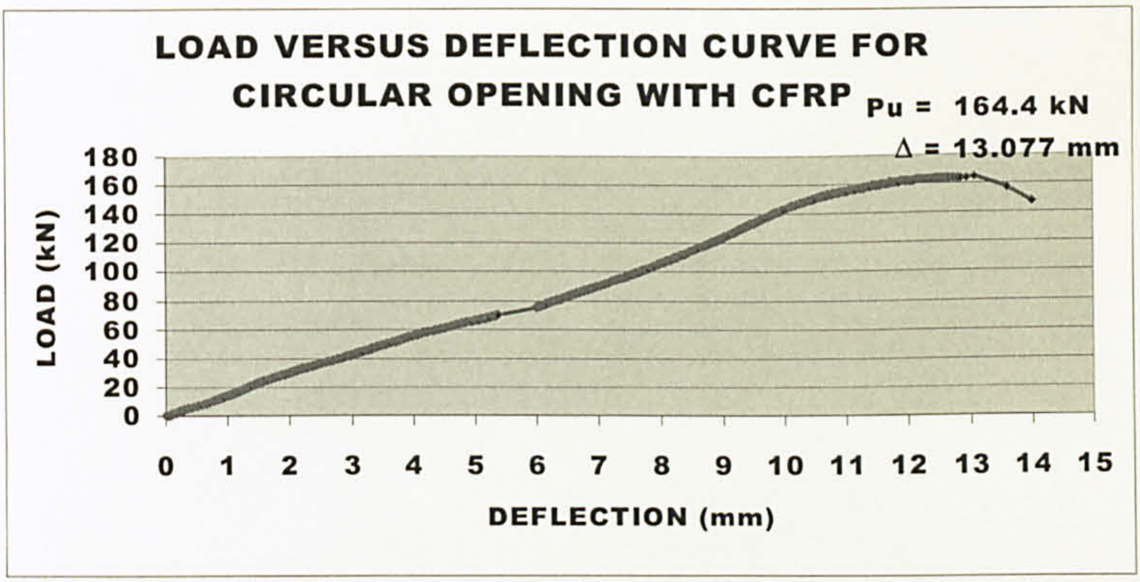


Figure 4.3.17: Graph plotted to show load versus deflection curve for circular opening with CFRP strips

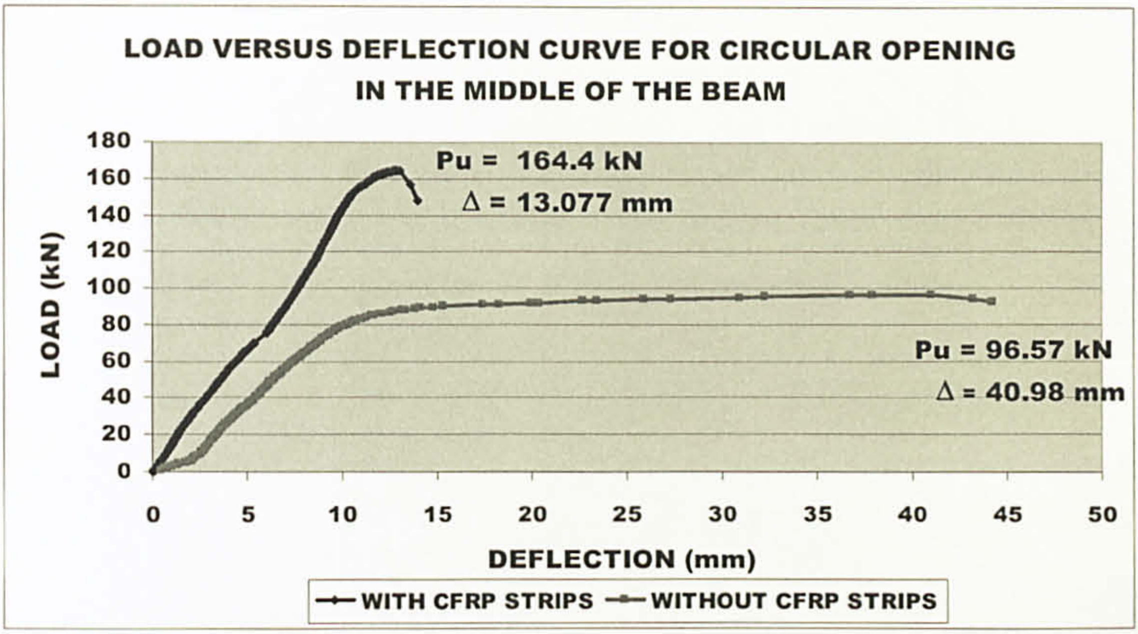


Figure 4.3.18: Graph plotted to show the comparison of load versus deflection curve for circular opening with and without CFRP strips

4.4 ANALYSIS OF RESULTS

This research was spread out over 2 FYP projects which studied 2 major aspects bending moment and shear of beam with opening under critical conditions. The critical shear zone is located at the support points on either side of the beam. However, the critical bending zone of the beam is at the center of the beam. This FYP is to study the effects of large circular and square opening in the critical bending zone as well as the configuration on CFRP used for strengthening the beams with opening. From the results obtained after carrying out the lab test for the beams with large square and circular opening with a control beam (solid beam) under the static load test, the summary of ultimate load obtained is a summarized in **Table 4.4.1** below:

Beam Characteristic (Beams without CFRP strengthening)	Ultimate strength under static condition (kN)	Deflection(mm)	% lost in strength due to opening in critical bending zone
Solid Beam (Reference Beam)	100.6	12.78	Nil
Beam with Square Opening	78.14	26.63	22%
Beam with Circular Opening	96.57	40.98	3.5%

Table 4.4.1: Summary of static load test (Beams without CFRP strengthening)

From **Table 4.4.1**, it can be observed that the deflection increases when there is opening in the beam. Circular opening beam has the highest deflection value if compared to the solid beam and square opening beam. From **Figure 4.3.5 and 4.3.7** it shows that the beams with square and circular opening bend and fail in around the opening area. It also shows that circular opening beam can stand more deflection compared to square opening and solid beam before it fails. Circular opening beam does not have any sharp corners like square opening beam. Therefore it can stand more deflection before it fails. Square opening corners must be made rounded off to decrease the stress concentrated at this area. It can be stated that the shape of the opening does affect the strength and the deflection of the beam at the critical bending zone.

Besides that, it can be observed that there is a small loss in strength of the beams due to the opening. The beam with circular opening has a small lost of 3.5% compared to the control beam. The beam with square opening have bigger lost that is 22% compared to the control beam. It shows that the openings in the beam causes strength lost due to concrete amount reduced when there are openings. This fact is more prominently illustrated in the comparison of the severity of crack patterns between beam with square opening and the beam with the circular opening. The deepness of the crack in the beam with the circular opening is much deeper than the beam with the square opening. It was observed that the crack lines appeared in the beam with the square opening **(Figure 4.3.5)** around the corners all the way outwards in an almost 45 degree angle to the circumference of the square and where it failed. The beam with the circular opening **(Figure 4.3.7)** had major diagonal crack, which lead the failure to traverse through the center of the opening. These shows that providing an opening reduces the strength of the beam significantly and therefore there is a need for strengthening at these zones of critical bending failure. The strengthening of these beams with opening is to be carried out using CFRP and tested under static load using self straining loading frame.

From the results obtained after carrying out the lab test for the beams with large square and circular opening with CFRP strips pasted under the static load test, the summary of ultimate load obtained is a summarized in **Table 4.4.2** below:

Beam Characteristic (Beams with CFRP strengthening)	Ultimate strength under static condition (kN)	Deflection(mm)	% increase strength by pasting CFRP strips at the failure zone under critical bending zone (Comparing with the beam which is not pasted with CFRP strips)
Beam with Square Opening (Beams with CFRP strengthening)	86.1	9.04	11%
Beam with Square Opening(Beams without CFRP strengthening)	78.1	26.63	Nil

Beam with Circular Opening(Beams with CFRP strengthening)	164.4	13.08	67%
Beam with Circular Opening(Beams without CFRP strengthening)	96.6	40.98	Nil

Table 4.4.2: Summary of static load test (Beams with CFRP strengthening)

From **Table 4.4.2** it shows that the strength of the beams with large opening increases when CFRP strips are pasted. Circular opening beam gain the most strength about 67% whereas square opening beam gain up to 11%. For the circular opening beam the CFRP strips were pasted perpendicular to the cracks surface, top, bottom and around the opening area. The CFRP pasted perpendicular to the crack surface prevents the cracks to continue and crack the beam. For the square opening beam the CFRP strips were only pasted in the opening area, top and bottom around the opening area. No CFRP strips were pasted perpendicular the crack surface. Therefore the cracks occur at the surface and the beam will fail faster than the circular opening beam. Anyways both of the beams with circular and square opening manage to increase the strength with CFRP strips pasted. After testing square opening beam, circular opening was test. Depending on the square opening beam result the CFRP strips were paste on the circular opening beam. Due to this circular beam manage to increase more strength compared to square opening beam. It can be concluded that CFRP strips can gain the beam strength even though there is large opening in the beam but the CFRP strips must be pasted perpendicular to the crack surface to obtain the maximum strength.

The analysis from the data obtained form the testing are as tabulated in **Table 4.4.3** below:

Beam	Square Opening	Circular Opening
Lost in strength due to opening compared to control Beam	22%	3.5%
Gain in strength due to CFRP compared to the beam before strengthening with opening	11%	67%
Gain in strength due to CFRP compared to the solid beam	14%	64%

Table 4.4.3: Analysis of testing results

The following **Table 4.4.4** describes the pattern of cracking of each beam from the initial location of cracks formation until the beam fails completely. From **Table 4.4.4**, it can be understood that the CFRP configuration used for the beam with circular opening has higher efficiency compared to the CFRP strengthening method used for the beam with the square opening. The CFRP strips have been found to be most effective when the fiber is perpendicular to the cracks itself. This indicates that the shape of the opening itself did not affect the capacity of CFRP to regain strength lost due to opening.

Beam	Description
Control Beam	• The first crack occurred at the center bottom section followed by multiple cracks forming on the left and right side of the center from the bottom upwards. • Lastly, the beam fails with severe crack at the support with minimal bending of Y12 bottom steel

	reinforcement.
Square Opening (Without CFRP Strengthening)	• Cracks started from down to the top of the beam. These cracks occurred at the center of the square working outward towards the end. All cracks appeared around the opening. • Approximately 18 major cracks formed before the beam failed at the center with an angled crack right through the diagonal corner of the square.
Circular Opening (Without CFRP Strengthening)	• Cracks started from down to the top of the beam. These cracks occurred at the center of the circular working outward towards the end. All cracks appeared around the opening. • Approximately 13 major cracks formed before the beam failed at the center with an angled crack right through the diagonal corner of the square.
Square Opening (CFRP Strengthening)	• For the beam with square opening the CFRP was used to completely cover the opening inside as well as the top and bottom of the beam around the opening due to the severe crack patterns observed at this section previously. • From the strengthening configuration of CFRP used no cracks was observed at the opening and neither at the side of the beam. All the cracks occurred at the sides of the opening from the bottom to top. • The beam failed at the connection sheets of CFRP itself at the center of the opening but at a higher strength then previously. Rebars at the center bended and concrete failed at the center due to the cracks.
Circular Opening	• For the beam with circular opening the CFRP was

(CFRP Strengthening)	pasted perpendicular at the crack surface, top and bottom section of the opening. The bottom and top of the beam at the center was pasted with CFRP according to the crack pattern previously observed. • There was less crack patterns observed at the diagonal of the circular opening as the CFRP sheet prevented the crack from spreading upward. The top reinforcement Y10 bent. • The beam eventually failed at the side of the opening area but with a higher strength.

Table 4.4.4: Beams and Cracks Description before it fails

CHAPTER 5

5.0 CONCLUSION

In conclusion there are several gained points from this research that is stated below:

1. The beam increases its strength by increasing the bending capacity by using CFRP strips even though there is large opening in the beam. From reading or journals, books, and thesis that are related to this study that is carried out by the previous researches proves that CFRP has been able to increase the bending carrying capacity of beams with large opening subjected to axial loading.
2. The shape of the opening does affect the loading capacity of the beam significantly under critical bending zone. Where circular opening beam lost less strength compared to circular opening beam.
3. Also, the bending cracks for opening with corners (square in this study) resulted in massive cracks appearing at this location compared to the beams with circular opening.
4. This research further proves that the capacity of Carbon Fibre Reinforced Polymer (CFRP) can increase the strength lost due to large opening with appropriate strengthening configuration and location of the CFRP.
5. The usage is maximized by application of CFRP perpendicular to expected crack pattern on beams with large opening in critical bending zone.

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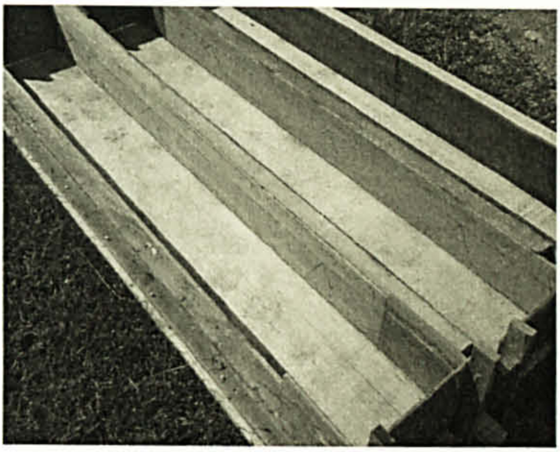
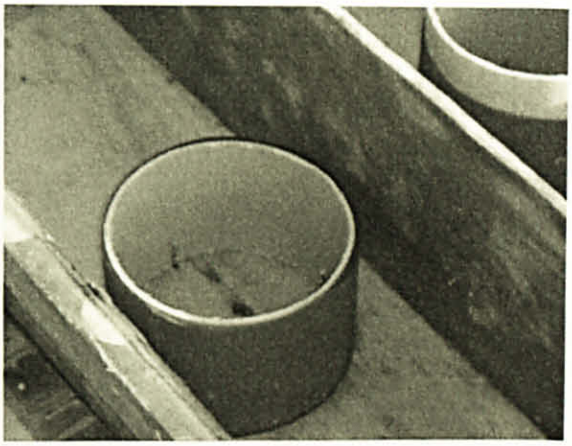
8. Thesis on Flexural strengthening of RC beams using CFRP strips Ahmad Shahrin Bin Mohamad 2004 UTP Library t TA 4189.C6 A286
9. BS 1881: Part 125:1986, Concrete Technology Laboratory Procedure manual, Mixing and Sampling Fresh Concrete, (1986) pp3
10. BS 1881: Part 111: 1983, Concrete Technology Laboratory Procedure Manual , Making and Curing Cubes and Test Beams, (1983) pp12

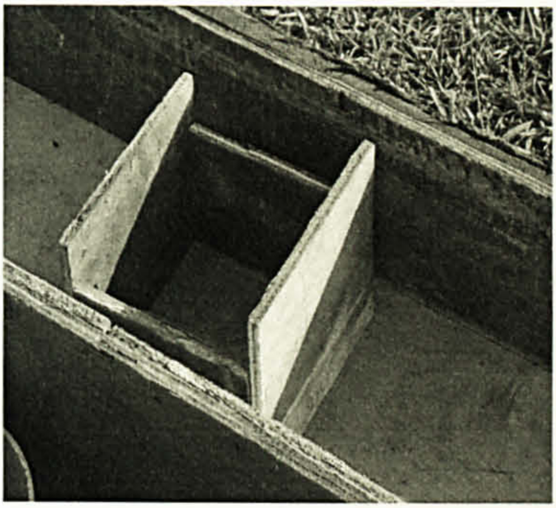
APPENDIXES 1 Pictures of Beams Casting



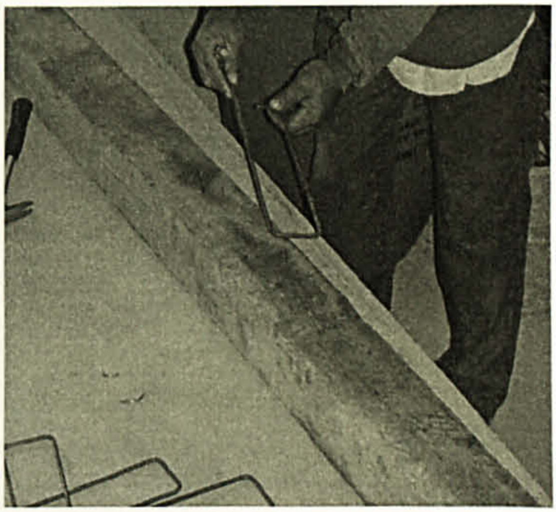
Formwork for the beam



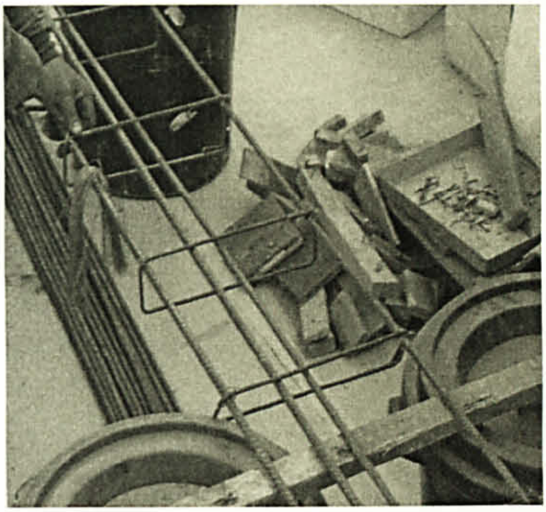
Circular opening formwork in the middle of the beam



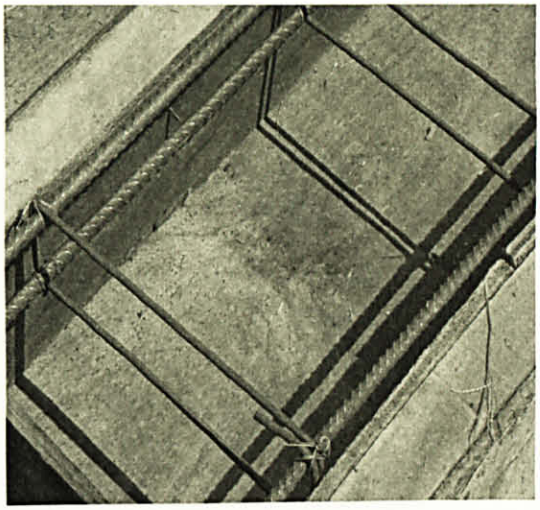
Square opening formwork in the middle of the beam



Link is bend before placing in the beam



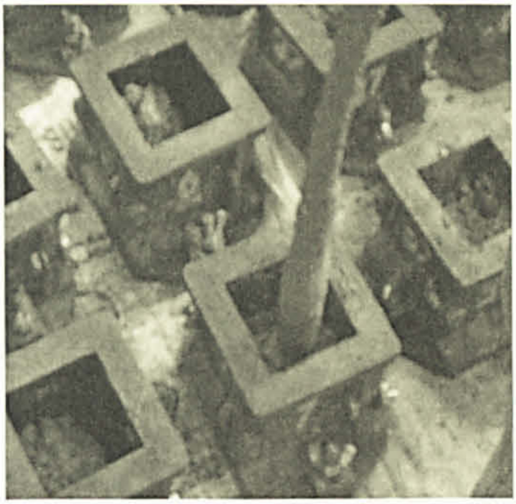
Links are tight to the main rebars



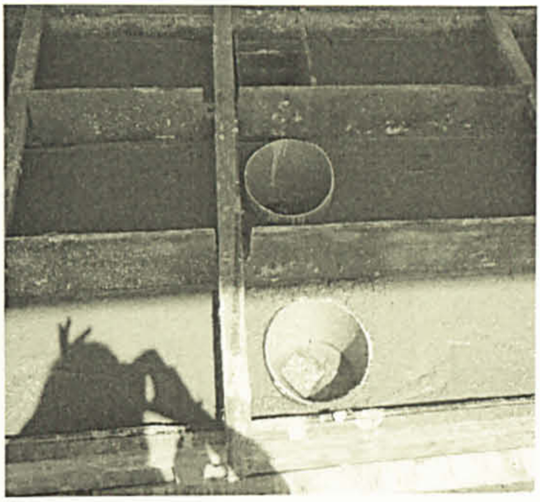
Links and rebars are placed in the formwork

Ready mix concrete is bought

Ready mix concrete is placed in the formwork



Cubes are prepared and a poker is used to vibrate



Casting of beams with large opening is done and waiting for to dry

APPENDIXES 2 Pictures of Cubes Casting

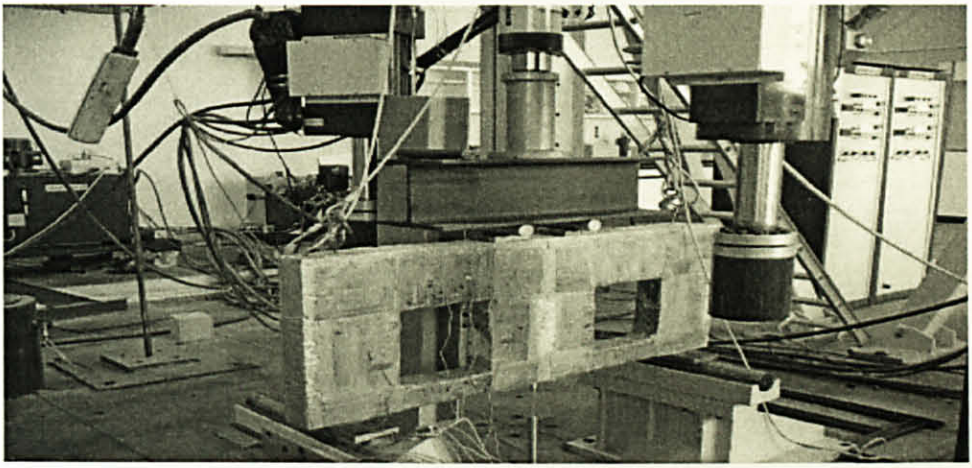
15 Cubes were cast to obtain the concrete strength

Concrete is been placed in the mould and the surface is being flatten

Moulds for 15 cubes are prepared

Sand and gravels are placed in the concrete mixture machine

APPENDIXES 3 Example of Test Set-Up



Edition 7.1.2008
Identification no. 332-15
Sikadur 30

Construction

Sikadur® 30

High-modulus, high-strength, structural epoxy paste adhesive for use with Sika CarboDur® reinforcement.

Description

Sikadur 30 is a 2-component, 100% solids, moisture-tolerant, high-modulus, high-strength, structural epoxy paste adhesive. It conforms to the current ASTM C-881 and AASHTO M-235 specifications.

Where to use

- Adhesive for bonding external reinforcement to concrete, masonry, steel, wood, stone, etc.
- Structural bonding of composite laminates (Sika CarboDur CFRP) to concrete.
- Structural bonding of steel plates to concrete.
- Suitable for use in vertical and overhead configurations.
- As a binder for epoxy mortar repairs.

Advantages

- Long pot life.
- Long open time.
- Tolerant of moisture before, during and after cure.
- High strength, high modulus, structural paste adhesive.
- Excellent adhesion to concrete, masonry, metals, wood and most structural materials.
- Fully compatible and excellent adhesion to Sika CarboDur CFRP composite laminate.
- Paste consistency ideal for vertical and overhead applications of Sika CarboDur.
- High abrasion and shock resistance.
- Convenient easy mix ratio A:B=3:1 by volume.
- Solvent-free.
- Color-coded components to ensure proper mixing control.

Coverage

Type S 512 CarboDur: approx. 50 LF/gal.; Type S 812 CarboDur: approx. 32 LF/gal.; Type S 1012 CarboDur: approx. 22 LF/gal.

Packaging

1 gal. units.

Typical Data *(Material and curing conditions @ 73°F {23°C} and 50% R.H.)*

Shelf Life — 2 years in original, unopened containers.

Storage Conditions — Store dry at 40°-95°F (4°-35°C). **Condition material to 65°-85°F (18°-29°C) before using.**

Color — Light gray

Mixing Ratio — Component 'A': Component 'B' = 3:1 by volume.

Consistency — Non-sag paste.

Pot Life — Approximately 70 minutes @ 73°F (23°C) (1 qt.)

Tensile Properties (ASTM D-638)

7 day	Tensile Strength	3,600 psi (24.8 MPa)
	Elongation at Break	1%
	Modulus of Elasticity	6.5×10^5 psi (4,482 MPa)

Flexural Properties (ASTM D-790)

14 day	Flexural Strength (Modulus of Rupture)	6,800 psi (46.8 MPa)
	Tangent Modulus of Elasticity in Bending	1.7×10^6 psi (11,721 MPa)

Shear Strength (ASTM D-732) **14 day** Shear Strength 3,600 psi (24.8 MPa)

Bond Strength (ASTM C-882): Hardened Concrete to Hardened Concrete

2 day (moist cure)	Bond Strength	2,700 psi (18.6 MPa)
2 day (dry cure)	Bond Strength	3,200 psi (22.0 MPa)
14 day (moist cure)	Bond Strength	3,100 psi (21.3 MPa)
	Hardened Concrete to Steel	2,600 psi (17.9 MPa)
2 day (moist cure)	Bond Strength	3,000 psi (20.6 MPa)
2 day (dry cure)	Bond Strength	2,600 psi (17.9 MPa)
14 day (moist cure)	Bond Strength	

Heat Deflection Temperature (ASTM D-648)

7 day [fiber stress loading=264 psi (1.8 MPa)] 118°F (47°C)

Water Absorption (ASTM D-570) **7 day** (24 hour immersion) 0.03%

Compressive Properties (ASTM D-695) - Compressive Strength, psi (MPa)

	40°F* (4°C)	73°F* (23°C)	90°F* (32°C)
4 hour	-	-	5,500 (37.9)
8 hour	-	3,500 (24.1)	6,700 (46.2)
16 hour	-	6,700 (46.2)	7,400 (51.0)
1 day	750 (5.1)	7,800 (53.7)	7,800 (53.7)
3 day	6,800 (46.8)	8,300 (57.2)	8,300 (57.2)
7 day	8,000 (55.1)	8,600 (59.3)	8,600 (59.3)
14 day	8,500 (58.6)	8,600 (59.3)	8,900 (61.3)
28 day	8,500 (58.6)	8,600 (59.3)	9,000 (62.0)

Compressive Modulus **7 day** 3.9×10^5 psi (2,689 MPa)

*Material cured and tested at the temperatures indicated.

How to Use

Surface Preparation

The concrete surface should be prepared to a minimum concrete surface profile (CSP) 3 defined by the ICRI surface-profile chips. Localized out-of-plane variations, including form lines, should not exceed 1/32 in. (1 mm). Surface must be clean and sound. It may be dry or damp, but free of standing water and frost. Remove dust, laitance, grease, curing compounds, impregnations, waxes, foreign particles, disintegrated materials, and other bond inhibiting materials from the surface. Existing uneven surfaces must be filled with an appropriate repair mortar (e.g., Sikadur 30 with the addition of 1 part oven-dried sand). The adhesive strength of the concrete must be verified after surface preparation by random pull-off testing (ACI 503R) at the discretion of the engineer. Minimum tensile strength, 200 psi (1.4 MPa) with concrete substrate failure.

Preparation work

Concrete - Blast clean, shotblast or use other approved mechanical means to provide an open roughened texture.

Steel - Should be cleaned and prepared thoroughly by blastcleaning to a white metal finish.

CarboDur - Wipe clean with appropriate cleaner (e.g. MEK).

Mixing

Pre-mix each component. Proportion 1 part Component 'B' to 3 parts Component 'A' by volume into a clean pail. Mix thoroughly for 3 minutes with Sika paddle on low-speed (400-600 rpm) drill until uniform in color. Mix only that quantity which can be used within its pot life.

To prepare an epoxy mortar: slowly add up to 1 part by loose volume of an oven-dried aggregate to 1 part of the mixed Sikadur 30 and mix until uniform in consistency.

Application

For bonded, external reinforcement:

Apply the neat mixed Sikadur 30 onto the concrete with a trowel or spatula to a nominal thickness of 1/16" (1.5 mm). Apply the mixed Sikadur 30 onto the CarboDur laminate with a "roof-shaped" spatula to a nominal thickness of 1/16" (1.5 mm). Within the open time of the epoxy, depending on the temperature, place the CarboDur laminate onto the concrete surface. Using a hard rubber roller, press the laminate into the epoxy resin until the adhesive is forced out on both sides. Remove excess adhesive. Glue line should not exceed 1/8 inch (3 mm). The external reinforcement must not be disturbed for a minimum of 24 hours. The epoxy will reach its design strength after 7 days.

For interior vertical and overhead patching: Work the material into the prepared substrate, filling the cavity. Strike off level. Lifts should not exceed 1 inch (25 mm).

Limitations

- Minimum substrate and ambient temperature is 40°F (4°C).
- Do not thin. Addition of solvents will prevent proper cure.
- Use oven-dried aggregate only.
- Maximum glue line of neat epoxy is 1/8 inch (3 mm).
- Maximum epoxy mortar thickness is 1 inch (25 mm) per lift.
- Minimum age of concrete must be 21-28 days, depending upon curing and drying conditions.
- Porous substrates must be tested for moisture vapor transmission prior to mortar applications.
- Not an aesthetic product. Color may alter due to variations in lighting and/or UV exposure.

Warning

Component 'A' - IRRITANT; SENSITIZER - Contains epoxy resin, calcium carbonate, and silica (quartz). Can cause skin sensitization after prolonged or repeated contact. Eye irritant. High concentrations of vapor may cause skin/respiratory irritation. Harmful if swallowed.

Component 'B' - CORROSIVE; SENSITIZER - Contains amines, calcium carbonate, and silica (quartz). Contact with eyes or skin causes severe burns. Can cause skin sensitization after prolonged or repeated contact. Eye irritant. May cause respiratory/skin irritation. Sanding of cured product may result in exposure to a chemical known in the state of California to cause cancer.

First Aid

Eyes: Hold eyelids apart and flush thoroughly with water for 15 minutes. **Skin:** Remove contaminated clothing. Wash skin thoroughly for 15 minutes with soap and water. **Inhalation:** Remove person to fresh air. **Ingestion:** Do not induce vomiting. **In all cases, contact a physician immediately if symptoms persist.**

Clean Up

In case of spills or leaks, wear suitable chemical resistant gloves/goggles/clothing, contain spill, collect with absorbent material, and transfer to suitable container. Ventilate area. Avoid contact. Dispose of in accordance with current, applicable local, state and federal regulations. Uncured material can be removed with solvent. Strictly follow manufacturer's warnings and instructions for use. Cured material can only be removed mechanically.

Handling & Storage

Avoid direct contact with skin and eyes. Wear chemical resistant gloves/goggles/clothing. Use only with adequate ventilation. In absence of adequate general and local exhaust ventilation, use a properly filled NIOSH respirator. Wash thoroughly after handling product. Launder clothing before reuse. Store in a cool dry well ventilated area.

Visit our website at www.sikaconstruction.com **1-800-933-SIKA NATIONWIDE**

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BSI
ISO 9000:2000

Construction

Product Data Sheet
Edition 0308 / 2
Sika® CarboDur® Plates

Sika® CarboDur® Plates

Pultruded carbon fiber plates for structural strengthening

System Description

Sika® CarboDur® plates are pultruded carbon fiber reinforced polymer (CFRP) laminates designed for strengthening concrete, timber and masonry structures.

Sika® CarboDur® plates are bonded onto the structure as external reinforcement using Sikadur®-30 for normal - or Sikadur®-30 LP epoxy resin for elevated application temperatures (for details on the adhesive see the relevant Product Data Sheet).

Uses

To strengthen structures for:

Load increase:

- Increasing the capacity of floor slabs and beams
- Increasing the capacity of bridges to accommodate increase axle loads
- Installation of heavier machinery
- Stabilising vibrating structures
- Changes of building use

Damage to structural elements:

- Deterioration of original construction materials
- Steel reinforcement corrosion
- Vehicle impact
- Fire
- Earthquakes

Service improvements:

- Reduced deflection
- Stress reduction in steel reinforcement
- Crack width reduction
- Reduced fatigue

Change in structural system:

- Removal of walls or columns
- Removal of slab sections for openings

Change of specification:

- Earthquakes
- Changed design philosophy

Design or construction defects:

- Insufficient / inadequate reinforcement
- Insufficient / inadequate structural depth

Characteristics / Advantages	■ Non corrosive ■ Very high strength ■ Excellent durability ■ Lightweight ■ Unlimited lengths, no joints required ■ Low overall thickness, can be coated ■ Easy transportation (rolls) ■ Simple plate intersections or crossings ■ Very easy to install, especially overhead ■ Outstanding fatigue resistance ■ Minimal preparation of plate, applicable in several layers ■ Combinations of high strength and modulus of elasticity available ■ High alkali resistance ■ Clean edges without exposed fibers thanks to the pultrusion process ■ Approvals from many countries worldwide

Tests

Approval / Standards	Deutsches Institut für Bautechnik Z-36.12-29, 2006: General Construction Authorisation for Sika® CarboDur®. SOCOTEC Rapport No. HX0823, 2000: Rapport d'enquete technique / cahier des charges - Sika® CarboDur® / SikaWrap® (French). NBI Teknisk Godkjenning, NBI Technical Approval, No. 2178, 2001 (Norwegian). ZAG, Technical Approval No. S418/99-620-2, za uporabo nacina ojacitev armirano betonskih in prednapetih elementov konstrukcij z dolepljenjem lamel iz karbonskih vlaken "Sika® CarboDur®" v Republiki Sloneniji (Slovenian). TSUS, Building Testing and research institutes, Technical approval No. 5502A/02/0633/0/004, 2003: Systém dodatocného zosilnovania zelezobetonovych a drevenych konstrukcil Sika CarboDur® (Slovak). Instytut badawczy drog i mostow, technical approval No. AT/2003-04-0336, System materialow Sika® CarboDur® do wzmacniania konstrukcji obiektow mostowych (Polish). Fib, Technical Report, bulletin 14: Externally bonded FRP reinforcement for RC structures, July 2001 (International). ACI 440.2R-02, Guide for the Design and construction of Externally Bonded FRP Systems for strengthening concrete structures, October 2002 (USA). Concrete Society Technical Report No. 55, Design guidance for strengthening concrete structures using fiber composite material, 2000 (UK). SIA 166, Klebebewehrungen, 2003 / 2004 (CH).

Product Data — Sika® CarboDur® CFRP plates

Form

Appearance / Colour	Carbon fiber reinforced polymer with an epoxy matrix, black.
Packaging	Cut to size according parts list in reusable packaging. Supplied in rolls of 250 m in reusable packing boxes.

Types

Sika® CarboDur® S — Tensile E-Modulus 165'000 N/mm²

Type	Width	Thickness	Cross sectional area
Sika® CarboDur® S1.525/60	15 mm	2.5 mm	37.5 mm²
Sika® CarboDur® S2.025/80	20 mm	2.5 mm	50 mm²
Sika® CarboDur® S512/80	50 mm	1.2 mm	60 mm²
Sika® CarboDur® S612/90	60 mm	1.2 mm	72 mm²
Sika® CarboDur® S613/100	60 mm	1.3 mm	78 mm²
Sika® CarboDur® S812/120	80 mm	1.2 mm	96 mm²
Sika® CarboDur® S912/140	90 mm	1.2 mm	108 mm²
Sika® CarboDur® S1012/160	100 mm	1.2 mm	120 mm²
Sika® CarboDur® S1014/180	100 mm	1.4 mm	140 mm²
Sika® CarboDur® S1213/200	120 mm	1.3 mm	156 mm²
Sika® CarboDur® S1214/220	120 mm	1.4 mm	168 mm²
Sika® CarboDur® S1512/240	150 mm	1.2 mm	180 mm²

Sika® CarboDur® M (steel equivalent) — Tensile E-Modulus 210'000 N/mm²

Type	Width	Thickness	Cross sectional area
Sika® CarboDur® M614/110	60 mm	1.4 mm	84 mm²
Sika® CarboDur® M914/170	90 mm	1.4 mm	126 mm²
Sika® CarboDur® M1014/190	100 mm	1.4 mm	140 mm²
Sika® CarboDur® M1214/230	120 mm	1.4 mm	168 mm²

Sika® CarboDur® H — Tensile E-Modulus 300'000 N/mm²

Type	Width	Thickness	Cross sectional area
Sika® CarboDur® H514/50	50 mm	1.4 mm	70 mm²

Storage

Storage Conditions / Shelf Life — Unlimited (no exposure to direct sunlight, dry).

Technical Data

Density — 1.60 g/cm³

Temperature Resistance — > +150°C

Fiber Volume Content — > 68% (type S)

Mechanical / Physical Properties

Plate Properties

		Sika CarboDur S	Sika CarboDur M	Sika CarboDur H
E-Modulus*	Mean value	165,000 N/mm²	210,000 N/mm²	300,000 N/mm²
	Min. value	> 160,000 N/mm²	> 200,000 N/mm²	> 290,000 N/mm²
	5% Fractile-Value	162,000 N/mm²	210,000 N/mm²	-
	95% Fractile-Value	180,000 N/mm²	230,000 N/mm²	-
Tensile Strength*	Mean value	3,100 N/mm²	3,200 N/mm²	1,500 N/mm²
	Min. value	> 2,800 N/mm²	> 2,900 N/mm²	> 1,350 N/mm²
	5% Fractile-Value	3,000 N/mm²	3,000 N/mm²	-
	95% Fractile-Value	3,600 N/mm²	3,900 N/mm²	-
Strain at break* (min. value)		> 1.70%	> 1.35%	> 0.45%
Design strain**		< 0.85%	< 0.65%	< 0.25%

* Mechanical values obtained from longitudinal direction of fibers.

**These values should be used for design as the maximum strains in the CFRP-plates and must be adapted to local design regulations as necessary. Dependent upon the structure and the load situation, they may also have to be decreased by the responsible Engineer according to requirements and standards.

System Information

Sika® CarboDur® + Sikadur®-30 or Sikadur®-30 LP

Application Details

Consumption

Width of plate	Sikadur®-30
50 mm	0.35 kg/m
60 mm	0.40 kg/m
80 mm	0.55 kg/m
90 mm	0.70 kg/m
100 mm	0.80 kg/m
120 mm	1.00 kg/m
150 mm	1.20 kg/m

Dependent on the surface plane, profile and roughness of the substrate as well as any plate crossings and loss or wastage, the actual consumption of adhesive may be higher.

Substrate Quality

Evenness / plane or level: (according to FIB14)
The surface to be strengthened must be levelled, with variations and formwork marks not greater than 0.5 mm. Plane and level of the substrate to be checked with a metal batten. Tolerance for 2 m length max. 10 mm and for 0.3 m length 4 mm. These tolerances shall be adapted to local guidelines if there are any. They might be more restrictive.

Substrate strength (concrete, masonry, natural stone) must be verified in all cases): Mean adhesive tensile strength of the prepared concrete substrate should be 2.0 N/mm², min. 1.5 N/mm². If these values can not be reached, then see the SikaWrap® fabric Product Data Sheets for alternative Sika® solutions.

Concrete must be older than 28 days (dependent on environment and strengths).

Substrate Preparation	*Concrete and masonry:* Substrates must be sound, dry, clean and free from laitance, ice, standing water, grease, oils, old surface treatments or coatings and any loosely adhering particles. Concrete must be cleaned and prepared to achieve a laitance and contaminant free, open textured surface. Repairs and levelling must be undertaken with structural repair materials such as Sikadur®-41 repair mortar or Sikadur®-30 adhesive, filled max. 1 : 1 by weight with Sikadur®-501 quartz sand. The prior wetting of the substrate with Sikadur®-30 improves the bond (wet in wet). If levelling has been conducted more than 2 days before applying the plates, the levelled surface has to be ground again to ensure a proper bond between Sikadur®-41 and Sikadur®-30 (see the relevant Product Data Sheets). *Timber surfaces:* Must be prepared by planing, grinding or sanding. Dust must be removed by vacuum. *Steel surfaces:* Must be prepared by blastcleaning to Sa 2.5 free from grease, oil, rust and any other contaminants which could reduce or prevent adhesion. Use the correct primer (see table). Be careful to avoid water condensation on the surfaces (dew point conditions). Priming can be done with Icosit-277 or with Sikagard®-63 N as temporary corrosion protection; or Icosit-EG1 as permanent corrosion protection.

	+10°C	+20°C	+30°C
1) Maximum waiting time between - Blastcleaning of steel and - Primer / or Sikadur®-30 (application without priming possible, if no corrosion protection is needed)	48 hours	48 hours	48 hours
2) Minimum waiting time between - Primer and - Sikadur®-30 application (**without** additional preparation of the Primer)	48 hours	24 hours	12 hours
3) Maximum waiting time between - Primer and - Sikadur®-30 application (**without** additional preparation of the Primer)	7 days	3 days	36 hours
4) Waiting time between - Primer and - Sikadur®-30 application (**with** additional preparation of the Primer)*	> 7 days	> 3 days	> 36 hours

*If additional preparation of the primer is necessary, it shall be done at earliest the day before application. After preparation of the Primer, the surface has to be cleaned / vacuumed free from dust.

Plate preparation:
Prior to the application of Sikadur®-30, solvent wipe the bonding surface with Sika® Colma Cleaner to remove contaminants. Wait until the surface is dry before applying the adhesive (> 10 minutes).

Application Conditions / Limitations

Substrate Temperature	See the Product Data Sheets of Sikadur®-30 and Sikadur®-30 LP.
Ambient Temperature	See the Product Data Sheets of Sikadur®-30 and Sikadur®-30 LP.
Substrate Moisture Content	See the Product Data Sheets of Sikadur®-30 and Sikadur®-30 LP.
Dew Point	See the Product Data Sheets of Sikadur®-30 and Sikadur®-30 LP.

Application Instructions

Mixing	See the Product Data Sheets of Sikadur®-30 and Sikadur®-30 LP.
Mixing Time	See the Product Data Sheets of Sikadur®-30 and Sikadur®-30 LP.
Application Method / Tools	Place the Sika® CarboDur® plate on a table and clean the unlabelled side with Colma Cleaner using a white rag. Wait > 10 minutes to allow the surface to dry completely. Apply the well-mixed Sikadur®-30 adhesive with a special "dome" shaped spatula onto the cleaned CarboDur® laminate. Apply the Sikadur®-30 adhesive carefully to the properly cleaned and prepared substrate, with a spatula to form a thin layer for substrate wetting. Within the open time of the adhesive, place the Sikadur®-30 coated Sika® CarboDur® plate onto the Sikadur® coated concrete surface. Using a Sika® rubber roller, press the plate into the adhesive until the material is forced out on both sides of the laminate. Remove surplus adhesive. Intersections / multiple layers: Where there are to be plate intersections or crossovers, the first Sika® CarboDur® plate should be cleaned with Sika® Colma Cleaner before overlaying with adhesive and then the second plate applied. If more than one plate is to be bonded together, they all have to be cleaned on both sides with Sika® Colma Cleaner - use Sikadur®-330 or Sikadur®-30 adhesive in these instances (for details see the Product Data Sheets of Sikadur®-330 and Sikadur®-30). Quality assurance: For quality control of curing rate and strength, samples may be made up on site if requested by code or project engineer. Average standard values after curing 7 days at +23°C are: - Compressive strength > 75 N/mm^2 - Flexural tensile strength > 35 N/mm^2 These values can differ by up to 20% dependent on the circumstances. The following are the most important factors which can have an influence on the mechanical properties of the samples: - Mixing ratio (A : B = 3 : 1 exactly) - Air entrapment in the sample (from mixing or filling into the mould!) - Curing temperature / time - Contamination of the adhesive! Therefore care should be taken to avoid these situations. When the Sikadur®-30 has cured, test for voids by tapping the surface of the plate with metallic object or impuls-thermography. Application Tools: Sika® Colma Cleaner: For cleaning of Sika® CarboDur® plate before bonding, cleaning of application tools. In 1 and 5 kg pails, 20 kg mini drum and 160 kg drum. Sika® CarboDur® Rubber Roller: For pressing the Sika® CarboDur® plate onto the surface. Sales unit 1 pce. Sika® Mixing Spindle: For minimizing air entrapment. Sales unit 1 pce.
Cleaning of Tools	Clean all tools and application equipment with Sika® Colma Cleaner immediately after use. Cured material can only be removed mechanically.
Potlife	See the Product Data Sheets of Sikadur®-30 and Sikadur®-30 LP.

Notes on Application / Limitations	A suitably qualified Engineer must be responsible for the design of the strengthening works. **This application is structural and great care must be taken in selecting suitably experienced and trained specialist labour.** Only apply plates within the open time of Sikadur®-30. Site quality control should be supported / monitored by an independent testing authority. Care must be taken when cutting plates. Use suitable protective clothing, gloves, eye protection and respirator. The Sika® CarboDur® system must be protected from permanent exposure to direct sunlight. Coating: The exposed plate-surface can be painted with a coating material such as Sikagard®-550 W Elastic or Sikagard®-ElastoColor W for UV protection. Maximum permissible service temperature is approx. +50°C. Note: When using the Sika® CarboHeater together with Sikadur®-30 LP this can be increased to max. +80°C (see the Sika® CarboHeater Product Data Sheet). The instructions in the Technical Data Sheet must be followed when applying Sikadur®-30 adhesive. Note: Detailed advice on the above must always be obtained from Sika® Services AG.
Fire Protection	If required Sika® CarboDur® plates may be protected with fire resistant material.

Value Base

All technical data stated in this Product Data Sheet are based on laboratory tests. Actual measured data may vary due to circumstances beyond our control.

Health and Safety Information

For information and advice on the safe handling, storage and disposal of chemical products, users shall refer to the most recent Material Safety Data Sheet containing physical, ecological, toxicological and other safety-related data.

Legal Notes

The information, and, in particular, the recommendations relating to the application and end-use of Sika products, are given in good faith based on Sika's current knowledge and experience of the products when properly stored, handled and applied under normal conditions in accordance with Sika's recommendations. In practice, the differences in materials, substrates and actual site conditions are such that no warranty in respect of merchantability or of fitness for a particular purpose, nor any liability arising out of any legal relationship whatsoever, can be inferred either from this information, or from any written recommendations, or from any other advice offered. The user of the product must test the product's suitability for the intended application and purpose. Sika reserves the right to change the properties of its products. The proprietary rights of third parties must be observed. All orders are accepted subject to our current terms of sale and delivery. Users must always refer to the most recent issue of the local Product Data Sheet for the product concerned, copies of which will be supplied on request.

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