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

NIRUSA A/P RATANARAJAH

CIVIL ENGINEERING
UNIVERSITI TEKNOLOGI PETRONAS

JUNE 2010

CERTIFICATION OF APPROVAL

SHEAR STRENGTHENING OF BEAMS WITH LARGE OPENING IN CRITICAL SHEAR ZONE (STATIC CONDITIONS)

By

Kirijaa A/P Ratanarajah

A project dissertation submitted to the
Civil Engineering Programme
Universiti Teknologi PETRONAS
In partial fulfilment of the requirement for the
BACHELOR OF ENGINEERING (Hons)
(CIVIL ENGINEERING)

Approved by,

(AP Dr. Nasir Shafiq)

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.

(KIRIJAA A/P RATANARAJAH)

ABSTRACT

This research study was conducted to investigate the shear strengthening of beams with large opening using CFRP strips. The principle focus was to determine the effects of the circular and square shape openings. The amount and configuration of CFRP strips was determined based on the failure behavior of the corresponding beam without strengthening. The amount of opening (circular and square) was kept as 8% of the beam elevation. The circular opening caused about 76 % loss of capacity compared to the solid beam and the square opening resulted in about 74 %.After applying CFRP; 46.22% capacity was regained for beam with square opening compared to solid beam. Similarly, for the beam with the circular opening regained 45.35% of capacity compared to solid beam.

ACKNOWLEDGEMENT

First and foremost, I am expressing my praise and gratitude to God for His guidance and blessing throughout the duration of my stay in Universiti Teknologi PETRONAS. I am truly grateful for being given the opportunity to complete my Final Year Project.

I would like to grab this opportunity to specially thank my supervisor Associate Professor Dr. Nasir Syafiq for his willingness to share his knowledge and for his supervision during my study on strengthening procedures for beams with large opening in critical shear zone with the use of Carbon Fiber Reinforced Polymer (CFRP). He has devoted a lot of time and patiently guided me with this research.

Apart from that, I would like to thank my lab technicians Mr. Hafiz and Mr. Johan for their help through my lab testing especially. They were very accommodating and helped tremendously. Without their help this project may not have been a success as the lab testing machines required skill and the maneuvering of large beams required experience. Also, would like to thank Mr. Kalaikumar a/l Vallyutham; Civil Engineering Department lecturer for his giving a hand during the lab work.

In addition to my wonderful and ever helpful supervisor and lab technicians, I would also like to take the opportunity to thank my internal examiners; Dr. Narayanan Sambu Potty and Assoc. Prof Ir Dr M Shahir Liew, both lecturers in the Civil Engineering Department for their constructive advice and recommendation.

Lastly would like to thank my family at home for their everlasting support mentally through this Final Year Project

TABLE OF CONTENT

LIST OF TABLES

LIST OF FIGURES

CHAPTER 1

1.0 Introduction

1.1 Background of Study

Concrete is a construction material composed of coarse aggregates, fine aggregates cement and water. The proportion of concrete is coarse aggregates (size more than 5mm): fine aggregates (size less than 5mm): cement is 4:2:1. Concrete solidifies and hardens after mixing with water and placement due to a chemical process known as hydration. The water reacts with the cement, which bonds the other components together, eventually creating a stone-like material.

Aggregates are naturally occurring sand or gravel which should not contain silica. The aggregates should be durable and clean (free from organic impurities and free from coating of dust), should provide volume stability. Weak aggregates can not be used to produce strong concrete. Aggregates come in two forms crushed and uncrushed. Crushed aggregates are angular in nature and rough in texture whereas uncrushed aggregates are smooth textured aggregates. The shape of the aggregates determines the workability and durability of concrete. Durable aggregates are aggregates that are hard and do not contain materials which are likely to decompose or change in volume when exposed to the weather or effect the reinforcement. Workability is defined as the ease with which fresh concrete is mixed, placed and consolidated. Improved workability improves the ease of batching, mixing, transporting, pumping and placing of concrete. Workability is usually measured by means of a slump test. The higher the slump the more workable the concrete mix. Fresh concrete is concrete from the time of mixing until the finishes of concrete surface at its final location in structure).

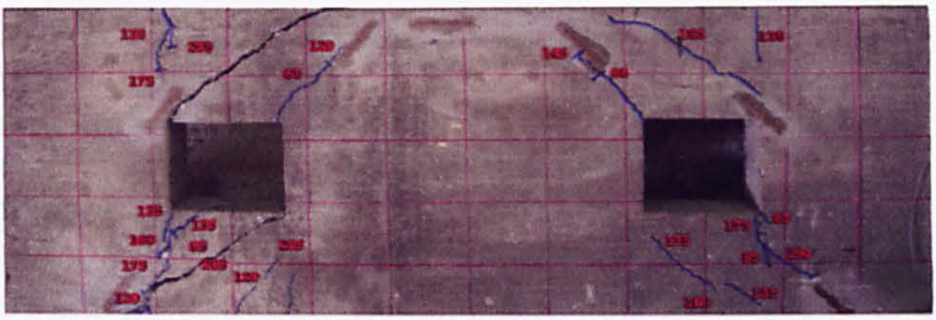
The surface texture (glassy, smooth granular), affects the bonds between the matrix and the aggregate particles which in turn affects the strength of concrete. Aggregates are usually classified into 4 categories; occurrence (natural or artificial), density (high density, low density), treatment (crushed or uncrushed) and size (fine or coarse). The moisture content of the particles play a great role in the water content used in the design mix.

The moisture content of particles have been classified into wet aggregates (Fully saturated internally and on the surface), bone dry (No water at all), air dry (some pores of the aggregates are filled with water), and saturated and surface dry (SSD) (which is saturated with water internally and dry on the surface placed in environment).

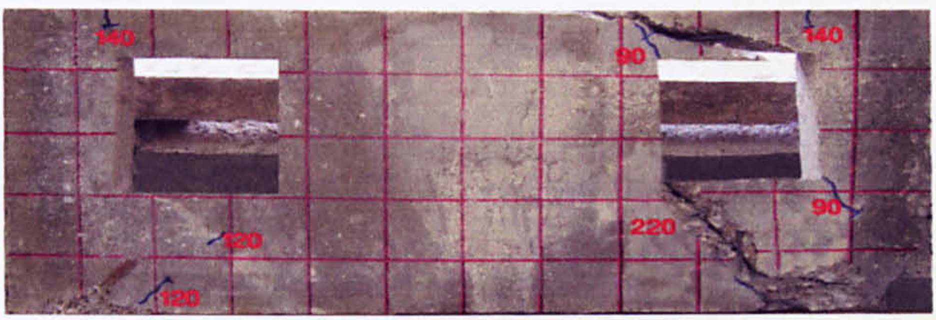
The main contents of cement are limestone and clay. They are made up of compounds of Calcium Oxide (CaO) and Aluminium Oxide(Al_2O_3). CaO, $CaCO_3$, Al_2O_3 and Fe_2O_3 (oxides) react with water during the hydration process to form Ca $(OH)_2$ and C-S-H gel. To obtain early strength, CaO, Al_2O_3 and $CaCO_3$ should be increased to obtain high early strength (C_3A, and C_3S) where C_3A is tricalcium aluminate and C_3S is tricalcium silicon (hydrates and hardens rapidly) . After which, the later strength of concrete is controlled by dicalcium silicon (C_2S). The main elements of the compound of concrete are Oxygen (O), Silicon (Si), Calcium (Ca), Ferum (Fe) and Aluminum (Al)

Concrete is used to make beams, columns, slabs, pavements and many other structures. Concrete reinforced beams generally carry vertical gravitational forces but can also be used to carry horizontal loads (i.e., loads due to an earthquake or wind). The loads carried by a beam are transferred to columns, walls, or girders, which then transfer the force to adjacent structural compression members. Internally, beams experience compressive, tensile and shear stresses as a result of the loads applied to them. Above the supports, the beam is exposed to shear stress. Large openings through reinforced concrete beams are usually required for the passage of utility ducts and pipes. These openings could be manipulated to different shapes and sizes and are most likely to be found close to the supports where shear is critical. Circular openings are most commonly found in construction to accommodate service pipes whereas the square ones are usually found to provide passage for air-conditioning ducts. These opening are located on either side of the beam closer to the supports resulting in the critical shear zone.

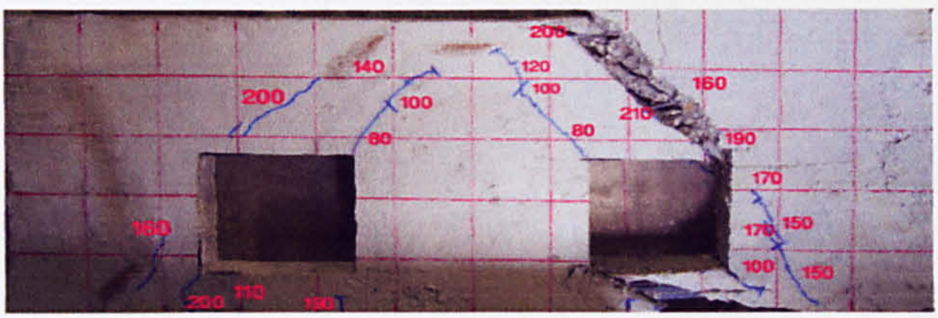
Figure 1.1 shows the failure mode due to shear loss for beams without Carbon Fiber Reinforced Polymer (CFRP) strengthening. Appendix 1 shows the opening regime of beams with dual openings at either end of the beams at different elevations of the beam; group [A]-center of web depth, group [B] – top of web depth, group [C] – bottom of web depth. However in this research, the design of the beam is fixed to have dual openings at the center section of the web on either side of the beam closer to the supports. These beams in Appendix 2 and 3 were subjected to failure in four point bending. A spreader beam was used to transfer load to the test specimen through two loading points 200mm apart. Table 1.1 in appendix indicates the test matrix studied by Tamer EI Maaddawy [16]. Appendix shows the failure Modes of CFRP – strengthened beams and Appendix 5 shows the strengthening scheme of CFRP. In this research a similar strengthening method will be adopted as the Specimen FS-200-C in Appendix 5. However, there will be variation in the dimensions of the beams as well as the shape of the opening. In this study, 2 of the test beams (one test beam with CFRP strengthening another without) will be cast with circular openings (230mm) in the web of 300mm, and another 2 test beams (one test beam with CFRP strengthening another without) of square openings of 210 X 210mm in the same 300mm web depth.



Specimen NS-150-C



Specimen NS-200-T



Specimen NS-200-B

Figure 1.1: Shear failure of beams with large opening [16]

1.2 Problem Statement

The provision for opening of desired shape, size and location in a RC beam has always been an issue between structural and M&E engineers. Sometimes; M&E engineers have 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 problems, an engineering solution through research activities is needed so that it can allow flexibility for M&E engineers to layout the ducting system with an optimum option.

1.3 Objectives and Scope of Study

The purpose of this study is to:

1. Determine the effects of circular and square shaped opening in critical shear zone of the beam

2. To develop a strengthening procedure using CFRP (Carbon Fibre Reinforced Polymers) that can ensure the regain of lost capacity of beam by providing about 8% of opening.

CHAPTER 2

2.0 Literature Review

Strengthening of concrete beams for shear with CFRP sheets is the method being used to study the arrangement of CFRP sheets which results in the highest shear carrying capacity for beams with large openings. When beams have large openings (10-20% of the web area of the beam), studies indicate a massive loss in shear strength of the beam. This in turn results in the need for strengthening of the beams for shear to overcome this problem. In this project, the composite material used for the strengthening purpose CFRP was chosen due to its various advantages. The following are the advantages of using CFRP for shear strengthening when compared to traditional construction material (Steel, wood & concrete) in the critical shear zone of the beam with large opening:

i. It has excellent resistance to corrosion
ii. High stiffness to weight ratio
iii. High strength to weight ratio
iv. Tailorability; the CFRP sheets can be arranged to the loading condition to optimize the performance.
v. It has a low weight which reduces transportation expenses and allows for some prefabrication that consequently reduces time at the job site.
vi. CFRP does not have a yield limit and more or less elastic up to failure.

When a strengthening material is added to the concrete it can be said that the shear mechanism becomes significantly more complicated. To study the behavior of CFRP experimental studies are required. The strengthening method used should have full acceptance of the worldwide strengthening procedures.

It is always favorable that bending failure occurs before shear failure in structures because shear failure often arises without any forewarning.

2.1 Strengthening of Concrete Structures with Composite Material

CFRP plates in concrete beams are used to strengthen for shear. Early studies were conducted by Drimoussis [6]. From this 2 very important facts were pointed out;

i. The failure of the specimens were governed by the strength of the concrete
ii. And that the anchorage of the sheets is a key consideration in design

Glass, aramid and carbon fiber had been used in a previous study of strengthening of concrete beams in shear, which stresses on the importance of considering the orientation of the fabric fibers [7]. From this research paper, it was accepted that this method yielded an increase in ultimate shear capacity of 60-150 %. Norris. et.al [8] in his research found that the increase in magnitude and the mode of failure was related to the direction of the reinforcing fibers.

CFRP placed perpendicular to crack in test beam	**CFRP placed obliquely to crack in test beam**
• Large increase in stiffness and strength was observed • Brittle failure occurred due to concrete rupture as a result of stress concentrations near the ends of CFRP wrap	• Smaller increase in strength and stiffness

Table 2.1: Effect of arrangement of CFRP sheets

Mode of failure associated with this off-axis application of CFRP was more ductile and was preceded by warning signs such as the snapping or peeling sounds of CFRP

The following was found through experimental investigation [9] on the response of concrete beam strengthened in shear using externally applied epoxy bonded in unidirectional CFRP strips:

i. An increase in load- carrying capacity in shear of RC beams while substantially reducing the shear cracks.
ii. Also the diagonal strips reaped better results then those strengthened with vertical side strips.

An extensive literature review in the view of shear strengthening of RC beams with CFRP composites has been taken by Chen & Teng [10]. In a recent publication of a book by Tong et ai. [11] The comprehensive treatment for shear in beams was presented. This study comprised of the design recommendations for shear strengthening of concrete structures with CFRP sheets or laminates.

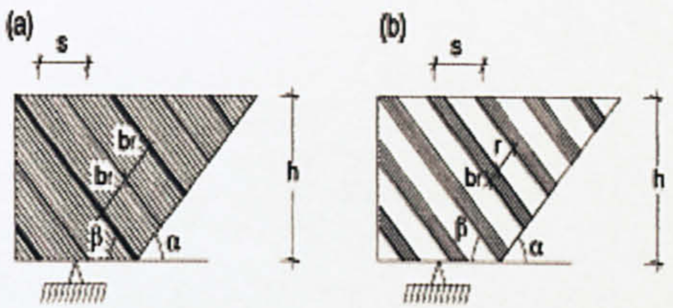


Figure 2.1: The difference between sheets and laminates

Where b_f=width of the sheets or laminates s = Vertical Distance between the sheets or the laminates

α =Angle of shear crack β = Inclination between the sheets or laminates

It is also been researched and found that the thinner the fiber used the better the utilization of the fabric. [12] The gain in shear strength caused by CFRP is primarily dependent on the num of layers of CFRP and the amount of internal shear steel reinforcement. The FRP shear strengthening system was found more effective when the fibers were oriented in a direction perpendicular to the potential diagonal shear cracks [13]. Externally bonded FRP systems were also found effective in eliminating the weakness caused by inclusion of an opening in the web of shallow RC beams [14, 15]. In this research 5 beams with the following criteria's would be tested for shear:

BEAM NO	1	2	3	4	5
CFRP strengthening	No	No	Yes	No	Yes
Shape of Opening	None	Circular (Φ230mm)	Circular (Φ230mm)	Square (210 X210)	Square (210 X210)
Length of Beam (mm)	2000	2000	2000	2000	2000
Design Strength (Mpa)	+/- 35	+/- 35	+/- 35	+/- 35	+/- 35
Number of openings	0	2	2	2	2
Location of opening	-	Center ends of the beams	Center ends of the beams	Center ends of the beams	Center ends of the beams

Table 2.2: Criteria's for 5 test beams

CHAPTER 3

3.0 Methodology

For this research the method used is similar to casting the cubes in moulds. However, as the beam dimensions are large and form-work is made to cast the concrete beams as the beams have large openings. Firstly, a mix design from the concrete batching plant is ordered for delivery on the day of casting. The beams are set to have a concrete of design strength +/- 35Mpa. The following steps are to be done before the beams can be cast:

1. Ordering concrete of G35 from batching plant to obtain optimum strength development of concrete in 28days. (Ready-Mix Concrete)
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 is batched to make test beams.
5. Making of test beams (5 Nos)

In this research, the shear loss due to the large web opening is to be studied, particularly for a square hollow section (210mm x210mm) and circular opening (Φ230mm). From the shear reinforcement using CFRP it can be determined how much of the loss of shear strength due to the large opening can be regained. As CFRP is an expensive material, the significance of using CFRP to regain the shear strength should be relatively feasible to be implemented in the industry. After the concrete trial mix design was checked the concrete beams for testing need to be prepared. Firstly, the preparation of the form work is done. This form work is not the regular type as special attention must be given to the hollow section. It must be taken into consideration that sufficient spacing is required below the hollow section for steel reinforcement bars as well as the cover. The hollow sections must be positioned at the center depth of the beam and placed at an equal distance away from either ends of the beams as illustrated in Figure 3.4 below. Also, the presence of links and their spacing must be allocated for carefully to avoid the wide opening. 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. The form work must be checked carefully for rebar positioning, location and spacing of links, tying of links, dimension of rebars and links as well as the positioning of the hollow section and concrete cover spacing to be maintained throughout. With that the form work can be applied with grease before the pouring of concrete. Concrete must be poured in 3 parts. 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 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. The curing of the concrete beams must be done after the casting to avoid cracking in the beams due to excessive rapid heat loss. The curing can be done by spraying water from time to time of the use of sand and a plastic sheet as well as polystyrenes. After 3 days, the form work can be removed. The beams are left for it to reach 28days and after which the beams that have to be reinforced with CFRP sheets can be done. Lastly, the beams are tested for the shear loss and the results will be compared to the beam without the opening and any CFRP strengthening.

3.1 Mixing and Sampling of Fresh Concrete [17]

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 of Cubes and Beams [18]

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

Apparatus: Form work for the test cubes and 100mmX100mmX100mm molds.

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. (However, since concrete was ordered from the batching plant, only the 28 days strength was taken).
i) 15 specimens are made for the mixture. Note: The similar procedure is adopted for the casting of test beam using form work.

Figure 3.1: Ply wood and used form work from previous castings reused to construct the form work of required dimension to avoid wastage.

Figure 3.2: Completed form work of 3 beams to be casted on 1 ply wood.

Figure 3.3: Cutting of steel reinforcement bars (Y10 and Y12)

Figure3.4: Special opening created at critical shear 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 3.5: Bending of R6 links (Φ 6mm) with dimension 3"x 11" or 76mmX 280mm.

Figure 3.6: Steel Reinforcement bar bending activity (Y10 and Y12). Bars are bent about 3.5"

Figure 3.7: Tying of R6 links to main rebars Y10 (2 nos top bars) and Y12 (2nos bottom bar) using steel wires. The links are placed at a distance 300mm C/C and adjusted to avoid passing through section of opening. (Opening is located 100mm offset from concrete surface as the concrete cover was set to be 100mm.)

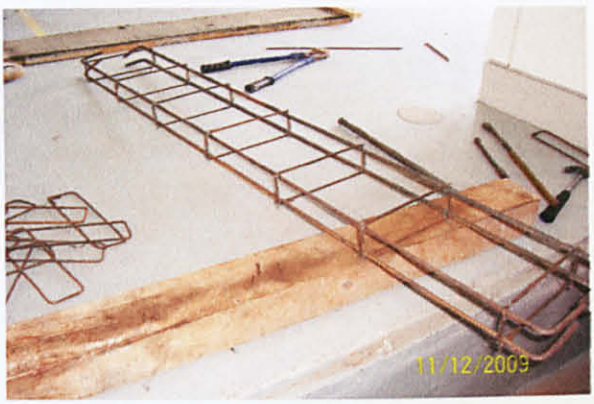


Figure 3.8: Completed steel reinforcement bars

Figure 3.9: Placing Reinforcement bars into form work

Figure 3.10: Pouring Concrete into form work

Figure 3.11: Concreted Beams to be cured for 2 weeks by using wet sacks to avoid rapid heat loss which could lead to cracking.

Figure 3.12: 15nos of cubes tested for compression strength

CHAPTER 4

4.0 Results and Discussion

From this research to study the shear strengthening of concrete beams with large openings, the following data was studied:

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

For the casting of the 5 no's of concrete beams, ready-mix concrete was used to maintain homogeneous concrete and to standardize the concrete batching. The decision to use ready-mix concrete was because large volumes of concrete was needed to cast for the beams and the mixer at the lab was insufficient to mix this volume resulting in 2 batches of concrete to be mixed for 1 beam. This method would obtain highly varying results due to inconsistency and may affect the study of the beams strength. Thus, ready-mix concrete was a more cost-effective and quality assured option.

4.1 Compression Test

The compression test was carried out for the 15 cubes (100mm x 100mm) were tested for 28 days compression test. The results of the compression test are as in the table below: (Using Ready – Mix Concrete G35)

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: Compression test results

4.2 Reinforcement Bar Dimensions

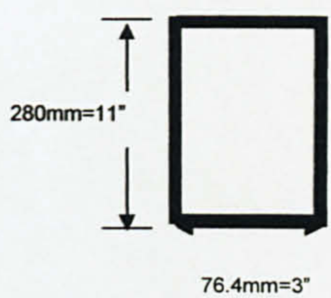


Figure 4.1: Cross Section Dimension of Beam Reinforcement

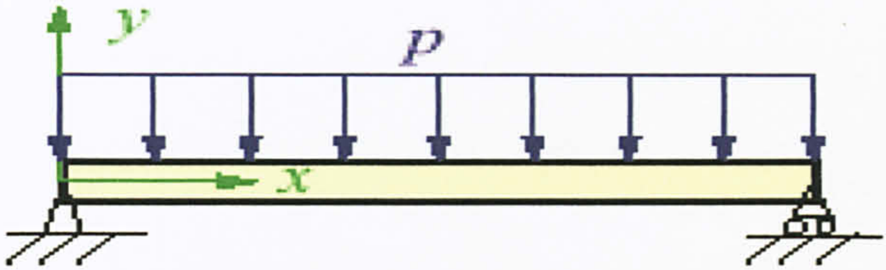
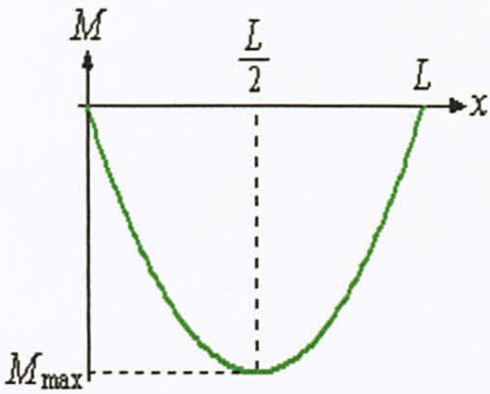


Figure 4.2: Simply Supported Beam with Uniform Load



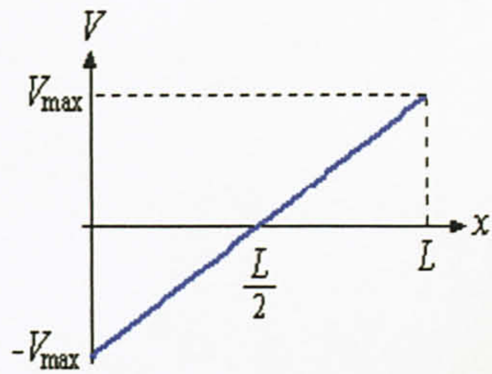


Figure 4.3: Moment Diagram (Beam without opening)

Figure 4.4: Shear Diagram (Beam without opening)

Note: Appendix 7 contains the calculation for the design of reinforcement bars to be used.

Shear Reinforcement Beam

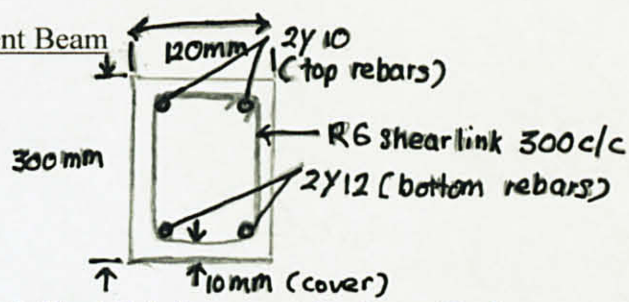


Figure 4.5: Steel Reinforcement for Beam Design

4.3 Static Load Test of Control Beam and Beams with Large Opening in Web at Critical Shear Zone (Circular and Square Opening of Beams without CFRP Strengthening)

Figure4.6: Preparation for static load for control beam using the self straining Loading frame attached to a dynamic actuator (500kN) simply supported.

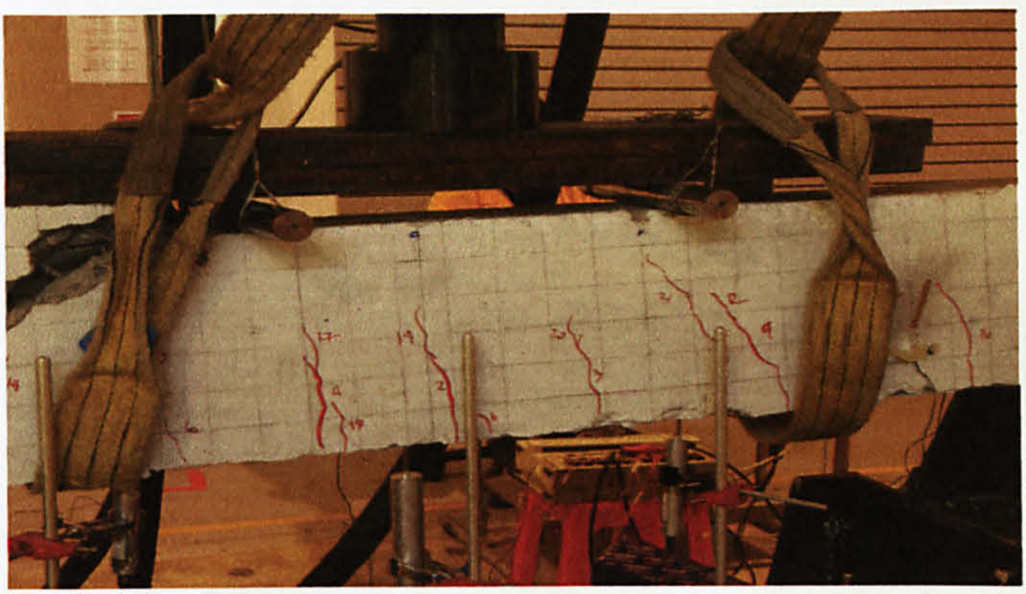


Figure 4.7: Crack pattern of control beam subjected to static load indicating failure in bending at center of beam.

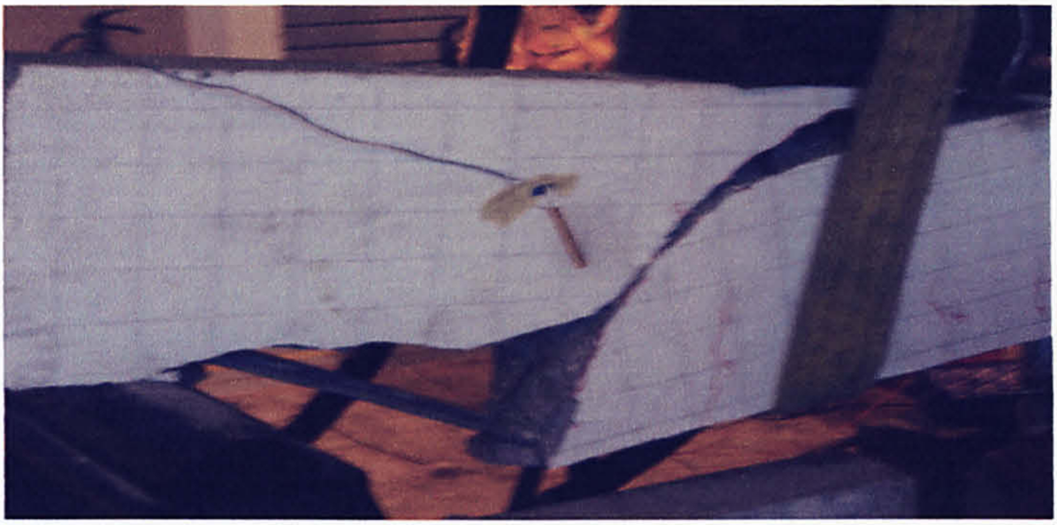


Figure 4.8: Failure of control beam at support by shear failure. Bottom Reinforcement Bar (Y12) bent.

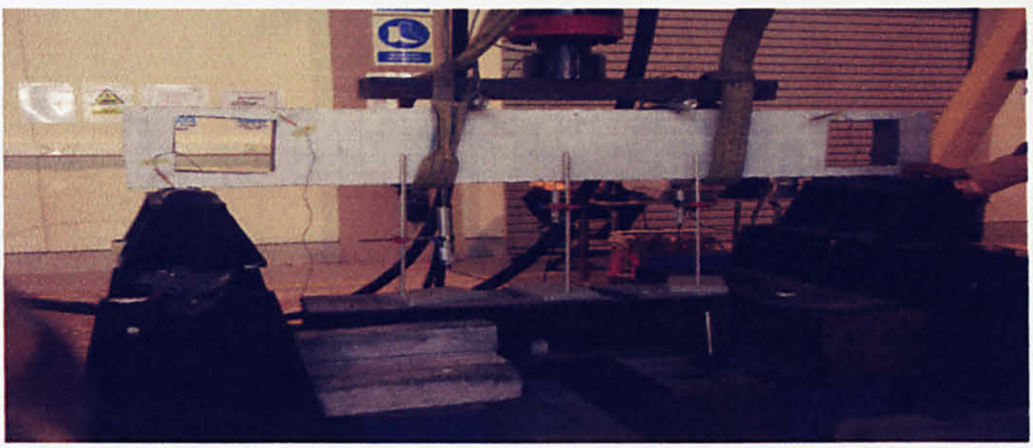


Figure 4.9: Preparation for static load for beam with large square opening in critical shear zone using the self straining Loading frame attached to a dynamic actuator (500kN) simply supported.

Figure 4.10: Failure of beam with large square opening at support.

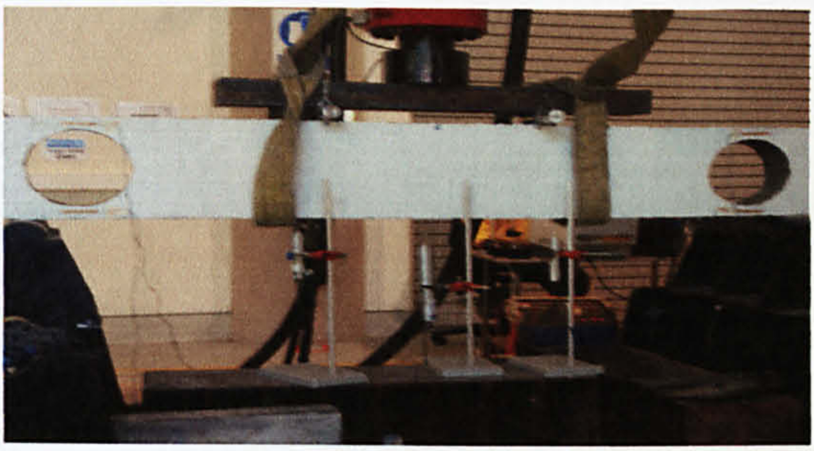


Figure 4.11:Preparation for static load for beam with large circular opening in critical shear zone using the self straining loading frame attached to a dynamic actuator (500kN) simply supported.

Figure 4.12: Failure of beam with large circular opening at support.

Please refer appendix 6 for the load versus deflection results for static load test.

Figure 4.13: Comparing severity of crack pattern between square opening and circular opening in critical shear zone.

4.4 Static Load Test of Beams with Large Opening in Web at Critical Shear Zone (Circular and Square Opening of Beams with CFRP Strengthening)

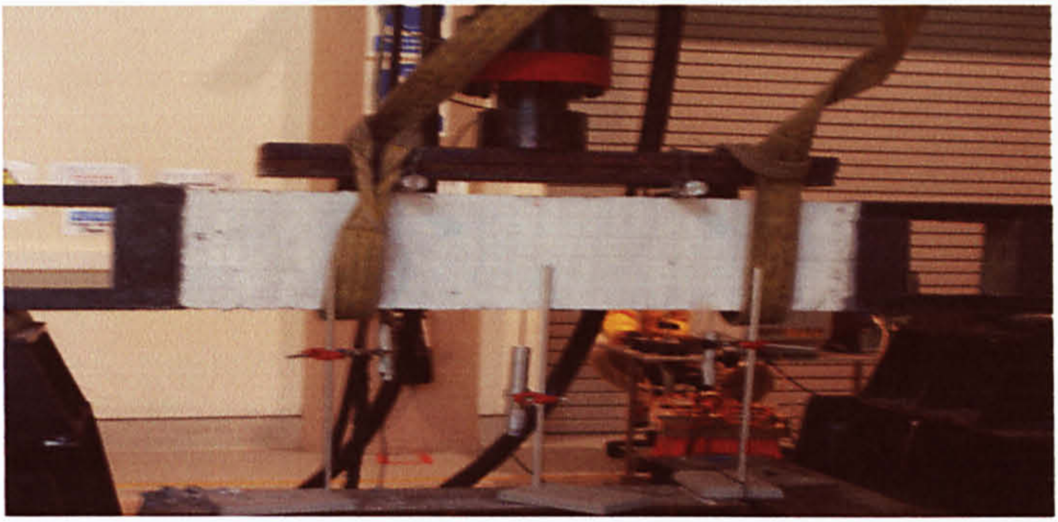


Figure 4.14: Preparation for static load for beam with large square opening in critical shear zone using the self straining Loading frame attached to a dynamic actuator (500kN) simply supported.(CFRP Strengthened)

Figure 4.15: Failure of beam with large square opening at support (CFRP Strengthened)

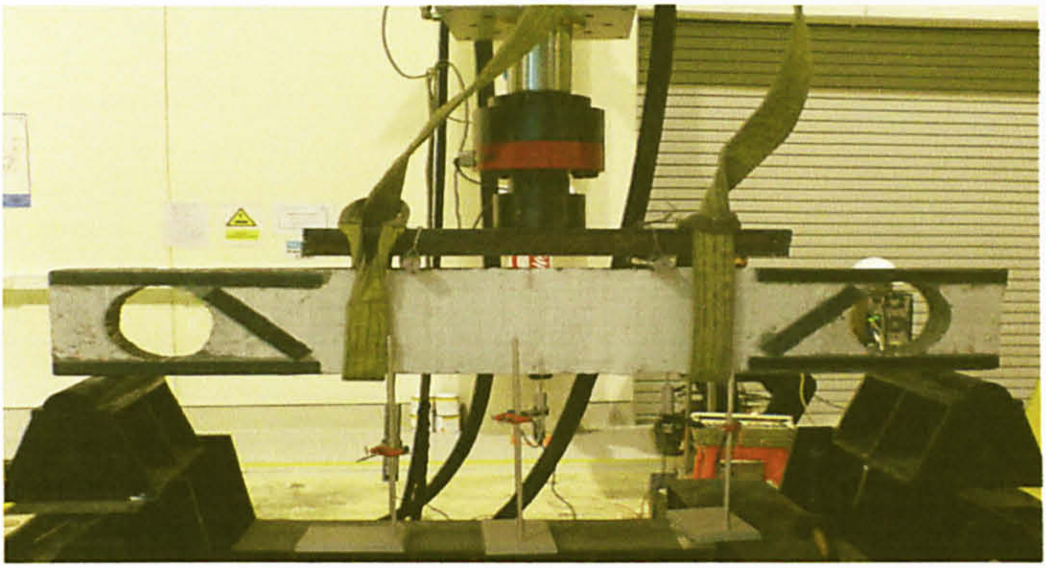


Figure 4.16: Preparation for static load for beam with large circular opening in critical shear zone using the self straining Loading frame attached to a dynamic actuator (500kN) simply supported.(CFRP Strengthened)

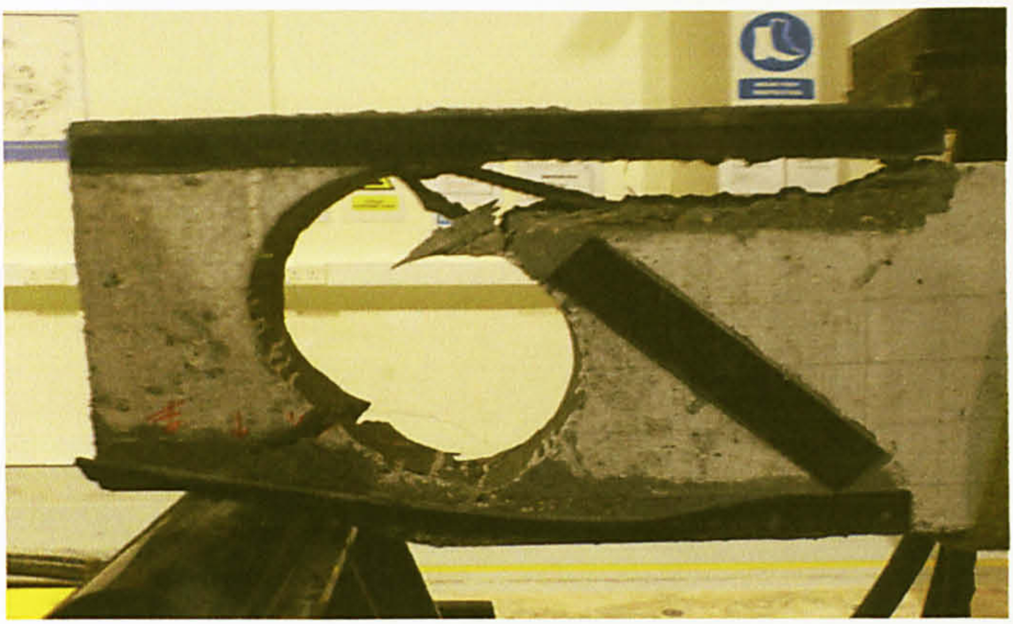


Figure 4.17: Failure of beam with large circular opening at support (CFRP Strengthened)

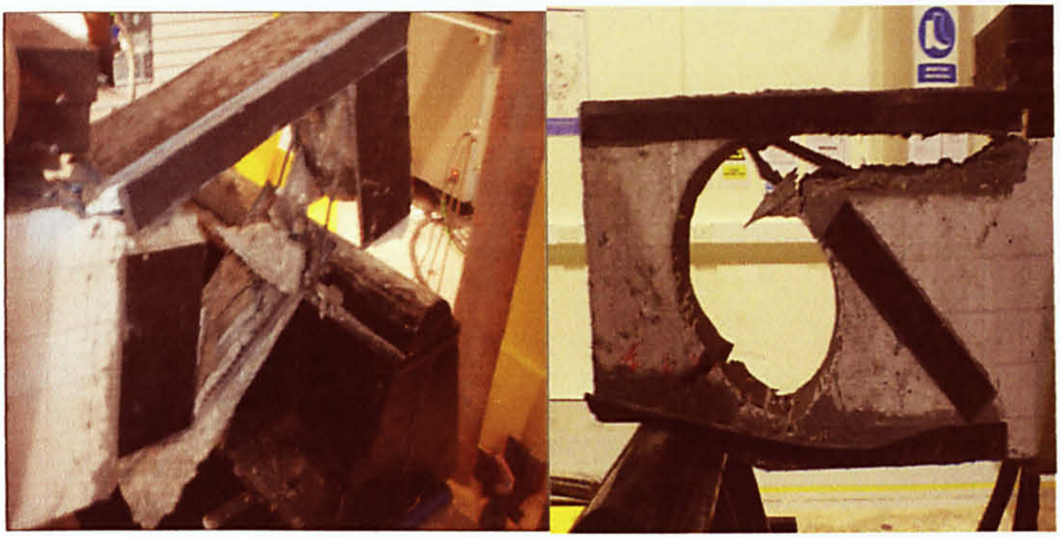


Figure 4.18: Comparing severity of crack pattern between square opening and circular opening in critical shear zone (CFRP Strengthened)

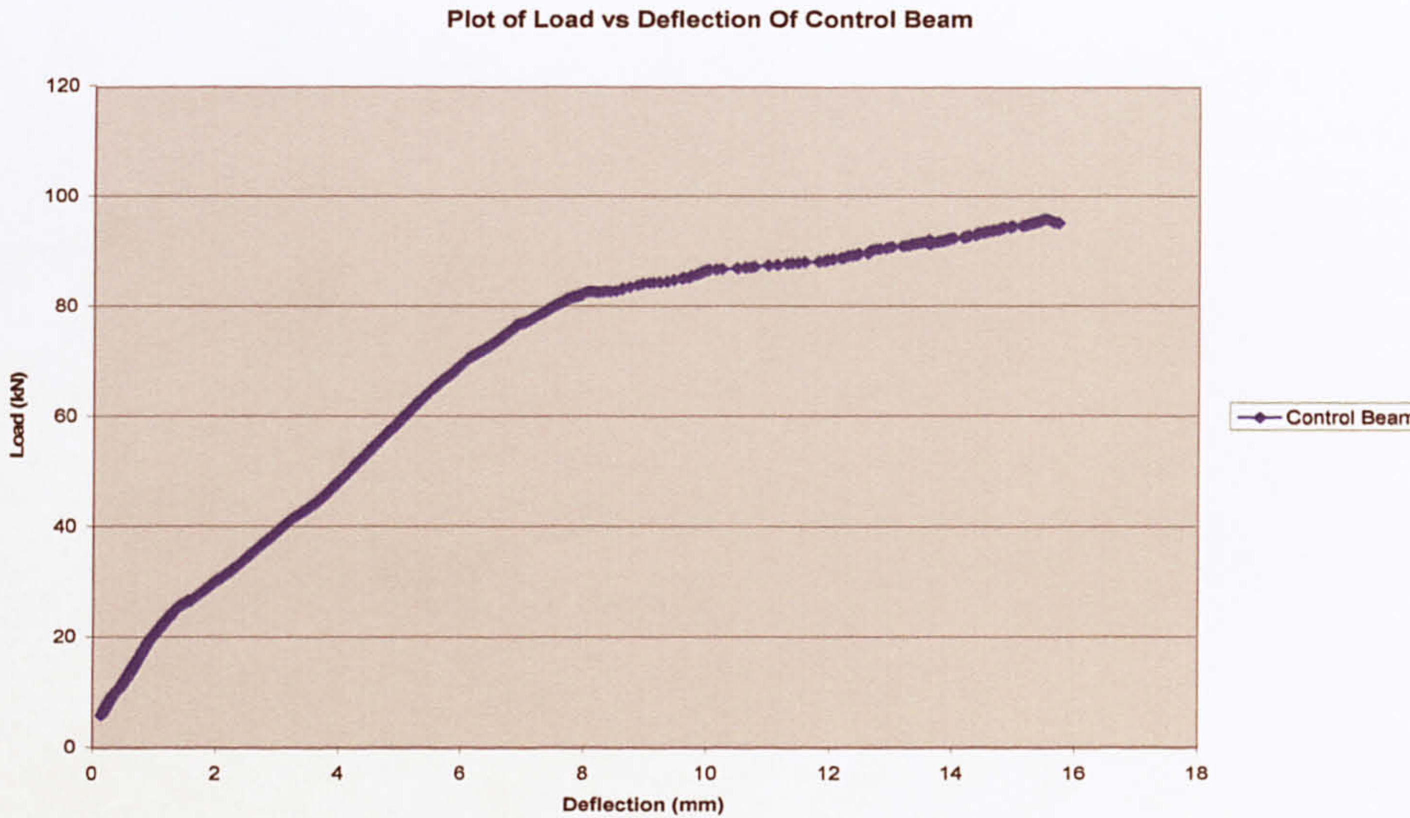


Figure 4.19: Load vs Deflection Curve for Control Beam

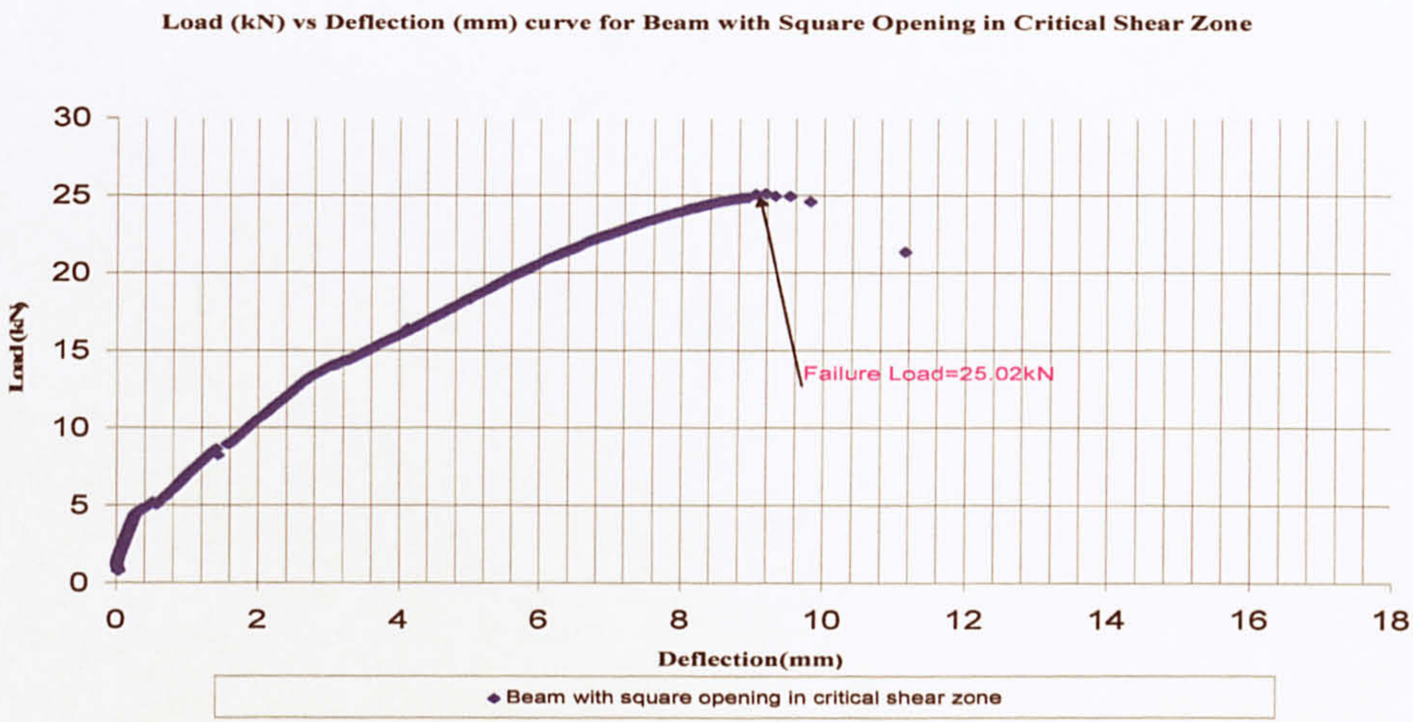


Figure 4.20: Load vs Deflection Curve for Beam with Square Opening (Without CFRP Strengthening)

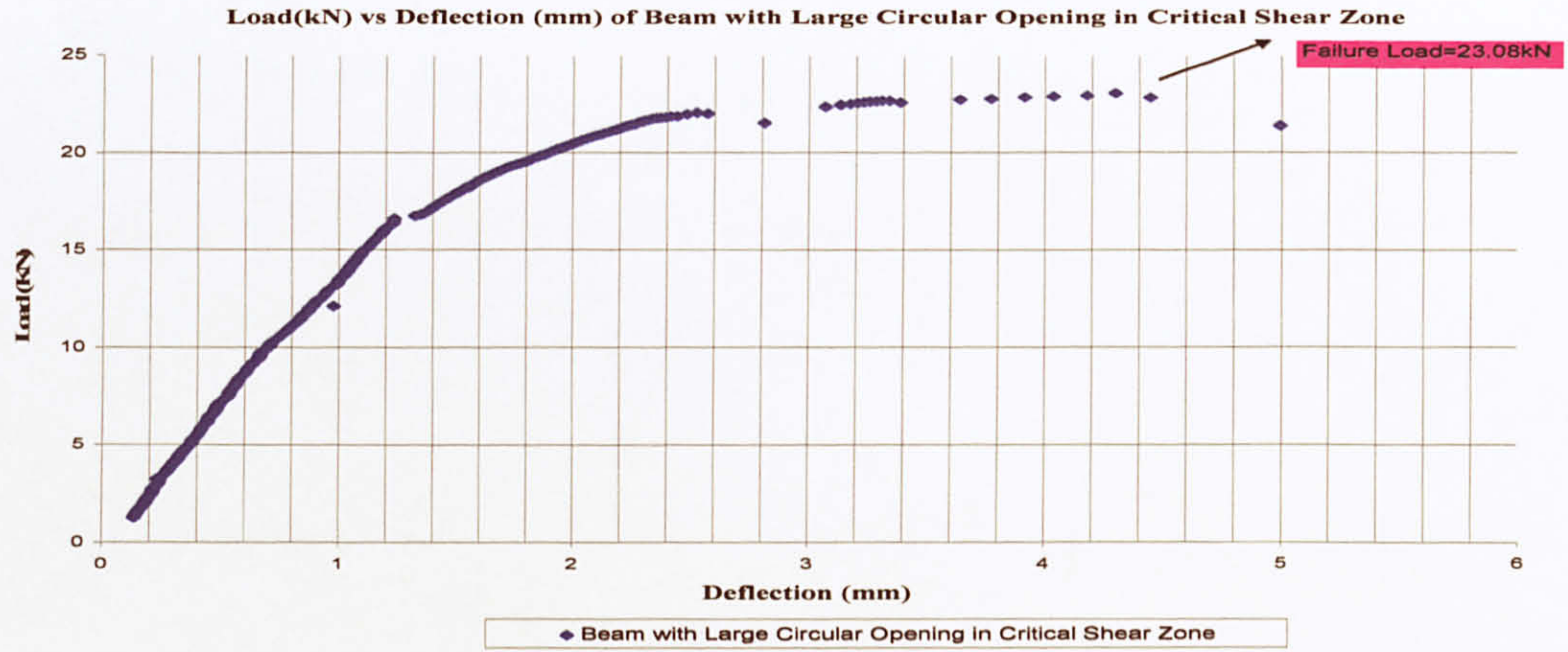


Figure 4.21: Load vs Deflection Curve for Beam with Circular Opening (Without CFRP Strengthening)

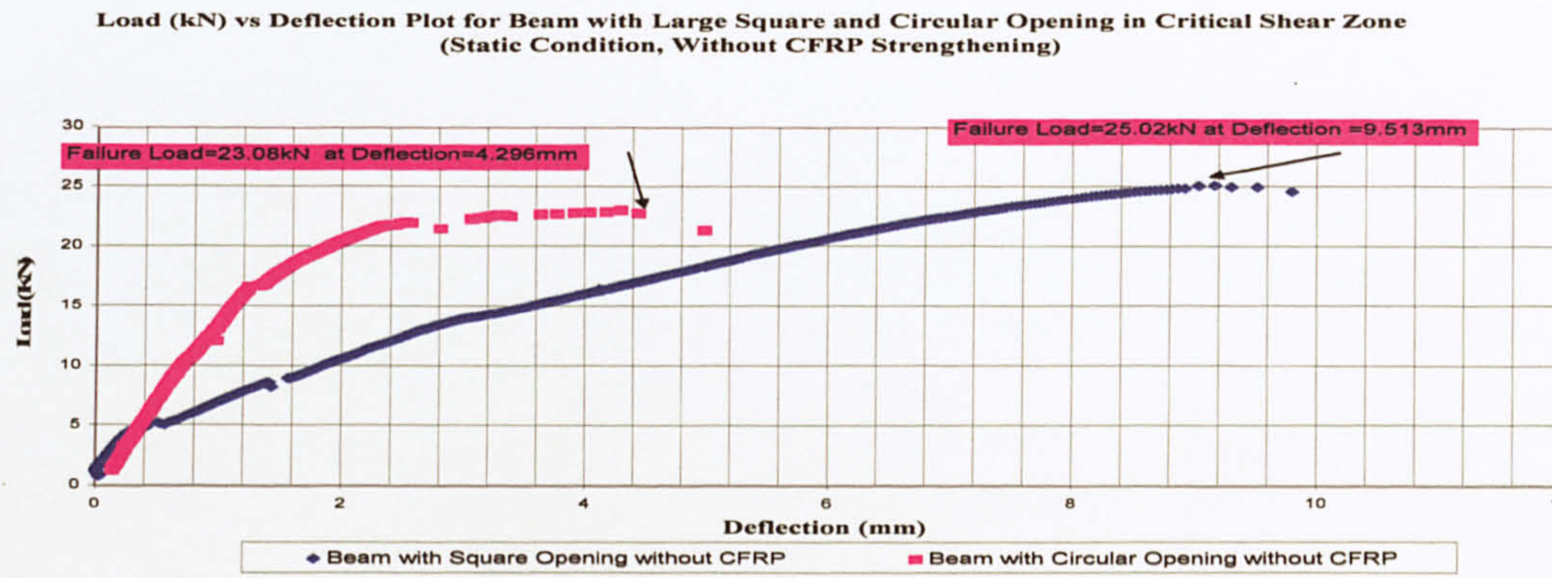


Figure 4.22: Comparison Plot of Load vs Deflection Curve between Beams with Square Opening and Beam with Circular Opening

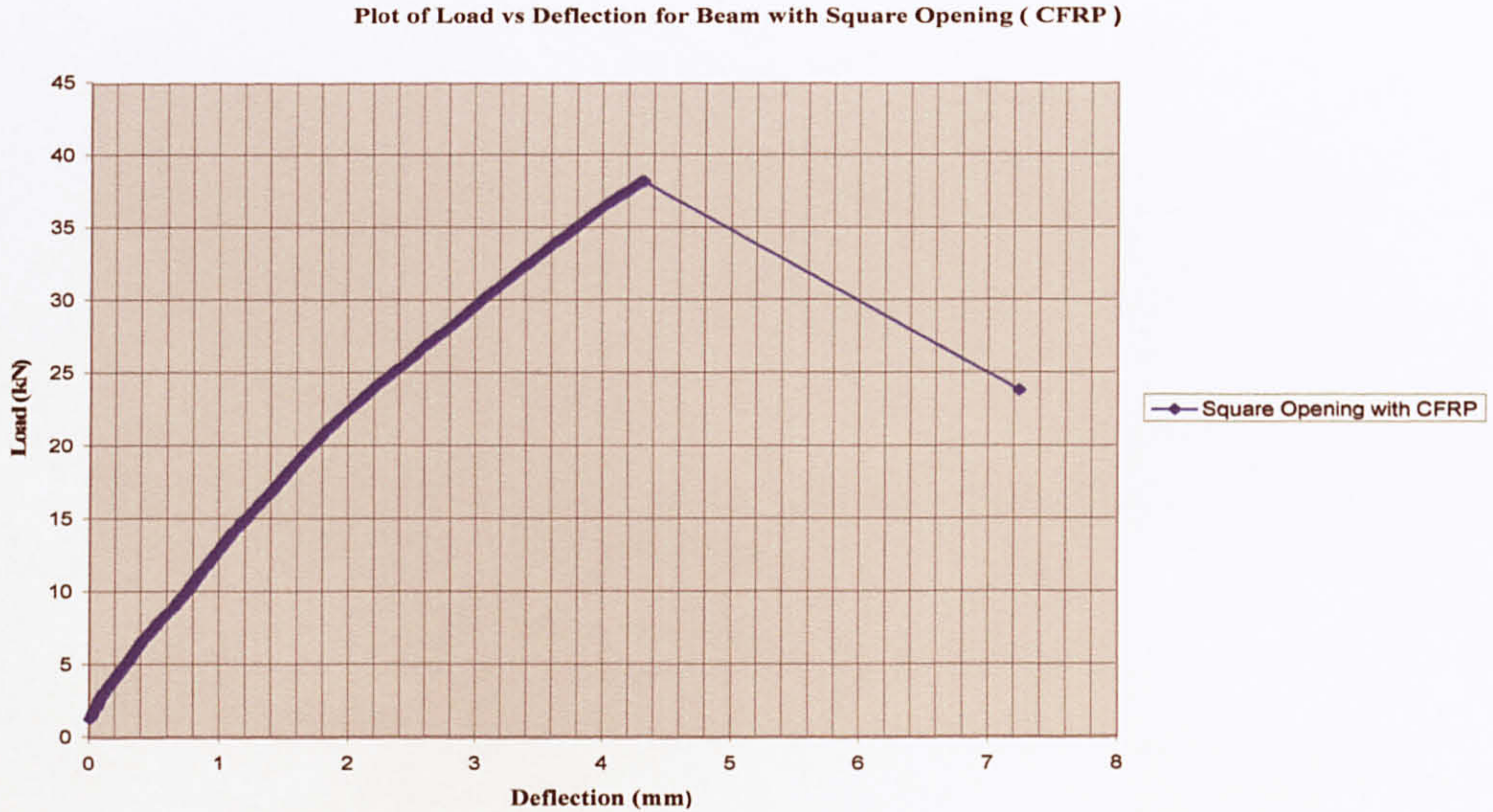


Figure 4. 25: Load vs Deflection Curve for Beam with Square Opening Using CFRP Strengthening

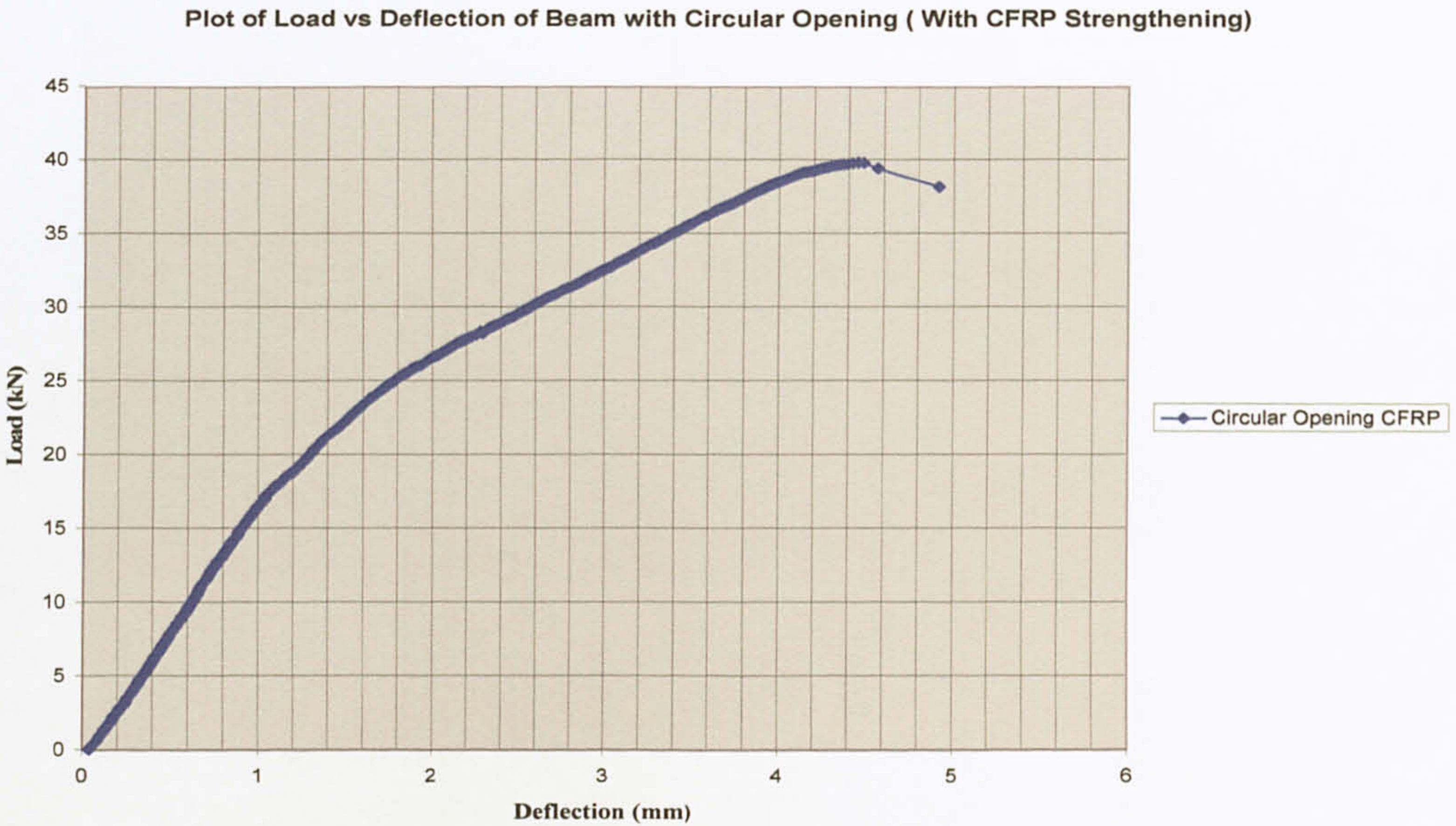


Figure 4.24: Load vs Deflection Curve for Beam with Circular Opening Using CFRP Strengthening

Figure 4.25: Comparison Plot of Load vs Deflection Curve between Beams with Square Opening and Beam with Circular Opening (With CFRP Strengthening)

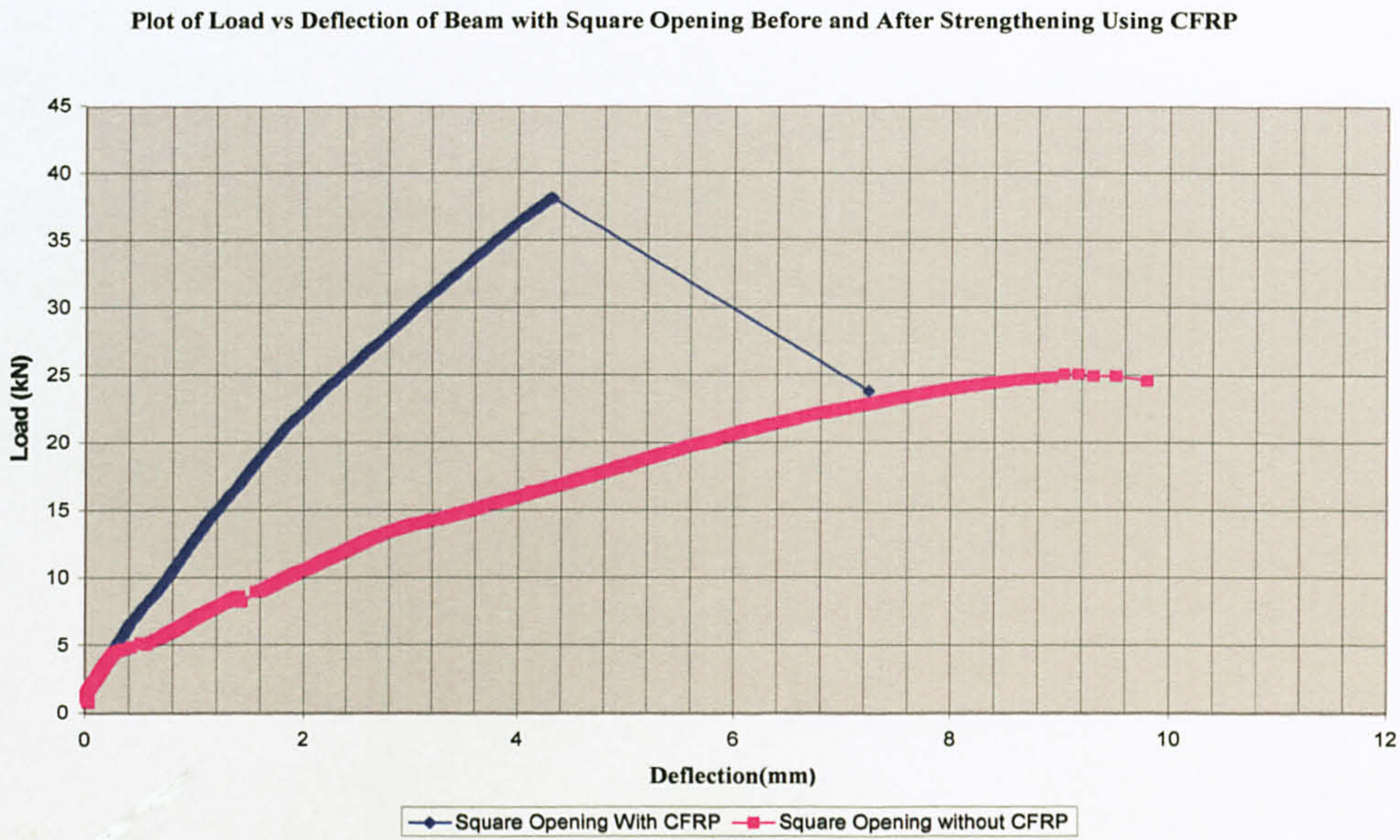


Figure 4.16 Comparison Plot of Load vs Deflection Curve between Beams with Square Opening Without and With CFRP Strengthening

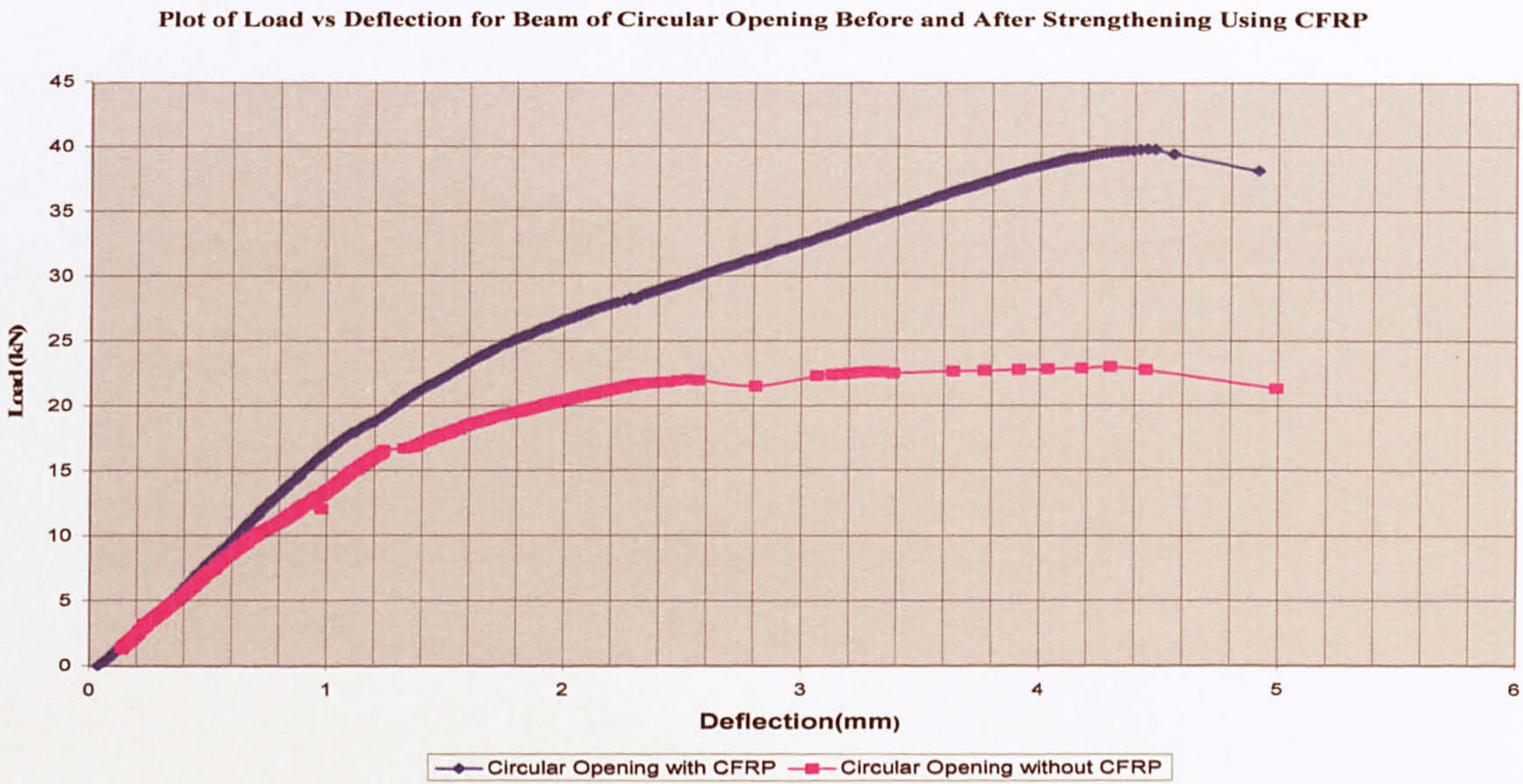


Figure 4.27: Comparison Plot of Load vs Deflection Curve between Beams with Circular Opening Without and With CFRP Strengthening

4.5 Analysis of Results

From the results obtained from the static load test carried out on the beams with large square opening, large circular opening and the control beam the summary of ultimate load is a summarized in table 4.2:

Beam Characteristic	Ultimate strength under static condition (kN)	Deflection(mm)	% loss in strength due to opening in critical shear zone
Control Beam	96.03	15.489	nil
Beam with Square Opening	25.02	9.513	73.95%
Beam with Circular Opening	23.08	4.296	75.96%

Table 4.2: Summary of static load test (Beams without CFRP strengthening)

From table 4.2, it can be observed that there is a severe loss in strength of the beams due to the opening. As expected, the beam with circular opening can be said to experience more severe loss up to 72.25% of its strength when compared to the control beam. This fact is more prominently illustrated in the comparison of the severity of crack patterns (figure 4.12) 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 around the corners all the way outwards in a almost 45 degree angle to the circumference of the square (figure 4.10).The beam with the circular opening had major diagonal crack, which lead the failure to traversed through he center of the opening. The results of the beam clearly indicate that providing an opening reduces the strength of the beam significantly and therefore there is a need for strengthening at these zones of critical shear failure. The strengthening of these beams with opening is to be carried out using CFRP and tested under static loading conditions to evaluate and compare the strengthening capacity and practicality of this strengthening measure.

From the results obtained from the static load test carried out on the beams with large square opening, large circular opening (CFRP) and the control beam the summary of ultimate load is a summarized in table 4.3:

Beam Characteristic	Ultimate strength under static condition (kN)	Deflection(mm)	% gain in strength due to opening in critical shear zone
Control Beam	96.03	15.489	nil
Beam with Square Opening	36.19	4.319	52.64%
Beam with Circular Opening	39.86	4.449	72.7%

Table 4.3: Summary of static load test (Beams with CFRP strengthening)

The analysis from the data obtained form the testing are as tabulated in Table 4.4 below:

Beam	Square Opening	Circular Opening
Loss in strength due to opening compared to control Beam	73.95%	75.90%
Gain in strength due to CFRP compared to the beam before strengthening	52.64%	72.7%
Percentage strength gained compared to the actual strength loss due to opening.	46.22%	45.35%
Total loss unable to be recovered after strengthening	27.73%	30.61%

Table 4.4: Analysis of testing results

This research is part of a larger study on beams with large opening by a postgraduate student. 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 shear zone as well as the configuration on CFRP used for strengthening the beams with opening. From the 5 nos of beams tested in shear the following table 4.5 describes the pattern of cracking of each beam from the initial location of cracks formation until the beam fails completely.

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 at the corners of the square working outward towards the concrete cover. All cracks appeared around the opening. • Approximately 9 major cracks formed before the beam failed at the support with an angled crack right through the diagonal corner of the square.
Circular Opening (Without CFRP Strengthening)	• Cracks initially begun at the supports diagonally through the circular opening. However, the crack pattern was not as severe as the beam with the square opening as there were only about 6 cracks which appeared before the beam failed.
Square Opening (CFRP Strengthening)	• For the beam with square opening the CFRP was used to completely cover the sides of the opening as well as the 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 center of the beam. • The beam failed at the connection sheets of CFRP itself at the corner of the opening but at a higher strength then previously. Links at support failed.

Circular Opening (CFRP Strengthening)	• For the beam with circular opening the CFRP was used at the top and bottom section of the opening and the bottom of the beam at the support under the opening and 1 sheet was placed perpendicular 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 with a similar pattern as beam without CFRP strengthening but with a higher strength.

Table 4.5: Beams and Crack Description on Beams in Shear

From table 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. This is because the beam with circular opening managed to regain 72.7% of the strength compared to the beam with square opening which only recovered 52.64% of the strength. The CFRP sheets have been found to be most effective when the fiber is perpendicular to the cracks itself. However, when the actual percentage of strength regained using CFRP to the control beam itself could be said to be almost similar for both the square opening and circular opening with 46.22% and 45.35% respectively. This indicates that the shape of the opening itself did not affect the capacity of CFRP to regain strength lost due to opening.

CHAPTER 5

5.0 Conclusion

Based on the results and discussion, following are the main conclusions drawn:

1. It is found that through this research for large opening in critical shear zone, the shape of the opening did not affect the loading capacity of the beam significantly. However, approximately 75% capacity was lost for both beams with square and circular opening due to large opening in critical shear zone.
2. Also, the shear cracks for opening with corners (square in this study) resulted in massive cracks appearing at this location compared to the beams with circular opening.
3. The capacity of Carbon Fiber Reinforced Polymer to regain strength lost due to large opening is almost 50% of capacity with appropriate strengthening configuration of CFRP sheets; CFRP applied perpendicular to expected crack pattern on beams with large opening in critical shear zone resulted in higher strength recovery.

CHAPTER 6

6.0 Cost Estimation

The cost of this project included cost of material and physical labor. The materials used included steel rebars of Y12 and Y10 and R6 links, G35 concrete and form work. The cost for 0.75m^3 of concrete was RM 150 and the labor cost for 2 general workers for bar bending and physical assistance was RM 300 for casting the 5 Nos of beams. In total, the cost for 5 nos of beams was approximately RM700. This total RM 700 includes the cost of reinforcement steel bars, Carbon Fiber Reinforced Polymer and plywood which was provided by Concrete Laboratory Block 14 UTP.

REFERENCES

1. Maruyama K. Recommendations for upgrading of concrete structures with use of continuous fiber. Concrete engineering series 41. JSCE, ISBN 4-8106-0355-5, 2001, p. 250.

2. Neale K. Strengthening reinforced concrete structures with externally-bonded fiber reinforced polymers. Design manual no. 4, ISBN 0-9689007-0-4. Canada: ISIS, September 2001, p. 198.

3. Täljsten B. Förstärkning av befintliga betongkonstruktioner med kolfiberväv eller kolfiberlaminat, dimensionering, material och utförande. Teknisk Rapport, Institutionen för Väg-och vattenbyggnad, Avdelningen för Konstruktionsteknik (in Swedish), 1999, 2000:16, ISSN 1402–1536, 2000, p. 133.

4. Täljsten B. FRP strengthening of existing concrete structures—design guidelines. Luleå University of Technology, ISBN 91-89580-03-6, 2002, p. 230.

5. FIB. Bulletin 14, externally bonded FRP reinforcement for RC structures. Technical report, task group 9.3 FRP (fiber reinforced polymer) reinforcement for concrete structures, ISBN 2-+88394-054-1, July 2001, p. 130.

6. Drimoussis A, Cheng JJR. Shear strengthening of concrete bridge girders using carbon fiber-reinforced plastic sheets. Fourth International Bridge Engineering Conference, vol. 1. San Francisco (California, USA), August 28–30, 1995:337–47.

7. M.J. Chajes, D.R. Januszka, T.R. Thomson, Jr. and W.W. Finch, Jr. , Shear strengthening of reinforced concrete beams using externally applied composite fabrics. *ACI Struct J* **92** 3 (1995), pp. 295–303.

8. T. Norris, H. Saadatmanesh and M.R. Ehsani , Shear and flexural strengthening of R/C beams with carbon fiber sheets. *J Struct Eng* **123** 7 (1997), pp. 903–911

9. O. Chaallal, M.-J. Nollet and D. Perraton , Shear strengthening of RC beams by externally bonded side CFRP strips. *J Compos Constr* **2** 2 (1998), pp. 111–114.

10. Chen JF, Teng JG. A shear strength model for FRP-strengthened RC beams. International Conference FRPRCS-5, vol. 1, University of Cambridge, ISBN: 0 7277 3029 0, July 2001:205–14.

11. J.G. Teng, J.F. Chen, S.T. Smith and L. Lam *FRP strengthened RC structures, ISBN 0-471-48706-6*, John Wiley and Sons Ltd, Baffins Lane, Chichester, West Sussex, PO19 1UD, England (2002) p. 254 .

12. Björn Täljsten – Strengthening concrete beams for shear with CFRP sheets Luleå University of Technology, Division of Structural Engineering, Department of Civil and Mining Engineering, 971 87, Luleå, Sweden, (2002) p.25

13. T. Triantafillou, Shear strengthening of reinforced concrete beams using epoxy-bonded FRP composites, *ACI Struct J* **95** (2) (1998), pp. 107–115.

14. M. Mansur, K. Tan and W. Wei, Effects of creating an opening in existing beams, *ACI Struct J* **96** (6) (1999), pp. 899–906.

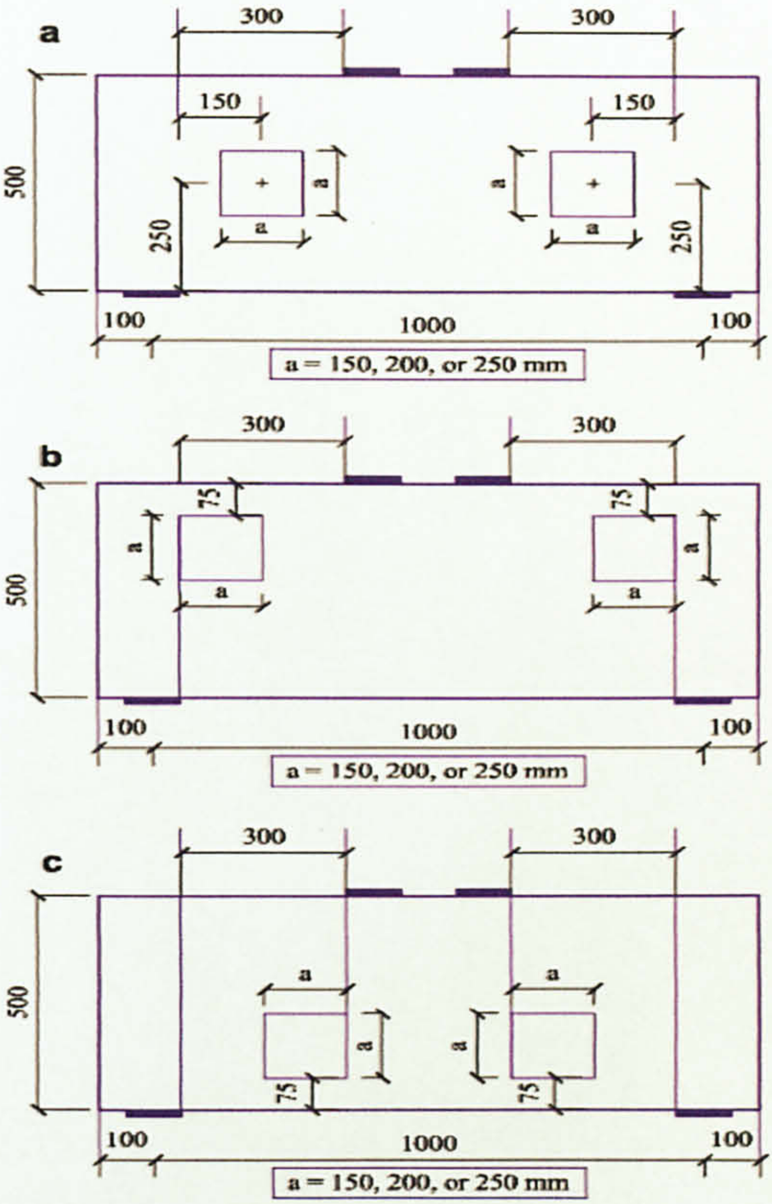
15. H.A. Abdalla, A.M. Torkey, H.A. Haggag and A.F. Abu-Amira, Design against cracking at openings in reinforced concrete beams strengthened with composite sheets, *Compos Struct* **60** (2003), pp. 197–204.

16. Tamer El Maaddawy and Sayed Sherif' FRP composites for shear strengthening of reinforced concrete deep beams with openings ,[a]UAE-University, Al-Ain, Abu Dhabi, P.O. Box 17555, United Arab Emirates Structural Engineering Department, Al-Wasl Al-Gadeed Consultants, Dubai, United Arab Emirates (2008), pp. 63

17. BS 1881: Part 125:1986, Concrete Technology Laboratory Procedure manual, Mixing and Sampling Fresh Concrete,(1986) pp3

18. BS 1881: Part 111: 1983, Concrete Technology Laboratory Procedure Manual , Making and Curing Cubes and Test Beams, (1983) pp12

APPENDIXES



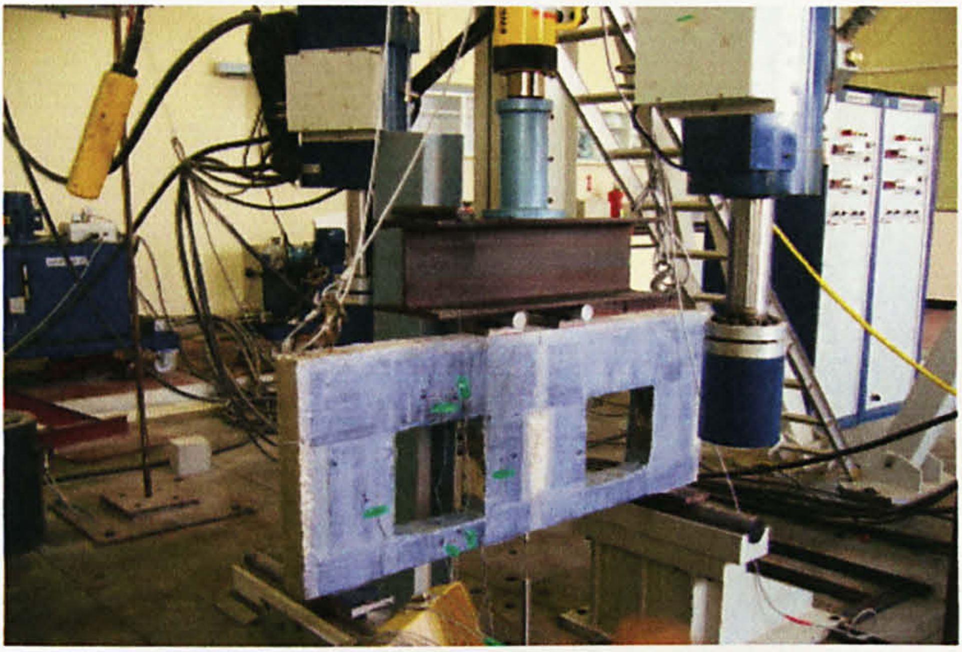
Appendix 1: Opening regimes (a) group [A], (b) group [B], (c) group [C] (unit in mm) [16]

Group	Specimen	Opening location	Opening size(mm)	External FRP strengthening
[A]	NS-150-C	Mid of shear span	150 × 150	No
	NS-200-C	Mid of shear span	200 × 200	No
	NS-250-C	Mid of shear span	250 × 250	No
	FS-200-C	Mid of shear span	200 × 200	Yes
	FS-250-C	Mid of shear span	250 × 250	Yes
[B]	NS-150-T	Top of shear span-near support	150 × 150	No
	NS-200-T	Top of shear span-near support	200 × 200	No
	NS-250-T	Top of shear span-near support	250 × 250	No
	FS-250-T	Top of shear span-near support	250 × 250	Yes
[C]	NS-150-B	Bottom of shear span-near loading point	150 × 150	No
	NS-200-B	Bottom of shear span-near loading point	200 × 200	No
	NS-250-B	Bottom of shear span-near loading point	250 × 250	No
	FS-250-B	Bottom of shear span-	250 × 250	Yes

Group	Specimen	Opening location	Opening size(mm)	External FRP strengthening
		near loading point		

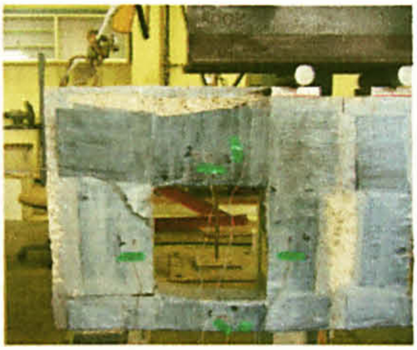
[a] NS and FS refer to no strengthening and FRP strengthening, respectively. 150, 200, and 250 refer to opening size of 150 × 150, 200 × 200, and 250 × 250 mm, respectively. C, T, and B refer to the opening location that is center of shear span, top of shear span-near support, and bottom of shear span-near loading point, respectively.

Appendix 2: Test Matrix

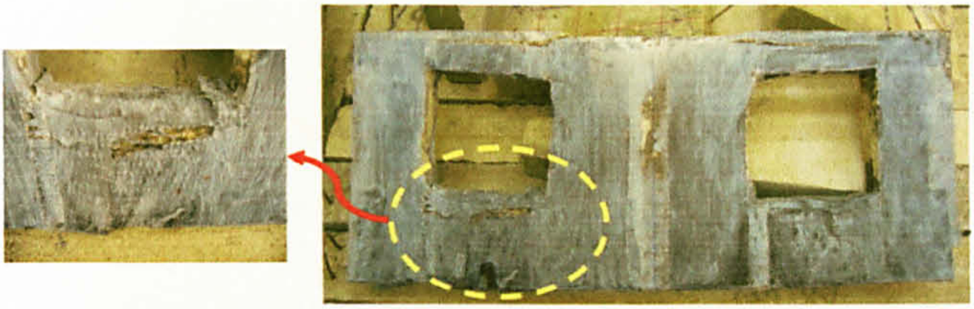


Appendix 3: Test set-up

Specimen FS-250-C

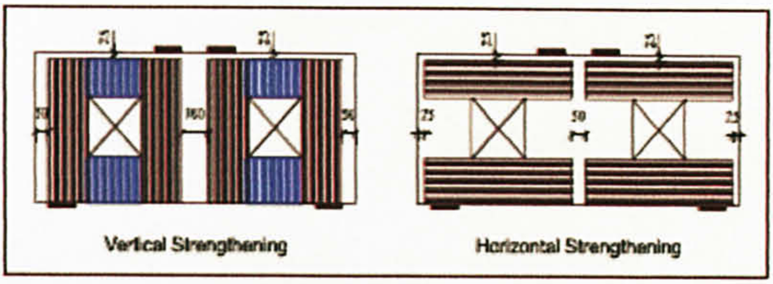


Specimen FS-250-B

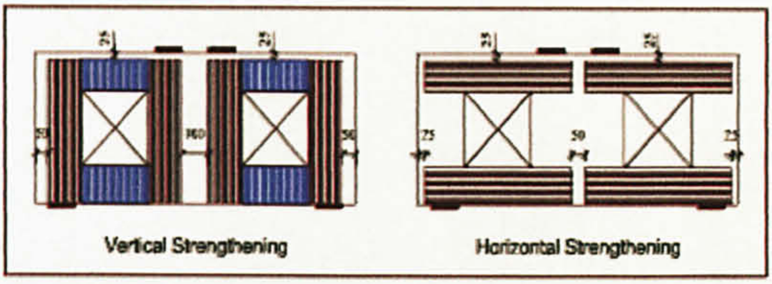


Specimen FS-250-T

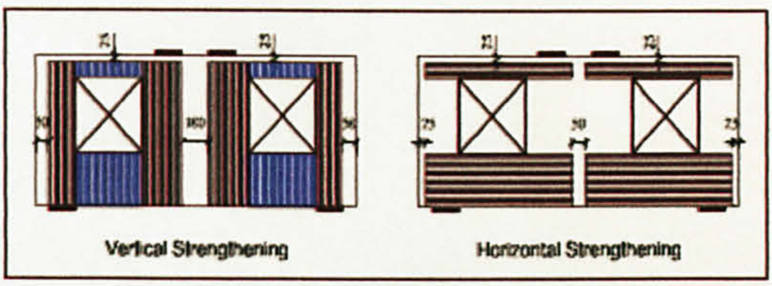
Appendix 4: Failure Modes of CFRP – strengthened beams



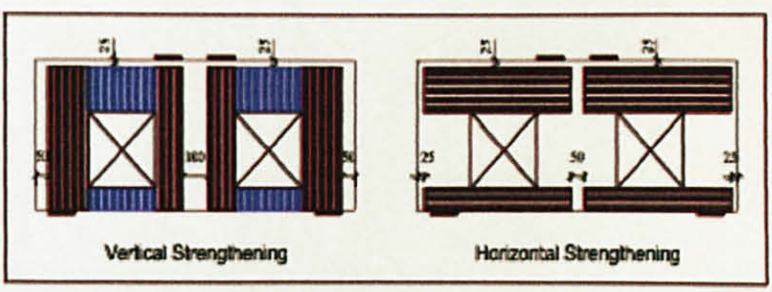
Specimen FS-200-C



Specimen FS-250-C



Specimen FS-250-T



Specimen FS-250-B

Appendix 5: CFRP strengthening scheme (unit in mm)

KIRIJAA A/P RATANARAJAH

10483

萬隆混合凝土產品有限公司

BAN LOONG READY-MIXED CONCRETE PRODUCTS SDN. BHD.

(Co. No. 431130-A)

HEAD OFFICE	: 9A & 9B, Jalan Koo Chong Kong, 30000 Ipoh, P.O. Box 591, 30760 Ipoh, Perak Darul Ridzuan, Malaysia. Tel: 05-2540189, 2549141, 2417873 Fax: 05-2558728
BERCHAM PLANT	: Lot 12637, Off Jalan Bercham, Ke Tanjung Rambutan, Ipoh. Tel: 05-5460810, 5476409 Fax: 05-5455972 H/P: 019-5126950
KUALA KANGSAR PLANT	: Lot No. 3695, Mukim of Kg. Buaya, Kuala Kangsar. Tel: 05-7771948
GERIK PLANT	: Lot 1301, Intan Road, Gerik. Tel: 05-7918980
BIDOR PLANT	: PT 5575, Kaw. Perindustrian Bidor, Jln. Sungkai, Bidor. Tel: 05-4270050 H/P: 012-5056950
BATU GAJAH PLANT	: Lot 6027, Jalan Changkat Larang, 31000 Batu Gajah. Tel: 05-3657550

Attention: Kirijaa.

CONCRETE MIX DESIGN CALCULATION

NO.	DESCRIPTION		VALUE
1.2	Product/Mix Grade & Type		35 NORMAL MIX
1.2	Characteristic Strength		35 N/mm² @ 28 days
1.3	Standard Deviation		4.00 N/mm² ~ Proportion Defective = 5%
1.4	Margin (k = 1.64)		1.64 x 4.00 = 6.6 N/mm²
1.5	Target Mean Strength		35 + 6.6 = 41.6 N/mm²
1.6	Free Water / Cement Ratio (W/C)		0.54
2.1	Cementitious Type	Type 1.	OPC (Complies to MS 522:1989)
		Type 2.	MASCRETE (Complies to MS 1227:1991 / MS 1387:1995)
2.2	Fine Aggregate Type		SAND (Mining Sand)
2.3	Coarse Aggregate Type		AGGR20 (20mm Granite Crushed Aggregate)
2.4	Admixture Type & Dosage	Type 1.	RETARDER 700 ml/100kg of cement
		Type 2.	S/CISER ml/100kg of cement
2.5	Additive Type & Dosage		N/A Nil kg/m³
3.1	Maximum Coarse Aggregate Size		20 mm Graded
3.2	Grading Fine Aggregate		BS 882
3.3	Relative Density of Combined Aggregates (SSD)		2.610
3.4	Proportion of Fine Aggregate (S/A Ratio)		45.3%
3.5	Proportion of Coarse Aggregate		54.7%
4.1	Workability - Slump Range		75 +/-25 mm
4.2	Air Content (Estimated)		2.0 % = 20 Ltr Abs/m³
4.3	Free Water Requirement		180 Ltr/m³ = 180 Ltr Abs/m³
4.4	Cementitious Content	Type 1.	335 kg/m³ 100% = 107 Ltr Abs/m³
		Type 2.	0 kg/m³ 0% = 0 Ltr Abs/m³
4.5	Total Cement Content		335 kg/m³ 100%
4.6	Total Aggregates Content		= 693 Ltr Abs/m³
			= 1810 kg/m³
4.7	Fine Aggregate Content		1810 x 45.3% = 820 kg/m³
4.8	Coarse Aggregate Content		1810 x 54.7% = 990 kg/m³
4.9	Designed Mix Proportion		1 : 2.4 : 3.0
4.10	Designed Density		= 2325 kg/m³

BATCH WEIGHTS PER CUBIC METER

GRADE 35 SLUMP RANGE : 75 +/-25 mm

Cement 1 OPC	Cement 2 MASCRETE	Fine Agg SAND	Coarse Agg AGGR20	Water	Admix 1 RETARDER	Admix 2 S/CISER	Additive N/A
335	0	820	990	180	2345	0	Nil

Note The above mix may be adjusted to suit site conditions or strength in accordance with the relative sections of MS 523.

PREPARED BY P.B.CHAN

APPROVED BY

Appendix 6: Design Mix of Concrete

Edition 7.1.2008
Identification no. 332-15
Sikadur 30

Sikadur® 30

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

Construction

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.

Appendix 7: Material on adhesive used for bonding.

Construction

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.

KEEP CONTAINER TIGHTLY CLOSED • KEEP OUT OF REACH OF CHILDREN • NOT FOR INTERNAL CONSUMPTION • FOR INDUSTRIAL USE ONLY

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

Regional Information and Sales Centers. For the location of your nearest Sika sales office, contact your regional center.

Sika Corporation
201 Polito Avenue
Lyndhurst, NJ 07071
Phone: 800-933-7452
Fax: 201-933-6225

Sika Canada Inc.
601 Delmar Avenue
Pointe Claire
Quebec H9R 4A9
Phone: 514-697-2610
Fax: 514-694-2792

Sika Mexicana S.A. de C.V.
Carretera Libre Celaya Km. 8.5
Fracc. Industrial Balvanera
Corregidora, Queretaro
C.P. 76920
Phone: 52 442 2385800
Fax: 52 442 2250537

BSI
ISO 9000:2000

Sika ®

Construction

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

Appendix 8: Manufacturer's technical sheets
For CarboDur CFRP.

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 doleplјenjem 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/mm^2	210,000 N/mm^2	300,000 N/mm^2
	Min. value	> 160,000 N/mm^2	> 200,000 N/mm^2	> 290,000 N/mm^2
	5% Fractile-Value	162,000 N/mm^2	210,000 N/mm^2	-
	95% Fractile-Value	180,000 N/mm^2	230,000 N/mm^2	-
Tensile Strength*	Mean value	3,100 N/mm^2	3,200 N/mm^2	1,500 N/mm^2
	Min. value	> 2,800 N/mm^2	> 2,900 N/mm^2	> 1,350 N/mm^2
	5% Fractile-Value	3,000 N/mm^2	3,000 N/mm^2	-
	95% Fractile-Value	3,600 N/mm^2	3,900 N/mm^2	-
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/mm^2, min. 1.5 N/mm^2. 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

Sika Kimia Sdn Bhd
Lot 689 Nilai Industrial Estate
71800 Nilai, Negeri Sembilan DK
MALAYSIA

Phone: +6 06 799 1762
Fax: +6 06 799 1980
e-mail: info@my.sika.com
www.sika.com.my