Repair of Corroded RC beams using Carbon Fibre Reinforced Polymer (CFRP) Laminates

by

Izan Nadia Bt Dahalan

Dissertation submitted in partial fulfillment of
the requirements for the
Bachelor of Engineering (Hons)
(Civil Engineering)

JUNE 2006

Universiti Teknologi PETRONAS
Bandar Seri Iskandar
31750 Tronoh
Perak Darul Ridzuan

CERTIFICATION OF APPROVAL

Repair of Corroded RC beams using Carbon Fibre Reinforced Polymer (CFRP) Laminates

by

Izan Nadia Bt Dahalan

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

Approved by,

(Dr. Nasir Shafiq)

UNIVERSITI TEKNOLOGI PETRONAS
TRONOH, PERAK
JUNE 2006

CERTIFICATION OF ORIGINALITY

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

Izah

IZAN NADIA BT DAHALAN

ABSTRACT

Strengthening of RC beams and Slabs for Flexural, Shear and Buckling is currently a major research task in the construction industry. The main reasons of strengthening structures are to restore and enhanced the load bearing capacity to reduce deflection at service loads, or to limit the width and distribution of cracks in concrete.

Use of externally bonded Carbon Fibre Reinforced Polymer (CFRP) Laminate has proved to be one of the solutions to this problem. CFRP is adhesively bonded to surfaces of reinforced concrete beams or slabs to increase their flexural or shear capacity.

To determine the flexural capacity of reinforced concrete beam that is reinforced or not reinforced by CFRP test should been done. The result is compared with the control beam and the effectiveness of CFRP as a repair method can be proved.

ACKNOWLEDGEMENT

Alhamdulillah, all praises be to Him that I have succeeded in completing my Final Year Project for two semesters starting from November 2005 to Jun 2006. Without His blessing, the project is impossible to be completed.

First of all, the author would like to convey his highest gratitude to Dr. Nasir Shafiq for his guidance and attention in helping the author accomplishing the project. His understanding and quality-based policy urged the author to give the best to achieve the goals of the project.

The author also would like to express deepest thanks to Dr. Waled Thanon for sharing his idea and giving suggestions to improve the project.

The compliment should also go to all Civil Engineering laboratory technicians and staff for bundles of information and assistance in completing this project especially to Mr. Johan Ariff, Mr. Zaini, and Mr. Meor. They help a lot in doing the laboratory works.

Not to forget the author family, course mates and friends for their cooperation and willingness in contributing their energy and support on the project especially to Mr. Bani, Ms. Norliza and Ms. Mimi Nur Laily. The same goes to all the people that have contributed in completing this project

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLE

INTRODUCTION

1.1 BACKGROUND OF STUDY

In this study four (4) RC beams with similar dimension and reinforcement; Control beam, Beam 1, Beam 2 and Beam 3 are to be tested for flexural capacity. One of the beams that represent a control beam was designed neutral, which not undergone for corrosion process and without presence of CFRP strips. The corrosion process was done by exposing the beam to the 3% Nacl solution for 28 days. The other two beams, Beam 1 and Beam 2 both were tested with the presence of CFRP strips but only Beam 1 will undergone the corrosion process. The last beam, Beam 3 was tested without the presence of CFRP strips but corrosion process was allowed. The failure mode and also the experimental result of the flexural capacity produced by each beam during the test were compared with the failure mode of control beam.

As the study is to prove the effectiveness of using CFRP to strengthening the RC beams, the result for RC beam tested with the presence of CFRP strips was expected to have higher percentage of flexural capacity compared to the beam that not reinforced with CFRP strips.

1.2 PROBLEM STATEMENT

Rehabilitation or structurally deteriorated or functionally obsolete RC structures is a major problem in the construction industry worldwide. The phenomena contribute to the reduction of load bearing capacity caused by mechanical damage or by material deterioration. These include corrosion of reinforcement or functional modification of the construction. CFRP is used to recover the condition or in other words to re-strengthened the structures for loading increase, damage to structural parts, serviceability improvement, change in structural system, change of specifications and design or construction defects.

1.3 OBJECTIVES OF THE STUDY

The main objectives of the study are:

- To determine the flexural capacity of reinforced beams strengthened with CFRP
- To determine the flexural capacity of reinforced beams not strengthened with CFRP
- To determine the flexural capacity of the corroded reinforced beams strengthened with CFRP.
- To prove the effectiveness of using CFRP in strengthening the reinforced structure by conducting the capacity testing

The project can be divided into several sections, which are:

- Literature review
- Experimental / Testing
- Data analysis

During the literature review, the author needs to do a thorough research about the properties of the CFRP laminates. The literature review consists of the theory and previous project or study that used the CFRP.

In experimental / testing section, the author needs to run flexural capacity test by using the Universal Testing Machine (UTM). The test will require reinforced concrete beam that is strengthened with CFRP laminates.

For data analysis section, the author needs to compare the result of the experimental data from different sample. The data then analyzed and discussed in order to present the test result of the project.

CHAPTER 2

LITERATURE REVIEW AND THEORY

2.1 Carbon Fibre Reinforced Polymer

FRP composites comprise fibres of high tensile strength within a polymer matrix. The fibres are generally carbon or glass, in a matrix such as vinylester or epoxy[1]. These materials are preformed to form plates under factory conditions, generally by the pultrusion process[1].

Fiber reinforced polymer composites have been used as structural materials since World War II, when they were first used in the construction of the British Spitfires[2]. Fibre reinforced polymer composites (FRP) began with cellulose fibre in phenolics in 1908, later extending to urea and melamine, and reaching commodity status in the 1940s with glass fibre in unsaturated polyesters [3].

Advancement in polymer composites such as FRP in civil infrastructures has been slow compared to other civil engineering materials. Before its application in civil engineering field, it is predominantly used in aerospace and marine industries. Over the past three decades, engineers became fascinated by its mechanical properties together with their customized fabrication techniques. FRP material systems are composed of fibers embedded in a polymeric matrix that exhibit several properties, which is suitable for structural reinforcing elements. There are three types of FRP commonly used: aramid fibers, glass fibers, and carbon fibers. Glass fibers are weak in aging and it should be protected from liquid attack. CFRP material has been proven to be more efficient than aramid and glass fibers when applied to concrete columns as external reinforcement. Carbon Fiber Reinforced Polymer is corrosion resistant, has high strength-to-weight ratio, high confinement strength, easy to install and maintain, fatigue resistant, non-magnetic, non-metallic, and durable[4]. The CFRP significantly enhances the strength and ductility of concrete. Also, CFRP are unaffected by electrochemical deterioration and can resist acids, alkalis, salt, and similar aggressive materials under a wide range of temperatures[4].

In recent years, use has increased of lightweight, nonmetallic fiber-reinforced composite materials to repair and strengthen concrete structures. A common repair method is to adhesively bond strips of thin composite laminates, also known as fiber-reinforced polymer or strips, to the surfaces of reinforced concrete beams or slabs to increase their flexural or shear capacity[5]. Typically these strips are attached to the soffits to increase the flexural capacity of the reinforced concrete element. The increased capacity can be as high as three times the beam's original ultimate strength, depending on such factors as reinforcing steel ration, concrete compressive strength, FRP ratio, FRP mechanical properties, and level of predamage to the beam[6]. Due to its noncorrosive properties, fiber reinforced polymer (FRP) reinforcement offers significant benefits for structures in a variety of applications where environmental exposure and potential for corrosion of steel reinforcement is a concern[7]. Such applications include bridge decks exposed to deicing salts, bridge abutments, containment structures, piles, and sea walls. FRP materials are extremely high in strength, but differ from steel typically used for concrete reinforcement in that they are lower in stiffness and exhibit a linear-elastic stress-strain behavior to failure.

Carbon Fibres are the stiffest and strongest reinforcing fibres for polymer composites, the most used after glass fibres. Made of pure carbon in form of graphite, they have low density and a negative coefficient of longitudinal thermal expansion. Carbon fibres are very expensive and can give galvanic corrosion in contact with metals. They are generally used together with epoxy, where high strength and stiffness required. Carbon Fibres are produced by the PAN and pitch methods, which are called precursors. In general carbon fibres are produced from PAN precursor fibres by three processing stages: (1) stabilization, (2) carbonization, (3) graphitization. (Refer to figure 2-1) In the stabilization stages, the PAN fibres are first stretched to align the fibrillar networks within each fibre parallel to the fibre axis, and then they are oxidized in air at about 200 to 220°C while held in tension.

The second stage in the production of high strength carbon fibres is carbonization. In this process the stabilized Pan based fibres are pyrolized (heated) until they become transformed into carbon fibres by the elimination of O, H and N from the precursor fibre. The carbonization heat treatment is usually carried out in an inert atmosphere in the 1000 to 1500°C range. During the carbonization process turbostratic graphitelike fibrils or ribbons are formed within each fibre which greatly increases the tensile strength of the material.

At third stage, or graphitization treatment, is used if an increase in the modulus of elasticity is desired at the expense of high tensile strength. During graphitization, which is carried above about 1800°C, the preferred orientation of the graphitelike crystallites within each fibre is increased.

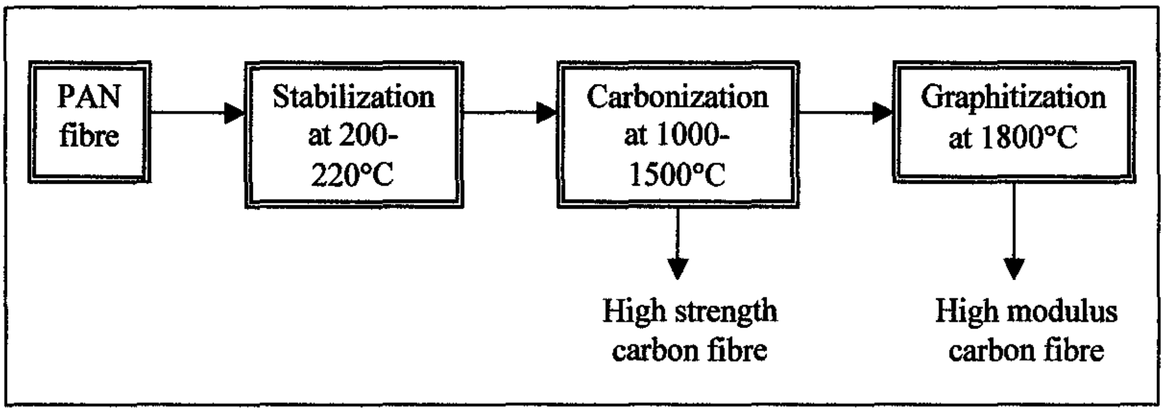


Figure 2-1 : Production Stage of Carbon Fibre

Carbon fibres have as brittle materials and their strength depend on their internal structures and presences and distribution of flaws and defects. In general, when modulus is higher, the strength is lower. Conventional reinforced concrete elements are designed to fail in a ductile manner. Premature peeling and debonding of CFRP fabrics from the structural elements leads to brittle and abrupt failure of repaired structures. The use of a high strength adhesive prolonged the onset of delamination of the CFRP from the concrete surface; this was the dominant mode of failure of the advanced composite, occurring at one-fifth of the advance composite's tensile strain capacity [8].

The main drive of the manufacturers over the past few years has been to produce fibres in the intermediate modulus range with improved strength. This is usually achieved by improving the quality of the precursor fibres and further stretching of fibres during production. In addition to mechanical properties, there are number of other characteristic of carbon fibres of interest to the composite engineer. Properties of material are one of the important factors to determine the strength of the material. Thinner CFRP plate thickness might have higher strength than thicker CFRP plate thickness because of the properties of the material. The properties of the CFRP are shown in table 2-1 [9].

Properties		Sika CarboDur XS	Sika CarboDur S
E-modulus (mean value)	N/mm^2	165 000	165 000
E-modulus (minimum value)	N/mm^2	>160 000	>160 000
Tensile Strength (minimum value)	N/mm^2	>2 200	>2 800
Tensile Strength at break (mean value)	N/mm^2	2 400	3 100
Strain at break (minimum value)	%	>1.36	>1.70

Table2-1: Properties of CFRP

2.1 Structural Adhesive Bonding

The feasibility of bonding concrete with epoxy resins was first demonstrated in the late 1940s, and the early development of structural adhesives is recorded by Fleming and King (1967). Since the early 1950s adhesives have become widely used in civil engineering. However, although the building and construction industries represent some of the largest users of adhesive materials, many applications are non-structural in the sense that the bonded assemblies are not used to transmit or sustain significant stresses (e.g. crack injection and sealing, skid-resistant layers, bonding new concrete to old). Truly structural application implies that the adhesive is used to provide a shear connection between similar or dissimilar materials, enabling the components being bonded to act as a composite structural unit.

The principal structural adhesives specifically formulated for use in the construction industry are epoxy and unsaturated polyester resin systems, both thermosetting polymers[10]. Two-part epoxies, first developed in the 1940s consist of a resin, a hardener or cross-linking agent, which causes polymerization, and various additives such as fillers, tougheners or flexibilisers, all of which contribute to the physical and mechanical properties of the resulting adhesive. Formulations can be varied to allow curing at ambient temperature, the so-called cold cure epoxies, the most common hardeners for which are aliphatic polyamines, whose use results in hardened adhesives which are rigid and provide good resistance to chemicals, solvents and water.

Fillers, generally inert materials such as sand or silica, may be used to reduce cost, creep and shrinkage, reduce exothermal and the coefficient of thermal expansion, and assist corrosion inhibition and fire retardation. Fillers increase the viscosity of the freshly mixed system but impart thixotropy, which is useful in application to vertical surfaces.

Unmodified epoxy systems tend to be brittle when cleavage or peel forces are imposed. Toughening of the cured adhesive can be achieved by the inclusion of a dispersed rubbery phase, which absorbs energy and prevents crack propagation. Epoxies are generally tolerant of many surface and environmental conditions and possess relatively high strength. They are preferred for bonding to concrete since, of all adhesives, they have a particularly high tolerance of the alkalinity of concrete, as well as moisture. By suitable formulation, their ability to wet out the substrate surfaces can even be achieved in the presence of water, the resin being able to disperse the water from the surface being bonded.

Unsaturated polyester resins were discovered in the mid-1930s and have adhesive properties obtained by cross-linking using a curing agent. They are chemically much more simple than epoxy resins but have a 10% contraction by volume during curing due to a volume change during the transition from the uncured liquid phase to the hardened resin resulting in further curing shrinkage. As a result of these factors, there are usually strict limits on the volume of material that can be mixed and applied at any one time and as a general rule polyester resins do not form as strong adhesive bonds as do epoxy resins. In storage, the polyester resins are also somewhat less stable and present a greater fire hazard than epoxies. These limitations significantly restrict their applications. The advantages of epoxy resins over other polymers as adhesive agents for civil engineering use can be summarized as follows:

- High surface activity and good wetting properties for a variety of substrates.
- High cured cohesive strength, so the joint failure may be dictated by the adherent strength, particularly with concrete substrates.
- May be toughened by the inclusion of a dispersed rubbery phase.
- Minimal shrinkage on curing, reducing bond line strain and allowing the bonding of large areas with only contact pressure
- Low creep and superior strength retention under sustained load.
- Can be thixotropic for application to vertical surfaces.
- Able to accommodate irregular or thick bond lines.
- Formulation can be readily modified by blending with a variety of materials to achieve desirable properties.

These various modifications make epoxy adhesives relatively expensive in comparison to other adhesives. However, the toughness, range of viscosity and curing conditions, good handling characteristics, high adhesive strength, inertness, low shrinkage and resistance to chemicals have meant that epoxy adhesives have found many applications in construction, for example, repair materials, coatings and as structural and non-structural adhesives[10].

CHAPTER 3

METHODOLOGY AND PROJECT WORK

3.1 FLOW CHART OF THE PROJECT

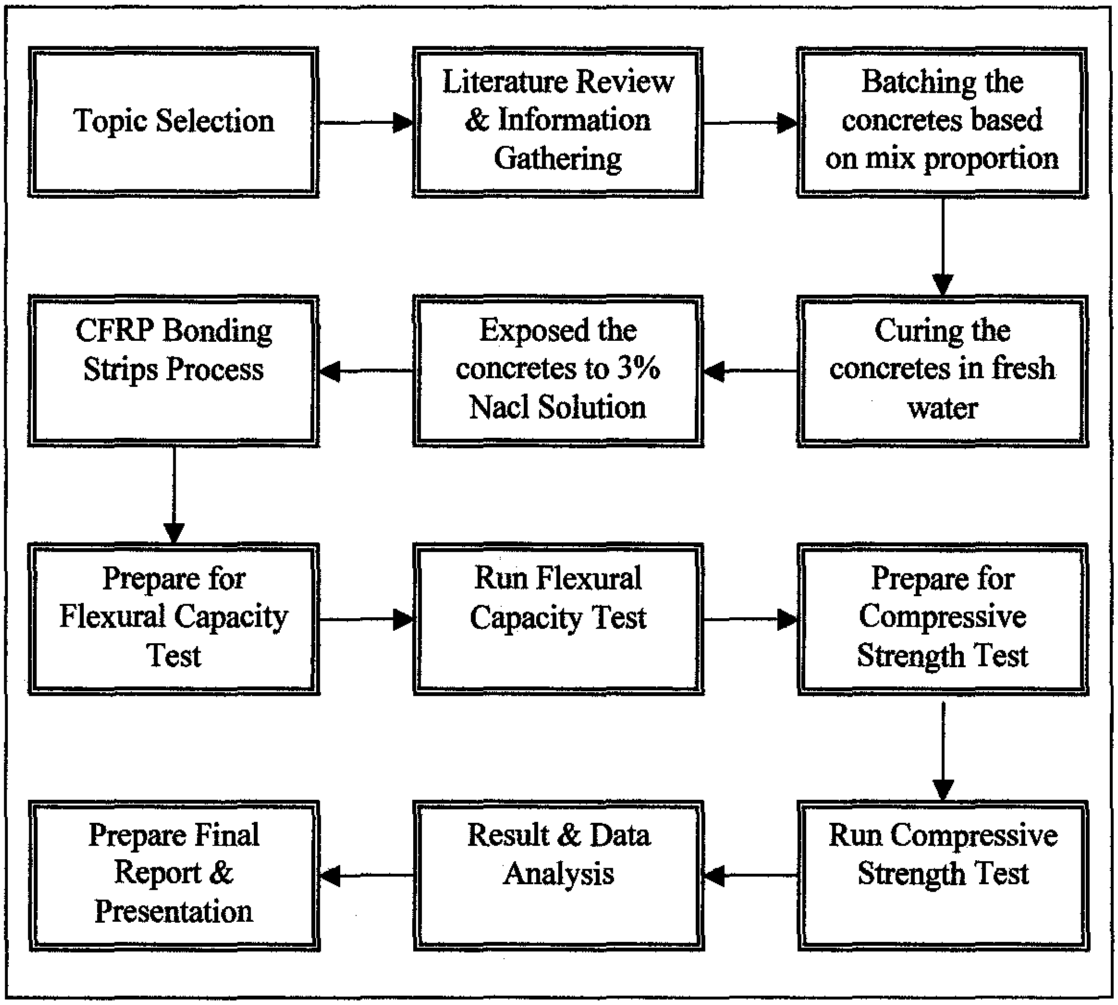


Fig 3-1: Flow chart of the methodology involve in completing the project

3.2 PROCEDURE IDENTIFICATION

The methodology and the procedure of the project are divided into several topics, which are:

3.2.1 TOPIC SELECTION

A few topics were proposed and each of them was evaluated in order to select the best topic for Final Year Project.

3.2.2 LITERATURE REVIEW AND INFORMATION GATHERING

Information regarding the CFRP, including the properties was investigated and gathered by referring to respective books, journal and thesis developed by external and internal parties. All the information were skimmed and selected based on importance and relevancy.

3.2.3 MATERIALS

3.2.3.1 Sika Carbodur – Heavy Duty Strengthening System

Sika Carbodur is a heavy duty CFRP strengthening system for reinforced concrete, masonry, stonework, steel, aluminium and timber. There are three types of the system component which are Sika Carbodur CFRP plates, Sikadur-30 adhesive for bonding reinforcement and Sika CarboDur prestressing system.

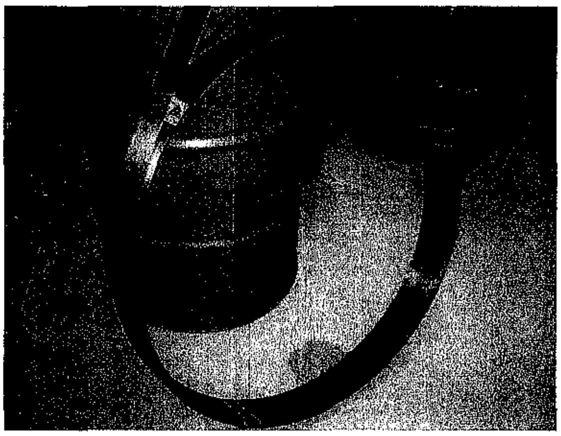


Fig 3-2: Carbon Fibre Reinforced Polymer bonded at the midspan of the reinforced beam with length of three quarter of the total length.

As a result of intensive research work at Federal Materials Testing and Research center (EMPA) in Dubendorf, it is now possible to make bonded reinforcement for reinforced concrete, masonry, stonework, steel, aluminium, and timber structures with corrosion resistant plates made of CFRP. Economical development work by Sika AG was made so that it is possible to apply the Carbodur systems, after preparation of the surface without any other installation.

The structure of the material that is mentioned to strengthen is for several purposes. The first purpose is for loading increase. The loading increase include the increased of live loads, increased of traffic loads, installation of heavy machinery in industrial buildings and changes in building utilization.

It also helps to strengthen the damage to structural parts. This includes the ageing of construction material, steel reinforcement corrosion, vehicle impact, fire and also earthquake. The CFRP also strengthen structure for service ability improvement, it helps to decrease deformation, stress reduction in steel reinforcement and crack width reduction.

The strengthened of structure also change in structural system which includes removal of walls and columns and removal of slab sections for openings. Beside it also change of specification, which include the earthquake and adjustment to changed design philosophy. Finally the CFRP strengthen structures for design or construction defects, which include insufficient reinforcement and insufficient structural depth.

The advantages of using CFRP are low in weight, availability in any length which mean that no joints is required, low overall thickness, easy to transport, laminate intersections are simple, economical application because no heavy handling and installation equipment, very high strength, available in various moduli of elasticity, outstanding fatigue resistance, high alkali resistance, no corrosion, clean edges without exposed fibres and general construction approval in many countries.

3.2.3.2 Epoxy Adhesives

Epoxies have favorable characteristics for repair applications, such as good adhesion, versatility, inertness, low shrinkage, rapid hardening and moisture resistance. They make excellent structural adhesives for bonding concrete to concrete and concrete to steel and after proper curing, posses five to eight times higher tensile and shear strength than ordinary Portland Cement Concrete (OPC), but much reduced Young's and shear modulus. As a result, bond failures are not generally expected to take place within the adhesive layer.

Epoxy resins used in civil engineering usually comprise two components. One is the resin itself and the other component is a hardening system. The manufacturers often supply adhesives by giving the resin and hardener components in substances of distinct colors. Mixing of the resin and hardener must be done thoroughly with a power mixture and carried out an appropriate time in accordance with the manufacturer's instructions. Normally, color contrast is not apparent when mixing is completed. Power mixing should be operated at low speed to prevent excessive temperature increase and air entrainment during the mixing operation. In addition, small batch mixing is recommended because the curing process is rapidly accelerated by the exothermic reaction, causing rapid hardening in larger batches.

In order to achieve successful bonding, surfaces that are to be attached must be strong, sound, dry and clean. Injection under pressure, vacuum, or coating and adhering under pressure are some of the techniques used for bonding. Bonding of fibre fabrics by direct application of resin is also possible with FRP. The main objective is to eliminate or minimize the formation of air bubbles, since those create discontinuities in the glue joint and weaken the bond strength by reducing the area of adhesive. When using plates, the bonded surfaces should be flat and compatible with each other. In the injection process, the flatness of a concrete substratum is not as severely required as in the press bonding process.

A monolithic body of concrete and adherent bonded with epoxy resin can transmit stress efficiently. However, since the elastic modulus of epoxy resin is much lower than that of adherent and concrete, the thickness of the epoxy resin layer should be minimized as far as possible. As the previous experiment that have been done, epoxy bonding of CFRP plates to tension surface of RC cracked beams can significantly increase ultimate flexural capacity.

The strength of adhesive joints made with epoxies depends on the degree of curing before opening the concrete to service. The time required for curing relies on the hardening rate of the epoxy resin at various temperatures, and can be obtained from the manufacturer. During curing, the joints must not be moved; otherwise cracks might develop at the interface, which could lead to loss of bonding by the ingress of moisture.

Two component epoxy resins systems which Sikadur 30 adhesives are particularly well suitable for the bonding of CarboDur laminates to concrete, steel wood or bricks. This type of adhesives has very high mechanical strengths as well a good chemical resistance against aggressive media. Good wetting properties on concrete and wood, assure good bond characteristics.

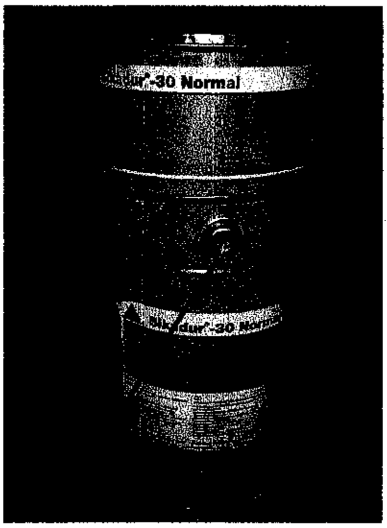


Fig 3-3: Sikadur-30 adhesives used to bond the CFRP laminates onto reinforced beam

The function of the adhesive layers is above all to transfer the forces acting onto the joined elements. The more a layer of adhesive is able to level such stress peaks, the greater the load-transferring portion of the bonded are will be.

The following properties are important for high strength structural bonding; high bonding forces onto elements to be joined, high cohesive strength of the adhesive, low tendency to creep, good resistance against humidity and alkalinity.

3.2.4 EXPERIMENTAL, LABORATORY WORK AND TESTING

The laboratory work covered the process of determine the flexural capacity of under reinforced concrete beams that was reinforced externally with CFRP. The work included producing four different reinforced beam, which has same geometrical dimension which proposed to be 150mm x 150mm x 750mm but undergone different condition in order to study the effectiveness of using CFRP as a repair method.

The control beam, which CFRP was not applied and also not exposed to 3% Nacl as a corrosion agent while the Beam 1 is exposed to the corrosion agent for 28 days and then will externally reinforced by CFRP with length and width of 550 mm and 100 mm and thickness of 1.2 mm before put it under flexural capacity test. Beam 2 not undergone the corrosion process but externally bonded with CFRP and for beam 3 it experienced the corrosion process but not reinforced with CFRP. The summarized of beam condition during the test are in Table 3-1:

	Corrosion Process		Presence of CFRP	
	Yes	No	Yes	No
Control Beam		*		*
Beam 1	*		*	
Beam 2		*	*	
Beam 3	*			*

Table 3-1: Different condition for different beam tested in the experiment

The reinforcement bar used was T12 bar for all both beams and R6 bar with 500mm length for the link.

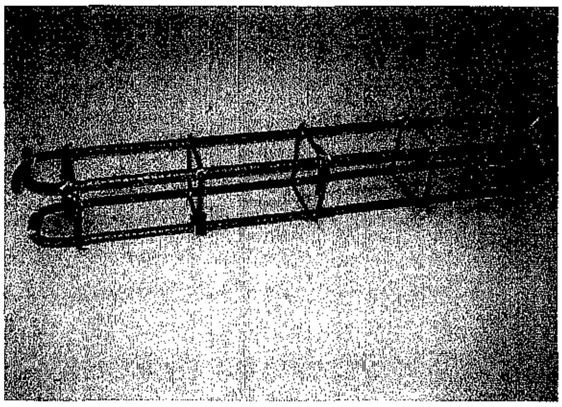


Fig 3-4: Reinforcement Bar of RC beams using T12 and R6 bar

The mix was a standard mix type, which was based on ingredients and proportion fully listed in BS 5328 : Part 2 : 1997 for several values of compressive strength up to 25 Mpa, measured on cubes. Standard mix was used only in minor construction such as housing. The mixture content of the concrete that used to produce the beam is shown in Table 3-2:

Material	Mix Ratio (by weight)	Mix Ratio (%)	Kg/m^3	Kg
Cement	1	14.71	751	12.68
Sand	2.3	33.82	1727	29.15
Coarse aggregate	3.5	51.47	2629	44.37
Water added			414	6.98

Table 3-2: Mixture Content of the Beam

The water cement ratio was 0.55 and the mixture content for the project was the same for all beams.

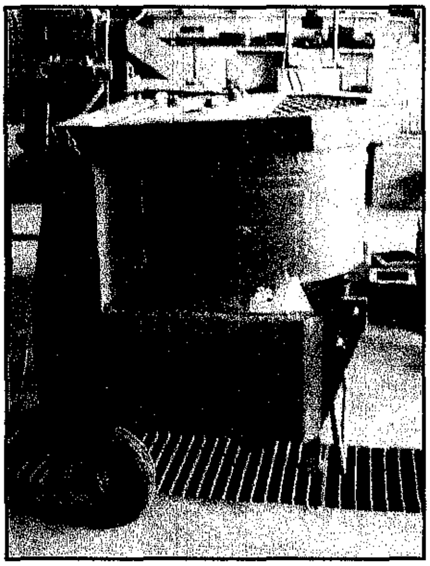


Fig 3-5: Concrete mixing process based on the mixture content specified. One batch of concrete can produce two beams with dimension of 150 mm x 150 mm x 750 mm

In order to obtain good concrete, the placing of an appropriate mix must be followed by curing in a suitable environment during the early stages of hardening. Curing is the name given to procedures used to promoting the hydration of cement, and consists of a control of temperature and the moisture movement from and into the concrete. More specifically, the objective of curing is to keep concrete saturated or as nearly as possible, until the originally water filled space in the fresh cement paste has been filled to the desired extent by the products of hydration of cement [1].

In this project control beam was cured in fresh water for 28 days before undergone the flexural capacity test, as it is the standard strength of concrete required. For the other beam, it was only cured for 7 days, which is the minimum duration for the concrete to hydrate. This was because of the time constraint, which the beam was then put under corrosion process for 28 days. However it should be added that concrete remote from the surface, that is at depth, is hardly subjected to moisture movement, which affects only an outer zone, typically 30mm deep, but occasionally up to a depth of 50mm. In reinforced concrete, this depth represents all or most of the depth of cover. Thus, concrete in the interior of a structural member is generally unaffected by curing, so that curing is of little importance with respect to a structural strength except in the case of very thin members[1].

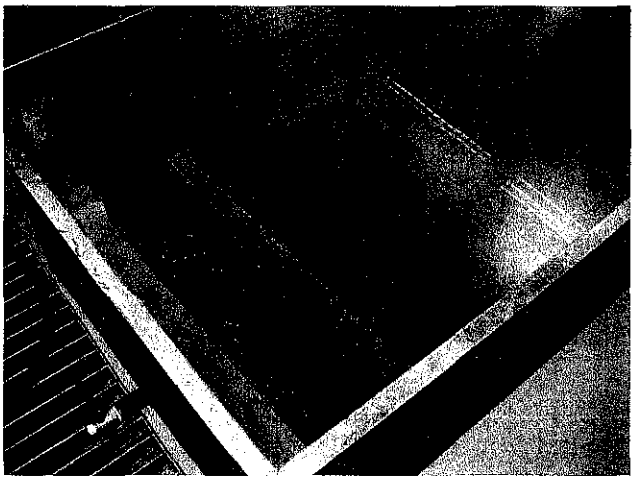


Fig 3-6: Concrete curing process in fresh water take place for 28 days for beam that will not be exposed to Nacl solution onward while for the beam that will be corroded is cured for only 7 days

The corrosion agent used in this project was Nacl with 3% concentration. To get the concentration of 3%, 3kg of Nacl was diluted in 100kg of fresh water. Only one beam was allowed for corrosion and to see the affect of corrosion clearer, the bottom part of the beam was exposed, which also exposed the small section of the reinforcement bar.

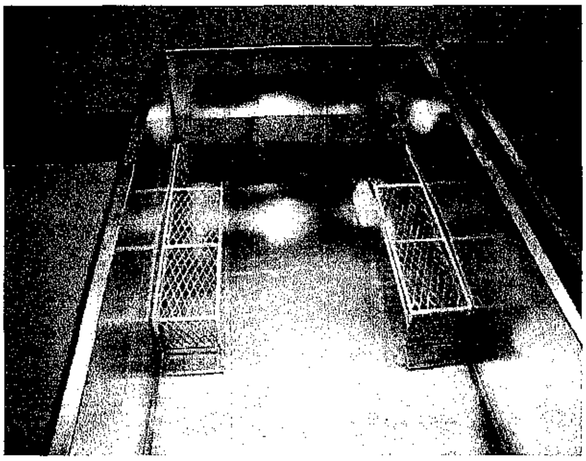


Fig 3-7: Corrosion process is done by exposing the reinforcement bar of the beam to 3% Nacl solution for 28 days which is the minimum duration for corrosion to occur

After the corrosion process was completed, the beam was externally bonded with the CFRP strips. However, before that the exposure area of the beam was filled with the Cement-Sand Mortar and left for 24 hours, which is the minimum time needed for the Sand-Cement Mortar to achieve its strength. On the real site, the concrete surface is cleaned with aided of equipment. Firstly, the concrete surface will be sandblasted before vacuumed or cleaned with compressed air or water. This shows how important to ensure the cleanliness of the concrete surface before the bonding process.

However in this study, the laboratory was not equipped with such equipment and the concrete surface was cleaned by using only sand papers. After that, then only the CFRP strips was attached to the beam surface with length of three quarter of the beam length (563 mm) using epoxy-resin adhesives; Sikadur-30 adhesives. The flexural capacity test was carried on after two days of the process of CFRP strips bonding to give time for the CFRP strips to achieve successful bonding with the beam surface.

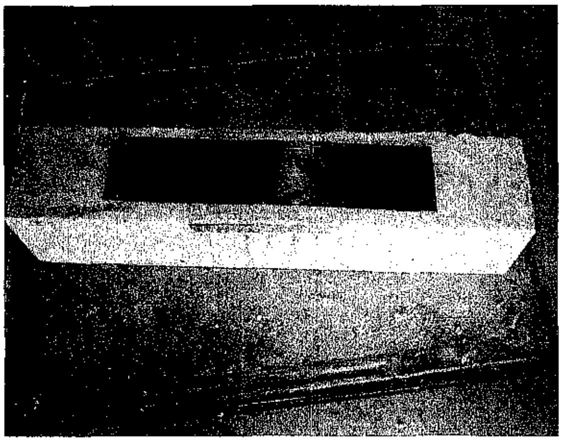


Fig 3-8: Process of CFRP strips bonding is done after the concrete surface is properly cleaned and epoxy adhesives is used as a bonding agent. To achieve a successful bonding, the bonded CFRP is left for two days before the test

The concrete flexural capacity test for the RC beam were required the strength of the concrete at 28 days. The testing of the flexural capacity of the RC beams was done using the Universal Testing Machine (UTM). Sika Carbodur 1012 and Sika Carbodur 1014 CFRP plates and Sikadur-30 adhesives were used for the strengthening and rehabilitation of the RC beams.

3.2.5 TOOLS AND EQUIPMENT

There were a few tools and equipment used during the process of producing the beam and testing work.

3.2.5.1 Universal Testing Machine

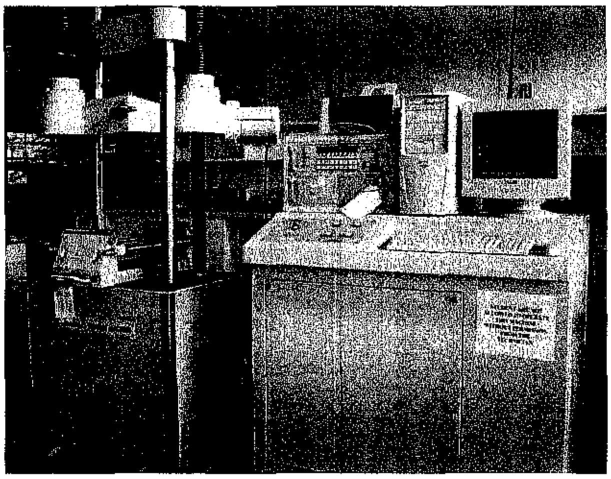


Fig 3-9: Universal Testing Machine is used to measure the maximum capacity the beam can resist

The Universal Testing Machine (UTM) was used during the flexural capacity test. The result data and the stress-strain curve for each beam tested was obtained automatically from the computer connected to the flexural capacity test machine.

3.2.5.2 Beam moulds

The beam moulds was used during the process of beam casting. The size of the mould used was 150mm x 150mm x 750mm.

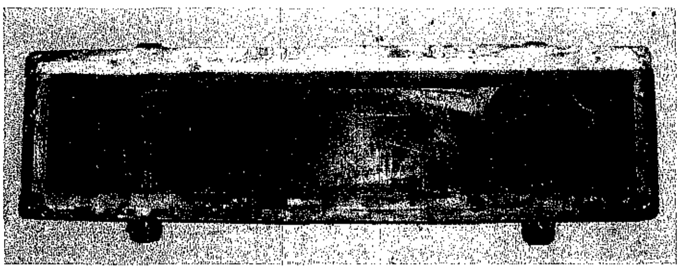
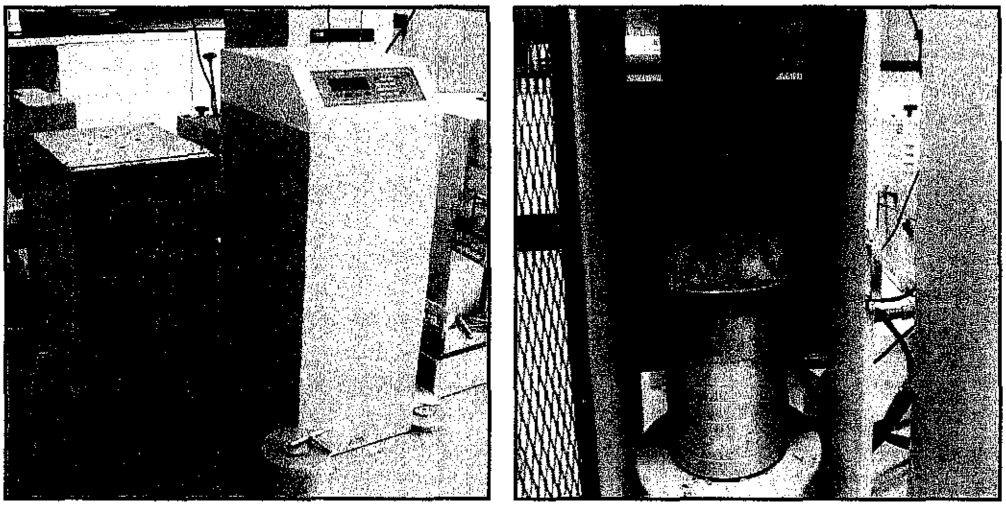


Fig 3-10: Mould used for concrete casting. The dimension is 150mm x 150mm x 750mm

3.2.5.3 500 KN Flexural and Compressive Strength Testing Machine

The Flexural and Compressive Strength Testing Machine was used to obtain the concrete strength used in the study.



3-11(a) 3.11(b)

Fig 3-11(a): 500 KN Flexural and Compression Testing Machine is a non-destructive testing to measure the 28 days compressive strength of the concrete.
Fig 3-11(b): The cube to be tested is placed at the center of the plate to ensure the load distribution during the test is even

CHAPTER 4
RESULTS AND DISCUSSION

4.1 Control Beam

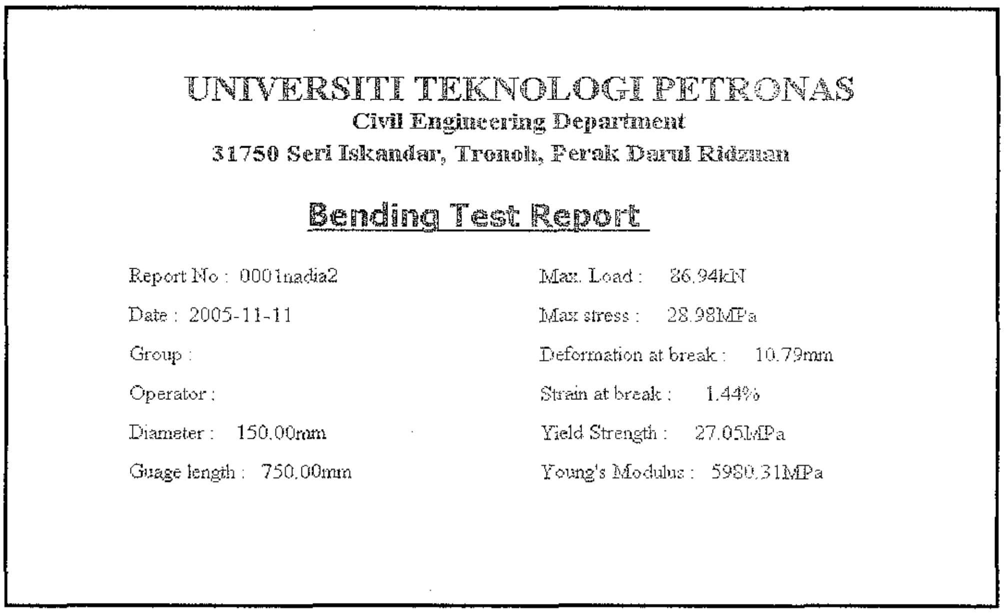
As the load from the Universal Testing Machine applied to the centre support of the beam, the crack of the beam started to appear at the centre support (refer to Figure 4-1)

Fig 4-1: Crack Flow of Control Beam

The yielding of the reinforcing tensile steel followed by concrete crushing at the centre support of the beam was occurred. The shear failure also took place creating a crack from the point load to the support (refer to Figure 4-2)

Fig 4-2: Control Beam Failure

The maximum load that the control beam can resist during the test is 86.94 kN (refer to Figure 4-3)


UNIVERSITI TEKNOLOGI PETRONAS
Civil Engineering Department
31750 Seri Iskandar, Tronoh, Perak Darul Ridzuan

Bending Test Report

Report No : 0001nadia2	Max. Load : 86.94kN
Date : 2005-11-11	Max stress : 28.98MPa
Group :	Deformation at break : 10.79mm
Operator :	Strain at break : 1.44%
Diameter : 150.00mm	Yield Strength : 27.05MPa
Guage length : 750.00mm	Young's Modulus : 5980.31MPa

Fig 4-3: Result of Flexural Capacity Test for Control Beam

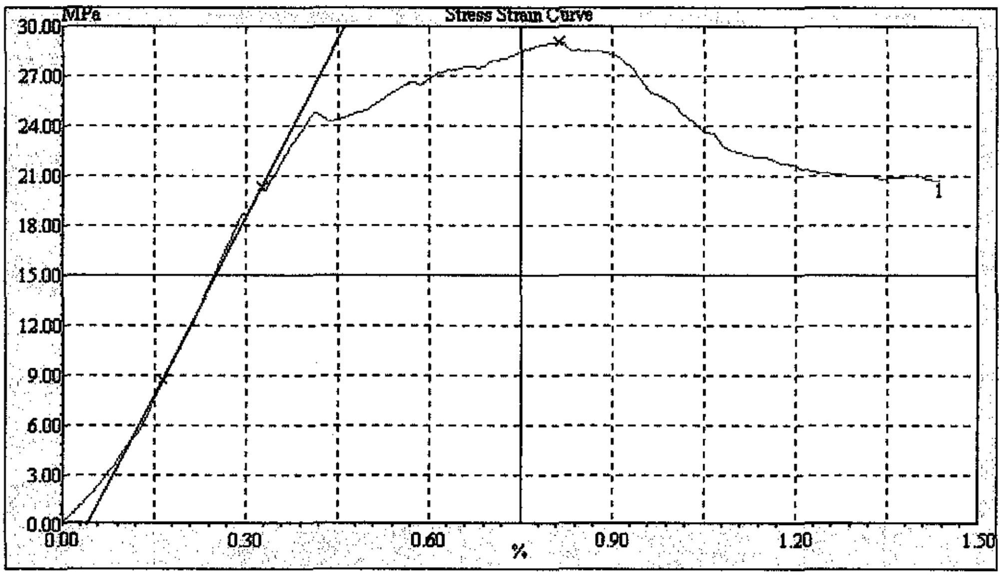


Fig 4-4: Stress-strain Graph for Control Beam

4.2 Beam 1

Beam1 exhibited crushing of concrete the central of the beam followed first crack line occurred at the central support of the beam (refer to Figure 4-5).

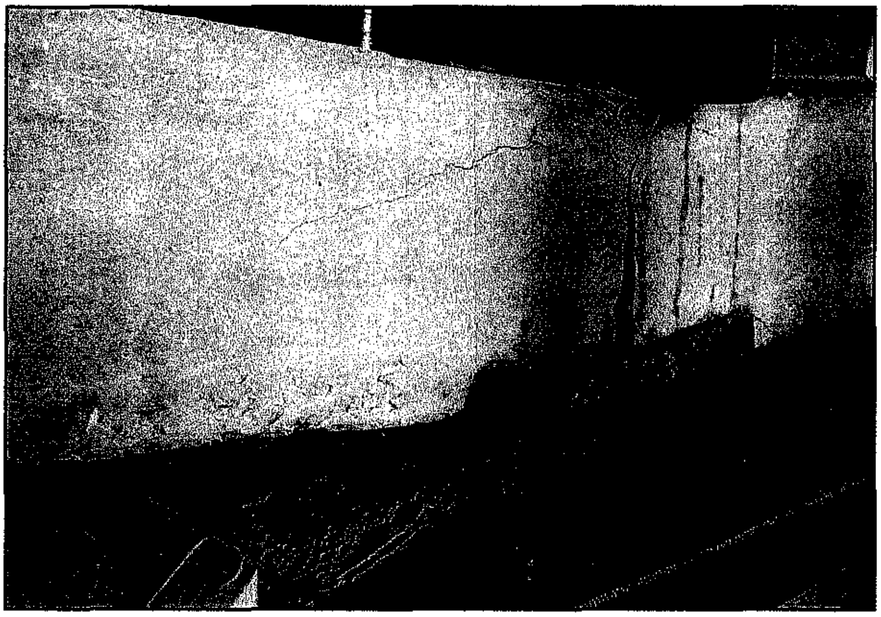


Fig 4-5: Crack Flow of Beam 1

The CFRP laminates was not failed, the beam failed due to the debonding failure of the epoxy adhesive to the concrete (refer to Figure 4-6).

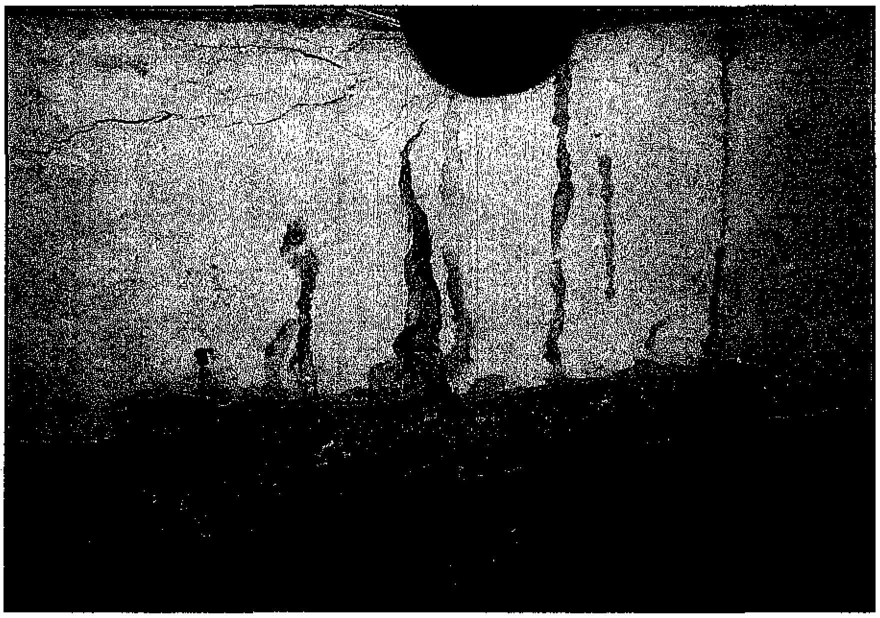


Fig 4-6: Beam 1 Failure

The maximum load that the beam 1 can resist during the test is 80.62 kN (refer to Figure 4-7)

UNIVERSITI TEKNOLOGI PETRONAS
Civil Engineering Department
31750 Seri Iskandar, Tronoh, Perak Darul Ridzuan

Bending Test Report

Report No : 00011	Max. Load : 80.62kN
Date : 2006-03-29	Max stress : 26.87MPa
Group :	Deformation at break : 20.20mm
Operator :	Strain at break : 2.69%
Diameter : 150.00mm	Yield Strength : 23.88MPa
Guage length : 750.00mm	Young's Modulus : 6478.45MPa

Fig 4-7: Result of Flexural Capacity Test for Beam 1

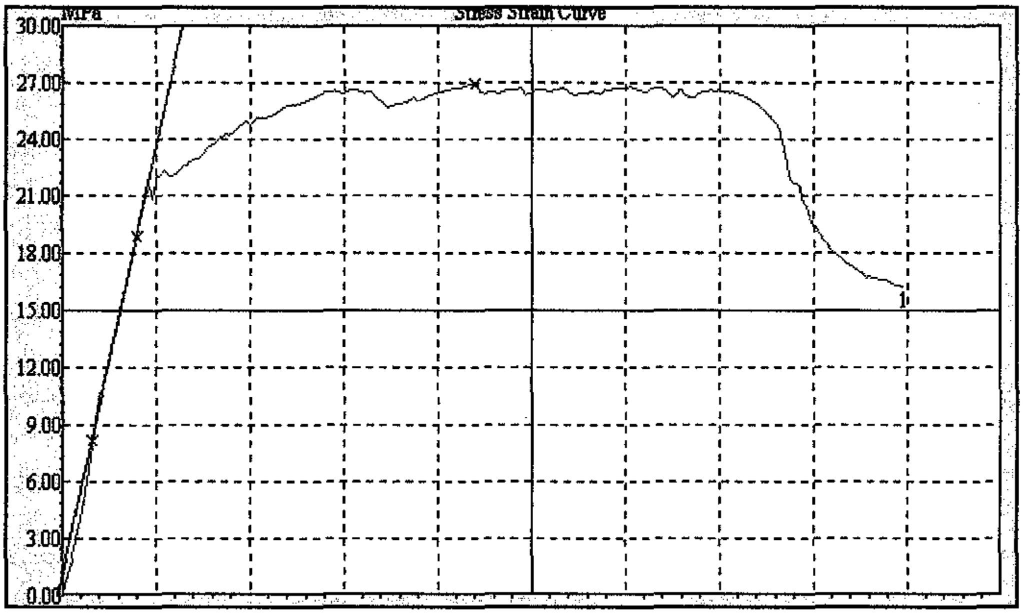


Fig 4-8: Stress-strain Graph for Beam 1

4.3 Beam 2

Beam 2 exhibited minor crushing of concrete at the centre of the beam (refer to Figure 4-9)

Fig 4-9: Crack Flow of Beam 2

The crack line occurred concentrate at the centre of the beam towards the support (refer to Figure 4-10)

Fig 4-10: Beam 2 Failure

The maximum load that the beam 2 can resist during the test is 109.49 kN (refer to Figure 4-11)

UNIVERSITI TEKNOLOGI PETRONAS
Civil Engineering Department
31750 Seri Iskandar, Tronoh, Perak Darul Ridzuan

Bending Test Report

Report No : 0001nadia1

Date : 2005-11-11

Group :

Operator :

Diameter : 150.00mm

Guage length : 750.00mm

Max. Load : 109.49kN

Max stress : 36.50MPa

Deformation at break : 21.64mm

Strain at break : 2.89%

Yield Strength : 31.62MPa

Young's Modulus : 8059.30MPa

Fig 4-11: Result of Flexural Capacity Test for Beam 2

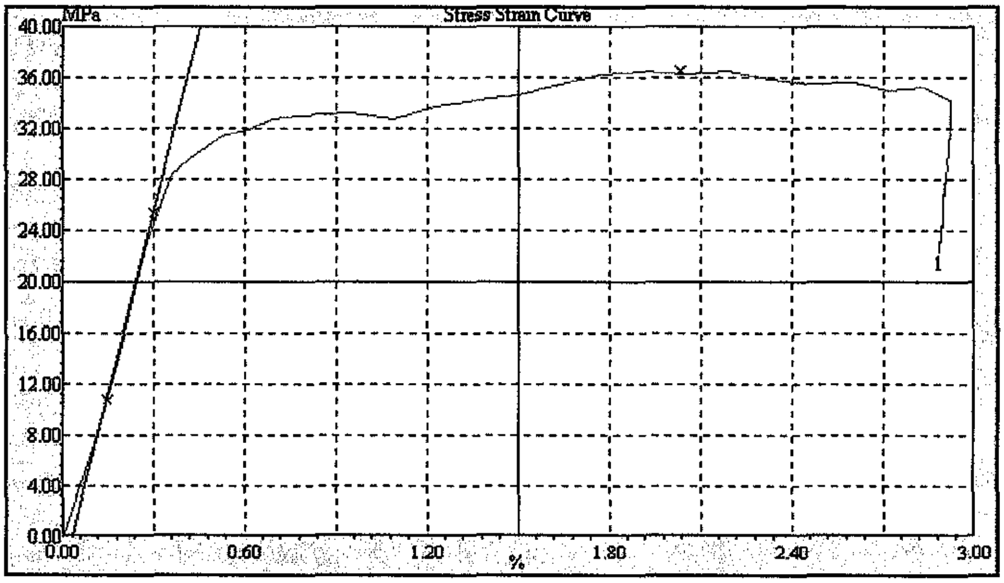


Fig 4-12: Stress-strain Graph for Beam 2

4.3 Beam 3

The crack line flow for beam 3 was quite similar to the control beam. There was concrete crushing at the centre of the beam followed by a few cracks started at the centre throughout the beam (refer to Figure 4-13)

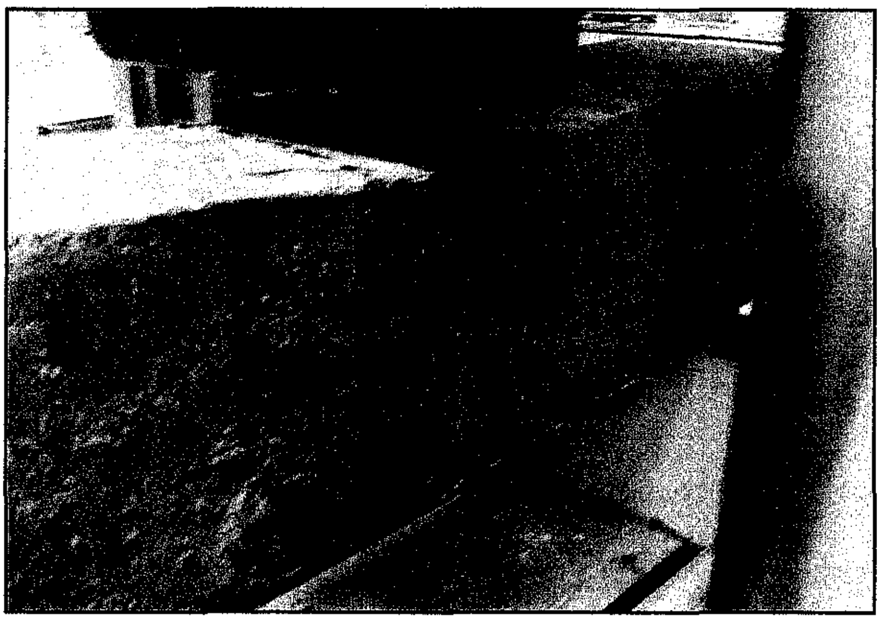


Fig 4-13: Crack Flow of Beam 3

There was also a crack from the point load towards the support (refer to Figure 4-14)

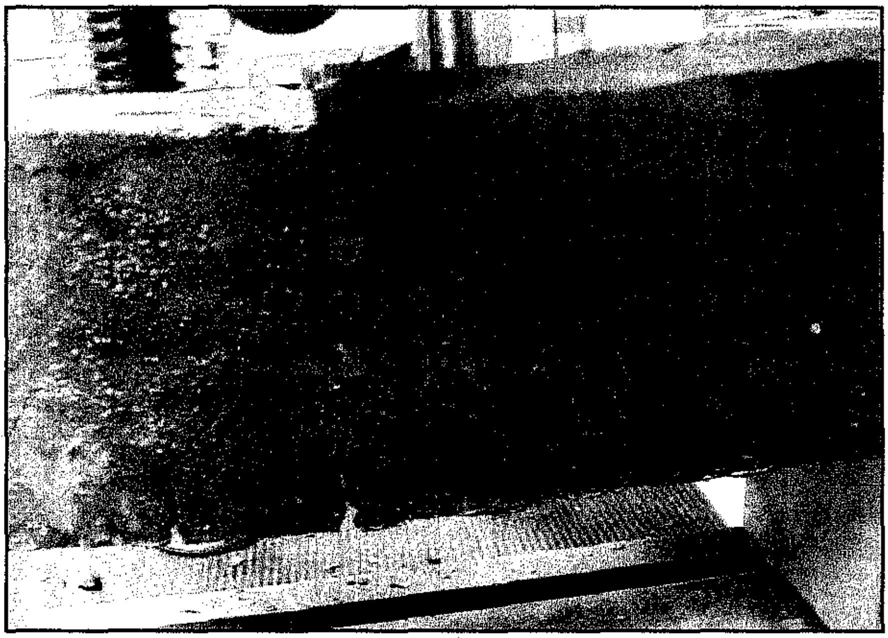


Fig 4-14: Beam 3 Failure

The maximum load that the beam 3 can resist during the test is 67.72 kN (refer to Figure 4-15)

UNIVERSITI TEKNOLOGI PETRONAS

Civil Engineering Department

31750 Seri Iskandar, Tronoh, Perak Darul Ridzuan

Bending Test Report

Report No : 00011	Max. Load : 67.72kN
Date : 2006-04-07	Max stress : 22.57MPa
Group :	Deformation at break : 17.59mm
Operator :	Strain at break : 2.34%
Diameter : 150.00mm	Yield Strength : 21.41MPa
Guage length : 750.00mm	Young's Modulus : 3543.71MPa

Fig 4-15: Result of Flexural Capacity Test for Beam 3

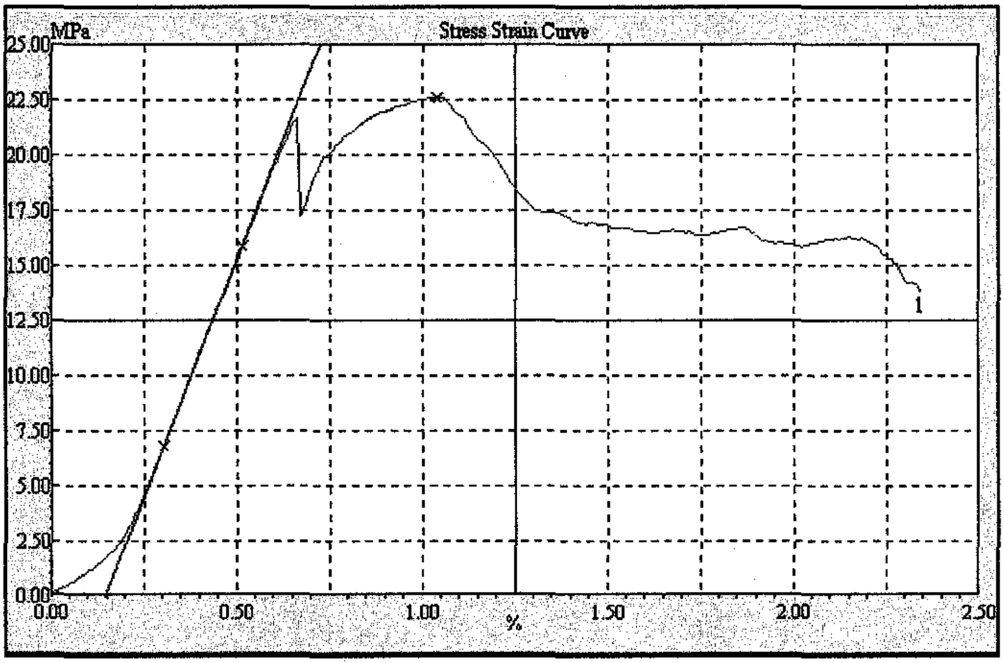


Fig 4-16: Stress-strain Graph for Beam 3

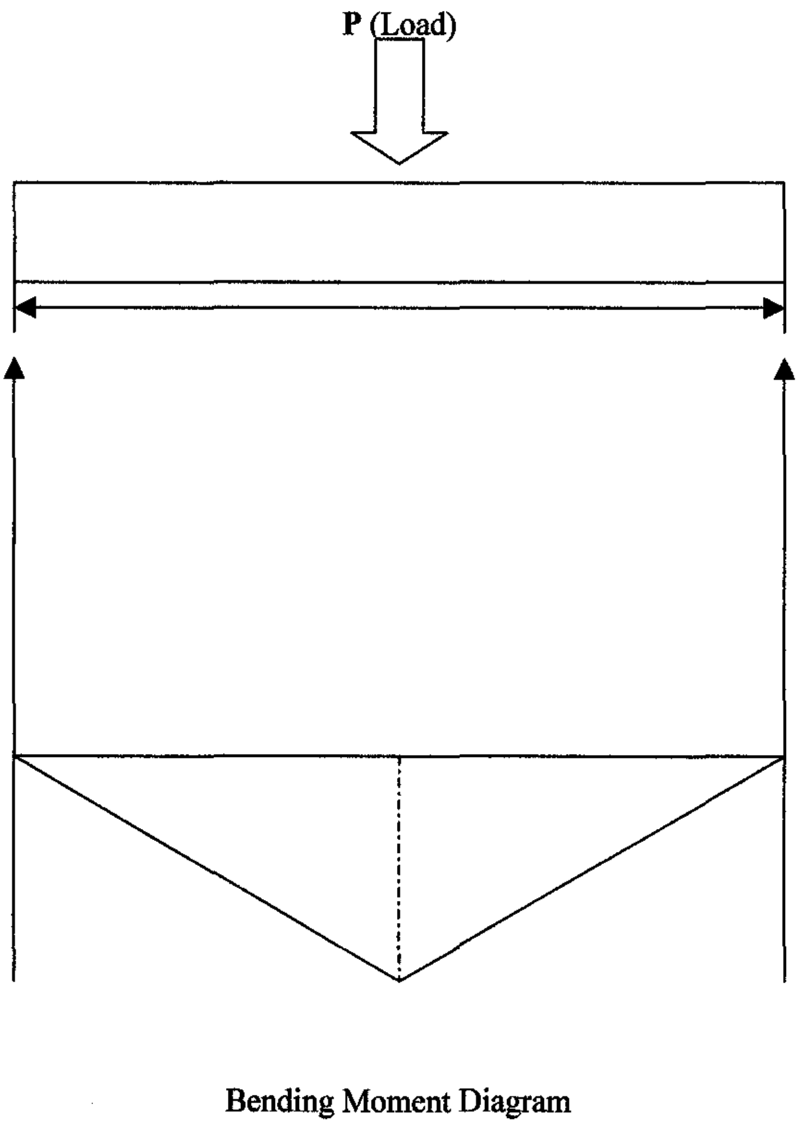
	Cube 1	Cube 2	Cube 3
Maximum Load (kN)	**875.4**	**858.8**	**872.6**
Stress, F_{cu} (N/mm^2)	**38.91**	**38.17**	**38.78**
Pace Rate (kN/s)	**6.80**	**6.80**	**6.80**

Table 4-1: Results for 28 days compressive strength of the concrete using 500 KN Flexural and Compression Testing Machine

	Load at failure		Deflection at failure		Failure mode
	P_{fail} (kN)	% of control	Δ_{fail} (mm)	% of control	
Control Beam	**86.94**		**10.79**		**Concrete crushing**
Beam 1	**80.62**	**No increment**	**20.20**	**No increment**	**Debonding failure**
Beam 2	**109.49**	**26%**	**21.64**	**100%**	**Shear-tension failure (anchorage failure)**
Beam 3	**67.72**	**No CFRP**	**17.59**	**No CFRP**	**Concrete crushing, Shear failure**

Table 4-2: Summary of the test results for Flexural Capacity Test using Universal Testing Machine

4.4 Moment Diagram



M = (PL) / 4

M – Moment

P – Flexural load

L - Length

Fig 4-17: Moment Diagram

4.5 Calculation

To determine the moment acting on the beam due to the applied load, some calculation was done. For this study, the moment was calculated based on the equation; M = (PL) / 4. There was only single load acting from the load actuators. The calculation steps of determining the moment value for this beam is shown below:

Moment Calculation

$M = (PL) / 4$

Control Beam

$M = (86.94)(0.6) / 4 =$ **13.04 kN-m**

Beam 1

$M = (80.62)(0.6) / 4 =$ **12.09 kN-m**

Beam 2

$M = (109.49)(0.6) / 4 =$ **16.42 kN-m**

Beam 3

$M = (67.72)(0.6) / 4 =$ **10.16 kN-m**

4.6 Discussion

According to the brittle fracture theory, failure is initiated by the largest crack, which is oriented in the direction normal to the applied load, and thus the problem is one of statistical probability of the occurrence of such a crack. This means that size and possibly shape of the specimen are factors in strength because for example, there is higher probability that a larger specimen contains a greater number of critical cracks, which can initiate failure.

In a truly brittle material, the energy released by the onset of crack propagation is sufficient to continue this propagation, because the cracks extends, the maximum stress increase and the brittle fracture strength decreases. In consequences, the process accelerates. However, in the case of cement paste, the energy released at the onset of cracking may not be sufficient to continue the propagation of a crack because it may blocked by the presence of a more ductile material which requires more energy to cause fracture.

For this study, beam that was strengthened with the CFRP laminates, has resulted in higher flexural capacity value. The used of CFRP laminates has prevented or acts as obstacle to prevent the crack to continue the crack propagation. The CFRP laminates helped them to achieve higher flexural capacity value.

Following is the common failure that occurred to the beam during the flexural capacity testing:

- Concrete crushing in compression before yielding of the reinforcing steel
- Yielding of Reinforcing steel in tension followed by rupture of the FRP laminate
- Yielding of reinforcing steel in tension followed by concrete crushing

- Bonding Failure (delamination laminate)
- Shear/tension Failure of the concrete substrate (anchorage failure)
- Diagonal tension failure resulting from shear in the section (shear failure)

Control beam experienced the concrete crushing in compression before yielding of the reinforcing steel. The beam failure was occurred through the centre of the beam mid-span. It was because the control beam does not reinforced with CFRP laminates and the concrete crushing was concentrated at the center of the beam when the concrete compressive strength exceeded its ultimate value in the zone of maximum moment and continued to fail through the area.

Beam 1 also experienced concrete crushing at the mid-span as the reinforcement. The beam supposed not to fail at the mid-span since the presence of CFRP throughout the mid-span. However, the CFRP started to delaminate first before it could resist more applied load due to debonding failure between the CFRP laminates and the concrete surface due to failure at the concrete-adhesive interface. This failure initiated at the flexural crack caused by the concrete crushing previously and propagated from there to the end of CFRP reinforcement. In addition this failure was also driven by the insufficient thickness of epoxy during the bonding process and also insufficient cover length of CFRP attached to the beam. The other factor could be the improper cleaning of concrete surface before the bonding process, which allowed dust and other small particles to weaken the epoxy composition. This debonding failure was undesirable because the CFRP laminate was not fully utilized.

Beam 2 exhibited shear-tension failure resulting from a combination of shear and normal tensile stress in the concrete in the plane of the longitudinal steel bars which also known as anchorage failure. This failure mechanism initiated at the end of the CFRP plate, resulted in the propagation of a horizontal crack, and caused separation of concrete cover. There were also crushing of concrete occured, but for that time since the CFRP was strengthened to the beam with a sufficient thickness of epoxy and proper concrete surface cleaning before the bonding process the debonding failure was prevented.

Beam 3 showed the failure mode that was quite similar to the control beam, as both of them are not strengthened with CFRP laminate. There was also concrete crushing at the mid-span, which led to the a few flexural cracks compared to the control beam that had only one flexural crack. This occurred as the flexural capacity of this beam has been reduced through the corrosion process.

Even each beam showed different failure mode, there was one type of failure that all beams had in common, which was shear failure. Shear failure occurred due to the small shear length (support to support length) and also the distance between the applied load and the support was too close.

CHAPTER 5
CONCLUSION AND RECOMMENDATION

5.1 Conclusion

Theoretically, there are four types of mix design; Designed Mix, Prescribed Mix, Standard Mix and Designated Mix. Since this project represented the minor construction only as a housing the standard mix was used. The selection of the reinforcement bar also took a housing construction as a basis. So that T12 bar used and for the link R6 chose.

Instead of submerged the beam into the 3% Nacl, the beam was only exposed to the Nacl, considering a structure was an onshore structure that exposed to the sea environment. Due to the time constraint, all the process was done within the minimum duration required. For instance, the beam that exposed to the corrosion was cured in the fresh water for only 7 days compared to the control beam, which is 28 day. Basically, the minimum duration for steel to get corroded with a result of metal loss is six months. But again, due to lack of time the beam was put under corrosion process only for 28 days. Therefore, there were only minor corrosion found on the beam and as expected there was no metal loss.

From the experiment, the flexural capacity of the beam 1 and beam 2, which both of them were strengthened with CFRP laminate were higher than the flexural capacity of the control beam and beam 3, which were not strengthened. The incretion showed by both strengthened beams was less than 50% and not meet the expectation. This happened due to premature failure for such as the debonding failure for beam 1. Even if the debonding failure was not occurred, the inadequate test condition itself did not allow the incretion as much as twice. That was what happened to the beam 2, which not experienced the debonding failure but shear-tension failure instead due to insufficient CFRP cover length.

As a conclusion, the use of CFRP laminates as a repair method to the corroded beam was proved to be an effective way since it had increased the flexural capacity of RC beams. Therefore, there s no doubt of using the CFRP laminates to solve the problem of the defect the deterioration of the RC members in the construction industry.

5.2 Recommendation

For this study, the author recommend that further research should be done in investigating the effectiveness of CFRP as a repair method. The premature failures such a debonding failure or ripping of the concrete cover should be avoided in order to fully utilized the CFRP throughout the experiment. The beam with a longer span should be used during the test and the larger universal testing machine also should be considered in order to gain the failure mode cause by the CFRP itself and not only due to the beam. Further research also might be done to investigate the effect of the CFRP enhancement on the offshore or marine structures since this study only cover the structures that exposed to the sea only.

CHAPTER 6

REFERENCES

1. Journal of Role of bonded fibre-reinforced composites in strengthening of structures by J J DARBY
2. Journal of Flexural Strengthening of Reinforced Concrete Beams by Mechanically Attaching Fiber-Reinforced Polymer Strips by Anthony J. Lamanna, A.M.ASCE1; Lawrence C. Bank, F.ASCE2; and David W. Scott, A.M.ASCE3
3. Journal of Flexural Strengthening of Reinforced Concrete Beams by Mechanically Attaching Fiber-Reinforced Polymer Strips by Anthony J. Lamanna, A.M.ASCE1; Lawrence C. Bank, F.ASCE2; and David W. Scott, A.M.ASCE3
4. Journal of World Survey of Civil Engineering Programs on Fiber Reinforced Polymer Composites for Construction by Amir Mirmiran, M.ASCE1; Lawrence C.
5. Anthony J. Lamanna, lawrences C.Bank and David W. Scott" Flexural strengthening of reinforced concrete beams using fasteners and fiber reinforced polymer strips"
6. Interaction of Carbon Fiber Reinforced Polymer and Lateral Steel Ties in Circular Concrete Columns as Confinement using Artificial Neural Network By Jason Maximino Co Ongpeng De La Salle University- Manila, Philippines Under Japan Society for Promotion of Science(JSPS) Tokyo Institute of Technology December 2003
7. Omar Faruk, (12th. March 2003). Natural and Wood Fibre Reinforced Polymer Composites. Retrieved August 7, 2005
8. Chajes, M.J., Thomson, T., Finch, W.W., and Januzka, T. 1994. Flexural strengthening of concrete beams using externally bonded composite materials. Construction and Building Materials, Vol 8., No 3, pp.191-201.
9. Sika Carbodur, edition 0203/1, product data sheet
10. Journal of Review of materials and techniques for plate bonding by L C HOLLAWAY AND M B LEEMING
11. A.M. Neville. "Properties of Concrete". Prentice Hall, 2002

12. A.F Ashour, S.A. El-Refaie, S.W. Garrity, 2003" Flexural Strengthening of RC beams using CFRP laminates" Elsevier
13. O. Rabinovitch and Y. Frosting, 1 December 2003 "Experiments and analytical comparison of RC beams strengthened with CFRP composites
14. Hollaway l. (Ed). "Polymers and Polymer Composites in Construction". Thomas Telford Ltd, London 1990, ISBN 0-7277-15216.
15. Hull D. "An Introduction to Composite Materials". Cambridge University Press, Cambridge, 1981.
16. Bank, F.ASCE2; Kenneth W. Neale3; J. Toby Mottram4; Tamon Ueda5; and Julio F. Davalos, A.M.ASCE6
17. Journal of BEHAVIOR OF NORMAL AND HIGH-STRENGTH CONCRETE FLEXURAL MEMBERS REINFORCED WITH FRP BARS by Faculty: Dr. David W. Dinehart, Dr. Shawn P. Gross, and Dr. Joseph Robert Yost Graduate Students: Erik Svensen, Ning Liu, and Peter Theisz Undergraduate Students: Nicole Aloi, Erika Rymsha, Matthew D'Angelo, and Michael Deitch
18. Journal of Analysis of Reinforced Concrete Beams Strengthened with FRP Laminates by Mahmood T. El-Mihilmy[1] and Joseph W. Tedesco,[2] Members, ASCE

APPENDICES

Appendix I - Concrete Mix Calculation (1:2.33:3.5;w/c = 0.55)

Appendix II – Beam's Dimension

Appendix III – Gantt chart for project progress

Appendix IV – Product data sheet

APPENDIX I

Base = 1 m^3 = 2400 kg

Volume of 1 beam = 0.15 * 0.15 * 0.75 = 0.01688 m^3

Total volume for 2 beams = 2 * 0.01688 m^3 = 0.03376 m^3

Add with 15% wastage = (0.15 * 0.03376 m^3) + 0.03376 m^3 = <u>0.03882 m^3</u>

Materials	Proportion	Weight (Kg)
Cement	1	12.6750
Sand	2.33	29.1546
Gravel	3.5	44.3657
Water	0.55	6.9718
Total	7.35	

Table 7-1: Concrete Mix Proportion

APPENDIX II

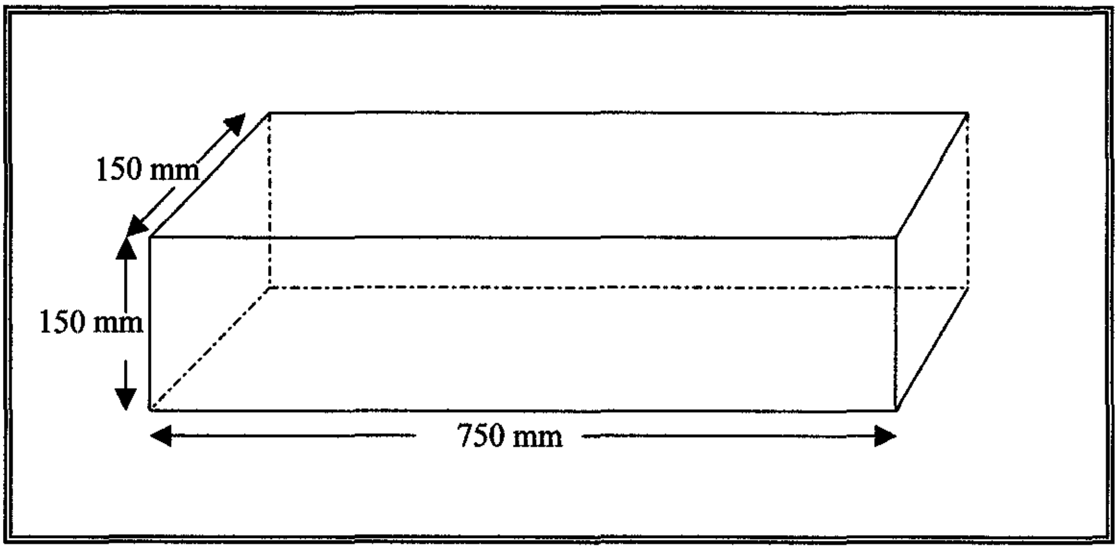


Fig 7-1: Control Beam Dimension

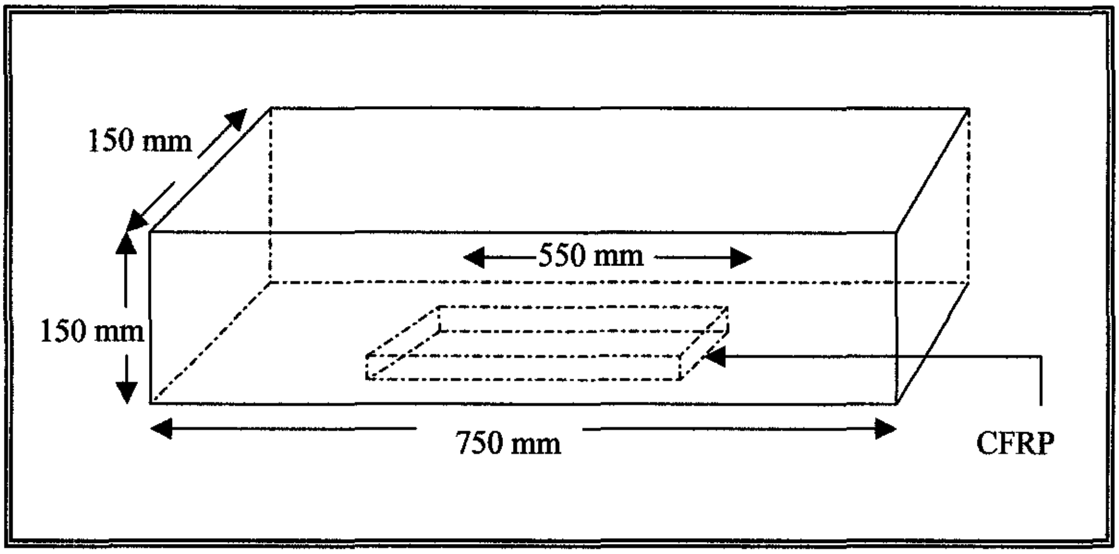


Fig 7-2: Beam strengthened with CFRP Dimension

APPENDIX III

GANTT CHART (first semester)

No.	Detail/Week	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	Selection of Project Topic														
	Topic assigned to students														
	Proposed Topic														
2	Preliminary Research Work														
3	Submission of Preliminary Report			12/8											
4	Project Work														
	Producing control beam														
	Flexural capacity test for 28 days														
5	Project Work														
	Producing reinforced beam														
	Experimental and testing work														
6	Submission of Progress Report														
7	Project Work														
	Analyze and discussed gathered data														
8	Project Work														
9	Submission of Interim Report														
10	Oral Presentation														

GANTT CHART (second semester)

No.	Detail/Week	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	Research work														
2	Project work														
	Producing Reinforced Beam 2														
	Producing Reinforced Beam 3														
	Corrosion Process for RC Beam 3														
3	Submission of progress report 1							17/02							
4	Experimental and Testing Work														
	Testing work (beam 2)														
	Testing work (beam 3)														
5	Result analysis														
	Data analysis and comparison														
7	Submission of progress report 2												4/03		
8	Submission of dissertation														11/05
															5/06
9	Oral Presentation														

APPENDIX IV

Product Data Sheet
Version no: 06/03, replaces 07/01

Sika® CarboDur®

Heavy-duty CFRP strengthening system

Positioning

Description

Heavy-duty CFRP strengthening system for reinforced concrete, masonry, stonework, steel, aluminum and timber. The system components include:

- Sika CarboDur CFRP plates
- Sikadur-30 adhesive for bonding reinforcement

Uses

The corrosion-resistant carbon fibre reinforced polymer (CFRP) plates are used as external reinforcement for reinforced concrete, masonry, stonework, steel, aluminium and timber structures. The system has been extensively tested at the Federal Materials Testing and Research Centre (EMPA) in Dübendorf, and it is possible to apply the CarboDur system, after preparation of the surface, without any mechanical fixings or temporary support.

To strengthen structures for:

Loading increase

- Increased live loads
- Increased traffic loads
- Installation of heavy machinery in industrial buildings
- Changes of building utilization

Damage to structural parts

- Deterioration of construction materials due to age
- Steel reinforcement corrosion
- Vehicle impact
- Fire
- Earthquakes

Serviceability improvement

- Decrease of deformation
- Stress reduction in steel reinforcement
- Crack width reduction

Change in structural system

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

Change of specifications

- Earthquakes
- Changes to design philosophy

Design or construction defects

- Insufficient reinforcement
- Insufficient structural depth

Advantages

- Low in weight
- Available in any length, no joints required
- Low overall thickness
- Easy to transport (rolls)
- Laminate intersections are simple
- Economical application - no heavy handling and installation equipment
- Very high strength
- Available in various moduli of elasticity
- Outstanding fatigue resistance
- High alkali resistance
- No corrosion
- Clean edges without exposed fibers
- General construction approval in many countries

Test reports / approvals

- EMPA, Report No. 154 490/1, 1994: Static loading tests on concrete beams strengthened with Sika CarboDur.
- EMPA, Report No. 154 490, 1994: Testing the Sika roll-on process on voids by infrared thermography.
- EMPA, Report No. 148 795, 1994: Fire test with Sika CarboDur strengthened RC beams.
- EMPA, Report No. 170 569e-1, 1999: Sika CarboDur Fatigue and Failure Test B1/B2.
- EMPA, Report No. 402'017E/2, 1998: Testing of prestressed CarboDur CFRP plate, beam V1.
- UCSD, SSRP Report, 2000: Post-strengthening of concrete slabs with externally bonded CarboDur CFRP plates-analytical approach and design recommendation.
- NTNV, Report No. R-9-00, 2000: Strengthening prestressed concrete beams with CarboDur CRFP plates.
- Deutsches Institut für Bautechnik Z-36. 12-29, 1997: General construction Authorisation for Sika CarboDur.
- SOCOTEC, Rapport No. HX0823, 2000: Rapport d'enquete technique / cahier des charges – Sika CarboDur / SikaWrap (French).

Availability

Sika CarboDur XS514 and XS1014 are stock items. All other types are available on request (with a suitable lead time).

Sika CarboDur XS Tensile E-Modulus 165,000 N/mm²

Type	Width (mm)	Thickness (mm)	Cross sectional area (mm²)
Sika CarboDur XS514	50	1.4	70
Sika CarboDur XS1014	100	1.4	140
Sika CarboDur XS1214	120	1.4	168
Sika CarboDur XS1514	150	1.4	210

Sika CarboDur S Tensile E-Modulus 165,000 N/mm²

Type	Width (mm)	Thickness (mm)	Cross sectional area (mm²)
Sika CarboDur S512	50	1.2	60
Sika CarboDur S612	60	1.2	72
Sika CarboDur S812	80	1.2	96
Sika CarboDur S1012	100	1.2	120
Sika CarboDur S1212	120	1.2	144
Sika CarboDur S1512	150	1.2	180
Sika CarboDur S614	60	1.4	84
Sika CarboDur S914	90	1.4	126
Sika CarboDur S1014	100	1.4	140
Sika CarboDur S1214	120	1.4	168

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

Type	Width (mm)	Thickness (mm)	Cross sectional area (mm²)
Sika CarboDur M514	50	1.4	70
Sika CarboDur M614	60	1.4	84
Sika CarboDur M914	90	1.4	126
Sika CarboDur M1014	100	1.4	140
Sika CarboDur M1214	120	1.4	168

Sika CarboDur UH Tensile E-Modulus 400,000 N/mm²

Type	Width (mm)	Thickness (mm)	Cross sectional area (mm²)
Sika CarboDur UH514	50	1.4	70

Packaging and Sizes

- Available in any length up to 250m long, for all sizes.
- Can be supplied in rolls of 250m or palletised in pre-cut sections.

Storage & Shelf Life

- Unlimited shelf life when stored in protective crates (with no exposure to direct sunlight).
- Sika CarboDur CFRP laminates are regarded as non hazardous for transportation. For information on Sikadur 30 refer to separate data sheet.

Product Data
Sika CarboDur plates

Form: Carbon fibre reinforced polymer with an epoxy matrix.
Colour: Black
Weight: 1.6g/cm^3 (50 mm wide strip = 100 gms/m approx).
Fibre volumetric content: > 70%

	CarboDur XS	CarboDur S	CarboDur M	CarboDur UH
Elastic Modulus (mean value)*	165,000 MPa	165,000 MPa	210,000 MPa	400,000 MPa
Elastic Modulus (min. value)*	>160,000 MPa	>160,000 MPa	>200,000 MPa	> 390,000 MPa
Tensile Strength (min. value)*:	> 2,200 MPa	> 2,800 MPa	> 2,800 MPa	> 1,800 MPa
Mean value of Tensile Strength at break*:	2,400 MPa	3,100 MPa	3,100 MPa	1,900 MPa
Strain at break (min. value)*:	> 1.35%	> 1.7%	> 1.35%	> 0.45%

Note: The above mechanical properties correspond to the longitudinal direction of the fibre.

Bonding adhesive: *Sikadur 30* - refer to separate data sheet for technical information.

Notes on design

General remarks

A Sika CarboDur plate has no plastic deformation reserve. Therefore the maximum bending resistance of a strengthened section is reached when plate failure occurs during steel yield and before concrete failure. The mode of failure is influenced by the plate cross-section. To limit crack widths and deformation the yield point should not be reached in the reinforcing bars under service conditions. Any shear cracks which occur must be prevented from causing displacement on the strengthened surface and shearing-off of the laminate. Stress and deformation calculations can be made by the normal methods. They should be verified in accordance with the New Zealand design standards, in conjunction with an internationally recognised design guide on externally bonded FRP reinforcement.

Condition of the structure

The following items should be included in an assessment of the existing structure:

- Dimensions (geometry, reinforcement, evenness of surface to be strengthened)
- Quality of existing construction materials
- Ambient climatic conditions
- Agreed conditions of service

Verifications

Design with Sika CarboDur should be done in accordance with the New Zealand Building Code and the relevant New Zealand design standards, and with reference to an internationally recognised design guide for FRP reinforcement, such as:

- *fib* Bulletin 14, Externally bonded FRP reinforcements for RC structures, July 2001.
- 440.2R-02: Design and Construction of externally bonded FRP Systems for Strengthening Concrete Structures, ACI Committee 440, 2002.
- Technical Report No. 55, Design guidance for strengthening concrete structures using fibre composite materials, The Concrete Society, 2000.

The design should include checks on:

Loading safety, in respect of:

- The non-strengthened structure (with allowance for a reduced total safety factor $\gamma > 1.0$)
- Strengthened structure (strains checked in terms of the mode of failure described above)
- Shearing of plate
- Anchorages

Fatigue resistance:.

- Check on concrete and steel stresses

Serviceability:

- Deformation (with average strains, assuming elastic behaviour of the structure and time-based strain changes in the concrete)
- Steel stresses (no plastic deformation in service conditions)
- Crack widths (by limiting the steel stresses under service conditions)

Application

Important notes

- The average adhesive tensile strength of the prepared concrete substrate must be 2.0 N/mm², with a minimum of 1.5 N/mm².
- The Sika CarboDur system must be protected from permanent exposure to direct sunlight.
- Maximum admissible service temperature is +50°C. When using Sika CarboDur Heating device together with Sikadur-30 LP it may be increased to max. + 70°C.

- Maximum substrate moisture content shall be 4 %. Minimum application temperature shall be +10°C.
- Ambient and substrate temperature during application must be minimum 3°C above dew point.
- The instructions in the Sikadur 30 Technical Data Sheet must be followed when applying Sikadur-30 adhesive.

Substrate

- After preparation, remove all dust from the surface with an industrial vacuum cleaner.
- The surface to be coated must be level, with no steps or formwork marks greater than 0.5 mm.
- Planeness of substrate shall be checked with a metal batten. The maximum allowable deviation over a 2 m length is 10 mm.

Reinforced concrete:
The substrate shall be clean, dry and free from grease, oil, loose particles and laitance.
Preparation: Sandblast or grind.

Timber, brickwork:
The substrate shall be clean, and free from grease, oil and loose particles.
Preparation: Sandblast, plane or grind.

Steel:
The substrate shall be clean, and free from grease, oil and rust.
Preparation: Sandblast or grind. (If the cleaned steel is not bonded to the structure immediately, the steel must be given one coat of Sikagard-62 to protect it from further corrosion.)

Application Conditions

CarboDur CFRP Plates

- If there are large blowholes or honey combs on the concrete surface, these must first be filled with a repair mortar. The Sikadur-30 adhesive must be used as a bonding layer to ensure a good bond with the concrete substrate. As repair mortar use Sikadur-41 or Sikadur-30 adhesive, filled max. 1 : 1 by weight with Sika Aggregate 501 quartz sand.
- Place the Sika CarboDur plate on a table and clean the blank side with Colma Cleaner using a white rag. Apply the Sikadur-30 adhesive with a roof shaped spatula onto the CarboDur laminate. Apply the well-mixed Sikadur-30 adhesive carefully to the properly prepared, dust free substrate with a spatula to form a very thin layer.
- Within the open time of the adhesive (which is dependant on temperature), place the coated Sika CarboDur plate onto the prepared concrete surface. Using a Sika rubber roller, press the plate into the epoxy adhesive until the material is forced out on both sides of the laminate.
- Remove surplus epoxy adhesive.
- Samples should be made up on site, and tested to check the curing rate of the adhesive and the compressive and flexural tensile strength after curing. Average values after 7 days curing at +23°C are:
  - Compressive strength >75 N/mm²
  - Flexural tensile strength >35 N/mm²
- Where CarboDur plates intersect, the top of the CarboDur plate that is applied first is to be degreased with Colma Cleaner.
- If several CarboDur plates are bonded together, they have to be cleaned on both sides with Colma Cleaner (i.e. every surface of the CarboDur plate that comes into contact with adhesive must be cleaned). Sikadur-330 is suggested as the adhesive for bonding CarboDur plates together.
- When the Sikadur-30 adhesive has cured, the Sika CarboDur plate has to be checked for hollows by tapping the plate lightly or by using impulse-thermography.
- The exposed plate surface can be painted with a coating material such as Sikagard-550 W Elastic.
- If required Sika CarboDur plates may be protected with fire resistant material.

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

Depending on levelness and roughness of substrate, as well as number of plate crossings, actual consumption of adhesive may be higher.

Construction

Cleaning	Clean tools immediately with Colma Cleaner. Wash hands and skin thoroughly in warm soapy water. Cured material can only be removed mechanically.

Recommendations for Sika CarboDur plates

Cutting	The cutting to length of Sika CarboDur plates is preferably done with a diamond cutting disk.

Important 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 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 proprietary rights of third parties must be observed. All orders are accepted subject to our current terms of sale and delivery. Users should always refer to the most recent issue of the Technical Data Sheet for the product concerned, copies of which will be supplied on request.

Handling Precautions

- Read the Sika CarboDur Material Safety Data Sheet before commencing work with this product.
- During cutting of Sika CarboDur plates wear goggles and dust masks with filter for finest dust, as well as one way gloves.
- The product can cause skin irritation (dermatitis). Apply barrier cream to hands and unprotected skin before starting work. Wear protective clothing (gloves, safety glasses). In contact with eyes or mucous membranes rinse immediately with clean warm water and seek medical attention without delay.
- Avoid contact with foodstuffs and utensils.
- If in doubt always follow the directions given on the pack or label.

Sika (NZ) Ltd
PO Box 71 001
Rosebank
Auckland
New Zealand

Phone: 0800 SIKA NZ 0800 745 269
Fax: 0800 SIKA FAX 0800 745 232
Email: info@sika.co.nz www.sika.co.nz