FLEXURAL STRENGTHENING USING CARBON FIBRE REINFORCED POLYMER (CFRP) STRIP ON REINFORCED CONCRETE (RC) SKEW BEAM

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By

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CERTIFICATION OF APPROVAL

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June 2009

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 contained herein have not been undertaken or done by unspecified sources or persons.

AZIZUL BIN HAWARI

Abstract

This report is experimentally conducted to determine the flexural effect of skew beams if CFRP is applied in the bottom middle of the beam. In the experiment, the author will test two types of skew beams which have an angle of 15° and 20°each. In both type of skew, the author will also test with different arrangements of CFRP application on the skew beam. The method used to test the beams in this experiment will be the double point loads test performed in 1/3 and full span length CFRP applied on the skew beams. The arrangement of the links will be 100mm from centre to centre and 1" for the four bars of reinforcement. The size of the beam used will be 230mm x 159mm x 2000mm. The investigation found out that full application of CFRP on the bottom of the beam will give highest elasticity among other two beams (control beams and 1/3 CFRP beam) but lower the ductility while 1/3 of the full length of the beams will give higher elasticity compare to control beam and retain some of ductility to the beams.

Acknowledgment

I would like to take this opportunity to thank God for His blessing so I can finish this research on time I also appreciate to everyone that has given me all the supports and guidance throughout the whole period of completing the final year project (FYP). Lot of thanks I would like to give to the university and the FYP coordinators that have coordinated and made the necessary arrangements, especially in terms of the logistics, for this study.

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CHAPTER 1 Introduction

1.1 Background of studies

In reality, skew beams are widely used especially in bridge structures. However, sometimes, old bridges could not be used to support the current live load because the design of the bridge does not meet with the current situation anymore. To demolish the bridge and rebuild it will be quite costly thus the solution to this problem in this modern world is to apply CFRP on the old bridge structures. This action can strengthen the capacity of the bridge without reconstruction which can cause time and money.

However, there are some issues that arise when using CFRP. CFRP is an expensive material. Due to this setback, civil engineers need to use it accordingly, which means only using the necessary amount it needs to increase the capacity of the bridge but in the most minimum CFRP usage as possible.

In this report, the author will try different arrangements of the CFRP on two different types of the skew beams. The aim is to search the best arrangement possible which will yield the highest capacity with the lowest cost incurred compare to all the others. The author wants to know whether 1/3 length of CFRP span will give same result as full length span of CFRP.

In this investigation, beams with 15° skew is chose because the beams is widely use while 20° skew beams is the worst case skew beams in bridge constructions. Further investigations are needed as the investigation is only limited to only two types of CFRP arrangement and only tested by using double statics load.

1.2 Problem Statement

Due to the expensive price of CFRP, the cost will be the main issue to be solve this report. The author will try to search the best solution for different types of skew beams. Experiments of different arrangement of the CFRP are conducted to search for the most optimum relationship between the cost and the capacity changes.

The idea is that 1/3 CFRP and full CFRP applied in the middle of the bottom beams of the beams will counter the torsinal force on the beams and bending moment of the skew beams. The author will try to determine from the results obtained which type of force will influence the skew beams the most.

The author will also determine whether it is relevant to use CFRP to increase the capacity of the beams. This is to verify if either the cost of demolishing the bridges and rebuilding it are much cheaper compared to applying the CFRP on the beams.

For old bridges, the old design of the bridges may not be suitable for the current condition because in the past, the bridges were designed to tolerate far lower service loads than they are experiencing today which were only used for cars and motorcycles loads and thus was designed only to meet those capacities. However in the current situation, lorries also use these bridges thus increasing the load of the bridge which will reduce its strength and endangering other users of the bridge. Consequently, its load design needs to be changed to meet the new live load.

On the other hand, to demolish and rebuild the bridge will cost a lot of time and money. In the long period, the old bridges cannot be put to use as they are being reconstructed. This will indirectly affect the economy nearby. In order to counter this problem, engineers have come up with the idea of applying CFRP on the old bridges. By applying the CFRP, it can increase the load capacity of the building, incurring less cost and time.

Despite solving the problem above, another question pops up as to how to apply CFRP optimally in order to reduce the cost of money incurred but at the same time increase the capacity of the bridge just enough for the current situation loads. In the worst case scenario, if the bridge uses skew beams applying the CFRP is another problem needed solving. That is why the author tries to answer those questions by conducting this experiment.

1.3 Objectives and Scope

The objective of this project is to find the optimum usage of CFRP on the old bridge that uses skew beams. The project will be started off by finding the effect of CFRP application. This is done by comparing the results of control beams to the results of CFRP applied on beams. This project also will determine which arrangement will be suitable to effectively increase the capacity of the skew beams.

Besides that, the project will ease some of the engineering works in low cost and minimum time requirement. This experiment will open new opportunity in bridge and structural engineer in order to increase the capacity of the structures without demolishing the old ones.

CHAPTER 2 Literature Review

2.1 Other CFRP investigations

Various studies have been conducted in CFRP and it has been proven to be easy to use, increases the capacity strength of the concrete beams, and has a high resistance to corrosion. Results from several research studies shows that CFRP will increase the beam capacity in different arrangements. Thus, it is easier to use CFRP to increase the capacity of the existing structure.

However, CFRP is an expensive material. Therefore, finding the optimum arrangement of the CFRP plate on the beams is a very important aspect. Previous researchers have also studied on the various arrangements of CFRP plate and CFRP bar as a replacement for steel bar in increasing the strength capacity of structures.

Studies performed by El-Refaie, Ashour and Garrity (2003) [2], showed that flexural capacity will increase the load capacity of the existing beams. This research has proven that CFRP can be used to retrofit existing structure such as bridges.

Other studies carried out by Ashour and Habeeb (2008) [3] has shown that CFRP bar also can be replacement for steel bar in the continuous beams. The result from study shows that CFRP can enhance the flexural capacity as well as control the deflection. However, beams reinforced with CFRP exhibit a wide crack in the middle support of the continuous beams.

From Ashour and Family (2006), the study has shown that CFRP reinforcement have higher flexural capacity compare to calculation by using ACI 440 and theoretical prediction. The result from the experiment shows that CFRP reinforcement can be calculated and predicted theoretically.

Using CFRP strips on existing structure by applying externally have been done before. The investigations also proved to increase the flexural strength of the beams and be one of the solutions to retrofitting old bridge [4-6]. Other than using CFRP strips externally, retrofitting such as post tensioning or jacketing with new concrete have been used as surface adhesive have been introduced in constructions [7].

Around in the middle of 1960s, steel plates are used to increase flexural strength of existing beams. The steels plate is applied externally on old structures by using epoxy as the bonding [8]. However, when using steel externally, it increases the cost of maintenance as the durability of the steel reduces due to corrosions.

Then, around 1980s, as fibre reinforced polymer (FRP) have been introduced to replace using steel plate externally. The applications are simply wrap or epoxy-bonded on the tension side of the beams to enhance their flexural strength [9]. Although CFRP is expensive materials compare to steel, however, compare to rebuild the whole structures, it save cost up to 20% just by applying the CFRP externally using epoxy-bonded methods and it still give the same end results[10].

When the techniques have been introduced in 1980s, many researchers also involve in determining the future usage of externally CFRP strengthening techniques around the past 15 years [5-7, 11-20]. There are 8 types of possible failure when applying CFRP externally [20, 21] however not all have been observed in the past 15 years researches. In simply supported beams, common failure will be (a) CFRP rupture in tension zone; (b) concrete crush in compression; (c) delamination between CFRP; and (d) peel off in curtail zone resulting combination of shear and tensile stresses in the plane of longitudinal steel bars [22].

In conclusion, from all the studies above, using CFRP can be concluded to increase the flexural value of the concrete beam. However, because CFRP have low ductility, further test and studies have to be conducted to evaluate the usage of CFRP in real structure. This investigation will be add one of the studies to investigate the effectiveness of using CFRP externally to increase flexural strength of skew beams.

2.2 Carbon Fibre Reinforced Polymer

Carbon fibre reinforced polymer or carbon fibre reinforced plastic (CFRP or CRP), is a very strong, light, and expensive composite material or fibre reinforced polymer. The composite material is commonly referred to by the name of its reinforcing fibres (carbon fibre).

Carbon fibre reinforced polymer has over the past two decades become an increasingly notable material used in structural engineering applications. Studied in an academic context as to its potential benefits in construction, it has also proved itself cost-effective in a number of field applications strengthening concrete, masonry, steel, cast iron and timber structures. Its use in industry can be either for retrofitting to strengthen an existing structure, or as an alternative reinforcing (or prestressing material) instead of steel from the outset of a project.

Retrofitting has become the increasingly dominant use of the material in civil engineering, and applications include increasing the load capacity of old structures (such as bridges) that were designed to tolerate far lower service loads than they are experiencing today, seismic retrofitting, and repair of damaged structures. Retrofitting is popular in many instances as the cost of replacing the deficient structure can greatly exceed its strengthening using CFRP.

Applied to reinforced concrete structures for flexure, CFRP typically has a large impact on strength (doubling or more the strength of the section is not uncommon), but only a moderate increase in stiffness (perhaps a 10% increase). This is because the material used in this application is typically very strong (e.g. 3000 MPa ultimate tensile strength, more than 10 times mild steel) but not particularly stiff (150 to 250 GPa, a little less than steel, is typical). Consequently, only small cross-sectional areas of the material are used. Small areas of very high strength but moderate stiffness material will significantly increase strength, but not stiffness.

CFRP can also be applied to enhance shear strength of reinforced concrete by wrapping fabrics or fibres around the section to be strengthened. Wrapping around sections (such as bridge or building columns) can also enhance the ductility of the section, greatly increasing the resistance to collapse under earthquake loading. Such 'seismic retrofit' is the major application in earthquake-prone areas, since it is much more economic than alternative methods.

If a column is circular (or nearly so) an increase in axial capacity is also achieved by wrapping. In this application, the confinement of the CFRP wrap enhances the compressive strength of the concrete. However, although large increases are achieved in the ultimate collapse load, the concrete will crack at only slightly enhanced load, meaning that this application is only occasionally used.

Specialist ultra-high modulus CFRP (with tensile modulus of 420 GPa or more) is one of the few practical methods of strengthening cast-iron beams. Typically, it is bonded to the tensile flange of the section, both increasing the stiffness of the section and lowering the neutral axis, thus greatly reducing the maximum tensile stress in the cast iron.

When used as a replacement for steel, CFRP bars could be used to reinforce concrete structures, however the applications are not common.

CFRP could be used as prestressing materials due to their high strength. The advantages of CFRP over steel as a prestressing material, namely its light weight and corrosion resistance, should enable the material to be used for niche applications such as in offshore environments. However, there are practical difficulties in anchorage of carbon fibre strands and applications of this are rare.

CFRP is a more costly material than its counterparts in the construction industry, glass fibre reinforced polymer (GFRP) and aramid fibre reinforced polymer (AFRP), though CFRP is generally regarded as having superior properties.

Much research continues to be done on using CFRP both for retrofitting and as an alternative to steel as a reinforcing or prestressing material. Cost remains an issue and long term durability questions still remain. Some are concerned about the brittle nature of CFRP, in contrast to the ductility of steel. Though design codes have been drawn up by institutions such as the American Concrete Institute, there remains some hesitation among the engineering community about implementing these alternative materials. In part this is due to a lack of standardization and the proprietary nature of the fibre and resin combinations on the market, though this in itself is advantageous in that the material properties can be tailored to the desired application requirements.

2.3 Epoxy

In chemistry, epoxy or polyepoxide is a thermosetting epoxide polymer that cures (polymerizes and crosslinks) when mixed with a catalyzing agent or hardener. Most common epoxy resins are produced from a reaction between epichlorohydrin and bisphenol-A.

Epoxy adhesives are a major part of the class of adhesives called "structural adhesives" or "engineering adhesives" (which also includes polyurethane, acrylic, cyanoacrylate, and other chemistries.) These high-performance adhesives are used in the construction of aircraft, automobiles, bicycles, boats, golf clubs, skis, snow boards, and other applications where high strength bonds are required. Epoxy adhesives can be developed to suit almost any application. They are exceptional adhesives for wood, metal, glass, stone, and some plastics. They can be made flexible or rigid, transparent or opaque/coloured, fast setting or extremely slow setting. Epoxy adhesives are almost unmatched in heat and chemical resistance among common adhesives. In general, epoxy adhesives cured with heat will be more heat- and chemical-resistant than those cured at room temperature. The strength of epoxy adhesives is degraded at temperatures above 350°C. [1]

Some epoxies are cured by exposure to ultraviolet light. Such epoxies are commonly used in optics, fibre optics, optoelectronics and dentistry.

CHAPTER 3 Methodology and Theory

3.1 Planning

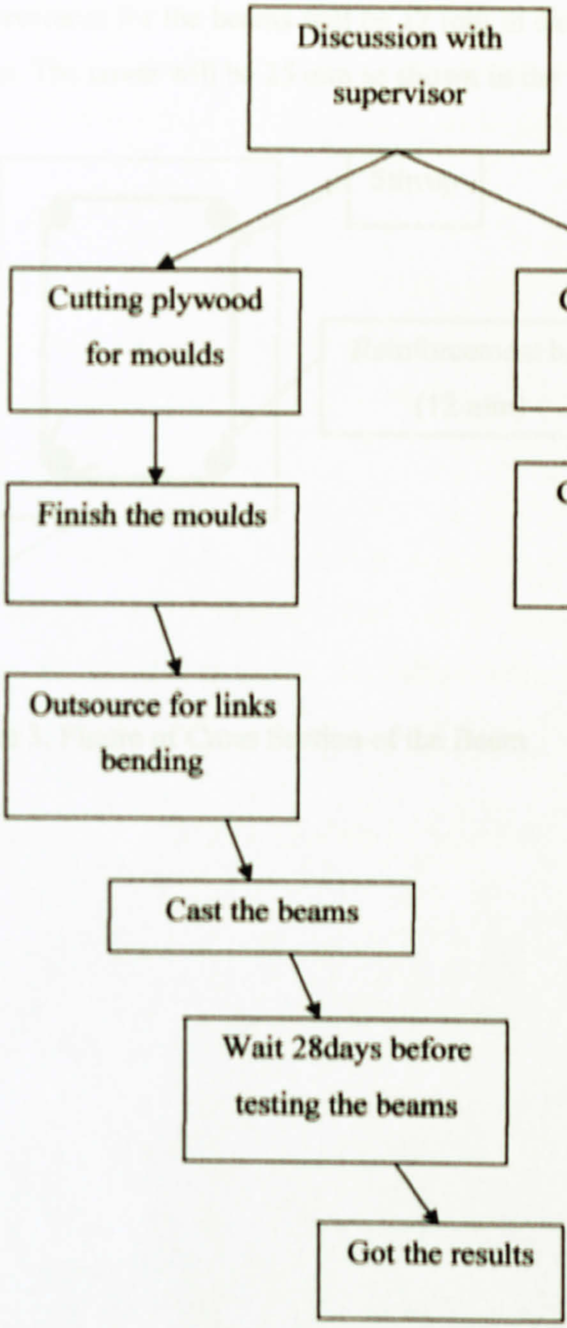

Figure 2. Flow of the Project

3.2 Procedure Identification

3.2.1 Cross Section of the Beams

The reinforcement for the beams will be 12 mm in diameter and will be positioned in the angle of the beams. The cover will be 25 mm as shown in the figure below:

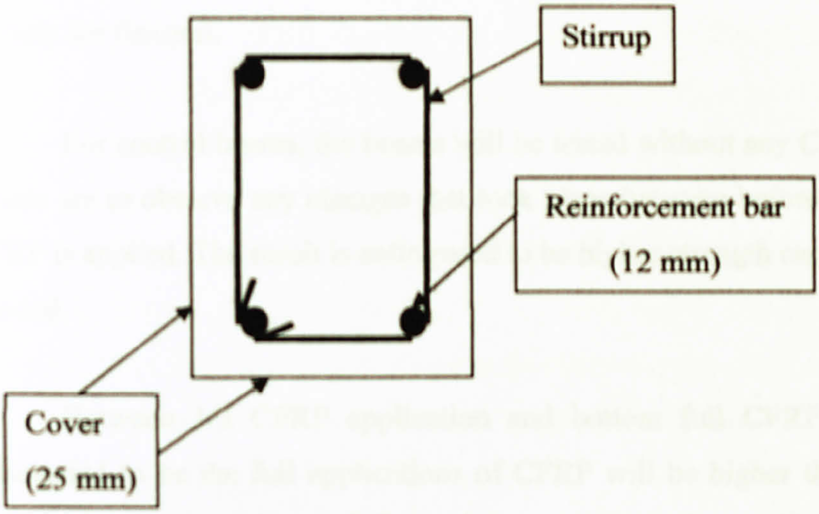

Figure 3. Figure of Cross Section of the Beam

3.2.3 Stirrups

To do the research only on flexural strength, the author has to increase the capacity to counter the shear stress failure. To do that, the stirrups of the beams have to be 100 mm range between centre to centre from the supports to 1/3 distance of the beams. This arrangement will increase the capacity of the beams to counter shear stress failures. So, the failure is anticipated to be only for flexural.

For control beams, the beams will be tested without any CFRP applications. This control beams are to observe any changes that took place between before CFRP is applied and after the CFRP is applied. The result is anticipated to be higher strength capacity on the beams with CFRP applied.

Between 1/3 CFRP application and bottom full CFRP applications, the results are anticipated to be the full applications of CFRP will be higher than 1/3 applications of CFRP. This is due to the failure of flexural beams where there will be more of bending moment compared to torsional force.

However, the results will show whether the hypothesis will be correct or not.

3.2.4 Reinforcement

The reinforcement of the beams will be 12 mm in diameter. This reinforcement will be the constant of this experiment. The author chose 12 mm in diameter steel reinforcement to make the flexural capacity less. So the failure will start from the flexural failure of the beams.

By applying CFRP, the flexural capacity of the beams is anticipated to increase. This shows that civil engineers can increase the capacity of the beams without replacing the beams or change the reinforcement inside the beams.

CFRP can also be used as a steel replacement for the beams but it is not commonly used nowadays. This is due to the fact that CFRP have higher tensile strength compared to steel but lower stiffness than steel. So, in some circumstances, the usage of CFRP to increase the tensile strength can be considered but to replace it is not suitable due to its low stiffness.

3.2.5 CFRP Application on the Beams

To complete the research, the author has to test the same type of beams but different application of CFRP arrangement. The work begins by testing the compressive strength of the design concrete. The values for three days show that the compressive strength is around 35MPa in average.

To apply the CFRP sheets on the beams, the usage of epoxy is needed. For the epoxy usage, two-component epoxy resin primer was prepared in accordance with the manufacturer's recommendations and is applied to the concrete substrate with a brush. When the primer has dried to a touch-dry state, two-component epoxy resin bonding adhesive was prepared in accordance with the manufacturer's recommendations and applied by brush over the touch-dry primer. The first layer of CFRP sheet was then placed by hand and pressed onto the adhesive with a rubber roller. Another layer of adhesive was applied over the CFRP sheet and was dispersed using a squeegee. Additional CFRP layers were applied in the same way onto the uncured wet adhesive.

The beams will be arranged in 20° and 15° skew. A centre point load test will be conducted to evaluate the capacity of the beam between with and without CFRP reinforcement on the beam.

In this research, the author tests CFRP plate on skew beam with different arrangement. The arrangement will be bottom beam arrangement for each degree of the skew beams. The arrangements will take place full length span and 1/3 length span in the centre of the beam to counter the highest flexural load of the beam.

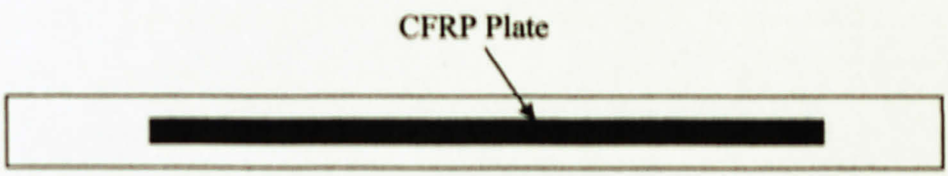

Figure 4. Plan View of CFRP arrangement

Figure 5. Side View of CFRP arrangement

The control beam was also tested to observe the different of flexural capacity before and after applying CFRP.

All beams are set with the same value of concrete compressive strength (35 MPa in design) and stirrup arrangement (100 mm from centre to centre). All beams are design in 100 mm x 150 mm x 2000 mm. The steel reinforcement will be two 12 mm in diameter of bars. The size of the CFRP plate will be different (1/3 and full from the span length of the beams) but the arrangement will be in bottom middle of the beams.

3.2.6 Double Point Loads Test

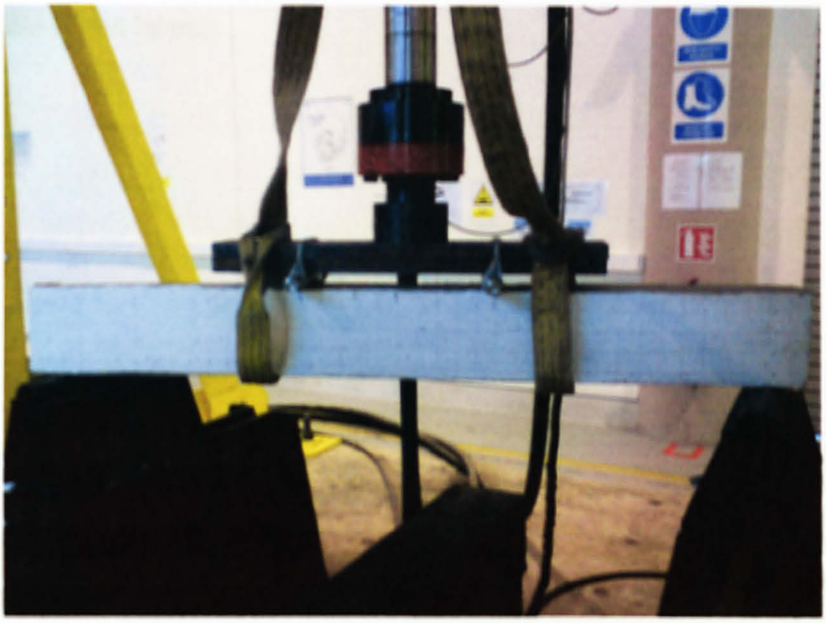

Figure 6 show on how the double statics points loads test operate

The description for double point loads test will be two loads apply on the 1/3 and 2/3from one of the support of the beams until the beams fail in flexural. In this case, all the beams will be applied with two point loads, one by one until all the beams rupture. The result of the ultimate load will be recorded in a computer program.

The point load machine consists with gages. The gages will be placed at the point which we want to determine the deflection of the beams. In this experiment, the gage will be place in the centre along with the load applied.

The size of the machine is around 4.5 m in height and 3 m in width. The size for beams testing is adjustable according to the size of the beams. The load will press by the hydraulic machine until the maximum load that the tester desire. In this case, the load will be the rupture load of the beams centre.

Even though a point load test does not reflect the life load situation of a bridge structures, it is assumed that the highest implication of the life load will be in the centre of the beams. So the test will only be taking one dead load at the centre to replace the live load. Moreover, the beams are simply supported beams and the highest bending moment will be when the live load at the middle of the beams.

3.3 Theory

3.3.1 Skew Beams Problems

In civil works, beams are something crucial for civil engineers to know. They are a lot of types of beams in this field. However, in this report, the experiment will only focus on testing retrofitting skew beams by applying CFRP on the beams.

There are a lot of researches studying on the uses of CFRP as a capacity enhancement of old beams and there are also more research conducted on skew beams. However, the goal of this particular research is to enhance the old research by applying CFRP on skew beams. If by applying CFRP on the skew beams will give satisfactory results, this will ease the retrofitting of old bridges in order to increase the capacity to counter the live load on the of the structures.

Even though skew beams are widely used especially in bridge constructions, there are a few problems regarding skew beams. In particular, the bracing between pairs of girders needed to be right and not skew, to be effective, but, when right was attached to points along the two girders that were not the same distance into the span and so deflected by unequal amounts. If the stiff bracing was not included in the structural modelling, these deflections were very unequal, and the forces induced in the bracing by such a difference in deflection became impossible to design for. When the effect of the bracing was included in the structural modelling, the deflections became markedly less unequal, and the forces in the bracing became manageable.

The ratio of distribution factor at any skew angle to the distribution factor at zero skew shows the effect of skew. The effect of the skew factor incorporated in the AASHTO LRFD code.

Skew had little effect for an angle of 20°, and for some models, the live-load distribution factor actually increased slightly. This finding is consistent with previous research (Bishara et al. 1993). At larger skew angles, the live-load distribution factor decreased with increasing skew.

In general, interior girders were more affected by skew than were exterior girders. The AASHTO LRFD skew factor appears to provide a reasonable approximation for the effect of skew in the various models.

3.3.2 Formula

To calculate the deflections, assume the beams are simply supported with a point load at the centre. The maximum deflection will be at the centre which is:

$$Y = \frac{P}{6EI}\left[\frac{3}{2}L^2a - \frac{3}{4}aL^2 - a^3\right]$$

Where Y= maximum deflection or the deflection at the centre

L= length of the beams

E= modulus of elasticity

I = moment of inertia

P=load applied on the beams

a=distance from one support to the closest load

The maximum bending moment occur at the centre of the beams. The formula will be:

M=Pa

Where M =maximum bending moment which occur in the centre of the beams

While, the maximum shear will close of the support of the beams given by:

V=P

Where V= maximum shear at the support of the beams

3.3.3 Typical Diagrams for Shear and Bending Moment

In simply supported beams with the load at the centre of the beams, the typical shear diagram will be as follows:

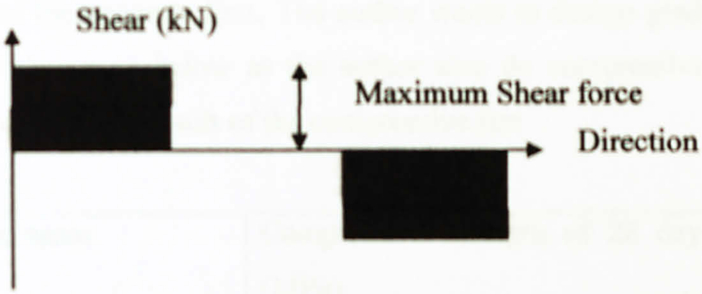

Figure 7. Diagram of Maximum Shear Force on the Beam.

While the bending diagram will be as follows:

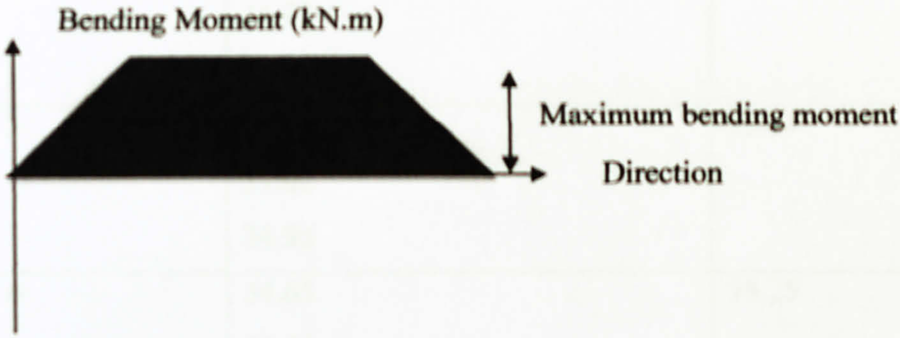

Figure 8. Diagram of Maximum Bending Moment of the Beam

CHAPTER 4 Results and Discussions

4.1 Results

Before the author starts the point load test on the skew beams, he needs to test the strength of the concrete first. The author wants to design grade 35 concrete. The results of the cube test shown as below as the author also do compressive test of the concrete from each beams. Below is the result of the compressive test

Beam name	Compressive strength of 28 days (MPa)	Average (MPa)
Beam 1	35.63 36.36 33.62	35.20
Beam 2	40.64 34.79 35.66	37.03
Beam 3	35.86 37.02 34.93	35.94
Beam 4	34.65 36.36 37.75	36.25
Beam 5	34.33 34.76 34.32	34.47
Beam 6	36.78 34.42 34.78	35.33

From the results above, the author decide to change the compressive strength to grade 35 because the results above show that the compressive strength of the beams close to 35MPa.

These changes occur due to the change of water cement ratio to increase the workability of the concrete mixture.

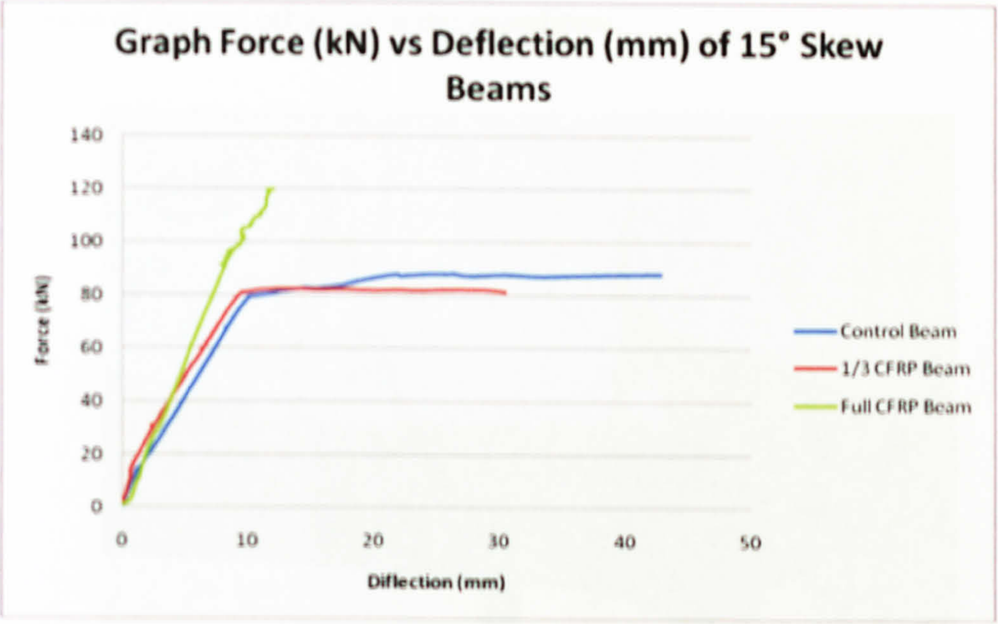

Figure 9, the graph force (kN) vs Deflection (mm) of 15° of skew beams.

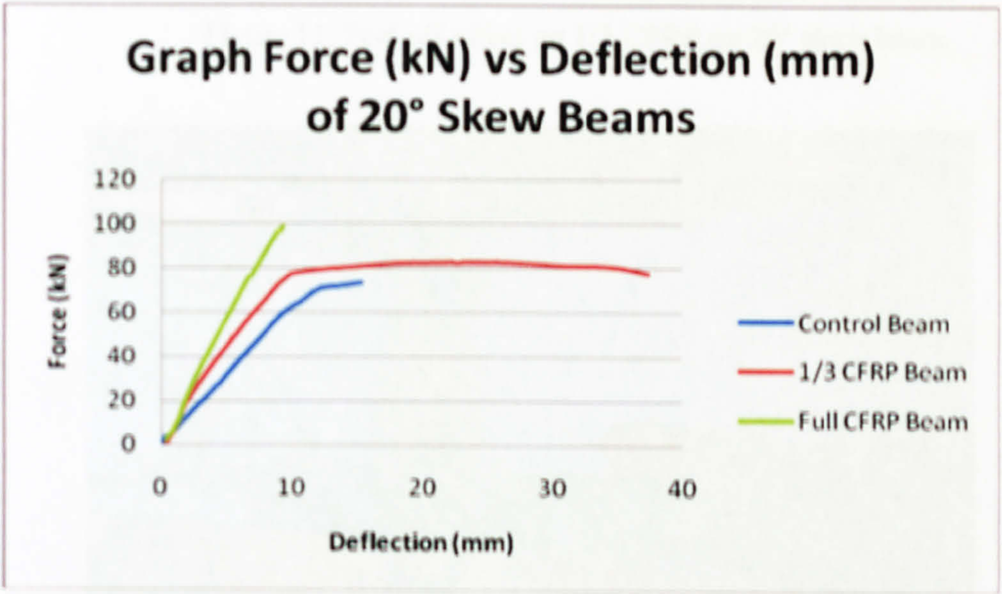

Figure 10, the graph force (kN) vs Deflection (mm) of 20° of skew beams.

The graph above shows pretty interesting results. The control skew beam gives lower elasticity compare to the strengthening beams with CFRP. However, the control beam gives more ductility compare to the strengthening beams. This occurrence may due to the peel off effect. Peel off effect occur when the beams about to bend, the CFRP try to straight it up and cause the concrete to cracks and follow the CFRP. For further understanding, the pictures below will show some of the peel off effect in this experiment.

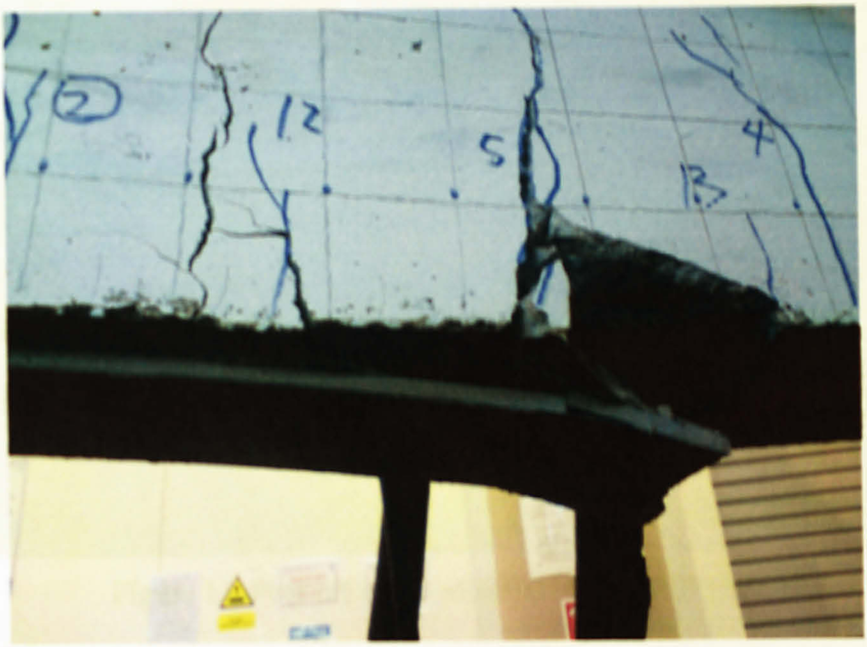

Figure 11, Peel off effect on 1/3 CFRP on 20° skew beam.

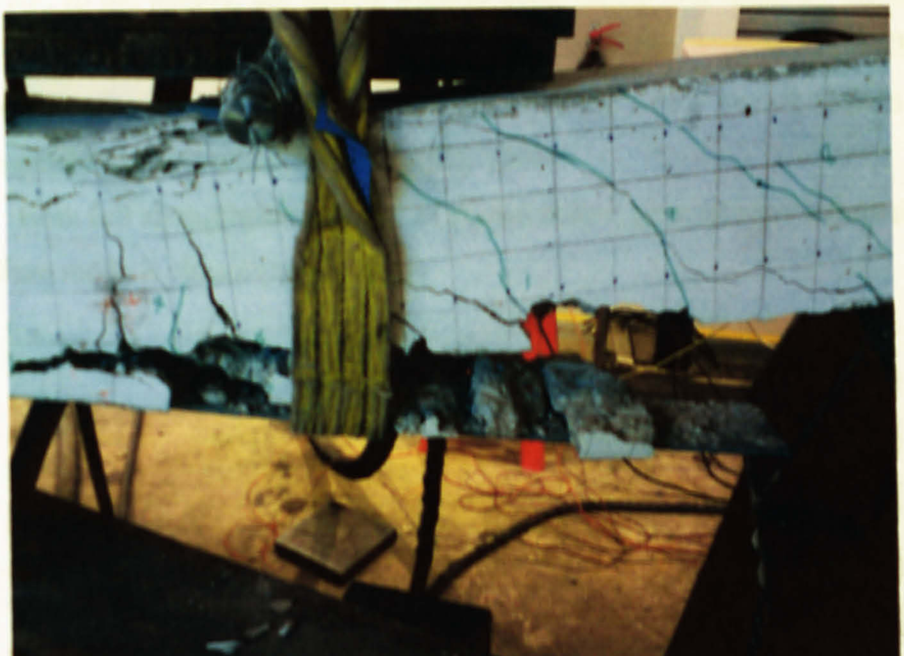

Figure 12, Peel off effect full CFRP on 20° skew beam.

Figure 13, Peel off effect of full CFRP on 15° skew beam.

Other explanation of the ductility reduction may cause by the higher resistance of the CFRP. In the testing, the beams want to bend further but resist by the CFRP applied on the beams. This makes the beams sustain higher load by depending on CFRP strength. However, in one point, the concrete that attach to the CFRP cannot sustain the load and start to cracks and fail without any ductility phase.

Both full strengthening graph, as shown below, give another interpretation of why the failure mode is abrupt (no ductility)

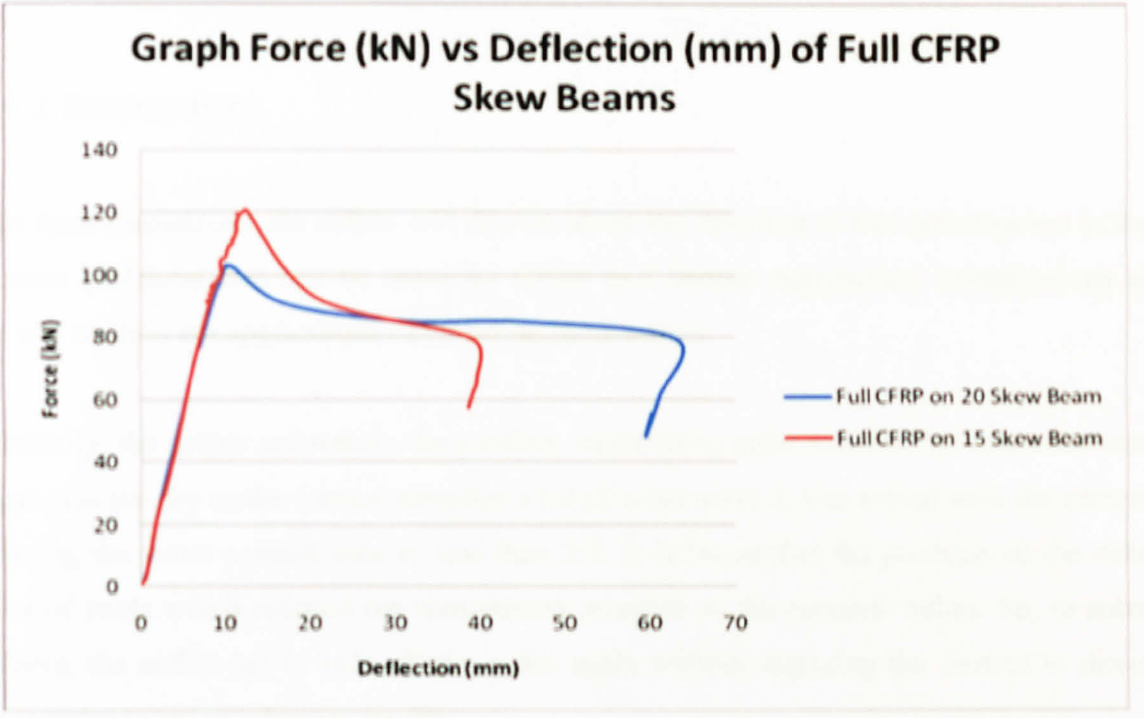

Figure 14, Graph of force (kN) vs deflection (mm) full CFRP on both of the skew beams.

The graph above shows that in the first phase (from 0 mm to 10 mm deflection), the beams in elastic condition. In the end of the elastic condition, some crack occurred and start the peel off effect. Then, in phase two (from 10 mm and above), the CFRP no longer strengthen the beams as the peel off effect occurred completely. In this phase two, only steel bar inside the beams hold the beams flexural strength. Then, the steel rebar gives the beams plastic deformation before the rebar fail and the beams collapse.

4.2 Discussions

In these discussions, the author will discuss about the direction of this investigation in the future, some problems that can be solve by CFRP and further suggestions investigations to enhance and confirm the applications of CFRP on skew beams

Initially, the author encounters the problem when doing cube test. For the first cube test, the cement was too dry so the cement absorbed a lot of water when it was mixed with the cement thus reducing the water-cement ratio to less than 2:1. It is found that the products of the cube have a lot of voids which reduced the compressive strength of the concrete cubes. So, to solve this problem, the author has to redo all the cubes again without exposing the cement to direct sunlight in order to get satisfactory results.

In today's world, there are a lot of bridges that needs rebuilding due to the increase in the amount of live load on the bridge. The increase in live load will result a lot of cracking on the bridge beams. Cracking not only can reduce the flexural strength of the beams but also can increase the cost of maintenance. This is due to the environment, like rainy days, water can penetrate through the cracking and corrode the steel bar inside the RC beams. There are necessary steps to be taken in order to increase the capacity and reduce cracks of the bridge to counter the new live load and increase the life span of the bridge. The easiest way to increase the capacity is by applying CFRP on the beams.

The problem of using skew beams is determining the design for the support. If the supports are not properly designed, there will be crack on the supports which can reduce the compressive strength of the support. Other skew beams such as different elevation skew beams will stress more on the lower elevations of the beams. So the design must properly include the weight of the beams to avoid any cracks close to the lower elevation support of the beams.

To complete the beams, the author has to do two moulds of the beams. The moulds will be reused until all the six beams are done. Two of the beams will be used as control beams.

Another two of the other beams will be 15° skew beams with different CFRP applied. The final two beams will be 20° skew beams with different CFRP applied. The 15° skew beams are use because the skew beams are widely used to build bridges and 20° skew beams as the worst case scenarios skew in bridge constructions.

With CFRP strengthening, the cracks of the beams can be controlled in the elastic phase of the beams. However, when the beams fail, the cracks is wider compare to the control beams. The figures below show the effect on cracking between control beam and CFRP strengthening beam.

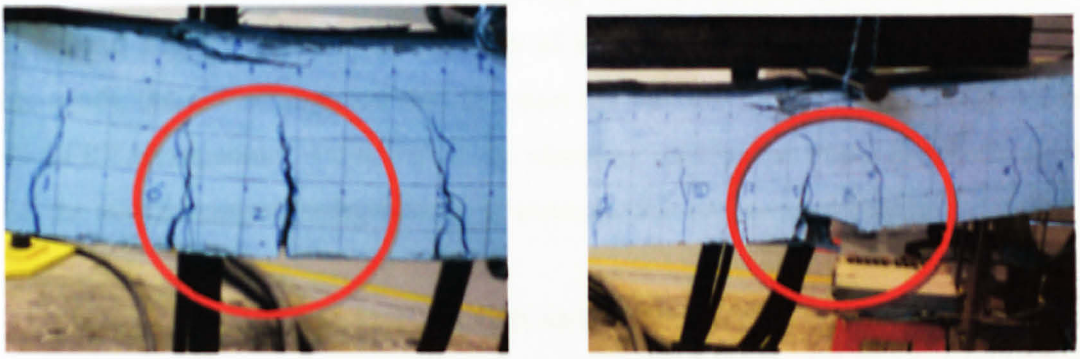

Figure 15, the figures show the size of crack between control beam (left) and the strengthening CFRP beam.

To get homogeneous mixture of the concrete, the author needs to change the mixing concrete procedures. In this case, the author put aggregates, some of the water first. Then, the sand and the rest of the water and cement will be put slowly during the mixing process. With this mixing concrete procedure, the homogeneous mixture of the concrete is achieved easily compare to the normal mixing concrete procedure.

CHAPTER 5 Conclusion and Recommendations

In order to find the best arrangement for CFRP application on the skew beams, the author started the experiment to determine the increase in strength between full CFRP application and 1/3 CFRP application on the bottom of the beams.

The author has found out that the full CFRP application will increase the elasticity of the beam but in the same time reduce the ductility of the beams. However, the 1/3 CFRP arrangement will slightly increase the elasticity of the beams while retain some of the ductility. From this result, the author suggests that to retain the ductility of the skew beams, we need to apply 1/3 CFRP arrangement. However, if the elasticity will be the major problems need to be improved, the author suggests using full CFRP arrangement on the skew beams.

This project will also open new research on the application of CFRP on the various types of skew beams. All this research will enhance the application of retrofitting on the old structure by using CFRP. Further investigation on skew beams like dynamics loading testing, different level skew beams, and tested more beams to really justify the results.

Even though CFRP is quite an expensive material but with optimum application, it will reduce the cost and time rather than the need to demolish the whole structure and rebuild a new one.

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Appendices

Appendix 1

Here are some pictures of the experiment.

Figure 17. Even though the stirrup is close spacing to encounter shear failure, in skew beams possibility is still there to fail in shear cause by the torsional force.

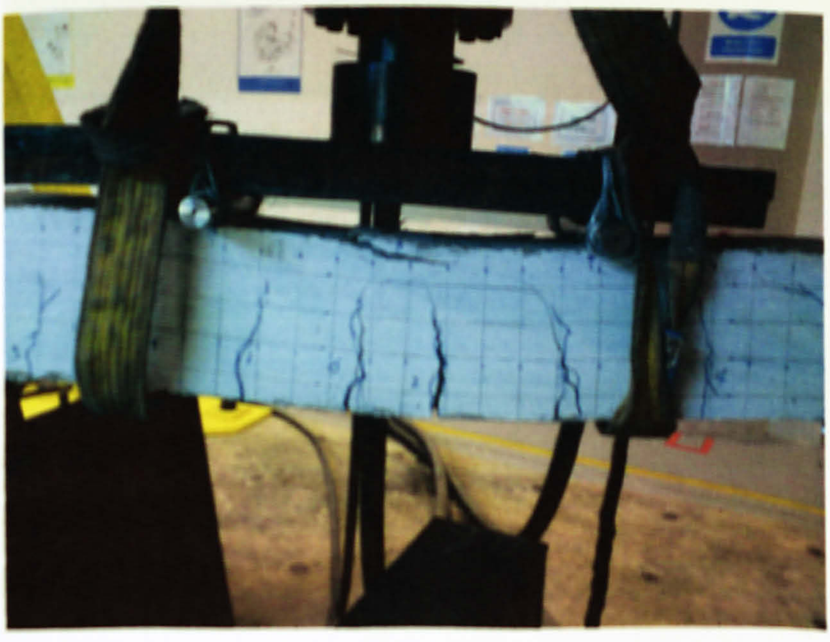


Figure 18. it shows the cracking and shear failure of the beam.

Figure 19. It shows the CFRP applied on 1/3 in the bottom middle of the beams.

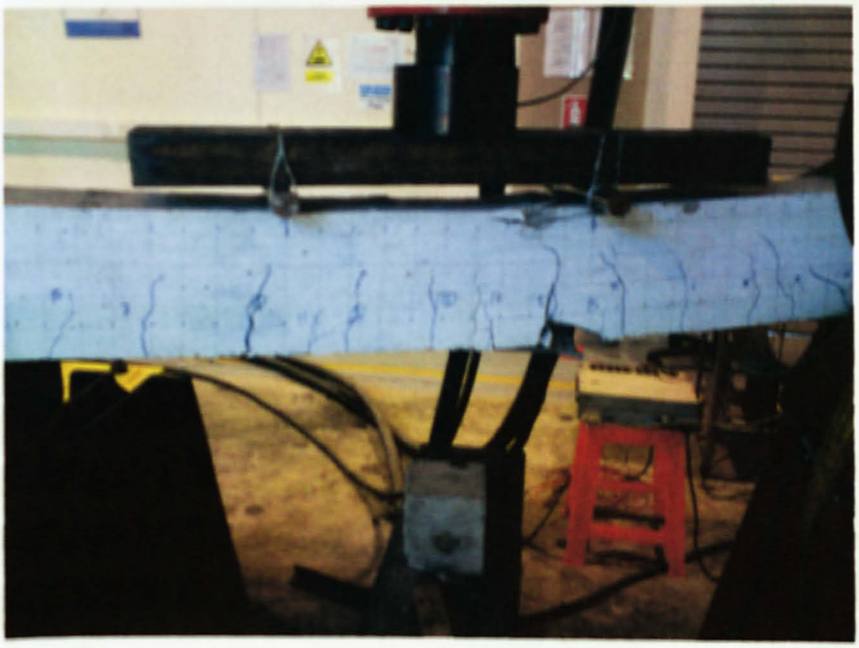


Figure 20. It shows the cracking much larger compare to control beams.

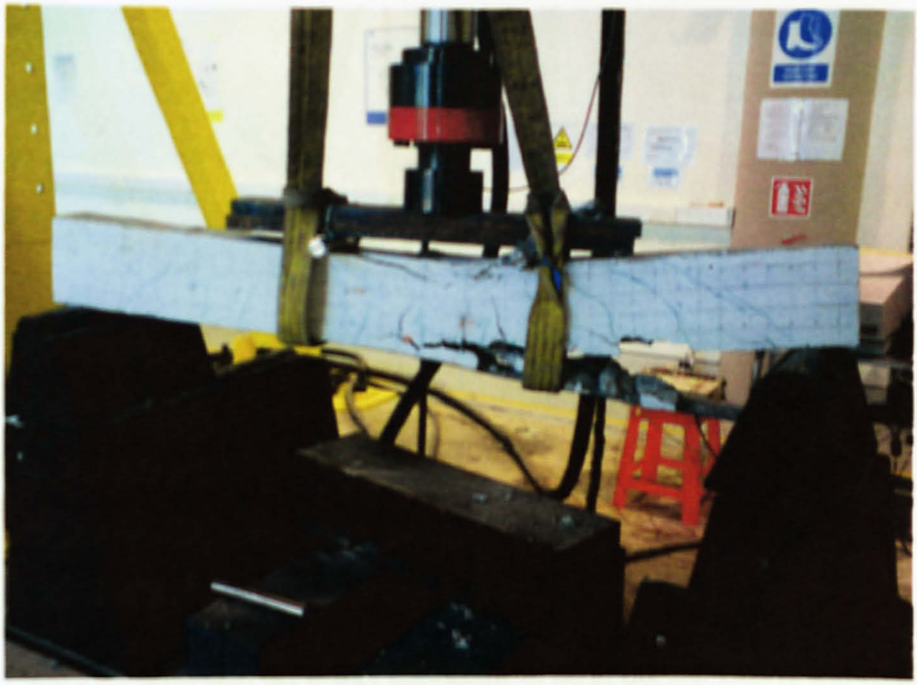


Figure 21. The full CFRP applied on the bottom of the beams give flexural failure show the peel off effect.

Figure 22. The beam put down after the test.

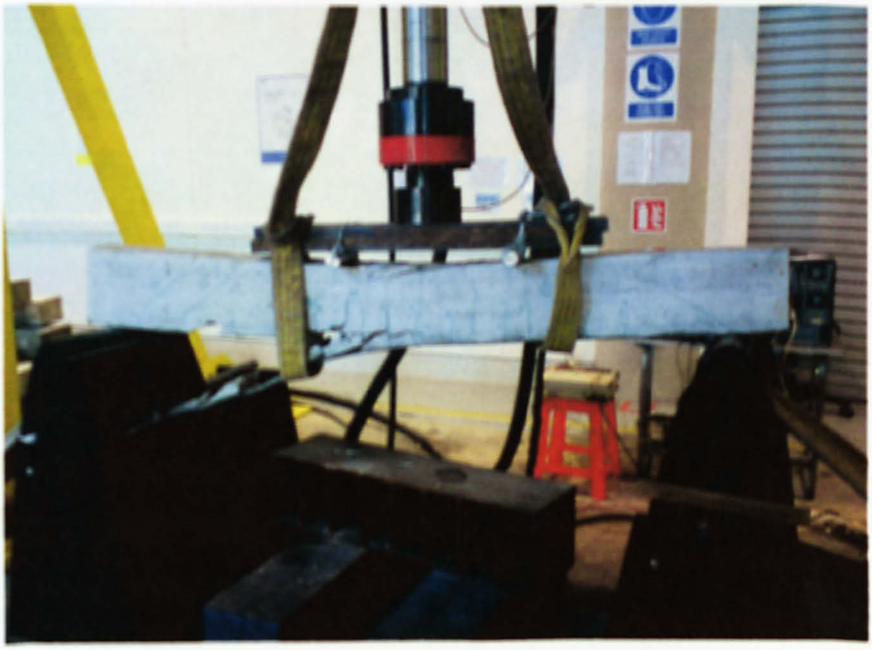


Figure 23. The peel off effect happened to be at the left side of the beam.

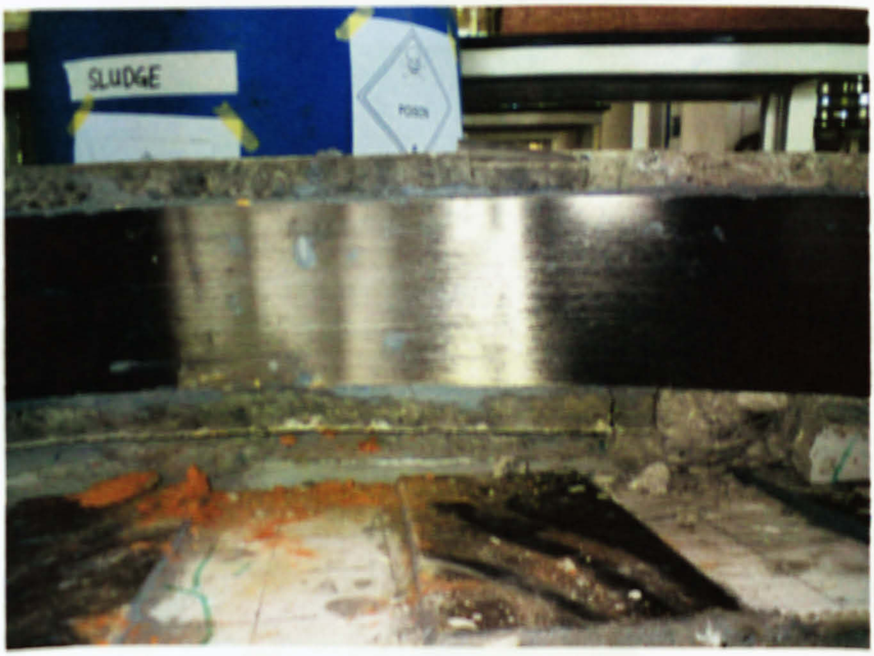


Figure 24. The CFRP here have some bending failure.

Figure 25 shows on how to transfer the beams to the testing machine.

Figure 26 shows on how to arrange the beams to the support machine.

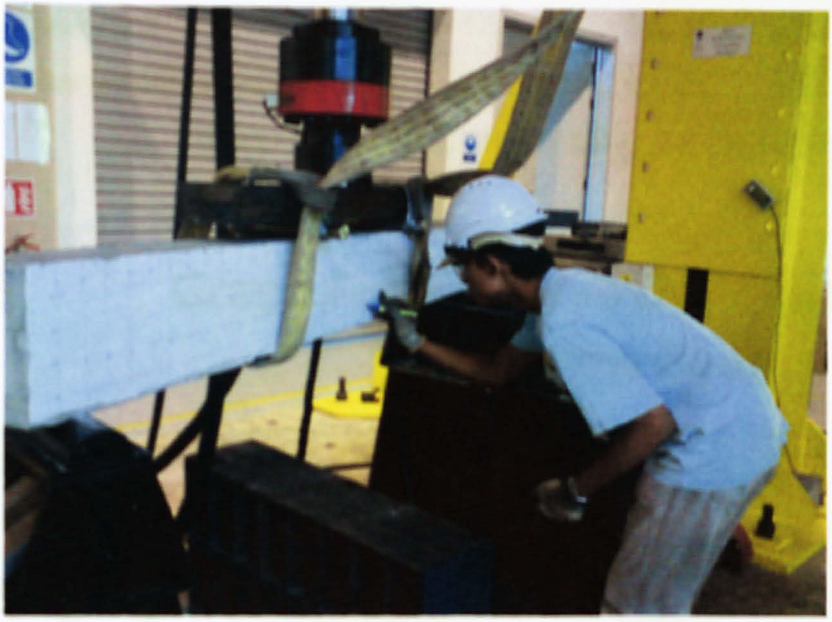
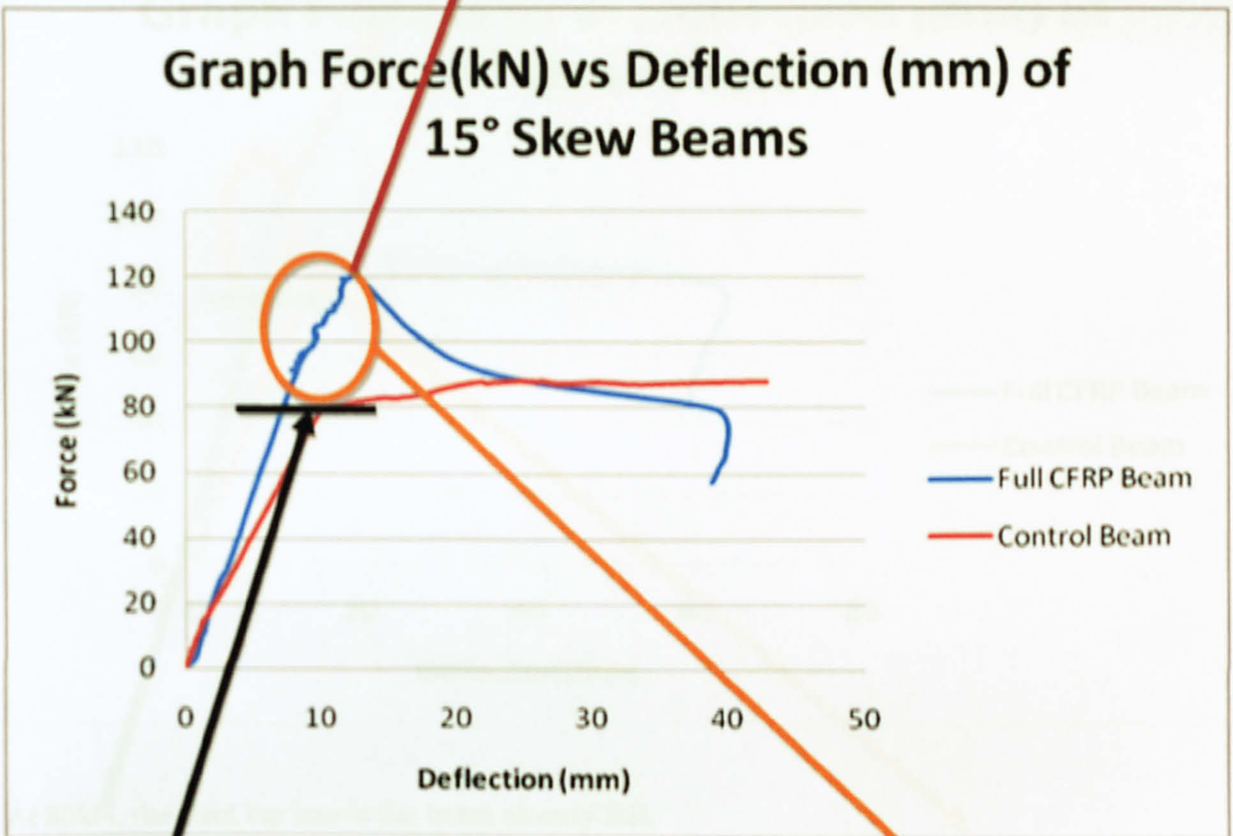


Figure 27 shows the author determining cracks during the testing progress.

Appendix 2

Other results comparison

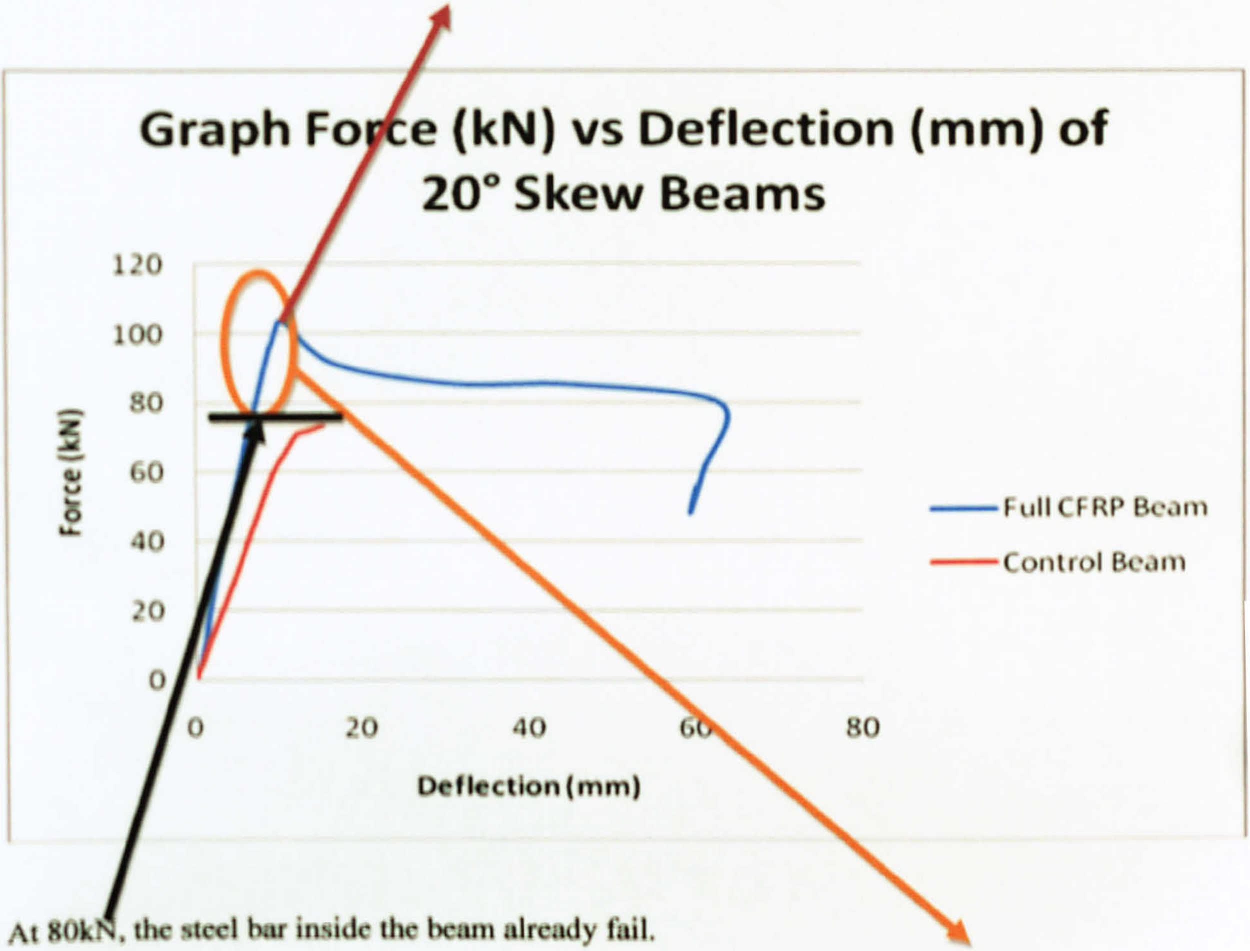
The point where the peel off effect occurred completely



At 80kN, the steel bar inside the beam already fail.

In this area, the beam only reinforce by CFRP.

This is the point when the peel off effect occurred completely.



At 80kN, the steel bar inside the beam already fail.

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