CERTIFICATION OF APPROVAL

Development of moment rotation capacity numerical procedure for FRP plated steel section

By

Muhammad Farhan Hafizuddin bin Abdullah

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Approved By,

....

(Dr Ibrisam Akbar)

UNIVERSITI TEKNOLOGI PETRONAS

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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 acknowledgement, and that the original work contained herein have not been undertaken or done by unspecified person or sources.

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(MUHAMMAD FARHAN HAFIZUDDIN BIN ABDULLAH)

ABSTRACT

Fiber Reinforced Polymer (FRP) is a popular subject in retrofitting nowadays. It is always associated with worked on enhancing the performance reinforced concrete and also steel structure. This paper highlights the theoretical works on FRP plated steel beams in terms of de-bonding failure. The program used to develop the analytical procedure is Microsoft Excel Spreadsheet. The program has been used before is FOTRAN and another program will be develop to study the behavior and performance of FRP plated steel section using spreadsheet. The validation of this study will be based on the parameters adopted from the previous study with addition of the current practice standards. Plated steel section used is I-beam with the FRP plate is reinforced on the bottom flange of the beam. The procedure will begin from cross section analysis, span analysis before it can be completed with the moment-rotation analysis.

ACKNOWLEDGEMENT

First of all, in the name of Allah, the most gracious and most merciful, I was blessed to have completed this report in time and with no harm.

My greatest gratitude will be to Mr. Ibrisam Akbar, for his kindness and teaching that has led me to proceed with the project. Without his guidance, it is sure for me to face so many difficulties in working with this project named 'development of moment rotation capacity numerical procedure for FRP plated steel section'. I am starting this work with very shallow knowledge and with Mr. Ibrisam showed me the light; it is getting so much easier than in the beginning.

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Lastly, I hope that with this project, it could beneficial to all in future findings and research. Thank you very much.

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ABBREVIATIONS AND NOMENCALTURES

P	single acting force
V	shear force
M_{max}	maximum moment
ε_s	the strain in steel
ϕ	curvature of strain in steel
d_{NA}	neutral axis at started of calculation which is 75mm
σ_s	stress in beam
E_s	modulus of elasticity which is 205 Gpa @ 7Gpa(yield)
σ_p	stress in plate
E_p	modulus of elasticity of FRP which is 155 Gpa
ε_p	strain in plate
F	force in beam, plate
A	affected area
d	depth of beam
tf	thickness of flange
tw	thickness of web
bf	length of flange
tp	thickness of FRP plate
bp	length of FRP plate

CHAPTER 1

1.1 Introduction

Steel beam is subjected to various loads and design to resist moment and shear load. There are various types of steel beam and all of them differ from one another on the sustainability towards load applied. Steel I-beam is very common in the construction, and retrofitting works on this particular beam section is very much necessary in order to improve the performance of steel beams. Fiber reinforced polymer (FRP) reinforced beam section is still new and there are many field and section to be studied.

Fiber Reinforced Polymer (FRP) is a material choice in the strengthening and rehabilitation of structures, mainly because its ease of use. The high stiffness-to-weight and strength-to-weight ratios of FRP combined with their superior environmental durability have made them appealing. FRP is also thin so it does not infringe upon the head room requirement compared to other materials, for example steel plates. Various journals and articles have been produced describing and highlighting the use of FRP as strengthening member of structures. The study of bond-slip relationship of steel and FRP, bond strength, and strengthening of various steel members are among studied that have been carried out rapidly. With the existing research, there are a lot of other fields yet to be explored about FRP and steel members. One of them is moment-rotation analysis of FRP plated steel section. This project is about development of numerical procedure in order to get and identify the moment-rotation behavior of steel members strengthening with FRP. This development will use Microsoft excel as the medium in expanding the study. All related works will be run in this software in order to obtain the solution.

1.2 Problem Statement

There are a few problems arises from previous study on FRP plated steel section. All of this problem may hinder the ultimate objective of the study itself.

Firstly, FRP is used as an external reinforce materials on the steel beam. So, in order to study the effectiveness of putting FRP on the beam, experimental works should be done. Samples regarding these two materials should be prepared and it has to be in a number of samples for accuracy purposes. So, it is very costly. The FRP alone could cost thousands of Ringgit Malaysia, plus with the steel beams that are going to be used, imagine the cost involved to carry out the experiment. Besides, having so many examples to be worked on is very exhaustive and time consuming. So, there will be so much time will be spent at the laboratory. The solution to this is to develop a numerical procedure which could simulate the behavior of FRP plated steel section. Detailed comparison should be made regarding the numerical procedure in order to achieve concurrent results with previous researches.

Secondly, the study on FRP plated steel section is very narrow. There are many external reinforcements applied on structure material, and many studies had been done on that particular reinforcement. Since FRP plated steel section is new, studies done are very limited. There is the necessity to broaden the scope of study in this area in order for us to get better understanding on FRP plated steel section. Since it is widely used in retrofitting works for reinforced concrete, so, the behavior of this joint of FRP and steel beam are in need of attention.

Thirdly, there is the need to check the contribution of FRP towards the ductility of steel beams. It is whether FRP reinforced on steel beams are the major factors that contribute to the sustainability of steel structure or not. It is also to know how well are the interaction between steel beams and FRP that is attach to it in order to increase the ability of this system to sustain load.

Lastly, the previous study on the developing numerical procedure for this moment-rotation capacity analysis is using Fortran™. It is programming software, like C++. Numerical procedure by using Fortran™ is rather difficult because it is new software and seldom used in normal works. In order for simpler analysis, the author has chosen to use Microsoft Excel™ spreadsheet. It is to check the compatibility of this software for developing numerical analysis spreadsheet that is reliable to be used.

1.3 Objective

The objectives of this study are as follow:

- Develop moment-rotation analysis using numerical approach in Microsoft Excel™ spreadsheet.
- Compare the effect of FRP on ductility of steel beam section.

1.4 Scope of Studies

The main aspects of study are divided into three sections which are cross-sectional analysis, span analysis and lastly moment-rotation numerical procedure.

1.4.1 Cross Sectional Analysis

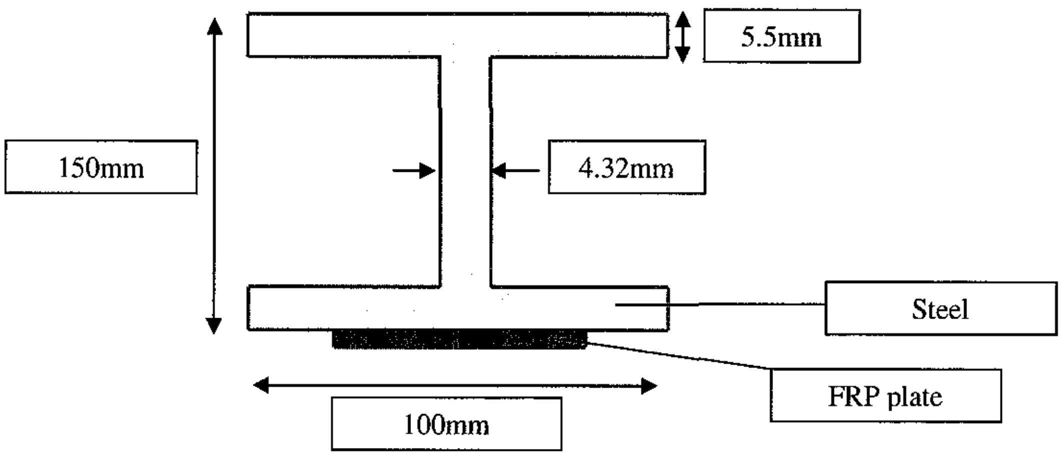


Figure 1: Cross section of beam

Cross section analysis is very important as preliminary requirement before proceeding with span analysis, bond-slip relation, and then moment-rotation analysis. This analysis assists in finding the position of new neutral axis, stress-strain distribution of the system, total force and also total moment of the system.

W150x14 I-beam

Particulars	Length (mm)
d	150
tf	5.5
tw	4.32
bf	100
tp	1
bp	50

TABLE 1: I-Beam particular for section W150x14

$\varepsilon s = 0.00152$ (guess)

$\varepsilon p = 0.0013$ (fixed)

Es = 205Gpa

Es = 7Gpa (yield)

Ep = 155Gpa

dNA = 75 mm

1.4.2 Span Analysis

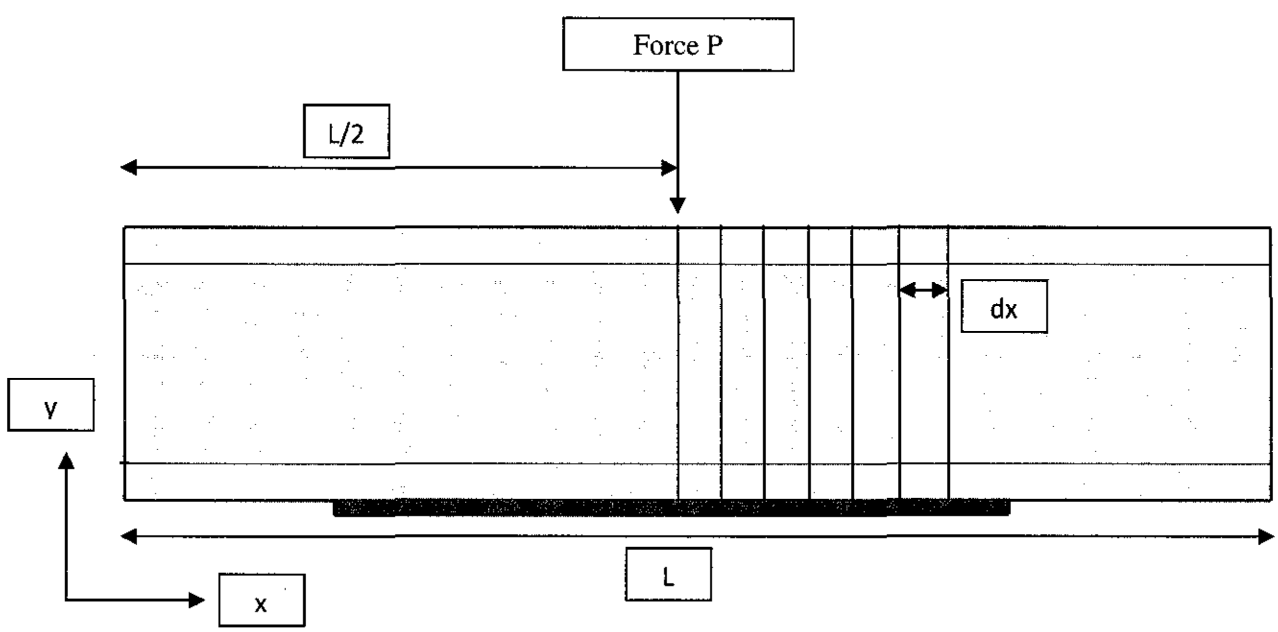


Figure 2: Span of beam

Based on Figure 2, the span section is cut into smaller segments. The increment of segments in X-direction is noted as dx, and the segments are made as small as 1mm per segment. This is to ensure results obtain as close to the theoretical value as possible. This beam is assumed to be a simply supported beam and it is loaded at the mid span of the beam. It is a point load P as shown in the above figure. Theoretical value of moment, Mx, is calculated and will be put as reference value for the calculation of total moment in the section 1.4.1 for each segment of the cross section.

The stress-strain of both materials is calculated in order to obtain the bond-slip relationship of this system. Slip is define as the ability of FRP to sustain load that act on it through the steel beam before it loss its bonding strength to the steel beam.

1.4.3 Moment-rotation Analysis (numerical procedure)

The ultimate objective of this study is to achieve the analysis in terms of numerical approach. In order to get to this, analysis of cross section and span which have been mentioned above, need to be completed first. There will be a few condition that need to be met before finally completed this numerical procedure in order to obtain the moment-rotation relationship. Detailed aspects of all the conditions will be discussed under methodology section in chapter 3.

CHAPTER 2

LITERATURE REVIEW

2.1 Moment-Rotation Curve

This moment-rotation curve as discussed in [Gioncu and Petchu, 1997] stated that one of the features is yielding of flange, Fyc corresponding with plastic moment in flange. The other feature is occurrence of full plastic moment, M_p of the whole beam section. The features are for Moment-rotation curve of a member under critically loaded condition in which spot several significant changes in the beam behaviour.

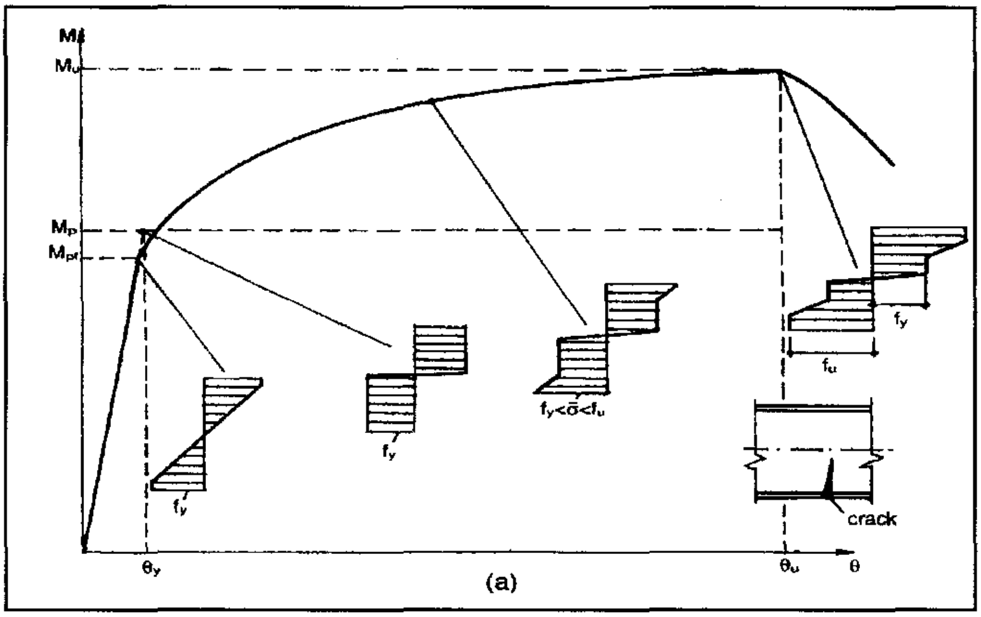


FIGURE 3: Moment-rotation curve of steel section

These four (4) states of steel are plastic, semi-compact, compact and slender. The slender state is where the beam fails. So, this study of moment-rotation capacity of composite steel and FRP is to analyze the moment in the composite, what is the moment produce before the composite of steel and FRP become slander and failed. We could see the stress behavior in the composite in what stage does it started to failed.

2.2 FRP Profiles

FRP systems have significant advantages over classical structural materials such as steel, including low weight, corrosion resistant and ease of application [Balaguru, 2009]. Due to lightweight, high strength and good fatigue and corrosion resistance properties, FRPs have been extensively used in the repair and strengthening aerospace structures [Baker, 1987]. Thus FRP is even better in structural retrofitting. The following shows the properties that would increase in advance of applying FRP reinforcement:

a) Stiffness for reduced deflections under service and design loads [Buyukozturk et al, 2004; Taljsten and Elfgren, 2000]
b) Ductility for improved seismic performance and blast resistance
c) Increase fatigue life, and
d) Improved durability against adverse environmental effects [Balaguru, 2009]

The behavior of FRP is linearly elastic up to failure and from experimental results done by other researchers show that the failure point of FRP is much further form the elastic limit of steel. Yielding of steel in tension is followed by rupture of FRP laminate. Meaning, even beyond the yielding of steel, the load-deflection curve will have substantial positive slope or flexural rigidity because of the contribution of FRP reinforcement.

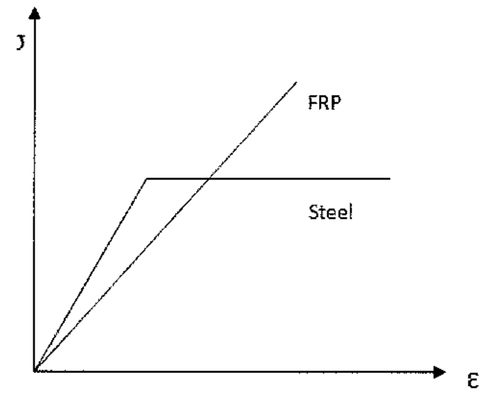


FIGURE 4: Stress-strain diagram of steel and FRP

2.3 Simply Supported Beam

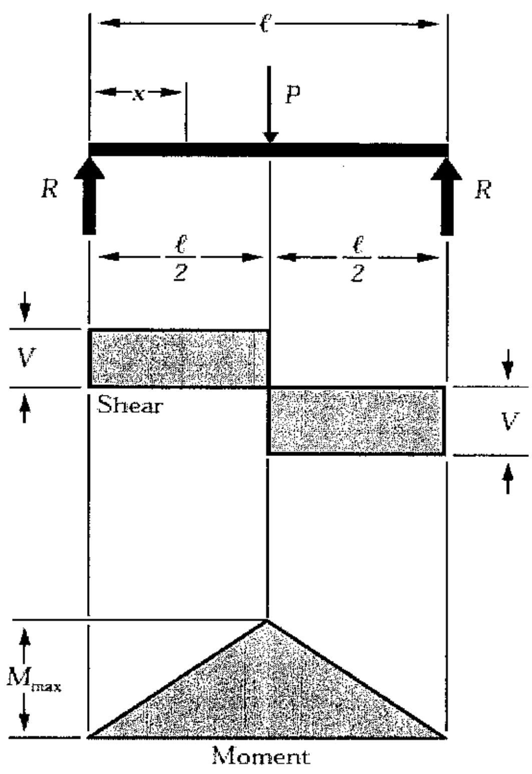


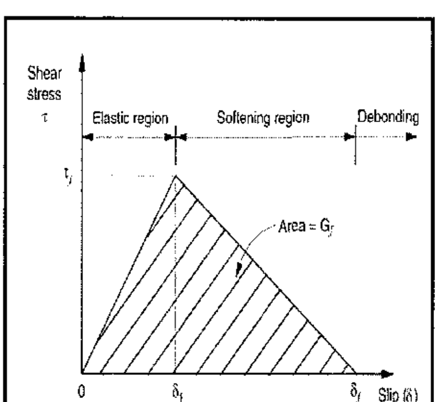
FIGURE 5: Simply supported beam force and bending moment diagram

Simply supported beam is the simplest type of loading that could be analyzed. Simply supported beam with single force acting at the centre of the beam span, as shown above, could be easily analyze. The figure showed the distribution of force and bending moment diagram of the beam. With given force, this entire diagram could be identified and further studies can proceed. It is given that Mmax is determined by PL/4. Where P is force acting on the beam and L is the length of beam. Besides Mmax, it is also possible to identify moment at any where

$Px/2 < Mmax < P(L-x)/2$. The equation has been modified to suit the category of finding the moment of that particular point. It is also assured that maximum deflection, Δmax, occurred at point where maximum bending moment occurred. The deflection is define as $Pl^3 / 48EI$. Other than that, deflection at point where $x < l/2$ is defined as $Px/48EI\ (3l^2 - 4x^2)$

2.4 Bond-Slip Relationship

One important characteristic for FRP bonded concrete or steel system is the bond slip relationship. It can be utilized to derive the effective bond length as well as bond strength. The bond-slip relationship is commonly determined from axial strains of the FRP measured with strain gauges along the bond length, or from load-displacement curve [1]. For the FRP-concrete system and CFRP-bonded steel system, the bond-slip relationship could be simplified as a bilinear model as below



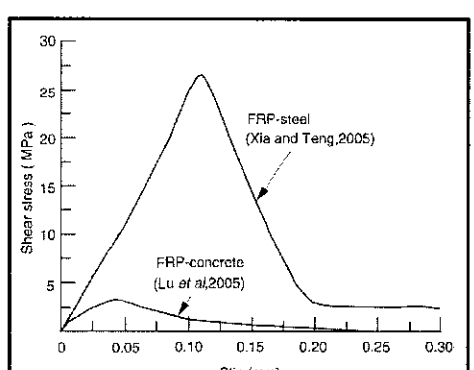


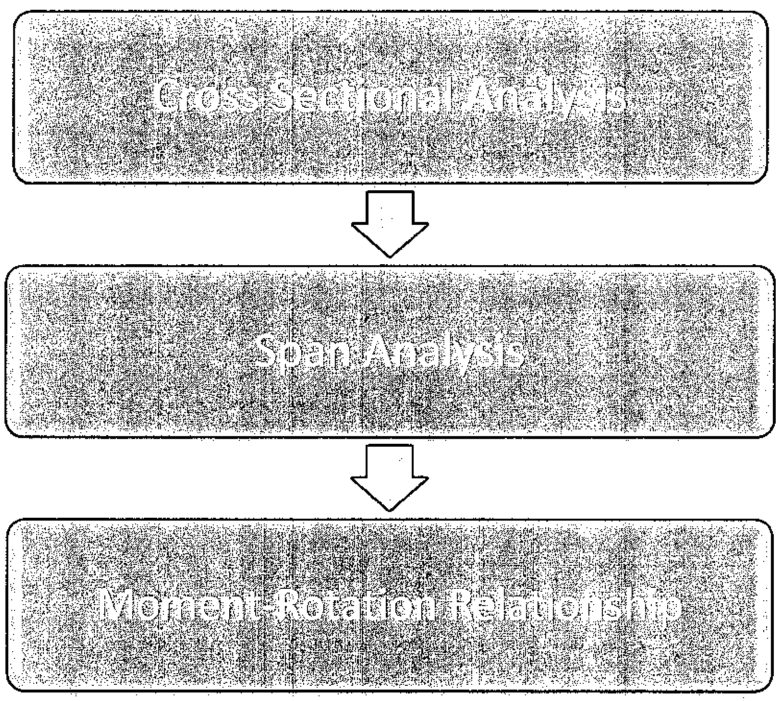
Figure 6: Bond-slip relationship

The main parameter used to define the bond-slip model is the local bond strength (τf), the slip at the peak shear stress (δ 1), and the slip when the shear stress reduces to zero (δf). The major concern in determining the bond-slip relationship from axial strains of the FRP is that the axial strains measured on the thin FRP plate generally show violent variations as a result of the discrete nature of the concrete crack [8]. However, this may not be the case in the FRP bonded steel system. It was demonstrated in [11] that a bilinear model, which is similar to that for concrete, could be adopted for CFRP-bonded steel system. The test set up is shown in figure 6. Debonding failure is indicated by the sudden increase in strain when the load level goes from 0.9Pmax to Pmax [1].

An example of the bond of the bond-slip relationship is shown in figure for the CFRP-steel system, together with an example for the CFRP-concrete system. It can be seen that the local bond strength (τf) and the slip at the peak shear stress (δ 1) are much larger in the CFRP-steel system than those in the CFRP-concrete system, although the differences in slip δf is not significant. Further research is needed to cover more variables, such as the modulus of the CFRP plates, and the bond length and thickness of the CFRP plates. Preliminary work was conducted by [12] to establish the bond slip relationships for steel joints bonded by CFRP sheets using the test set-up shown. It was found that the bond-slip relationship might be simplified to a bilinear model. In order to determine the values of τf, δ 1 and δf, more test are needed.

CHAPTER 3

METHODOLOGY



This particular study involves the author to develop spreadsheet using Microsoft Excel™ that will be used in the cross sectional analysis, span analysis and also moment-rotation relationship in the end. Material properties of both beam and FRP plate is used in the early stage to setup the parameter and calculation for the cross sectional analysis.

3.1 Numerical Procedure

3.1.1 Cross Sectional Analysis

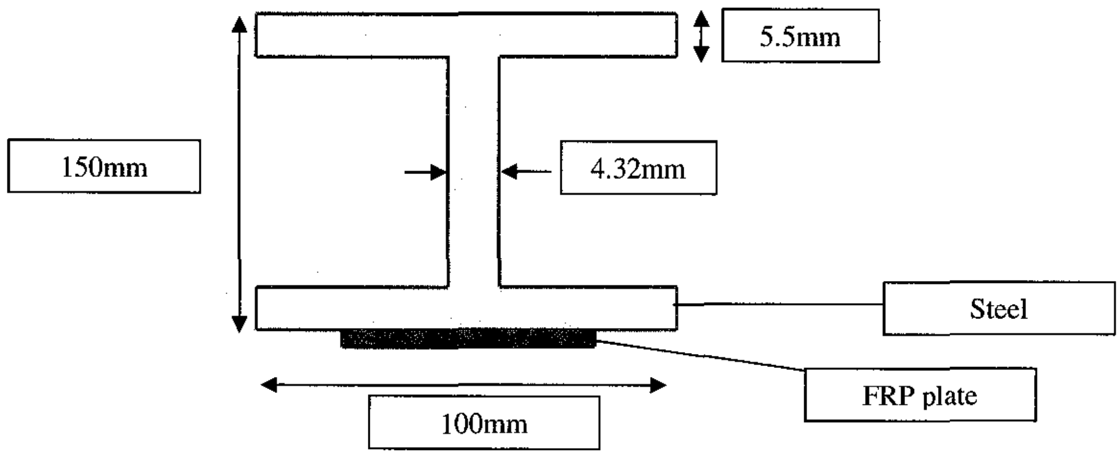


Figure 7: Beam cross section

Analysis of this numerical procedure started with the cross sectional analysis of the steel beam. For this beginning stage, the author is calculating for the stress, strain, total force and also the new neutral axis in the system. Since the beam is symmetrical, the other face will have the same value and hence, the study will only be concentrated on one sided.

Strain of FRP is taken at 0.0013 while the strain of steel is guessed to be 0.0015. With existing value, we managed to solve the value for curvature. The formula is as shown:

$$\varepsilon_s = \phi d_{NA}$$

ε_s is the strain in steel

ϕ is curvature of strain in steel

d_{NA} is neutral axis at starting of calculation which is 75mm

Then, the value of strain, stress and forces is calculated at 1mm increment and 150 in total. Graphs are produced to visualize the strain, stress and forces that act in the subject of study. Below shown is the equation used in order to obtain the value of stress in beam at particular places. Value of Modulus of Elasticity, E_s, varies with the value of the strain in steel. It consist of linear and non-linear part, linear part govern the material properties of steel in the part where the steel is under loading, and non-linear part govern the part of loading beam in the yielding state. The spreadsheet is being observe closely so that it is concurrent with the material properties so that result obtain is reliable for analysis later on. Both steel and plate is calculated to produce result that reflects the real situation of FRP plated steel section.

$$\sigma_s = \varepsilon_s \, . \, E_s$$

where:

σ_s is stress in beam

ε_s is strain in beam

E_s is modulus of elasticity which is 205 Gpa @ 7 Gpa (yield)

$$\sigma_p = \varepsilon_p \, . \, E_p$$

where:

σ_p is stress in plate

ε_p is strain in plate

E_p is modulus of elasticity of FRP which is 155 Gpa.

Shown below is the equation involved in calculating total force in the system. It is calculated by multiplying stress with area of beam. This area is either the flange or web of the beam. Since the increment, d_y is set to be 1mm, the area will be the same as the length of the web and flange of the beam. Total force in the system is the result of force in compression and tension. For this analysis, the submission of both force need to be in equilibrium. So, the total forces have to be zero or approximately zero. But, some adjustment is made which is, the equilibrium state is acceptable in the range of plus minus five (5) percents from zero. So, the total force in the tension and compression are acceptable if the number falls in between this range.

$$F = \sigma . A$$

Where:

F is force in beam, plate

σ is stress in beam, plate

A is affected area

3.1.2 Span Analysis

All results in cross section analysis need to be fully completed before this numerical procedure could be proceed with the span analysis. In the analysis, the author assumed that the system is a simply supported beam with a point load at the mid span. The theoretical moment, M_{max} could be calculated by using the equation shown previously in the chapter 2: *literature review* section 2.3 simply supported beam. To summarize, the equation is as below:

$$M_{max} = PL / 4$$

Where:

P is point load acted on the beam

L is the length of span

Above equation could be simplified further in finding moment distribution when the point is more or less than L/2. Shown is the simplified equation to be used when such condition happen:

$$\text{When } x < L/2 : Mx = (P\text{-}x) / 2$$

$$\text{When } x > L/2 : Mx = P (L\text{-}x) / 2$$

The numerical procedure to calculate the total moment at particular point will now depends on the curvature, ϕ. The curvature will be adjusted so that it will favor the total moment result so that it reflects the theoretical moment found using above equation. The result should be similar to the theoretical value so that we could compare the results and also at the same time shown the reliability of this numerical procedure.

CHAPTER 4

RESULT AND DISCUSSION

4.1 Cross sectional analysis

Initial step is to make assumptions on the value of the parameters required in order to start the numerical procedure. Table below shown the data used for developing this numerical procedure:

εs (guess)	0.0015
εp (fixed)	0.0013
Es	205
Ep	155
Es (yield)	7

Table 2: material properties of steel and FRP

tw (mm)	4.32
bf (mm)	100
d (mm)	150
tp (mm)	1
bp (mm)	50
Af (mm^2)	100
Aw (mm^2)	4.32
Ap (mm^2)	50

Table 3: section properties of steel I-beam

All data shown above is used in order to calculate the stress, strain, total force and also neutral axis of the new system. Calculation of all mentioned before is very close related to one another. So, close observation need to be made to the value inserted and also arguments used to ensure it reflects the real situation of the system and also it will give the right value theoretically. Below are the summary of all the initial result obtain which is the total force in the system.

P_{plate} (kN)	$\Sigma P_{tension}$ (kN)	$\Sigma P_{compression}$ (kN)	$\Sigma Pc / \Sigma Pt$ (%)	neutral axis, y (mm)
10.075	224.6563	-218.215	0.029518239	76

Table 4: Summary of all forces in initial condition

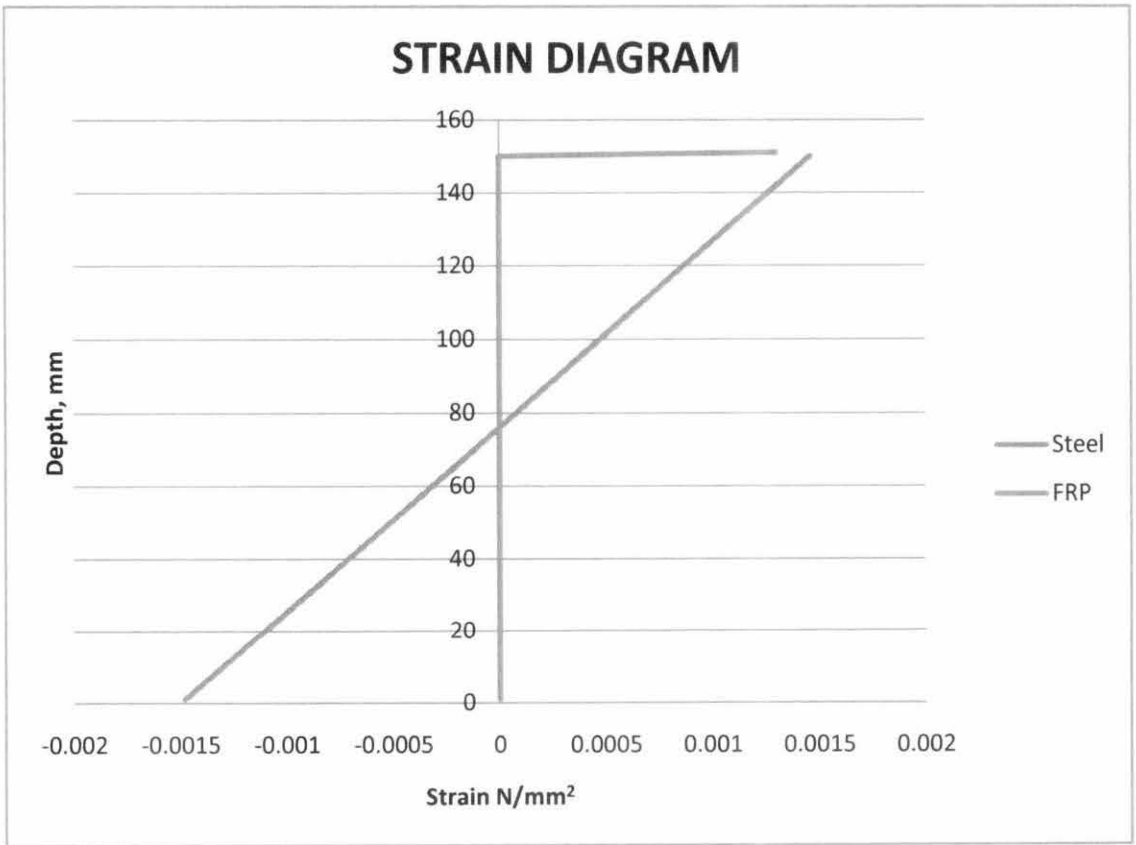


Figure 8: Strain diagram of Steel and FRP in beam at initial position

The result obtain clearly indicate that current preliminary calculations are still do not suffice for further research on moment-rotation topic. There are many others perimeters need to be fulfilled before proceeding with the analysis. Up to this point, non-linear part of the stress-strain of the subject is yet to be corrected to meet the criteria of the material properties of steel and FRP.

Below graph represent calculation made to obtain stress of steel using relation of strain of steel and Young's Modulus of Elasticity. The interception of the line to the axis is the neutral axis of the system. The calculation is not yet completed as many arguments need to be filled before the curve on the graph will represent the real value and shape for steel while loading and yielding. The result shown only for the initial condition while it is in the linear part.

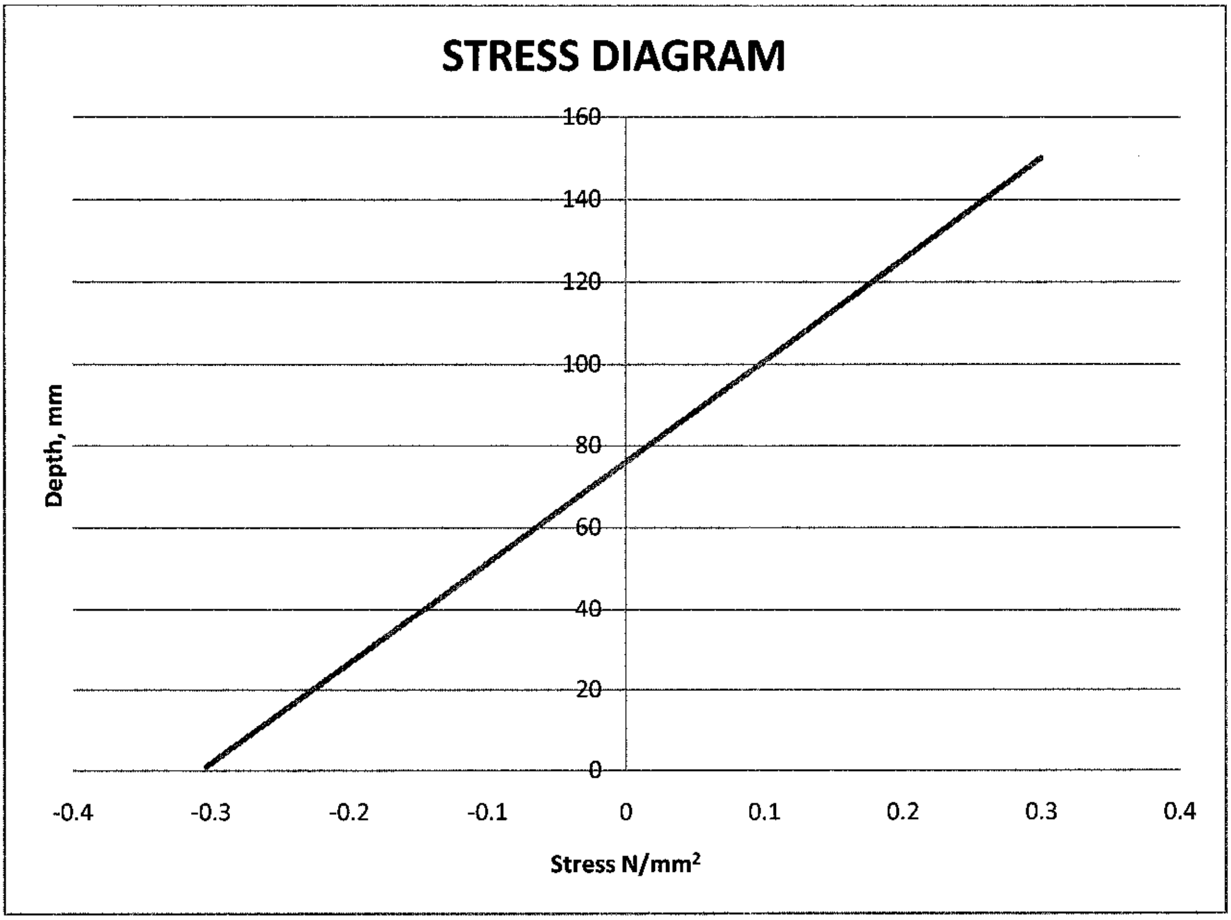


Figure 9: Stress diagram of steel beam

Total force is calculated as one of the preliminary requirement before continuing to the analysis of moment rotation. The desired result should consist of balance force in positive and negative value, so that the percentage of compression and tension forces is in the range of 5% from zero, which indicate the forces are approximately in the balance. The existance of FRP has resulted in the shifted of neutral axis of this reinforced plated steel.

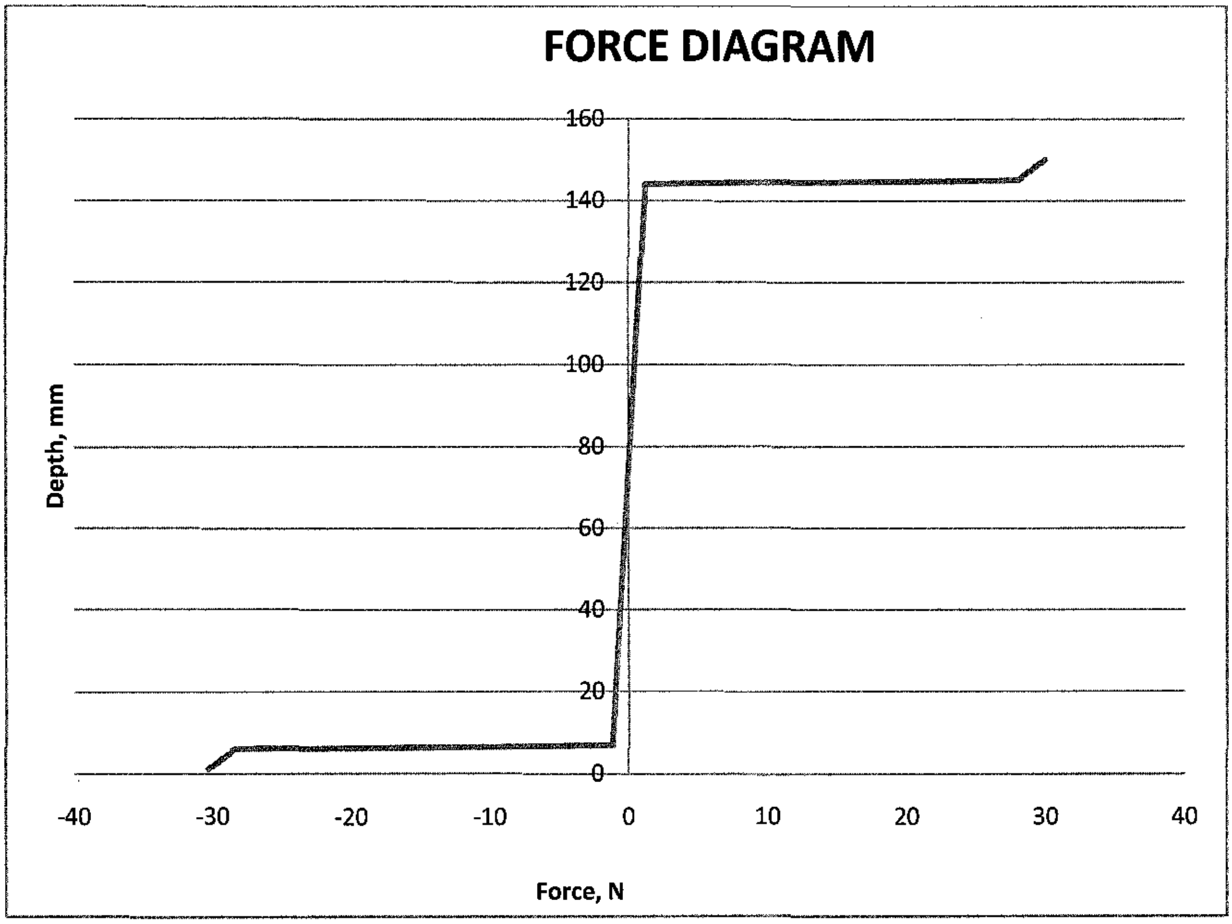


Figure 10: Force diagram of beam

All the preliminaries steps need to be settled before tha moment rotation analysis could take in. There are few more steps which are total moment of the beam, moment distribution along the span and also bond-slip relation between steel and FRP plate. Preliminaries works are essential as the analysis would be directly using value and calculation steps in the preliminary stage. Failure in establishing the preliminaries works will result in a no-solution at all. The cross sectional need to be done before we could start to proceed with span analysis.

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1 Conclusion

From this research, the author can conclude that:

I. Based on the preliminaries works done, it seems that moment-rotation capacity analysis could be establised by using numerical approach developed using Microsoft Excel™ spreadsheet. It is vital to ensure that all parameters of beams, FRP and material properties of both steel beams and FRP is chosen correctly. However, all works need to be complited first before the moment-rotation capacity analysis could be completed.

II. Function and formulas in the Microsoft Excel™ spreadsheet should be learned fully in order to ensure the smoothness of this project during developing the numerical procedure. The author having so much difficulties in handling the spreadsheet which hinder this research to be completed. Familiarizing with the spreadsheet functions and formulas will assist in completing the analysis.

5.2 Recommendation

I. There should be adjunct lecture, or short courses on the software provided/offered in assisting student with projects that needed students to familiarize with computer software. Projects that are related to the computer software and programming is hard to cope with and very differ to experimental works where the students will be somehow assisted in the lab.

II. The study is so much easier when the initial condition and parameters is started closer to the actual value. It saved up times and allow student to proceed with works much faster. That should be continued in the future regarding this topic of project.

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